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THE CHARACTERIZATION AND MINERALOGICAL STUDIES OF COPPER ORE IN RANGIN FLEZ INDUSTRIES, KERMAN, IRAN

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Abstract

In this project the aim is the characterization and mineralogical studies of ROM ore by the XRF-XRD Technique for identification of minerals under polarizes microscope the study of ore minerals like Chalcopyrite, Pyrite, Hematite, Mica, etc., has been identified, the studies show that about 5% are opaque minerals. Mineralogical studies show that the major gangue minerals are such as Siderite, Quartz and Pyrite. Pyrite could be observed in the forms of dark mineral in polished specimens that include 10% of mineral, by counting it. Liberation studies indicate that +75 microns is the optimum liberation size and thus, recommended for flotation unit of the Rangin Flez plant.

Keywords: Altered phases, Chalcopyrite, Characterization, Copper ore, Geometallurgy, Miduk, Mineralogy, Pyrite.

1. Introduction

Historically, the most profitable copper mines have been the giant porphyry deposits that supply up to 60% of the world's copper [1]. The majority of the existing copper mines, as well as new discoveries, are increasingly operating under stricter operational, financial and environmental regulations, in more remote areas, on deeper, harder and more mineralogically complex ores [2, 3]. According to Baum et al. [2], a potential solution enabling improved efficiency is through the more efficient use of the inherent mineralogical properties of the ore body, which ultimately governs minerals beneficiation performance. The importance of designing and operating plants using mineralogy data is becoming increasingly more widely recognized through the discipline of process mineralogy [4-6]. As stated by Baum et al. [2], process mineralogy can be utilized to identify, diagnose and predict the behaviour of an ore during mineral processing and as such can be used to predict and optimize mining and mineral separation processes. The ore mineralogy and, more importantly, the texture of an ore control how the ore can be mined and processed [7]. This information can be used in forecasting the plant performance [3, 8]. Both process mineralogy and geometallurgy however, rely on the availability of mineralogical information characterizing the composition of the valuable gangue minerals and the textural interrelationships [2, 3, 6, 9, 10].

Based on a study by Baum [6], in turn, this information can be used in understanding and predicting ore throughput, grade and recovery to forecast potential downstream problems linked to ore variability ultimately leading to a reduction of the associated processing risks. Non-metallic unwanted gangue minerals that are often present are Quartz, Feldspar and Sericite [11, 12]. Henley [13] describes process mineralogy as the application of mineralogical information to predict metallurgical performance, adding that if process mineralogy is to be effective, the mineralogist must have comprehensive mineralogical data and a good understanding of what this information means to the metallurgist [2, 13, 14]. This was accomplished by merging two disciplines, mineral processing and mineralogy, whereby mineralogical information such as bulk mineralogy, liberation and gangue mineralogy would be given to the metallurgist to use in conjunction with pilot plant testing chemical data (i.e., assays) to characterize, diagnose and predict the potential performance limitations during operations [2, 13].

These units are based on a review of geological data including host rock, alteration, grain size, texture, structural geology, grade, sulphide mineralogy and metal ratios with focus on characteristics, which are known to affect metallurgical performance [9, 15]. Process mineralogy has been used to solve and understand problems that occur throughout the mining cycle [16-19]. Cropp et al. [1] discuss examples of porphyry copper deposits where process mineralogy has been used to evaluate the effect textural variations and gangue mineralogy have on copper recovery by flotation. An investigation by Bradshaw et al. [20] showed how process mineralogy was used to identify the cause of low Chalcopyrite recoveries at the Kennecott Utah Copper Concentrator [20].

In this study, we focused on the mine and pilot plant are located at 40 km North East of Shahr-e Babak, region of Kerman Province, near to Miduk mine. The feed to the pilot plant has been provided from Miduk copper mines. It has occurred on Sanandaj Sirjan Zoon, Orumiyeh Daughter Zoon, in central parts of IRAN, and that is one of the copper deposits in the forms of distribution (porphyry) in the host rocks. The important porphyry mineralization could be seen on Oromie-Poldokhtar zone, Fig. 1 shows Oromie-Poldokhtar zone and research area.

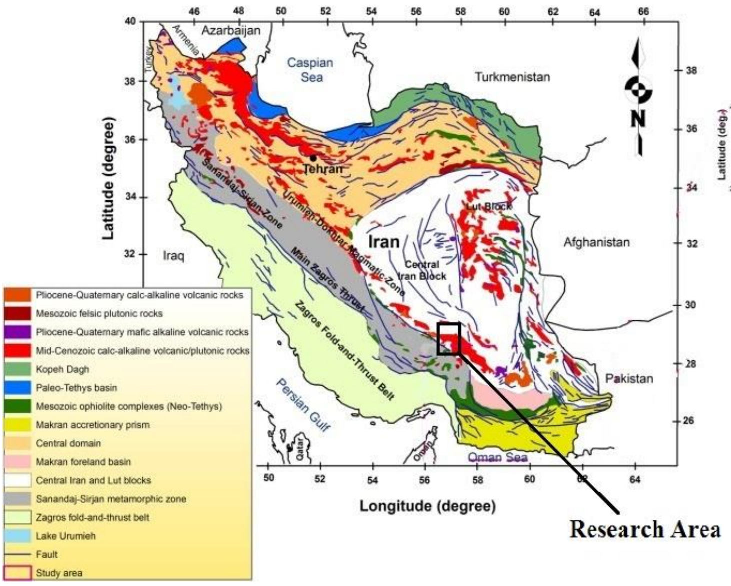


Fig. 1. Geological map of Oromie-Poldokhtar zone (red colour from Northwest to Southeast of Iran) [21].

According to Pellant [22], the most important sources of copper are native Copper, Chalcopyrite, Chalcocite, Bornite, Covellite, Malachite and Azurite; but the most abundant mineral in the area is Chalcopyrite.

2. Materials and Methods

During field visit, about 40 hand-picked specimens were collected for mineralogical studies (using photomicrographic analysis of polished and thin sections of the samples). These representative samples were drawn by sampling time interval from belt conveyor every ten minutes, as a result, more than 200 kg of samples were taken for the various analyses and tests. The sample was crushed in two stages with a Jaw crusher and cone crusher respectively and the crushed products classified to 100% passing 1.4 mm as applied the plant's comminution circuit. The crushed products were thoroughly mixed for homogenization (or uniform distribution) and then subjected to further sampling by riffling to get four batches of one kg each for chemical analyses, sieve analyses, XRD and XRF studies. In additional the above studies, 10 polished sections and 7 thin sections were prepared for mineral identification and liberation studies of a mineral by examination under a polarizing Dual-purpose microscope. Wet sieve analysis was also performed and each size fraction from the result of the analysis was subjected to chemical compositional analysis by AAS and XRF to determine the copper distribution in each size fraction. Additionally, the distribution of copper in the samples studied under the polished as well as thin sections for the purpose of determining liberation size by modal counting under the polarized microscope was confirmed by XRD, analysis.

Each size fraction from the sieve analysis, the polished and thin section were carefully studied to determine the degree of liberation as shown in the section on page 10. Similarly, the results of wet sieve analysis complemented by chemical compositional analysis by AAS and XRF gave copper distribution in each of the size fractions as represented in Table 1. Results of photomicrographic and modal analysis of polished and thin sections of each size fraction, which was also confirmed by XRD analysis, indicate the presence of minerals such as Chalcopyrite, Hematite, Quartz, and few others as the major minerals in ore as outlined in Table 2 and XRD curves in Fig. 2. We used the ASTM standard in all calculation and analyses.

Table 1. Chemical analysis (XRF).

Composition	Percentage	Composition	Percentage
SiO_2	56.1	TiO_2	0.66
Al_2O_3	15.9	Na_2O	0.58
K_2O	5.4	CuO	0.8
SO_3	5.4	CaO	0.16
Fe_2O_3	7.2	La-Lu	<1
MgO	1.2	LOI	6.61

Table 2. XRD results.

Type of minerals	
Quartz	Clinochlore
Muscovite	Feldspar
Alunite	Chalcopyrite
Sanidine	Hematite

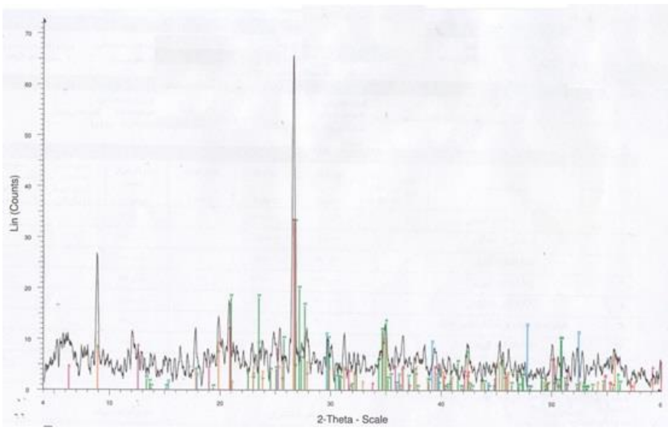


Fig. 2. XRD curves.

3. Results and Discussion

3.1. Mineralogical studies of size fractions

Results of size distribution analysis of the ore from Miduk Copper Mine was performed in order to determine the degrees of liberation to understand the relationship of ore and gangue minerals showed that 75 micron is the size of liberation as shown in Table 3. As you can see in Table 3 and Fig. 3, the most copper grade (0.92 % Cu) is also in the same size fraction.

Table 3. Result of the sieve analysis.

Mesh no.	Micron	Weight retained (g)	Percent retained	Percent passed	Cu total (%)	CuO
1	1000	168.95	16.30	83.69	0.57	0.06
2	710	158.13	15.25	68.43	0.71	0.07
3	500	126	12.15	56.28	0.77	0.08
4	355	97.11	9.37	46.91	0.8	0.1
5	250	85.45	8.24	38.66	0.73	0.11
6	180	53.52	5.16	33.50	0.91	0.11
7	106	116.05	11.19	22.30	0.88	0.13
8	75	65.7	6.33	15.96	**0.92**	0.13

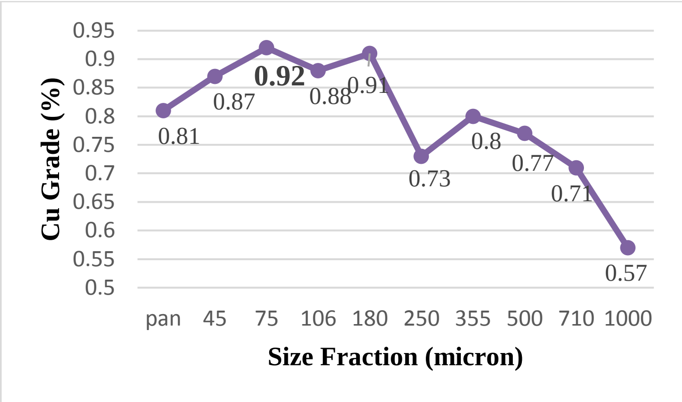


Fig. 3. Size fraction on Cu grade.

3.2. Chemical analysis

The results of chemical compositional analyses by AAS and XRF on samples collected from the ROM are presented in Table 2.

3.3. Identification of the host rock

The thin sections and polished sections prepared from samples (Fig. 4) shows the distribution of opaque minerals [23]. On the basis of mineralogical studies of thin and polished sections, it is discovered that the host rock has been altered and minerals such as Quartz and Sericite (in fine grains of Muscovite and Illite) were identified as shown in polished sections and figures.

Minerals in this kind of association can be separated by washing with Sodium and Potassium elements in the regular component, minerals of aluminium and magnesium silicate [24, 25]. Based on Robb [26], the alteration of filik mineral depends upon of copper porphyry minerals, but it associated by mesothermal with precious metals and massive sulphides within felsic rocks.

Studies of thin section show that the most important and abundant of the ore minerals are Sericite with fine grains, Quartz, and Pyrite (Fig. 5), altered and weathered Feldspar (Fig. 6), Primary Biotite (Fig. 6) and Secondary Biotite (Fig. 7). Pyrite is the most abundant mineral observed in a polished section with opaque appearance under the ore microscopic constituting about 10 to 15% of grains, which is covering 90% of opaque phase. It is clear that Pyrite is the mineral dispersed on the polished sections as shown in Fig. 4.

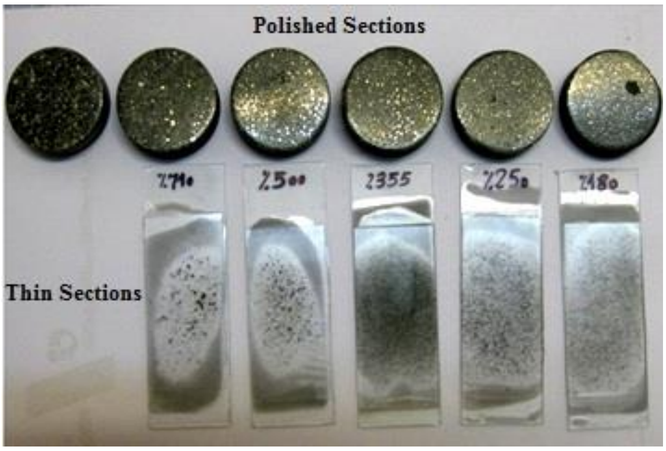


Fig. 4. Polished and thin sections for micrographic studies.

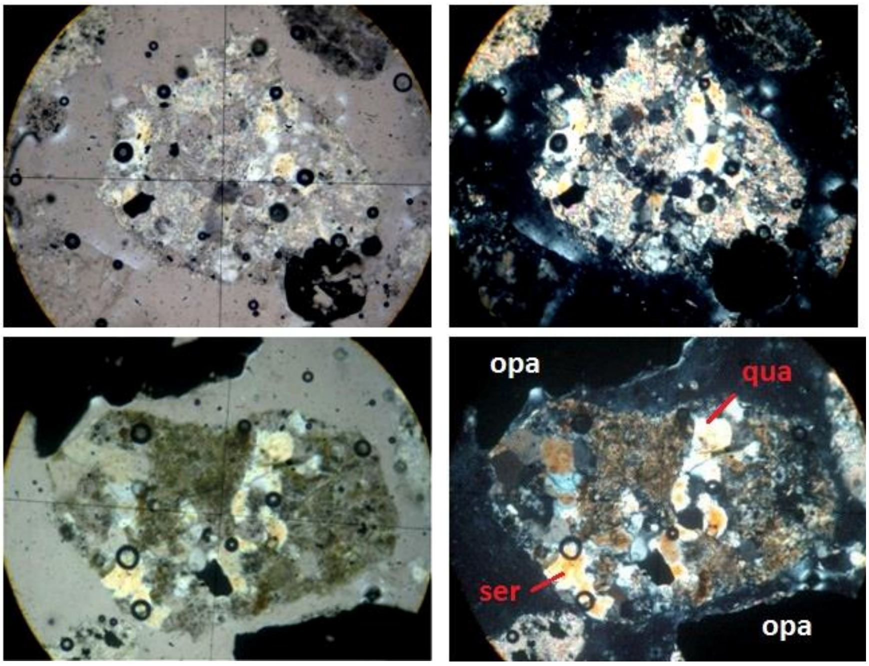


Fig. 5. Opaque minerals with Sericite and Quartz in Pyrite phase (ppl : 1 mm).

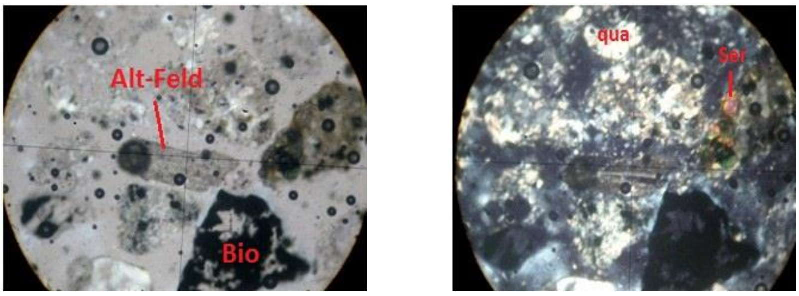


Fig. 6. Altered Feldspar along with less clay mineral ppl : 1 mm.

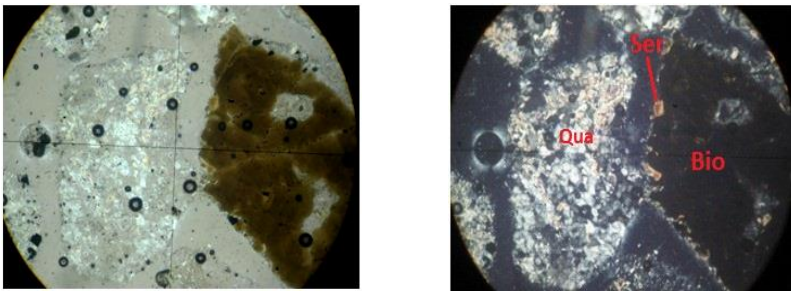


Fig. 7. Illustrated Sericite-Quart along with Biotite ppl : 1 mm.

3.4. Mineralogical studies of copper phase

More than 90% of the opaque mineral are grains of Pyrite, which covered on the polished sections and could be considered as opaque gangue mineral (Fig. 8). Microscopic studies show that the important mineral identified is Chalcopyrite along with Pyrite (Fig. 9).

Some minerals are observed to have been altered as shown by the alteration of mineral grains such as Chalcopyrite to Chalcocite (Fig. 10).

Figure 11 shows grains of altered Chalcopyrite to Chalcocite-Covellite with grade of 70-90 %, which are interlock with Pyrite.

Figure 12 shows a grain with a grade of 70-90% Chalcopyrite with the size of 150 microns with less alteration to Chalcocite-Covellite.

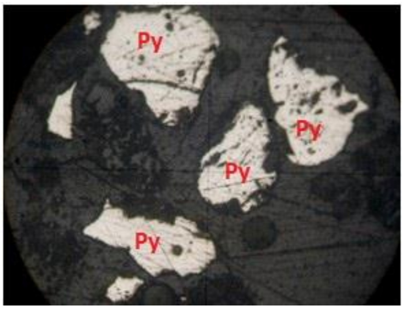


Fig. 8. Free Pyrite mineral. ppl : 1 mm.

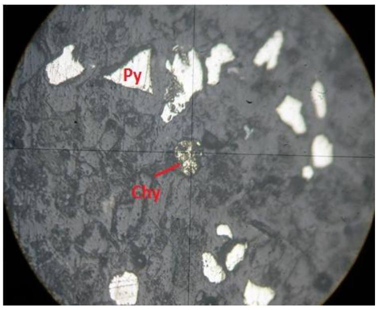
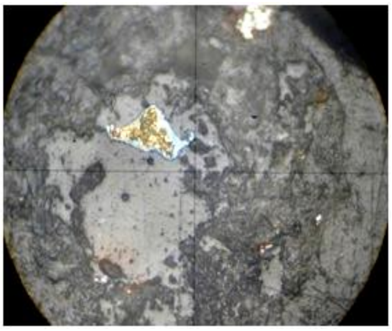


Fig. 9. Relative abundance of Pyrite compares to Chalcopyrite.



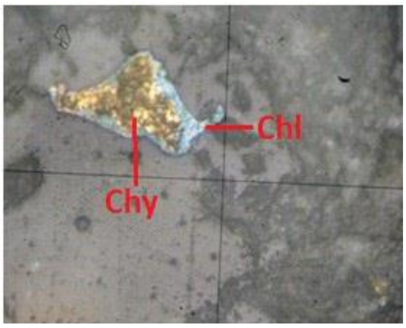


Fig. 10. Chalcopyrite along with altered Chalcocite. ppl : 500 microns.

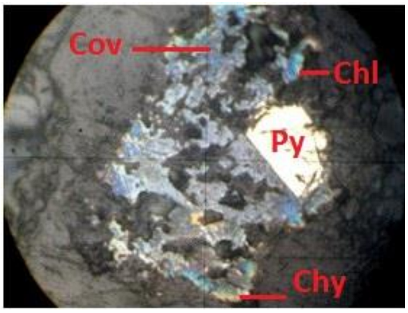


Fig. 11. Altered grains of Chalcopyrite to Chalcocite-Covellite (blue-dark blue) with grade of 70-90%.

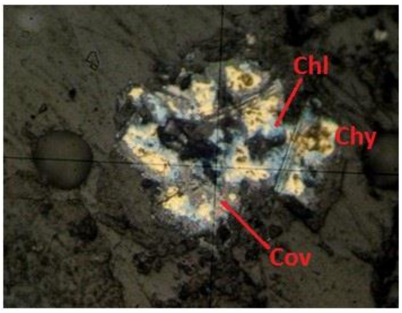


Fig. 12. Grain of Chalcopyrite with minimum alteration.

3.5. XRD studies

This method has been used for identification of minerals and their crystallization characteristics as well as for assessing the abundance of each mineral phase in a mixture of the 75 microns representative sample used for the analysis employing a Philips powder diffraction unit. The XRD studies show that copper is present in abundance in the ore.

3.6. Grain survey and sieves analysis

The standard sieve analysis carried out on representative samples produced sieve size fractions, which were subjected to chemical analysis to determine the amount of copper present in each fraction. Table 3 shows the percentage of copper in each size fraction and Fig. 13 presents the cumulative size distribution plot for particles passing. This figure shows that a greater percentage of grains in the sample have sizes less than 1000 microns and less than 20 percent of grains have a size in the range of 75 microns.

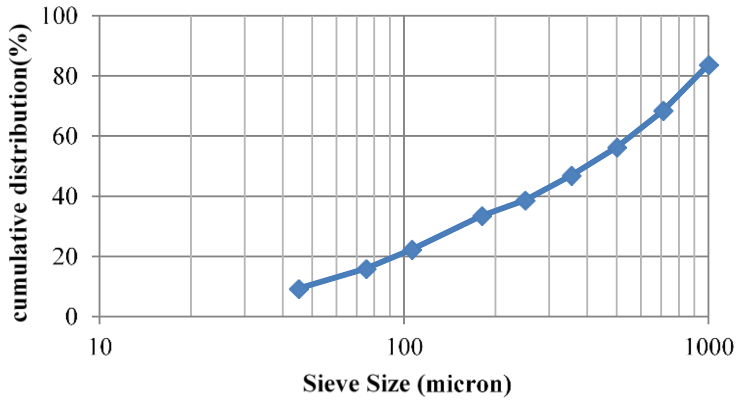


Fig. 13. Cumulative passed weigh, *d_{80}*.

3.7. Determination of free particles size distribution

To determine free particles size distribution, the quantity and quality of grains (free and locked) in the test samples were analysed from which, the quantity of copper is estimated [27]. The chemical analysis results and grains counting (modal analysis) in each of the size fractions were employed to determine the percentage of Chalcopyrite and alternated minerals such as Chalcocite and Covellite in the samples [27]. Grade analysis of all size fractions shows that grain with a grade less than 10% copper and grain size in the range of 10-30%, 30-50%, 50-70%, 70-90% and more than 90% copper grade has been segregated.

The free particles, and particle size distribution were estimated by counting specific grains in each size fraction of the samples under the ore microscope and determined using Eq. (1) [27].

$$\text{Degree of liberation} = \frac{\text{volume of free valuable minerals}}{\text{volume of available valuable minerals}} \tag{1}$$

3.7.1. Coarse particles

As explained earlier the opaque phase has been covered on the particles size fraction, and Pyrite is the most important sulphide phase in the polished sections. As explained earlier the opaque phase has been covered on the particles size fraction, and Pyrite is the most important sulphide phase in the polished sections. For this reason and based on the result obtained, most of the Pyrite mineral is presented almost in all size ranges and less Chalcopyrite is seen in addition to the copper sulphide in the range of 50-150 microns and in the coarse particles at about 500 microns. Coarse particles are less abundant in quantity compared to the fine grains. This is the reason for the predominance of free copper in the fine fraction making up to 10% of the count. For this reason, none of the free grains of copper is found in the polished sections and specimens as can be seen in the fractions from +1 mm, +710 microns and +500 microns. Therefore, the degree of liberation in such size fraction is zero.

3.7.2. +355 micron size fraction

In this size fraction, we found the copper mineral grains with high assay values. In a count of 16 grains, 3 grains have a grade of 19%, 11 grains assay 11% and the remaining 2 grains have assay grade value of between 10-70%. Only 70% of copper grains in this size fraction assayed less than 10% grade. Thus, high-grade values are projected for this size range as the majority of free copper minerals with more than 90% assay are seen here. In the polished section specimens, 57 grains were counted and recognized out of which, 16 grains (20%) are copper and the rest of up to 46% contained Pyrite with more than 90% in 30 grains. Therefore, in this size, fraction only Pyrite has been liberated instead of Chalcopyrite, which constitutes is more abundant at approximately 65% while the amount of Pyrite is less than 10% since only 5 grains of are present. This means that only 11% of grains are interlocked with Pyrite and silicate phase and rest of grains are Pyrite and are free.

3.7.3. Size fraction of +250 microns and +180 microns

Evidence of free copper phase is presented in the polished sections at this size fraction +250 microns. The degree of liberation for copper phase (Chalcopyrite, Chalcocite and Covellite) is about 60% (Table 4). The mineralogical studies of polished sections at +180 microns shows that the degree of liberation is approximately 67%, which is about 7% greater than the liberation at +250 microns. Figure 14 shows the degree of liberation in important size fraction as for grain counted and free grain that makes a degree of liberation.

Table 4. Detail of liberation size in +75, +180 and +250 micron size fraction.

Size fraction (micron)	The number of grain counted that *X* is percentage of copper mineral						Grain counted	Degree of liberation
	$x = 100$	$x = 80$	$x = 60$	$x = 40$	$x = 20$	$x = 10$		
+250	6	1	3	2	1	2	15	60
+180	11	1	5	2	2	3	24	67
+75	29	-	-	-	-	2	31	99

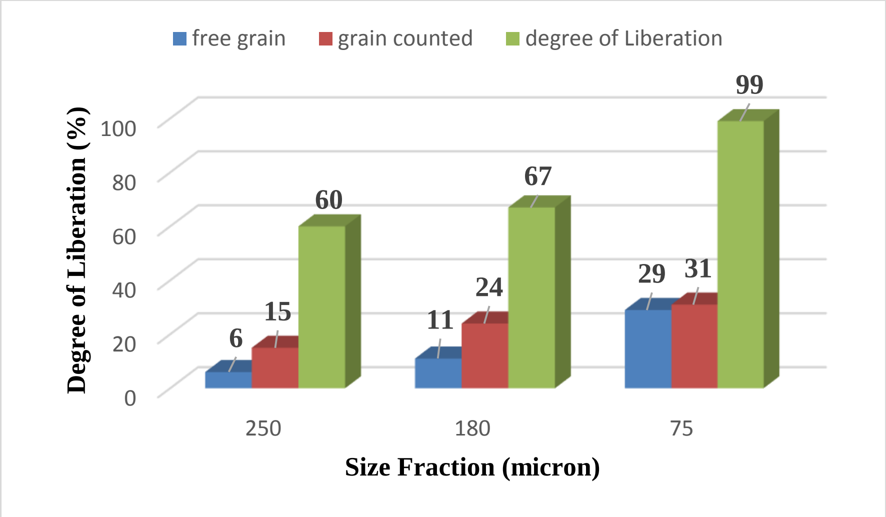


Fig. 14. Degree of liberation in important size fraction.

3.7.4. +75 micron size fraction

Mineralogical studies reveal that approximately all of the copper grains are liberated in this size fraction. The degree of liberation is about 99%. Therefore, in this size fraction, copper, as well as Pyrite, is completely liberated. Table 4 shows the details of liberation studies. As stated by Fuerstenau and Han [28], in smaller sizes, such as +45 microns, there was no complete review due to the fact that the flotation could not be efficient.

4. Conclusions

Based on results of the investigation and studies carried on the feed (run-off-mine - copper ore) of Rangin Flez pilot the following conclusions can be made:

- The major gangue minerals are silicate minerals and are approximately 56% and cleaning stage of the flotation it must be depressed by suitable reagents namely silicate sodium and the minor gangue in percentage and importance comparison is Pyrite that also must be depressed too with suitable reagents.
- The major ore minerals are Chalcopyrite and altered Chalcocite and Covellite.
- On the basis of size fraction analysis, mineralogical studies, modal analysis and chemical compositional analysis, two size fractions (+75 and +180 microns) of the ore are closer to each other in terms of liberation and value contents.
- Based on the sieve analysis, chemical analysis, and mineralogical studies, the liberation size has been estimated to be at +75 microns.

Nomenclatures

d_{80}	d_{80} is the diameter at which, 80% of the sample's mass is comprised of particles with a diameter less than this value (Fig. 13)

Abbreviations

AAS	Atomic Absorption Spectroscopy
ASTM	American Society for Testing and Materials
LOI	Lost on Ignition
La-Lu	Lanthanum and Lutetium
ppl	Plane Polarize Light
ROM	Run of Mine
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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