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Economic impact of derangements on mining process – Case study: Sidi Chennane

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Abstract

In Sidi Chennane, Central Morocco, the cost of phosphate mining is often influenced by problems bound to the existence of sterile bodies called derangements. These bodies consisting of a waste rocky material affect the sedimentary phosphate series, and thus disturb the phosphate extraction process. In this work, we attempt to analyze and quantify the economic impact of these sterile bodies on the cost of phosphate mining in Sidi Chennane. The work is carried out through a prototype model prepared as a real mining trench, using data collected during our internships in the Sidi Chennane mining field. The results of this work show that the cost of removing derangements increases the cost of phosphate mining for the entire cycle of production, drilling, blasting, ripping, dozing, loading, and hauling. It is concluded, therefore, that the outcomes of this work are of great importance for obtaining an accurate understanding of phosphate mining when confronted derangements. This can be adapted to analyze and interpret such similar structures in phosphate mines around the world (e.g. Taïba phosphate mine in Senegal).

1. Introduction

The derangements of Sidi Chennane or sterile bodies can be defined as a waste material included within the sedimentary phosphate series, and disturb its regularity (Figure 1). These bodies are one of the common challenges for mining engineers and managers of the l'Office Chérifien des Phosphates (OCP). They are generally hard and compact, conical or sub-circular, varying in diameter from 10 m to more than 150 m, and composed of silicified limestone or limestone blocks within an argillaceous matrix [1]. The derangements are under a Quaternary cover (topsoil) without any privileged order, and cannot be directly mapped from the surface using the direct exploration methods. In many cases, their detection and delimitation require mechanical drilling, which increase the cost of phosphate mining [2, 3]. In this context, different studies were performed to evaluate and quantify these sterile bodies using various methods and techniques [4] [5] [6].

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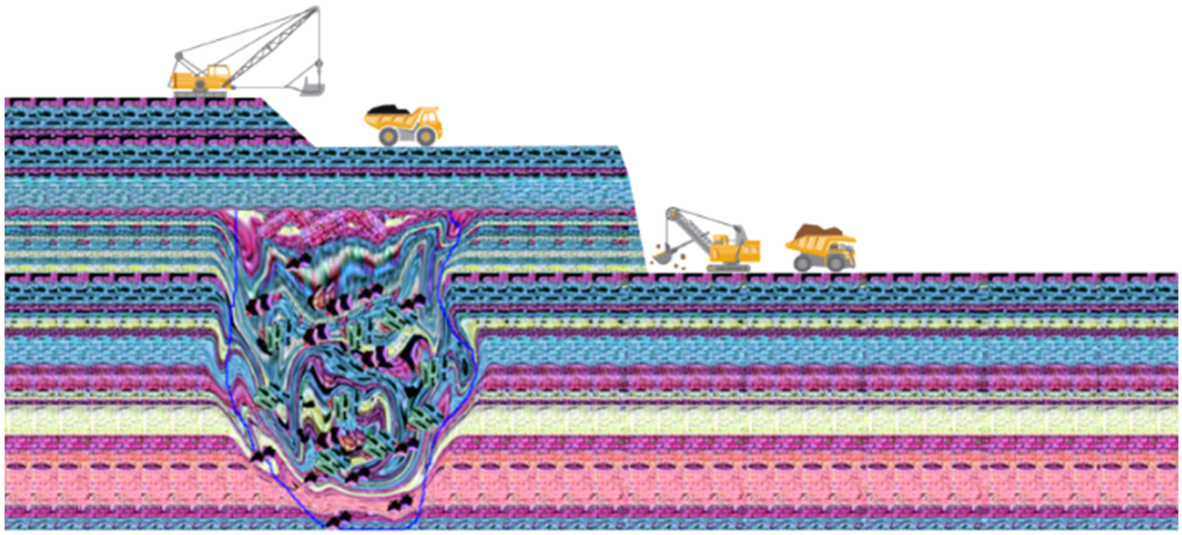

Figure 1. Illustrations of a derangement included within the phosphate series.

The geological and geo-physical research carried out in Sidi Chennane have shown that the origin of the derangements is linked to the progressive downfall of the underground cavities formed by the dissolution of the Senonian gypsiferous layers situated at the base of the phosphate series; other studies reveal that the origin of these bodies may be supergene, even pedological [7].

The presence of the derangements causes two kinds of problems: (1) from the economical side, as they are masked by the Quaternary cover, it is not easy to determine exactly their part in the overall volume of the deposit, which gives a bad reserve estimation; (2) from a technical side, it is necessary to constrict the drilling pattern by adding supplementary holes in order to delineate the boundaries of the derangement. Furthermore, as they are generally hard and compact, it is necessary to increase the quantity of explosives required to fill the boreholes during the blasting stage. Sometimes they remain indestructible after blasting, and they cause many mobility problems for vehicles.

For all these reasons, the OCP engineers took this problem very seriously, providing effective responses. Various exploration methods such as prospect drilling and/or geo-physical surveys were used to delineate the deranged areas [8], which will optimize the mining operations and minimize these economic and impacts.

In this work, we attempt to evaluate the cost of phosphate mining in Sidi Chennane deposit both with and without the presence of derangement. The work was performed through a prototype model prepared as a real mining trench, using the data collected from the Sidi Chennane mining field such as the thickness of the phosphate layers and interlayers, and the size of the derangements. This study has been applied to the entire cycle of production including drilling, blasting, ripping, dozing, loading, and hauling.

1.1. Studied area - Sidi Chennane

Sidi Chennane is the main and the largest phosphate deposits exist in Ouled Abdoun basin, Central Morocco. It is located in the Beni Mellal-Khenifra region, about 35 km SE of Khouribga city, and approximately 206 km to the SE of the capital Rabat. This sedimentary phosphate deposit covers a total area of over 5000 hectares [9]. It is bounded on the west by meridian 372500 (Lambert), on the South, by meridian 22800 (Lambert), on the East, by the RP 22 road, and to the North, by the outcrops of the basement of the phosphate series (Figure 2).

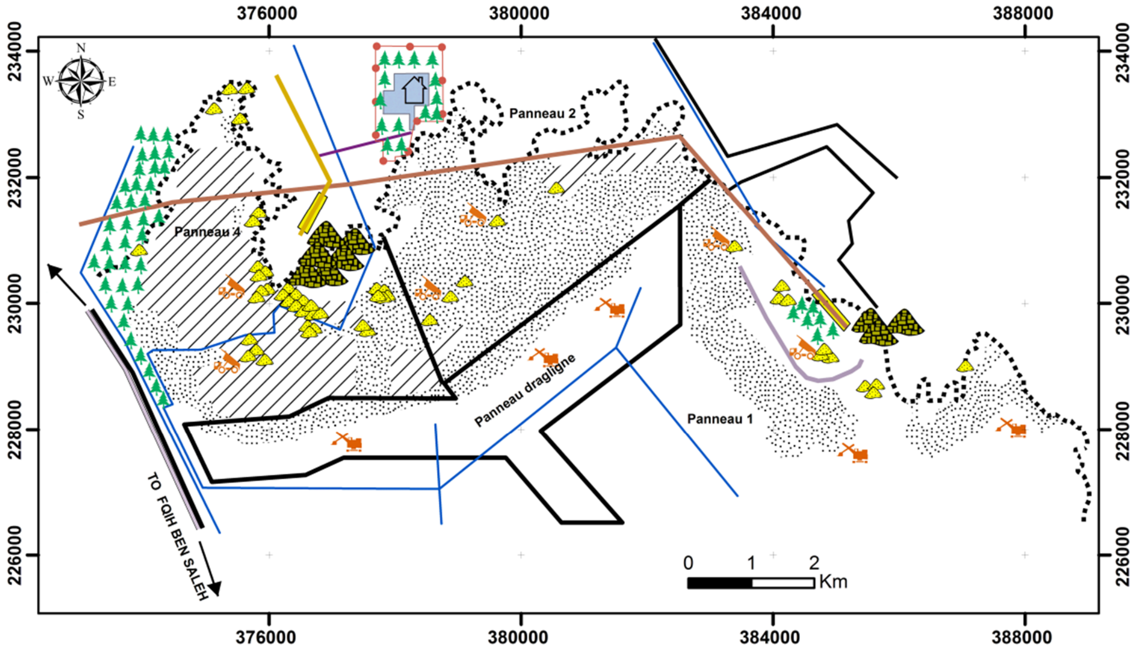

Figure 2. Plan view of Sidi Chennane mine.

The phosphate series of Sidi Chennane resulted from a large transgression, which occurred in the mid-Cretaceous era (Figure 3) [10]. It was deposited as a sequence of high-quality sedimentary phosphate layers with regular interbedded layers of marl and limestone. The whole sedimentary sequence of an average thickness of about 50 m was covered by a thin Quaternary cover [11, 12].

In this deposit, the phosphate is mined in open-pit by the OCP Group since 1921 [13]. This method is considered more efficient than the underground method since the phosphate is located near the surface at 40 m depth [14]. It provides low operating costs, high productivity, and good safety condition. However, the open-pit method is known to generate more waste rock than the underground method, which may present various potential environmental impacts.

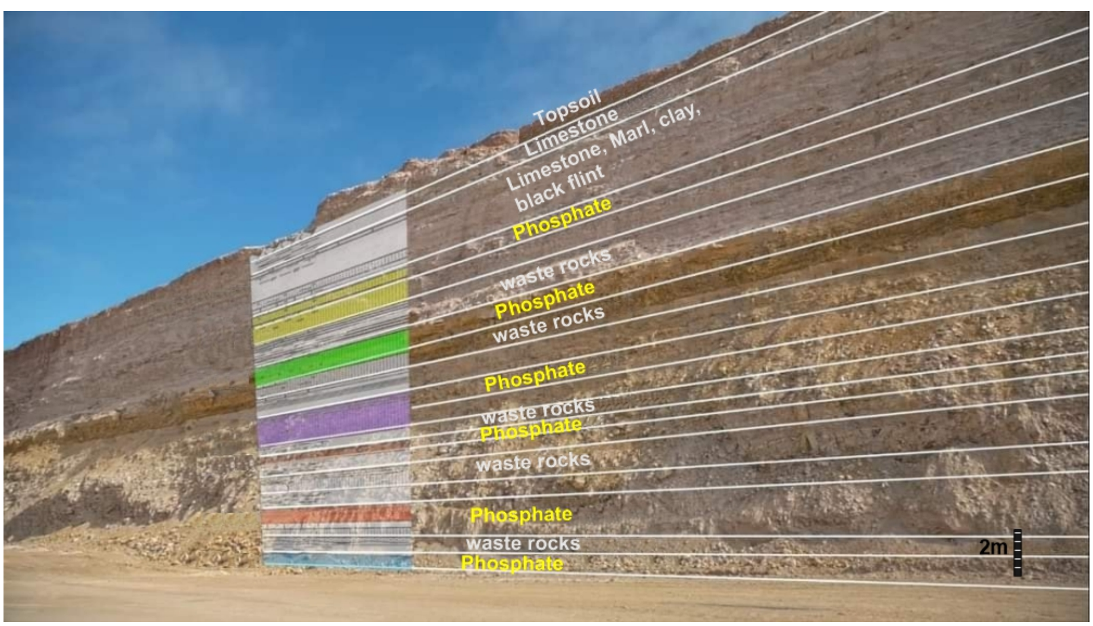

Figure 3. Sidi Chennane phosphate series.

1.2. Phosphate mining process

Phosphate mining is much more than recovering ore from the ground. Phosphate mining is really a sequence of activities including: reconnaissance exploration, phosphate grade and tonnage determination, and the feasibility of mining. It is most complex, with hundreds of workers employed and several million dollars invested [15].

In Sidi Chennane, the phosphate mining consists of cutting the deposit into panels (panneau); the panel is then cut into multiple trenches of 40 m × 1000 m to allow flexibility in the mine planning, and facilitate the extraction of the phosphate. The process involves mining the deposit trench by trench through a production cycle consisting of drilling, blasting, ripping and dozing, loading, and hauling [16], as illustrated below in Figure 4.

Open-pit method is usually non-selective but sometimes the selective method may provide a relatively high-grade mine product. The choice of the mining method is considered one of the most critical mining engineering focus since it is a potential economic parameter for the mining company [17, 18]. In Sidi Chennane, the selective method is the one adopted. This method consists of taking separately the phosphate layers without being salted by the interlayers of marl and limestone to protect the quality of the phosphate [19, 20].

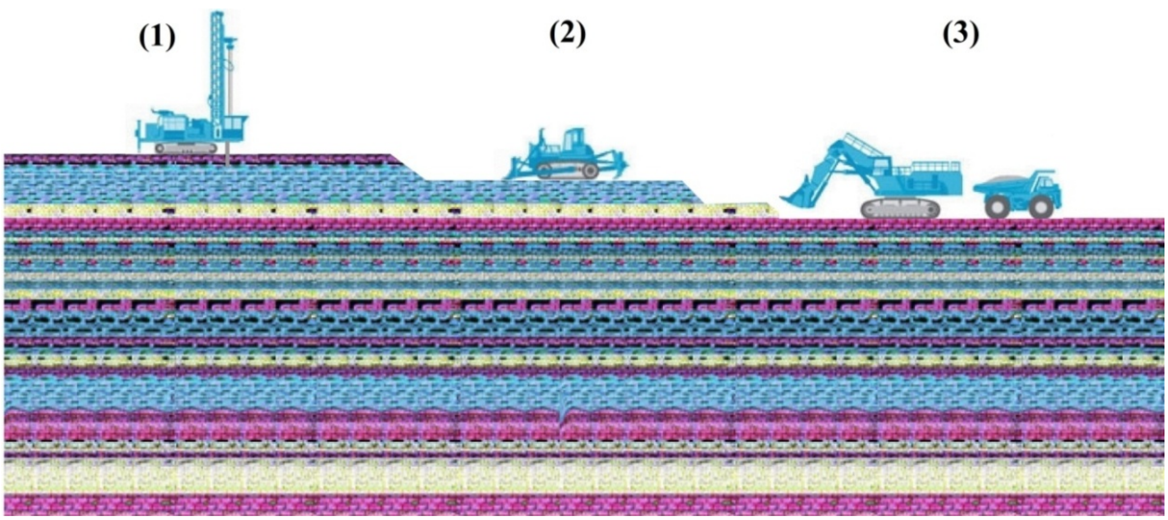

Figure 4. Schematic view of main phosphate mining stags. (1) Drilling and blasting; (2) ripping and dozing; (3) loading and hauling.

The mining operation begins by removing the overburden that covers the phosphate layers. The overburden composed of weathered rocks and topsoil might need drilling at variable grid spacing depending on its thickness and hardness. The boreholes are charged with explosives and blasted in order to break the rock into a loadable part. Then, the blasted rocks will be removed and deposited directly as a waste stream by the huge electric walking dragline M8400, or pushed by the Caterpillar D11 blade to the already pit mined areas to expose the phosphate layers.

The phosphate rock is then removed by loader or shovels, crushed, screened to various size fractions, and transported to the washing plant using a long and straight belt structure, which carries more than 2,000 metric tons of rock per hour.

2. Materials and Methods

In order to pursue the outlined objectives, we started by defining a prototype model of an exploitation trench containing two separate derangements. The work was carried out using the data collected during our internships carried out in the Sidi Chennane mining field.

The prototype model is prepared as a real phosphate trench of 1000 m x 40. It consists of two phosphate layers 3 m thick, separated by siliceous marly and clayey interlayers 2 m thick. The layers are crossed by two sterile bodies of different sizes (Figure 5).

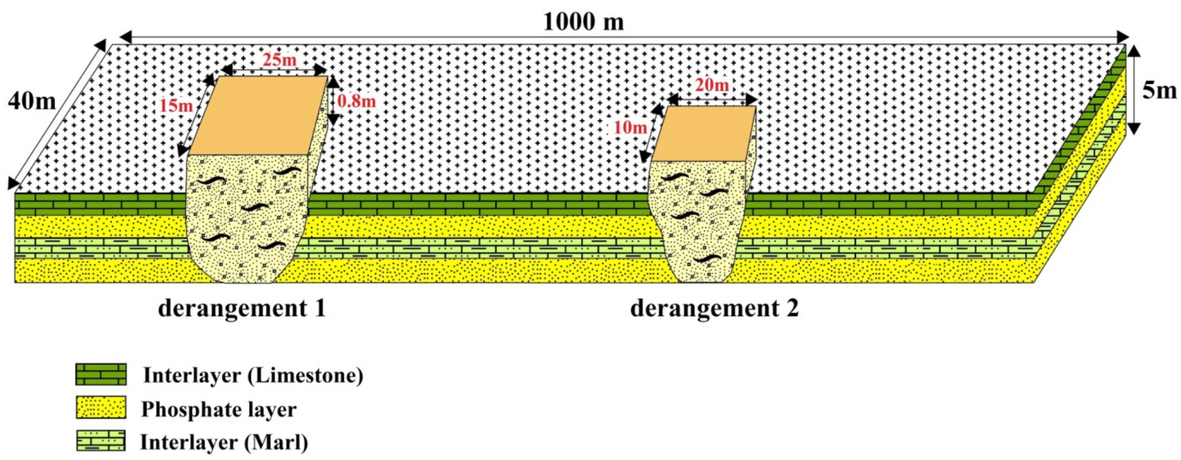

Figure 5. Representation of prototype trench model (1000m x 40).

Once all the prototype model information is compiled, the mining operation costs are categorized into four main groups: (1) drilling cost; (2) blasting cost; (3) ripping and dozing cost; and (4) the cost of loading and hauling [21]. These costs are also classified into two main groups: (a) mining in the presence of derangements; (b) mining in the absence of derangements.

- **Calculation of cost of drilling stage**

The cost of the drilling operation is estimated as follows:

$$\text{Operation cost} = \text{number of holes} \times \text{cost of 1m drilled} \times \text{drilling depth}$$

The number of holes performed can be calculated using the following equation:

$$\text{Number of holes} = \frac{\text{surface}}{\text{drilling pattern}}$$

Faced with the derangements, the drilling pattern is restricted. Therefore, the number of holes increases, and can be calculated using the following equation:

$$\text{Number of holes} = \frac{\text{total surface - surface of derangement}}{\text{drilling pattern 1}} + \frac{\text{surface of derangement}}{\text{drilling pattern 2}}$$

- **Calculation of cost of blasting stage**

The blasting operation cost is determined as follows:

$$\text{Operation cost} = \text{volume of interlayer} \times \text{cost of 1 m}^3 \text{ blasted}$$

First, the volume of the interlayer is calculated through the following equation:

$$\text{Volume of interlayers} = (\text{length} \times \text{width}) \times \text{thickness of interlayers}$$

Faced with derangements, the operation cost is changed, and can be calculated as follows:

$$\text{Operation cost} = \text{deranged volume} + \text{underanged volume}$$

The volume of derangement can be calculated using the equation:

$$\text{Volume of derangement} = (\text{surface of derang } 1 + \text{surface of derang } 2) \times \text{thickness of derang}$$

- **Calculation of cost of ripping and dozing stage**

The ripping and dozing operation cost is defined as follows:

$$\text{Operation cost} = \text{volume of interlayer} \times \text{cost of } 1\text{m}^3 \text{ picked}$$

Face with the derangement, the operation cost is changed, and can be estimated using the following equation:

$$\text{Operation cost} = \text{totale volume } \times \text{cost of } 1\text{m}^3 \text{ picked}$$

The total volume is calculated as follows:

$$\text{Total volume} = \text{deranged volume } \times \text{volume of interlayer}$$

- **Calculation of cost of loading and hauling stage**

The cost of this operation is obtained using the following equation:

$$\text{Operation cost} = \text{volume of phosphate} \times \text{cost of } 1\text{m}^3 \text{ mined}$$

First, the volume of phosphate is calculated as follows:

$$\text{Volume of phosphate} = \text{surface} \times \text{thickness of phosphate layers}$$

Note that because the U.S. dollar is the currency most used in international transactions, the costs have been reported in this work in “US$” by converting the “Moroccan Dirham”. The exchange rate used in this paper is: 1 Moroccan Dirham = 0.1 United States Dollars.

3. Results and Discussion

Considering that the phosphate mining process is divided into four main stages, the effect should be considered at each stage, since each stage has a certain specificity.

At each of the stages mentioned above, the potential impact of derangements could be recognized. It can be linked mainly to the material, to the mining engines, to the method of exploitation used, to variations in the prices of the explosives, to the necessary mining activity services, and so on.

3.1. Stage 1- Drilling operation

- **Drilling in the absence of derangements**

In the absence of derangements, the operation cost is calculated by multiplying the number of holes by the cost of 1m drilled (5 US$) and by the depth (5 m). It should be noted that the drilling pattern used by the engineers of the OCP group is generally regular (7x7 m). First, the number of holes has to be calculated:

$$\text{Number of holes} = \frac{1000 \times 40}{7 \times 7} = 816$$

Operation cost =816 × 5 × 5 = 20 400 US$

- **Drilling in the presence of derangements**

Faced with the derangement, the drilling pattern is completely modified. It is necessary to tighten it by adding supplementary holes. Hence, the drilling pattern 7×7 m has to be reduced to 5×5 m.

The operation cost is obtained by multiplying the number of intact holes by the depth of phosphate series (5 m), and the number of holes presenting a derangement by the depth of derangements (5.8 m).The sum of the two will be multiplied by the cost of 1m drilled (5 US$). First, the number of holes must be calculated:

$$\text{Number of holes} = \frac{40000-(375+200)}{7\times 7} + \frac{(375+200)}{5\times 5} = 827$$

Operation cost = [(804x5) + (23x5.8)] x 5=20767 US$

3.2. Stage 2 - Blasting operation

- **Blasting in the absence of derangements**

For a standard phosphate mining case, the operation cost is determined by multiplying the volume of the interlayer by the cost of 1m^3 blasted (0.95 US$). First, the volume of the interlayer must be calculated:

$$\text{Volume of interlayers} = (1000 \times 40)\times 2 = 80000\ \text{m}^3$$

The operation cost = 80000 × 0.95= 76000 US$

- **Blasting in the presence of derangements**

Faced with the derangement, it is necessary to increase the quantity of explosives in the holes. The quantity of explosive required to fill a 5.8 m deep is 193 Kg. In our case study, the number of the holes presenting a derangement is 23, which means that the quantity of explosive necessary to fill 23 holes is (23×193= 4439 Kg). The cost of explosives (Nitrate Fuel – Ammonix) is 0.5 US$ per 1 kg. Therefore, the total cost of explosives is (4439× 0.5 = 2219.5 US$). It should be noted that the cost of other accessories (electric detonators, detonating cord …) is nearly 2121.5 US$.

The operation cost is the sum of the cost of the deranged volume and the cost of the underanged volume. The cost of the underanged volume, it can be expressed by subtracting the volume of derangements from the volume of the interlayers; this last must be multiplied by the cost of 1 m^3 blasted (0.95 US$). First, both the deranged volume and the underanged volume must be calculated:

$$\text{Deranged volume} = [(375+200)\times 5.8] = 3335\ \text{m}^3$$

Underanged volume = 80000 - 3335 = 76665m^3

Cost of underanged volume = 76665 × 0.95= 72831.75 US$

Cost of deranged volume = Cost of explosives + Cost of other accessories

Cost of deranged volume = 2219.5 + 2 121.5 = 4341 US$

Operation cost = 72831.75 + 4341= 77172.75 US$

3.3. Stage 3 - Ripping and dozing operation

- **Ripping and dozing in the absence of derangements**

In the absence of derangements, the cost of the ripping and dozing operation is calculated by multiplying the volume of interlayer by the cost of 1 m^3 pickled (0.37 US$).

Operation cost = 80000 × 0.37 = 29600 US$

- **Ripping and dozing in the presence of derangements**

Faced with derangements, the operation cost is obtained by multiplying the total volume by the cost of 1m^3 pickled (0.37 US$). First, the total volume is calculated using the following equation:

Total volume= [(375+200) × 3.8] + 80000= 82185 m^3

Operation cost = 82185 × 0.37 = 30408.45 US$

3.4. Stage 4 - Loading and hauling

In this step, the phosphate layer is recovered and the waste material (derangements and interlayers) are abandoned. The operation cost is obtained by multiplying the volume of phosphate by the cost of 1 m^3 extracted (0.918 US$). First, the volume of phosphate is calculated as follows:

Volume of phosphate= (40000 × 3) = 120000 m^3

Operation cost = 120000 × 0.918= 110160 US$

In this last mining operation, in general, the volume is the same in both cases; this means that the cost of this operation remains more or less unchanged when faced with derangements.

4. Conclusions

This work was designed to show the impact of derangements on the phosphate mining cost in the Sidi Chennane deposit, Morocco. A prototype model was considered, and the cost mining including drilling, blasting, ripping, dozing, loading, and hauling with and without consideration of derangements was calculated and compared.

The result of this work shows that the cost of the whole production cycle increases when the extraction confronted with derangements. During the drilling stage, it is necessary to restrict the drilling pattern by adding additional holes, resulting in an additional cost of 367 US$. During the blasting stage, the excessive consumption of explosives leads to an additional cost of 1172 US$. In addition, the ripping and dozing of the deranged materials entail an additional cost of 808 US$. Moreover, the existence of the derangements entails the risk of machine accidents when they climb a disturbed area, reduce the performance of machines, equipment (tricone, drilling collar), and transport trucks.

This pilot study cannot be used only as an efficient key to understand the economic impact of derangements in phosphate mining project in Sidi Chennane but can lead to an interesting assumption about using the same approach to assess other phosphate mining operating around the world.

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تأثیر اقتصادی اختلالات بر فرآیند استخراج – مطالعه موردی: سیدی چنّانه

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چکیده:

در سیدی چنّانه، مراکش مرکزی، هزینه استخراج فسفات اغلب تحت تأثیر مشکلاتی است که به وجود اجسام استریل به نام اختلالات مرتبط است. این اجسام متشکل از مواد سنگی ضایعاتی بر سری فسفات رسوبی تأثیر می گذارند و در نتیجه فرآیند استخراج فسفات را مختل می‌کنند. در این کار، ما تلاش می‌کنیم تاثیر اقتصادی این اجسام استریل را بر هزینه استخراج فسفات در سیدی چنّانه تحلیل و کمی سازی کنیم. این کار از طریق یک مدل اولیه تهیه شده به عنوان یک ترانشه معدنی واقعی، با استفاده از داده‌های جمع‌آوری‌شده در طول دوره کارآموزی ما در معدن سیدی چنّانه انجام شد. نتایج این کار نشان می‌دهد که هزینه حذف اختلالات هزینه استخراج فسفات را برای کل چرخه تولید، حفاری، انفجار، حفاری، بارگیری و باربری افزایش می‌دهد. بنابراین نتیجه‌گیری می‌شود که نتایج این کار برای دستیابی به درک دقیق استخراج فسفات در هنگام مواجهه با اختلالات از اهمیت بالایی برخوردار است. این را می‌توان برای تجزیه و تحلیل و تفسیر چنین ساختارهای مشابه در معادن فسفات در سراسر جهان (به عنوان مثال معدن فسفات طیبه در سنگال) تطبیق داد..

کلمات کلیدی: گروه OCP، اولد عبدون، سری فسفات، مراکش مرکزی، معدن فسفات.