Mineralogical Study of Zard Koh and Kulli Koh Iron Ore Deposits of Pakistan

SULTAN AHMED KHOSO*, MUHAMMAD ISHAQUE ABRO**, AND MUHAMMAD HASSAN AGHEEM***

ABSTRACT

Zard Koh and Kulli Koh are two recently discovered iron ore deposits, existing in the Chagai district, Balochistan, Pakistan. PSM (Pakistan Steel Mill Limited) is interested to utilize these ore deposits at priority. Purpose of the present study was to assess the mineralogy of the Zard Koh and Kulli Koh iron ore deposits, as it plays a vital role in the selection of an appropriate processing method. The mineralogical study of ore deposits was carried out by XRD (X-Ray Diffraction), XRF (X-Ray Fluorescence), SEM (Scanning Electron Microscope) attached with EDS (Energy Dispersive Spectroscope) and SM (Stereomicroscope) techniques. Results indicated that the Zard Koh ore is mainly composed of 60.15% maghemite, 23.57% pyrite, 4.07% chlorite, 10.30% grossular and 1.65% admontite minerals. The chemical analysis revealed that Zard Koh iron ore contains an average of 54.27% Fe, 12.73% S, 8.70% Si, 3.07% Al, 4.07% Ca, and 2.16% Mg. Similarly, the mineralogical study of the Kulli Koh iron ore indicated that, ore is containing 51.16% hematite, 29.24% quartz, 8.89% dravite, and 8.76% kaolinite minerals. Elemental analysis of different samples indicated that Kulli Koh iron ore contains an average composition of 40.23% Fe, 20.67% Si, 3.44% Ca, 3.81% Al and 3.25% Mg. Mineralogical study of the Zard Koh and Kulli Koh iron ore deposits suggested that these ore deposits can be beneficiated cost-effectively by using magnetic separation techniques.

Key Words: Mineralogy, Zard Koh, Kulli Koh, Maghemite, Magnetic Separation, Chagai, Balochistan.

1. INTRODUCTION

Pakistan is endowed with abundant iron ore deposits, some of them have been investigated and estimated and some are still under investigation. Among the other indigenous iron ores, the Zard Koh and Kulli Koh are two newly discovered iron ore deposits of Pakistan. These national assets are distributed nearby the Dalbandin town, Chagai district, Balochistan, Pakistan. However, the specific quantification for the exact tonnage for Zard Koh and Kulli Koh iron ore deposits have not been carried out yet but estimates put the ore reserves are more than 100 million tons of raw ore respectively.

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Geologically, the Dalbandin iron deposits are associated with sanjrani volcanic [1]. PSM is interested to utilize these national assets for the production of iron and steel at priority. However, these iron ores in their raw state cannot be used directly into the ore smelter, and require a satisfactory concentration technique for their up gradation. In this regards, beneficiation study of Zard Koh and Kulli Koh iron ores was carried out in the Department of Metallurgy & Materials Engineering, Mehran University of Engineering & Technology, Jamshoro, Pakistan. The mineralogical investigation has been made in the initial phase of the study in order to envisage the beneficiation technique. Therefore, the purpose of this paper is to present the mineralogy of the Zard Koh and Kulli Koh iron ore deposits evaluated while course of the beneficiation study.

Many researchers used various analytical techniques for the mineralogical study of natural iron ore body [2-8]. Mineralogical characterization of the Dilband iron ore deposits of Pakistan was carried out by XRD, EDS attached with EDS, XRF and SM techniques [2]. Mineralogical constituents of a low grade Indian iron ore were studied through XRD and SEM analysis [3]. XRF and EDS techniques were used for the elemental chemistry of ore samples, XRD for crystallography, and SEM and SM techniques were used for surface morphology of the samples [4-6]. Using these techniques, mineralogy of Zard Koh and Kulli Koh iron ore deposits of Pakistan was successfully determined. It is worth mentioning here that, the mineralogical investigations of the Zard Koh and Kulli Koh ore deposits have not been reported as per the knowledge of the authors.

2. MATERIALS AND METHOD

The Zard Koh and Kulli Koh iron ore samples of different locations were received from PSM, Karachi. As received samples were in the form of lumps ranging in size from 7-10 cm. They were crushed and ground into different size fractions and then stored in air tight plastic bags. For the mineralogical study, different samples of each iron ore were analyzed under petrological, mineralogical and elemental analysis techniques. JEOL JSM-6380L SEM and Lieca SM were used for analysis of petrographic features, Bruker D-8 XRD was used for mineralogical study, and EDS attached with SEM and XRF spectrometer were used for elemental analysis. The operating parameters of the equipment used are reported elsewhere [9].

3. RESULTS AND DISCUSSION

3.1 Mineralogy of Zard Koh Iron Ore

The XRD spectrums of the representative samples of Zard Koh iron oreare shown in Fig. 1. XRD patterns, shown in Fig. 1, indicated that major peaks developed at 2θ of 35.65°, 33.12°, 12.40°, 33.76°, and 17.40°. The analysis of these patterns using EVA software, it was noted that ore is mainly composed of maghemite, pyrite, chlorite, grossular and admontite minerals. The major peaks corresponding to specific mineral is presented in Table 1.

Presence of these minerals in Zard Koh ore was confirmed by their elemental chemistry carried out through XRF technique. The XRF results of Zard Koh iron ore samples are given in Table 2 which indicates that average distribution of Fe, S, Si, Al, Ca, and Mgin the Zard Koh
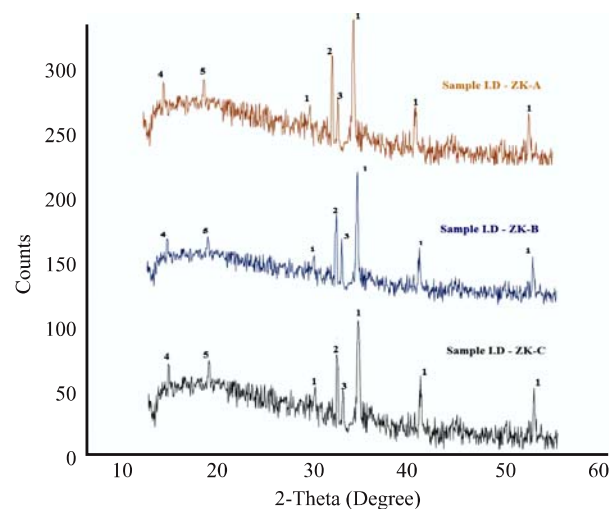

FIG. 1. XRD PATTERNS OF ZARD KOH IRON ORE SAMPLES (1) MAGHEMITE, (2) PYRITE, (3) GROSSULAR, (4) CHLORITE, (5) ADMONTITE

ore is 54.27, 12.73, 8.70, 3.07, 4.07 and 2.16% respectively. Moreover, the Zard Koh ore is containing some other minor elements like Mn, P, Cu, Ni, Cr and Ti, however, their concentration exists in traces. It is appreciable to note that the elemental analysis of the samples is in accordance with the minerals identified from the analysis of XRD pattern.

By using the XRF results as shown in Table 2, the SQ (Semi-Quantitative) analysis of these minerals was determined from each sample. The distribution of minerals in each sample is given in Table 3 which indicates that 60.15% maghemite, 23.57% pyrite, 4.07% chlorite, 10.30% grossular and 1.65% admontite are averagely present in the Zard Koh iron ore.

TABLE 1. ZARD KOH MINERALS WITH THEIR MAJOR PEAKS AT XRD PATTERNS

Mineral	Major Peak (2Θ)	Mineral	Major Peak (2Θ)
Maghemite	35.65°	Chlorite	12.40°
Pyrite	33.12°	Admontite	17.40°
Grossular	33.76°		

Further evidences were collected from SM and SEM attached with EDS. From SM analysis, it was noted that mostly the particles of five different colors viz: dark black, brass yellow, gray, orange and some colorless particles are present in Zard Koh ore. Keeping in view the optical properties of the minerals, the dark black particles were identified as maghemite, brass yellow as pyrite, gray as chlorite, orange as grossular and colorless as admontite minerals. The different minerals identified in the Zard Koh ore body using SM are shown in Fig. 2.

The SEM images along with EDS point analysis of the different grains in Zard Koh ore samples are given in Fig. 3. Under SEM and EDS analysis, chemistry of grains was used for the identification of minerals present in Zard Koh iron ore. Therefore, the grains of maghemite, pyrite, chlorite, grossular and admontite grains were identified by the % distribution of their major elements Fe, S, Al, Ca, and Mg, respectively. The grain containing higher percent of Fe without S was conceived as maghemite, whereas grain containing Fe and S was

TABLE 2. XRF RESULTS OF ZARD KOH IRON ORE SAMPLES

Sample ID	Major Elements					
	Fe (%)	S (%)	Si (%)	Al (%)	Ca (%)	Mg (%)
ZK-A	54.12	14.25	8.51	2.15	4.03	2.13
ZK-B	54.78	11.61	10.21	3.33	4.17	2.19
ZK-C	53.91	12.32	7.39	3.74	4.01	2.17
Average	54.27	12.73	8.70	3.07	4.07	2.16

TABLE 3. S.Q ANALYSIS OF THE MINERALS PRESENT IN ZARD KOH IRON ORE

Sample ID	Semi-Quantitative Analysis (%)				
	Maghemite	Pyrite	Chlorite	Grossular	Admontite
ZK-A	60.19	24.88	4.11	10.61	1.34
ZK-B	61.16	22.33	4.07	10.21	1.34
ZK-C	59.11	23.49	4.04	10.07	2.28
Average	60.15	23.57	4.07	10.30	1.65

anticipated as pyrite. By this way, the grains of grossular, chlorite and admontite were identified having higher percent of Ca, Al and Mg, respectively.
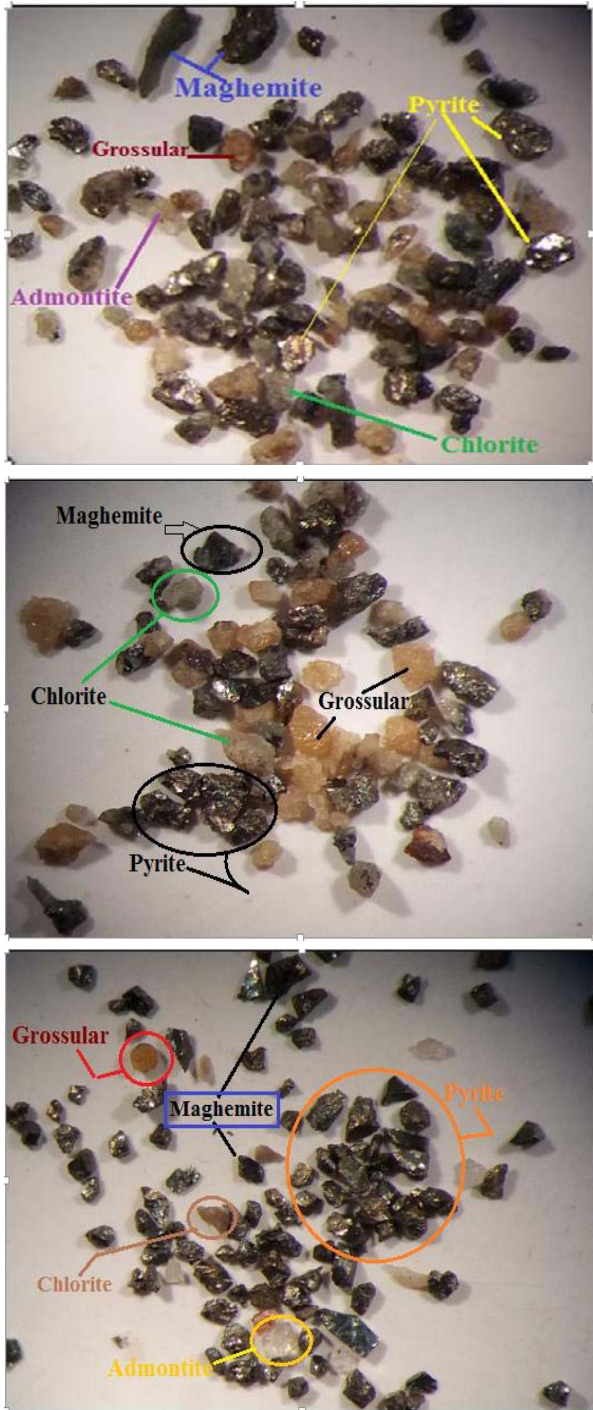
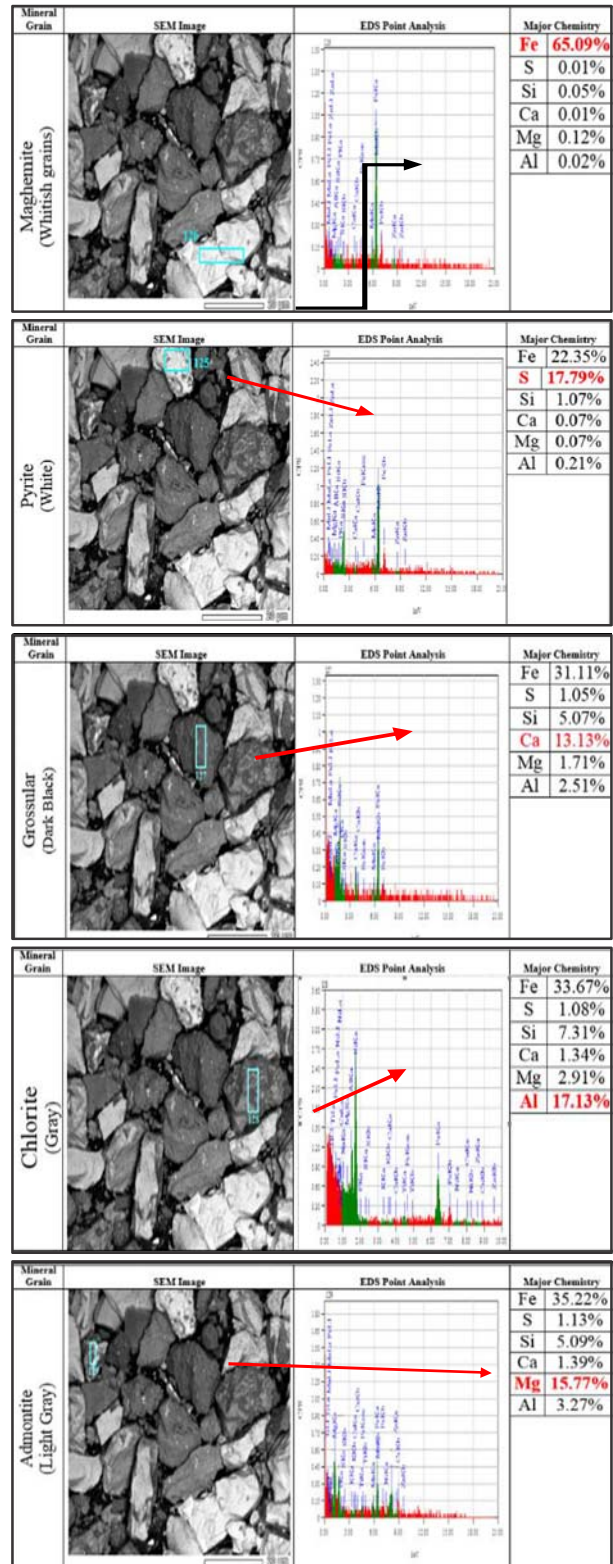*FIG. 2. STEREOMICROSCOPE IMAGES OF ZARD KOH ORE SAMPLES*

FIG. 3. SEM and EDS Analysis — Major Chemistry

Mineral Grain	Fe	S	Si	Ca	Mg	Al
Maghemite (Whitish grains)	65.09%	0.01%	0.05%	0.01%	0.12%	0.02%
Pyrite (White)	22.35%	17.79%	1.07%	0.07%	0.07%	0.21%
Grossular (Dark Black)	31.11%	1.05%	5.07%	13.13%	1.71%	2.51%
Chlorite (Gray)	33.67%	1.08%	7.31%	1.34%	2.91%	17.13%
Admontite (Light Gray)	35.22%	1.13%	5.09%	1.39%	15.77%	3.27%

FIG. 3. SEM AND EDS ANALYSIS OF TYPICAL MINERAL GRAINS IN ZARD KOH IRON ORE

It can be seen from the SEM and EDS analysis given in Fig. 3, that the maghemite (Fe enriched grain) and pyrite (S enriched grain) have almost similar whitish appearance. Whereas, the appearance of grossualr, chlorite and admonitite grains was found to be dark black, gray and light gray respectively. In order to fix the difference in appearance between maghemite and pyrite further extensive study of ore samples was carried out. For this, the samples were splited into ferromagnetic, paramagnetic and diamagnetic category using their magnetic susceptibility. The presence of higher proportion of maghemite and pyrite grains in ferromagnetic and diamagnetic part of the Zard Koh ore samples is witnessed from the XRD spectrum shown in Fig. 4(a-b). The SEM analysis of ferromagnetic and diamagnetic grains shown in Fig. 4 clearly demonstrated that both minerals have similar appearance. The diamagnetic portion of the Zard Koh ore sample was obtained using the is dynamic magnetic separator set at 1.5A current. Similar efforts were made to identify the grains of chlorite, grussular and admontite under SEM.

Furthermore, it is widely acknowledged from the literature [4], that in SEM images the appearance of maghemite mineral is almost similar to that of pyrite.

3.2 Mineralogy of Kulli Koh Iron Ore

Likewise Zard Koh ore, the mineralogy of Kulli Koh iron ore deposit was analyzed from the results of XRD, XRF, SM and SEM attached with EDS. The XRD spectrums of the representative samples of Kulli Koh iron ore are shown in Fig. 5. XRD spectrums indicates that the major peaks were developed at 2θ of $33.25°$, $26.26°$, $34.68°$, and $12.59°$. Using the EVA software, the presence of kaolinite, quartz, dravite and hematite minerals was noted at 2θ of $12.59°$, $26.26°$, $34.68°$, and $33.25°$ respectively.

The elemental chemistry of the ore samples, given in Table 4, is an additional evidence of the presence of these minerals in Kulli Koh iron ore. Elemental analysis indicates that the average distribution of Fe, Si, Al, Ca, Mg, in the Kulli Koh ore is 40.23, 20.67, 3.81, 3.44, and 3.25% respectively.
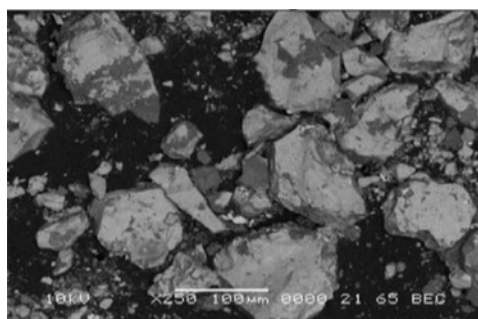
(a) FERROMAGNETIC PART/MAGHEMITE
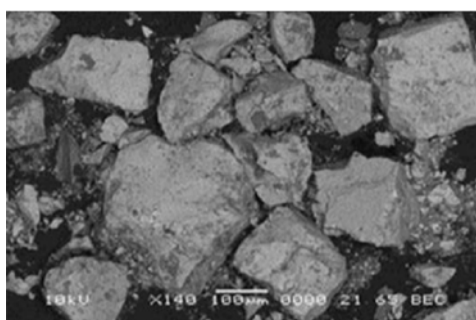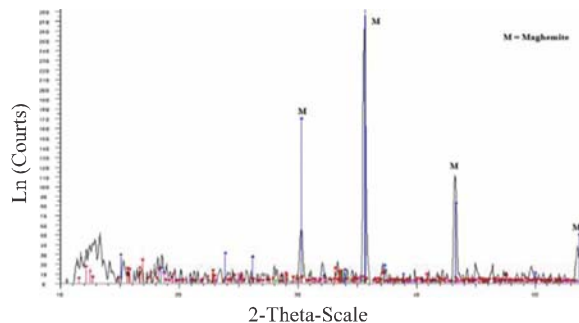
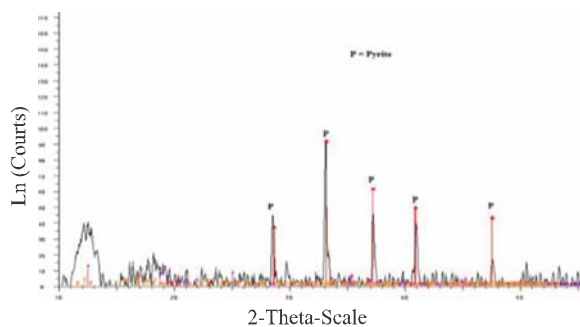*(b) DIAMAGNETIC PART (PYRITE AT 1.5A CURRENT*

FIG. 4. SEM AND XRD ANALYSIS OF MAGHEMITE AND PYRITE RICH GRAINS

Mehran University Research Journal of Engineering & Technology, Volume 36, No. 4, October, 2017 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

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The SQ (Semi-Quantitative) analysis of each sample of the Kulli Koh iron ore is given in Table 5, which indicates that 51.16% hematite, 29.24% quartz, 8.89% dravite, and 8.76% kaolinite minerals are averagely present in the Kulli Koh iron ore deposit.

The witnesses of hematite, quartz, dravite, and kaolinite mineral stones present in the Kulli Koh ore body were collected from the images of SM and SEM attached with EDS. SM images shown in Fig. 6(a-c), indicates that mostly
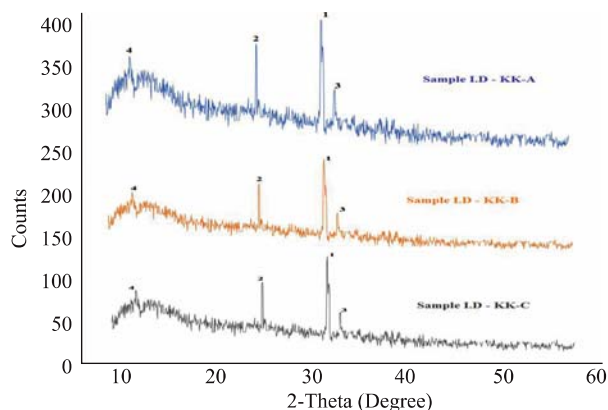

FIG. 5. XRD SPECTRUMS OF KULLI KOH IRON ORE SAMPLES (1) HEMATITE, (2) QUARTZ, (3) DRAVITE, (4) KAOLINITE

TABLE 4. XRF RESULTS OF KULLI KOH IRON ORE SAMPLES

Sample ID	Major Elements				
	Fe (%)	Si (%)	Al (%)	Ca (%)	Mg (%)
ZK-A	38.54	20.74	3.95	3.23	2.80
ZK-B	42.91	22.65	3.73	3.68	3.43
ZK-C	39.23	18.61	3.76	3.40	3.53
Average	40.23	20.67	3.81	3.44	3.25

TABLE 5. SQ ANALYSIS OF THE MINERALS PRESENT IN KULLI KOH IRON ORE

Sample ID	Semi-Quantitative Analysis (%)			
	Hematite	Quartz	Dravite	Kaolinite
ZK-A	48.20	30.95	8.81	11.09
ZK-B	53.17	29.60	9.87	6.63
ZK-C	52.11	27.18	7.98	8.55
Average	51.16	29.24	8.89	8.76

the grains of four different appearances viz. black (sometimes with shining appearance), colorless, gray, and reddish particles are present in Kulli Koh ore. By using the optical properties of the minerals, the black particles with shining appearance were recognized as hematite, colorless grains as quartz, reddish as dravite and gray as kaolinite minerals respectively. During SM analysis, it was noted that the hematite grains showed different appearances. In few samples the hematite rich grains reflected the light with brilliant luster and appeared as shining grains (Fig. 6(b)), whereas in some cases its appearance was black (Fig. 6(a and c)). It is widely acknowledged in the literature [4] that hematite of micaceous or specularite nature may adapt different appearance under SM depending upon the position of the grain with respect to incident light. Thus, it was conceived from SM images that hematite in Kulli Koh iron ore is of micaceous or specularite nature. It is worth mentioning here, that the presence of micaceous or specularite hematite in Pakistan iron ore deposits is rarely reported.

SEM and EDS analysis of the Kulli Koh ore samples was also carried out for further confirmation of these minerals. SEM images along with EDS analysis of different grains present in Kulli Koh ore are given in Fig. 7. EDS point analysis technique was used to determine the chemistry of each grain present in the Kulli Koh ore samples, and finally the particles of hematite, quartz, dravite and kaolinite minerals were recognized. Mineral chemistry of each grain, given in Fig. 7, indicates that white grains in the SEM images are hematite (Fe enriched particles) and quartz grains (Si enriched particles) appeared in dark black color. Whereas, the grains of dravite (Mg enriched particles) and Kaolinite (Al enriched particles) are in gray and light gray colors respectively. From the SEM images, the micaceous or specularite nature of hematite was confirmed, because of its blocky or platy crustal structure.
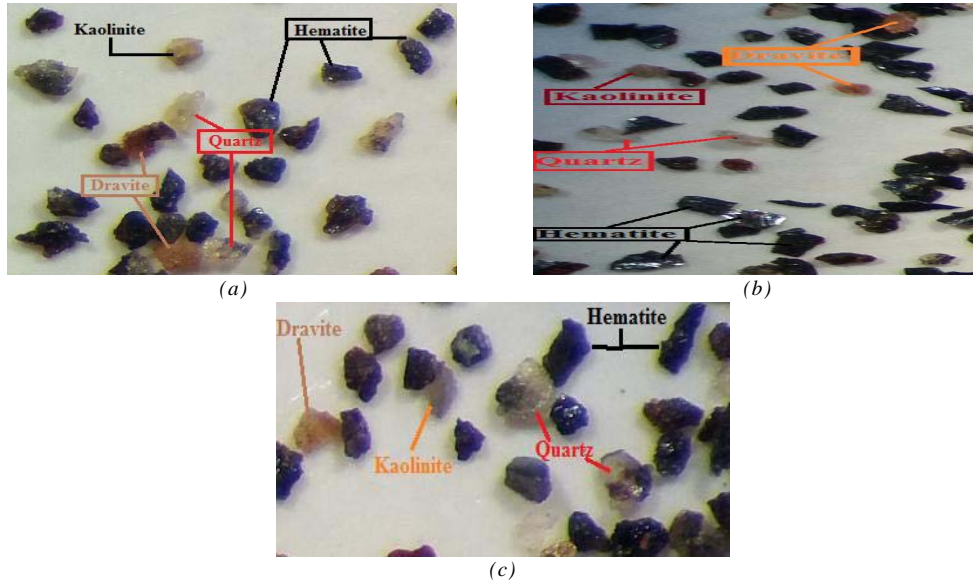
(a)   *(b)*

(c)

FIG. 6. SM IMAGES OF KULLI KOH IRON ORE SAMPLES

FIG. 7. SEM AND EDS ANALYSIS OF TYPICAL MINERAL GRAINS IN KULLI KOH IRON ORE

4.   CONCLUSION

In the present paper, detail mineralogy of the Zard Koh and Kulli Koh iron ore deposits is investigated. Followings major conclusions were drawn from the entire study:

(i)   Zard Koh iron ore is composed mainly of 60.15% maghemite, 23.57% pyrite, 4.07% chlorite, 10.30% grossular and 1.65% admontite minerals. Whereas Kulli Koh ore is containing 51.16% hematite, 29.24% quartz, 8.89% dravite, and 8.76% kaolinite minerals.

(ii)   The pyrite in the Zard Koh and quartz in Kulli Koh are the major gangue minerals, and both are diamagnetic in nature. Whereas, maghemite to be ferromagnetic in Zard Koh oreand hematite to be paramagnetic in Kulli Koh ore are the major source of Fe. It's worth mentioning here that, the hematite in Kulli Koh iron ore deposits is of micaceous in nature.

(iii) Keeping in view the mineralogy of the ores and magnetic property of the valuable and gangue part, it is envisaged that magnetic separation for both minerals would be suitable technique to upgrade these ores.

(iv)   The micaceous nature of hematite in the Kulli Koh ore deposits suggest that density separation technique would not produce good results.

ACKNOWLEDGMENT

REFERENCES

[1]   Islam, N., and Khan, J.A., "Kulli Koh Iron Ore Deposits, District Dalbandin, Chagai, Balochistan, Pakistan: A Case Study", International Conference on Earth Science, National Centre of Excellence in Geology, University of Peshawar, Pakistan, August 29-31, 2014.

[2]   Abro, M.I., Pathan, A.G., Mallah, A.H., and Bohm, A., "Mineralogical Characterization of Dilband Iron Ore Deposits of Balochistan, Pakistan", Mehran University Research Journal of Engineering & Technology, Volume 27 No. 2, pp. 206-210, Jamshoro, Pakistan, April, 2008.

[3]   Rao, D.S., Kumar, T.V., and Rao, S.S., "Mineralogy and Geochemistry of a Low Grade Iron Ore Sample from Bellary-Hospet Sector, India and Their Implications on Beneficiation", Journal of Minerals & Materials Characterization & Engineering, Volume 8, No. 2, pp. 115-132, 2009.

[4]   Bilqees, R., Haqqani, F., and Khan, F., "Mineralogical Characterization and Evaluation of Manganese Ore from Bajaur Agency, Khyber Pakhtunkwa, Pakistan", Journal of Himalayan Earth Sciences, Volume 47, No. 1, pp. 1-8, 2014.

[5]   Ogwuegbu, M., Onyedika, G., Hwang, J.Y., Ayuk, A., Peng, Z., and Andriese, M., "Mineralogical Characterization of Kuru Cassiterite Ore by SEM-EDS, XRD and ICP Techniques", Journal of Minerals & Materials Characterization & Engineering, Volume 10, No. 9, pp. 855-863, 2011.

[6]   Mohanty, J.K., Jena1, M.S., and Paul, A.K., "Integrated Mineralogical Characterization of Banded Iron Ores of Orissa and Its Implications on Beneficiation", Journal of Minerals and Materials Characterization and Engineering, Volume 11, pp. 1133-1142, 2012.

[7]   Kiptarus, J.J., Muumbo, A.M., Augustine, B., and Stephen, K., "Characterization of Selected Mineral Ores in the Eastern Zone of Kenya: Case Study of Mwingi North Constituency in Kitui County", International Journal of Mining Engineering and Mineral Processing, Volume 4, No. 1, pp. 8-17, 2015.

[8]   Abro, M.I., Pathan, A.G., and Mallah, A.H., "Assessment of Mesh of Liberation of Dilband Iron Ore, Pakistan", Mehran University Research Journal of Engineering & Technology, Volume 29, No. 3, pp. 455-464, Jamshoro, Pakistan, July, 2010.

[9]   Khoso, S.A., "Beneficiation of Zard Koh and Kulli Koh Indigenous Iron Ore Deposits", M.E. Thesis, Mehran University of Engineering & Technology, Jamshoro, Pakistan, 2016.