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MINERALOGICAL AND PHYSICO-CHEMICAL CHARACTERIZATION OF BARITE WASTES FROM AIN MIMOUN DEPOSIT (KHENCHELA, ALGERIA)

Purpose. Mineralogical and physico-chemical study conducted on barite wastes from Ain Mimoun deposit (Algeria) aimed at characterizing theses wastes which occupy thousands of hectares in the vicinity of the plant and present a crucial problem for the population and environment.

Methodology. The investigation was carried out by X-Ray Diffractions (XRD), Scanning Electron Microscope (SEM), X-Ray Fluorescence (XRF), Infrared Rays (IR) and microscopy analysis in addition to thin sections analysis.

Findings. On the one hand, the wastes contain the sulfate of barium as a useful mineral with an acceptable grade of 19.7 %, and, on the other hand, they contain associated gangue minerals that are represented by calcite and silica (17 and 46.1 % respectively) in addition to clays as presented by alumina oxide (8.32 %).

Originality. The originality of this research is the characterization of theses wastes with the purpose of confirming their negative effect on the population and environment which poses a crucial problem.

Practical value. The results obtained supplement the information on barite wastes of Ain Mimoun and allow suggesting a suitable enrichment method which will be applied with the aim of obtaining a high-grade barite ore complying with the requirements of consumers.

Keywords: *Ain Mimoun, barite ore, waste, characterization, valorization, Algeria*

Introduction. Barite is one of the most important industrial minerals; it contributes largely to the economic and industrial developments in the world. It is used in several industries such as drilling mud, in production of industrial wares such as glass, radiation shields and as a source for barium-based chemicals in addition to paints, textiles, paper, rubber, plastics, medicines, cosmetics productions and as a value addition in cars, electronics, TV screens industries. It is also applied in radiology for X-Ray examination of the digestive system as an absorber of radiation [1, 2].

The efficient and economical use of barites depends on qualities and properties comparable to generally acceptable specification standards.

Barite is mainly produced from primary barite deposits, where barite has been considered the useful mineral. However, there is a growing trend in ore processing which contains barite as a gangue mineral, which can be applied as a secondary mineral [3, 4]. In recent years, the growing demand of raw material coupled with deterioration and exhaustion of high-grade ore resources have made a serious problem on a the global scale, and the processing of low-grade barite represents the actual solution not only for ensuring the continued availability of raw materials meeting the current demand but also for the environmental consideration [5, 6].

Research studies on valorization are linked with physico-chemical and mineralogical composition of minerals and their liberation size of useful minerals from gangues [7] where extracted material of barite ores is generally enriched using magnetic separation, gravity separation, flotation and other mineral processing methods. Magnetic separation is carried out according to the magnetic differences between barite and iron oxide minerals, commonly used in the sorting of barite raw material which require a low percentage of iron oxides. With gravity separation, namely, when raw ore is processed by washing, crushing and grading of the mud, jig, shaking table or other gravity separation methods, a better quality concentrate can be obtained (80 %). Flotation is often used to treat such barite ore in the case of quite complicated composition. As for fine-grained disseminated ore and the tailings of gravity separation, the flotation method is better where it can greatly improve the grade of the barite concentrate. Therefore, flotation in the barite processing has a large development space

[8, 9]. Flotation technology is applied on finely disseminated ores to separate the barite mineral from the associated gangue components. A large number of barite producers utilize the flotation only to recover and improve the grade of barite [10–12].

In Algeria there are several mines of barite ore, the most important ones are located in the north of the country in Ain Mimoun (Khenchela), Boucaid (Tissemsilt), Mellal (Tlemcen) and Koudiat Safia (Medea). In addition, mining research has made it possible to highlight several deposits in the South-West of Algeria near the state of Bechar including Draïssa South-West, Djebel Draïssa, Draïssa North-East and Draïssa Guelb El Tahtani with total reserves of 7 million tons of barite ore [13].

The treatment of this mineral at Ain Mimoun (Khenchela) is carried out using gravimetric separation by jigging where the reject issues of beneficiation method, on the one hand, contain an acceptable grade of barite sulfates and, on the other hand, occupy thousands of hectares in the vicinity of the plant, presenting a crucial problem for the population and environment.

These characteristics of barite wastes pose a problem, and raise a challenge for mineral processing researchers to enrich its grade and to reduce the environmental impact while obtaining merchant products.

Study area description. Ain Mimoun deposit is extending on the northern flank of the anticlinal of Khenchela, on a total area of 614 hectares. The deposit is located about 10 kilometers North of Tamza town, 8 km of the South-West of the Daira of El Hamma and about 16 km to the West of Khenchela city where it is related administratively. The geographic location is illustrated in Fig. 1.

Local Geology. *Morphology of the mineralized body*: The contact sill-rock country is:

Brechique: If the rocks are soft, marls, marly sandstone and marly limestone.

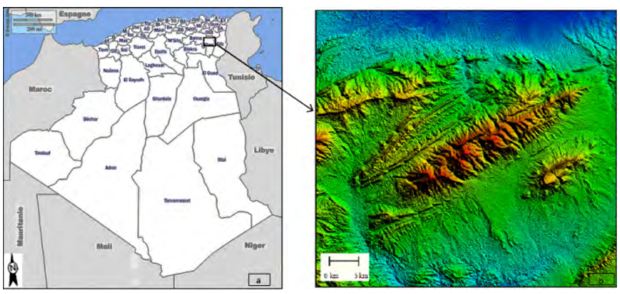
Well net: If the rocks are limestones, dolomites and consolidated sandstone.

The thickness or capacity of the veins is:

1. Sup. of 1 meter up to 3 m: in the tender series.
2. Inf. of 1 meter: in the hard series.

The length and shape of the veins also vary according to the nature of the country:

- in the marl series, the veins are a little curved and can sink deeply;



a *b*

Fig. 1. Geographical location of the studied area:

a – geographic map of Algeria; b – DTM digital terrain model of the area of the studied mines

- in the most carbonated series, the veins are straight in shape, but usually broken by post-mineralization breaks;
- the barite veins terminate at the end either as a bevel or fork.

Mineral paragenesis barite comes in two types:

Barite 1: of aggregates with fibrous and actinic form structure.

Barite 2: or barite of the second stage, is presented by smaller crystals (from 0.03 to 0.2 mm) forming isometric granular ranges between the barite 1.

The Quartz comes under two generations:

Quartz 1: cast, gray, in the form of allotriomphic separations (from 0.1 to 0.5 mm), develops in the part of the contact of the vein and contains a large number of intercalations of country rocks.

Quartz 2: found in the barite mass with form of automorphic crystals, prismatic (from 0.2 to 1.2 mm) as well as separations in broom.

The panabase: in the form of rounded and angular shaped grains (from 0.05 to 0.5 mm) forms the dissemination in barite along the weakened links. In free cavities, the panabase forms as larger separations accompanied by prismatic quartz.

The chalcopyrite: occurs as irregular separations along cracks in Barite.

The sphalerite: rounded grain shapes (0.01 to 0.2 mm) are found within the barite belonging to the salbands.

The cinnabar is represented by the scattering of grains (from 3 to 4 mm) together with the panabase and develops in the part of the vein that joins the salbands.

The calcite is in the form of separations with irregular contours (from 0.02 to 0.3 mm), also found in rocks in the form of venules.

The coarse-colored brown-colored dolomite is developed in the central part as venules and irregular separations.

The iron hydroxides are regularly dispersed in contacts along cracks, as well as in inter-grain expanses.

The malachite and azurite are found in the form of separation and isolated nests, as results of the oxidation of copper.

Generally, these metalliferous indices are negligible and have no economic interest.

Acid mining drainage (AMD). Acid mining drainage (AMD) from mining wastes is one of the current environmental problems in the field of mining pollution that requires most action measures. This term describes the drainage generated by natural oxidation of sulfide minerals when they are exposed to the combined action of water and atmospheric oxygen [14].

Algeria is privileged to feature the occurrence of many minerals, often in large quantities and of strategic importance to it. The country has several deposits which produce large quantity of wastes. One of the most important of them is the barite of Ain Mimoun – Khenchela, where the wastes of processing operation are deposited in the nature (Fig. 2) and because barite ore is rich in sulfates in addition to the stock conditions in the presence of oxygen and rain water, all these make AMD simply to be real and cause an important influence on the environment.

Fig. 2. Stock of wastes of barite processing of Ain Mimoun

The overall goal is to perform a profound characterization and propose an environmental managing in order to reduce impacts of barite wastes.

Methods and materials. ***Sampling.*** A series of samples of Ain Mimoun barite wastes were taken from the stock of wastes. Total quantity of samples is estimated at 100 kg of weight, they have been taken from several points so that they are completely covering the lot (to represent various types of mineralization). The choice of sampling points was random to ensure better representativeness of the samples because this method ensures as much as possible that every unit in the lot has an equal chance of being available in the sample. The taken samples have a maximal diameter of 200 mm.

Size Analysis. The size analysis was operated using the quantity of 600 grams which was dried in an oven at 105° C for 24 hours in order to avoid clogging of material in the sieves. The operation has been carried out in an automatic sieve shaker of D407 type and sieves series assembly of: 16, 8, 4, 2, 1, 0.5, 0.25, 0.125 and 0.053 mm. The sample is sieved for 40 minutes with magnitude of 60 mm/g. The refusal mass of each sieve is weighed using a scale with an accuracy of 0.01 g.

Determination of the density of each size fraction. Density is the ratio of the density of a solid to the density of the liquid used (water, in general). There are several methods to determine the density; we use the method of Chatelier in our present study according to API standard.

Mineralogical analysis.

XRD analysis was carried out using a PANALYTICAL diffractometer characterized by current and voltage equal to 40 mA, 45 Kv, respectively.

XRF analysis was done in the Elegant Materials Research Unity (EMRU) at Farhat Abbas – Setif 1-University, using wave length dispersion X-Fluorescence microscopy type Rigaku ZSX Primus IV.

IR analysis was applied with a spectrometry type SHIMADZUE FTRI 8400S.

MEB analysis was carried out using a machine type JEOL, JSM-6390.

Microscopy analysis. The refusal masses prepared with size analysis were washed using a sieve with an aperture of 0.074 mm under water flow rate equal to 0.39 m^3/h in order to eliminate clay materials to permit a clear view under petrographic microscope, on the one hand, and to find the liberation sizes, on the other hand.

Results and discussion. ***Particle size analysis.*** The results of sieving analysis are presented in Table 1. It is noted that the majority mass appears in the coarse fractions [+8, +4, +2, +1 and +0.5] by 78.85 %, which confirms the iron ore hardness. The rest minority products appear in the fine fractions [+0.25 mm +0.125, +0.053 and –0.053 mm].

The particle size analysis curve is of a concave shape so the material contains more coarse particles than fine particles. It shows us that the refusal of the slice (+4 mm) constitutes 51.21 % of the total volume of the starting sample. The fillers (–53 μ) constituted only 3.43 % of the total sieved mass.

Determination of the density of each size fraction. The results of the density of each size fraction of Ain Mimoun barite wastes are shown in Table 2 where it is not-

Table 1

Results of particle size analysis of Ain Mimoun barite wastes

Particle size (mm)		Yield (%)	Cumulated refusals (%)
+16		1.71	1.71
–16	+08	21.78	23.49
–08	+04	19.96	43.45
–04	+02	16.68	60.13
–02	+01	12.36	72.49
–01	+0.5	8.07	80.56
–0.5	+0.250	5.47	86.03
–0.250	+0.125	5.12	91.15
–0.125	+0.053	4.54	95.69
–0.053	+0	4.31	100
TOTAL		100	–

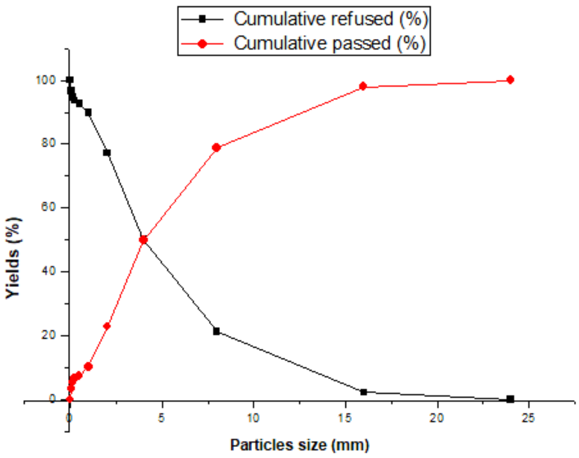


Fig. 3. The curve of the particle size analysis of Ain Mimoun barite wastes

Table 2

Results of density of size fractions

Particle size (mm)		Yield (%)	Density
+16	2.11	2.92	
–16 +08	19.10	2.81	
–08 +04	29.00	3.06	
–04 +02	27.00	3.04	
–02 +01	12.52	3.12	
–01 +0.5	3.00	3.06	
–0.5 +0.250	0.87	3.17	
–0.250 +0.125	1.01	3.22	
–0.125 +0.053	1.96	3.15	
–0.053 +0	3.43	3.20	
TOTAL	100	–	

ed that the grain size fractions richest in $BaSO_4$ are [–0.250 +0.125] and [–0.053 +0.00].

Mineralogical analysis by X-ray diffraction (XRD). The mineralogical characteristics of barite wastes showed the presence of the principal minerals sought and are indicated in Fig. 4. It is observed that barite, quartz, dolomite and calcite are the mineral phases present in the analyzed sample.

IR spectrometry. The results of infrared spectrophotometric analysis of Ain Mimoun barite wastes are shown in Fig. 5 and Table 3 it has revealed several main bands which confirm the correlation of different components of barite wastes.

XRF of raw material. The chemical analysis results are presented in Table 4. It is observed that silica (SiO_2), calcite (CaO) and sulfat of barium ($BaSO_4$) are the dominant compounds (75.80 %, the three) in the sample further alumina (Al_2O_3) ferrous oxide (Fe_2O_3).

SEM and EDS analysis. The microscopic observation was carried out under a scanning electron microscope (SEM). The results obtained confirm the previous results obtained by XRD and XRF analysis; Fig. 5 shows the presence of barite grains, calcite, dolomite and quartz.

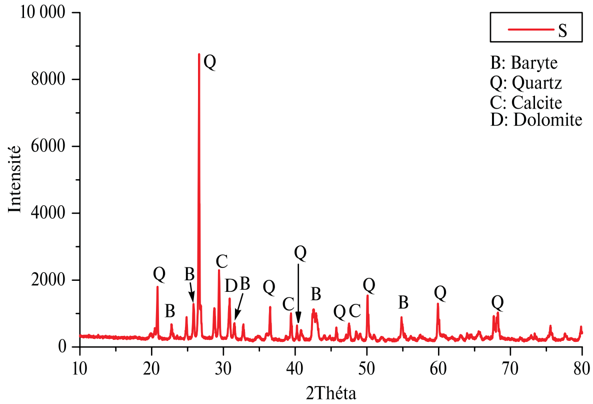


Fig. 4. X-ray diffraction spectrum of Ain Mimoun barite wastes

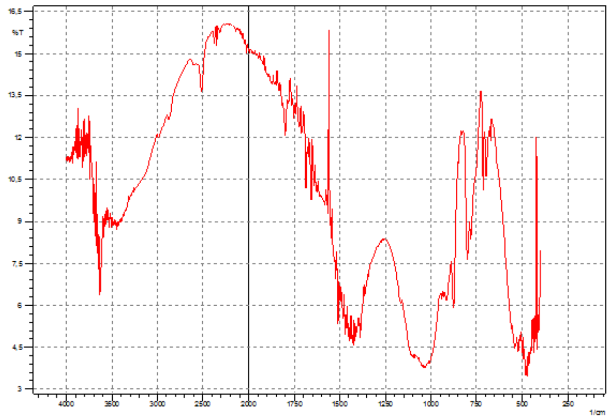


Fig. 5. Infrared spectrum of Ain Mimoun barite wastes

Table 3

Position and identification of the bands observed in the IR spectrum

Position in cm^{-1} and band intensity, cm^{-1}	Band identification
3650	Construction water band
3600	Band of OH construction
1100	Band of Si-O vibration
850	Band of Fe-O link
780	Band of Si-O-Al link
490	Deformation of Fe-O link

% T: Transmittance (%) 1/cm: Wave number (cm^{-1})

Thin sections. Four different thin sections were made from the collected barite wastes, where they were viewed under polarized light (Figs. 6–9), it showed the presence of dolomite grains associated with barite and quartz (Fig. 6), the barite grains appears with a prismatic forms (Fig. 7) and with prismatic slats form which were made by a rolling extinction (Fig. 8), the presence of calcite band in the background of barite mineral was also noted (Fig. 9).

The abbreviations of minerals names mentioned in Figures are extracted from [15].

Microscopic analysis. Microscopic observation showed that the ore has a coarse dissemination, the liberation of the useful minerals of its gangue begins from the fractions size of [–0.5 +0.25], [–0.25 +0.160], [–0.160 +0.100] and [–0.100 +0.074] mm. For better microscopic observation, samples of these fractions size were washed and dried.

The observation with binocular microscope is only qualitative, its shows the presence of Barite grains associated with gangue minerals (quartz and calcite) in the size class [–0.5 +0.25] (Figures). There are also grains of barite surrounded by gangue minerals (quartz and calcite) for the fraction of [–0.25 +0.160] (Figures). Nevertheless, in the particle size class of [–0.160 +0.100] and [–0.100 +0.074] mm the grains with barite minerals are almost totally liberated.

XRF of particle sizes. The results of the chemical analysis show that the barite content in the classes (–0.25

Table 4

XRF Results of Ain Mimoun barite wastes

$BaSO_4$	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	Fe_2O_3	CuO	ZnO	SrO	PbO
19.74	2.01	8.31	46.1	0.09	1.80	17.0	4.20	0.06	0.06	0.42	0.21

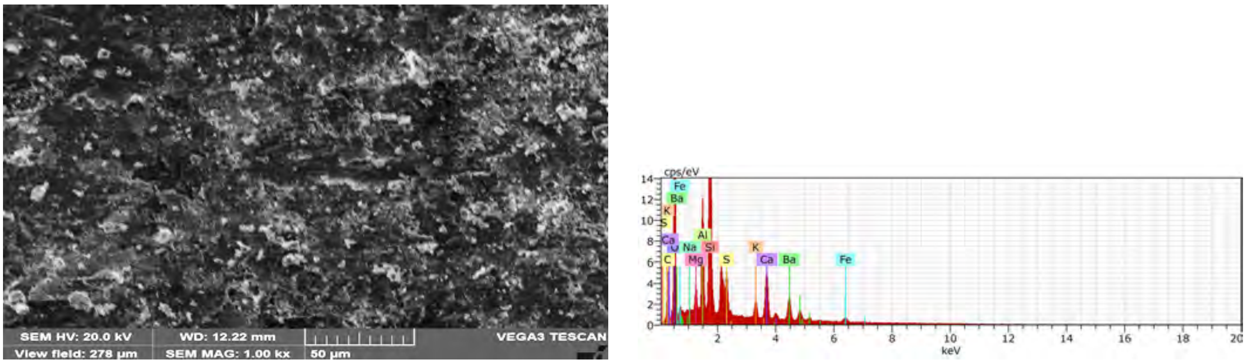


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Fig. 6. SEM and EDS of Ain Mimoun barite wastes

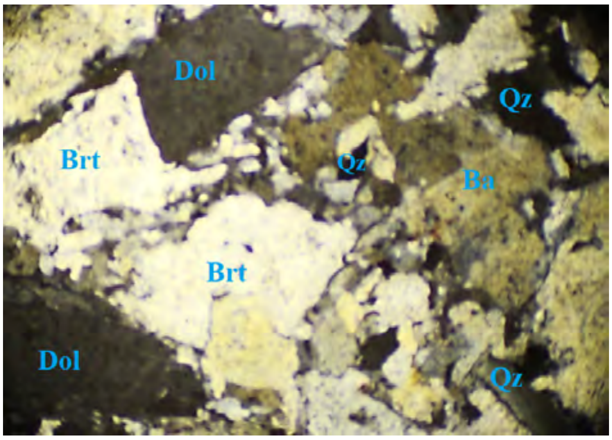

Fig. 7. The 1st thin section under polarized light: dolomite grains associated with barite and quartz (Dol: dolomite, Brt: barite, Qz: quartz)

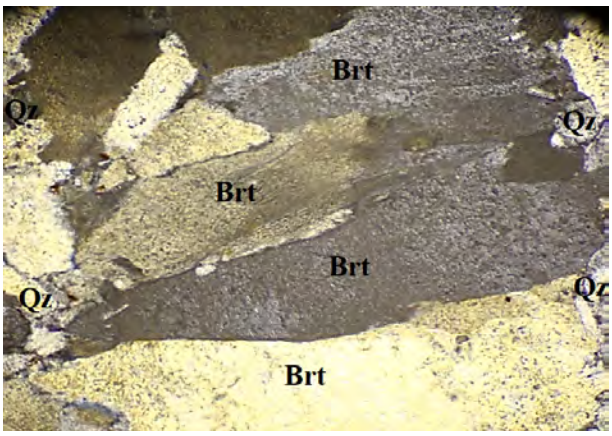

Fig. 8. The 2nd thin section under polarized light: grains of quartz with prismatic barite (Qz: quartz, Brt: barite)

+ 0.16) (0.16 + 0.1) (-0.1 + 0.074) reaches 70 %, while that of the class - 0.074 mm is 27.3 % (Fig. 5). For this purpose, the product must be reduced to 0.1 mm for

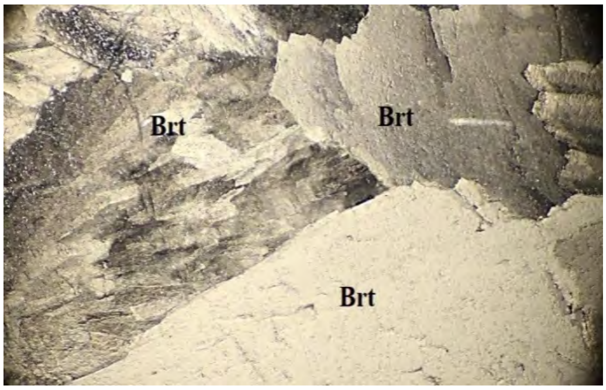

Fig. 9. The 3rd thin section under polarized light: prismatic slats of barite which were made by a rolling extinction (Brt: barite)

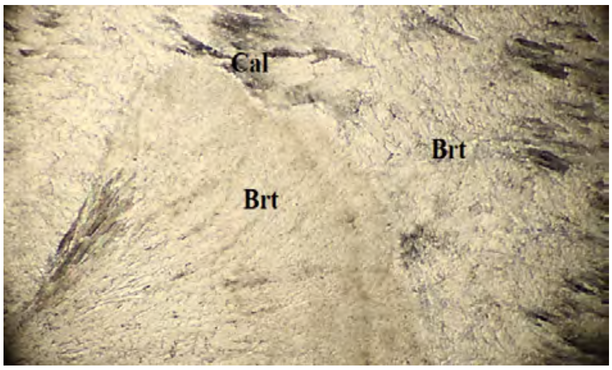

Fig. 10. 4th thin section under polarized light: calcite band in the background of barite mineral (Cal: calcite, Brt: barite)

better extraction, because the maximum release occurs at this limit.

Conclusion. The experimental results in the presented study lead to the following conclusions:

- the barite wastes of Ain Mimoun deposit, on one hand, contain an acceptable grade of barium sulfate

Table 5

Content of $BaSO_4$ in the size fractions of Ain Mimoun barite wastes

Size classes (mm)		$BaSO_4$ content (%)
–0.50	+0.25	37.1
–0.25	+0.16	69.4
–0.16	+0.10	71.1
–0.10	+0.074	69.7
–0.074	+0	27.3

($BaSO_4$) as a useful mineral with 19.7 % and, on the other hand, it contains associated gangue minerals which are presented by calcite and silica with 17 and 46.1 %, respectively, in addition to clays which are presented by alumina with 8.32 %;

- characteristics of barite wastes where they are rich in sulfates in addition to the stock conditions in the presence of oxygen and rain water make Acid Mining Drainage (AMD) simply to be real and cause an important influence on the environment;

- the research suggests enhancing further study of Ain Mimoun barite wastes in order to confirm the prior results (mineralogical characterization) and then to permit a suitable enrichment method to be applied with the aim of obtaining a high-grade barite ore which complies with the requirements of consumers (petroleum and pharmaceutical industries and others).

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Мінералогічна та фізико-хімічна характеристика відходів бариту з родовища Айн Мімун (Хеншела, Алжир)

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Мета. Мінералогічне й фізико-хімічне вивчення відходів бариту родовища Айн Мімун (Алжир) з метою дати характеристику даних відходів, що займають тисячі гектарів на території навколо підприємства та представляють серйозну проблему для населення й навколишнього середовища.

Методика. Дослідження проводилося із застосуванням дифракції рентгенівських променів (ДРП), растрового електронного мікроскопа (РЕМ), рентгенівської флуоресценції (РФ), інфрачервоних променів (ІЧП), а також мікроскопічного та шліфового аналізів.

Результати. Відходи містять, з одного боку, сульфат барію, що є корисним мінералом із допустимим вмістом 19,7 %, а з іншого боку, вони містять асоційовані порожні породи, представлені

кальцитом і кремнієм (17 і 46,1 % відповідно), на додаток до глині, у вигляді оксиду алюмінію (8,32 %).

Наукова новизна. Новизна даного дослідження полягає в описі характеру даних відходів з метою підтвердження негативного впливу на населення та навколишнє середовище, що представляє серйозну проблему.

Практична значимість. Отримані результати доповнюють дані про відходи бариту родовища Айн Мімун та дозволяють запропонувати відповідний метод збагачення, що буде застосовуватися з метою отримання високосортного бариту, який відповідає вимогам споживача.

Ключові слова: *Айн Мімун, барит, відходи, характеристика, валоризації, Алжир*

Минералогическая и физико-химическая характеристика отходов барита из месторождения Айн Мимун (Хеншела, Алжир)

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Цель. Минералогическое и физико-химическое изучение отходов барита месторождения Айн Мимун (Алжир) с целью дать характеристику данных отходов, которые занимают тысячи гектаров на территории вокруг предприятия и представляют серьезную проблему для населения и окружающей среды.

Методика. Исследование проводилось с применением дифракции рентгеновских лучей (ДРЛ), растрового электронного микроскопа (РЭМ), рентгеновской флуоресценции (РФ), инфракрасных лучей (ИКЛ), а также микроскопического и шлифового анализов.

Результаты. Отходы содержат, с одной стороны, сульфат бария, который является полезным минералом с допустимым содержанием 19,7 %, а с другой стороны, они содержат ассоциированные пустые породы, представленные кальцитом и кремнием (17 и 46,1 % соответственно), в дополнение к глине, в виде оксида алюминия (8,32 %).

Научная новизна. Новизна данного исследования заключается в описании характера данных отходов с целью подтверждения негативного влияния на население и окружающую среду, что представляет серьезную проблему.

Практическая значимость. Полученные результаты дополняют данные об отходах барита месторождения Айн Мимуни и позволяют предложить подходящий метод обогащения, который будет применяться с целью получения высокосортного барита, соответствующего требованиям потребителя.

Ключевые слова: *Айн Мимун, барит, отходы, характеристика, валоризация, Алжир*

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