الجمهورية الجزائرية الديمقراطية الشعبية
République Algérienne Démocratique Et Populaire
وزارة التعليم العالي والبحث العلمي
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
جامعة الشهيد الشيخ العربي التبسي – تبسة
Université Echahid Cheikh Larbi Tebessi – Tébessa
معـــــــهد المـــــناجم
Institut des Mines
قسم المناجم و الجيوتكنولوجيا
Département Mines Et Géotechnologie

MEMORY

Presented in order to obtain the Master's degree

Field of study: Mining Engineering

Option: VRM

Characterization and management of waste: The case of the DJBEL ONK mine (Bibliographic Research)

By:

KERTIMI Abderrahim

In front of the jury:

Dr. BOUZENZANA. A	**Président**	**MCA**	**Université Echahid Cheikh Larbi Tebessi – Tébessa**
Dr. AOUATI.M	**Encadreur**	**MAA**	**Université Echahid Cheikh Larbi Tebessi – Tébessa**
Dr. Mansour.K	**Examinateur**	**MAA**	**Université Echahid Cheikh Larbi Tebessi – Tébessa**

Academic year: 2023/2024

Acknowledgement

First and foremost, we begin by offering our heartfelt thanks and praise to Allah, invoking His greatest names.

We would like to extend our sincere gratitude to Mr. Aouati M., whose belief in us, along with his guidance and support, has been invaluable throughout this journey.

We also wish to thank all the participants who contributed to our research and generously gave their time, helping to make this endeavor both possible and successful.

Lastly, we express our deep appreciation to all our teachers, who have tirelessly imparted their knowledge to us over these many years

Dedication

We lovingly dedicate this humble work to our esteemed parents, our cherished siblings, our dear relatives, and beloved friends. To all our classmates, esteemed professors, and to everyone who has supported us, whether from nearby or afar, we extend our heartfelt gratitude. Your encouragement and assistance have been invaluable, and this achievement is as much yours as it is ours.

List of figures:

Figure 1:Deposit's map 5
Figure 2: Mechanical preparation scheme 4
Figure 3: Scrubbing scheme 5
Figure 4: Dedusting scheme 6
Figure 5: Geographic map of the wilaya of Tébessa 8
Figure 6: Geological situation of the deposits in the Djebel Onk region 9
Figure 7. Cross Section of Djebel Onk 9
Figure 8: Stratigraphy of the Djebel-Onk deposit (Ranchin G., 1963) 14
Figure 9: Stratigraphic and structural sections of the northern and southern flanks of Djebel Onk Mining Research and Exploitation Company. (E.R.E.M): 15
Figure 10: Synthesis of phosphate resources on the southern flank of Djebel OnkBureau of Research and Mining Geology (B.R.G.M) 18
Figure 11: Structure of white, black and red phosphors 22
Figure 12: Heavy metals in phosphate waste of normal product in parts per million 28
Figure 13: Change of elements concentration in phosphate waste of normal product in percentage ... 28
Figure 14: Change of elements concentration in phosphate waste of special product in percentage.28
Figure 15: Heavy metals in phosphate waste of special product in parts per million……..…….29
Figure 16: SEM and EDS of refusal of +15 mm of normal product……..……32
Figure 17: SEM and EDS of refusal of +15 mm of special product……..…32
Figure 18: SEM and EDS of refusal of +1 and +2 mm of normal product……32
Figure 19: SEM and EDS of mud……...……33
Figure 20: XRD of refusal of +15 mm of normal product……..……34
Figure 21: XRD of refusal of +15 mm of special product……..……34
Figure 22: XRD of refusal of +1 and +2 mm of normal product……...……35
Figure 23: XRD of mud……..……35

List of tables:

Table 1: Geological Reserves Of The Djebel Onk Deposit 17
Table 2: Mineralogical composition of the Djebel Onk phosphate ore..... 22
Table 3: The chemical composition of the commercial product of Djebel Onk [10]..... 23
Table 5: The chemical composition of the rejected slices of special product 27
Table 4: The chemical composition of the rejected slices of normal product..... 27
Table 6: Chemical analysis by element range for the special product 30
Table 7: Chemical analysis by element range for the normal product 30
Table 8: Chemical formula of the studied minerals 33

Contents:

1. General introduction: 1

1.1. Background and Significance: 1

1.2. Objectives of the Research: 2

1.3. Scope and Limitations: 2

1.4. Summary: 2

2. Processing Plant: 2

2.1. Mechanical Preparation: 3

2.1.1. Crushing: 3

2.1.2. Grinding: 3

2.1.3. Screening: 3

2.2. Scrubbing: 4

2.2.1. Drying: 5

2.3. Processing (Dedusting): 5

Introduction to the Djebel Onk Region: 7

3. Geographical Setting of Djebel Onk : 7

4. The climate : 8

5. Geologie Part: 9

5.1. Djemi djema deposit: 10

5.2. Concentrations: 10

5.3. Kef es sennoun deposit : 10

5.4. Concentrations: 10

5.5. The bled el hadba deposit: 11

5.6. The bettita deposit: 11

5.7. The djebel onk-north deposit: 11

6. Stratigraphy of the Kef Essnoun Deposit: 11

6.1. Tertiary : 12

6.1.1. Paleocene: 12

6.1.2. Eocene: 12

6.1.3. Miocene: 13

6.2. Quaternary: 13

7. Structural and Tectonic Overview of the Kef Essenoun Deposit: 15

7.1. Reserves: 16

8. Expliotation: 19

8.1. Description of the Kef Essenoun Deposit: 19

The Kef Essenoun deposit is an important geologically well-known deposit that presents mining conditions suitable for conventional mechanized open-pit mining: The significance of the deposit lies in: 19
8.2. Exploitation at Kef Essenoun: 19
A- Earthmoving : 19
8.3. Loading: 20
8.4. Transport: 21
8.4. Characteristics Of Phosphate: 21
8.5. Mineralogical composition of the Djebel Onk phosphate ore: 22
8.6. Composition chimique du produit marchand de phosphate de djebel onk : 23
9. Physicochemical Analysis: 26
10. Elemental Analysis: 26
11. Mineralogical Characterization: 26
11.4. Leaching Tests: 26
11.5. Sequential Extraction: 26
11.6. Microscopic Imaging: 27
12. Geochemical Modeling: 27
13. Environmental Risk Assessment: 27
14. Chemical analysis by slice by atomic absorption: 29
15. The Scanning Electron Microscope (SEM) and (EDS): 31
16. X-ray Diffraction (XRD): 33
17. Discussion and breaking down results: 36
18. Introduction: 38
19. Effective management of mining waste involves several key steps: 38
20. Dangerous elements in the phosphate ore: 39
20.4. Toxicity of Cadmium in Mining Waste: 39
20.4.1. Sources of Cadmium in Mining Waste: 39
20.4.2. Pathways of Cadmium Exposure: 39
20.4.3. Health Effects of Cadmium Toxicity: 39
20.4.4. Environmental Impacts: 40
20.5. Toxicity of Lead in Mining Waste: 40
20.5.1. Sources of Lead in Mining Waste: 40
20.5.2. Pathways of Lead Exposure: 40
20.5.3. Health Effects of Lead Toxicity: 41
20.6. Toxicity of Copper in Mining Waste: 41
20.6.1. Sources of Copper in Mining Waste: 41
20.6.2. Pathways of Copper Exposure: 41
20.7. Toxicity of Zinc in Mining Waste: 42

20.7.1. Sources of Zinc in Mining Waste: ***42***
20.7.2. Pathways of Zinc Exposure: ***43***
20.7.3. Health Effects of Zinc Toxicity: ***43***
20.7.4. Environmental Impacts: ***43***
21. Managing Mining Waste: ***43***
21.4. Environmental Desulfurization: ***43***
21.5. Backfill: ***44***
21.5.1. Underground Backfill: ***44***
21.5.2. Pit Backfill: ***45***
21.6. Densification: ***45***
21.6.1. Thickened Tailings: ***45***
21.6.2. Paste Tailings: ***45***
21.6.3. Densification Techniques in Mining: ***46***
21.6.4. Thickened Tailings: ***46***
21.6.5. Paste Tailings: ***46***
21.6.6. Filtered Tailings: (Innovating Waste Management in Mining): ***46***
21.6.7. Layered Deposition: ***47***
21.6.8. Sterile Rock Inclusions: ***47***
21.6.9. Costs of Management and Rehabilitation of Mine Tailings: ***47***
22. Introduction:……..***49***
23. Overview of Phosphate Waste Calcination:……...***49***
24. Calcination Techniques for Phosphate Waste:……..***49***
25. Benefits of Phosphate Waste Calcination:……50
26. Environmental Impacts:……...……***50***
27. Recent Advancements in Calcination Technology:……...***51***
28. Mitigation Strategies:……51
29.Conclusion:……...……***51***
References: ***53***

1. General introduction:

The Characterization and Management of Waste: The Djbel Onk Mine Case Study. This research focuses on the phosphate ore rejections generated by the Djebel El Onk phosphate complex in Tebessa, Algeria [1].

1.1. Background and Significance:

The Djebel El Onk phosphate complex has been operational since 1965, and throughout its history, waste resulting from the beneficiation process has been indiscriminately dumped in the adjacent valley without proper treatment or recycling [1].

These waste materials, known as phosphate sludge, contain valuable substances but also pose serious environmental risks. Chemical analyses reveal that the sludge contains approximately 20.2% phosphate (P2O5) along with various heavy metals such as Uranium, Cadmium, Zinc, Copper, and Arsenic.

The presence of these heavy and radioactive metals threatens the health of residents, affects vegetation, and impacts livestock in nearby populated areas. Moreover, the contamination of groundwater and surface water exacerbates the environmental challenges [2].

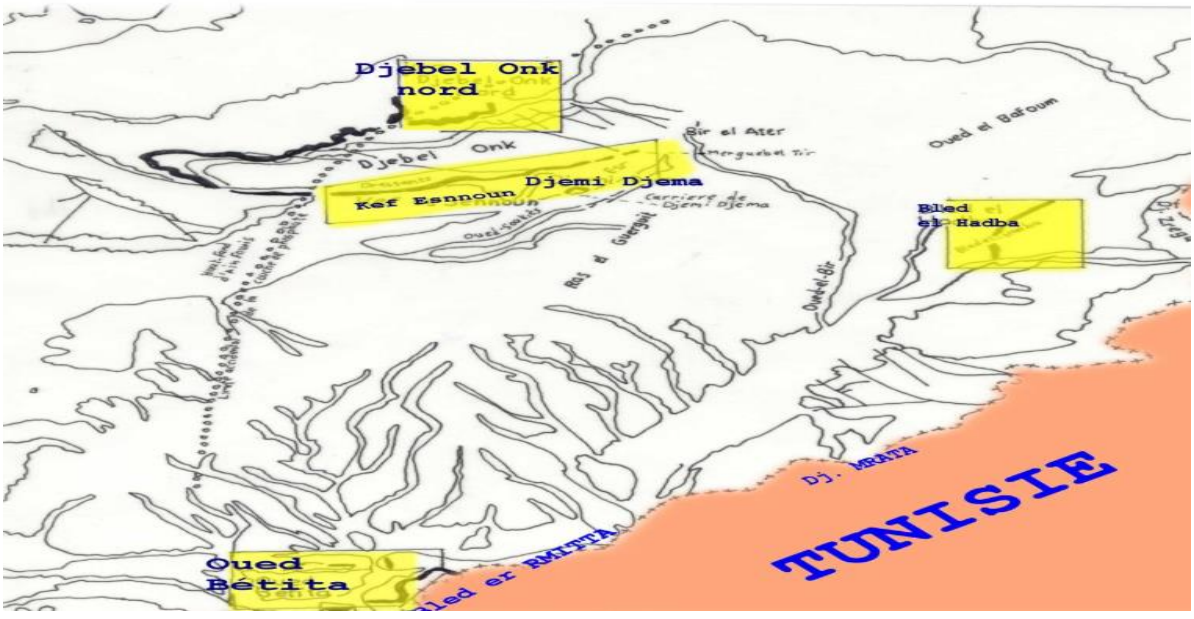


Figure 1:Deposit's map

1.2. Objectives of the Research:

The primary objective is to systematically review the mineralogical and chemical characterization of the phosphate sludge rejected by the Djebel Onk treatment complex.

By understanding the composition and properties of this waste material, the research aims to develop suitable methods for its revaluation. This involves finding ways to extract value from the sludge while mitigating environmental risks [4].

1.3. Scope and Limitations:

The study focuses specifically on the phosphate ore rejections from the Djebel Onk complex.

It aims to propose viable environmental solutions for managing these waste materials, considering their impact on local communities, ecosystems, and water sources.

However, the research does not address other types of mining waste or waste from different sources beyond the Djebel Onk complex [4].

1.4. Summary:

In summary, this research seeks to transform a potential environmental disaster into an opportunity for sustainable waste management and economic benefit. By characterizing and revaluing the phosphate sludge, it aims to contribute to both environmental protection and the national economy.

2. Processing Plant:

The processing of phosphate ore from Djebel Onk occurs in two distinct stages. The first stage involves mechanical preparation, encompassing the following operations: crushing, grinding, and screening. The second stage consists of actual phosphate ore treatment, with separate processing lines for dry and wet methods [1].

2.1. Mechanical Preparation:

Mechanical preparation aims to reduce the size of ore blocks and liberate valuable components from gangue. It includes three primary operations: crushing, grinding, and screening [5].

2.1.1. Crushing:

The goal of crushing is to reduce block sizes from 1000mm to a maximum of 200mm. This is achieved using two crushers:

- Gyratory cone crusher "BABITLESS" with a capacity of 1000 T/h and a reduction ratio of five (5).
- Impact crusher "HAZEMAG" is equipped with a scalping system, capable of 1200 T/h and a reduction ratio of up to sixty (60) [5].

2.1.2. Grinding:

Grinding reduces the size of the crushed product to 20 mm, achieving a reduction ratio of ten (10). This operation involves:

- Two hammer mills (Wedag), each with a production capacity of 300 t/h.
- One impact crusher (Triman) with a production capacity of 500 t/h.
- The ground product is then transferred to the screening workshop [5].

2.1.3. Screening:

Screening aims to remove products larger than 15mm using:

- One (01) vibrating screen (Wedag) with a capacity of 250 t/h.
- Two (02) inclined screens (Triman) each with a capacity of 500 t/h.

This operation achieves a 90% efficiency by weight. The crushed product from Kef Essnoun feeds two inclined vibrating screens (Hazemag) with a capacity of 600 t/h and an aperture of 15 mm. Rejected material from these screens is recycled back to the crushers and then transported to discharge hoppers and spoil heaps. The primary objective of mechanical preparation is to produce product sizes smaller than 15mm for use in the subsequent processing lines [5].

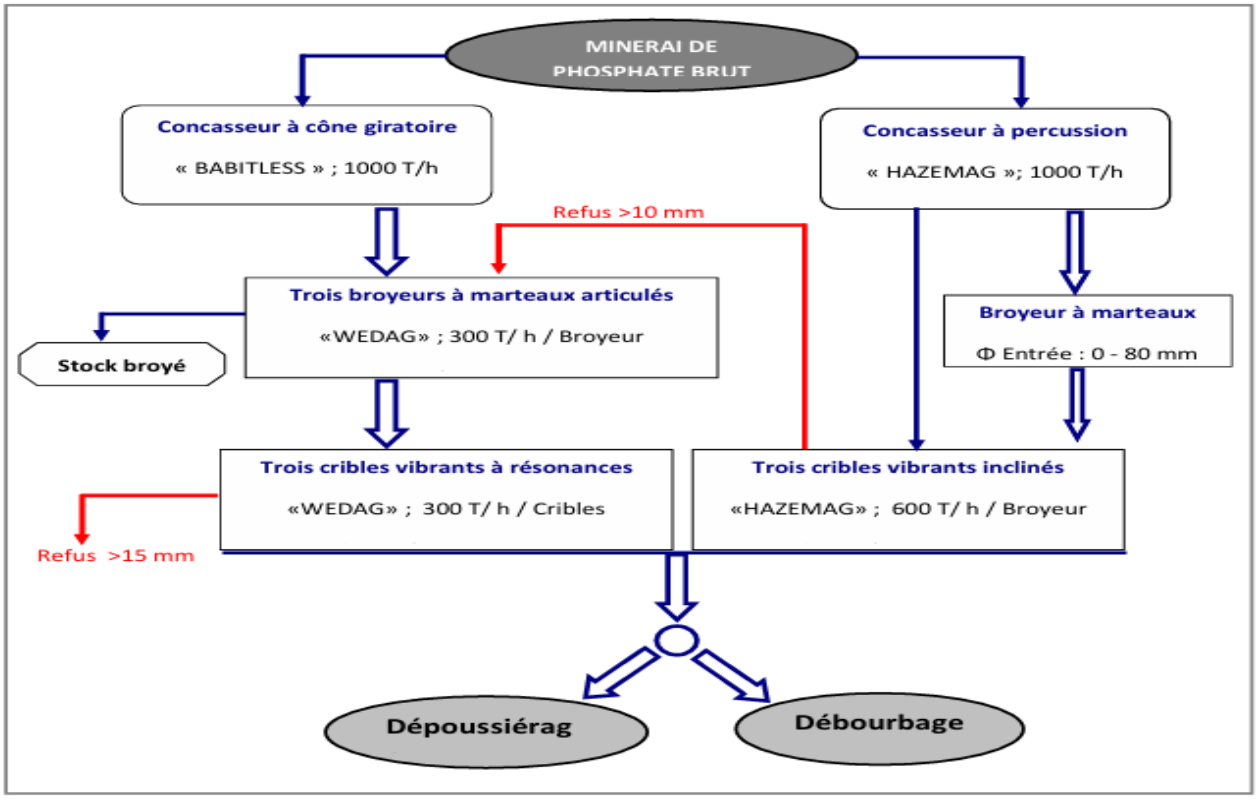


Figure 2: Mechanical preparation scheme

2.2. Scrubbing:

The purpose of scrubbing is to remove clays, silicates, organic materials, and salts from the ore. This operation includes :

- Pulping: Mixing the screened material smaller than 15 mm with water at a solid/liquid ratio of 2/3 (T/m²).
- Wet screening using curved screens with a cut-off size of 1.25 mm.
- Classification and hydrocycloning: Separation processes to classify the ore particles and further remove fine materials.
- Filtration: The high-quality product is squeezed in intermediate presses to obtain a dewatered product with a P2O5 content ranging from 63% to 64.5% [5].

2.2.1. Drying:

The dewatered product, with a moisture content of approximately 5-7%, undergoes drying to achieve a marketable product with a moisture content of 1%. Two methods are used for drying:

- Calcination furnace drying (B1): Vertical drying furnace with an hourly flow rate of 70 T/h/line in the preheating compartment, reaching temperatures up to 100°C.
- Horizontal furnace drying: This includes two horizontal rotary furnaces where the dewatered product is dried in a fluidization chamber at temperatures around 105°C ± 5°C. The product undergoes evaporation to remove absorbed water [5].

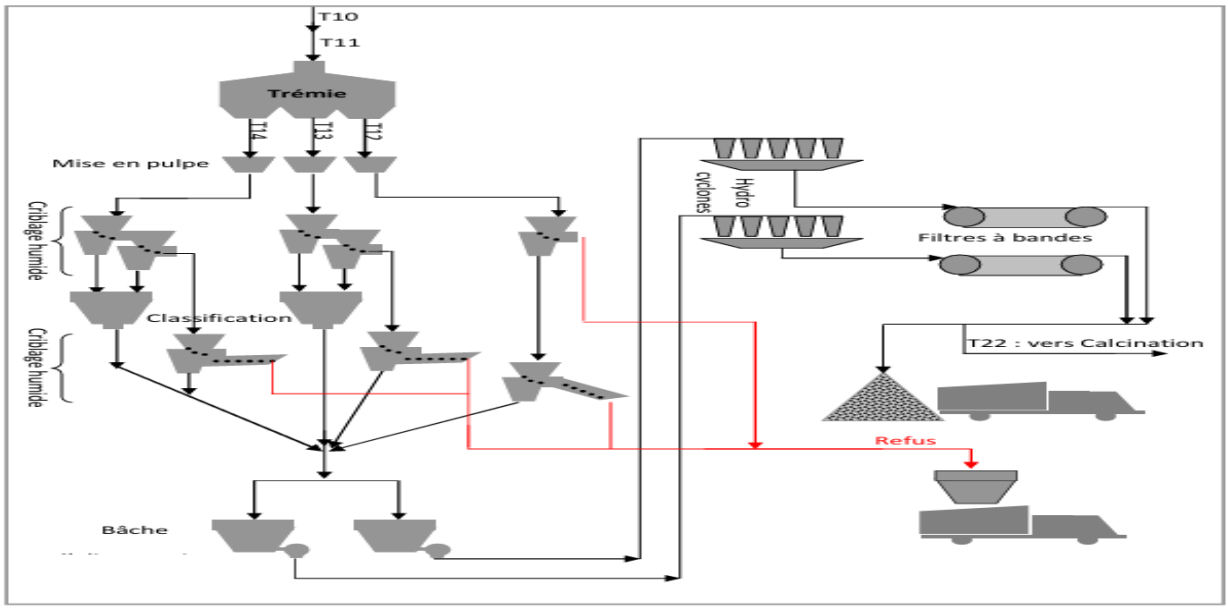


Figure 3: Scrubbing scheme

2.3. Processing (Dedusting):

Dry processing takes place in dedusting workshops (DK2 and DK3) and involves a physico-mechanical process to enrich phosphate ore to approximately 29-30% P2O5. This process is based on dry processing technology and includes:

- Attrition milling: Using attrition mills to release gangue from phosphate grains [5].
- Turbo air classification (TSV): Enriching the product by removing fine particles smaller than 0.08 mm using fans [5].
- Screening at 2mm and 0.8mm: Removing particles larger than 2mm and 0.8mm respectively, to achieve the desired product specifications [5].

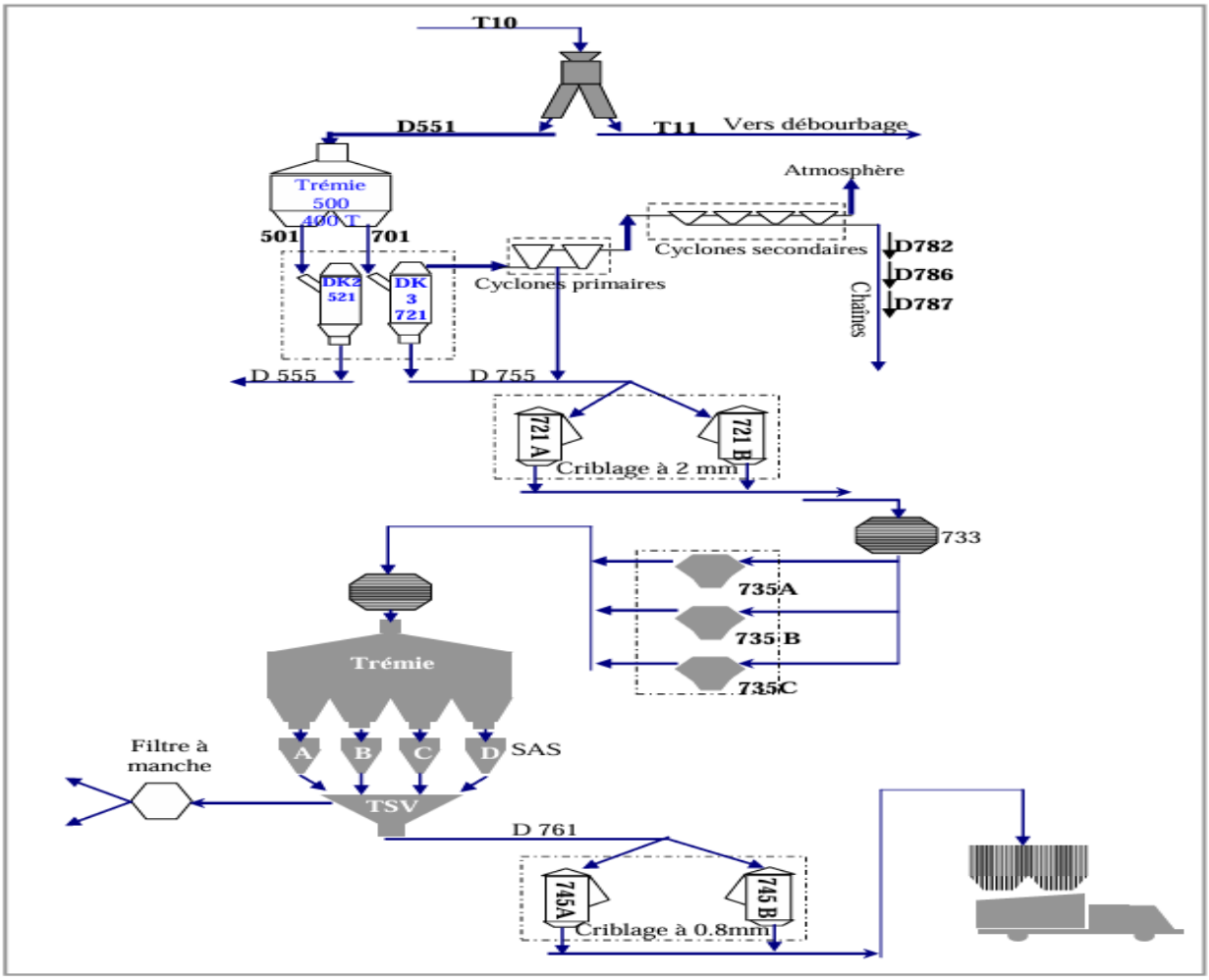


Figure 4: Dedusting scheme

Introduction to the Djebel Onk Region:

The first information about phosphates in the Djebel Onk area dates back to the last century, with intensive explorations beginning from the early 20th century through the 1960s. Among the studies conducted, those by Visse L.D. during 1951-1952 stand out for their comprehensiveness, estimating the mineable reserves in the Djemi Djema area at 96.40 million tons.

From 1960 to 1962, a detailed exploitation study of Djemi Djema was carried out, and the processing facilities were completed in 1965. Quarrying operations commenced concurrently with the establishment of these facilities to provide the necessary materials for the initial trials, which started at the end of 1965 and lasted throughout 1966.

The Djebel Onk area is located in the eastern part of the Nememcha Mountains, which are part of the Saharan Atlas. Djebel Onk features a calcareous mountainous region whose southern side steeply descends under the deposits of the Miocene and Quaternary. The phosphate deposit in the area is of a sedimentary stratiform type, representing a western extension of similar deposits found in Tunisian territory. This deposit belongs to a Tahitian geological formation, beginning with an initial important but heavily clayey phosphate deposit, followed by black marl layers and then the main phosphate bed, which is about 30 meters thick, topped by a natural carbonate formation.

3. Geographical Setting of Djebel Onk:

The Djebel Onk site is located in the northwest of the Algerian Sahara, specifically to the east of the Nememcha mountains, approximately twenty kilometers from the Algerian-Tunisian border (see Figure 1). This area is part of the Tebessa province, about one hundred kilometers away, with the nearest city being Bir el Ater. The site is connected to Bir el Ater by National Road No. 16 (Annaba – El-Oued) and by a railway line that transports phosphate to the port of Annaba, 340 km away.

The mountainous terrain of the region is very diverse. Djebel Onk reaches an altitude of 1338 meters at Guern el Kebech, with the landscape featuring a typically dry wadi. The climate of the area is semi-desert.[5]

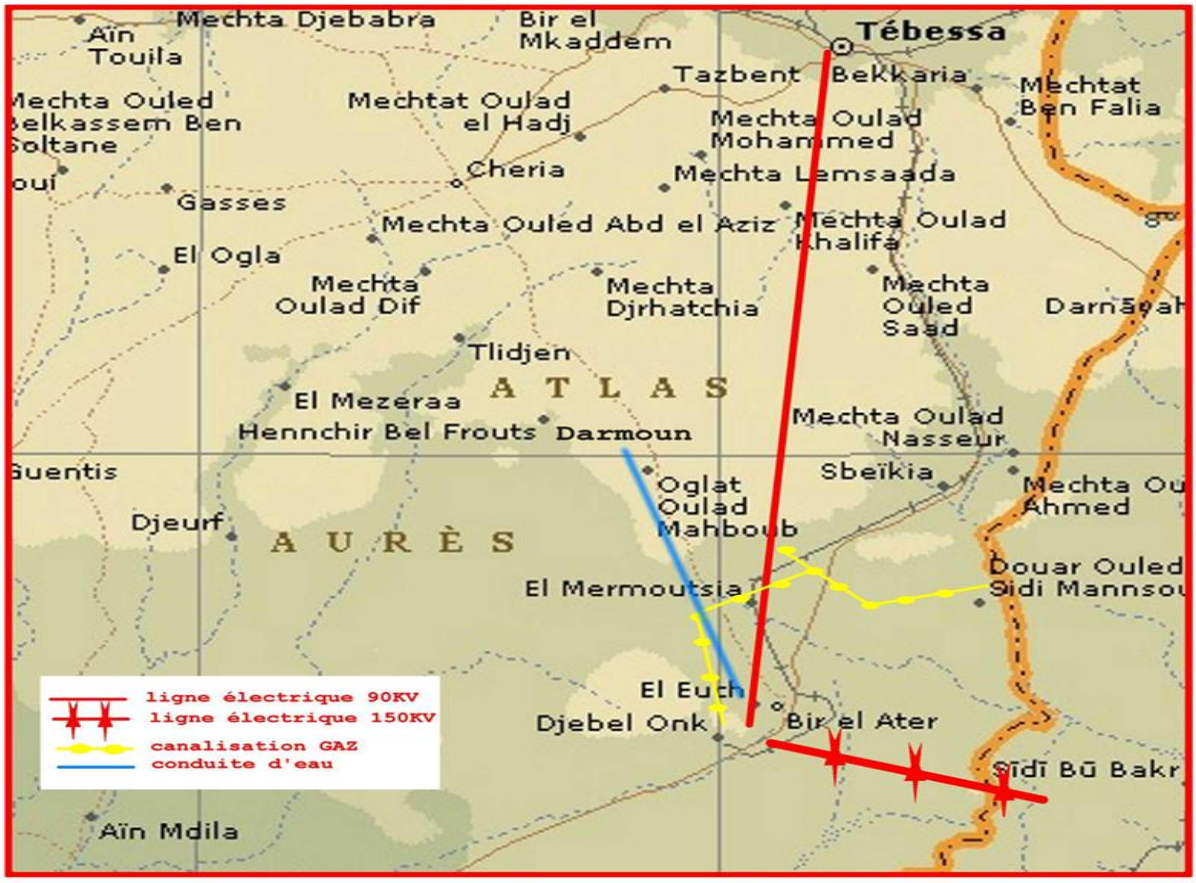


Figure 5: Geographic map of the wilaya of Tébessa

The Djebel Onk mining area, referenced in figure 2, is divided into several sites:

- Oued Btita
- Bled el Hadba
- Djebel Onk South (which includes Djemi Djema and Kef Essenoun)
- Djebel Onk North **[1]**

4. The climate :

Climate is semi-arid, marked by a continental influence with distinct seasons—a severe, cold winter and a hot summer where temperatures can exceed 45°C. Annual precipitation averages 300 mm. [5]

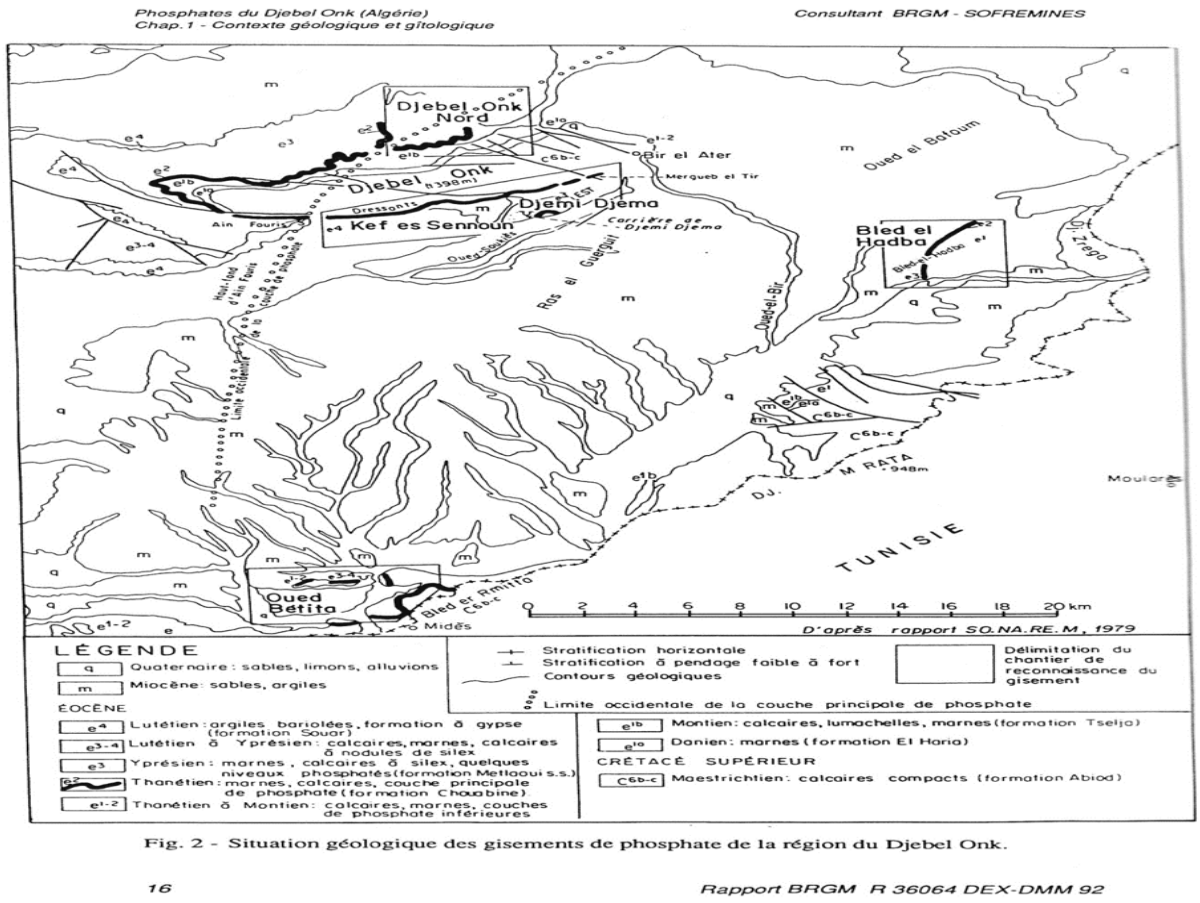


Figure 6: Geological situation of the deposits in the Djebel Onk region

5. Geologie Part:

The Djebel Onk massif is an asymmetrical anticline, shaped like a knee, oriented at an 80° angle towards the north. The north flank has gentle dips under 15°; in contrast, the south flank descends very rapidly, forming an impressive cliff, with strata that are sometimes vertical and even overturned. The entire structure is affected by numerous faults and displacements. [6]

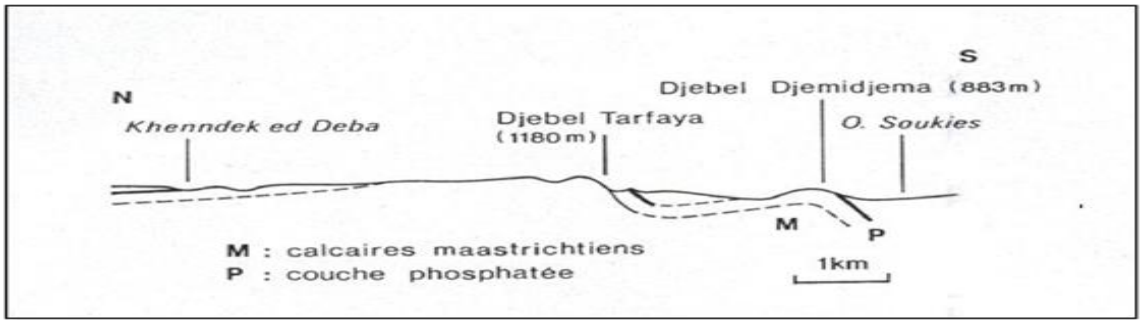


Figure 7. Cross Section of Djebel Onk

5.1. Djemi djema deposit:

Located 750 meters south of the great anticline of Djebel Onk, there is a distinct small subdued anticline of Djemi-Djema. This anticline has an axis oriented at 70 degrees east, but it has a limited lateral extension, which makes it resemble a small branch anticline or a dome, situated at the heart of the upper Thanetian phosphate and the lower marly Thanetian. Lithologically, the phosphate layer is overlain by light gray dolomitic limestones with brown flint, and white clayey limestones with intercalations of fine sands. [6]

Topographically, Djebel Djemi-Djema rises as a hill reaching up to 40-50 meters above the surrounding plain.

The Djemi-Djema deposit consists of two mining fronts that are 1500 meters apart. Both fronts display nearly the same lithological succession.

5.2. Concentrations:

The Djemi-Djema west site exhibits relatively consistent average P2O5 concentrations throughout the deposit, ranging between 24 and 25%, with average MgO concentrations of 3 to 4%.[7]

5.3. Kef es sennoun deposit:

The deposit is located in the extension of the southern dip of the antiformal fold of Djebel Onk, structured primarily due to post-Miocene tectonic activity. Lithologically, the Kef Essennoun deposit comprises, from bottom to top, a calcareo-dolomitic series with flint from the Ypresian, topped by Lutetian marly limestones, then by Miocene sands, and Quaternary alluviums. Most of the deposit consists of a single layer of dark, gray-black phosphate without sterile carbonate intercalation. Toward the northeast of the deposit, from a layer of light brown-beige oxidized phosphate underlying the black phosphate layer, the proportion of the two types of ore is 75% for the former and 25% for the latter. [8]

5.4. Concentrations:

The average P2O5 concentrations are quite stable across the entire extent of the deposit, ranging between 25.05% and 27.94%. The magnesium oxide (MgO) averages are low and nearly constant throughout the deposit, rangi;ng between 2% and 3%, with an overall average of 2.61%.

5.5. The bled El hadba deposit:

Located 14 km southeast of Djebel Onk and 6 km from the Algerian-Tunisian border, this site is notable for the reappearance of the phosphate layer. The outcrop on the southern flank of the synclinal megastructure divides the anticlines of Djebel Onk and Djebel Zrega.

The phosphate layer is only thick on the southern flank of Djebel Onk; however, the phosphate sedimentation is more heterogeneous with a decrease in the frequency of grains.

5.6. The bettita deposit:

The Bettita deposit is the most remote of all the deposits; it is located 45 km southeast of the mining center of Djemi-Djema, and is only 2 to 4 km away from the Mides deposit and Tunisia.

The phosphate series in this deposit has a thickness of about 35 to 45 meters. [6]

5.7. The djebel onk-north deposit:

This deposit, situated 6 km north of the Djemi-Djema mining center, is part of the northern flank of the Djebel Onk anticline. With a gentle northward dip, this area is characterized by a gradual reduction in the thickness of the phosphate layer, moving westward and northward until it completely disappears on the slopes of the Ain Fouris high ground. The thickness of the phosphate layer ranges from 14 to 18 meters. The decrease in thickness is accompanied by more heterogeneous phosphate sedimentation, with contributions of detrital quartz related to the high ground area to the west. The phosphate layer is completely eroded by the anti-Miocene erosion, which progressively truncates the series from west to east. **[4]**

6. Stratigraphy of the Kef Essnoun Deposit:

The oldest sediments identified in the Djebel Onk region are from the Cretaceous period. At Djebel Onk, where mining is currently taking place from bottom to top (see figure 5)

- Cretaceous

Maestrichtian: Massive, compact limestones (sometimes with fossil imprints).

6.1. Tertiary :

6.1.1. Paleocene:

A- Danian: Characterized by marls and clayey marls.

B- **Montian: Limestones,** dolomitic limestones, fossiliferous limestone with intercalations of marls and dolomites.

C- Thanetian: The Thanetian is divided into two parts:

- **Lower Thaneti**an: Marly shales with irregular intercalations of limestone with gastropods, phosphatic intercalations appear in the upper part of the marls.
- **Upper Thanetian**: Comprised of dark gray or brown phosphates ranging from soft phosphates at the bottom to coprolitic phosphates with coarse grains. It also contains shell fragments, teeth, and fish bones. [7]

The thickness of the layer is estimated at 30 m, and lithological variations of the phosphate layers have led to the following lithological description:

Fine pseudoolithic phosphate

Coprolitic phosphate.

6.1.2. Eocene:

A- Ypresian: Divided into upper and lower parts:

- **Lower Ypresian**: Limestones with phosphatic intercalations, dolomitic limestones, and flint levels.
- **Upper Ypresian**: Comprised of limestones, dolomitic limestones. It contains intercalations of phosphatic rocks, flint levels, and quartz geodes.

B- Lutetian: Divided into two parts

- **Lower Lutetian:** Marked by facies change, with the first beds being soft white marls with quartz geodes and flint, interspersed with limestones.
- **Upper Lutetian:** Characterized by evaporitic facies of gypsum and whitish dolomites. Further south is the Bled El Hadba deposit and further still the Bettita deposit.

6.1.3. Miocene:

Miocene sediments rest on the various terms of eroded tertiary. It is represented by conglomerates, coarse-grained sands, white to medium to fine-grained sands, non-calcareous with clayey intercalations, schistose clay, sandstones, white gravels, and pebbles. [7]

6.2. Quaternary:

Quaternary deposits cover most of the terrain, consisting of sandy deposits, gravels, and blocks. The stratigraphic section carried out on the Kef Essnoun deposit shows the following lithological succession:

The wall of the phosphate bundle is represented by dark, foliated marls from the lower Thalesian, in which, locally in the upper part, two thin levels of submetric dolomitic phosphates are situated.

The productive layer is represented by gray to black phospharenites with a thickness varying from 22m in the Northeast to 43m in the Southwest (average 30.50m). The phosphates of the productive layer of the Kef Essnoun deposit have P2O5 contents ranging from 25.05 to 27.94% and MgO contents from 2 to 3%. The average CaO/P2O5 ratio varies from 0.1 to 1.87%. SiO2 contents vary from 0.1 to 2.50%.

Above the productive layer, the summit dolomitic phosphate has an irregular thickness. It is generally expressed throughout the deposit except in boreholes "S4, S20, S32". This formation is of lower thickness in the Southwest and thicker in the Northeast. [7]

Above the summit layer appears the calcareo-dolomitic series with flint of the Ypresian, above which the Lutetian limestones are locally deposited, followed by the Miocene sands and the recent (alluvial) Quaternary deposits. The total thickness of the sterile overburden varies from 40m in the North (S28) to 198m in the South (S39). [7]

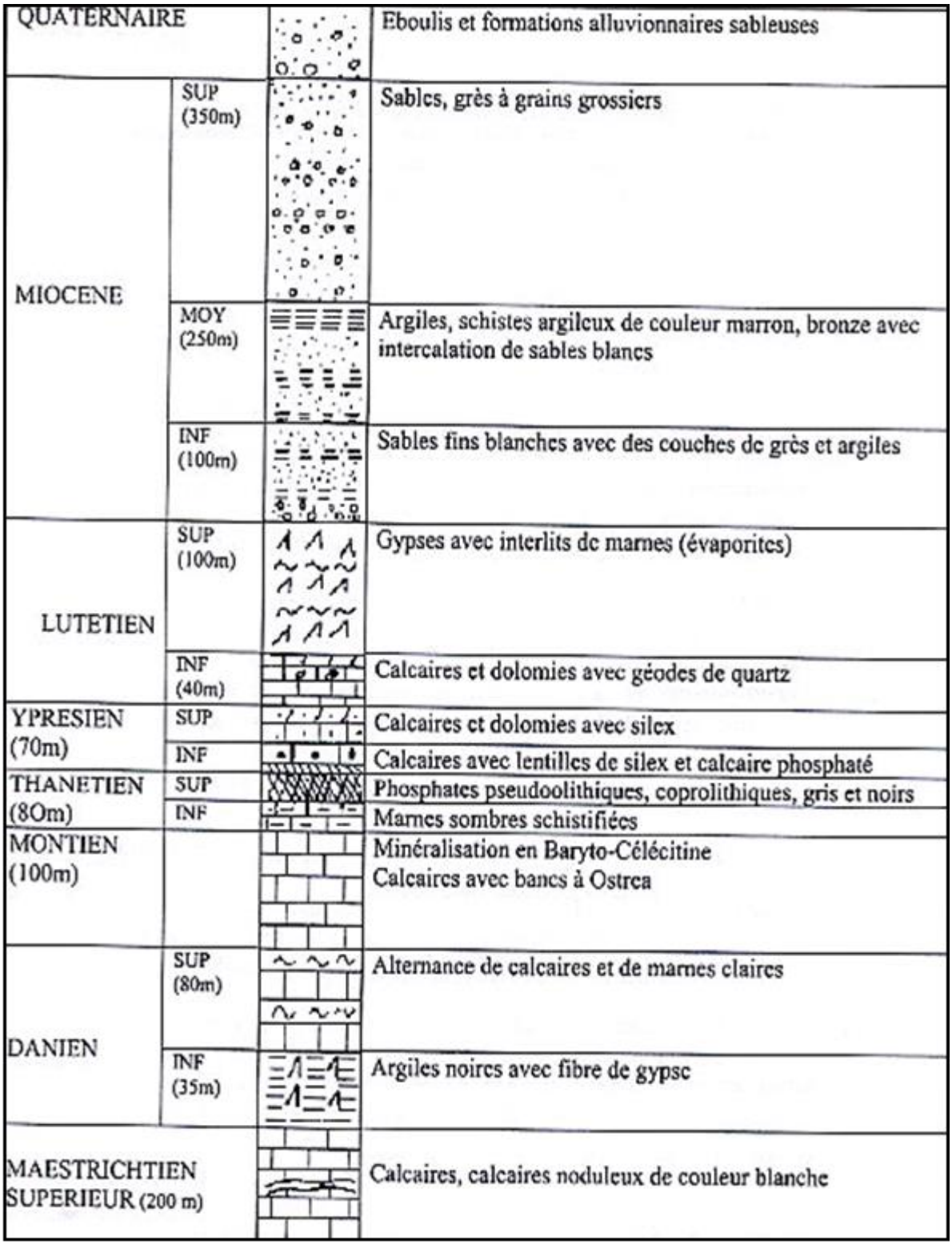


Figure 8: Stratigraphy of the Djebel-Onk deposit (Ranchin G., 1963)

7. Structural and Tectonic Overview of the Kef Essenoun Deposit:

The Kef Essenoun deposit is defined by a straightforward geological structure, resembling a sloped monocline or "table" inclined at a consistent angle of "5 to 10°" toward the south. In the southern region of this monocline, a notable slope break is observed where the dip of the strata reaches 20° at the points between boreholes S11 and S7, S18 and S26, S21 and S26. This minor slope discontinuity is characterized by a rapid increase in the thickness of the sterile overburden, particularly sands. The area is intersected by a system of three major, flexible north-northwest to south-southeast oriented faults. These faults, while traversing through the deposit, do not significantly alter the geometry of the phosphate-bearing layer, especially within the monocline zone. In the standing section of Kef Essenoun, which extends in a northeast 75° east direction, the geological dynamics—both ductile and brittle—have caused a dramatic shift in the dip of the phosphate layer that is exposed at the surface. Here, the dip angle becomes sub-vertical or steeply sloped towards the Southeast or Northwest. To the northeast of these upright formations, the sequence is overturned, with the phosphate layer diving at an angle of 30 to 60° towards the Northwest. Meanwhile, in the central segment of these upright structures, the phosphate stratum maintains a normal sequence, sloping towards the South. [7]

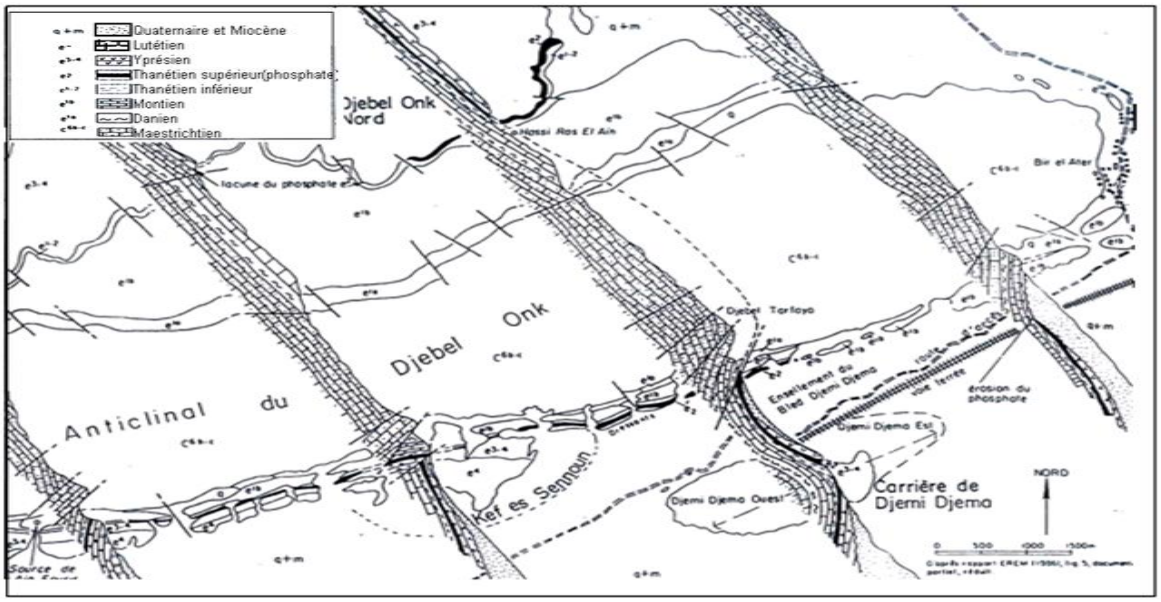


Figure 9: Stratigraphic and structural sections of the northern and southern flanks of Djebel Onk Mining Research and Exploitation Company. (E.R.E.M)

7.1. Reserves:

The Kef Essnoun deposit is segmented into four blocks designated for reserve calculation (KS1, KS2, KS3, KS4):

Block KS1: Covering an area of 22.4 km² with a productive layer thickness of 30 meters (ore density of 2.3), it contains proven phosphate reserves of 168 million tons at 26.58% P2O5 and 2.6% MgO.

Blocks KS2 and KS4: These blocks cover areas of 0.20 km² and 1.23 km², respectively. They are identified as potential reserve zones that have not been confirmed by drilling and are located in the deeper parts of the deposit, extending from the explored areas. Their geological reserves are estimated at 14 million tons and 85 million tons, respectively.

Block KS3: With an area of 0.72 km², this block corresponds to probable reserves found along the southern edge of the Kef Essnoun table. With a layer thickness of 30 meters, its geological reserves amount to 50 million tons. It's important to note that for the peripheral area of the Kef Essnoun table, Ferphos reports reserves of 38.5 million tons (Amani and Harkat 1991). Out of the 218 million tons of ore in blocks KS1 and KS3, 75% are dark grey to black phosphates, and 25% are reserves of lighter phosphates.

The total reserves of blocks KS2, KS3, and KS4 amount to 149 million tons, roughly corresponding to the 228 million tons classified in categories C1 and C2 by EREM. The discrepancy between these figures can be attributed to the different geometries of the blocks considered. EREM adopted a larger polygon extending southward for the C2 category reserves. As this area has not been explored by drilling, we have chosen to limit its area.

In summary, the total geological reserves of the deposit are 317 million tons of ore at 26.53% P2O5 and 2.16% MgO, consisting of 168 million tons of proven reserves (Kef Essnoun table), 50 million tons of probable reserves (slope break area south of the table), and 99 million tons of possible reserves in deeper parts of the deposit.

The audit of numerous geological data available for the potential Kef Essnoun deposit, and a synthesized overview of these data, indicate that this deposit will be pivotal to the development project planned by Ferphos.

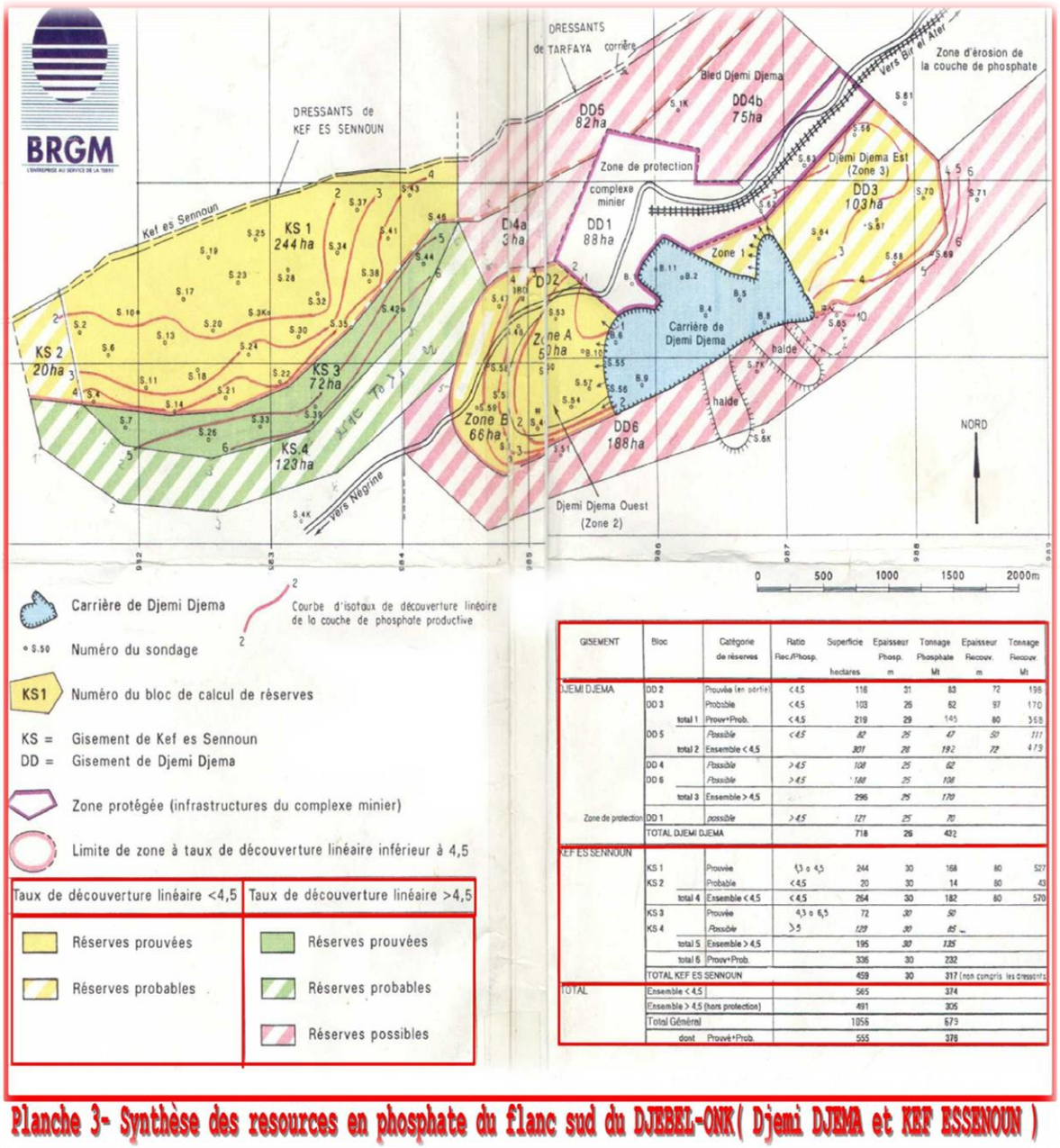
All data from 32 core drillings, carried out on a 250 x 300 m grid, along with the chemical analysis results of the phosphate layer provided by EREM, are reliable. They affirm the geometric and physicochemical characteristics of the deposit.

The phosphate layer exhibits relatively constant and uniform characteristics across the entire recognized extent of the deposit, covering an area of 3.16 km² (3.5 x 0.9 km). Its structure is predominantly monocline, dipping (10 to 15) degrees south (Kef Essnoun table), except at its southern edge where there is a minor slope break dipping (18 to 21) degree into the deeper synform areas. The thickness of the phospharenite layer ranges from (24 to 43 m) (average thickness of 30.5m), without sterile intercalations. Notably thick layers ranging from 35 to 40 m (43 m in borehole S7) characterize the entire southwest part of the deposit.

In total, phosphate resources in the Kef Essnoun deposit, across blocks KS1, KS2, KS3, and KS4, add up to 317 million tons. (Figure 5) clearly illustrates the distribution of phosphate reserves along the southern flank of Djebel Onk. [7]

Table 1: Geological Reserves of The Djebel Onk Deposit

Gisement	**Carrière (tons)**	**Sous-terrain (tons)**	**Total (tons)**	**Hypothétiques (tons)**	**Total General (tons)**
Djemidjema	150,000,000	214,000,000	364,000,000	185,150,000	549,150,000
Kefessenoun	196,000,000	135,000,000	331,000,000	188,500,000	519,500,000
Tarfaya	14,000,000	-	14,000,000	-	14,000,000
Total Onk Sud	360,000,000	349,000,000	729,000,000	373,650,000	1,102,650,000
Bled elHadba	319,689,850	-	319,689,850	480,000,000	799,689,850
Djebel Onk Nord	31,000,000	61,000,000	92,000,000	-	92,000,000
Oued Bettita	-	125,000,000	125,000,000	50,000,000	175,000,000
Total Hadba et Onk Nord	350,689,850	186,000,000	536,689,850	530,000,000	1,066,689,850
Total Général	710,689,850	535,000,000	1,265,688,850	903,650,000	2,169,338,850



GISEMENT	Bloc	Catégorie de réserves	Ratio Rec./Phosp.	Superficie hectares	Epaisseur Phosp. m	Tonnage Phosphate Mt	Epaisseur Recouv. m	Tonnage Recouv. Mt
DJEMI DJEMA	DD 2	Prouvée (en partie)	< 4,5	116	31	83	72	198
	DD 3	Probable	< 4,5	103	26	62	97	170
	total 1	Prouv+Prob.	< 4,5	219	29	145	80	368
	DD 5	Possible	< 4,5	82	25	47	50	111
	total 2	Ensemble < 4,5		301	28	192	72	479
	DD 4	Possible	> 4,5	108	25	62		
	DD 6	Possible	> 4,5	188	25	108		
	total 3	Ensemble > 4,5		296	25	170		
Zone de protection	DD 1	possible	> 4,5	127	25	70		
	TOTAL DJEMI DJEMA			718	26	432		
KEF ES SENNOUN	KS 1	Prouvée	4,3 à 4,5	244	30	168	80	527
	KS 2	Probable	< 4,5	20	30	14	80	43
	total 4	Ensemble < 4,5	< 4,5	264	30	182	80	570
	KS 3	Prouvée	4,3 à 6,5	72	30	50		
	KS 4	Possible	> 5	123	30	85		
	total 5	Ensemble > 4,5		195	30	135		
	total 6	Prouv+Prob.		336	30	232		
	TOTAL KEF ES SENNOUN			459	30	317 (non compris les dressants)		
TOTAL	Ensemble < 4,5			565		374		
	Ensemble > 4,5 (hors protection)			491		305		
	Total Général			1056		679		
	dont	Prouvé+Prob.		555		378		

Figure 10: Synthesis of phosphate resources on the southern flank of Djebel OnkBureau of Research and Mining Geology (B.R.G.M)

8. Expliotation:

8.1. Description of the Kef Essenoun Deposit:

The Kef Essenoun deposit is an important geologically well-known deposit that presents mining conditions suitable for conventional mechanized open-pit mining: The significance of the deposit lies in:

- The quality of its ore.
- Its reserves.
- Favorable geomineral conditions.
- Simple technical parameters.
- Its ease of exploitation (depth less than 100 m, high grade from 25 to 35 m). The Kef Essenoun deposit is characterized by:
- A highly rugged northern zone.
- A monoclinal extension of layers towards the south at a dip angle (10-12°) beyond outcrops, and another asymmetrical extension where the phosphate layers are deeper.
- Its proximity to outcrops, resulting in the lowest possible stripping ratio.
- Ore rich in P2O5 ranging between 25.05 to 27.94% with an average of 26.53% and low in MgO with a content ranging between 1.3 and 3% for an average of 2.61%.
- Absence of sand.
- Easy access to other areas (expansion and advancement). [7]

8.2. Exploitation at Kef Essenoun:

A- Earthmoving:

This involves digging and moving materials (waste and ore) to carry out stripping, road opening, and bench construction. It is done using tracked bulldozers (CATERPILLAR). Graders prepare the work platforms for the drilling rigs. B- Blasting It consists of detaching rock masses using explosives and fragmenting materials obtained under predetermined conditions outlined in a blasting plan. Proper stripping at the phosphate bench platform is essential before drilling

operations. Drilling The drilling equipment is selected according to the parameters of the mining plan, and drilling is divided into two types: primary and secondary drilling: [8]

- **Primary drilling:**

carried out by drill rigs operating discontinuously in a 2x8 pattern. The drill rigs are ATLAS COPCO crawler-mounted drills (DfM60mm, productivity = 60m/h), and 684/686 drills (INGERSOLL-RAND on pneumatic tires with Df = ø60mm, productivity = 32m/h).

- **Secondary drilling:**

conducted by the CRAWLAIR (FUKUKAWA) drilling carriage with Df = 76mm, productivity = 26 m/h (for benches) or 13 m/h (for blocks), operating discontinuously in a 2x8 pattern. Blasting Achieving proper rock fragmentation is accomplished by adjusting:

- ✓ Drill hole spacing and diameter.
- ✓ Explosive loading density.
- ✓ The number of charges placed in the blast holes. Blasting is carried out using pyrotechnic and electrical methods with electrical initiation. The type of explosives used at Djebel El Onk is bulk ANFOMIL (each bag contains 25 Kg) and cartridge Marmanite or Brisant explosives (of various lengths: 50-65-80). [8]

B- Loading and Transport:

This operation involves removing blasted products and loading them onto trucks. The equipment used includes excavators, loaders, and trucks. At Kef Essenoun, the loading equipment consists of KOMATSU loaders, X150RB excavators, an electric shovel (609), and trucks: HITACHI with a capacity of 65 tonnes and CATERPILLAR with a capacity of 50 tonnes. The performance of shovel-truck operations will be optimized by maximizing shovel capacity without causing delays for trucks.

8.3. Loading:

a. **Waste:**

The average hourly performance achieved by the loading equipment was around 515 t/h compared to a planned performance of approximately 394 t/h, resulting in a positive deviation of 121 t/h, indicating efficient utilization of loading resources.

b. **Phosphate:**

The average hourly performance achieved by various loaders is around 359 t/h compared to a planned performance of approximately 180 t/h, resulting in a significant positive deviation, which also reflects the efficiency of unloading equipment. [8]

8.4. Transport:

a. Waste:

The average hourly performance achieved by trucks was around 199 t/h compared to a planned performance of approximately 140 t/h, indicating a positive deviation of around 19 t/h, reflecting efficient utilization of transport resources.

b. Phosphate:

The average hourly performance achieved by trucks was around 134 t/h compared to a planned performance of 140 t/h, resulting in a deficit of 6 t/h due to the following constraints:

- Aging of the CATERPILLAR truck fleet.
- Distance of the work sites from the crusher (BABITLESS).
- Long waiting times at the crushing station due to downstream non-admission.

8.4. Characteristics Of Phosphate:

a. THE COMPOSITION AND ORIGIN OF ROCK:

Rock phosphate deposits are either of volcanic origin or the remains of marine animal skeletons, which, like those of land animals, consist of a mixture of phosphates and calcium carbonates. Over time, on the seabed, the carbonates have been replaced by fluorine, which has the effect of making the ore more stable.

b. PHYSICAL CHARACTERISTICS:

The physical characteristics of natural phosphates are less important than their chemical composition regarding phosphorus availability. However, they still have an impact on it.

The main physical characteristics used are compactness, porosity, fineness of grinding, and active surface area.

As a general rule, the reactivity of rock phosphate, and thus its availability, increases when its density decreases and its active or specific surface area increases. The active surface area tends to increase with the fineness of the particles, although the results vary greatly from one type of phosphate to another. This practically means that the finer a rock phosphate is ground, the more phosphorus may be available. [8]

c. Chemical and mineralogical characterization

It is an element of group 15 (VA) in the periodic table of elements. Therefore, it is trivalent in its ground state. The industrial manufacturing process produces tetrahedral-tetraphosphorus according to the reaction: [8]

$$6\ Ca3(PO4)2 + 6\ SiO2 + 10\ C \rightarrow 6\ CaSiO3 + 10\ CO + P4$$

There are at least eight allotropic varieties of pure phosphorus depending on the degree of catenation.

White phosphorus (A cubic, B hexagonal) consists of tetrahedra. Black phosphorus, orthorhombic or rhombohedral, consists of folded sheets associated with each other. Red phosphorus consists of chains of polymerized tetrahedra, less reactive than white phosphorus and non-toxic. It is used by the industry.

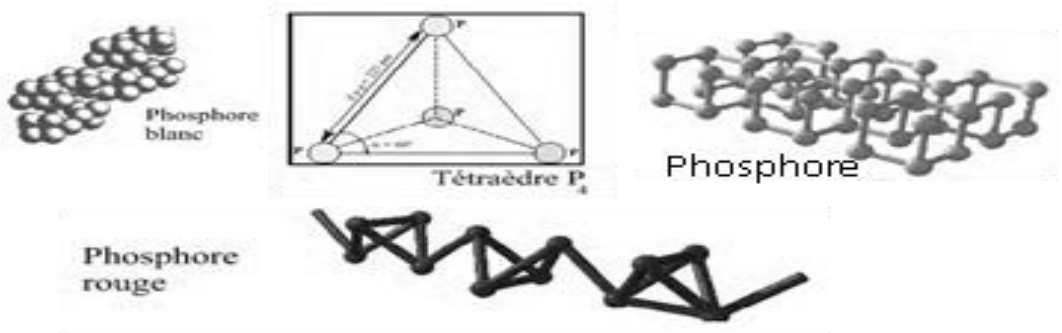


Figure 11: Structure of white, black and red phosphors

8.5. Mineralogical composition of the Djebel Onk phosphate ore:

Table 2: Mineralogical composition of the Djebel Onk phosphate ore

Eléments	**Symbole chimique**
Phosphate tricalcique	$Ca_3(PO_4)_2$

Carbonate de calcium	$Ca\ CO_3$
Carbonate de magnésium	$Mg\ CO_3$
Dolomie	$Ca\ Mg\ (CO_3)_2$
Oxyde de fer	$Fe_2\ O_3$
Gypse	$Ca\ SO_4$
Sulfate de soude	$Na_2\ SO_4$
Chlorure de calcium	$Ca\ Cl_2$
Quartz	$Si\ O_2$
Alumine	$Al_2\ O_3$
Sulfate, fluore et matières organiques	S, F, C

8.6. Composition chimique du produit marchand de phosphate de djebel onk :

Table 3: The chemical composition of the commercial product of Djebel Onk [10]

Elément Majeurs	**%**
Anhydride Phosphorique (P_2O_5)	29,50----30,00
Anhydride Carbonique (CO_2)	6,50----7,20
Anhydride Sulfurique (SO_3)	2,50----3,00
Oxyde de calcium (CaO)	48,50----50,00
Oxyde de Magnésium (MgO)	0,90----1,35
Oxyde de Fer (Fe_2O_3)	0,35----0,40
Oxyde de d'Aluminium (Al_2O_3)	0,40----0,50

Oxyde de Sodium (Na_2O)	1,00----1,20
Oxyde de Potassium (K_2O)	0,08----0,15
Oxyde de Silicium (SiO_2)	2,00----3,00
Humidité (H_2O)	0,80----2,00
Perte au feu (CO_2 déduit)	2,50----4,00
Fluor (F)	2,50----3,50
Chlore (Cl) en ppm	400----900
C-Org	0,20----1,00

CHAPTER II

9. Physicochemical Analysis:

This method involves analyzing the physical and chemical properties of the phosphate sludge. Researchers assess parameters such as particle size distribution, specific surface area, density, and porosity [1].

Techniques like X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) help identify mineral phases and elemental composition [1].

10.Elemental Analysis:

Researchers determine the elemental composition of the waste material. Techniques like inductively coupled plasma-optical emission spectroscopy (ICP-OES) or inductively coupled plasma-mass spectrometry (ICP-MS) are commonly used [1].

These analyses reveal the presence and concentration of heavy metals (e.g., Uranium, Cadmium, Zinc, Copper, Arsenic) in the sludge [1].

11.*Mineralogical Characterization:*

X-ray diffraction (XRD) is crucial for identifying the mineral phases present in the phosphate sludge. It helps determine the crystalline structure and composition.

Fourier-transform infrared spectroscopy (FTIR) provides information about functional groups and chemical bonds in the waste material [1].

11.4. Leaching Tests:

Researchers perform leaching tests to assess the mobility of heavy metals from the sludge. These tests simulate environmental conditions (e.g., rainfall) and measure metal leaching into water.

The results guide decisions on waste management and potential revaluation [1].

11.5. Sequential Extraction:

Sequential extraction procedures fractionate the waste material based on metal associations (e.g., exchangeable, carbonate-bound, organic-bound, residual fractions).

This helps understand metal speciation and bioavailability [1].

11.6. Microscopic Imaging:

Scanning electron microscopy (SEM) provides high-resolution images of the sludge's surface morphology [1].

Energy-dispersive X-ray spectroscopy (EDS) coupled with SEM allows elemental mapping [1].

12.Geochemical Modeling:

Researchers use geochemical models to predict metal behavior under different environmental conditions [1].

These models consider factors like pH, redox potential, and complexation reactions [1].

13.Environmental Risk Assessment:

By combining data from the above methods, researchers assess the potential risks posed by heavy metals in the waste material [1].

Risk assessment considers exposure pathways (e.g., ingestion, inhalation) and potential impacts on human health and ecosystems [1].

Samples	CO_2, %	Mg, %	Coef-ficient	MgO, %	P_2O_5, %	Fe, %	Coef-ficient	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 7: The chemical composition of the rejected slices of normal product

Samples	CO_2, %	Mg, %	Coef-ficient	MgO, %	P_2O_5, %	Fe, %	Coef-ficient	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

Table 4: The chemical composition of the rejected slices of special product

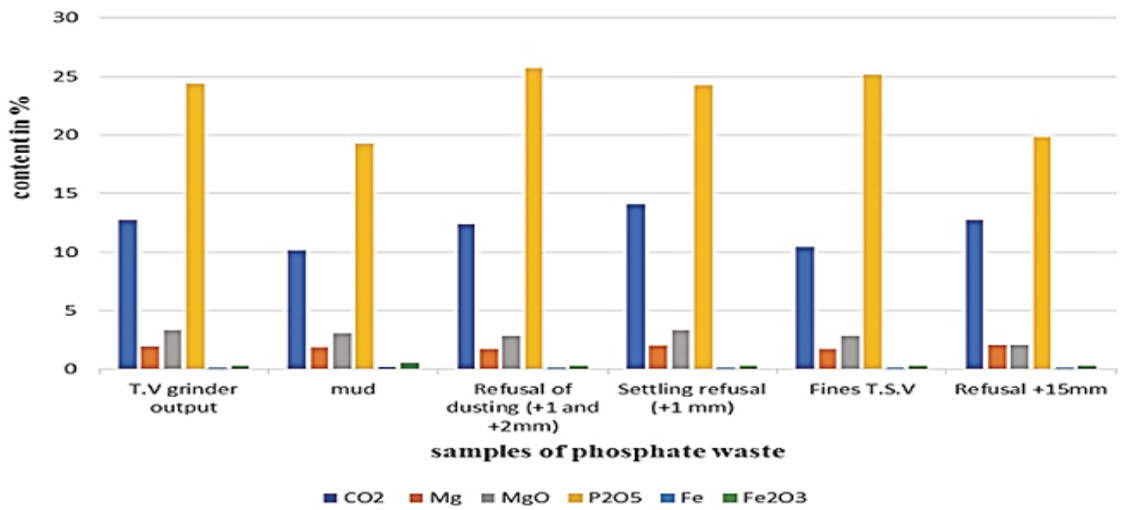


Figure 12: Change of elements concentration in phosphate waste of normal product in percentage

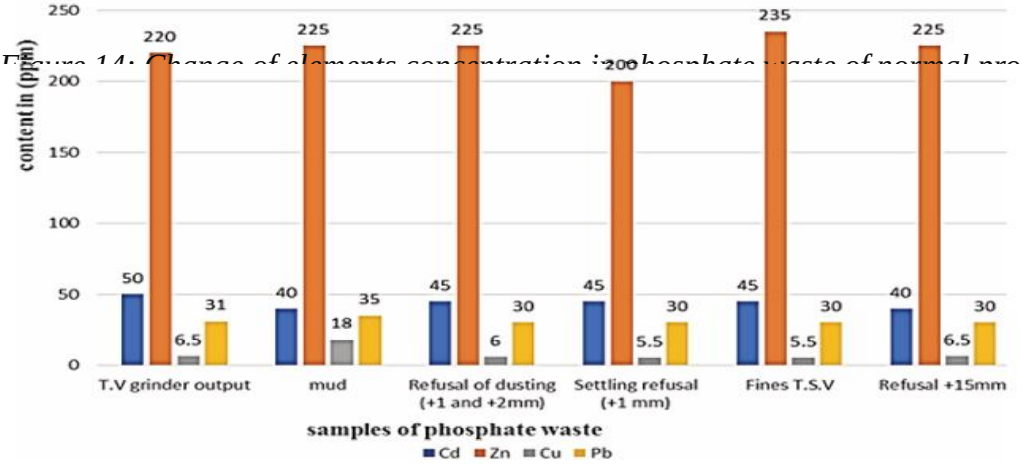


Figure 13: Heavy metals in phosphate waste of normal product in parts per million

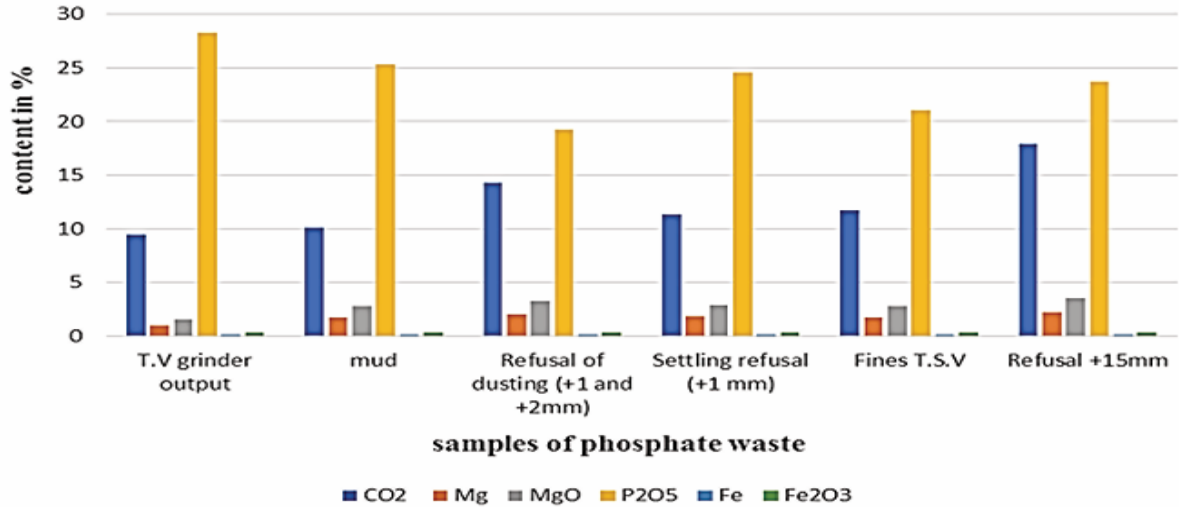


Figure 14: Change of elements concentration in phosphate waste of special product in percentage

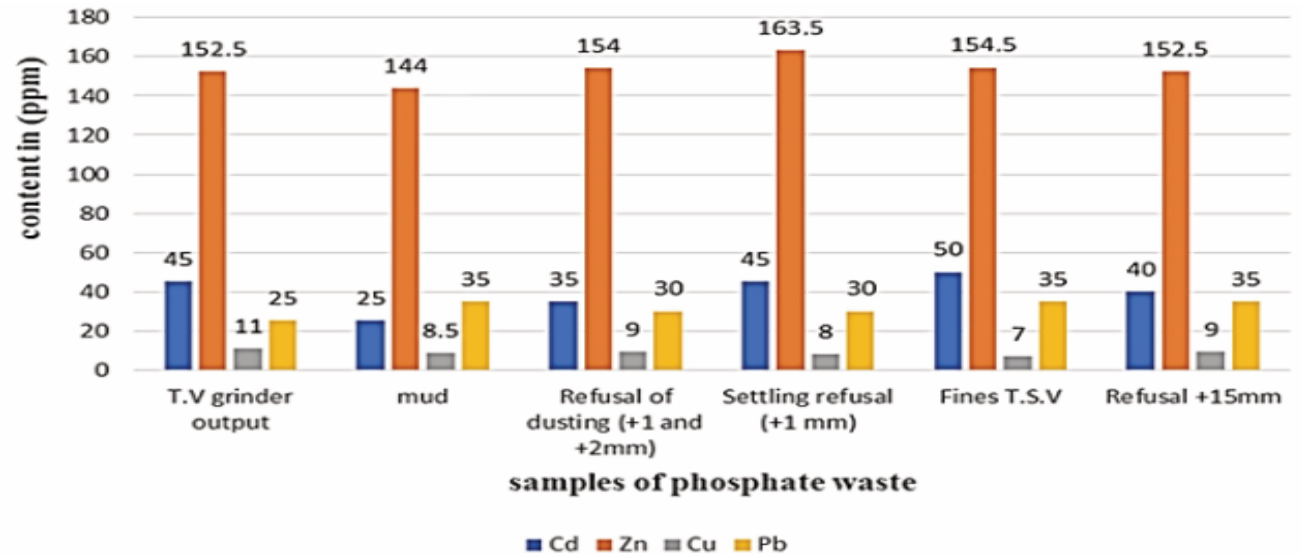


Figure 15: Heavy metals in phosphate waste of special product in parts per million

14.Chemical analysis by slice by atomic absorption:

Chemical analysis using atomic absorption on thin slices allows for a more in-depth examination and determination of chemical properties. The results shown in Tables 3 and 4 reveal that the P2O5 content is much higher in the waste material compared to the raw phosphate sample. Specifically, the (–1 + 0.100 mm) section of the rejection (+1 mm) and the (+1, +2 mm) section of the normal product, as well as the (–15, +10 mm) and (–4, +0 mm) slices in the rejection +15 mm for the special product, contain significant levels of P2O5 [1]. Therefore, this material should be utilized rather than discarded to avoid environmental issues [1].

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 6: Chemical analysis by element range 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	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

Table 7: Chemical analysis by element range for the special product

15.The Scanning Electron Microscope (SEM) and (EDS):

Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were used to analyze the phosphate content in the tailings. Figure 6 illustrates the results for the +15 mm reject of the normal product, the +15 mm reject of the special product, the (+1, +2 mm) reject of the normal product, and the mud [1].

Additionally, EDS spectra were obtained for the sample, revealing the elements present, including carbon (C), oxygen (O), magnesium (Mg), aluminum (Al), silicon (Si), phosphorus (P), molybdenum (Mo), calcium (Ca), and iron (Fe) in various proportions. The spectra indicated that calcium, oxygen, and phosphorus were the most abundant elements [1].

Depending on the amount of phosphate particles, matrix, and organic matter in each sample, several microscopic facies were observed. Phosphate particles appeared in various forms: coprolites, which are spherical to irregular, typically larger than 250 µm, and sometimes several millimeters in size; pellets, which are ovoid to rounded, light to dark, and 200 to 250 µm in diameter, formed from fragmented coprolites and occasionally cemented by calcareous, clayey, or siliceous materials [1].

In the surrounding formation, phosphorites in the northern sector are found in thin strata. While coprolites of various sizes, shapes, and colors are abundant, pellets are less common. These features suggest that the original depositional environment experienced minimal changes during the formation of the phosphorite particles [1].

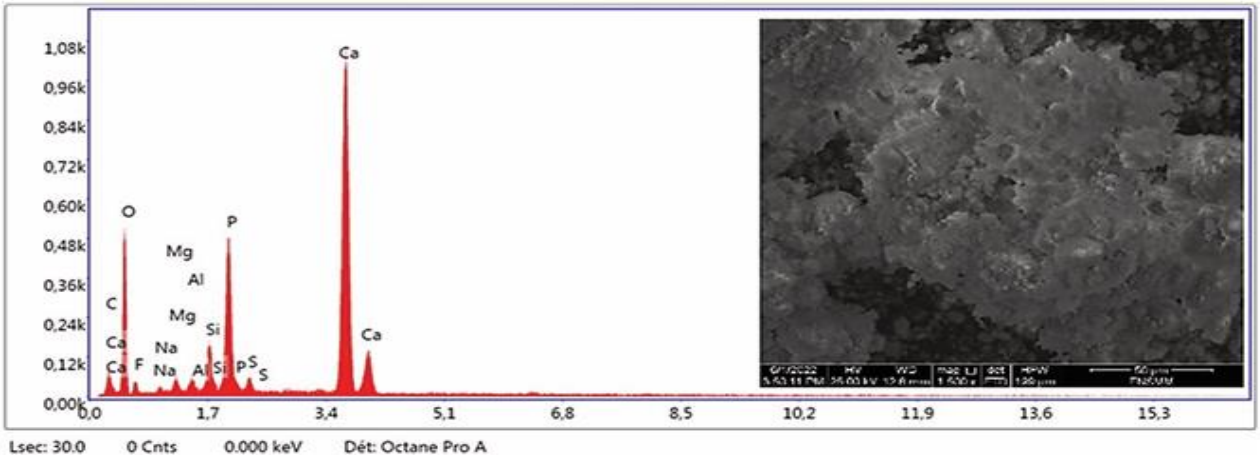


Figure 16: SEM and EDS of refusal of +15 mm of normal product

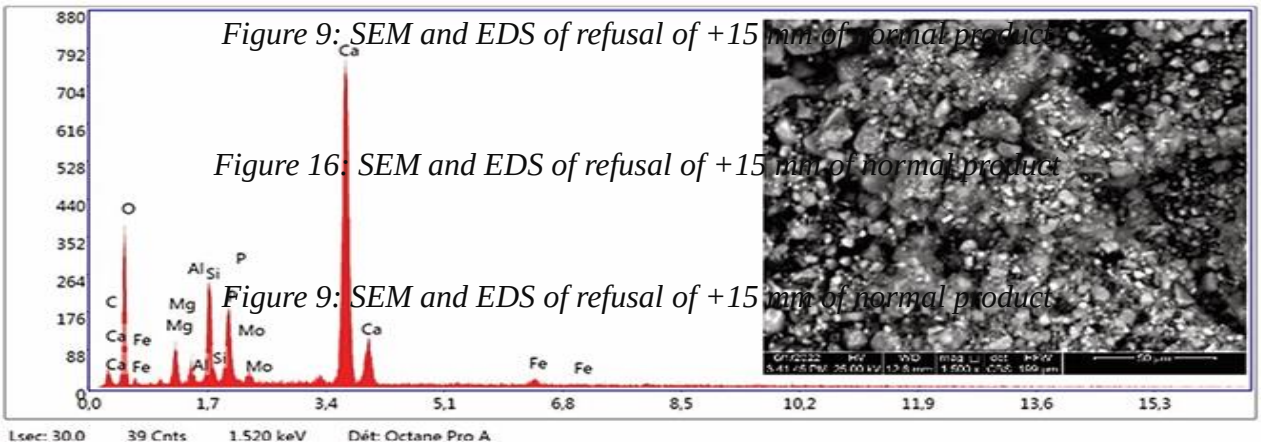


Figure 17: SEM and EDS of refusal of +15 mm of special product

Figure 10: SEM and EDS of refusal of +15 mm of special product

Figure 19: SEM and EDS of mudFigure 17: SEM and EDS of refusal of +15 mm of special product

Figure 10: SEM and EDS of refusal of +15 mm of special product

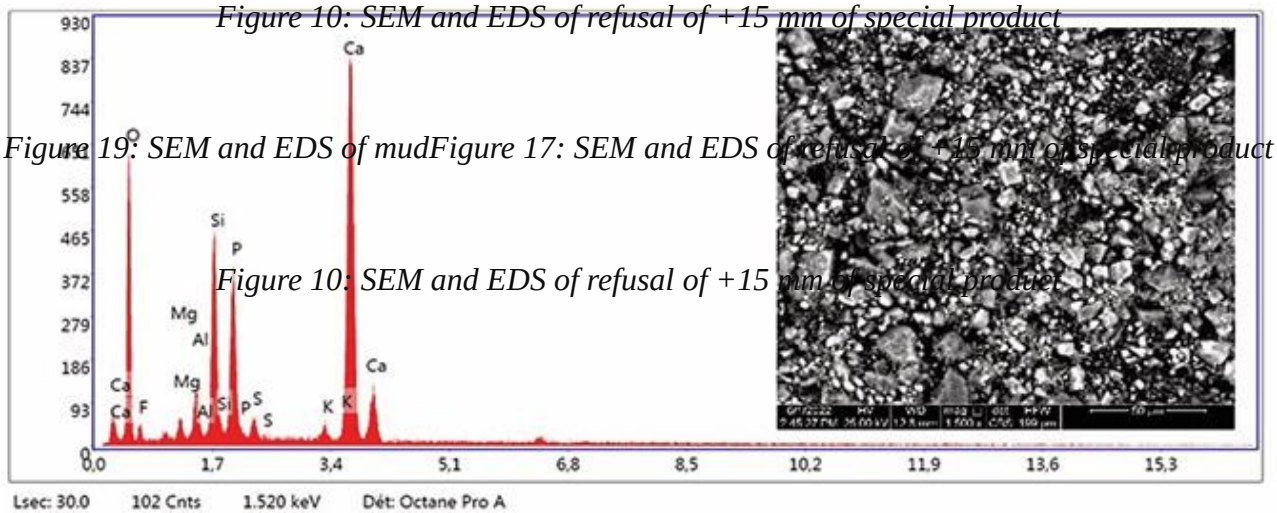


Figure 18: SEM and EDS of refusal of +1 and +2 mm of normal product

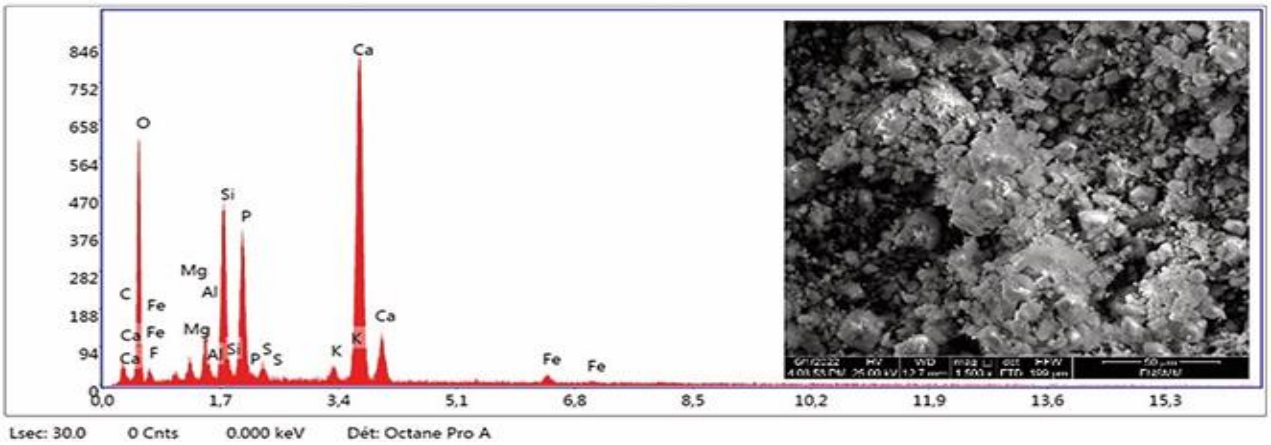


Figure 19: SEM and EDS of mud

16.X-ray Diffraction (XRD):

X-ray diffraction (XRD) analysis revealed that the primary phosphate mineral in all samples is fluoroapatite (FA). Additionally, apatite, carbonated fluoroapatite, monazite, and dolomite were identified, forming the matrix of phosphorite grains. Figure 7 presents various XRD patterns of the samples, specifically the +15 mm waste of the normal product, the +15 mm waste of the special product, the (+1, +2 mm) waste of the normal product, and the sludge [1].

According to the XRD analysis, the phosphate waste samples contain the minerals listed in Table 5, along with their chemical formulas. The XRD study indicates that the samples of phosphate waste (+15 mm normal product, +15 mm special product, +1and +2mm special product, and mud) are predominantly composed of fluoroapatite and dolomite [1].

The most significant phosphate release peaks at 2 thetas (°) are observed at 31.07 (8000), 33.52 (3000), 31.02 (4900), 62.70 (160), and 64.70 (400). These results clearly confirm the presence of

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	$Ca_5(PO_4,CO_3)_3F$

Table 8: Chemical formula of the studied minerals

phosphate in the samples [1].

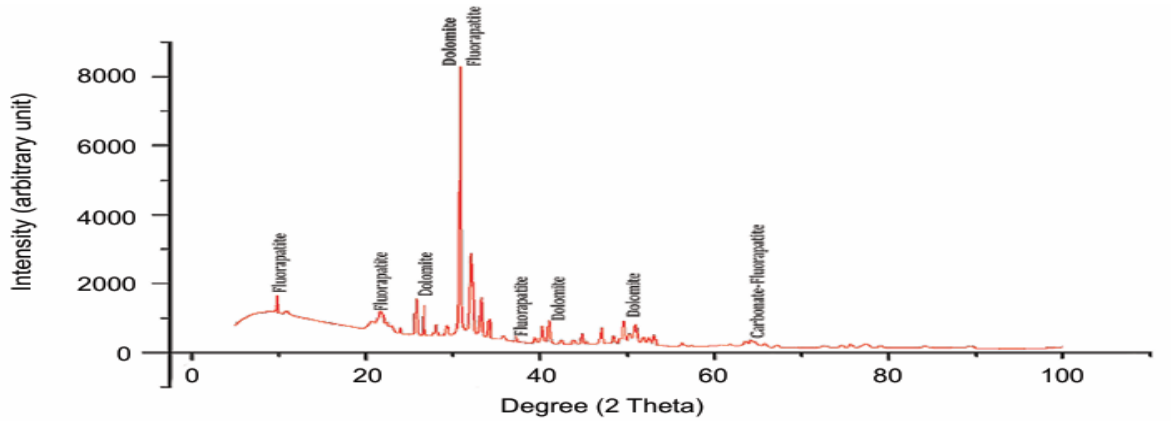


Figure 20: XRD of refusal of +15 mm of normal product

Figure 23: XRD of mudFigure 20: XRD of refusal of +15 mm of normal product

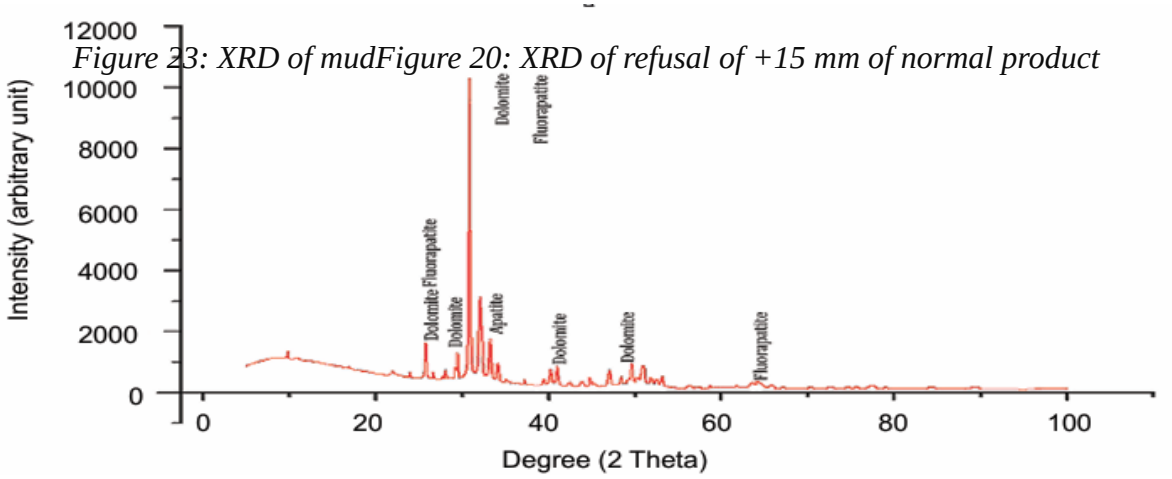


Figure 21: XRD of refusal of +15 mm of special product

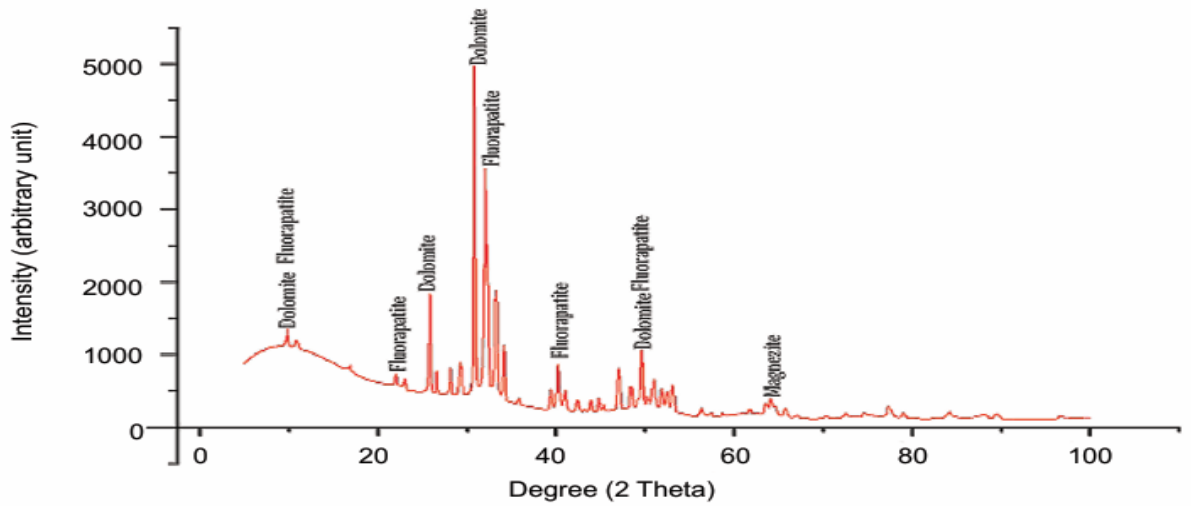


Figure 22: XRD of refusal of +1 and +2 mm of normal product

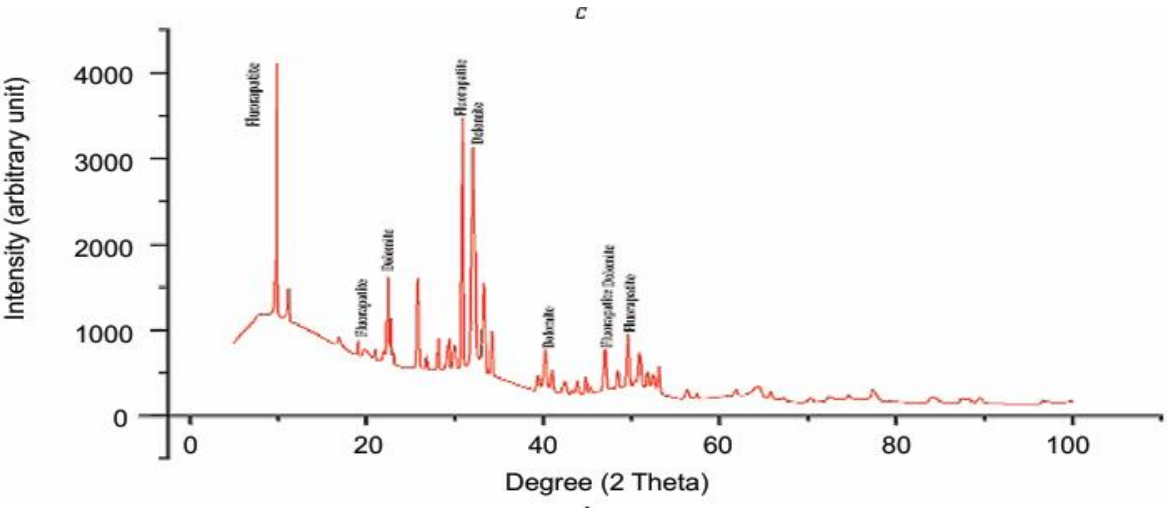


Figure 23: XRD of mud

17.Discussion and breaking down results:

Based on the comprehensive chemical analyses conducted on samples from both normal and special products, it is evident that there is a notable concentration of phosphates, as determined by X-ray analysis. For instance, the waste material of +15 mm size contains 27.81 and 27.58 P2O5, while the mud contains 19.29 and 25.31 P2O5. Similarly, in the waste material of (+1 and +2 mm), P2O5 levels are recorded at 30.70 and 25.25, respectively, indicating the presence of the crucial element fluoroapatite [1].

In terms of heavy metals, particularly cadmium and lead, it's notable that cadmium levels range from 40 to 50 ppm in normal product samples, with a slight decrease ranging from 25 to 50 ppm in the special product. Lead concentrations in both products are significant, ranging from 25 to 35 ppm, posing environmental and ecosystem risks [1].

Zinc levels in the special product are nearly double those found in the normal product, especially in the fine TSV sample. This presents a threat to the environment and human health, as the fine particles in this sample are easily transported through the air and can be inhaled. Moreover, this sample is heavily contaminated with heavy metals [1].

Given these findings, it is imperative to take appropriate measures to mitigate environmental risks, such as implementing effective waste management strategies and possibly considering remediation efforts to reduce heavy metal contamination [1].

CHAPTER III

18. Introduction:

The mining sector has played a crucial role in the socio-economic growth of nations with exploitable mineral resources. This industry facilitates the development of these resources through stages like exploration, development, construction of mining facilities, and the production of commercially valuable materials.

Mining operations generate substantial waste during mineral extraction and processing. Typically, this waste is stored in dumps for waste rock and containment areas for concentrator residues, often directly at the mining site. Depending on the local climate and the physical, chemical, and mineral nature of the waste, it can release harmful inorganic pollutants into the surrounding environment. In recent years, after mining activities cease, companies must start planning the restoration and rehabilitation of the mining area. Proper waste management has gained importance to address the significant environmental impacts observed in many countries globally. This practice is generally followed in developed nations, where strict regulations compel mining companies to consider site closure right from the beginning of operations.

Mining waste poses a dual environmental threat by generating acid and releasing heavy metals.

19. Effective management of mining waste involves several key steps:

- Characterizing the waste
- Treatment during operations (environmental desulfurization)
- Ensuring the stability of waste rock
- Managing treatment sludge
- Reclaiming mining waste
- Restoring mining sites using a multi-layer process
- Controlling water flow
- Predicting acid mine drainage

In Algeria, there are numerous abandoned and active mining sites. Currently, Algeria has 1,484 active mining sites. Additionally, 346 sites have been granted permits but have not started work, 78 are under preparation, 556 are inactive, and 38 are abandoned. These abandoned sites lack restoration or rehabilitation plans, leading to water, fauna, and flora contamination due to climatic conditions and exposure to natural elements like water, air, and temperature [3].

20. Dangerous elements in the phosphate ore:

Phosphate ore, the raw material for phosphate production, is naturally occurring and not pure calcium phosphate. It contains various trace substances. When processed, some of these substances remain in the phosphate waste, posing potential storage issues. These are considered contaminants. Key among these are heavy metals, which are challenging to remove from phosphates and are highly toxic to humans and ecosystems due to their chemical and physical properties [3].

Essential heavy metals found in phosphates are vital for the growth and development of living organisms in small amounts. Cd, Pb, Zn, Cu, tend to accumulate in living organisms, are not used, and do not degrade chemically or biologically, instead accumulating in the soil and biosphere [3].

20.4. Toxicity of Cadmium in Mining Waste:

20.4.1. Sources of Cadmium in Mining Waste:

Cadmium, a highly toxic heavy metal, is a significant pollutant resulting from mining activities. It is commonly found in metal ores, particularly those containing zinc, lead, and copper. During mining and ore processing, cadmium is released into the environment, contaminating waste rocks and mine tailings. Additionally, smelting and refining operations emit cadmium into the air, which can subsequently pollute nearby soil and water [3].

20.4.2. Pathways of Cadmium Exposure:

Cadmium enters the food chain through plants grown in contaminated soils and bioaccumulates in aquatic organisms in polluted water bodies. It can also contaminate drinking water when mining waste leaches into groundwater or surface water supplies. Airborne cadmium particles from mining activities pose a respiratory exposure risk when inhaled [3].

20.4.3. Health Effects of Cadmium Toxicity:

Chronic cadmium exposure can lead to severe health issues, including kidney damage, bone disease, and increased cancer risk. Cadmium is a potent carcinogen that can damage DNA and disrupt cellular functions, leading to tumor formation. It also hampers the absorption and utilization of essential metals like zinc and calcium, aggravating its toxic effects [3].

20.4.4. Environmental Impacts:

Cadmium contamination severely affects ecosystems, reducing biodiversity and disrupting food webs. Aquatic organisms, such as fish, crustaceans, and mollusks, are especially vulnerable to cadmium toxicity, which can bioaccumulate up the food chain. Agricultural productivity is also compromised, as cadmium pollution reduces crop yields and quality [3].

20.5. Toxicity of Lead in Mining Waste:

Lead is a highly toxic heavy metal that poses significant risks to human health and the environment, particularly in the context of mining operations [3].

20.5.1. Sources of Lead in Mining Waste:

Mining activities can release lead into the environment through several pathways:

- Lead Ore: Lead is often found in close proximity to other metals like zinc, copper, and silver. During mining and processing, lead can be released into the air and water [3].
- Lead-Based Products: Mining operations may use lead-based products, such as lead-acid batteries, lead-based paints, and lead-containing ceramics, which can contaminate soil and water [3].
- Soil and Water Contamination: Lead can leach into soil and water from mining waste, posing a significant risk to human health and the environment [3].

20.5.2. Pathways of Lead Exposure:

Individuals can be exposed to lead from mining waste through [3]:

- Inhalation: Lead particles can be inhaled, leading to respiratory exposure and potential health effects [3].
- Ingestion: Lead-contaminated soil and water can be ingested, leading to gastrointestinal exposure and potential health effects [3].
- Dermal Contact: Lead particles can come into contact with the skin, leading to dermal exposure and potential health effects [3].

20.5.3. Health Effects of Lead Toxicity:

Exposure to lead from mining waste can have severe health consequences, including:

- Neurological Effects: Lead exposure has been linked to neurological damage, including decreased IQ, behavioral problems, and hearing loss [3].
- Reproductive Effects: Lead exposure has been linked to reproductive problems, including infertility, miscarriage, and birth defects [3].
- Cancer Risk: Lead exposure has been linked to an increased risk of certain cancers, including leukemia and lymphoma [3].
- Environmental Impacts: Lead contamination from mining waste can also have significant environmental impacts, such as:

    - Soil Contamination: Lead contamination in soil can persist for decades, posing a long-term risk to ecosystems and human health [3].
    - Water Contamination: Lead contamination in water can have devastating effects on aquatic ecosystems and human health [3].
    - Food Chain Contamination: Lead can bioaccumulate in food chains, posing a risk to human health through consumption of contaminated food [3].

20.6. Toxicity of Copper in Mining Waste:

Copper is a highly toxic metal that poses significant risks to human health and the environment, particularly in the context of mining operations. Here are some key points on the toxicity of copper in mining waste [3]:

20.6.1. Sources of Copper in Mining Waste:

- Mining Activities: Copper is often extracted from copper ore through mining and processing, which can release copper into the environment through air and water pollution [3].
- Tailings Storage: Copper tailings, which are waste materials left over from copper mining, can contain high levels of copper and other toxic metals [3]. These tailings can leach into water bodies and soil, contaminating the environment [3].

20.6.2. Pathways of Copper Exposure:

- Inhalation: Copper particles can be inhaled, leading to respiratory exposure and potential health effects [3].

- Ingestion: Copper-contaminated soil and water can be ingested, leading to gastrointestinal exposure and potential health effects [3].
- Dermal Contact: Copper particles can come into contact with the skin, leading to dermal exposure and potential health effects [3].
- Health Effects of Copper Toxicity:
- Neurological Effects: Copper exposure has been linked to neurological damage, including decreased IQ, behavioral problems, and hearing loss [3].
- Reproductive Effects: Copper exposure has been linked to reproductive problems, including infertility, miscarriage, and birth defects [3].
- Cancer Risk: Copper exposure has been linked to an increased risk of certain cancers, including leukemia and lymphoma [3].
- Environmental Impacts:

    - Soil Contamination: Copper contamination in soil can persist for decades, posing a long-term risk to ecosystems and human health [3].
    - Water Contamination: Copper contamination in water can have devastating effects on aquatic ecosystems and human health [3].
    - Food Chain Contamination: Copper can bioaccumulate in food chains, posing a risk to human health through consumption of contaminated food [3].

20.7. Toxicity of Zinc in Mining Waste:

Zinc is a highly toxic metal that poses significant risks to human health and the environment, particularly in the context of mining operations. Here are some key points on the toxicity of zinc in mining waste [3]:

20.7.1. Sources of Zinc in Mining Waste:

- Mining Activities: Zinc is often extracted from zinc ore through mining and processing, which can release zinc into the environment through air and water pollution [3].
- Tailings Storage: Zinc tailings, which are waste materials left over from zinc mining, can contain high levels of zinc and other toxic metals. These tailings can leach into water bodies and soil, contaminating the environment [3].

20.7.2. Pathways of Zinc Exposure:

- Inhalation: Zinc particles can be inhaled, leading to respiratory exposure and potential health effects [3].
- Ingestion: Zinc-contaminated soil and water can be ingested, leading to gastrointestinal exposure and potential health effects [3].
- Dermal Contact: Zinc particles can come into contact with the skin, leading to dermal exposure and potential health effects [3].

20.7.3. Health Effects of Zinc Toxicity:

- Neurological Effects: Zinc exposure has been linked to neurological damage, including decreased IQ, behavioral problems, and hearing loss [3].
- Reproductive Effects: Zinc exposure has been linked to reproductive problems, including infertility, miscarriage, and birth defects [3].
- Cancer Risk: Zinc exposure has been linked to an increased risk of certain cancers, including leukemia and lymphoma [3].

20.7.4. Environmental Impacts:

- Soil Contamination: Zinc contamination in soil can persist for decades, posing a long-term risk to ecosystems and human health [3].
- Water Contamination: Zinc contamination in water can have devastating effects on aquatic ecosystems and human health [3].
- Food Chain Contamination: Zinc can bioaccumulate in food chains, posing a risk to human health through consumption of contaminated food [3].

21.Managing Mining Waste:

Effective management and control of mining waste are essential to mitigate its continuous environmental damage [3].

21.4. Environmental Desulfurization:

The simultaneous presence of water, air, and sulfides causes acid mine drainage. To prevent this, one of these three components must be removed. Several methods exist to manage the harmfulness of mining waste [3]:

- Water Covers: These block oxygen from reaching the residues by storing them in natural or artificial lakes created with dikes [3].
- Multilayer Covers: These prevent oxygen from infiltrating the waste by maintaining a saturated middle layer that acts as a capillary barrier. Since oxygen diffusion in water is minimal, this protects the underlying sulfide waste [3].
- Neutralizing Liquid Effluents and Precipitating their Chemical Load as Sludge: The sludge is then collected and stored [3].

These methods are expensive and require ongoing site monitoring. Recently, environmental desulfurization has been proposed as an effective and relatively low-cost solution. This technique allows for the removal of sulfur minerals from the remaining minerals, optimizing the process by considering the neutralization potential of the mining waste. This ensures only the necessary amount of acid-generating minerals are separated, while the rest is balanced by acid-neutralizing minerals [3].

21.5. Backfill:

Mining activities alter the landscape, leading to surface waste accumulation and pit formation. Regulations impose taxes on surface-stored mining waste. Backfilling mitigates surface material issues, enhances structural stability, and reduces environmental pollution risks. There are two backfill types : underground and pit backfill [3].

21.5.1. Underground Backfill:

The main purpose of underground backfilling is to stabilize tunnels and recover support pillars. There are three types [3] :

- Rock fill: Made from mining waste, sometimes mixed with cement paste for added strength, transported by trucks or conveyors to underground sites [3].
- Hydraulic fill: Composed of concentrator tailings, water, and hydraulic binders, transported through pipelines [3].
- Cemented paste fill: The most common type, consisting of densified concentrator tailings with 75%-85% solid content. Hydraulic binders are added for cohesion during cementation, with water added to achieve 70%-80% solid concentration. The component ratios ensure long-term stability [3].

21.5.2. Pit Backfill:

Pit backfilling uses the space from open-pit mining to store residues. This can be done sequentially with multiple pits or after mining operations conclude. Sequentially, residues fill old pits with materials from active ones. Post-operation, residues fill the pit [3].

Pit backfilling reduces closure costs by utilizing existing containment structures, eliminating dam-related instability. It also aims to cover and flood residues to prevent oxidation. However, backfilled pits connect to surface and groundwater, potentially impacting drinking water, aquatic life, wildlife, and recreational activities if contamination occurs [3].

21.6. Densification:

The amount of water required in conventional concentrator tailings management stages is a challenge in arid regions worldwide. Densification of residues partly addresses these challenges by removing some water, thereby enhancing their mechanical properties (density, shear strength). There are several levels of residue densification, with the three most common categories being thickened tailings, paste tailings, and filtered tailings [3].

21.6.1. Thickened Tailings:

Thickening of tailings involves increasing the solid content to around 45% to 70%. The primary goal of this technique is to improve their geotechnical behavior. After thickening, the residue resembles a viscous fluid rather than particles suspended in a solution. Thickened residues exhibit higher homogeneity and density compared to conventional residues. Thickening is achieved using thickeners ranging in diameter from a few meters to over 100 meters, after which the thickened residues are pumped to storage locations. They have a critical flow velocity but do not separate during sedimentation. Thickened residues can be deposited from dams or central towers to form a conical structure. The resulting slope varies between 0.5% and 4%, typically around 3% for thickened residues [3].

21.6.2. Paste Tailings:

The surface deposition technique for paste tailings draws inspiration from underground backfills developed in the 1970s. Paste tailings are dense and do not segregate during pauses. High-density thickeners are usually employed to increase the solid concentration to about 60% to 70%. The material is then transported to another structure where a certain amount of water is added to achieve the desired consistency [3].

21.6.3. Densification Techniques in Mining:

Mining operations face water management challenges in arid climates, prompting the adoption of residue densification techniques to enhance mechanical properties. Densification categories include thickened tailings, paste tailings, and filtered tailings [3].

21.6.4. Thickened Tailings:

Thickening increases solid content to 45%-70%, primarily improving geotechnical behavior. Resulting in a viscous fluid-like consistency, thickened residues offer higher homogeneity and density than conventional types. Thickening involves thickeners of varying diameters (from meters to over 100 meters), with residues pumped to storage locations. They maintain critical flow velocity without sediment separation, often forming conical structures from dams or central towers, with slopes typically around 3% [3].

21.6.5. Paste Tailings:

Inspired by underground backfills, paste tailings are dense and non-segregating during handling. High-density thickeners raise solid concentrations to 60%-70%, adjusted with water for desired consistency in subsequent handling [3].

21.6.6. Filtered Tailings: (Innovating Waste Management in Mining):

Filtered tailings offer a practical solution for small to medium-sized mines, yet their feasibility in larger copper operations hinges on energy costs and land acquisition expenses for expanded facilities [3].

Developed to mitigate liquefaction risks and facilitate transport in frigid climates, filtered tailings boast the highest solid concentration among the three techniques discussed [3].

Filtration employs high-pressure or vacuum methods to extract water from tailings, utilizing drum filters, vertically or horizontally stacked compression plates, and belt filters. Pressure filtration through vacuum belt systems is tailored to diverse materials, with a staged process ensuring gradual water removal, contingent upon particle size distribution and mineral composition impacting filtration efficacy. Adaptive technologies must accommodate fluctuating mining outputs while mitigating economic impacts [3].

Deployed, spread, and compacted on surfaces, filtered tailings form stable, dense stacks, offering benefits like water and process agent recycling, enhanced storage density, and reduced containment instability risks [3].

21.6.7. Layered Deposition:

Layered deposition involves sequentially placing each material, unlike mixing where tailings are blended before deposition [3].

Horizontal layering of tailings occurs in cells several meters thick, sized according to site requirements. Once a cell fills with waste, a layer of sterile material may be added before placing another row of tailings on top. This technique enhances physical stability [3].

21.6.8. Sterile Rock Inclusions:

Over time, tailings consolidate, increasing internal density and shear strength. However, this consolidation process is gradual and often continues post-mining. Coordinated placement of sterile rocks within tailings storage facilities can accelerate consolidation and compartmentalize storage areas, minimizing potential failure consequences [3].

The technique of sterile rock inclusions involves placing linear drains of sterile rocks as successive lifts occur in tailings storage facilities [3].

21.6.9. Costs of Management and Rehabilitation of Mine Tailings:

Several mine tailings management methods have been developed recently, particularly in developed countries with stringent environmental regulations. Unit costs range from $17k/ha for simpler cases to $30k to $100k/ha for oxygen barrier cases, and exceeding $200k for encapsulation. Costs associated with restoring Acid Forming Rock (AFR) generating sites are approximately $70k/ha [3].

CHAPTER IV

22. Introduction:

The calcination of phosphate waste is an essential process for managing industrial by-products from phosphate rock processing. This process not only reduces the volume of waste but also transforms it into valuable materials that can be reused in various industrial applications [11]. By heating phosphate waste to high temperatures, calcination facilitates the thermal decomposition of unwanted compounds, making the waste more stable and less hazardous [12]. This paper explores the historical development, chemical principles, techniques, benefits, environmental impacts, and recent advancements in the calcination of phosphate waste.

23. Overview of Phosphate Waste Calcination:

Historical Background:

The practice of calcining phosphate waste has evolved significantly over the years. Initially, waste management practices were rudimentary, leading to considerable environmental pollution and inefficient resource utilization [13]. Over time, advancements in technology and increased environmental awareness have driven the development of more efficient and sustainable calcination methods [13].

Chemical Principles:

Calcination of phosphate waste involves heating the material to temperatures typically ranging from 600°C to 1000°C [12]. This thermal treatment induces several chemical reactions, including the decomposition of organic matter and the release of volatile compounds such as carbon dioxide and sulfur oxides [2]. These reactions stabilize the waste and can enhance the recovery of valuable elements such as phosphorus and calcium [2].

24. Calcination Techniques for Phosphate Waste:

Rotary Kilns:

Rotary kilns are commonly used for the calcination of phosphate waste. These rotating cylindrical reactors provide uniform heating and effective mixing of the waste material, leading to consistent calcination outcomes [4]. Parameters such as rotation speed, temperature control, and residence time are crucial for optimizing the process [4].

Fluidized Bed Reactors:

Fluidized bed reactors offer significant advantages for calcining phosphate waste, including improved heat transfer and efficient gas-solid contact [5]. In these systems, waste particles are suspended in a hot gas stream, which enhances the calcination process and improves the quality of the end product [5]. Fluidized bed reactors are particularly suitable for fine-grained waste materials [5].

Flash Calciners:

Flash calciners rapidly heat phosphate waste to high temperatures, achieving calcination within seconds [6]. This method is highly efficient and reduces the thermal decomposition of unwanted compounds, making it ideal for producing high-quality calcined waste products [6]. Flash calcination is also energy-efficient, requiring less fuel than traditional methods [6].

25. Benefits of Phosphate Waste Calcination

Waste Reduction:

Calcination significantly reduces the volume of phosphate waste, thereby alleviating disposal challenges and minimizing environmental footprints [1]. The process transforms bulky, unstable waste into more manageable and stable forms [1].

Resource Recovery:

Calcination facilitates the recovery of valuable resources from phosphate waste, such as phosphorus and calcium, which can be reused in various industrial applications [7]. This recovery not only reduces the need for virgin materials but also promotes the circular economy [7].

Environmental Protection:

By stabilizing hazardous components and reducing the release of toxic substances, calcination helps protect the environment from pollution associated with phosphate waste [8]. The process also decreases the potential for leaching and groundwater contamination [8].

26. Environmental Impacts:

Emissions and By-products:

Calcination of phosphate waste generates emissions, including carbon dioxide, sulfur oxides, and particulate matter, which can have adverse environmental and health effects if not properly controlled [9]. The process also produces solid by-products such as calcium oxide and fly ash, which require appropriate handling and disposal [9].

Waste Management:

Effective management of calcination by-products is crucial for minimizing environmental impacts. This involves the treatment and safe disposal of solid residues, as well as the capture and reduction of gaseous emissions [10]. Advanced waste management practices can further enhance the sustainability of the calcination process [10].

Regulatory Standards:

Adherence to regulatory standards is essential for the sustainable operation of calcination facilities. Governments and environmental agencies have established guidelines for emissions, waste handling, and disposal to protect public health and the environment [11]. Compliance with

these standards ensures that calcination processes are conducted responsibly and sustainably [11].

27. Recent Advancements in Calcination Technology:

Technological Innovations:

Recent technological advancements in calcination have focused on improving efficiency and reducing environmental impacts [12]. Innovations include the development of more efficient reactors, the use of alternative energy sources, and the integration of advanced emission control systems [12].

Case Studies:

Case studies of modern calcination facilities demonstrate the successful application of advanced technologies and best practices [13]. These examples highlight the potential for significant improvements in energy efficiency, waste reduction, and environmental performance [13].

28. Mitigation Strategies:

Emission Control:

Effective emission control strategies are essential to mitigate the environmental impact of phosphate waste calcination [10]. This includes the use of scrubbers, filters, and other technologies to capture and reduce emissions of harmful gases and particulate matter [10].

Sustainable Practices:

Sustainable practices in phosphate waste calcination involve optimizing process parameters, reducing energy consumption, and minimizing waste generation [10]. The adoption of circular economy principles, such as recycling and reusing by-products, can further enhance the sustainability of the calcination process [10].

29. Conclusion:

The calcination of phosphate waste is a crucial process for managing industrial by-products and reducing environmental impacts. The benefits of calcination, including waste reduction, resource recovery, and environmental protection, underscore its importance. However, the environmental impacts, particularly emissions and by-products, require careful management. Technological advancements and sustainable practices are essential for mitigating these impacts and ensuring the long-term viability of phosphate waste calcination. Future research should continue to explore innovative solutions to enhance the efficiency and environmental performance of this critical process.

REFERENCES

References:

1.Rachid Salhi & Djamel Nettour & Mohamed Chettibi & Cherif Gherbi & Aissa Benselhoub & Stefano Bellucci, 2023. "Characterization of phosphate wastes of Djebel Onk mining complex for a sustainable environmental management," Technology audit and production reserves, PC TECHNOLOGY CENTER, vol. 3(3(71)), pages 11-19, May.

2.She W, Guo L, Gao J, Zhang C, Wu S, Jiao Y, Zhu G. Spatial Distribution of Soil Heavy Metals and Associated Environmental Risks near Major Roads in Southern Tibet, China. Int J Environ Res Public Health. 2022 Jul 8;19(14):8380. Doi: 10.3390/ijerph19148380. PMID:35886230; PMCID: PMC9318444.

3.Kheloufi Said & Berkani Yasser, 2021."Utilisation des rejets phosphatés

Pour la fabrication des terres cuites " Université A. MIRA-BEJAIA

Faculté de Technologie Département de Mines et géologie, pages 24-34.

4.Tahri, T., Narsis, S., Bezzi, N., Grairia, A., Benghadab, K., & Benselhoub, A. (2023). Environmental polluting effects of liquid wastes and phosphate sludge generated by the Djebel Onk mining complex. Journal of Geology, Geography and Geoecology, 32(1), 178-184. https://doi.org/https://doi.org/10.15421/112317

5.Bilal Boumaza, Rabah Kechiched, Tatiana Vladimirovna Chekushina, Trace metal elements in phosphate rock wastes from the Djebel Onk mining area (Tébessa, eastern Algeria): A geochemical study and environmental implications, Applied Geochemistry, Volume 127, 2021, 104910, ISSN 0883-2927, https://doi.org/10.1016/j.apgeochem.2021.104910.

6. Brochures established at the Study and Development Department (DED) of SOMIPHOS Enterprise Bir El Ater 2017**.**

7. S. CHABOU. (1987). Doctoral thesis. Study of the Tertiary phosphate series of Djebel Onk**.**

8. C. KAKI RA LIAB S YESSOUFOU and C. ZEVOUNOU. (2007), Stratigraphy and phosphogenesis of the Paleogene Benin (Benin Bay) proceedings of the 1st UAC colloquium on cultural and technological sciences water sciences.

9. Brochures established at the chemical laboratory level of SOMIPHOS Enterprise Bir El Ater 2017**.**

10. Sheets of chemical analyses conducted by the chemical laboratory of SOMIPHOS Enterprise Bir El Ater**.**

11.Becker, P. (1989). *Phosphates and phosphoric acid: Raw materials, technology, and economics of the wet process.* Marcel Dekker.

Habashi, F. (2010). *Phosphoric Acid: Purification, Uses, Technology, and Economics.* CRC Press.

12.Sis, H., & Chander, S. (2003). Reagents used in the flotation of phosphate ores: A critical review. *Minerals Engineering, 16*(7), 577-585.

Yi, X., & Wuang, L. (2015). Recent developments in phosphorus removal and recovery from wastewater. *Journal of Environmental Management, 151*, 1-9.

13.Zhang, J., & Muhammed, M. (2001). Mineral processing techniques for recycling investment casting shell. *Hydrometallurgy, 59*(2-3), 259-268.

14.Smith, J. (2008). Environmental impacts of industrial calcination processes. *Journal of Industrial Ecology, 12*(3), 342-358.

15.Jones, A., & Wilson, B. (2014). Waste management in phosphate processing: Best practices and regulatory standards. *Environmental Science & Technology, 48*(5), 2890-2896.

16.Thompson, D. (2012). Regulatory challenges in the phosphate industry. *International Journal of Environmental Regulation, 14*(2), 113-125.

17.Green, R., & Patel, S. (2020). Technological innovations in phosphate calcination. *Advances in Industrial Engineering, 25*(1), 45-63.

18.Harris, M., & Smith, L. (2017). Sustainable practices in industrial waste management. *Journal of Cleaner Production, 142*, 273-281.

19.White, P. (2015). Regulatory frameworks for environmental protection in the phosphate industry. *Environmental Policy and Governance, 25*(3), 189-200.

20.Brown, T., & Green, H. (2018). Innovations in calcination technology for waste management. *Journal of Sustainable Mining, 17*(2), 67-75.

21.Black, R., & Mitchell, J. (2019). Case studies in modern calcination facilities. *Industrial Engineering Journal, 28*(4), 213-228.