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Mineralogical and beneficiation studies of the Fe-Cu ores of Dammal Nisar, Chitral, NW Himalayas Pakistan

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Abstract

Medium-grade iron and copper ore deposits occur in the Dammal Nisar area of southern Chitral, NW Pakistan. They are distributed as 20 to 200m^2 size lens-shaped bodies in the metavolcanic and metasedimentary rocks of the Gawuch Formation along the eastern contact of the arc–related Mirkani granitoids. Detailed mineralogical investigation using petrographic, X-ray Diffraction and SEM-EDX techniques shows that these deposits consist of magnetite, hematite and malachite as the principal ore minerals while occasional chalcopyrite and pyrite are also observed. Quartz, garnet, olivine, epidote, calcite, pectolite, serpentine and foshagite occur as the associated gangue phases. Two main paragenetic stages can be recognized in these deposits based on petrographic and field observations. Olivine and garnet represent the prograde skarn mineralogy while retrograde mineral assembladge is characterized by epidote, amphibole and serpentine. On the basis of proximity to the Mirkani granitoids and prograde and retrograde skarn mineralogy, the studied ore bodies may be classified as skarn-type magnetite deposits.

Being medium-grade in their current form, different beneficiation techniques including gravity separation, magnetic separation and froth flotation were employed to assess the up-gradation potentials of the Dammal Nisar ores. The results reveal that an average Fe_2O_3 concentrate of 89.15 wt. % at 48% recovery and 90.7 wt. % at 55% recovery are obtainable through a combination of gravity and magnetic separation techniques after sample feeds with 72-75 wt. % Fe_2O_3 contents are pulverised at 20 and 25 minutes, respectively. As such, the studied ores can be utilized in steel manufacturing. Furthermore, average product of 1.91 and 5.55 wt. % Cu is obtainable through froth flotation, from the studied ore samples showing 0.28 to 0.68 wt. % Cu. Besides, more than 60% of the samples grain size is reduced to <106 microns, when subjected to a grinding interval of up to 25 minutes thereby enhancing liberation of ores from their associated gangue phases. The better liberation results in a relatively higher recovery of both iron and copper minerals.

Keywords: Iron and copper ores; skarn mineralogy; beneficiation; Dammal Nisar; Chitral.

1. Introduction

The ongoing efforts for bringing improvements in the existing infrastructure including construction of new highways like China-Pakistan Economic Corridor (CPEC) in Pakistan have made working on enrichment of a variety of low-grade ore deposits increasingly feasible. This will in turn result in production of cost effective, quality metallic products to fulfill the increasing demand of Pakistan.

Normally iron ores with $\geq$ 70 % Fe_2O_3 are considered suitable for use in steel manufacturing. Iron ore with lesser Fe content and high Al:Si ratio cannot be used directly for metal production. These low grade deposits, therefore, require the enrichment through suitable physical and/or chemical beneficiation processes in order to liberate ore minerals from gangue. Liberation of ore minerals from the crushed fraction depend on the grade, the grain size and mutual textural relationship between the gangue and ore phases. Conventional practices such as gravity, flotation and magnetic methods are, however, less effective in separating ultrafine particles and slimes.

In Pakistan, there are widespread occurrences of low to medium-grade metal ores e.g., the deposits of Mn and Cu in Mohmand, Bajaur and Waziristan Agencies, Mn deposits in Abbottabad district and Sb, Fe, Cu, and W deposits in Chitral (Kazmi and Abbas, 2001; Zahid et al., 2013). The iron deposits of Pakistan are mainly of sedimentary (i.e. lateritic beds along major unconformities), volcanogenic or contact metasomatic origin

(Ahmad, 1969; WPIDC, 1970 Asrarullah, 1978; Astromineral, 1978; Miller et al., 1991; Hussain and Karim, 1993; Abbas et al., 1998). Also notable among the iron ores are the magnetite-rich bodies of Dammal Nisar lying ~32 km south of Drosh on the Mirkani-Afghanistan road (Figs. 1-2). The economic significance of these ores was evaluated by some of the earlier workers (e.g. Kidwai and Imam, 1958; WPIDC, 1970; Astromineral, 1978). Hosted in a complex sequence of igneous and metamorphic rocks, the Dammal Nisar magnetite ore reserves are estimated about 3.7 million tons by Kidwai and Imam (1958) and 6.5 million tons by Ali (1963) on the basis of magnetic prospecting. Prospects for the occurrence of copper ore (possibly porphyry-type), in the Andean-type granodiorite sills of the study area, have also been discussed (Fletcher, 1985). Showings of copper mineralization are reported to occur in the Mirkani granite (Aslam et al., 2007). Malachite, a hydroxylated Cu-carbonate [Cu_2CO_3 $(OH)_2$] formed by weathering of near-surface Cu sulphides (Mulaba and Bell, 2005) is also commonly observed in the study area. Tahirkheli et al. (1996, 2012) associated the Cu-mineralization with granodiorite-diorite sills/dykes of Kohistan batholith in the vicinity of Karakoram-Kohistan suture in Chitral (Fig. 1) and suggested that magmatic fluids have played significant role in producing Cu-mineralization.

However, studies regarding the genesis of Fe-Cu mineralization in Damal Nisar area and its beneficiation potential have not been accomplished so far. Based on the close proximity of the studied Fe-Cu ores to calc-alkaline Mirkani granitoids of the western Kohistan batholith calc-silicate mineralogy, petrographic and trace element geochemistry of magnetite minerals, these deposits are classified as skarn-type hydrothermal deposits (Our study in progress). This paper presents and discusses results of detailed studies regarding mineralogical characterization and beneficiation of the medium-grade Fe and low-grade Cu ores from Dammal Nisar and its sorroundings (Fig. 2) using different particle size proportions. The shaking table and dry magnetic separation technique was used for beneficiation of Fe-ores while froth flotation technique was applied for upgradation of Cu-ores.

2. Geology of the study area

The study area of Dammal Nisar is located to the south-east of Drosh town in district Chitral, at latitude 35° 19″ 00′ to 35° 25″00′ N and longitude 71° 40″ 00′ to 71° 43″ 00′ E (Fig. 2). Lithostratigraphically, the area is comprised of metamorphosed volcanic and sedimentary rocks that are classified into Drosh, Purit and Gawuch Formations on the basis of lithological variations (Pudsey et al., 1985). These rocks constitute the north-westernmost continuation of intra-oceanic Kohistan island arc (KIA; Fig.1). KIA formed in Cretaceous to Tertiary time by magmatic processes above a north dipping intaroceanic subduction zone within the Tethys Ocean more probably close to Eurasian plate (Coward et al., 1987; Khan et al., 1997; Bignold and Teloar, 2003). KIA, after initial collision with Eurasian plate was followed by collision (at its southern boundary) against Indian plate which caused obduction of KIA from mantle rocks at the base to volcano-sedimentary sequences at the top (Tahirkheli, 1979; Coward et al., 1986; Treloar et al., 1996). Lithostratigraphically, the Kohistan island arc, sandwitched between Karakoram-Kohistan suture and Main mantle thrust zone in the north and south respectively, is subdivided into six major rock groups. These rock units from north to south include the mafic-ultramafic Jijal complex, the Kamila amphibolite, the gabbronorite-dominated Chilas complex, the predominantly granitic Kohistan batholith, Chalt and associated volcanics and Yasin group metasediments (Fig. 1). These units are mainly comprised of plutonic and/or volcanic rocks ranging from felsic through mafic to ultramafic composition and are overlain by volcanic and volcanosedimentary sequence (Tahirkheli et al., 1982; Bard, 1983; Searle, 1999). The Aptian Albian meta-volcano-sedimentary sequence of the study area is correlatable with the Chalt volcanics of eastern Kohistan island arc (Pudsey et al., 1985; work in progress).

The magnetite-rich Dammal Nisar ores, the subject of the present study, occur in the metamorphosed volcanic and sedimentary rocks (marbles and quartzites) of the Gawuch Formation as thin bands and lenses with minor concentration of Cu mineralization asindicated by malachite staining that at places also contain chalcopyrite and pyrite (Fig. 3). The ore-hosting rocks of the Gawuch Formation are intruded by the Mirkani granitoids of the Kohistan batholith (Pudsey et al., 1985; Hueberger et al., 2007; Figs.1-2). The latter itself represents one of the most significant units of KIA which consists of various isolated plutons, dykes and sills of calc-alkaline gabbroic to leucogranitic composition (Petterson and Windley, 1986; Kazmi and Jan, 1997). The Kohistan batholith (KB) is believed to have formed in three stages spanning over 102-29 Ma (Petterson and Windley, 1986) and ranging from initial subduction to post-collisional magmatism. The Mirkani granitoids, western part of KB, consist of diorite, granodiorite and granitic units of calc-alkaline nature which yield LA-ICP-MS U-Pb zircon ages of 120-121Ma (work in progress; Fig. 2).

3. Materials and methods

Four samples (each weighing 12 kg), representing both the Fe and associated Cu-ores, were collected from four ore bodies in the study area (Fig. 2). Following crushing, all the samples were divided into two six kg portions. After thorough mixing and conning, one-half of each of the six kg portions was saved as duplicate sample. The resulting samples were then transferred to a mill for further grain size reduction by grinding for 20 and 25 minutes interavls. After thorough coning and quartering, each of the samples was subdivided into sub-samples for gravity separation and magnetic separation (one kg), froth flotation (one kg), and sieve analysis (500 gm) and head sample analyses (500 gm). The gravity separation was conducted with Wilfley Table. Dry high intensity magnetic separation was performed on the concentrate, obtained through shaking table process, using magnetic roll separator with a permanent field intensity of about 1.5 tesla. Three parameters, namely splitter inclination, belt speed and feed rate are preset. Flotation Machine was used for flotation, while British standard sieves were used for sieve analysis. The two sample groups having grinding times (GT) of 20 and 25 minutes respectively and different grain size proportions, as mentioned above, were diluted in float cell to a density of 30% solid and 70 % distilled water and checked for viscosity problems (if any). The agitation time was continued for 6-8 minutes (Metso, 2006). The milled slurry was regularly agitated at 1700 RPM so as to ensure homogenous suspension of the solids. Reagents specified for each step (Table 1) were added and conditioning was performed regularly. Air rotameters were episodically used for induction of air. The stirring process resulted in the formation of froth concentrate which overflowed the flotation cell and was subsequently collected in a Jar. The left-over froth at the top of cell was collected with the help of manual scrapper after every 15 seconds. All the concentrates and the head samples were further pulverized for accurate wet geochemical analysis through Atomic Absorption Spectrophotometer (AAS). Thin section preparation and petrographic examination of the ores were carried out at the Department of Geology, University of Peshawar, Pakistan and the scanning electron microscope with energy dispersive system (SEM-EDX) investigation was conducted at the Department of Geological Sciences, Stockholm University, Sweden. X-Ray Diffraction (XRD) analysis of the Fe-ores was conducted at the Centralized Resource Laboratories (CRL), University of Peshawar, while the beneficiation studies were carried out at the Material Testing Laboratories, Directorate General Mineral and Mines, Peshawar.

4. Results and discussion

4.1. XRD and SEM analysis

Hosted in a composite of meta-volcano-sedimentary rocks, the magnetite dominated Fe-Cu deposits occur close to the contact between Gawuch Formation and the Mirkani granitoids (Figs. 2 and 3d). These deposits usually occur as small to medium (20 to 250 m2) and massive bodies in Dammal Nisar area but can also occur in dissiminted form (Figs. 3 a, e, g, i and 4 f). The studied Fe-ores are fine-grained and mainly consist of magnetite and magnetite-hematite phases (Figs 3i, 4d). The hematite, giving reddish-brown streak, seems as alteration product of magnetite (Figs. 3 g, i and 4d). Copper occurs mainly as oxides in the form of malachite while pyrite, chalcopyrite are the sulphide phases occurring in minor amounts (Figs. 3g-h, 4a). Malachite occurs as surface coatings on the Fe-ores and host rocks as well as fracture fills (Fig. 3h-i). Based on field and petrographic observation, two paragentic mineral assembladges can be recognized. Garnet, olivine, represent prograde mineral assembladge while epidote, amphibole, serpentine shows retrograde mineralogy (Figs. 3-4). These mineral assembladges are typical of Fe-skarn deposits as occurring worldwide (Meinert, 2005). Mineral phases determined through petrographic observation were further confirmed with XRD analysis (Fig. 5a-b). Some new minerals like foshagite and pectolite were also recognized through XRD analysis. SEM-EDX analysis of the magnetite ores shows around 67.3 to 71.8 % Fe with minor impurities of Ca, Al and Si. (Fig. 6a-d).

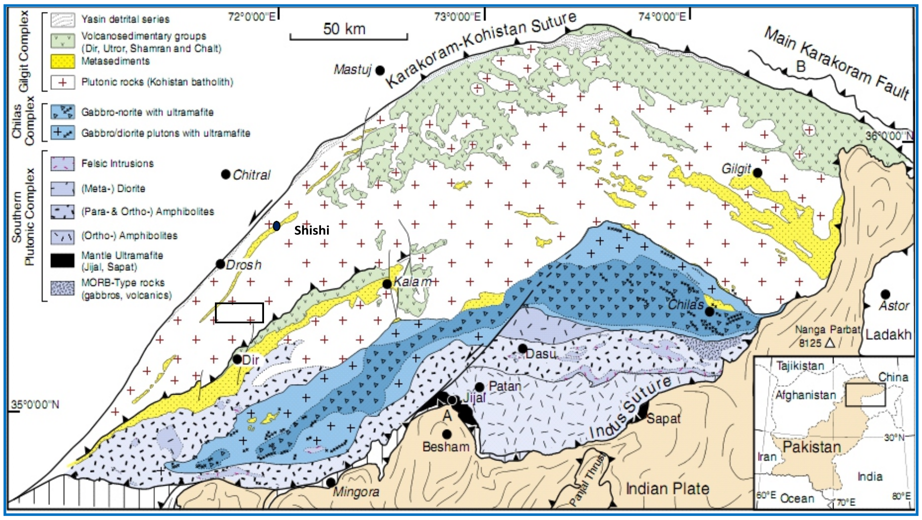

Fig.1. Geological Map of Kohistan island arc (Jagoutz et al., 2011). Rectangle is showing location of study area.

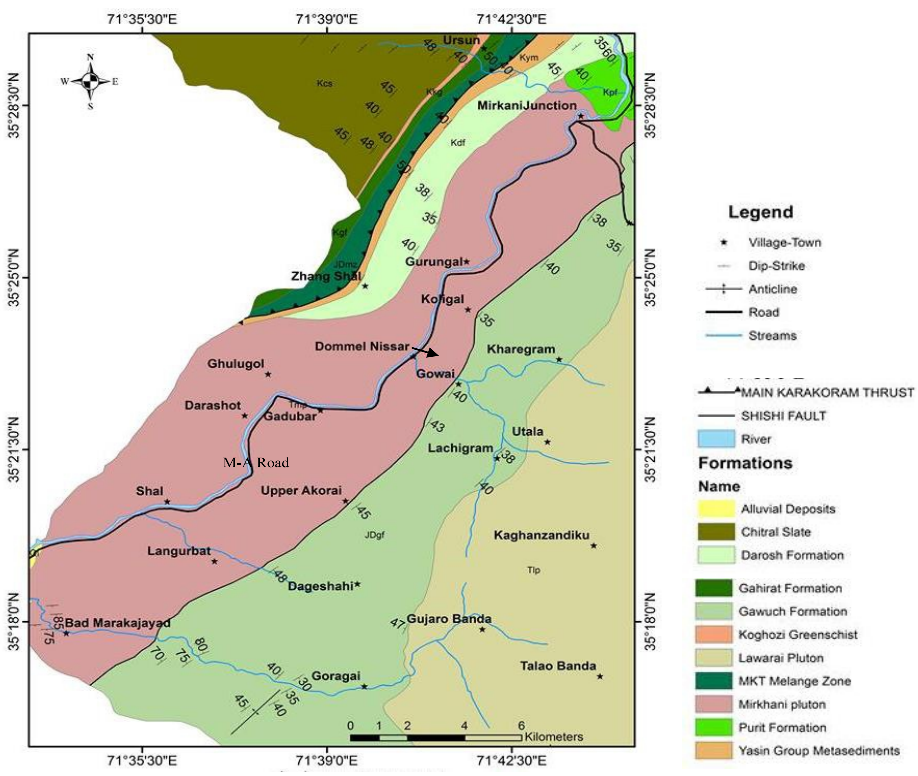

Fig. 2. Geological Map of the study area (Redrwan after Haq et al., 2006)

Table1. The details of reagents used during froth flotation

Description	Type	Conditioning Time (min.)	amount used
Sodium Hydroxide	PH Stabilizer	Pre-adjustment	0.5-1gram
Sodium Tri-Ethyl Zinthate	Oxide collector	2-3 minutes	0.2 gram
Cynamide 3302 (US)	Promoter	3-5 minutes	3 drops
Sodium Silicate	Silica Depressor	3-5 minutes	0.2 gram
Frother (88)		10 minutes	3 drops

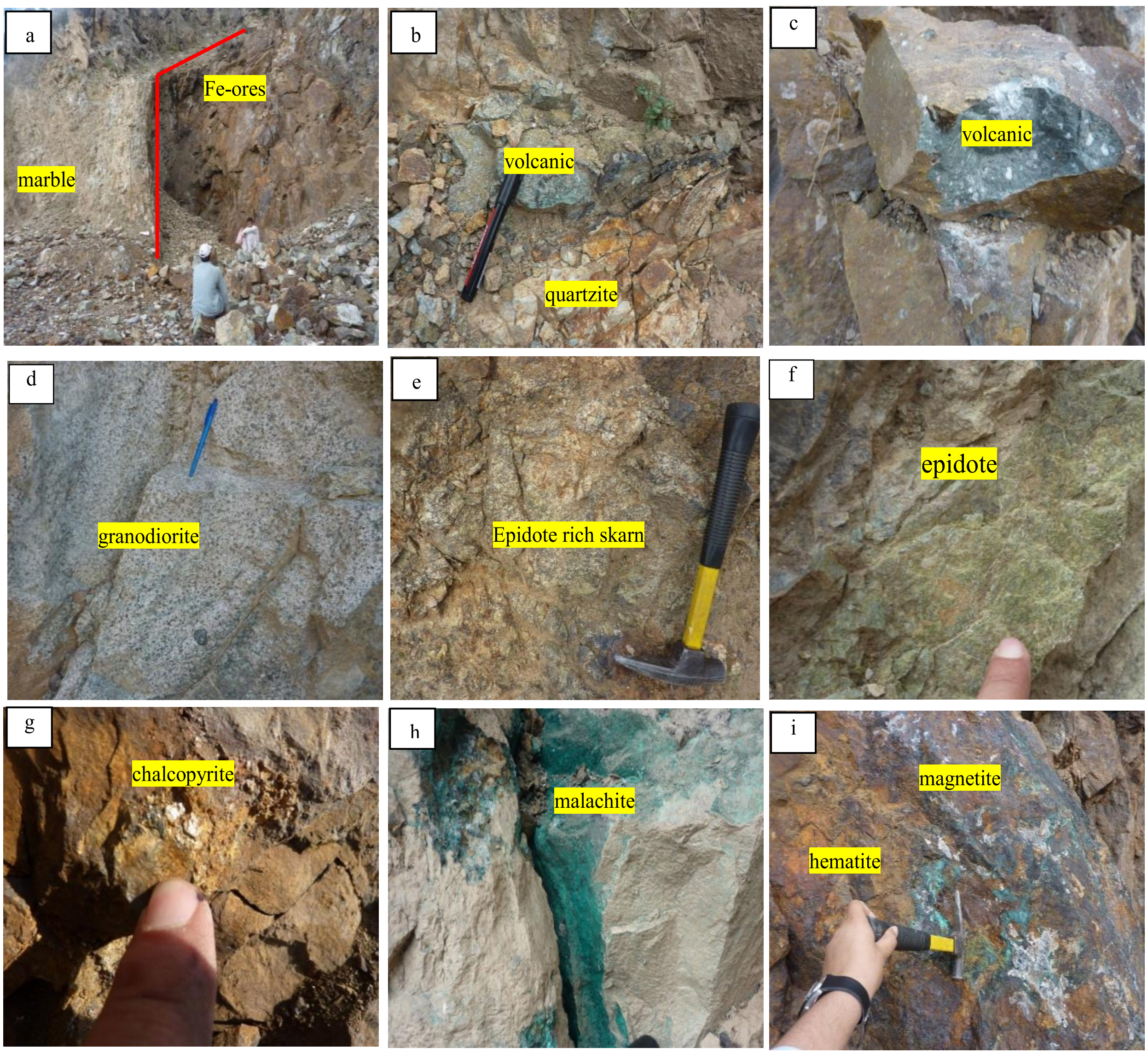

Fig. 3. Field photographs of the study area, a) contact between carbonate and Fe-ores; b) conformabale contact between quartzite and volcanic; c) volcanic host rock of porphyritic nature; d) Mirkani granitoid; e) epidotised rock containing dissiminated magnetite grains; f) epidote-rich skarn; g) Fe-ores showing chalcopyrite-pyrite grains; h) malachite mineralization along the fracture; i) massive magnetite-hematite ore, also having malachite staining.

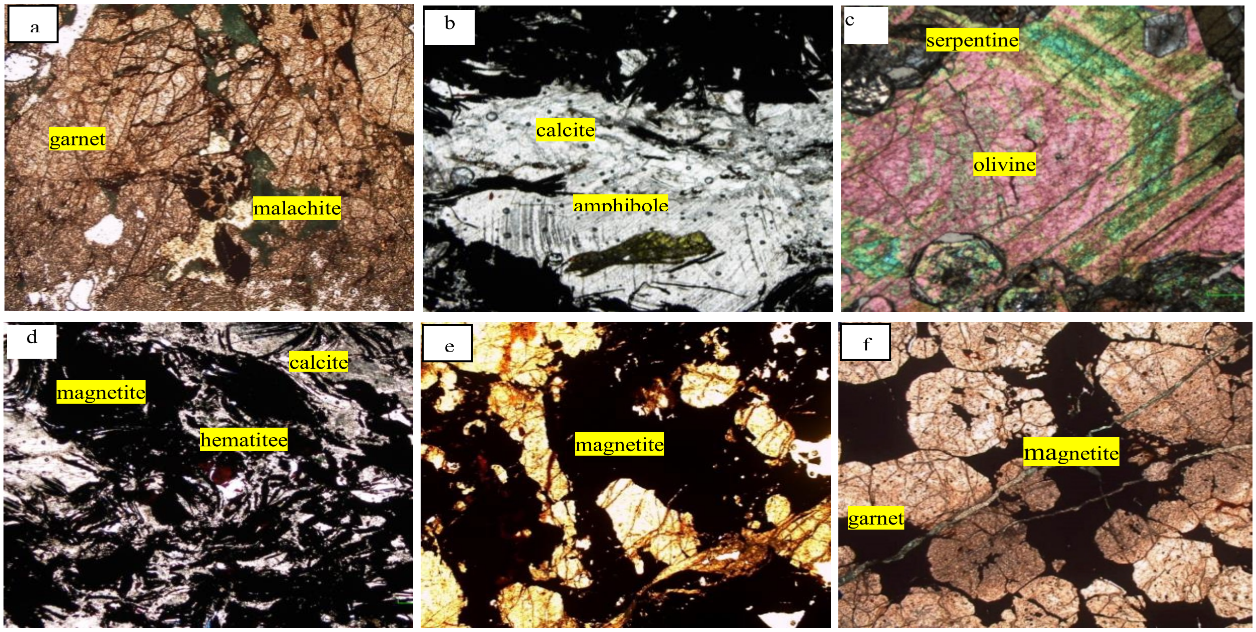

Fig. 4. Photomicrographs of the Dammal Nisar ores, a) garnet rich rock showing malachite and magnetite; b) crystalline calcite partially replaced by magnetite and amphibole; c) Olivine and serpentine; d) very fine-grained magnetite with associated hematite (reddish); e) secondary hematite replacing magnetite and garnet along fractures; f) malachite veins traversing fine-grained magnetite and garnet.

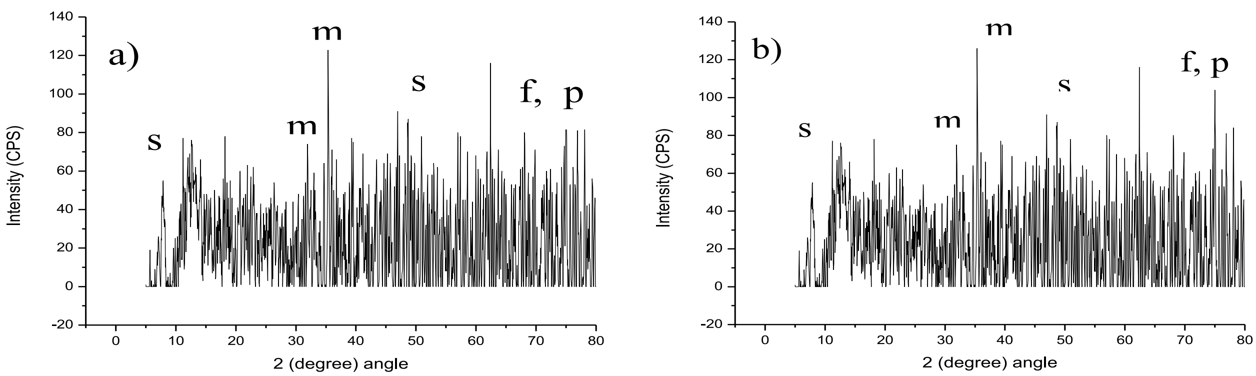

Fig. 5. a-b) Representative XRD pattern for magnetite minerals
Note: s = serpentine, m = megnetite, f= foshagite, p = pectolite

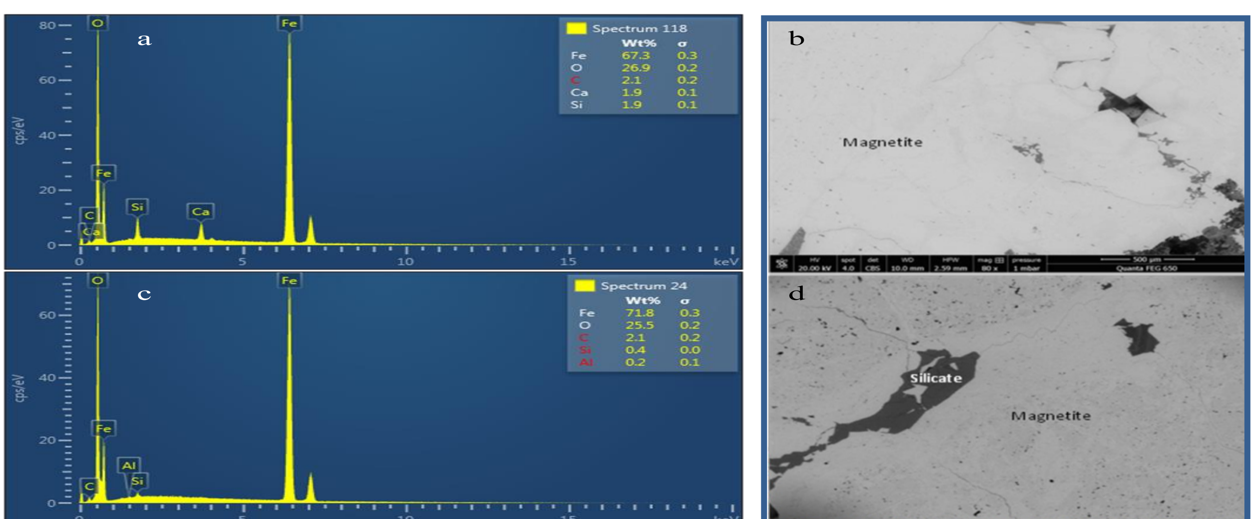

Fig. 6. a, c) EDX analysis of representative magnetite phases, (b, d) SEM images showing homogenous magnetite (light color) with the associated gangue.

5. Chemical analysis

Chemical analysis of head samples are shown in the Table 2. According to the Table, the amount of Fe_2O_3 is ranging from 72-75.04 wt. % (mean=73.78 wt. %) in the head samples while Cu concentration is ranging from 0.28 to 0.68 wt. % (mean = 0.48 wt. %). Variable concentrations of SiO_2 and CaO also occur.

6. Gravity separation

The values of Fe_2O_3 were upgraded through gravity separation process in the range of 82 to 88.4 wt. % (mean = 86.15 wt. %) for the samples pulverised at 20 minutes (Table 3). An average increase, from 86.15% to 87.8% (range = 84-90.4%), is observed in the Fe_2O_3 concentration on increasing the grinding time up to 25 minutes and hence the recovery percentage also improves from 47.9% (obtained at GT = 20) to 55 %. This increase in both wt. % and recovery potential (Tables 3 and 4) is attributed to the better liberation of ore phases from their associated gangue (garnet, olivine, serpentine, epidote etc). In order to confirm that better grade results are due to decrease in size, all the samples were divided into 2 size classes i.e. 250 to 106 microns and <106 to < 45 microns and were analyzed accordingly (Table 4). These analyses confirms high concentration of Fe_2O_3 in smaller size class (<106 um; Table 4).

7. Magnetic separation

The recovered gravity concentrates, were dried and processed through high magnetic concentration method (Table 3). The results shows that gravity concentrates, having average values of 86.15 (GT = 20 minutes) and 87.8 (GT = 25 minutes) wt. % Fe_2O_3, can be upgraded to 89.15 wt. % and 90.7 wt.% respectively. Hence, it is revealed that a further increase of 3.00 and 2.9 wt. % Fe_2O_3 can be achieved through magnetic separation.

8. Froth flotation

Froth flotation technique is also performed on the samples ground at 20 and 25 minutes intervals (Table 3). In this case the concentration of copper is also optimised in the ranges of 1.23-3.3 (mean = 1.91) and 2.4-10.4 wt. % respectively (mean = 5.55 wt. %) for the mentioned groups (Table 3). The Cu is, thus, recovered in the float concentrate samples at the rate of 45% and 64% for 20 minutes and 25 minutes size fractions respectively (Table 3). From the study, it is indicated that the samples with relatively high proportion of small size fractions (25 minutes grinding fractions) showed higher concentration of Cu (5.55 wt. %) as compared to that of 20 minutes grinding fractions (1.91 wt. % Cu). Hence, it is also confirmed, that at relatively lower grain size, copper minerals are easily separated from their gangue and, therefore, higher recovery is obtained. Similar to Fe-concentration, higher values of Cu are also obtained in the lower size class (Table 3).

From the above results (Tables 2, 3, 5) and Fig. 7 (a-e), it is revealed that more than 60 % of the particles are reduced to 106 µm at GT of 25 minutes while less than 50% of this fraction (< 106 µm) is achieved at grinding interval of 20 minutes. It is observed that the percentage of metals increase with increase in the amount of lower size fraction (<106 µm). Hence, it is revealed that better liberation of the gangue from their associated ores takes place at the lower size fraction. It is further assumed that a further decrease in size may decrease the recovery because of the increased hydraulic action during Shaking Table process. Additionally, further decrease in size may also affect the recovery of pure Cu because more fine particles of Fe-oxides get collected in Table 3. Details of analysis of shaking table, magnetic separation and froth flotation.the froth concentrate which wil will contaminate the former.

Table 2. Geochemical analysis of the head samples

Sample No.	Sample Name	Fe_2O_3	SiO_2	CaO	Cu
49	M1	72.00	14.50	10.60	0.65
50	M1a	74.00	16.04	6.44	0.68
51	M2	75.04	5.8	12.6	0.28
52	M4	74.09	10.4	13.4	0.29

Table 3. Details of analysis of shaking table, magnetic separation and froth flotation.

Sample Name	Type	Grinding time:20 minutes (wt.%)				Grinding time:25 minutes (wt.%)			
	Oxide/element	Fe_2O_3	SiO_2	CaO	Cu	Fe_2O_3	SiO_2	Cao	Cu
M1	Shaking conc.	82	8.3	8	0.65	82	9.8	8	0.78
	Magnetic.conc.	88	6.3	6	0.12	90	5.9	4.8	0.1
	Floatation conc	56.8	19.9	16.5	1.23	58	15.5	14.3	10.4
M1a	Shaking conc.	86	8.4	3.4	1.1	88	4.6	4.3	0.5
	Magnetic.conc.	88	4.2	4.8	0.17	90	6.3	3.4	0.3
	Floatation conc.	82.8	8.3	4.4	3.3	49.2	22.5	12.8	6.9
M2	Shaking conc.	88.4	2.1	5.4	0.1	90.4	2.3	4.3	0.1
	Magnetic.conc.	90.6	0.06	8.4	BDL	92	5.08	2.4	BDL
	Floatation conc.	72	5.2	13.8	1.4	73	4.4	8.11	2.4
M4	Shaking conc.	88.2	6.6	3.4	0.1	88.8	6.6	3.5	0.29
	Magnetic.conc.	90	0.6	8.8	0.03	90.8	2.9	4.8	0.19
	Floatation conc.	62	16.16	14.9	1.72	70	12.5	14.8	2.5

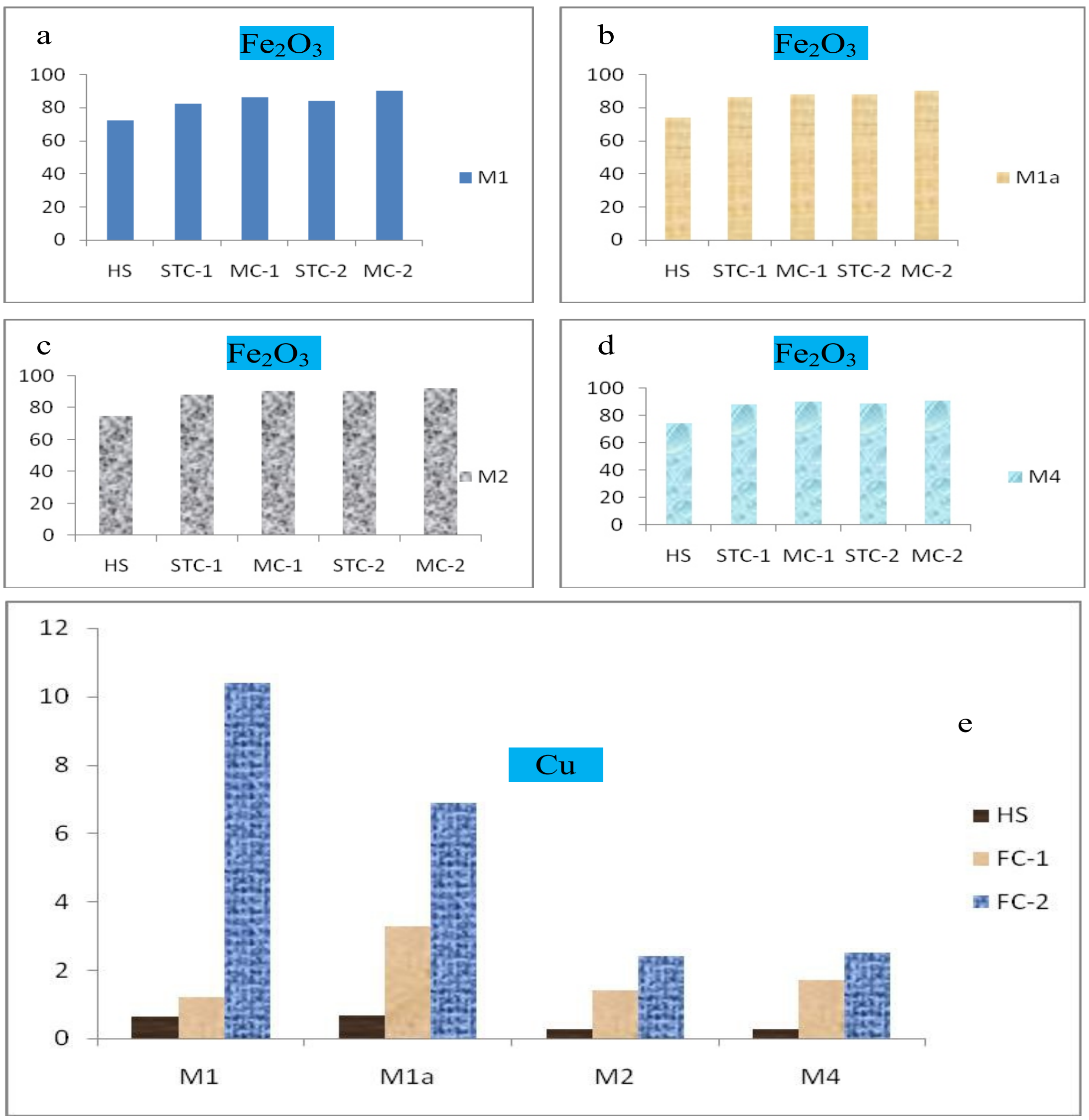

Fig. 7. (a-e). Increasing trends observed in % recovery at 25 minutes grinding duration. Note: HS = Head sample), STC-1, 2= shaking table concentrates at 20 minutes and 25 minutes grinding repectively, MC-1, 2 = Magnetic concentrates at 20 and 25 minutes grinting respectively, FC-1, 2= flotation concentrate at 20 and 25 minutes intervals.

Table 5. Sieve analysis and wt. % of samples ground at two different time intervals

Grinding time	Sieve Size (μm)	Mesh	Wt. in grams retained	Wt. % retained	Cum.Wt.% retained	Cum.Wt.% Passing	Fe_2O_3 (Wt.%)	Cu (Wt.%)
M1 (20 minutes)	250	60	44.6	22.3	22.3	77.7	79.4	0.71
	150	100	47.6	23.8	46.1	53.9		
	106	150	27.4	13.7	59.8	40.2		
	75	200	21.3	10.65	70.45	29.55	89.67	0.95
	63	240	14.4	7.2	77.65	22.35		
	45	325	26.2	13.1	90.75	9.25		
	<45	<325	18.1	9.05	99.8	0.2		
M1 (25 minutes)	250	60	0	0	0	100	80.1	0.9
	150	100	0.4	0.2	0.2	99.8		
	106	150	9.8	4.9	5.1	94.9		
	75	200	29.8	14.9	20	80	91.21	11.2
	63	240	20.1	10.05	30.05	69.95		
	45	325	13.8	6.9	36.95	63.05		
	<45	<325	126.1	63	99.95	0.05		
M1a (20 minutes)	250	60	46.5	23.25	23.25	76.75	80.02	0.64
	150	100	42.7	21.35	44.6	55.4		
	106	150	23.7	11.85	56.45	43.55		
	75	200	24.5	12.25	68.7	31.3	90.8	2.9
	63	240	19.6	9.8	78.5	21.5		
	45	325	10.4	5.2	83.7	16.3		
	<45	<325	31.6	15.8	99.5	0.5		
M1a (25 minutes)	250	60	5.8	2.9	8.2	91.8	85.5	0.68
	150	100	8.4	4.2	7.1	92.9		
	106	150	25.3	12.65	19.75	80.25		
	75	200	19.9	9.95	29.7	79.3	92.2	7.2
	63	240	18.2	9.1	38.8	61.2		
	45	325	68.5	34.25	73.05	26.95		
	<45	<325	53.5	26.75	99.8	0.20		
M (20 minutes)	250	60	42.4	21.2	21.2	78.8	82.12	0.44
	150	100	51.3	25.65	46.85	53.15		
	106	150	29.6	14.8	61.65	38.35		
	75	200	19.3	9.65	71.3	28.8	91.9	0.85
	63	240	15.5	7.75	79.05	20.95		
	45	325	26.4	13.2	92.25	7.75		
	<45	>325	14.5	7.25	99.5	0.5		
M2 (25 minutes)	250	60	0.2	0.1	0.1	99.9	82.8	0.52
	150	100	28.2	14.1	14.2	85.8		
	106	150	32.9	16.45	30.65	69.35		
	75	200	38.8	19.4	50.05	49.95	92.01	1.6
	63	240	44.1	22.05	72.1	27.9		
	45	325	52.7	26.35	98.45	1.55		
	<45	>325	14.5	7.25	99.5	0.5		
M4 (20 minutes)	250	60	43.4	21.91	21.91	78.09	80.21	0.25
	150	100	48.2	24.33	46.24	53.76		
	106	150	26.5	13.38	59.62	40.38		
	75	200	22.2	11.21	70.83	29.17	92.23	0.38
	63	240	15.5	7.82	78.65	21.35		
	45	325	25.1	12.67	91.32	8.68		
	<45	>325	17.2	8.68	99.6	0		
M4 (25 minutes)	250	60	0	0.00	0	0	81.1	0.28
	150	100	0.2	0.10	0.10	99.9		
	106	150	11.5	5.78	5.88	94.02		
	75	200	27.6	13.87	19.75	80.15	92.93	0.75
	63	240	22.4	11.26	31.01	68.89		
	45	325	65.5	32.91	63.92	35.98		
	<45	>325	70.8	35.58	99.49	0		

Wt. =weight, cum. = cummulative

Conclusion

The Fe-oxide deposits and their associated Cu-ores have dozens of commercial grade individual occurrences hosted within the metamorphosed volcano-sedimentary lithologies of Gawuch Formation. Field features like occurence of these deposits at the contact of arc-related Mirkani granitoids, and the prograde and retrograde mineral assembladges associated with Fe-ores (e.g., olivine, garnet, amphibole, serpentine, epidote) characterize these deposits as Fe-skarn deposits similar to those found world wide.

Beneficiation study shows that these deposits are upgradable up to the specifications required for steel making and can, therefore be used in steel industry. A combination of relatively better recovery and grade, however, can be achieved through the gravity separation followed by magnetic separation technique as the grain size fraction below 106 µm increases. This is due to the fact that a lower grain size, more gangue phases are liberated from the ore minerals. This study concludes that an average recovery of 55 % Fe_2O_3 is possible at an average of 90 wt. % by using a combination of gravity separation and high intensity magnetic separation techniques. The study also reveals that the associated cupper deposits, mostly oxides, are also upgradable through froth flotation technique by 10 times. An average of 5.55 wt.% Cu with a recovery of 64% can also be obatained through froth floation from head samples having an average of 0.48 wt. % Cu. It yields a recovery of 64% through an increase in the Cu wt.% by 10 times.

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