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CHARACTERIZATION OF PHOSPHATE WASTES OF DJEBEL ONK MINING COMPLEX FOR A SUSTAINABLE ENVIRONMENTAL MANAGEMENT

The objects of the research are phosphate ore rejections – industrial waste resulting from the treatment of phosphate ore by different processes (particle size separation, calcination, physicochemical process, electrostatically process, etc.). These discharges are generally stored in specially constructed sedimentation ponds. However, its storage for a long period leads to serious environmental problems because they contain heavy and radioactive metals that affect nearby communities. They contaminate groundwater and surface water through the infiltration of caustic solution laden with rare metals. To remedy these environmental disasters and manage these concerns, it is necessary to upgrade the discharges from the Djebel Onk complex and give an added value to the national economy. The start-up of the Djebel El Onk phosphate complex, in the province of Tebessa was in 1965, since that date, all the waste resulting from the beneficiation process has been dumped in the valley adjacent to the complex without any treatment or recycling, it should be noted that the Djebel Onk phosphate complex generates huge quantities of phosphate sludge (more than 4000 tons per day). This waste is relatively rich in useful substance. The results of chemical analyzes reveal that these sludge's contain around 20.2 % of phosphate (P_2O_5) with the presence of different heavy metals such as Uranium, Cadmium, Zinc, Copper, and Arsenic ect. Those metals threaten life of local residents and affects vegetation, livestock in nearby populated areas. However, this work systematically reviews the mineralogical and chemical characterization of the phosphate sludge rejected by the Djebel Onk treatment complex to develop a suitable method for their revaluation. In our work, in this viable environmental perspective, we try to highlight the use of wastes as an alternative raw material in building materials. The impact of heavy metals on the environment and health is determined by the chemical species, concentration, bioavailability and transport through food chains, unless they are released into nature due to the consequences harm they create. Certain elements, such as mercury, lead, cadmium, zinc, copper, etc., have no function in maintaining body balance and are immediately dangerous.

Keywords: *Tailings, physic-chemical analysis, heavy metals, environment, Djebel El Onk phosphate complex, Kef Essennoun deposit in Algeria.*

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1. Introduction

Recent studies have revealed that the mining industry generates more than 14 milliard tones of wastes globally [1, 2]. These can cause significant environmental problems, particularly acid mine drainage (AMD) due to its acidity and metal content. The main impacts are felt at the level of water quality, but soils, sediments, air, biocenosis and humans can be affected [3]. Indeed, mining activity can unbalance natural environments in several ways: through the transformation of landscapes, the deposition of solid waste and the discharge of liquid and atmospheric effluents [4, 5]. This can inevitably harm the environment and the living conditions of neighboring populations. In addition, this large volume of releases leaves a large environmental footprint both spatial in terms of the storage area and temporal in terms of the time scales over which the releases must be managed and remediated. Therefore, the continued production of industrial mining waste is considered a major environmental problem that could have a detrimental effect on the national economy and the ecology of the country. In addition, phosphorus contributes to the enrichment of water in phosphorus (phenomenon eutrophication of water). Eutrophication of water causes a proliferation of aquatic plants, thus favoring less desirable species, such as pollution-tolerant species, some of which can be [6, 7]. Therefore, sustainable management is essential. Consequently, the management of mining waste is a subject of great importance in the exploitation of mineral resources because of their irreversible environmental impacts. The physicochemical composition of tailings presents a myriad of additional challenges to producing physically and chemically

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stable landscapes that do not threaten the environment [7, 8]. Failure to recycle wastes can lead to serious, costly and sometimes catastrophic consequences. There have been 300 recorded cases of tailings accidents worldwide since the 1920s, including 17 cases in recent years. These residues, even if neutralized, must be managed in a sensible and safe manner in order to safeguard the environment, nature, and human health [9]. To remedy these environmental disasters and manage these concerns, it is necessary to upgrade the discharges from the Djebel Onk complex and give added value to the national economy. It should be noted that the Jebel Onk mining complex generates huge quantities of phosphate sludge (more than 4000 tons per day). The results of chemical analyzes reveal that these sludge contains around 20.2 percent of phosphate with the presence of different heavy metals such as Uranium, Cadmium, Zinc, Copper, and Arsenic. However, this work systematically reviews the mineralogical and chemical characterization of the phosphate sludge rejected by the Djebel Onk treatment complex to develop a suitable method for their revaluation. *The aim of this paper* is to highlight the use of wastes as an alternative raw material in building materials. The practical experimentation analysis approach can be used to solve this problem [10, 11]. Therefore, we are interested in studying the environmental impacts of phosphorus. As a case study we took the Kef Essennoun deposit of the Djebel Onk basin, Algeria.

to the Middle Eocene (Lutetian). This marine series is approximately 500 m thick. It is unconformably covered by a thick Miocene continental sandy-clayey sequence, followed by Quaternary filling in synclinal structures and fossilizing the pre-Miocene age series [15].

The Djebel-Onk deposit (Fig. 1), has 317 Mt of total geological reserves, of which 168 Mt are proven reserves (Kef Essnoun), 50 Mt are probable reserves and 99 Mt are possible reserves in the deeper parts of the deposit. The ore from these reserves has a P_2O_5 content of 26.53 % and a magnesium oxide content of 2.16 %. 10,000 tons per day ore are processed by the washing plant at a P_2O_5 content of 25 % [16]. In most cases, the term «trace metal contamination», which includes Cr, Mn, Ni, Cu, Zn, As, Cd and U, refers to an increase in the total levels of metals present in the environment at as a result of significant anthropogenic inputs. Their presence in trace amounts in the air, soil and water can have serious negative effects on all organisms [17, 18].

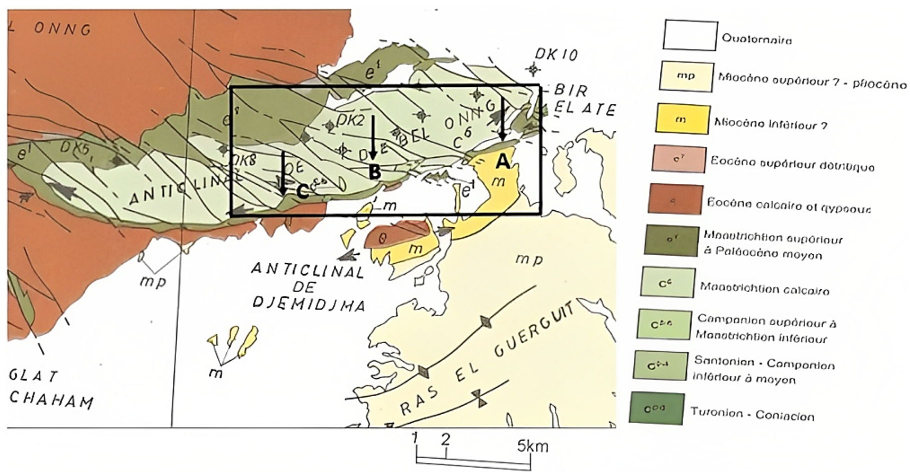

Fig. 1. Sampling map: Samples A, B and C

2. Materials and Methods

2.1. Presentation of our case study. Mining, in particular the extraction and processing of phosphate ore, is one of the most important sectors of the economy of emerging countries, such as Algeria [12]. The Algerian phosphates of the Djebel Onk basin are found in Tertiary marine deposits of the Lower Paleocene and Eocene. This mining region is home to numerous indices as well as five phosphate deposits: Djemi-Djema, Djebel Onk Nord, Bled El Hadba, Oued Betita and Kef Essennoun. This last deposit, the target of our investigation, is located in southeastern Algeria, 9 kilometers south of the city of Bir El Ater and 20 kilometers from the Algerian-Tunisian border [13]. As a reminder, phosphate ores are classified into three types according to their P_2O_5 content: low-grade ores contain 12–16 % P_2O_5, intermediate-grade ores contain 17–25 % P_2O_5 and high grade contain 26–32 % P_2O_5. Commercial phosphate resources are those that can be mined and processed cheaply to produce a concentrate that contains more than 28 % P_2O_5 [14].

Upper Thanetian phosphate deposits may be found in the Jebel Onk area. The phosphate layer is approximately 30 m thick. The regional structure of these terrains is a sequence of extremely asymmetric anticlines and synclines with faults in their sides, with N80°E axes near Djebel Onk. The region's exposed sedimentary sequence spans a geological succession from the Upper Cretaceous (Maestrichtian)

Concentrations of heavy metals are usually found around active and abandoned mining regions, particularly if mining discharges are not well-treated [19]. One of the current challenges in the mining industry is to develop environmentally friendly ore processing and waste reuse technology based on natural processes. The continued production of industrial mining waste is considered a major environmental problem that could have a detrimental effect on the national economy and the Algerian ecology. A viable environmental option is the use of wastes as an alternative raw material in construction materials [20].

2.2. Evaluation and characterization. Minerals that are at least 5 times denser than water are classified as heavy metals. Heavy metals can be either basic (Mo, Mn, Cu, Ni, Fe, Zn) or nonessential (Mo, Mn, Cu, Ni, Fe, and Zn), (Cd, Ni, As, Hg, and Pb) [21]. They pose difficulties for the environment, humans, and animals when they are abundant in the nature [1]. If these metals are present in higher concentrations than the enormous standard, they are poisonous. Essential heavy metal deficiencies have an impact on human health and agricultural productivity. Even at low quantities, non-essential metals are hazardous. They are not converted into other intermediate chemicals and do not degrade in the environment.

Heavy metals are released into the environment because of industrial, residential, agricultural, pharmaceutical, and technical applications, as well as phenomena such as volcanic eruptions and rock weathering [22].

This promising method allows to recover phosphate waste for use as an alternative raw material in building materials [20, 23]. This practice allows to recover a large substantial quantity of residues and, consequently, their effect on the environment, while contributing to the preservation of non-renewable natural resources heavily used in construction (clays, limestone, sand and others) [24]. Let's use chemical analysis of the releases, atomic absorption spectrometry, X-ray diffraction and scanning electron microscopy.

The chemical analysis (granulo-chemical analysis) of the phosphate discharges of the different particle size fractions was carried out using a series of sieves nested on top of each other, the opening dimensions of which decrease from top to bottom. The analyses carried out relate to two products (normal product and special product). AA 400 atomic absorption spectrometry was used to determine metal (Cd, Fe, Cu, Zn, and Pb) and magnesium oxide MgO concentrations. The P_2O_5 was tested using a Technico Auto Analyzer [25, 26]. Atomic absorption spectrophotometry is essentially a method of quantitative analysis which makes it possible to measure around sixty chemical elements in the state of traces (in very small quantities: a few ppm) contained in a solution. It is also the most widely used technique at present, it adapts well to all biological and environmental matrices. The mineral phases were detected by the powder X-ray diffraction (XRD) method. The measurement conditions: scanning range (5–100°), scanning step 0.01, scanning speed 8 °/min, continuous scanning mode, λ=1.54 Å. The scanning electron microscope (SEM) is one of the most flexible tools to study and analyze the morphology of microstructures and characterizations of chemical composition [7]. The SEM was read again in order to know the size and the distribution of the granules of the samples. Scanning electron microscopy/energy dispersive spectroscopy X-ray spectrometry (SEM/EDS) is a frequently used technique. An elemental microanalysis method capable of locating and measuring all periodic elements except H, He and Li [27].

3. Results and Discussion

3.1. Chemical composition of phosphate releases by atomic absorption

3.1.1. Global chemical analysis by atomic absorption. The chemical composition of the phosphate discharges from Djebel Onk is presented respectively in Table 1 for the normal product and Table 2 for the special product. According to these relevant results, let's obtain via the chemical analysis of the two products PN and PS that the phosphate waste is rich in P_2O_5. Therefore, they can be valued. For more confirmation, we pushed the analyzed in depth by the following processes of slice-by-slice analysis, X-ray diffraction and scanning electron microscopy analysis. This allows to confirm the detection of P_2O_5 in each sample of phosphate releases. Following all of the chemical analysis by atomic absorption (AA400), we estimated the high concentration of heavy metals, particularly in the following elements Pb and Cd in the sludge samples, Fine TSV and scrap +15 mm. In addition, a concentration level of MgO in particular at the rejection +1 and +2 mm, rejection +15 mm. This can therefore negatively affect the concentration of P_2O_5, since each time the percentage of MgO is increased, the percentage of P_2O_5 is reduced and the reciprocal is true. In general, the values obtained by chemical analysis clearly show that the P_2O_5 values for the discharges of the two products (PS and PN) are very encouraging for their enrichment as shown in the Fig. 2–5.

Table 1

The overall chemical composition of phosphate reject (normal product)

Samples	CO_2, %	Mg, %	Coefficient	MgO, %	P_2O_5, %	Fe, %	Coefficient	Fe_2O_3, %	Cd	Zn	Cu	Pb
									ppm			
T.V grinder output	12.73	1.96	1.658	3.32	24.38	0.124	2.33	0.288	50	220	6.5	31
Mud	10.16	1.84	1.658	3.05	19.29	0.218	2.33	0.507	40	225	18	35
Refusal of dusting (+1 and +2 mm)	12.41	1.72	1.658	2.85	25.69	0.124	2.33	0.288	45	225	6	30
Settling refusal (+1 mm)	14.04	2.01	1.658	3.33	24.23	0.124	2.33	0.288	45	200	5.5	30
Fines T.S.V	10.45	1.74	1.658	2.88	25.15	0.124	2.33	0.288	45	235	5.5	30
Refusal +15 mm	12.73	2.09	1.658	2.09	19.81	0.124	2.33	0.288	40	225	6.5	30

Table 2

The overall chemical composition of phosphate reject (special product)

Samples	CO_2, %	Mg, %	Coefficient	MgO, %	P_2O_5, %	Fe, %	Coefficient	Fe_2O_3, %	Cd	Zn	Cu	Pb
									ppm			
T.V grinder output	9.43	0.98	1.658	1.54	28.31	0.14	2.33	0.32	45	152.5	11	25
Mud	10.08	1.7	1.658	2.73	25.31	0.14	2.33	0.32	25	144	8.5	35
Refusal of dusting (+1 and +2 mm)	14.31	2	1.658	3.23	19.28	0.13	2.33	0.30	35	154	9	30
Settling refusal (+1 mm)	11.38	1.8	1.658	2.90	24.58	0.12	2.33	0.27	45	163.5	8	30
Fines T.S.V	11.71	1.7	1.658	2.73	21.05	0.13	2.33	0.30	50	154.5	7	35
Refusal +15 mm	17.89	2.2	1.658	3.56	23.71	0.12	2.33	0.27	40	152.5	9	35

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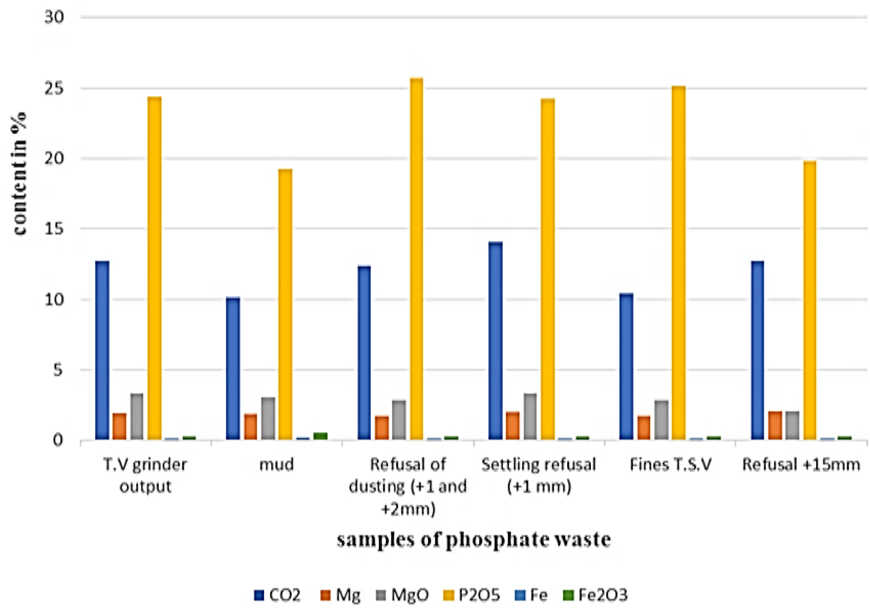

Fig. 2. Evolution of the content of elements in the phosphate waste of the normal product (in %)

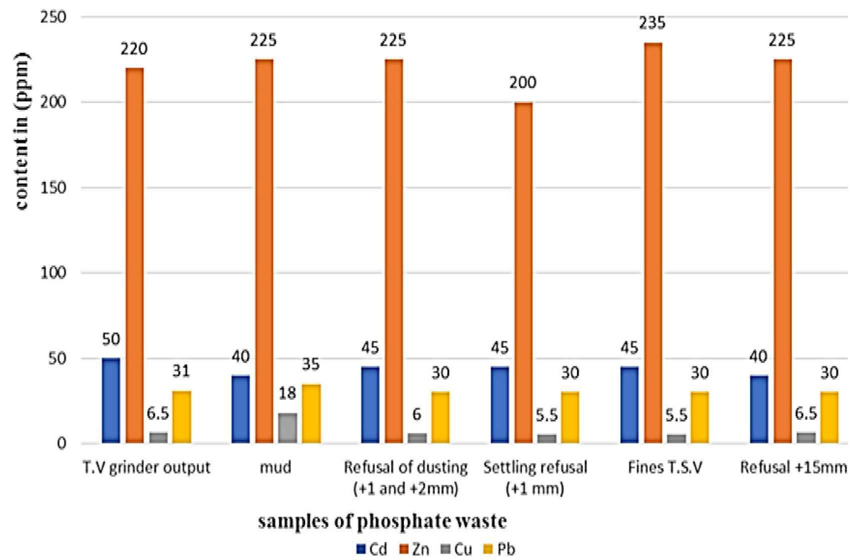

Fig. 3. Heavy metals in waste from the normal product (in ppm)

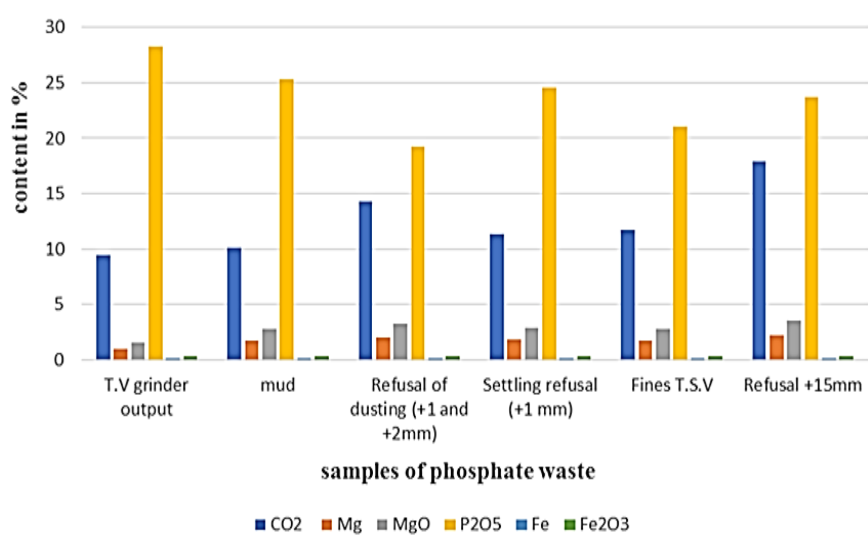

Fig. 4. Different elements in the phosphate waste of the special product (in %)

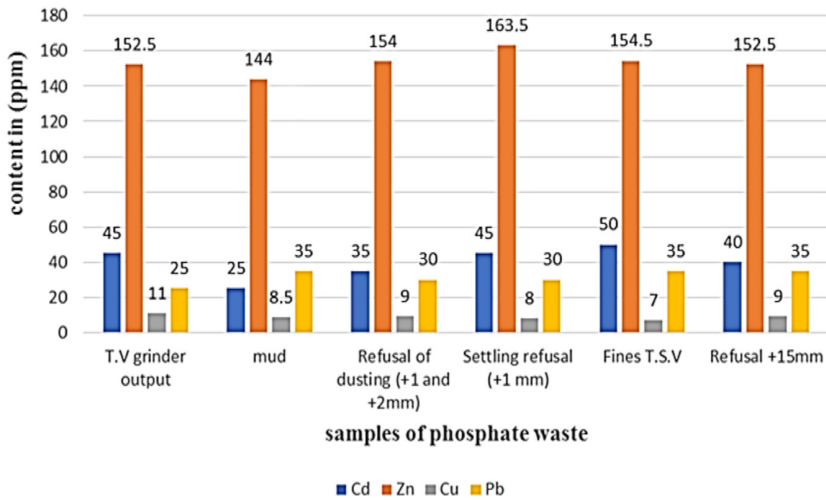

Fig. 5. Heavy metals in phosphate waste in the special product (in ppm)

3.1.2. Chemical analysis by slice by atomic absorption. Slice-by-slice chemical analysis allows for deeper analysis and achievement of chemical properties.

The results obtained (Tables 3 and 4) indicate that the fraction of P_2O_5 is very important in the wastes than the raw phosphate sample, the section (–1+0.100 mm) of the rejection (+1 mm), thus the rejection (+1, +2 mm) for the normal product, also for the slices (–15, +10 mm) and (–4, +0 mm) in the refusal +15 mm for the special product contains significant levels of P_2O_5. This is why it must be valued and not thrown away so as not to cause problems for the environment.

Table 3

Chemical analysis by element range (CO_2, MgO, and P_2O_5): for the normal product

Samples	CO_2		MgO		P_2O_5		
	Volume	%	Mg	*1.658	Before	After	Average
T.V grinder output slice +125 mm	100	16.61	1.8	2.98	24.55	24.66	24.60
T.V grinder output slice –125+0.9 mm	64	10.63	1.4	2.32	27.91	28.16	28.03
T.V grinder output slice <0.9 mm	90	14.95	1.9	3.15	20.72	20.85	20.78
Refusal +1 mm slice +1 mm	96	15.94	1.9	3.15	22.06	22.30	22.18
Refusal +1 mm slice –1+0.100 mm	60	9.97	0.75	1.24	29.59	29.95	29.77
Refusal +1 mm slice <0.100 mm	82	13.62	1.4	2.33	22.69	22.88	22.78
Refusal +1 and 2 mm slice +1 mm	80	13.29	1.3	2.16	24.40	24.71	24.55
Refusal +1 and 2 mm slice –1+0.100 mm	56	9.30	0.7	1.16	30.49	30.92	30.70
Refusal +1 and 2 mm slice <0.100 mm	78	12.96	1.3	2.16	24.03	24.29	24.16
Refusal +15 mm slice +15 mm	108	17.87	0.67	1.11	27.86	27.46	27.81
Refusal +15 mm slice –15+10 mm	42	6.95	1.3	2.15	25.22	25.12	25.17
Refusal +15 mm slice –4+0 mm	62	10.26	2.3	3.81	17.71	17.62	17.67

Table 4

Chemical analysis by element range (CO_2, MgO, and P_2O_5): for the special product

Samples	CO_2		MgO		P_2O_5		
	Volume	%	Mg	*1.658	Before	After	Average
T.V grinder output slice +125 mm	73	12.13	1.3	2.16	28.90	29.34	29.12
T.V grinder output slice –125+0.9 mm	72	11.96	1.1	1.82	28.61	28.02	28.31
T.V grinder output slice <0.9 mm	80	13.29	1.3	2.16	24.60	25.04	24.82
Refusal +1 mm slice +1 mm	104	17.27	1.7	2.82	22.86	23.23	23.04
Refusal +1 mm slice –1+0.100 mm	60	9.97	0.81	1.34	26.9	26.9	26.9
Refusal +1 mm slice <0.100 mm	124	20.60	1.8	2.98	15.23	15.36	15.29
Refusal +1 and 2 mm slice +1 mm	102	16.94	1.6	2.65	23.57	24.10	23.83
Refusal +1 and 2 mm slice –1+0.100 mm	54	8.97	0.56	0.98	25.1	25.4	25.25
Refusal +1 and 2 mm slice <0.100 mm	100	16.61	1.7	2.82	19.71	19.99	19.85
Refusal +15 mm slice +15 mm	100	16.55	2.1	3.48	21.18	21.08	21.13
Refusal +15 mm slice –15+10 mm	72	11.92	1.6	2.65	24.72	24.61	27.67
Refusal +15 mm slice –4+0 mm	52	8.61	0.91	1.62	27.65	27.51	27.58

3.2. The scanning electron microscope SEM and EDS. Scanning electron microscopy (SEM) and EDS were also performed to determine tailings phosphate content. Fig. 6 shows: reject +15 mm of normal product, reject +15 mm of special product, reject (+1, +2 mm) of normal product and mud respectively.

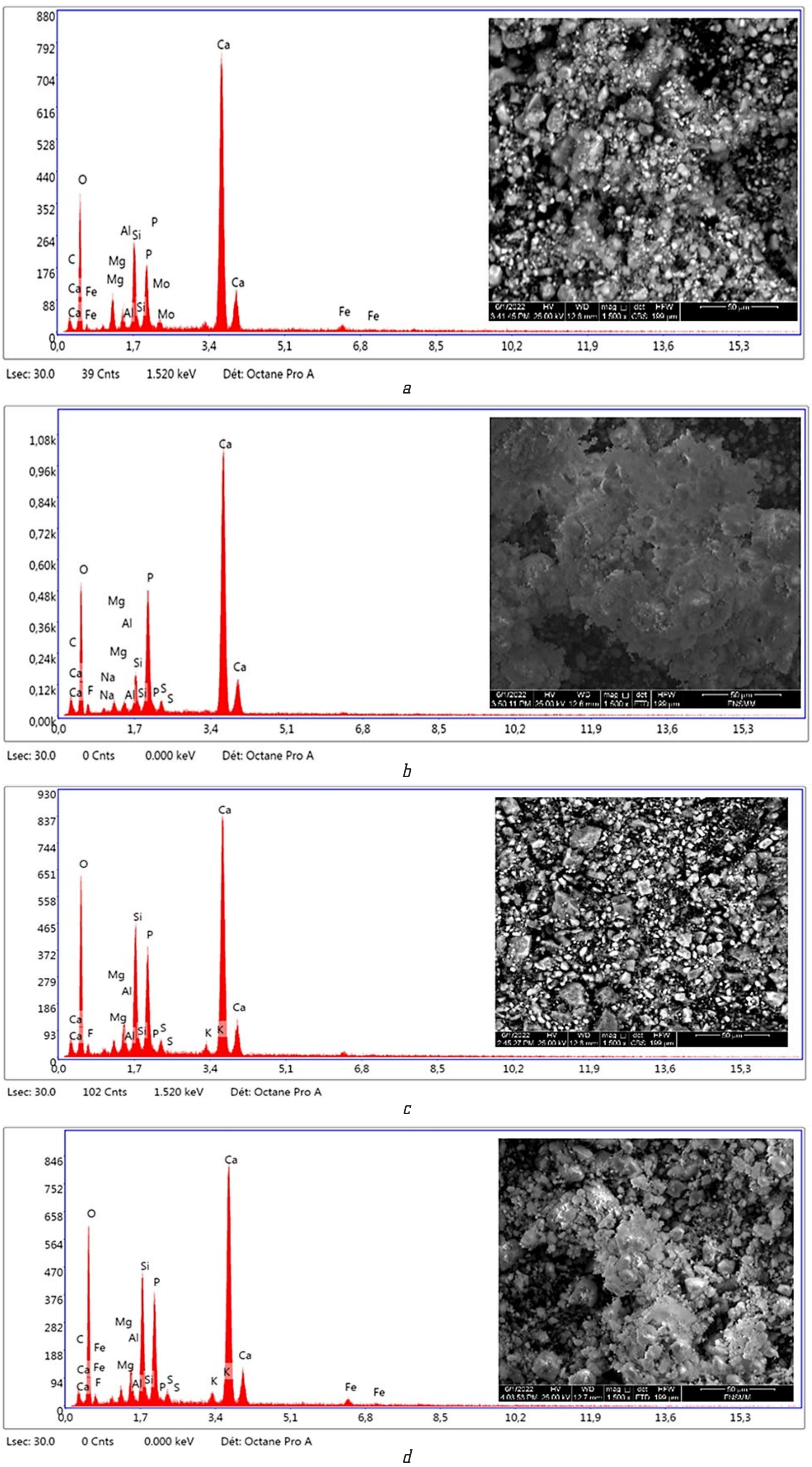

Fig. 6. SEM and EDS for analysis (*a* – refusal +15 mm of the Np; *b* – refusal +15 mm, Sp; *c* – refusal +1, +2 mm, Np; *d* – mud)

Additionally, EDS spectra were obtained for the sample, showing the constituent elements of the phosphate release sample like C, O, Mg, Al, Si, P, Mo, Ca, and Fe in different ratios. It shows the highest level of calcium, oxygen and phosphorus.

Depending on the amount of phosphate particles, matrix and organic matter present in each sample, several microscopic facies can be observed. Phosphate particles come in a variety of configurations: coprolites, which are spherical to irregular and generally measure more than 250 μm and sometimes reach a few millimeters. Pellets, ovoid to rounded, light to dark and 200 to 250 μm in diameter, are formed during the fragmentation of coprolites and are sometimes cemented by calcareous, clayey or siliceous materials. Within the surrounding formation, the phosphorites of the northern sector are found in thin strata. While coprolites of all sizes, shapes and colors are plentiful, pellets are less common. These characteristics imply that there was minimal modification of the initial depositional environment during the formation of the phosphorite particles.

3.3. X-ray diffraction (XRD). The XRD diffractograms on all samples show that the primary phosphate mineral is fluoroapatite (FA). Apatite, carbonated fluoroapatite, monazite and dolomite have been discovered and form the matrix of phosphorite grains. Fig. 7 represent different XRD of all the samples showing respectively the waste +15 mm of the normal product, the waste +15 mm of the special product, the waste (+1, +2 mm) of the normal product and the sludge). According to the XRD analysis, the phosphate waste samples consist of the minerals listed in Table 5 with their chemical formula. The DRX study indicates that this sample of phosphate wastes (waste +15 mm normal product, waste +15 mm special product, waste +1 and +2 mm special product, mud) is mainly composed of fluoroapatite and dolomite.

The most significant phosphate release peaks at 2 theta (°) are: 31.07 (8000), 33.52 (3000), 31.02 (4900), 62.70 (160) and 64.70 (400). Therefore, these results clearly confirm the presence of phosphate in our samples.

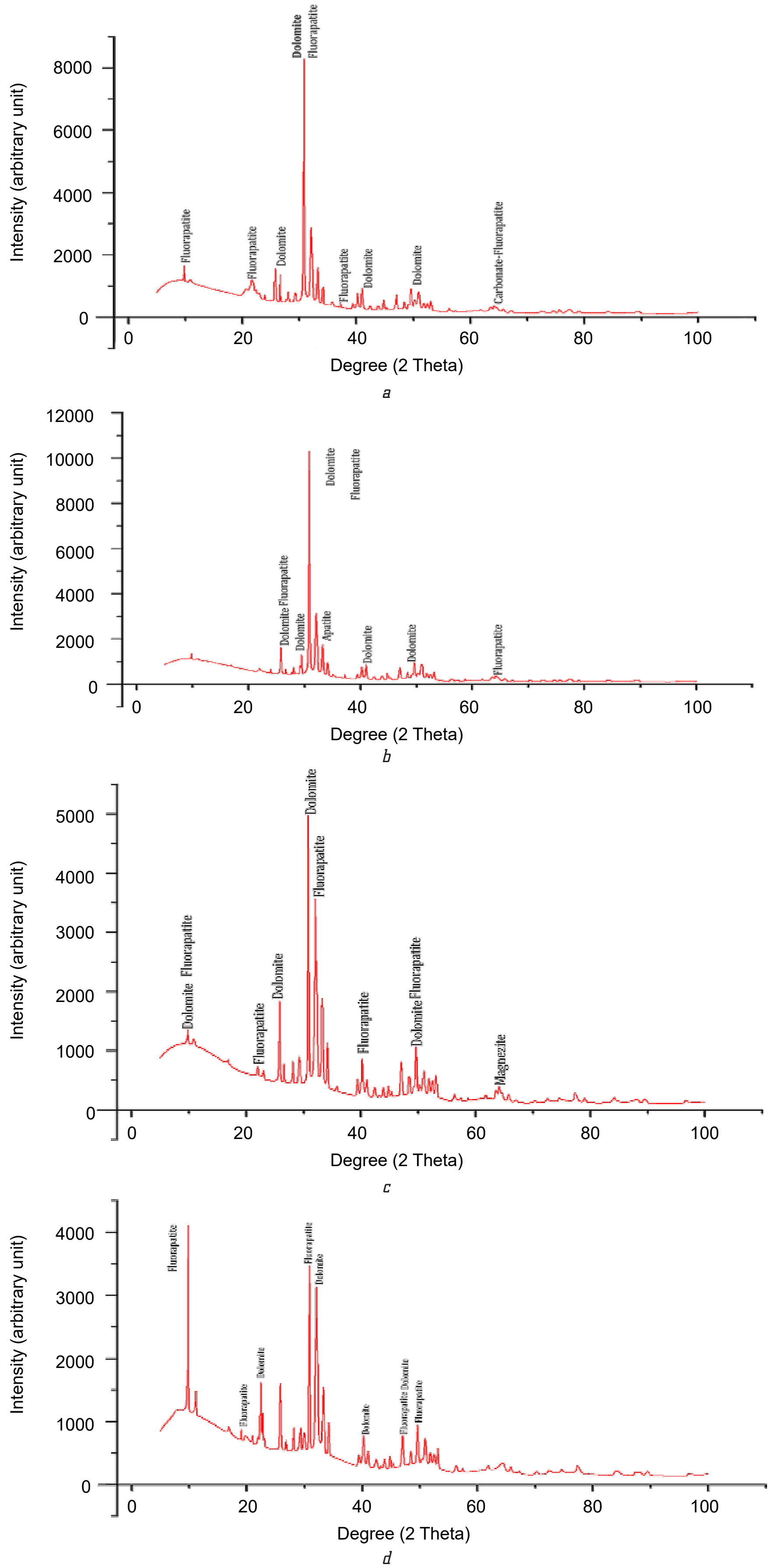

Fig. 7. XRD samples (*a* – waste +15 mm, Np; *b* – waste +15 mm, Sp; *c* – waste +1, +2 mm, Np; *d* – mud)

Table 5

Chemical formula of the studied minerals

Name	Chemical formula
Fluorapatite	$Ca_5FO_{12}P_3$
Dolomite	C_2CaMgO_6
Monazite	$Ce(PO_4)$
Apatite	$Ca_5(PO_4)_3(OH,F,Cl)$
Carbonate-fluoro-apatite	$Ca_5(PO_4,CO_3)_3F$

3.4. Discussion and recommendation. Based on the results of full and partial chemical analyses of samples of normal and special, it is obvious that there is a high concentration of phosphates in the samples evaluated by X-ray. For example, waste +15 mm contains 27.81 and 27.58 P_2O_5 and, mud contains 19.29 and 25.31 P_2O_5.

Also in waste (+1 and +2 mm), 30.70 and 25.25 P_2O_5, as validated by X-ray analysis, in the presence of the essential element fluorapatite.

Concerning heavy metals, particularly cadmium and lead, let's notice that high results for cadmium range from 40 to 50 ppm for normal product samples. In the case of the special product, let's detect a small decrease in the readings, ranging between 25 and 50 ppm. Lead levels in both products are significant, ranging from 25 to 35 ppm, posing a danger to the environment and ecosystem.

The zinc values in the special product are nearly double those obtained in the normal product, particularly in the fine TSV sample, posing a threat to the environment and human health because the particles in this sample are very fine, allowing them to be easily transported through the air or inhaled. It is heavily laden with heavy metals.

To reduce the risk of heavy metal contamination, increase the production capacity of the complex, and therefore minimize the rate of the useful substance (P_2O_5) in the wastes, let's recommend the measurements:

– Renewal the processing and beneficiation equipment's of the raw phosphate ores;

– Review the comminution and grinding equipment to avoid overgrinding of the ores to be enriched and to reduce the rate of fines particles, which are considered as a disruptive factor in the upgrading, process;

– The installation of ore processing machines that can separate very thin slices, such as the Jemeson cell, which can reach 15 μm;
– Recycling of wastes after their storage in heaps fitted out for this purpose;
– Installation of filters at the outlets of the thickeners, which could reduce the release of, slimes rich in P_2O_5 into the wadi;
– To search for a more efficient and more profitable beneficiation method, which made it possible to decrease the rate of P_2O_5 in the wastes;
– Storage wastes rejected from thickeners and reinforcement of regulatory resources;
– Primary prevention of heavy metal contamination includes awareness and communication campaigns aimed at the public, mainly around the complex;
– Take samples in the surroundings of the complex and even in the regions of the wadi where the evacuation of waste has been done for more than 65 years;
– Strict application of environmental protection standards when evacuating wastes outside the complex;
– Acquisition of heavy metal detectors which can facilitate the early detection of pollution in the vicinity;
– Carry out control surveys of local residents to control their contamination with heavy metals and take the necessary sanitary measures.

3.5. Limitations and directions of research development. Although the Djebel Onk region conceals enormous reserves of phosphate ore (1 Billion tons), the phosphate production remains very modest; it is less than 700 M tons per year. From a practical point of view, the results of this work can be used at the company to choose the adequate method to improve the quality of the product and to increase the complex capacity production of phosphate.

On the other hand, the qualitative and quantitative study carried out allowed to give an overview of the environmental state of the study area through the results of the analyses carried out, in particular those related to heavy metals, which are thrown into the chance in phosphate wastes.

Our study was carried out on various grain size ranges of phosphate wastes rejected by Djebel Onk phosphate complex, for example (+1, +2 mm), +15 mm, and by different analysis methods: chemical analysis, XRD analysis, SEM analysis. These gave us made it possible to identify the waste from the complex, to highlight the existence of heavy metals. The letters threaten the environment, the citizen's, to point out the enormous quantity of useful substance in P_2O_5 released in the discharges and that it must recover. Future studies will need to go deeper into the waste samples to find relevant environmental factors. A qualitative investigation would validate this research activity due to the promising values contained in the outcomes.

4. Conclusions

Phosphates are not only used in the field of agriculture but also for technical applications. It constitutes a very wide and heterogeneous range of products, which differ both in their structure (phosphate, polyphosphate, and pyrophosphate) and in their uses: Manufacture of fertilizers, phosphoric acid, building materials (phosphogypsum). Fertilizer needs will continue to intensify continuously at a rate of 2.4 % per year [28]. Thus, to cater for this demand the mining industry must find methods of beneficiation of less rich ores while the rejections of our study are rich, it exceeds 21 % in P_2O_5. Therefore, it is suggested as a beneficiation method the use of the Jameson cell in the phosphate ore-processing scheme, which makes it possible to recover the fine particles, which represent the majority of the phosphate wastes rejected from the Djebel Onk complex, being reclaimed by the Jameson cell, which will allow for high recovery of useful ore from the tailings. On the other hand, the flotation process by the Jameson cell will also allow the capture of heavy metals such as Cadmium, Zinc, Copper, Arsenic, etc. The majority of these heavy metals are drained with the fine particles, which will allow to reduce the negative impacts on the environment and preserve the health of human beings living near the Djebel Onk mining site.

All the analysis carried out on the samples of phosphate wastes for the two products (normal and special) give encouraging results for the recovery of these wastes, and their integration into the production chain for a possible use of these wastes as alternative raw materials (in building materials). These results allow to recover a large substantial quantity of residues and, consequently, their effect on the environment, while contributing to the preservation of non-renewable natural resources heavily used in construction (clays, limestone, sand and others). On the one hand, in addition to removing or lowering the percentages of excessive heavy metals that emerged in chemical analysis findings, such as the percentages of Lead and cadmium (30 to 35 ppm for Lead) and (25 to 50 ppm for cadmium) in all samples, while cadmium, if its value exceeds 30 ppm, is considered toxic.

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Conflict of interest

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Data availability

The manuscript has associated data in a data repository.

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