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ANALYSIS OF THE ENVIRONMENTAL IMPACT OF PHOSPHATE MINING ON THE EXAMPLE OF DJEBEL ONK DEPOSIT (TEBESSA), ALGERIA

The object of the study is natural phosphates, which play a major role in various industrial sectors, ranging from agriculture to pharmaceuticals, via the metallurgy and chemistry. In Algeria, their importance in the international market is significant, thanks to the deposits of Djebel Onk, located in the south-eastern part of the region of Tebessa. However, the mining and processing of these phosphates lead to waste significant, both in liquid form than in solid, raising significant environmental concerns. In this perspective, a thorough analysis is necessary for a rational and hard reliable, ensuring the preservation of the environment. This research was undertaken to quantify and analyze the distribution of various heavy metals in the phosphate waste generated by Djebel Onk plant (Kef Essennoun deposit). These wastes are crucial to achieve the objectives of sustainable development in relation to public health and the environment. The work focuses on the study of samples of the different releases of the treatment processes. These latter were subjected to a characterization of different analysis techniques, qualitative and quantitative, namely: XRD, IR, XRF, SEM and AAS. The results obtained distinguish differences are notable between the levels recorded by the raw phosphate and those samples wastes of treatment processes. Thus, the waste produced consists of 59.2 % dolomite, 20.5 % calcite, and 19.8 % fluorapatite. The presence of kaolinite was also noted in these residues, though in a small proportion (0.5 %). It has also been noted that these concentration of the elements in trace metal increases relatively with the decrease of the diameter of the grain size, in particular in the mud. This shows that the efficiency of the modes of treatment will allow for some cases, reduce the concentration of elements in the phosphate studied. This opens up promising research opportunities for scientists and engineers to develop more efficient and advanced treatment methods.

Keywords: sustainable exploitation, phosphate tailings, mineral processing, heavy metals, environmental impact.

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1. Introduction

Algeria is one of the leading producers of phosphate in the world with a production capacity estimated from 2.3 to 2.5 million tons per year, thanks to the deposits of Djebel Onk located in the South East region of Tebessa [1, 2]. The mining complex of Djebel Onk belongs to the group FERFOS specializing in the mining and processing of phosphates. The plant of Djebel Onk is set up to process and produce a phosphate rich in P_2O_5 , designed for different industries. The entire production is of the order of a few billion tons exported as raw material, to multiple countries around the world [3–5].

During the enrichment of minerals, the separation and enrichment processes not only generate a concentrate rich in mineral species, but also produce a significant quantity of waste in liquid and solid form [6]. Storage in the open air in parks residues lead to environmental impacts that are considerable, particularly for heavy metals [7–10]. These are micro pollutants metal, which can contaminate the environment and public health. They constitute a serious problem when they are involved in the pollution of water and soil.

Their toxicity can be strong damaging to the environment, but their accumulation along the food chain, which may have damage effects on human health, fauna and flora [11–13].

The composition of the phosphate rock mainly depends on its type and its origin. The phosphate rock sedimentary contain a high concentration of heavy metals such as U, Th, Cd, As, Sb, V, Cr, Zn, Cu, Ni, etc. [11, 14, 15]. As there are currently no commercial means of eliminating these pollutants, their concentration in the waste is decisive for the possibilities of recycling. These levels vary depending on the source of phosphate but also in the processes of treatment and enrichment [11, 16–20]. For this reason, and in order to obtain the best characterization results, it is possible to decide to take samples at different stages of phosphate ore beneficiation.

The treatment of raw ore (crushing, grinding and screening) to obtain phosphate rich in P_2O_5 followed by beneficiation by dust removal, must settling, drying and demagnetization generates five types of waste: screen waste, phosphate sludge from the underflow and curved grate, TVS dusts and hydrocyclone waste greater than 2 mm. The valuation of these waste is a major concern of the search,

because to our knowledge, studies on the phosphate Algerian, have focused only on the natural ore and waste from the generated by the treatment processes have not been investigated and no comprehensive study has been conducted on this topic.

Given the concerns about the impacts of phosphate mining and processing which generally focus on the environment and human health. This study covers a characterization of wastes from Djebel Onk phosphate, the purpose of which is to determine the distribution and the level of presence of heavy metals in these wastes. The environmental impact of these heavy metals, which are directly or indirectly linked to a rational and sustainable phosphate treatment, is the subject of this study. The result will provide a summary update of current research in this field.

Therefore, this topic is started with the aim of quantifying and understanding the distribution of different heavy metals in phosphate waste. Indeed, the current methods of quantification and valorization of these waste are unsuitable for achieving the sustainable development objectives, which generate negative impacts on the environment and human health. It is within the framework of this axis that our work is focused.

Thus, *the aim of this work* is to carry out a physico-chemical and mineralorganic characterization of the various waste with a view to their valorization. For this purpose, it is possible to take the samples at the crushing station (raw phosphate <15 mm and screening waste >15 mm), then it is possible to take 4 samples from the treatment chain (2 samples in the dry way and two samples in the wet way). To achieve our objectives, let's use different analysis techniques such as: Granulometric analysis, XRD, IR, FRX, SEM and AAS.

2. Materials and Methods

2.1. Djebel Onk mining complex presentation

The region of Djebel Onk is located in the South East of Algeria, about 100 kilometers of Tebessa and 20 km of the border between Algeria and Tunisia, on the road that connects Tebessa to El Oued departments [11, 21–23]. The massif of Jebel Onk is a collection of limestone 20 km long, which rises to 1198 m altitude in Djebel Tarfaya [24–26]. This massif is the eastern end of the mountains of Nemémcha which extends to the East of the massif of the Aurès mountains [27]. The region of Djebel Onk (Fig. 1) is subdivided into 5 mining sectors: Deposit of Djemi Djema, Deposit Kef Essenoun, Deposit of Djebel Onk North, Deposit, Wadi Betita and Deposit of Bled El Hadba [2, 28].

In our studies, let's interest the deposit of Kef Essenoun. The phosphate field of Kef Essenoun is an important deposit relatively well known geologically. Its development was in July 2003, its proximity to existing treatment facilities, the quality of its ore, its reserves in the categories industrial, and these technical parameters opening, give it a priority and strategic as to the operation and the treatment of its product.

The geology of the Kef Essenoun deposits is relatively simple, with the phosphates in the same layer. The surrounding layers dip slowly, monoclinaly depending on the inclination of the relief, towards the south, with the layers dipping at a rate of 10 to 15 degrees [11, 29]. The phosphate-bearing layer of the Kef Essenoun deposit has a thickness of approximately 35 m [1, 30].

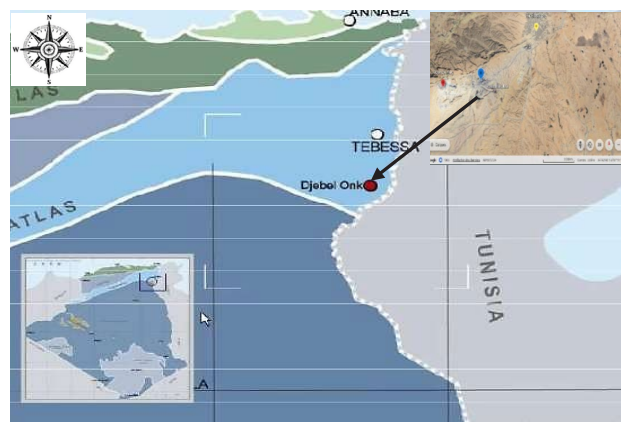


Fig. 1. Geographical location of the region of Djebel Onk [21, 24]

Has Djebel Onk deposit Kef Essenoun is the main lodge is currently operated under the open sky. The method of operation is a succession of completion of the works, removal of waste rock and ore in a set order. For technical and economic reasons, the ore extracted from the deposit is virtually no marketable directly. It must undergo a certain transformation, which is to purify the ore by removing the gangue. The ore from the quarry has to undergo mechanical preparation, the aim of which is to release the useful substance from the gangue and reduce the size of the blocks from $D_{max}=1200$ mm down to 15 mm.

On the one hand, the product smaller than 15 mm coming from the mechanical preparation workshop which feeds the dry treatment process (the dedusting process) has for objective to have a product rich in phosphate. On the other hand, a part is sent to the wet processing line (the settling process) which consists of pulping the screened product, then feeding a wet screening stage in order to eliminate siliceous and clay materials greater than 1 mm [11, 31].

2.2. Sampling and parameters

2.2.1. Points of sample collection. Before it is ready for processing, rock phosphate has to go through a number of treatment stages, including mechanical preparation and enrichment, in order to obtain the desired quality. At the Djebel Onk mining complex, the treatment processes are geared towards the production of a specific grade of phosphate, known as the merchant product. There are two main treatment processes:

- wet process: desliming;
- dry process: dedusting.

However, the beneficiation of phosphate ore does not produce a product that works on its own, but generates a large quantity of liquid or solid waste. To this aim, in order to carry out our research work, it is possible to take the samples following the processing scheme adopted at the Djebel Onk complex. Fig. 2 shows the UTM points at which the samples studied were taken.

Stage of mechanical preparation after screening 15 mm, there are two samples, namely:

- 1) waste+15 mm (constituted as of the first waste);
- 2) screened product – 15 (power supply in the chain of treatment).

In the dry process the fraction <15 mm, the operation of the mechanical preparation, the ore follows a drying in order to remove the thin part of the silica and fluidizer up to a moisture content of 2 %.



Fig. 2. Position of the sampling points (google earth Image)

Then, the treated product goes through an operation of screening at a size of 2 mm to remove the maximum number of coarse particles. The way is then crushed by a hammer mill to release the grains rich in phosphate. Then, it undergoes separation by a turbo selective ventilator to eliminate fines smaller than 1 mm. After that, a second operation of screening is necessary to remove particles +1 mm. Finally, the final concentrate of -1 mm fraction in the content of P₂O₅ is obtained from about 29 % by weight.

Dry method, two samples can be distinguished:

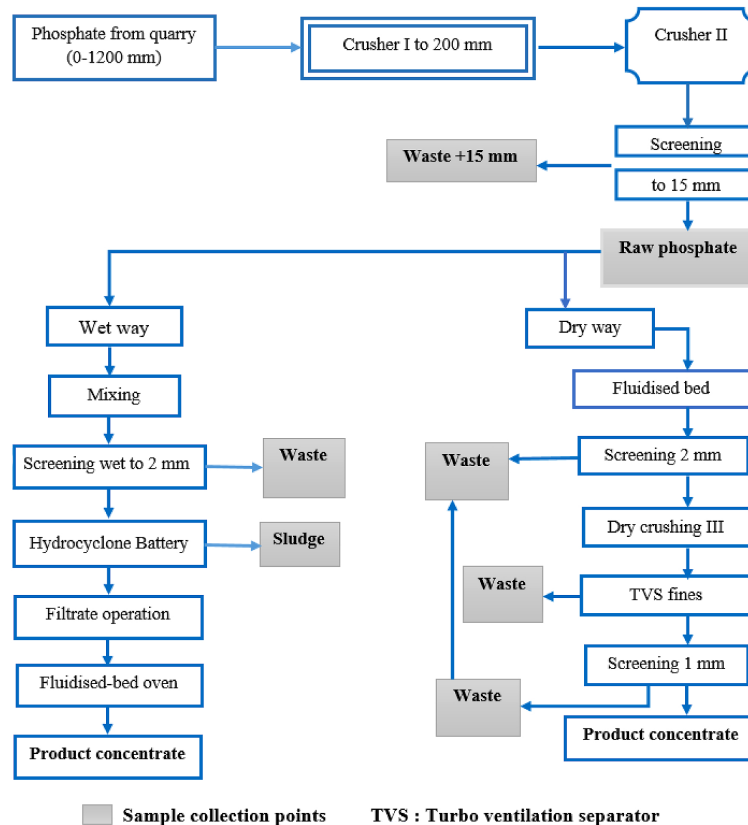
- 1) waste dust (+2 mm);
- 2) fine STV, waste of turbo separator ventilation.

In this process, a curved grate is used to remove large grains of size (+1 mm), followed by hydrocyclone disaggregation to produce a pulp. The latter allows the classification of the fine particle size of (-0.08 mm) resulting in a low concentration of P₂O₅. Finally, the product is dried using a rotary kiln until a humidity of less than 0.2 % is obtained with a production of approximately 34.32–35.24 % by weight of P₂O₅.

In the wet way, there are two sampling points are:

- 1) waste of the grid curve +2 mm, wet screening;
- 2) settled waste (overflow sludge).

Fig. 3 shows the scheme technological processing of phosphates in the complex mining of Djebel Onk showing the waste sampled.



■ Sample collection points TVS : Turbo ventilation separator

Fig. 3. Diagram of the processing of phosphates in the mining complex of Djebel Onk showing the waste sampled

2.2.2. Sample preparation. Before carrying out the necessary analyses on the selected samples, let's first prepare the samples taken, to ensure that they were as representative as possible. To this end, measuring the characteristics of a material requires the presence of a sample, as representative as possible, of a batch of material from which it comes, as well as its form, so that the required analyses can be carried out.

Sampling in the laboratory involves particle size reduction, homogenization and volume reduction (quartering). One part is used for sieve analysis and the other for chemical and mineralogical characterization. The latter is subjected to grain size reduction operations down to less than 80 μm using a Fritsch grinder.

2.2.3. Description of the equipment used. Particle size analysis: Waste samples from the wet process were oven dried for 24 h at 105 °C and then stored. After settling for 48 h they were separated into two phases: solid (S) and liquid (L). All the samples were sieved on a sieve column in a Retsch-type shaker machine operating with sieves with a diameter of 200×50 mm, the quantities of particles present on the sieves were weighed by a balance with an accuracy of 0.01 g at the laboratory level of the Djbel Onk complex, Tebessa. Based on previous studies on this type of ore, let's limit the sieving time to 15 minutes to avoid any significant error due to the crushing effect.

2.2.4. Mineralogical and petrographical analysis. Scanning electron microscope (SEM) observations: The morphologies of the samples are characterized by scanning electron microscopy (SEM) using a QUANTA 250 device manufactured by FEI company in Romania, at an acceleration voltage of between 10 and 15 Kv at the laboratory of the Higher National School of Technology and Engineering. This allows high-resolution images of the surface of the sample to be obtained and gives a diffractogram (EDX) which proves the chemical elements contained in the mineral surface [32–34].

Analysis by Fourier Transform Infrared Spectroscopy (FTIR): Analyses by infrared spectroscopy (FTIR) were carried out at the technical platform laboratory at the Constantine Polytechnic School using a BRUKER INVNIO R instrument, manufactured by BRUKER company in United Kingdom. The frequencies observed for the characteristic absorption bands correspond to the normal vibrations of the various radicals used in the composition of the ore and the waste studied.

X-ray diffraction (XRD) analysis: Identification of the mineral phases in the samples studied was carried out by X-ray diffraction using an X Pert Pro Panalytical powder diffractometer, manufactured by Malven Panalytical company in UK, using the $\text{K}\alpha_1$ line of copper with wavelength $\lambda=1.54 \text{ \AA}$. The diffractograms were recorded from $2\theta=10^\circ$ to 80° , with a step of 0.01° at the CRAPC laboratory, Béjaia. The results obtained for the samples studied are shown in the diffractograms below.

2.2.5. Chemical analysis. Characterization of major elements: The sample to be analyzed placed under a beam of X-rays. Under the effect of these X-rays, the atoms making up the sample change from their fundamental state to an excited state. The excited state is unstable, so the atoms tend to return to their fundamental state, releasing energy in the form of X-ray photons (this is the phenomenon of X-ray fluorescence). Analysis of this secondary X-ray radiation provides information about the nature of the chemical elements present in a sample, as well as their mass concentration.

The various samples studied were analyzed by Sci-Aps X200 X-ray fluorescence, series 02110 manufactured by Sci-Aps company in USA, at the CRAPC laboratory in Béjaia.

Characterization of metallic trace elements: Trace element analysis is been carried out using atomic absorption spectroscopy (AAS) manufactured by Sci-Aps company in USA. Flame atomic absorption is a method that essentially measures metals in solution. This method of elemental analysis requires the measurement to be taken from an analysis (element to be measured) transformed into the state of free atoms. The sample is been heated to between 2,000 and 3,000 degrees so that the chemical combinations in which the elements are involved are destroyed. For trace metals, using appropriate hollow cathode lamps for each element determined after extraction with nitric acid.

3. Results and Discussions

3.1. Particle size distribution

According to the results obtained, it is possible to conclude that the performance level recorded in the size fractions of less than 500 μm in the wastes of the chain of treatment and in the food, that is to say, in the fine particles. It is important to note that the power supply is the mesh of liberation optimal separation of the element's nitrogen, phosphate.

However, the coarse particle size fractions (> to 500 μm) recorded significant proportions by weight, in particular in discharges >15 mm (33.84 %), Table 1 and Fig. 4.

Table 1

Physical characteristics and particle size distribution of the samples studied

Designation	Percentage by weight (%)				
	Raw phosphate <15 mm	Wastes >15 mm	Dry waste +2 mm	Fine TSV	Wet waste +2 mm
>10	0.00	0	0	0.00	0.00
10	0.00	33.84	5.7	0.00	6.97
4	0.95	1.95	9.08	0.00	11.71
2	0.52	0.51	4.86	0.00	4.06
1	1.45	0.84	5.76	0.00	3.02
0.5	6.99	3.47	4.83	0.00	4.31
0.25	50.19	28.67	35.45	0.00	33.48
0.125	29.09	18.72	22.79	7.38	24.00
0.05	8.69	8.74	8.02	74.3	8.70
<0.05	2.12	3.26	3.51	18.32	3.75
TOTAL	100	100	100	100	100

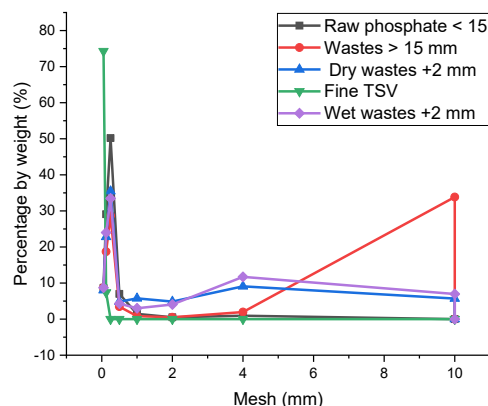


Fig. 4. Distribution of the particle size of the samples studied

3.2. Distribution, petrography and mineralogy

3.2.1. Micrographs SEM. Observations of the microscope scanning electron carried out on these samples studied are shown in the micrographs of Fig. 5, *a-f*. A way in general, they confirm the presence of the element's nitrogen, phosphate, dolomite, of quartz and sometimes clay:

– These samples of raw phosphate before moving on to the processing chain present the rains of phosphates and of an ovoid shape and a rectangular shape and are sometimes broken. The chemical analysis by EDX confirmed the presence of the elements – nitrogen, phosphate, and those of the gangue in particular dolomite (Fig. 6).

– The waste +15 mm are mainly composed of an abundance of grain phosphate compounds and the gangue characterized by carbonate minerals (dolomite), calcite and quartz.

– The waste from process treatment has compositions mineralogical similar and are characterized by a high power of crystals dolomitic with an abundance of elements phosphate purposes. The mud is made up of grains of phosphate bonded cement dolomitic more marked than the other samples.

– These wastes are composed of 59.2 % of dolomite, 20.5 % of the calcite, and 19.8 % of the Fluor apatite. In addition, it is necessary to mention the presence of kaolinite in these residues, but in low proportion (0.5 %).

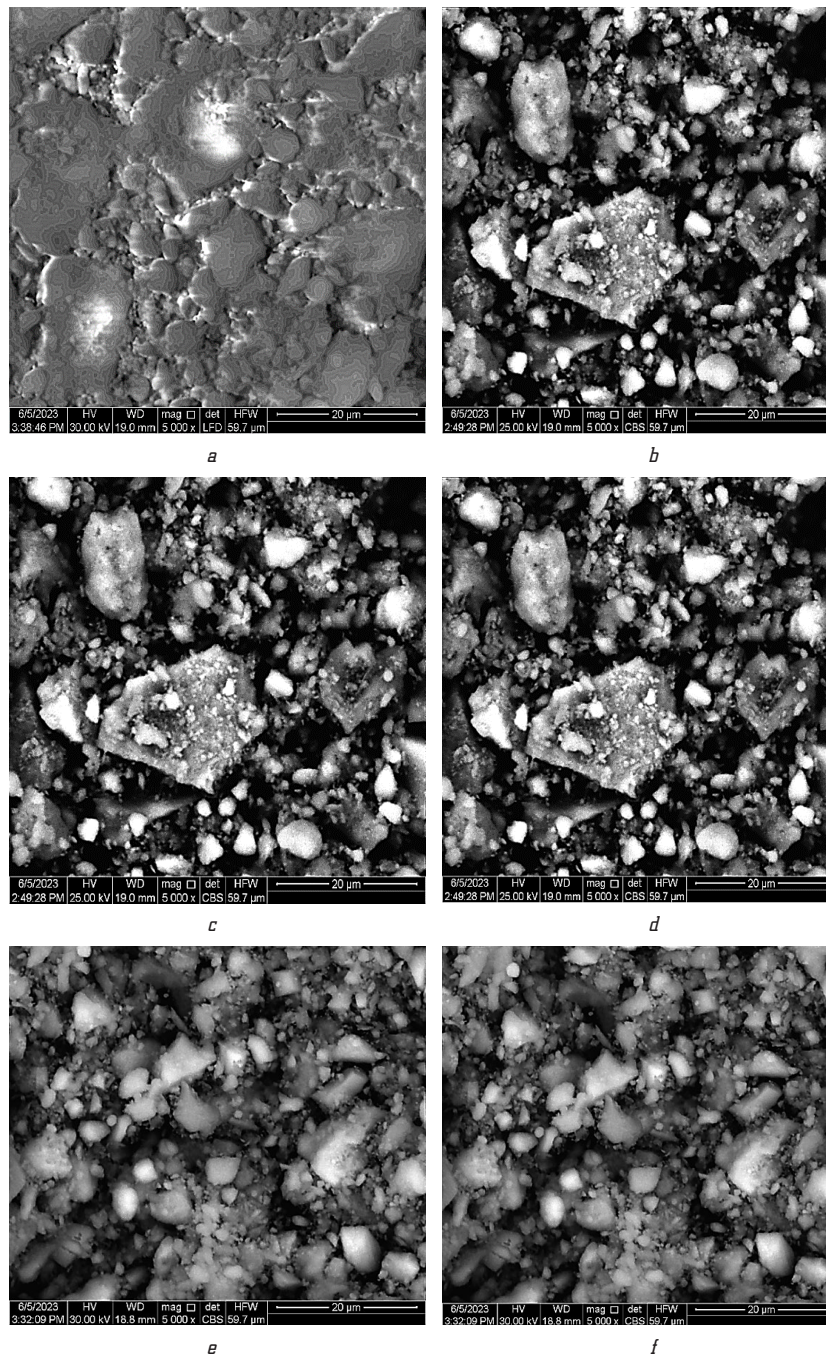


Fig. 5. SEM micrographs:

a – the samples of raw phosphate; *b* – the sample of dry waste (*R*+15 mm); *c*, *d* – the waste end of the lane dry representing (*R*+2 mm) and waste of TSV, respectively; *e*, *f* – samples of the wet representative (*R*+1 mm), and a sample of the mud, respectively

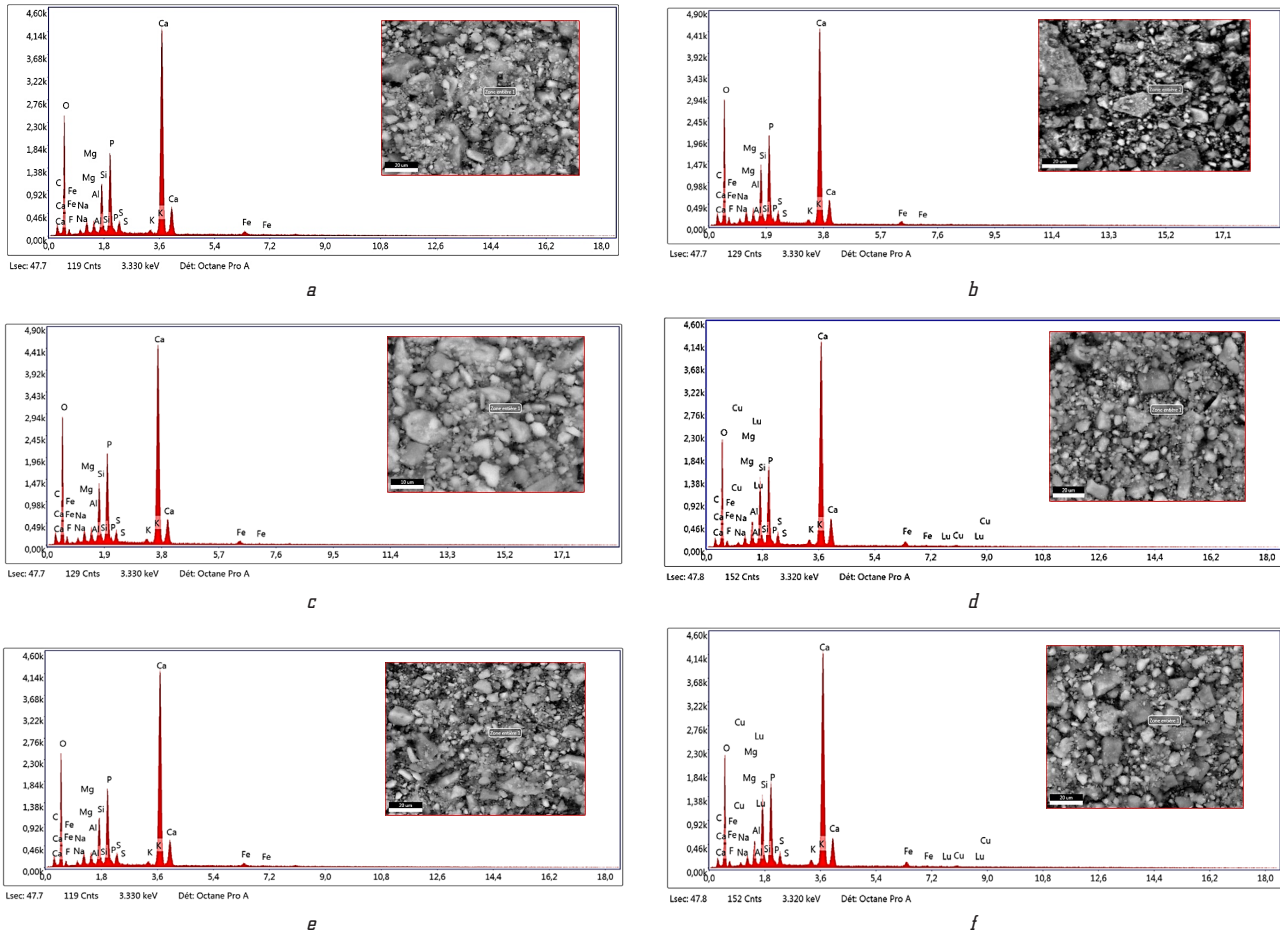


Fig. 6. EDS for SEM:

a – samples of raw phosphate; *b* – the sample of dry waste (*H*+15 mm); *c* – the waste end of the dry path representing (*H*+2 mm); *d* – the discharge end of the dry path TSV; *e*–*f* – samples of the wet representative (*H*+1 mm), and a sample of the mud, respectively

3.2.2. Infrared spectrometry. The identification of the mineral phases in the samples studied has been achieved by the analysis of the infrared spectrometry (IR) in all the samples studied (Fig. 7). The identification has put out several bands, in particular those attributed to the carbonate, phosphate, and hydroxide ions OH – apatite. The peaks characteristic of the elements – nitrogen, phosphate and carbonate apatite are not very intense, which leads one to infer that the fine fraction is not rich in phosphate. On the other hand, the band is most intense in the mortality samples represent the gangue carbonate; view the presence of carbonates (calcite and dolomite).

The identification and the positions of the bands observed in the IR for the different samples studied reported in Table 2.

The infrared spectrum of the crude ore (Fig. 7, *a*) shows a broad band in the zone of elongation of the hydroxyl. These peaks are located at 3377 cm^{-1} and 3746 cm^{-1} . The spectrum is also of the bands at 1646 cm^{-1} characteristic of carbonates. Let's assign the band located at 1424 cm^{-1} in the groups CO_3^{2-} apatite. The band located at 1037 cm^{-1} and 603 cm^{-1} , 267 cm^{-1} 569 cm^{-1} corresponds to deflections, respectively, to the Si-O and to the groups of ions, phosphates (PO_4^{3-}) and (PO_4^{2-}). The bands detected at 468 cm^{-1} , 602 cm^{-1} and 872 cm^{-1} may correspond to elongation of P-OH groups HPO_4 .

The infrared spectrum of sterile +15 mm (Fig. 7, *b*) is virtually identical to that of the rejection of enrichment of the ore-bearing. Let's observe the same bands in the IR spectra that represent the samples studied. In this spectrum, a band appears in the region of the stretching of hydroxyl radicals, and to certain positions. In addition, let's distinguish a small band around 1600 cm^{-1} and 1650 cm^{-1} , corresponding to the deformations angular des bonds O-H of water molecules. Bands characteristic of the carbonates are also present 1470 cm^{-1} , 1430 cm^{-1} and 850 cm^{-1} . Other bands are common to the two distinct phases. The band towards 1010 cm^{-1} is attributed either to the stretching of Si-O, to either of the groups of phosphates (PO_3^{3-}). The band to 260 cm^{-1} is attributed to the deformation of either Si-O-Si, groups phosphates (PO_3^{3-}).

3.2.3. Analysis by XRD. Analysis by XRD allows identifying the phases mineralogical major and minor each sample, namely the carbonate hydroxyl apatite and Fluorapatite, as well as the elements of the matrix (dolomite, calcite). To be able to follow the evolution of these minerals by sample.

The comparative analysis of the intensity of fluorapatite phase for all samples is around to 32°, shows that this phase is important in the raw phosphate and waste+15 mm. Therefore, it is rich in fluorapatite, which

justifies the need for a more efficient treatment process for the recovery of raw phosphate.

The analysis also shows that the dolomite phase is more intense after the treatment of raw phosphate, particularly

in the dry waste +2 mm. In the other enrichment processes (settling), there is the calcite clinoptilolite phase showing that this phase is important in the mud, these results presented in Fig. 8.

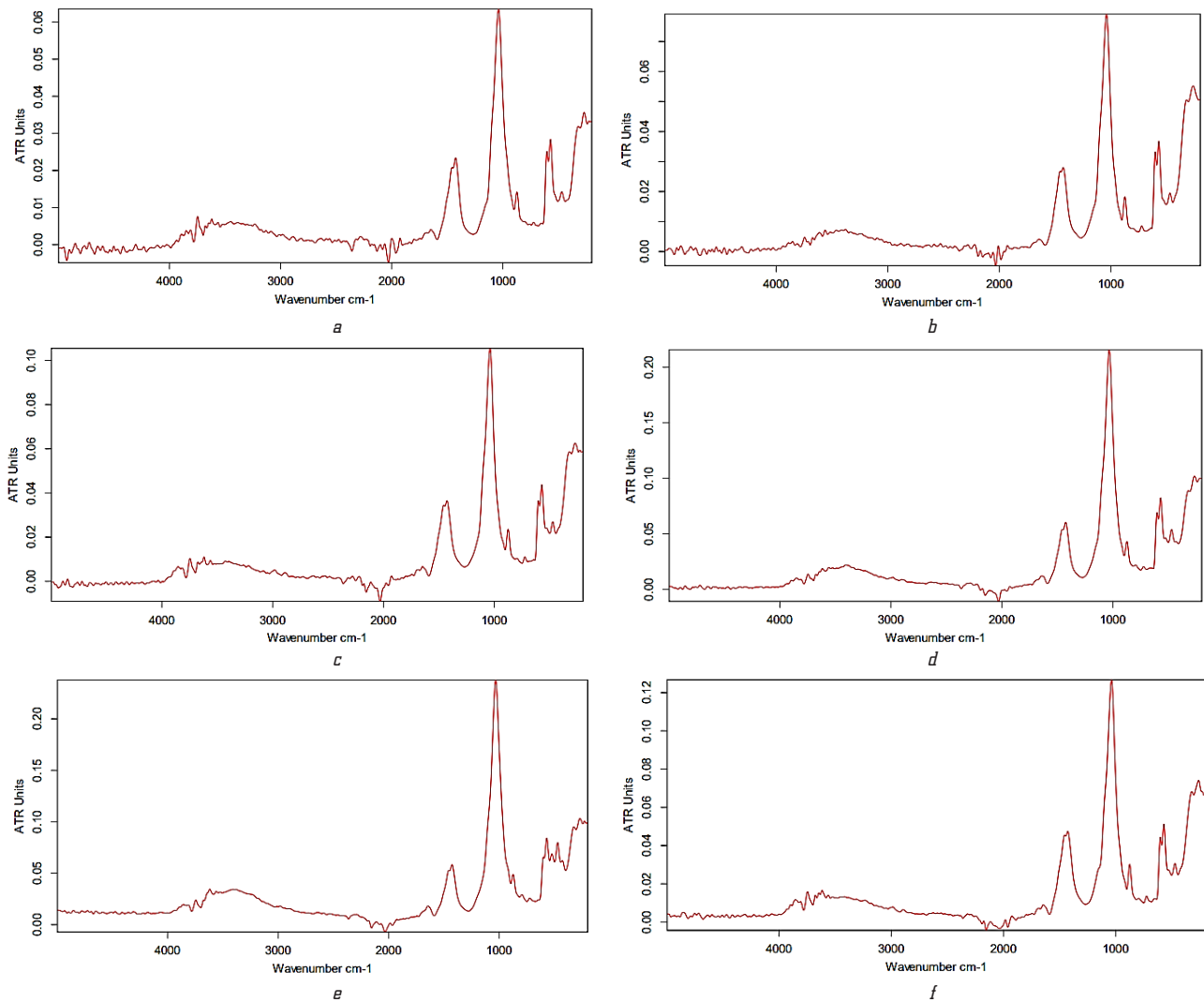


Fig. 7. IR spectra of the samples studied:
a – raw phosphate; *b* – dry waste (*R*+15 mm); *c* – dry waste (*R*+2 mm); *d* – TSV waste; *e* – wet waste (*R*+1 mm);
f – sample of the mud

Table 2

Position and identification of the bands observed by IR samples studied

Identification of band	Position (cm ⁻¹) and intensity of the bands					
	Raw phosphate <15 mm	Waste >15 mm	Dry waste +2 mm	Fine TSV	Wet wastes +2 mm	Mud
Ions PO ₄ ⁻³	1037	1039	1038	1032	1037	1031
Ions PO ₄ ⁻²	569	570	570	568	570	568
CO ₃ ⁻² apatite	1424	1426	1426	1424	1426	1425
CO ₃ ⁻²	1646	1643	1648	1639	1645	1643
P-H	2179	2222	2220	2174	2176	2112
Elongation OH, OH bound to the Ca(OH) ₂	3745	3377	3746	3404	3745	3617
P-O-C	722	723	723	723	724	723

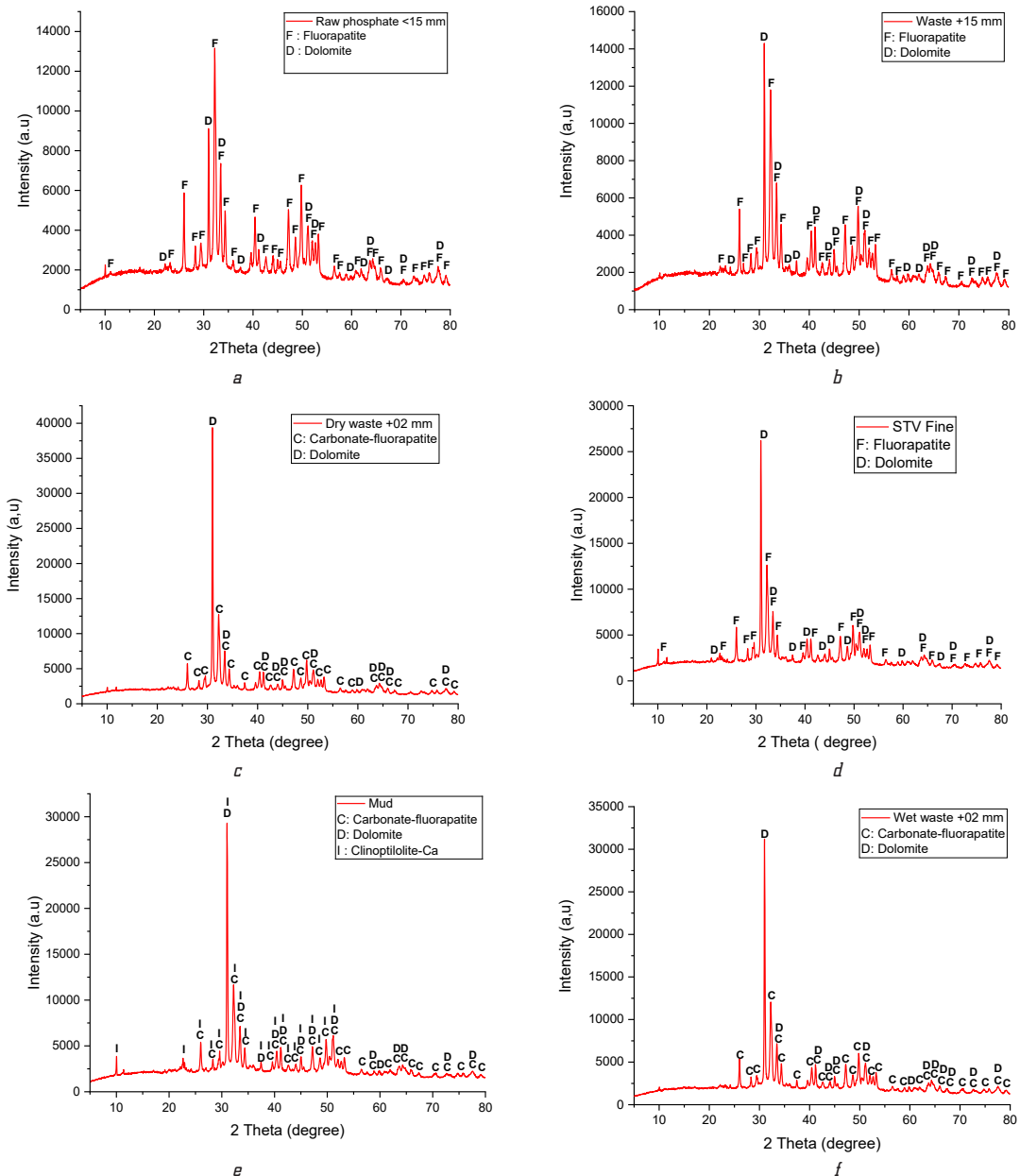


Fig. 8. XRD results of the samples studied:

a – raw phosphate <15 mm; b – waste +15 mm; c – dry waste +02 mm; d – STV fine; e – mud; f – wet waste +02 mm

3.3. Chemical composition

3.3.1. Distribution of major elements by fluorescence of X-rays (XRF). The analyzed sample placed under a beam of X-rays under the effect of these latter, the atoms in the sample pass to an excited state. The state excite is unstable and the atoms tend to return to the ground state by releasing energy in the form of X-ray photon, it is the phenomenon of X-ray fluorescence). The analysis of the radiation allows the time to get to know the nature of the chemical elements present in a sample as well as their mass concentration. The results are been presented in Table 3.

The product is powered and the release of various methods of treatment contains a content of CaO can be reached 43.51 %, so they mainly constitute the gangue carbonate. The content of P₂O₅ in this waste is included between 8.92–11.40 %. This confirms the effectiveness of

the treatment process (settling). It is important also to note that all samples are impure vis-a-vis the CaO, MgO and SiO₂ as a percentage and significant other items in the minority percentage, such as Fe₂O₃, K₂O.

The results obtained have shown the presence of several trace elements, such as the alkali metals (Rb), transition metals (Cr, Ni, Cu, Zn and Y), metals, alkaline earth (Sr). These elements exist in low quantities and their concentrations differ depending on the type of the sample and depending on the element considered.

3.3.2. Distribution of trace elements metallic by spectrometry of atomic absorption (AAS). For trace metals, using lamps cathodes hollow appropriates for each element measured after performing the extraction of nitric acid. The elements characterized are Cd, Zn, Cu, Hg and Pb. These results obtained are been presented in Table 4.

Table 3

Results of chemical analyses fluorescence of X-ray (XRF) of the different samples studied

Types of samples Type of the elements	Raw phosphate -15 mm	Waste +15 mm	Dry waste +2 mm	Fine TVS	Wet waste +2 mm	Mud
P ₂ O ₅	30.18	26.12	23.53	25.53	26.10	20.44
Cad	60.88	58.51	54.08	55.17	60.28	46.30
MgO	2.89	4.71	4.58	3.47	6.05	4.00
SiO ₂	9.80	9.99	10.93	15.32	11.92	20.30
Fe ₂ O ₃	0.77	0.73	0.68	0.99	0.77	1.07
K ₂ O	0.27	0.26	0.27	0.46	0.28	0.54
Al ₂ O ₃	3.31	3.12	3.36	3.82	3.61	5.03
Cr ₂ O ₃	3.64	0.05	0.05	0.06	0.05	0.09
SO ₃	6.22	5.94	5.24	7.07	6.82	5.34
CuO	ND	ND	0.00	0.00	ND	0.03
NiO	ND	ND	ND	to 0.01	ND	0.00
ZnO	0.02	0.02	0.02	0.02	0.02	0.04
Ors	0.31	0.28	0.25	0.25	0.29	0.21
Y ₂ O ₃	0.02	0.02	0.02	0.02	0.03	0.02
WO ₃	0.03	0.01	0.01	ND	0.01	ND

Note: ND – no data

Table 4

Results of analysis by atomic absorption spectrometer samples of raw phosphate and waste by means dry and wet

Designation	Raw phosphate <15 mm	Waste >15 mm	Dry waste +2 mm	Fine TSV	Wet waste +2 mm	Mud
Cadmium (ppm)	23	21	22	21	21	32.5
Copper (ppm)	10.9	10.7	13.65	12.2	10.55	16.85
Zinc (ppm)	100	100	100	100	100	100
Lead (ppm)	66.50	62	80.5	72	74.5	159

The results obtained show generally that all samples are relatively rich in metals Cu, Zn, Pb and Cd. This is due to the presence of ores of sphalerite and galena. In the whole, the concentrations of Zn, Pb, Cd and Cu in the sample of discharges studied are important, in particular, those recorded in the sludge phosphate compared to the raw phosphate. The mean concentrations of Zn, Cd and Pb in the samples of sludge phosphate proved to be much more than the other releases from the processing chain.

However, it important to note that cadmium is more concentrated in rock phosphate than in the waste from two process of treatment and the stage of primary screening, this can be explained by the fact that the concentrations of Cu, Zn, and Pb increase with the decrease of the grain size, while the Cd concentration decreases as grain size increases.

3.4. Recommendation

This research clearly shows that the relationship between mining wastes, in particular, that studied in our research, and its environmental impact is of crucial importance for improving the efficiency of ore treatment processes and reducing the environmental impact of heavy metals. This will enable to obtain quality products and properly manage this waste, reusing it in other processing industries. Success can achieve through:

a) implementation of an effective control system to manage the risks associated with these wastes and to reduce the impact of pollutants from quarry and processing plant;

b) construction of an effective control system to manage the drainage of acid waters of the ponds, in order to prevent the contamination of groundwater and surface water resulting from the treatment process;

c) establishment of a monitoring strategy in real-time to oversee the management of the waste and the quality of treatment processes;

d) development of the practical recovery of the heavy metals presents in the waste phosphate.

3.5. Perspectives and Study Limitations

The results obtained highlight significant differences between the levels recorded in raw phosphate and those in the samples of process waste. The various analytical techniques applied to the different types of waste collected revealed a strong correlation between their chemical and mineralogical composition on one hand, and their environmental impacts on the other. Consequently, the waste materials are composed of 59.2 % dolomite, 20.5 % calcite, and 19.8 % fluorapatite. Additionally, kaolinite was detected in these residues, though in a minor proportion (0.5 %).

Furthermore, it was observed that the concentrations of trace metal elements tend to increase as the grain size decreases, particularly in sludge. This clearly demonstrates that the efficiency of treatment methods can, in certain cases, reduce the concentrations of trace elements in the natural phosphate under study. This finding opens up research opportunities for scientists and engineers to develop

more effective treatment methods. Therefore, the suggested methods must consider the proportions and concentrations in the waste to minimize environmental impacts.

4. Conclusions

Based on this research, it can be concluded that this study focused on the degree of impact of heavy metals compounds of waste from the chain of treatment of phosphate Kef Essennoun of Djebel Onk. The various analysis techniques used on the different types of discharges loading have revealed a close correlation between the chemical composition and mineralogical on the one hand, and their environmental impacts on the other:

- the results of the particle size analysis by sieving reveal that the mass yield in all the samples studied is in the particle size fraction below 500 μm . In addition, these results confirm the effectiveness of fragmentation and highlight the influence of the residence time in the mill on the granulometry of the ore, making the treatment process more cost-effective;
- the SEM results obtained confirm that grinding has a considerable influence on the liberation of phosphate elements and on the form of the grain;
- the mineralogical study of the ore, phosphate, carried out by X-ray diffraction (XRD), on the raw phosphate, as well as on the waste, reveals the presence of the main mineral phases such as hydroxyl apatite, the carbonate hydroxyl apatite, the carbonate fluorapatite, fluorapatite and dolomite. However, the mineral phases minor (with intensities lower) such as calcite, quartz and montmorillonite also observed. In addition, the predominance of the dolomite in the fine fraction also observed;
- the results of the chemical X-ray fluorescence (XRF) analyses show that the waste from the various treatment processes consists mainly of CaO carbonate gangue. The P_2O_5 content in the rejects is low, confirming the effectiveness of the treatment process, in particular the settling process. The results also indicate the presence of several trace elements, such as alkali metals (Rb), transition metals (Cr, Ni, Cu, Zn and Y) and alkaline earth metals (Sr);
- in the atomic absorption spectrophotometric analysis, it was observed that the rejects are richer in metallic trace elements than the raw phosphate sample. On the other hand, metallic trace elements considerably increased in the solid part of the sludge, which is attributed to the predominance of degrees of liberation of these elements and probably to the efficiency of this treatment process.

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Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Use of artificial intelligence

The authors confirm that artificial intelligence technologies were not utilized in the creation of the current work.

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