الجمهورية الجزائرية الديمقراطية الشعبية
People's Democratic Republic of Algeria
وزارة التعليم العالي والبحث العلمي
Ministry of Higher Education and Scientific Research
جامعة الشهيد الشيخ العربي التبسي – تبسة
Echahid Cheikh Larbi Tebessi University – Tebessa
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Institute of Mines
قسم المناجم و الجيوتكنولوجيا
Department of Mines and Geotechnology

Dissertation

Presented for the award of the Master's degree

Field: Mining Engineering

Option: VRM

Theme

Treatment and recovery of Djebel-Onk phosphate carbonates for their use in the industrial sector

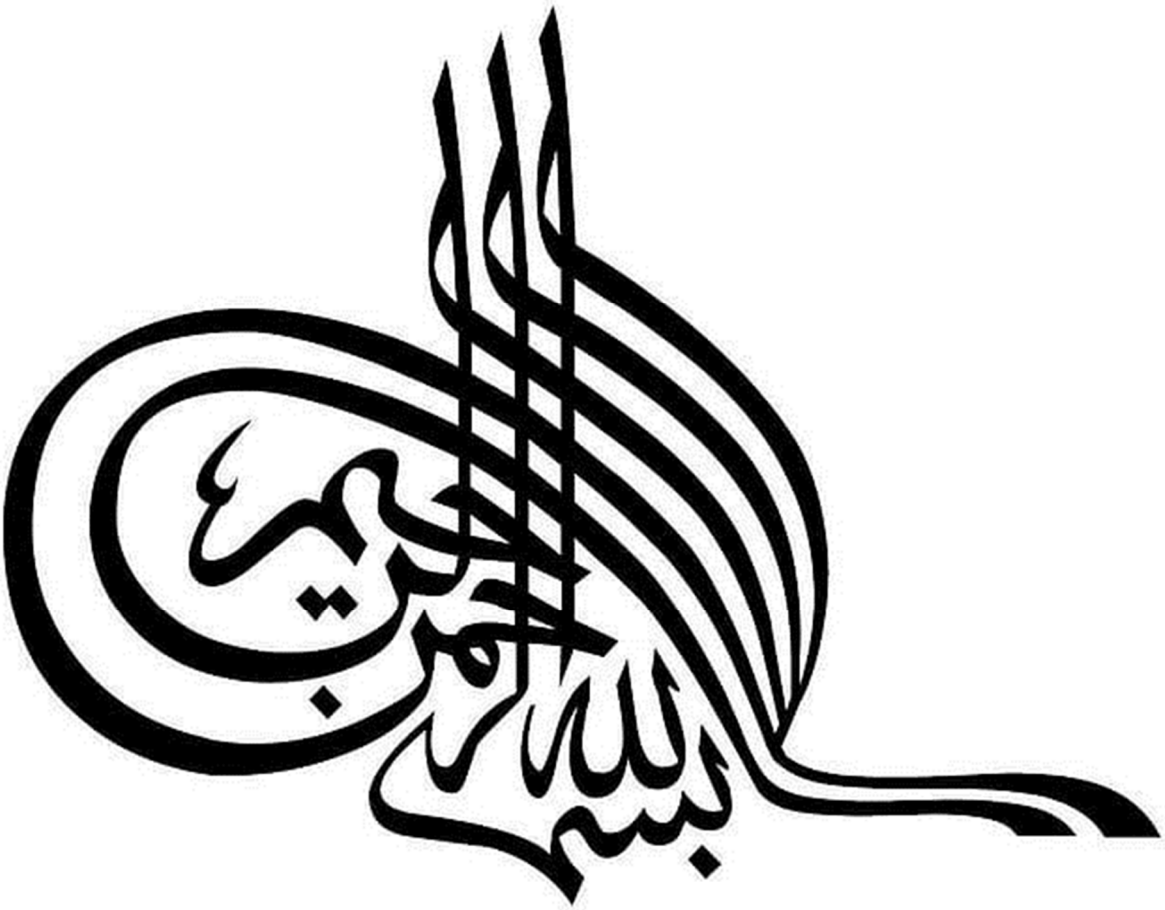
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Academic year 2023/2024


بسم الله الرحمن الرحيم

Acknowledgement

First and foremost, We start by thanking and praising ALLAH by his gratest names.
We want to give much thanks for Dr, BOUZENZANA .A who believed in us and gave us what we need and more from guidance and support throughout this whole journey.
Apart of all of that, thanks for every participants who contributed to our research and gave us their precious time to make It possible and successful.
Also big appreciations to all our teachers who did not hesitate to fill our minds with knowledge over all of these long years.

Dedication

we dedicate this humble work to our honorable parents, brothers, relatives, loved ones, all our classmates, honorable professors, and everyone who has helped us from near or far.

MALAOUI Islam *** ZERFAOUI Chihab

الجمهورية الجزائرية الديمقراطية الشعبية
وزارة التعليم العالي والبحث العلمي

مؤسسة التعليم العالي : جامعة الشهيد الشيخ العربي التبسي – تبسة

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السيد (ة)...زرقامي شهاب.....الصفة : طالب، أستاذ باحث، باحث دائم : ...طالب.....

الحامل لبطاقة التعريف الوطنية رقم : .....402486253..... و الصادرة بتاريخ .....2022/07/30.....

المسجل بمعهد .....المناجم.....قسم.المناجم والجيوتكنولوجيا.....

و المكلف بانجاز أعمال بحث (مذكرة التخرج، مذكرة ماستر، مذكرة ماجستير، أطروحة دكتوراه)، عنوانها :

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.....

أصرح بشرفي أني ألتزم بمراعاة المعايير العلمية و المنهجية و معايير الأخلاقيات المهنية و النزاهة الأكاديمية المطلوبة في انجاز البحث المذكور أعلاه.

التاريخ:.....2024/06/25.....

إمضاء المعني (ة)

الجمهورية الجزائرية الديمقراطية الشعبية
République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur
et de la Recherche Scientifique
Université Larbi Tebessi – Tébessa
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وزارة التعليم العالي و البحث العلمي
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Année universitaire : 2023/2024 Tébessa le :

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الجمهورية الجزائرية الديمقراطية الشعبية

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الحامل لبطاقة التعريف الوطنية رقم: ..١١٩٧١٢٠٤٠٥..و الصادرة بتاريخ: 2019.06.03

المسجل بمعهد: ..المناجم والحيوكلنولوجيا.. قسم:..المناجم والحيوكلنولوجيا.....

والمكلف بانجاز أعمال بحث (مذكرة التخرج ، مذكرة ، ماستر ، أطروحة دكتوراه) عنوانها

.....مذكرة تخرج.....

.....

أصرح بشرفتي أني ألتزم بمراعاة المعايير و المنهجية و معايير الأخلاقيات المهنية و النزاهة الأكاديمية المطلوبة في انجاز البحث المذكور أعلاه

التاريخ: .....25 جوان 2024

إمضاء المعنى (ة)

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عون رئيسي للادارة الاقليمية

25 جوان 2024

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Abstract

This study titled in "Treatment and Recovery of Djebel-Onk Phosphate Carbonates for Their Use in the Industrial Sector" focuses on the beneficiation of phosphate ores from the Djebel-Onk region in Algeria. It addresses the challenges posed by carbonate impurities in phosphate mining, which reduce economic viability and environmental sustainability. The research explores innovative techniques for separating phosphates from carbonates using reverse flotation, optimizing the process to enhance extraction efficiency. The study also investigates the potential of converting residual carbonates into valuable industrial products, contributing to local economic development. Through a multidisciplinary approach, the dissertation aims to improve the sustainability and profitability of phosphate mining and processing operations

Keywords: Phosphate Carbonates – Treatment- Recovery – flotation

Résumé

Cette étude intitulée "Traitement et récupération des carbonates phosphatés de Djebel-Onk pour leur utilisation dans le secteur industriel" se concentre sur l'enrichissement des minerais de phosphate de la région de Djebel-Onk en Algérie. Elle aborde les défis posés par les impuretés carbonatées dans l'extraction du phosphate, qui réduisent la viabilité économique et la durabilité environnementale. La recherche explore des techniques innovantes pour séparer les phosphates des carbonates en utilisant la flottation inversée, optimisant le processus pour améliorer l'efficacité de l'extraction. L'étude examine également le potentiel de conversion des carbonates résiduels en produits industriels précieux, contribuant ainsi au développement économique local. Grâce à une approche multidisciplinaire, la dissertation vise à améliorer la durabilité et la rentabilité des opérations d'extraction et de traitement des phosphates.

Mots-clés : Carbonates de phosphate – Traitement – Récupération – Flottation

الملخص :

تركز هذه الدراسة بعنوان "معالجة واستعادة كربونات الفوسفات من جبل عنق لاستخدامها في القطاع الصناعي" على تحسين خامات الفوسفات من منطقة جبل عنق في الجزائر. تتناول الدراسة التحديات التي تفرضها الشوائب الكربونية في تعدين الفوسفات، والتي تقلل من الجدوى الاقتصادية والاستدامة البيئية. تستكشف الأبحاث تقنيات مبتكرة لفصل الفوسفات عن الكربونات باستخدام التعويم العكسي، وتحسين العملية لزيادة كفاءة الاستخراج. كما تدرس الدراسة إمكانات تحويل الكربونات المتبقية إلى منتجات صناعية ذات قيمة، مما يسهم في التنمية الاقتصادية المحلية. من خلال نهج متعدد التخصصات، تهدف الأطروحة إلى تحسين استدامة وربحية عمليات استخراج ومعالجة الفوسفات.

الكلمات المفتاحية: كربونات الفوسفات – معالجة – استعادة – تعويم

GENERAL INTRODUCTION

General introduction.

With the growing concern for ensuring the sustainability of phosphate resources, research and development in the treatment and conversion of sedimentary carbonates, such as those found in the Djebel Onk region, into valuable resources for various industries have gained significant attention. Djebel Onk is known for its rich deposits of phosphates and carbonates, presenting opportunities for exploring and developing efficient techniques for extracting phosphorus and carbonates and converting them into useful industrial products.

These efforts include innovations in carbonates extraction processes, including modern techniques for separating phosphates from carbonates and increasing extraction efficiency. Additionally, research is needed to devise methods for converting the remaining carbonates into valuable products used in a variety of industrial applications, thereby contributing to local economic growth and reducing reliance on non-renewable natural resources.

In essence, our research and development in the treatment and conversion of carbonates from phosphate deposits in Djebel Onk represent a vital opportunity to achieve sustainable use of carbonates resources and enhance industrial development locally and beyond

Problematic:

Despite the abundance of phosphate reserves worldwide, the presence of carbonate impurities significantly diminishes the economic viability and environmental sustainability of phosphate mining and processing operations. Conventional beneficiation techniques often fall short in efficiently separating carbonate minerals from phosphate ores, leading to increased processing costs and environmental impact.

Moreover, the valorization of carbonate-rich phosphate ores remains a largely unexplored territory. While phosphorus is the primary target for extraction, the co-product or by-product potential of carbonate minerals is frequently overlooked. This oversight represents a missed opportunity for maximizing resource utilization and minimizing waste generation in the phosphate industry.

Addressing these challenges requires a multidisciplinary approach encompassing mineral processing, chemistry, engineering, and environmental science. By advancing our understanding of carbonate-phosphate interactions and developing tailored treatment methodologies, we can unlock the full potential of phosphate deposits while mitigating the associated environmental footprint.

In this study, we aim to explore innovative strategies for the treatment and valorization of phosphate carbonates. Through a combination of experimental investigations, process optimization, and techno-economic analysis, we seek to develop sustainable solutions that

enhance the efficiency, profitability, and environmental sustainability of phosphate mining and processing operations.

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Chapter I
General Part

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.

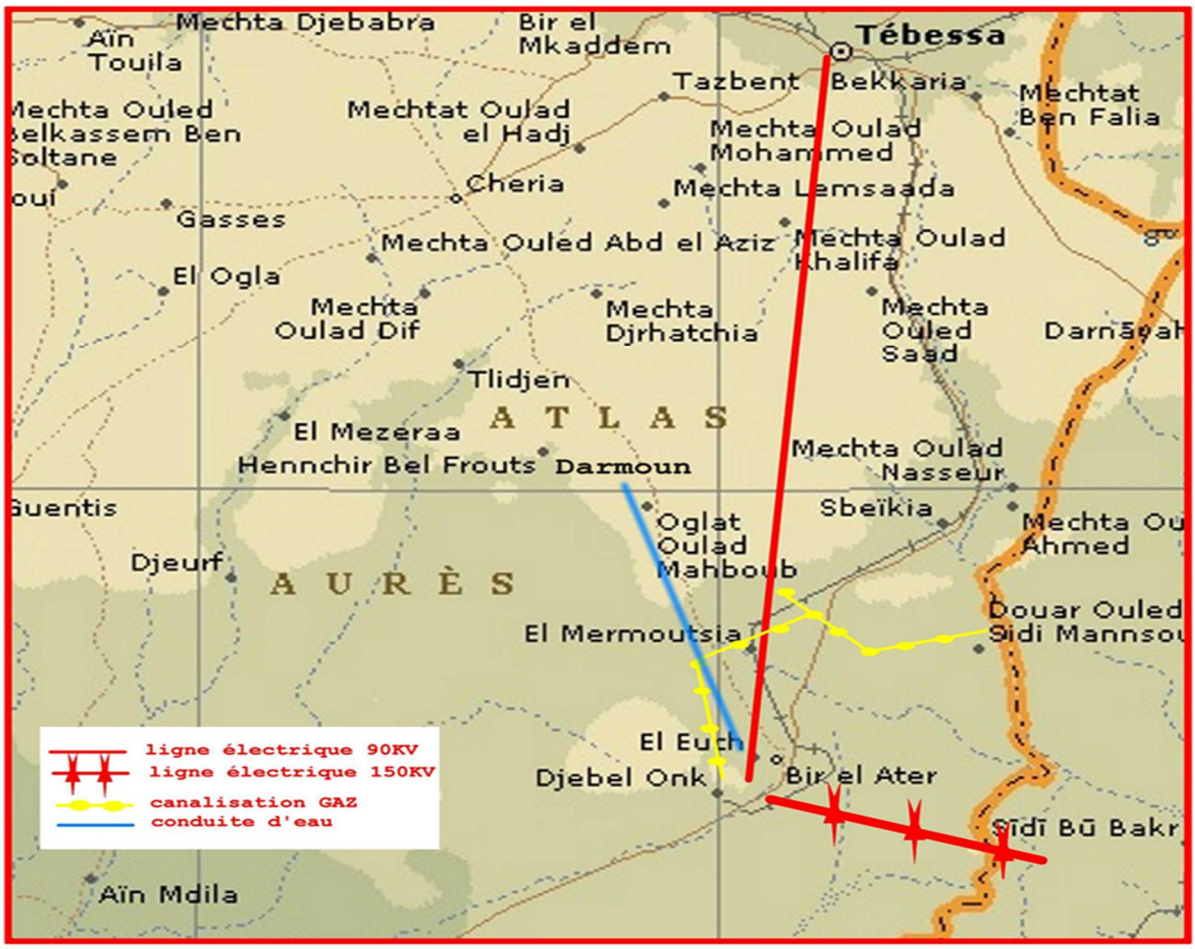
From 1960 to 1962, a detailed exploitation study of Djemi Djema was carried out, and the processing facilities were completed in 1965. Quarrying operations commenced concurrently with the establishment of these facilities to provide the necessary materials for the initial trials, which started at the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

1. 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..**[1]**



CARTE DE LA SITUATION DE LA WILAYA DE TEBESSA

Figure 1: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]**

2. 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. **[1]**

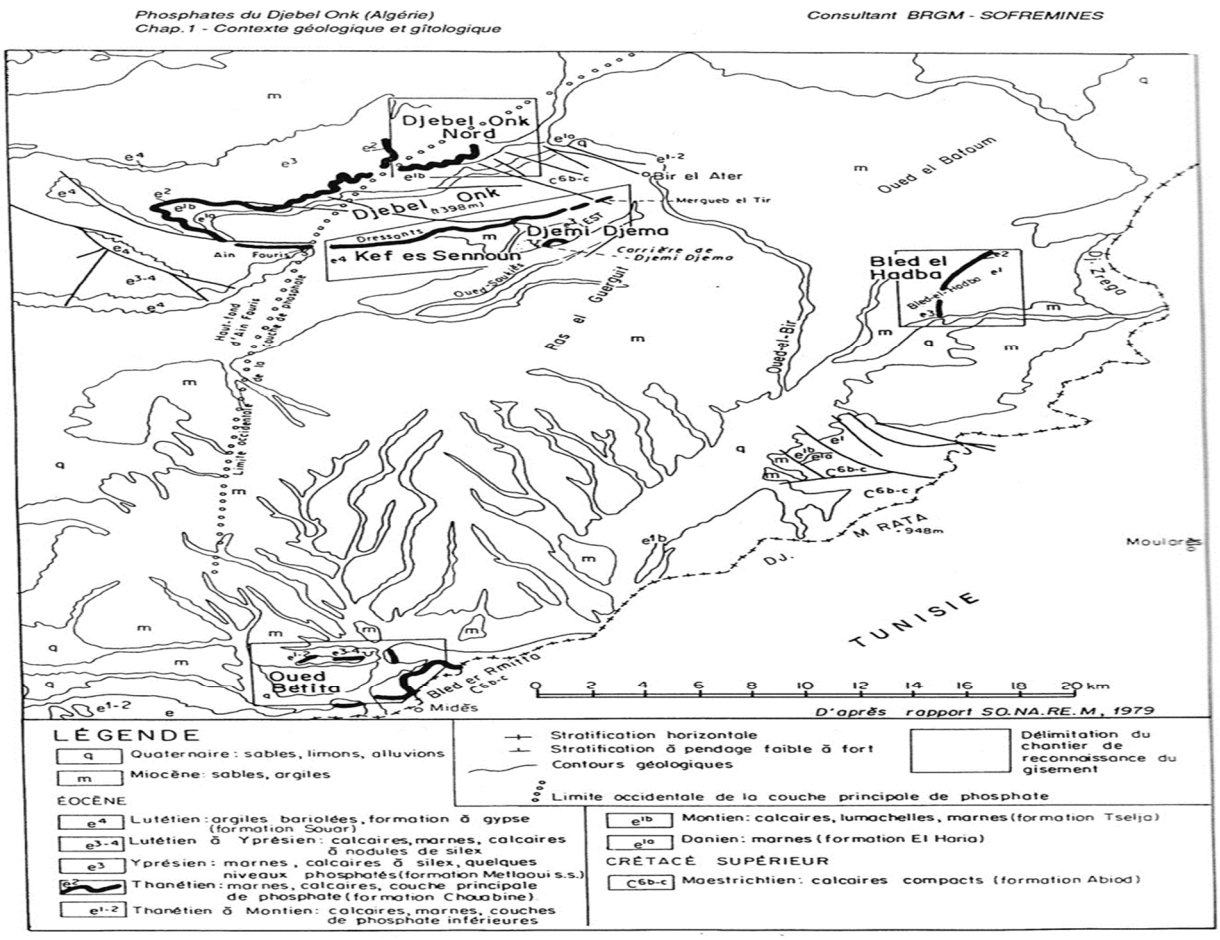


Fig. 2 - Situation géologique des gisements de phosphate de la région du Djebel Onk.

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Figure 2: Geological situation of the deposits in the Djebel Onk region

3. 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. **[2]**

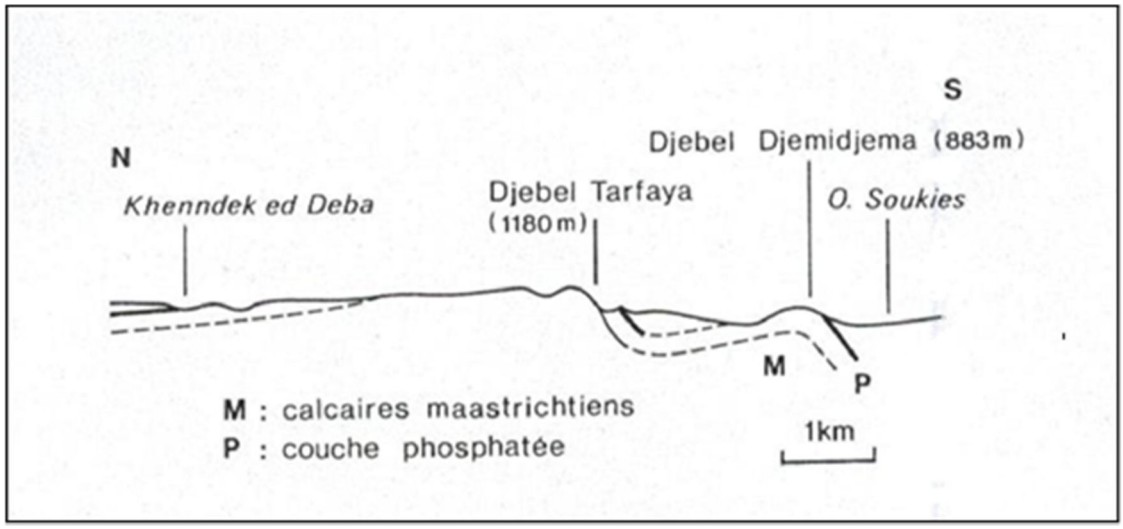


Figure 3. Cross Section of Djebel Onk

3.1.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. **[2]**

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.

- **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%.**[3]**

3.2.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. **[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, ranging between 2% and 3%, with an overall average of 2.61%.

3.3.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.

3.4.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. **[2]**

3.5.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]**

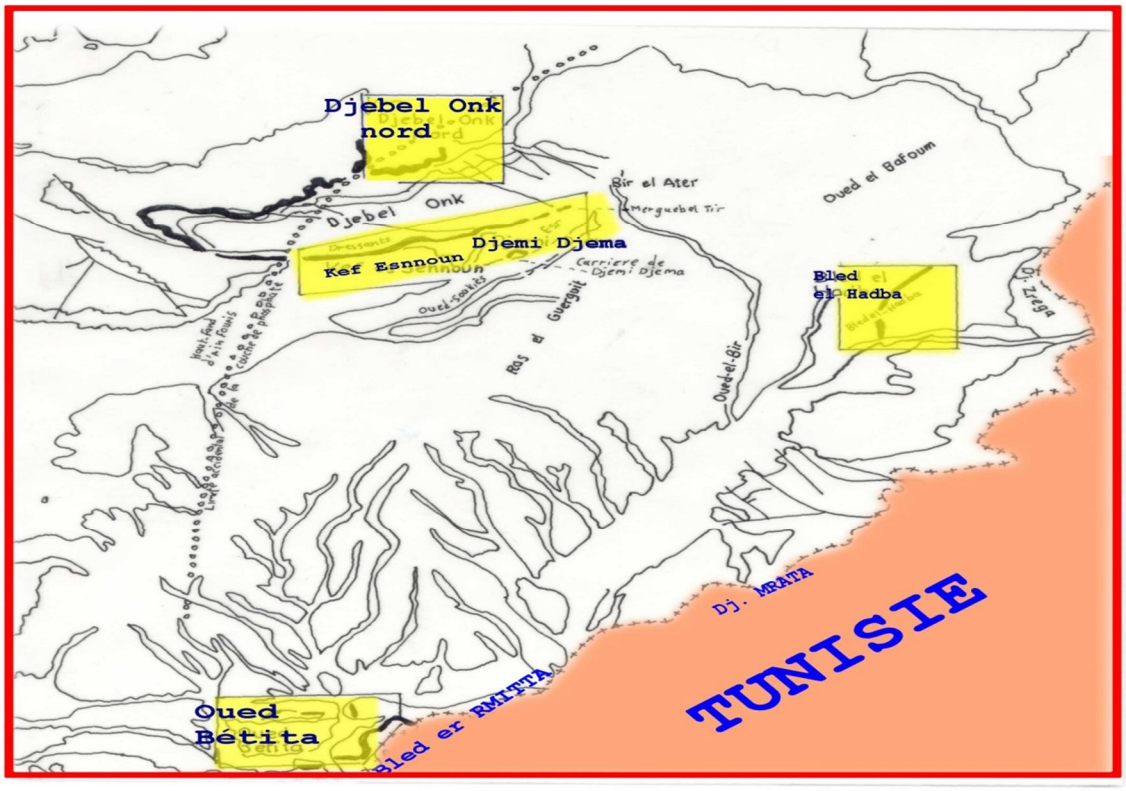


Figure 4: The Djebel Onk deposits

4. 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).

4.1.Tertiary

4.1.1. 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. **[5]**

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.

4.1.2. 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 a facies change, with the first beds being soft white marls with quartz geodes and flint, interspersed with limestones.

• **Upper Lutetian**

Characterized by an evaporitic facies of gypsum and whitish dolomites. Further south are the Bled El Hadba deposit and further still the Bettita deposit.

4.1.3. 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. **[5]**

4.2.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. **[5]**

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). **[5]**

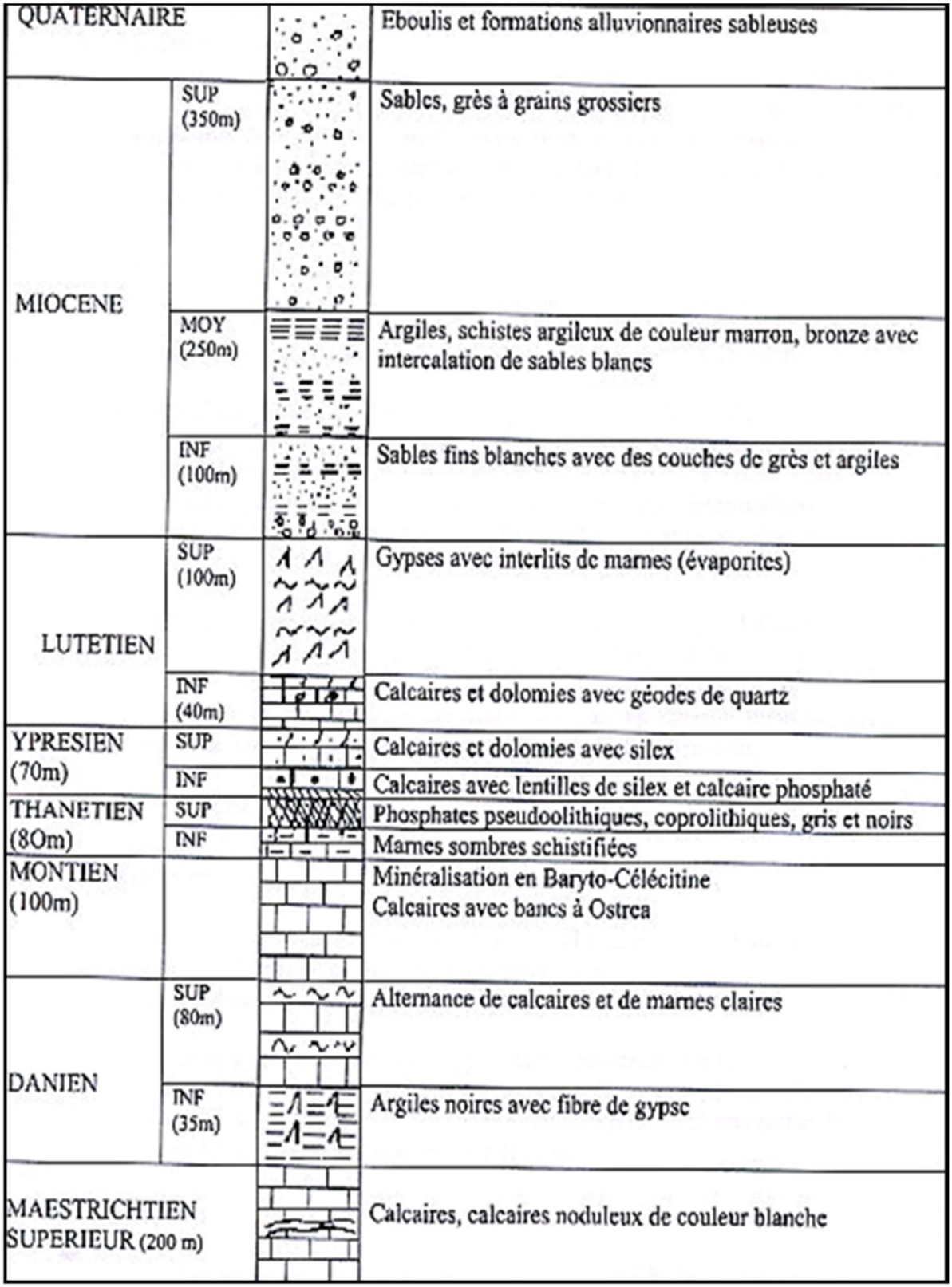


Figure 5: Stratigraphy of the Djebel-Onk deposit (Ranchin G., 1963)

5. 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. **[5]**

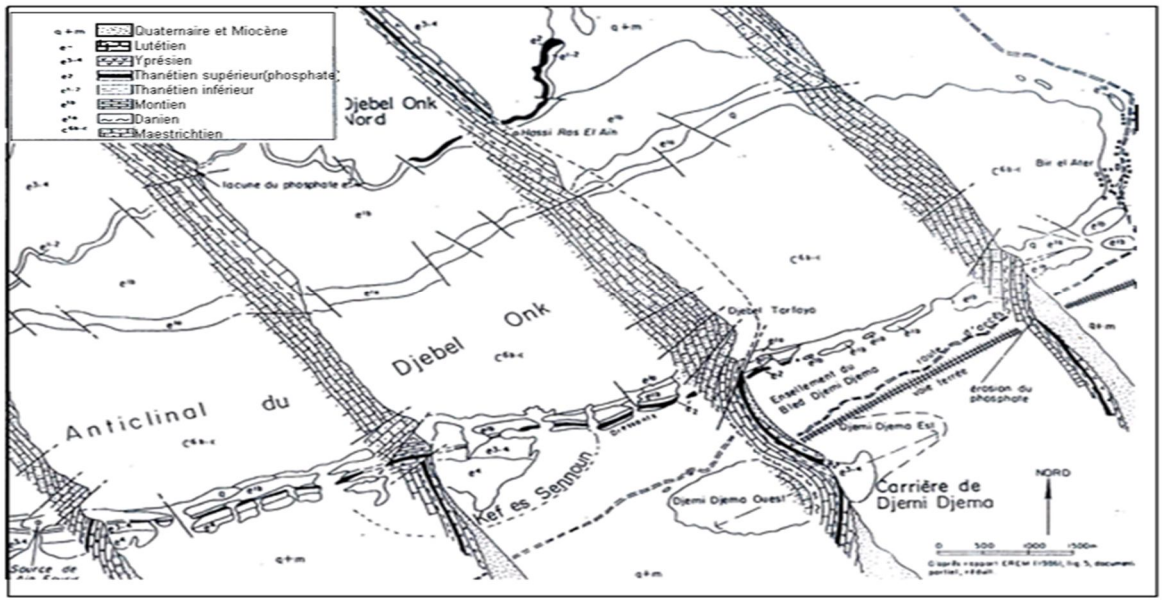


Figure 6.Stratigraphic and structural sections of the northern and southern flanks of Djebel Onk Mining Research and Exploitation Company. (E.R.E.M)

5.1.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.

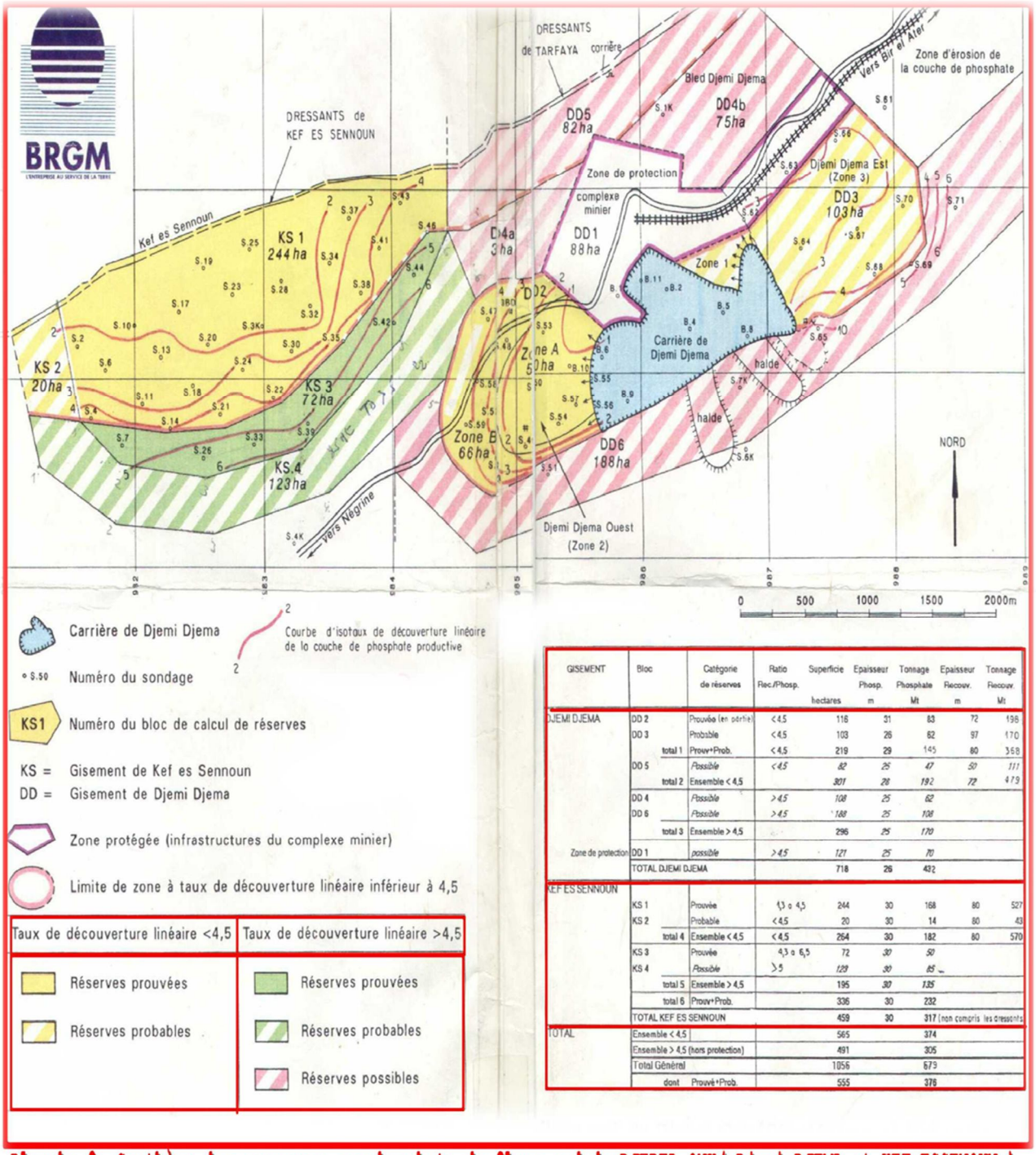
The phosphate layer exhibits relatively constant and uniform characteristics across the entire recognized extent of the deposit, covering an area of 3.16 km² (3.5 x 0.9 km). Its structure is

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) degrees 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. **[5]**

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	129	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		376		

Planche 3- Synthèse des resources en phosphate du flanc sud du DJEBEL-ONK(Djemi DJEMA et KEF ESSENOUN)

Figure 7: Synthesis of phosphate resources on the southern flank of Djebel OnkBureau of Research and Mining Geology (B.R.G.M

6. Expliotation

6.1.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). **[5]**

6.2.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: **[6]**

- **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). **[6]**

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.

6.3.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. **[6]**

6.4.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.

6.5.Characteristics Of Phosphate [6]

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. **[6]**

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: **[6]**

6 Ca3(PO4)2 + 6 SiO2 + 10 C → 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.

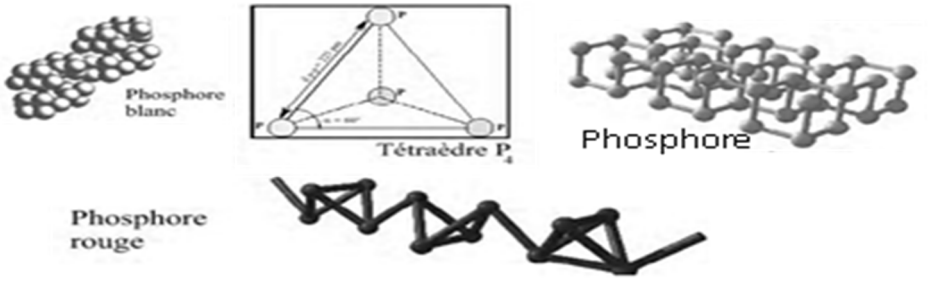


Figure 8: Structure of white, black and red phosphors

6.5.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

6.6.Composition chimique du produit marchand de phosphate de djebel onk [7]

Table 3:The chemical composition of the commercial product of Djebel Onk[7]

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

7. Traitement factory

The processing of phosphate ore from Djebel Onk is carried out in two well-defined stages. The first stage is mechanical preparation, which includes the following operations:

- Crushing.
- Grinding.
- Screening.

The second stage comprises the actual phosphate ore treatment. In this stage, it is noted that there are two processing lines, one dry and the other wet.

7.1.Mecanical preparation

Mechanical preparation aims to reduce the dimensions of the ore blocks and liberate the valuable components from their gangue. It involves the following three operations: Crushing, grinding, and screening. **[7]**

7.2.Crushing

The purpose of this operation is to reduce the size of the blocks from 1000mm to a maximum of 200mm.

It is carried out using the two crushers :

- Gyratory cone crusher "BABITLESS" with a capacity of 1000 T/h With a reduction ratio of five (5) .
- Impact crusher "HAZEMAG" equipped with a scalping system with a capacity of 1200 T/h With a reduction rate of up to sixty (60) .

7.3.Grinding

This operation involves reducing the size of the crushed product to a dimension of 20 mm, with a reduction rate of ten (10) .

This process involves two hammer mills (Wedag) with a production capacity of 300 t/h each, and one impact crusher (Triman) with a production capacity of 500 t/h. The crushed product will then be transported to the screening workshop .

7.4. **Screening**

This operation aims to eliminate the product with dimensions greater than 15mm using

- one (01) vibrating screen (Wedag) with a capacity of 250 t/h and two (02) inclined screens (Triman) with a capacity of 500 t/h.
- The efficiency of this operation reaches 90% by weight. On the other hand, the crushed product from Kef Essnoun feeds two inclined vibrating screens (Hazemag) with a capacity of 600 t/h and an opening of 15 mm.

The rejects from these screens are recycled and returned to the crushers. The rejects from the screens are transported to a discharge hopper and then to spoil heaps. The primary goal of mechanical preparation is to have a product size smaller than 15mm to serve the two processing lines.

7.5.Wet treatment (Settling)

This operation takes place in the flotation workshops (DK1), aiming to enrich the ore to a content of 63/65% P2O5. This type of treatment includes the following operations:

a. Settling

The purpose of this operation is to remove clays, silicates, organic materials, as well as salts... It consists of the following operations: pulping, wet screening (curved screens), classification, hydrocycloning, and filtration.

b. Principle

The screened material with dimensions smaller than 15 mm is pulped with water in a solid/liquid ratio of 2/3 (T/m²), and then fed to the curved screens, which operate with a cut-off of 1.25 mm. The helical rotation hydrocyclones recover the material passing through the curved screens, aiming to eliminate fractions smaller than 0.8 mm. The very low-phosphate fine particles are directed towards the thickener, while the high-quality product is squeezed in intermediate presses, resulting in a dewatered product with a P2O5 content ranging from 63 to 64.5%. It is then sent to the second operation. **[7]**

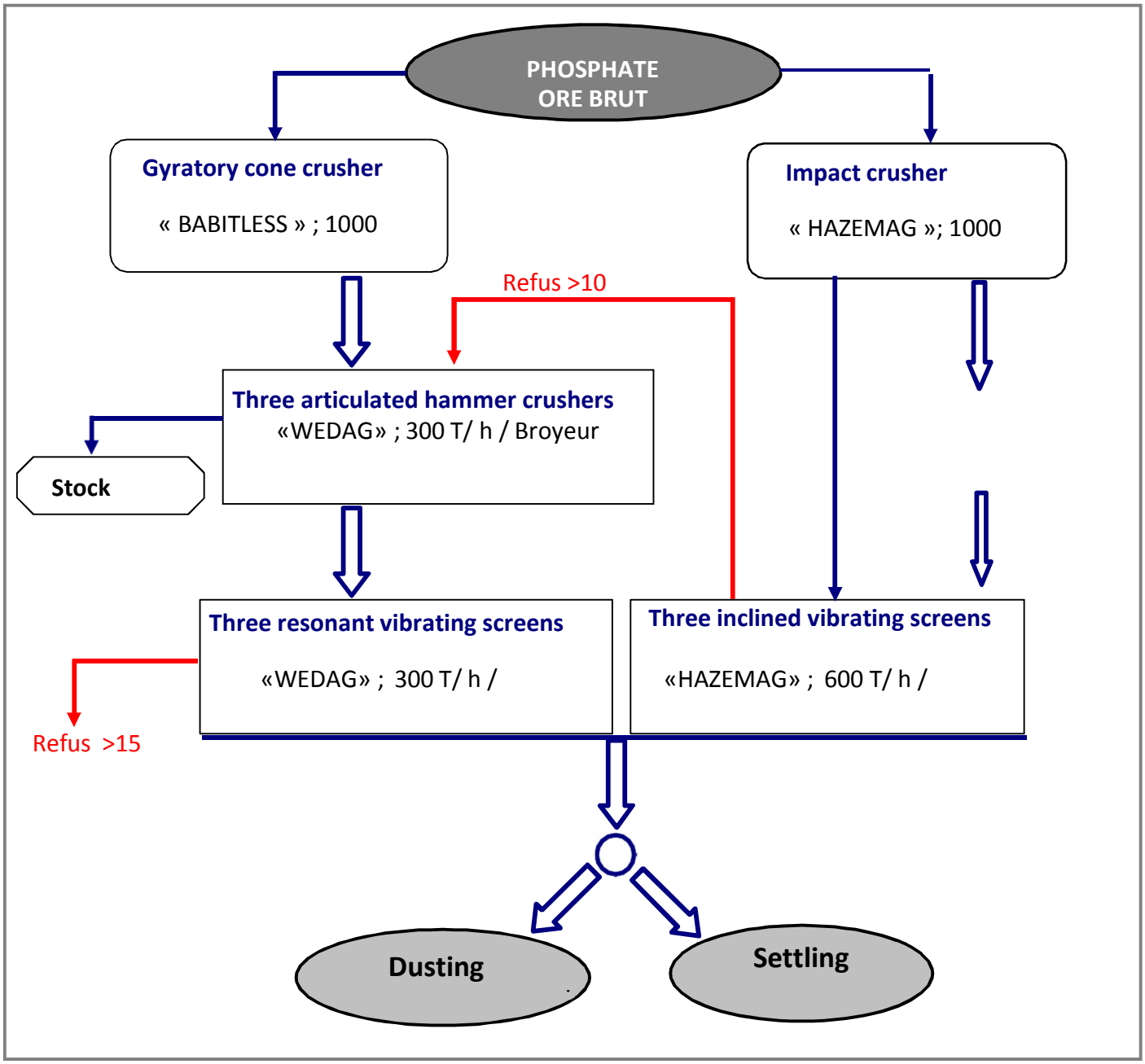


Figure 9: Schematic of mechanical preparation

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7.6.Drying

The dewatered product is a semi-finished wet product that requires dehydration until obtaining a marketable product with a moisture content of 1%. Drying is done using two methods:

- Drying by calcination furnace
- Drying by horizontal furnace

a. calcination furnace drying (B1)

For this purpose, the calcination process in the vertical drying furnace has been modified with an hourly flow rate of 70 T/h/line (preheating compartment) at a temperature reaching 100°C.

b. Horizontal furnace drying

This workshop comprises two horizontal rotary furnaces with an adjusted temperature of 105°C ± 5°C. These furnaces are rotary in motion, where the dewatered product is dried in a fluidization chamber, forming a suspended fluidized bed that spans the length of the furnace. The product undergoes evaporation of the water absorbed in the product. **[7]**

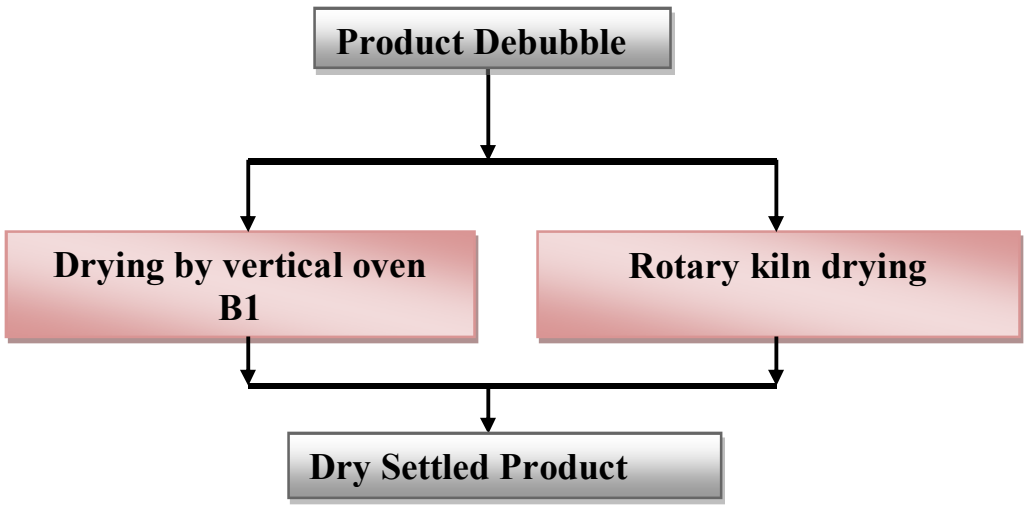


Figure 10:Schematic of the drying process

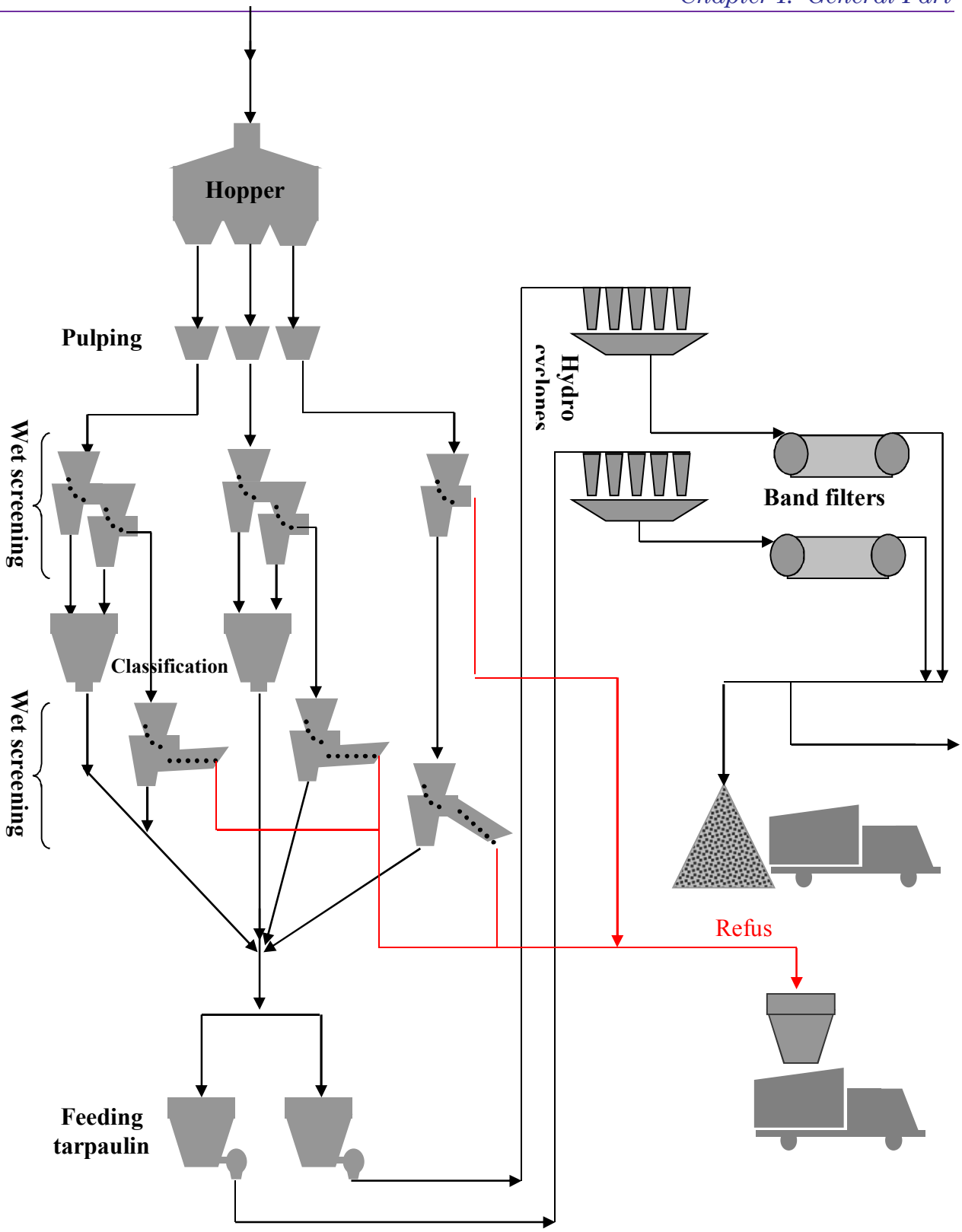


Figure 11; clearing diagram

c. Dry Processing (Dedusting)

This operation takes place in the dedusting workshops (DK2 and DK3) and is a physico-mechanical process for enriching phosphate ore to obtain an average concentrate of 29 to 30%

P2O5. It is a process derived from dry processing technology, primarily based on decarbonization through impact and size adjustment.

The main goal of this type of treatment is to dry-enrich a product from the quarry with 54 to 56% P2O5, crushed and screened to 15 mm, containing 5 to 7% moisture, to bring it to commercial quality with a P2O5 content of 65 to 68% and particle sizes between 0.8mm and 0.08mm. Each line has a capacity of 230 T/h for feed and 137.5 T/h for output, with a weight yield of 60 to 62% in order to process and dry-enrich the product, it must undergo five (5) preparation and enrichment operations. **[7]**

d. Fluidized bed drying

The purpose of this operation is to reduce the moisture content of the product to 1% and also eliminate some of the finest solids by entraining them with the fluidization gases. It consists of two drying furnaces, which are divided into two behaviors:

- Combustion and dilution.
- Drying by fluidization.

- **Screening at 2 mm**

This operation involves removing product particles larger than 2mm using screens equipped with a 2mm sieve. It allows the rejection of larger particles (>2mm) such as limestone, while particles smaller than 2mm are accepted and directed to the crushers (weight yield 88%).

- **Attrition milling**

To release a portion of the gangue from the phosphate grains and allow for better final enrichment through size separation, attrition mills equipped with a rotor carrying hammers and a grinding chamber are used. **[7]**

- **Selection by turbo air classifier (TSV)**

The purpose of this operation is to enrich the product by removing fine particles smaller than 0.08mm using fans.

- **Screening at 0.8 mm**

Similar to the 2mm screens, this operation rejects phosphate grains larger than 0.8mm

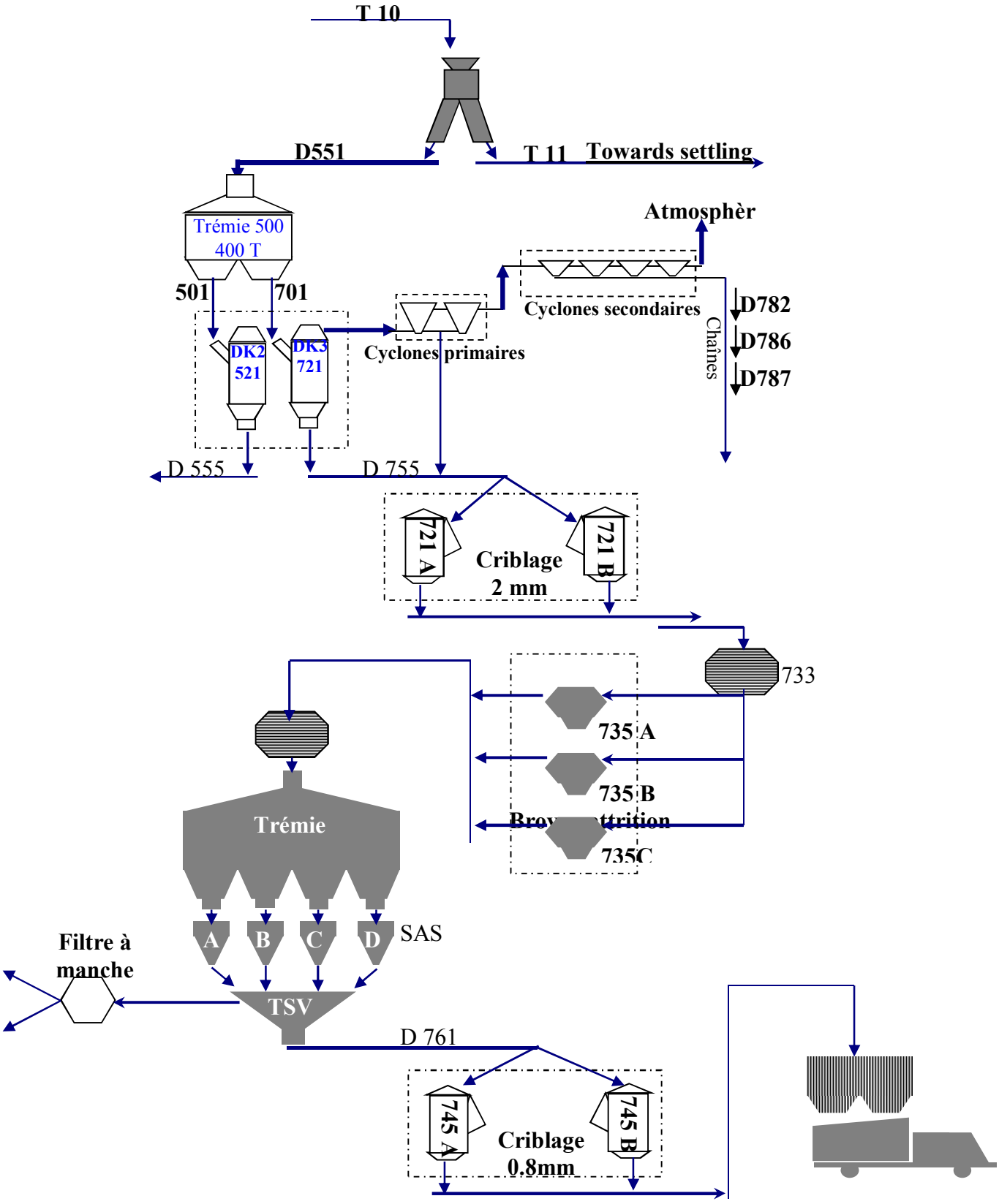


Figure 12:Dust removal technology diagram

Conclusion

Algerian phosphate is the most exploited national mining resource, considered both a significant source of foreign exchange and a key element of the mining sector. The Djebel Onk Sud region is known for its Cretaceous, Tertiary, and Quaternary sediments covering most of the area. Its structure is relatively simple, characterized by a sub-horizontal monocline and brachyoanticline at the DjemiDjema mountain. This region features two types of faults: NNW-SSE and N 75°E. Djebel Onk's deposits are classified among the world's largest due to their high phosphate quality.

To obtain marketable products, Djebel-Onk mine operates through two processing methods: wet and dry processing. Algeria is rich in natural resources, with significant mining potential in its soil. Tremendous efforts have been made in this field, particularly in research, prospecting, and exploitation of natural resources. The development of heavy and light industries is closely linked to the production and quality of finished products.

Chapter II
Carbonates in D-O ore

1. Types of carbonates

There are several types of carbonate minerals, each with unique characteristics and applications:

1.1.magnesium carbonates

these carbonates play a role in mantle metasomatism and deep recycling processes. they are associated with sources of alkali basalts and have specific isotopic signatures like δ26Mg and δ66Zn**[8]**

1.2. calcium carbonates

calcium carbonates are an important class of minerals. the anhydrous CaCO3 types include calcite, aragonite, and vaterite. other forms are the monohydrate monohydrocalcite (CaCO3·H2O), the hexahydrate ikaite (CaCO3·6H2O), and an amorphous form. **[8]**

1.3. magnesian calcites

these are a type of calcium carbonate where some of the calcium is replaced by magnesium, forming the formula Ca1−nMgnCO3. The amount of magnesium substitution (n) can vary from 0.058 to 0.342.

These carbonate minerals have diverse applications in geology, chemistry, and industry, ranging from their role in geological processes to their use in polymer synthesis and CO2 sequestration.

In djebel onk we have two types of carbonates

- Carbonate de calcium Ca CO3
- Carbonate de magnesium Mg CO3**[8]**

2. Usage

2.1. Calcium carbonate CaCO3

The industrial applications of Calcium Carbonates include:

2.1.1. Adhesives and sealants

Precipitated calcium carbonates have applications in adhesives and sealants, contributing to the adhesive properties and sealing capabilities of various products.

2.1.2. Food and pharmaceuticals

Calcium carbonates are used in the food and pharmaceutical industries for various purposes. They can act as dietary supplements, pH regulators, and anti-caking agents in food products. In pharmaceuticals, they are utilized in antacids and calcium supplements.

2.1.3. Paints and coatings

Calcium carbonates are incorporated into paints and coatings to enhance properties like opacity, brightness, and viscosity. They contribute to the overall quality and performance of these products.

2.1.4. Paper industry

In the paper industry, calcium carbonates are used as fillers and coating pigments. They improve the brightness, opacity, and smoothness of paper, enhancing its printability and overall quality.

2.1.5. Construction materials

Calcium carbonates are essential components in the construction industry. They are used in the manufacturing of cement, concrete, and other construction materials, contributing to the strength and durability of structures.

These applications highlight the versatility and importance of calcium carbonates in various industrial sectors, ranging from food and pharmaceuticals to construction materials and coatings.**[9]**

2.2.Magnesium carbonate MgCO3

Magnesium carbonates have several important industrial applications:

2.2.1. Scale inhibition

Magnesium carbonates are utilized in industrial processes for scale inhibition. They play a crucial role in controlling scale formation, which is essential for various industrial applications.

2.2.2. Cement and concrete manufacturing

Magnesium carbonates are used in the manufacturing of cement and concrete. They contribute to producing durable concrete structures in the construction industry.

2.2.3. Co_2 usage

Advanced pseudopolymorph control of magnesium carbonates using structural properties of amines has been explored for CO2 utilization. This involves post-treatment of desalinated brine, indicating a potential role of magnesium carbonates in carbon capture and utilization technologies.

2.2.4. Humidity control and adsorption

A novel, template-free, amorphous magnesium carbonate nanostructure with a high surface area (~800 m2/g) has been synthesized. This nanostructure exhibits unique moisture sorption properties, including a 50% larger adsorption c3apacity than hygroscopic zeolite-Y at low relative humidities. These properties make it useful for applications such as humidity control, industrial adsorbents, and filters.

These applications demonstrate the versatility of magnesium carbonates in various industrial processes, from scale inhibition and construction materials to carbon capture and humidity control technologies. **[9]**

3. Characteristics

3.1.Carbonate de calcium Ca CO3

Calcium carbonates have several key characteristics:

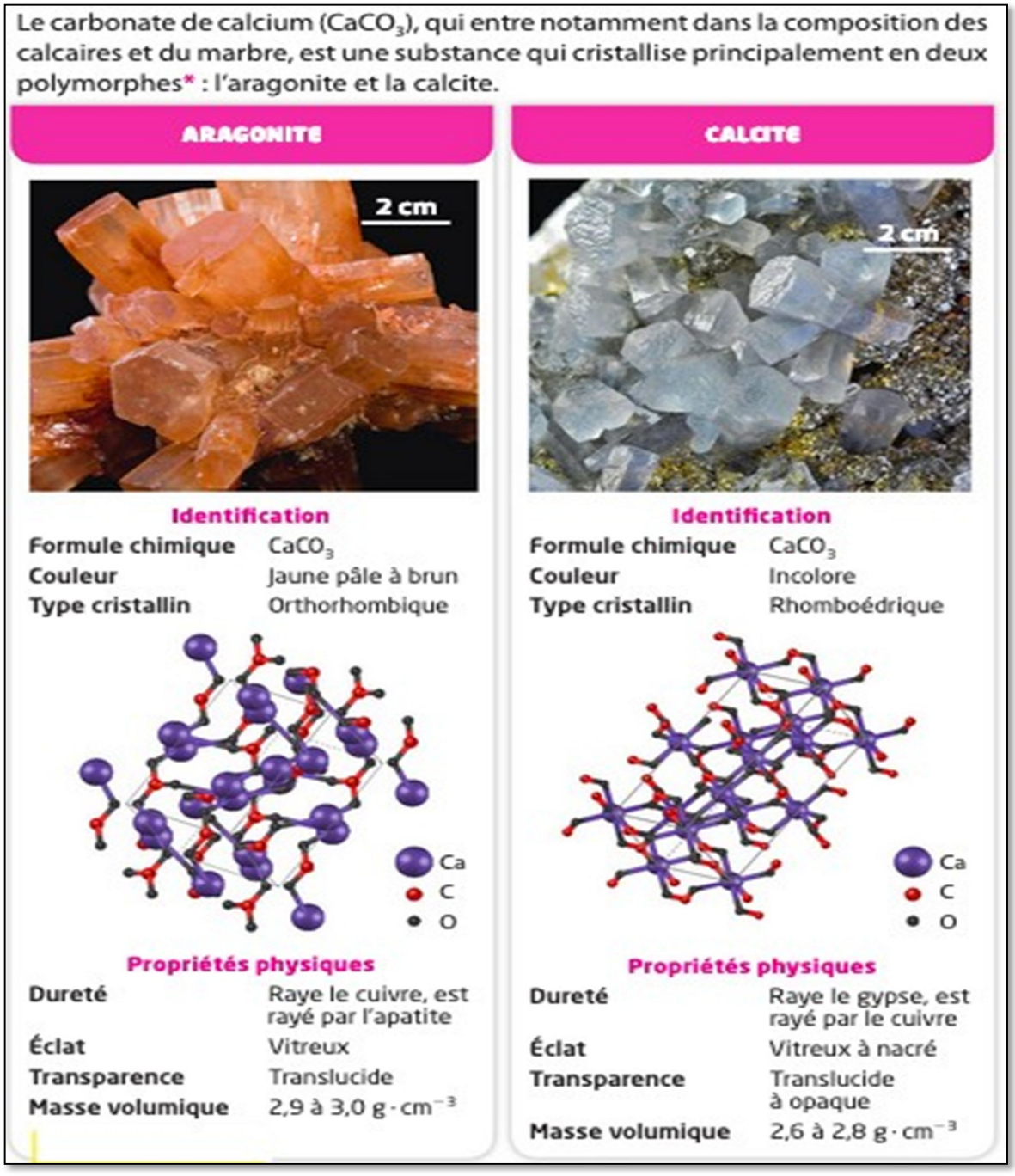


Figure 13; Identification and physical properties of calcium carbonates

3.1.1. Crystal structures

The anhydrous CaCO3 types include calcite, aragonite, and vaterite. Other forms are the monohydrate monohydrocalcite (CaCO3·H2O), the hexahydrate ikaite (CaCO3·6H2O), and an amorphous form. **[10]**

3.1.2. Polymorphism

Calcium carbonates exhibit different polymorphs, including calcite, aragonite, and vaterite. Calcite is considered the most thermodynamically favorable structure at ambient conditions. **[10]**

3.1.3. Magnesian calcites

Some calcium in calcite can be replaced by magnesium, forming magnesian calcites with the formula Ca1−nMgnCO3. The amount of magnesium substitution (n) can vary from 0.058 to 0.342. **[10]**

3.1.4. Solubility

The solubility of calcium carbonates in water and simple aqueous electrolyte solutions has been extensively studied and critically evaluated. Thermodynamic data for each form consistent with different models and the CODATA key values for thermodynamics have been presented. **[10]**

3.1.5. Crystal structure and properties

The crystal structure of calcium carbonates is well-established, with possible refinement of variable parameters. Numerous qualitative correlations exist between crystal structure and specific physical and chemical properties. Theoretical calculations of properties from the structure have also been successful.

These characteristics highlight the importance of understanding the fundamental properties of calcium carbonates, which is crucial for their various industrial applications and geological significance. **[10]**

3.2. Magnesium carbonate mg co_3

The characteristics of Magnesium Carbonate (MgCO3) include:

3.2.1. Formation conditions

Magnesium carbonates have been identified in various terrestrial environments, including ultramafic rock-hosted veins, carbonated peridotite, alkaline lake and playa deposits, and diagenetic replacements within lime and dolostones. They form in distinct settings with specific textures and mineral assemblages

3.2.2. Textural features

Dominant textures of magnesium carbonates include fine-grained or microcrystalline veins, nodules, and crusts. Microbial influences on formation are recorded in various structures like thrombolites, stromatolites, and filamentous microstructures.

3.2.3. Isotopic signatures

Isotopic compositions of magnesium carbonates provide insights into their formation processes. Different isotopic signatures in ultramafic rock-hosted magnesium carbonates indicate formation by processes like low-temperature meteoric water infiltration, hydrothermal alteration, or metamorphic processes.

3.2.4. Sources of carbon and magnesium

Studies have used mineral assemblages, fluid inclusions, and isotopic analyses to determine the sources of carbon and magnesium for magnesium carbonates. These analyses also help in understanding the temperatures of formation of magnesium carbonates.

These characteristics of magnesium carbonates are crucial for understanding their formation, properties, and implications in various geological and environmental processes. **[11]**

4. Composition

4.1.Calcium carbonate Ca CO_3

Calcium carbonates are an important class of minerals with the chemical formula CaCO3. They have several key characteristics:

4.1.1. Chemical composition

Calcium carbonates consist of calcium (Ca), carbon (C), and oxygen (O) atoms. The chemical formula is $CaCO_3$, where one carbon atom is bonded to three oxygen atoms, forming a carbonate group (CO_3), and the carbonate group is bonded to one calcium atom. **[9]**

4.1.2. Crystal structures

The anhydrous $CaCO_3$ types include calcite, aragonite, and vaterite. Other forms are the monohydrate monohydrocalcite ($CaCO_3 \cdot H_2O$), the hexahydrate ikaite ($Ca\ CO_3 \cdot 6H_2O$), and an amorphous form.

4.1.3. Polymorphism

Calcium carbonates exhibit different polymorphs, including calcite, aragonite, and vaterite. Calcite is considered the most thermodynamically favorable structure at ambient conditions.

4.1.4. Magnesian calcites

Some calcium in calcite can be replaced by magnesium, forming magnesian calcites with the formula $Ca1-nMgnCO_3$. The amount of magnesium substitution (n) can vary from 0.058 to 0.342. **[9]**

4.1.5. Density

The density of calcium carbonates varies depending on the specific polymorph:

- ✓ Calcite: 2.71 g/cm³
- ✓ Aragonite: 2.93 g/cm³
- ✓ Vaterite: 2.54 g/cm³

These characteristics highlight the importance of understanding the fundamental properties of calcium carbonates, which is crucial for their various industrial applications and geological significance

4.2. Carbonate de magnesium $Mg\ CO_3$

Magnesium Carbonate ($MgCO_3$) is a mineral with the following key characteristics:

4.2.1. Chemical composition

Magnesium carbonate consists of magnesium (Mg), carbon (C), and oxygen (O) atoms. The chemical formula is $Mg\ CO_3$, where one carbon atom is bonded to three oxygen atoms, forming a carbonate group (CO_3), and the carbonate group is bonded to one magnesium atom. **[12]**

4.2.2. Crystal structure

Magnesium carbonates can form plate-like crystals of hydromagnesite ($Mg5(CO_3)4(OH)2·4H_2O$). These plate-like crystals can assemble into complex aggregates with calcite ($CaCO_3$) crystals.

4.2.3. Density

The density of magnesium carbonate is not explicitly stated in the provided search results. However, the bulk density of a mixture of calcium carbonate and magnesium carbonate is mentioned to be less than or equal to 250 kg/m³ and more than or equal to 80 kg/m³, as measured by standard EN459.2.

4.2.4. Formation conditions

Magnesium carbonates form in five distinct terrestrial settings: ultramafic rock-hosted veins, the matrix of carbonated peridotite, nodules in soil, alkaline lake and playa deposits, and as diagenetic replacements within lime and dolostones.

4.2.5. Isotopic signatures

Isotopic compositions of magnesium carbonates provide insights into their formation processes. Different isotopic signatures in ultramafic rock-hosted magnesium carbonates indicate formation by processes like low-temperature meteoric water infiltration, hydrothermal alteration, or metamorphic processes.

These characteristics highlight the importance of understanding the fundamental properties of magnesium carbonates, which is crucial for their various geological and environmental **[12]**

Conclusion

Carbonates are crucial and diverse minerals that play vital roles across various geological and industrial domains. These minerals range from calcium carbonates to magnesium carbonates, each with unique characteristics and wide-ranging applications.

Calcium carbonates, including their crystalline forms such as calcite, aragonite, and vaterite, as well as their hydrated forms like monohydrocalcite and ikaite, are extensively used in industries such as food, pharmaceuticals, paints, paper, and construction. This widespread use underscores their significant economic and industrial importance.

On the other hand, magnesium carbonates are pivotal in industrial processes, including scale inhibition, cement and concrete manufacturing, humidity control, and CO2 utilization technologies. Their unique properties and formation conditions make them indispensable in these applications.

The physical and chemical properties of both calcium and magnesium carbonates, including crystal structure, density, and solubility, are fundamental to understanding their diverse applications. Extensive studies on these properties facilitate the effective utilization of carbonates in various industrial and environmental processes.carbonates across different industries.

In conclusion, this comprehensive study highlights the importance of calcium and magnesium carbonates in various fields, reflecting the ongoing need for research and development to maximize the economic and environmental benefits of these essential minerals

Chapter III

Treatment Experimental Part

Introduction

In this chapter, we will focus on studying carbonates and exploring methods for their treatment. Carbonates are essential components in various industrial and environmental contexts, including compounds such as calcium carbonate and magnesium carbonate, which are abundant in nature and present in a wide range of materials and products.

The study will involve analyzing the properties of these carbonates, such as their density, hardness, and percentage compositions in the formations we are investigating. Additionally, we will explore effective methods for treating these carbonates, whether for use in manufacturing or for environmentally friendly and economically viable disposal.

The aim of this research is to deepen our understanding of carbonate properties and to develop innovative solutions for managing them and enhancing their industrial and environmental applications.

1. Caractérisation et analyses possibles

Table 4: Rejections chemical analysis results

Concentration	P□O	CaO	MgO	SiO	ALO.	FeO,	S	F	CO
(%)	20.70%	42.70%	5.30%	1.95%	0.46%	0.41%	0.88%	2.22%	20.90%

By focusing on the concentrations of **CaO** and **MgO** in the chemical analysis results of the rejections, we can conclude the following:

- The concentration of **CaO** is 42.70%.
- The concentration of **MgO** is 5.30%.**[13]**

Analysis:

- **CaO Percentage**:
    - **CaO** constitutes a significant portion of the chemical composition of the rejections, with a concentration of 42.70%. This indicates that calcium oxide is the primary component in the rejections and can significantly influence their properties and the methods of handling them.
- **MgO Percentage**:
    - **MgO** has a considerably lower concentration of 5.30%. Although this percentage is not negligible, it is much less significant compared to the concentration of **CaO**.

Conclusions:

- **Focus on CaO**:
    - Given that **CaO** forms a major part of the chemical composition of the rejections, focusing on its study and analysis can yield more effective and meaningful results.
    - Research and practical efforts can be directed towards improving or modifying the properties of the rejections based on the high calcium oxide content.
- **Minimize Focus on MgO**:
    - Although **MgO** has a relatively moderate concentration, its impact is significantly less compared to **CaO**.
    - Therefore, it is more practical to minimize the focus on studying **MgO** and instead concentrate more on **CaO** to achieve more valuable outcomes

Table 5: Properties of the principal constituents

Composition	Density (g/cm³)	Hardness	Tenor (%)
Ca□(PO□)□	3-3.5	5	26.00
CaCO□	2.72	3-2.5	48.05
MgCO□	3-3.2	3.5-4.5	0.50
Al□O□	2.5	Flaky	0.80
Fe□O□	5.26	5-6	0.70
CaSO□	2.32	2	-
Na, Ca (SO□)□	2.80	2.5-3	-

Analysis:

- **CaCO□ (Calcium Carbonate)**:
    - Density: 2.72 g/cm³
    - Hardness: 3-2.5
    - Tenor: 48.05%
- **MgCO□ (Magnesium Carbonate)**:
    - Density: 3-3.2 g/cm³
    - Hardness: 3.5-4.5
    - Tenor: 0.50%

Conclusions:

- **High Tenor of CaCO□:**
    - **CaCO□** has a high tenor of 48.05%, indicating that calcium carbonate is a major constituent in the composition. This high concentration makes it a significant component to study.
- **Low Tenor of MgCO□:**
    - **MgCO□** has a very low tenor of 0.50%, which is considerably less significant in comparison to **CaCO□**. This low concentration suggests that magnesium carbonate does not play a major role in the overall composition. **[13]**

Focus on CaO:

Given the high concentration of **CaCO□** (48.05%), which translates to a high concentration of **CaO** (calcium oxide) in the rejections, it is evident that the study should focus on **CaO**. The **MgO** (magnesium oxide) content is relatively insignificant due to its low tenor of 0.50%, making it less impactful and less worthy of focused study.

Given these conclusions, our future studies and analyses will concentrate on CaO to develop effective strategies for handling and improving the properties of the rejections. **[13]**

2. Calcium Carbonate Solubility

The solubility of calcium carbonate (CaCO□) refers to the maximum amount of CaCO□ that can dissolve in a given volume of solvent under specific conditions, usually expressed in terms of grams of CaCO□ per liter of solution. The solubility of CaCO□ is influenced by several factors, including temperature, pH, and the presence of other ions. **[14]**

2.1. Temperature:

When temperature rises, the solubility of calcium carbonate (CaCO□) increases. This is because higher temperatures provide more energy for the dissociation of ions, leading to a greater concentration of calcium ions (Ca^{2+}) and carbonate ions (CO_3^{2-}) in solution. The dissolution process of $CaCO_3$ is endothermic, meaning it absorbs heat from its surroundings, and higher temperatures enhance this process.

Supporting Studies: Research, such as those from RSC Publishing, have demonstrated this relationship through experiments where they observed an increase in $CaCO_3$ solubility as temperature increased. These studies provide empirical evidence for the influence of temperature on $CaCO_3$ solubility. **[14]**

2.2. pH:

The pH of a solution significantly affects the solubility of CaCO□. In alkaline conditions (higher pH), the solubility decreases because the increased concentration of hydroxide ions (OH^-) reacts with calcium ions to form insoluble calcium hydroxide ($Ca(OH)_2$). Conversely, in acidic conditions (lower pH), the solubility increases because the decreased concentration of hydroxide ions allows more calcium ions to remain in solution. Acidic conditions also promote the dissolution of $CaCO_3$ by increasing the concentration of hydrogen ions (H^+), which react with carbonate ions to form bicarbonate (HCO_3^-), thus preventing the formation of solid $CaCO_3$.

Supporting Studies: Research from RSC Publishing and Oxford University Press corroborates these observations, demonstrating how pH variations affect $CaCO_3$ solubility. These studies provide insights into the mechanisms behind pH-mediated changes in $CaCO_3$ solubility.

Presence of Other Ions:

The presence of other ions in a solution can either increase or decrease the solubility of $CaCO_3$. For instance, magnesium ions (Mg^{2+}) can enhance solubility by forming soluble complexes with carbonate ions, such as magnesium carbonate ($MgCO_3$). These complexes are more soluble than pure $CaCO_3$, leading to an increased concentration of calcium and carbonate ions in solution.

Supporting Studies: Studies from MDPI highlight the complexity of ion interactions and their influence on $CaCO_3$ solubility. By examining various ions' effects in natural water systems, these studies contribute to a better understanding of the factors affecting $CaCO_3$ solubility in real-world scenarios. **[14]**

Experimental Procedure to Study the Solubility of Calcium Carbonate ($CaCO_3$)

To study the solubility of calcium carbonate ($CaCO_3$) under different conditions such as temperature, pH, and the presence of other ions, a systematic experimental approach can be followed. Here's a step-by-step guide to conducting such an experiment:

- ✓ Materials Needed:
- ✓ Pure calcium carbonate ($CaCO_3$) powder
- ✓ Distilled water
- ✓ Hydrochloric acid (HCl) and sodium hydroxide (NaOH) for pH adjustments
- ✓ Magnesium chloride ($MgCl_2$) or other ionic salts
- ✓ Thermometer
- ✓ pH meter or pH indicator strips
- ✓ Analytical balance
- ✓ Magnetic stirrer with heating plate
- ✓ Filtration apparatus (filter paper and funnel)
- ✓ Volumetric flasks and beakers

- ✓ Pipettes and burettes

2.3. Procedure:

a. Preparation of Saturated $CaCO_3$ Solution:

- ✓ Add a known excess amount of $CaCO_3$ powder to a beaker containing distilled water.
- ✓ Stir the mixture using a magnetic stirrer to ensure continuous mixing and allow it to reach equilibrium. This might take several hours or overnight.

b. Temperature Variation:

- ✓ Prepare a series of beakers with the $CaCO_3$ saturated solution.
- ✓ Place each beaker on a heating plate set to different temperatures (e.g., 10°C, 25°C, 40°C, 60°C).
- ✓ Measure the temperature of each solution using a thermometer.
- ✓ Allow the solutions to reach the desired temperatures and maintain them for a sufficient time to ensure equilibrium.

c. pH Variation:

- ✓ Adjust the pH of the $CaCO_3$ saturated solutions using HCl to lower the pH and NaOH to raise the pH.
- ✓ Use a pH meter to accurately measure and adjust the pH of each solution to desired values (e.g., pH 4, pH 7, pH 10).
- ✓ Ensure the solutions are well-mixed after each addition of HCl or NaOH.

d. Presence of Other Ions:

- ✓ Add known concentrations of other ionic salts (e.g., $MgCl_2$) to separate beakers containing the $CaCO_3$ saturated solution.
- ✓ Stir the mixtures to dissolve the added salts and reach equilibrium.

e. Filtration:

Once equilibrium is reached in each beaker, filter the solutions to remove any undissolved $CaCO_3$.

Collect the filtrates in clean volumetric flasks.

f. Quantitative Analysis:

- ✓ Use an analytical balance to weigh the filtered $CaCO_3$.
- ✓ Measure the concentration of calcium ions (Ca^{2+}) in each filtrate using titration with a standard EDTA solution or an atomic absorption spectrophotometer (AAS). **[14]**

By following this procedure, you can systematically study the solubility of calcium carbonate under various conditions and gain a deeper understanding of the factors affecting its dissolution.

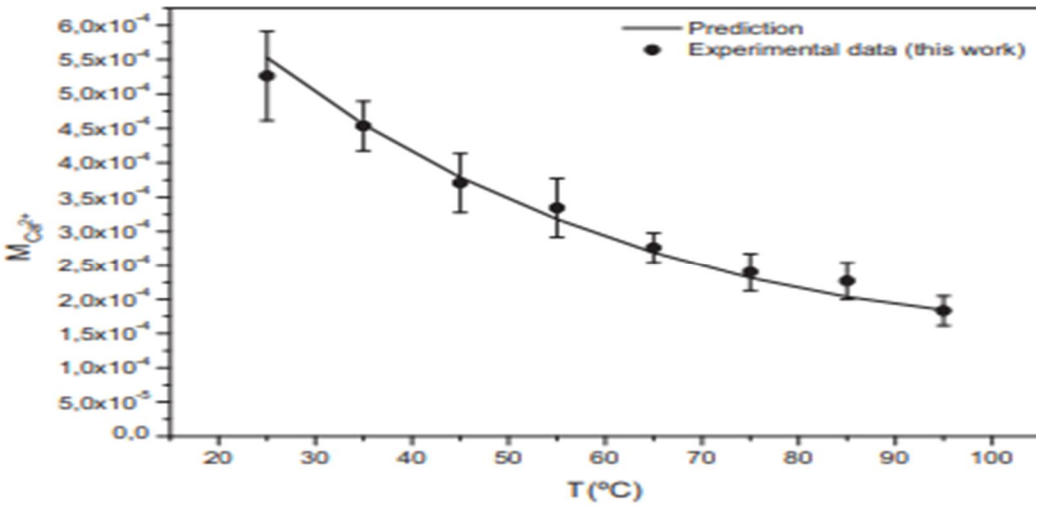


Figure 14:influence of the temperature on the CaCO□.sotubility

2.3. Analysis:

a. Temperature Effect:

As the temperature increases from 20°C to 100°C, the solubility of CaCO□ decreases from approximately $5.8x10^{-4}$ M to about $1.8x10^{-4}$ M.

This inverse relationship indicates that $CaCO_3$ becomes less soluble in water at higher temperatures, which aligns with the principles of thermodynamics. As temperature increases, the dissolution reaction, which is endothermic, becomes less favorable.

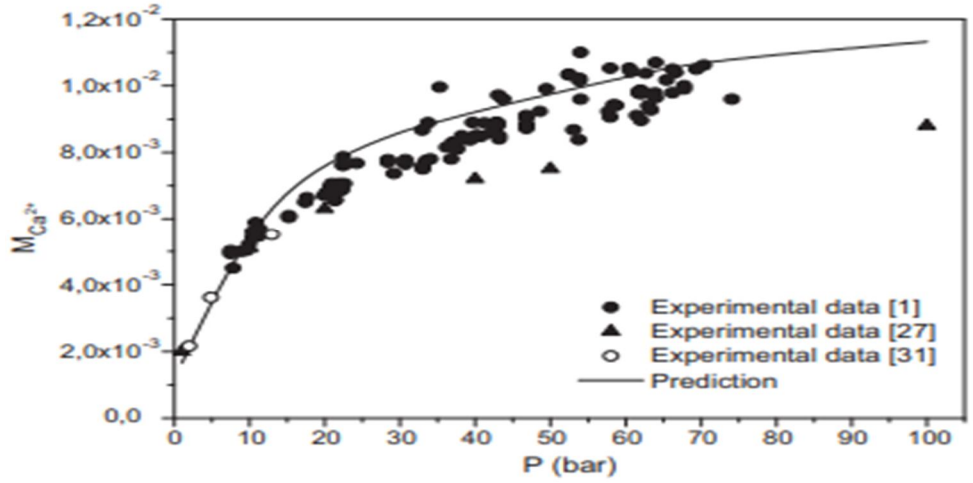


Figure 15:influence of the temperature on the $CaCO_3$ .sotubility T=100°C

b. Observations:

The solubility of $CaCO_3$ increases with increasing pressure.The experimental data from different sources generally agree with each other and the prediction, although there is some scatter.The prediction line fits well with the overall trend of the experimental data. **[15]**

Table 6: The solubility of CaCO□ increases

Experiment	T(°C)	P(bar)	C_{NaC}(mol dm^{-1})	pH	$C_{Ca+2}{}^{b}x10^{4}$(mol dm^{-1})
1	25	1	0.0	8.31	5.26±0.65
2	35	1	0.0	8.34	4.53±0.36
3	45	1	0.0	8.31	3.7±0.43
4	55	1	0.0	8.34	3.34±0.43
5	65	1	0.0	8.35	2.75±0.22
6	75	1	0.0	8.33	2.39±0.27
7	85	1	0.0	8.35	2.27±0.27
8	95	1	0.0	8.34	1.83±0.22
9	25	1	0.6	9.34	9.23±0.37
10	25	1	1.2	9.41	11.01±0.07
11	25	1	1.8	9.67	10.70±0.30
12	25	1	2.4	9.95	10.10±0.46
13	95	1	0.6	8.43	7.92±0.40
14	95	1	1.2	8.54	9.11±0.56
15	95	1	1.8	8.80	8.16±0.33
16	95	1	2.4	9.00	7.40±0.15

Solubility of CaCO□ decreases as temperature increases from 25°C to 95°C.

Conclusion: Higher temperatures reduce CaCO□ solubility due to the endothermic nature of its dissolution.

c. Effect of NaCl Concentration:

The effect of sodium chloride (NaCl) on the solubility of carbonate ores depends primarily on its concentration and the temperature of the system. Here's an explanation based on the information provided:

- At 25°C:

Observations: Solubility of carbonate ores increases with higher NaCl concentration.

Conclusion: The increased ionic strength from NaCl enhances the solubility of carbonate ores. Higher ionic strength facilitates greater electrical potential in the solution, aiding dissolution reactions.

- At 95°C:

Observations: Solubility of carbonate ores also increases with NaCl, but to a lesser extent compared to 25°C.

Conclusion: At higher temperatures, the effects of ionic strength oln solubility are somewhat diminished. This could be due to changes in the solubility equilibrium and thermal effects on chemical reactions.

In general, NaCl can increase the solubility of carbonate ores due to increased ionic strength in aqueous solutions, with the magnitude of this effect varying with temperature. **[13]**

d. Effect of pH:

Observations: Higher pH generally reduces CaCO□ solubility, though this was not varied within the same conditions.

Conclusion: Increased hydroxide ions at higher pH form insoluble calcium hydroxide.

Experimental studies involve systematically measuring CaCO□ solubility under controlled conditions to understand how temperature, pH, and the presence of other ions affect it. By varying these factors and observing the resulting changes in solubility, researchers can quantify their respective impacts.

Experimental studies provide empirical evidence for the relationships between different factors and CaCO□ solubility. They offer concrete data that validate theoretical models and contribute to a more comprehensive understanding of CaCO□ dissolution behavior.

Models are developed based on experimental data to predict CaCO□ solubility under various conditions. These models consider factors such as temperature, pH, and the presence of other ions to simulate CaCO□ solubility accurately. By incorporating known relationships and mathematical formulations, these models can forecast solubility trends and outcomes.

Conclusion: The solubility of calcium carbonate (CaCO□) is a complex phenomenon influenced by temperature, pH, and the presence of other ions. Understanding these factors is crucial for various applications, including environmental science and industrial processes, where CaCO□ solubility plays a significant role.

By comprehensively examining the factors affecting CaCO□ solubility and developing predictive models, researchers can optimize processes, mitigate environmental impacts, and improve overall efficiency in relevant industries.

This detailed explanation provides a thorough understanding of the factors influencing CaCO□ solubility, their underlying mechanisms, and the significance of experimental studies and predictive models in this context. **[15]**

Concentration of Calcium Carbonate (CaCO□) Solutions

To concentrate calcium carbonate (CaCO□) after dissolving it in a solution, follow these steps:

1. Determine Solubility and Concentration:
    - Purpose: Measure the concentration of Ca^{2+} ions in the solution.
    - Method: Use titration with a standard EDTA solution or Atomic Absorption Spectroscopy (AAS) to accurately determine the calcium ion concentration.
    - Expected Outcome: Obtain the precise concentration of Ca^{2+} ions in the solution.
2. Final Concentration:
    - Purpose: Concentrate the solution to obtain pure calcium carbonate.
    - Method: Gently heat the solution and allow gradual evaporation until only carbonates remain.
    - Expected Outcome: Achieve the final concentration of calcium carbonate.
3. Evaporation and Drying:
    - Purpose: Evaporate the solution to obtain pure calcium carbonate.
    - Method: Use a water bath to slowly evaporate water without unwanted reactions affecting the carbonates.
    - Expected Outcome: Evaporate the solution to concentrate the carbonates.
4. Collecting Carbonates:
    - Purpose: Collect the precipitated carbonates in powder form.
    - Method: Use a filtration tool to separate the precipitated carbonates from the solution.
    - Expected Outcome: Obtain the concentrated carbonates in powder form.
5. Storage:
    - Purpose: Store the concentrated carbonates to prevent contamination or loss.
    - Method: Store the carbonates in a tightly sealed container to protect from moisture in the air.
    - Expected Outcome: Maintain the purity and concentration of the carbonates.
6. Final Analysis:
    - Purpose: Verify purity and concentration of the dried carbonates.
    - Method: Use analytical techniques such as infrared spectroscopy.
    - Expected Outcome: Ensure high-quality, concentrated calcium carbonate.

By following these steps, you can effectively concentrate calcium carbonate after dissolution, ensuring a high-purity and high-quality product. **[16]**

Conclusion

The solubility of calcium carbonate ($CaCO_3$) is a complex phenomenon influenced by several key factors, including temperature, pH, and the presence of other ions.

Temperature: The solubility of $CaCO_3$ increases with rising temperature because the dissolution process is endothermic, absorbing heat and increasing the concentration of dissolved ions.

pH: $CaCO_3$ solubility increases under acidic conditions due to the formation of bicarbonates and decreases under alkaline conditions due to the formation of insoluble calcium hydroxide.

Presence of Other Ions: Certain ions, such as magnesium, can enhance the solubility of $CaCO_3$ by forming more soluble complexes with carbonate ions. **[15]**

Experimental Studies and Predictive Models: Experimental studies provide critical data that help develop predictive models for $CaCO_3$ solubility under various conditions. These models are essential for optimizing industrial processes and mitigating environmental impacts.

Overall, understanding the factors affecting the solubility of calcium carbonate is crucial for improving efficiency in industrial applications and protecting the environment**[15]**

3. Reverse flotation

Reverse flotation is a method for separating carbonates from phosphates in phosphate ores with a carbonate gangue. It involves several steps: **[17]**

- ✓ **Conditioning**: The ore is conditioned with a phosphate depressant, such as sodium fluosilicate, fluosilicic acid, phosphoric acid, or sulfuric acid. This reduces the floatability of phosphates and promotes the flotation of carbonates.
- ✓ **Reverse Flotation**: The conditioned ore is treated with a collector, mainly consisting of a phosphoric ester, such as phosphoric esters, polyoxyalkylated phosphoric esters, or polyoxyethylated phosphoric esters. This allows for the selective flotation of carbonates.
- ✓ **Separation of Silicates**: If the starting ore also contains silicates, the flotation residue containing phosphates is conditioned with a cationic collector, such as primary amines or their salts (primary amine acetates). This enables the separation of silicates by flotation.

Reverse flotation in an acidic medium is the method that appears to provide the best separation contrast between the gangue carbonates (calcite, dolomite) and the phosphate apatite. It allows for high-yield recovery of a residue containing phosphate compounds, efficiently removing the carbonates by flotation. **[17]**

3.1. Reverse Flotation Process for Separating Calcium Carbonate from Phosphate Ore

To separate calcium carbonate from phosphate ore by reverse flotation, the following specific steps can be applied:

a. **Pretreatment**: The ore is pretreated to enhance the selectivity of the flotation. This may include surface preparation methods such as desliming, degreasing, and demineralization to reduce particle size and improve mineral reactivity.

b. **Reverse Flotation**: Reverse flotation is used to separate carbonates from the phosphate ore. Specific reagents such as phosphate depressants and carbonate collectors are added to promote the flotation of carbonates. The pH is adjusted to maximize the selectivity of the separation.

c. **Direct Flotation**: Direct flotation is used to separate phosphates from the phosphate ore. Specific reagents such as anionic collectors and carbonate depressants are added to promote the flotation of phosphates.

d. **Conditioning**: Conditioning the ore with micro-emulsions can be used to improve the selectivity of the separation. This helps to modify the surface of the minerals and facilitate flotation.

e. **Dilution**: Dilution of the ore with water can be used to enhance the selectivity of the separation. This helps to reduce the concentration of impurities and improve phosphate recovery.

f. **Product Analysis**: The flotation products are analyzed to determine the content of phosphates and carbonates. This allows for verification of the separation efficiency and adjustment of flotation parameters if necessary.

In summary, separating calcium carbonate from phosphate ore requires a combination of pretreatment, reverse flotation, direct flotation, conditioning, dilution, and product analysis to improve the selectivity of the separation and the recovery of phosphates. **[17]**

3.2. Effective Reagents for Reverse Flotation of Carbonates in Phosphate Ore

The most effective reagents for reverse flotation of carbonates in phosphate ore are:

a. Oleic acid: Used in the study conducted by the University of Bejaia to separate carbonates from phosphates in Djebel Onk phosphate ore.

b. Aero-promoter 710: Utilized in the study by the University of Bejaia for separating carbonates from phosphates in Djebel Onk phosphate ore.

c. Pine oil: Employed in the study by the University of Bejaia for separating carbonates from phosphates in Djebel Onk phosphate ore.

d. Double sodium and potassium tartrate: Utilized in the study by the University of Bejaia for separating carbonates from phosphates in Djebel Onk phosphate ore.

e. Phosphoric esters: Used in patent FR 2489715A1 for separating carbonates from phosphates in carbonate gangue phosphate ores.

f. Polyoxyethylene phosphoric esters: Employed in patent FR 2489715A1 for separating carbonates from phosphates in carbonate gangue phosphate ores.

g. Commercial products: Utilized in patent FR 2489715A1, such as HOE F 1415 and HOE F 2711 from Hoechst Company, BEYCOSTAT LP4A and LP9A-NA-DA from GERLAND Company, for separating carbonates from phosphates in carbonate gangue phosphate ores. **[17]**

These reagents are used to depress phosphates and float carbonates, facilitating effective separation of these minerals in phosphate ore

3.3. Experimental Protocol:

Introduction:

Through the review of articles on the separation of calcium carbonate from phosphate ore using the reverse flotation process, it becomes evident that achieving optimal separation and recovery results depends on following precise experimental protocols. These protocols include essential steps such as sample preparation, attrition tests, and the use of various flotation reagents. [18]

Sample Preparation:

The process begins with sample preparation through several stages, including:

- **Crushing**: To break down the ore into smaller particles.
- **Homogenization**: To ensure a uniform distribution of particles.
- **Sieving**: To separate particles according to their size.

These steps ensure that representative samples reflecting the actual properties of the ore are obtained. [18]

Attrition Tests:

Articles indicate that attrition tests are conducted under optimal conditions, which include:

- **30% solids concentration**: To achieve an appropriate pulp density.
- **Agitation speed of 1100 rpm**: To provide sufficient energy for removing coatings.
- **Conditioning time of 5 minutes**: To ensure adequate interaction of reagents with particles. [18]

These tests effectively remove clayey and siliceous coatings from phosphate grains and reduce MgO content in dolomite particles. [18]

Flotation Reagents:

Articles review the use of four main flotation reagents (R1, R2, R3, and R4), each with a specific composition:

- **R1**: Oleic acid, phosphoric acid, ethanol, and sodium hydroxide.(2500 1000 800 2000/T)
- **R2**: Oleic acid, aluminum sulfate, sodium potassium tartrate, ethanol, and sodium hydroxide. .(2500 500 1200 800 2000/T)
- **R3**: Oleic acid, diesel fuel, ethanol, and sodium hydroxide. (2500 500 800 2000/T)
- **R4**: Oleic acid, pine oil, ethanol, and sodium hydroxide. (2500 1000 800 2000/T) [18]

Results of Using Flotation Reagents:

- **Reagent R4** demonstrated the highest efficiency, achieving a recovery rate of 79.84%.
- **Reagent R2** ranked second with a recovery rate of 75.21%.
- **Reagent R3** achieved a recovery rate of 72.51%.
- **Reagent R1** showed the lowest efficiency with a recovery rate of 70.75%.

These results confirm that selecting the appropriate reagent significantly affects the efficiency of the separation process. The presence of dolomitic and siliceous materials in the fine fraction (-250+40 μm) may influence the performance of flotation reagents. [18]

Analysis of Results:

Articles highlight the importance of choosing suitable reagents based on the specific characteristics of the phosphate ore. Reagent R4 proved to be the most effective, emphasizing its role in achieving the best separation results. [18]

Recommendations:

Articles suggest that future research could focus on:

- Improving the formulations of flotation reagents.
- Exploring additional conditioning techniques to enhance overall efficiency.
- Reducing the cost of the flotation process. [18]

Conclusion:

In conclusion, articles confirm the effectiveness of the reverse flotation process in separating carbonates from phosphate ore, with the best results achieved using reagent R4. These findings underscore the critical role of reagent selection and process optimization in enhancing the recovery and purity of phosphate concentrates, paving the way for further research to improve the process even more. [18]

Re-concentrating Carbonates after Reverse Flotation

To re-concentrate carbonates after the reverse flotation process, several sequential steps can be employed to improve carbonate purity and separate remaining impurities. These steps include:

Washing:

Purpose: Remove residual chemicals and fine suspended impurities.

Method: Use clean water to wash the floated products from the reverse flotation process.

Expected Outcome: Reduce the content of undesirable materials in the carbonates.

Settling:

Purpose: Separate heavier carbonates from lighter materials.

Method: Allow the heavier particles to settle at the bottom of a tank while lighter materials are drained off from the top.

Expected Outcome: Obtain a more purified carbonate concentrate.

Re-flotation:

Purpose: Further increase the purity of the carbonates.

Method: Use conventional flotation with the addition of new chemical collectors, such as improved carbonate collectors (e.g., fatty acids or alkyl salts).

Expected Outcome: Enhance the purity of carbonates by re-floating to remove any remaining impurities.

Drying:

Purpose: Remove excess water from the concentrated carbonates.

Method: Use thermal dryers or natural air drying.

Expected Outcome: Obtain dry, concentrated carbonates ready for use or further processing.

Analysis and Quality Control:

Purpose: Ensure the final carbonate concentrate meets the required standards.

Method: Conduct chemical and physical tests on the concentrated sample to determine carbonate purity.

Expected Outcome: Ensure high-quality carbonates that meet specified standards.

Storage and Packaging:

Purpose: Properly store the concentrated carbonates to maintain their quality.

Method: Use sealed containers to keep the product pure and protect it from contamination and moisture.

Expected Outcome: Provide high-quality concentrated carbonate products ready for shipment and use in various applications.

By following these integrated steps, carbonates can be effectively re-concentrated after the reverse flotation process, ensuring a high-purity, high-quality product. [19]

3.4. Conclusion:

Overall, the comprehensive exploration of calcium carbonate (CaCO□) solubility underscores its complex nature influenced by temperature, pH, and the presence of other ions. Temperature variations demonstrate an inverse relationship, where higher temperatures reduce solubility due to the endothermic dissolution process. pH shifts impact solubility significantly, with higher pH promoting insoluble calcium hydroxide formation and lower pH enhancing CaCO□ dissolution through bicarbonate formation. Additionally, the presence of ions like magnesium can modify solubility by forming soluble complexes.

Experimental studies from sources such as RSC Publishing, Oxford University Press, and MDPI provide empirical evidence validating theoretical models and offer insights into optimizing industrial processes and environmental management practices related to calcium carbonate. These studies enhance our understanding and application of CaCO□ solubility under diverse conditions.

In parallel, studies and tests on phosphate ores highlight reverse flotation as an effective method for separating carbonates from phosphate ores containing carbonate gangue. This process involves critical steps from conditioning with phosphate depressants to using specific collectors for flotation, potentially including silicate separation if present in the ore. By employing appropriate reagents like phosphoric acids and phosphate derivatives, efficient separation between phosphates and carbonates can be achieved with high recovery rates. Experimental protocols for pulp preparation, flotation testing, and product analysis underscore key factors for optimizing separation efficiency.

In conclusion, both areas of study contribute significantly to advancing our knowledge and practical applications in mineral processing and environmental science, emphasizing the ongoing importance of research in refining techniques for managing calcium carbonate and optimizing phosphate ore

GENERAL CONCLUSION

General Conclusion

In summary, this exploration has delved into three key areas of mineral study and industrial application: Algerian phosphate mining, carbonate minerals, and calcium carbonate ($CaCO_3$) solubility. Algerian phosphate resources, particularly those in the Djebel Onk Sud region, stand as pivotal components of Algeria's mining sector, contributing significantly to its economy through extensive processing methods and industrial applications.

Carbonate minerals, encompassing calcium and magnesium carbonates, play indispensable roles across various industries due to their unique properties and widespread applications. From construction to pharmaceuticals, these minerals are integral to numerous industrial processes, highlighting their economic importance and the ongoing need for research and development.

Meanwhile, the study of $CaCO_3$ solubility underscores its complex behavior influenced by temperature, pH variations, and the presence of different ions. This understanding is crucial for optimizing industrial processes and environmental management practices related to calcium carbonate, facilitating its efficient use in diverse applications.

Furthermore, research on phosphate ores has emphasized reverse flotation as an effective technique for separating carbonates from phosphate minerals, enhancing recovery rates and refining beneficiation processes. This methodological approach, supported by empirical studies and experimental protocols, underscores the critical role of tailored reagents and precise conditions in achieving optimal separation efficiencies.

In conclusion, these integrated studies contribute significantly to advancing our knowledge and practical applications in mineral processing and environmental science. They underscore the importance of ongoing research in refining techniques for managing calcium carbonate and optimizing phosphate ore beneficiation, thereby ensuring sustainable resource utilization and industrial development.

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