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A NEW MINING METHOD FOR REOPENING THE OPENCAST MINE OF KEF ESSENNOUN

Purpose. To treat the stability problem of the phosphate Kef Essennoun quarry in the mining field of Jebel Onk located in the Northeastern part of Algeria.

Methodology. To achieve these objectives, we started by monitoring the unstable area, using two monitoring systems: control stations and inclinometer. We then carried out a digital assessment of the Northwestern edge stability of the quarry under the current operating conditions of exploitation. After that, we proposed a new operating plan for the reopening of the depot under the required security conditions. At the end, we carried out an assessment of the edge stability, as the work to reopen and develop the Kef Essennoun quarry progressed.

Findings. The results show that, under the current operating conditions of exploitation, the Northwestern edge of the Kef Essennoun quarry is unstable (FS < 1). The backfilling of the pilot pit of the mine, lead to the assurance of the mine walls stability, by increasing the values of safety factors with a rate of more than 30 %.

Originality. The backfilling of the pilot pit of the mine and the resumption of top-down mining exploitation will ensure the stability of the quarry during and after the operating exploitation mining.

Practical value. The study of the stability of the embankments bleachers, the edges of the quarries and the facings of the slag heaps during the open pit mining of useful ores deposits is an essential step that must be done gradually according to the development of mining works to guarantee the safety of personnel, materials, reserves and the environment.

Keywords: *Tebessa, Algeria, safety factor, embankments stability, mine reopening*

Introduction. The stability of quarries slopes and open-pit mines remains one of the crucial and fundamental questions for the useful mineral deposits exploitation [1]. It has a direct influence on work security in the mine, on the techniques and technologies used and on the operating exploitation conditions of these deposits [2].

Given its importance, several authors have treated this topic during their research [3–5] to optimize the parameters influencing the edge stability of opencast mining.

The determination of the optimal slope angle, ensuring the stability of the mining pit is a crucial step during the exploitation of the deposits because this angle has a double influence: 1) safety: an edge angle being too high can become a bank deformation factor, resulting slippage on the mine edges and causing unpleasant damage; 2) economical: in very deep mines, a change in the slope angle by a few degrees leads to a change in the stripping volumes, amounting to millions of cubic meters, which influences the project's profitability [2, 6].

The Kef Essennoun phosphate open pit mine has been a subject of a major landslide in 2007, which lead to the buried reserves and therefore the closure of the main pit [7, 8]. After a brief observation and in order to ensure the continuity of production, the company SOMIPHOS ordered the resumption of the exploitation operations by reopening the quarry at another location. However, the problem stability has not been solved in a lasting reliable manner.

In the present study, we have dealt at the same time with a security, technical, technological and environmental problem concerning the assessment of edge stability and the reopening of the Kef Essennoun phosphate quarry in the Djebel Onk mine, with the aim to provide objective, solid and sustainable solutions for the maximum extraction of the reserves of the deposit under the best conditions.

Presentation of the study area. ***Geographical location.*** The Kef Essennoun phosphate deposit belongs to the Djebel Onk mining field in Northeastern part of Algeria. It is located approximately 10 km southwest of the town of Bir El Ater, 100 km south of the town of Tebessa and 20 km from the Algerian-Tunisian border (Fig. 1) [8].

Geomorphological context. The structure of the Jebel Onk region is an anticlinal stretching for about 20 km along an axis 70° E and a width of about 3 km [9]. This asymmetric anticline was described as a post-Pliocene anticlinal

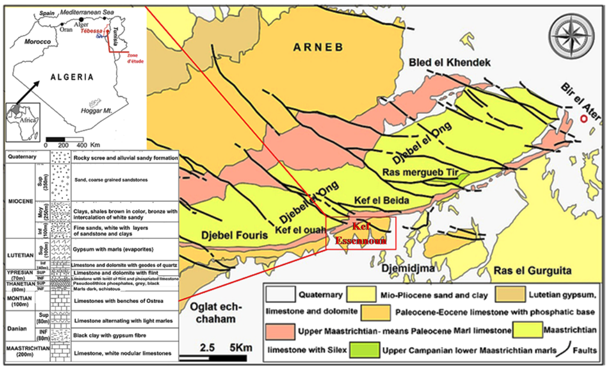


Fig. 1. Geographical and geological situation of the study area

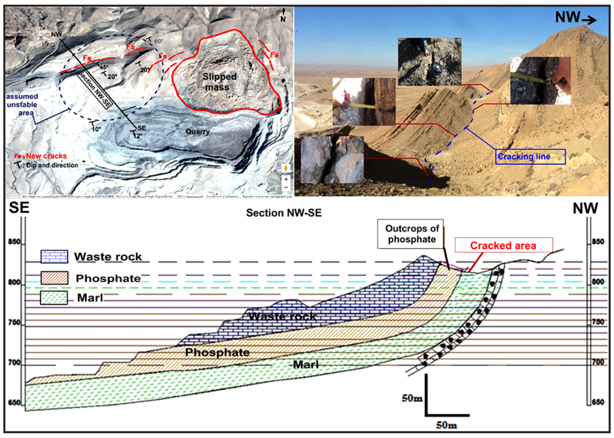


Fig. 2. Location of new cracks on the NW edge of the Kef Essennoun quarry

flexure. Morphologically, we can subdivide this area into two parts:

1. The Southern part: where the mining operation takes place, this area is characterized by a simple structure and is in the form of monocline table with a regular dip from 5 to 10° toward the South.

2. The Northern part: where the Kef Essennoun crest line is located (900 à 1000 m), is made up by massive Maastrichtian limestone and characterized by a more or less rugged morphology.

Geological setting. The stratigraphy series of the Jebel Onk region, in which the Kef Essennoun phosphate deposit belongs, is constituted by a stratification of layers that pass from Maastrichtian at the base to the Miocene at the top, surmounted by Quaternary deposits made up of scree and sandy alluvial formations (Fig. 1). The phosphate mineralization of the deposit is of an upper Thanetian age, represented by a layer that can rich more than 30 m thick [10].

Tectonic and structural aspect. The study area is located on the southern side of the Djebel Onk anticline. This zone is crossed by a three major NW-SE trending faults without distorting the geometry of the geological layers. On the other hand, in the Kef Essenoun area, extended northward (70° E), the flexible and fracturing tectonics has resulted in the abrupt change of the layers dipping with a nearly sub-vertical dip, steeply inclined to the southeast. Regarding the current tectonic activity, the deposit geological structure has not undergone any tectonic activity [11].

Socio-economic significance. Phosphate is one of the greatest Algerian mineral wealth with total geological resources estimated at 2 million tons. It is a fundamental pillar of the mining sector and of the national economy. The annual production of the phosphate ore exceeded two (2) million tones, in terms of exports in 2021, the majority of which came from the Kef Essennoun deposit.

As a result and with the objective of developing the extraction of this ore, Algeria launched in 2022 a mega project with an investment of approximately seven (07) billion USD. This project will induce a significant socio-economic growth in the eastern part of the country.

Methods. ***Appearance of recent cracks.*** After the gigantic slide of the Northern edge of the quarry in 2007, the fronts of the bleachers were reoriented towards the South, West and Northwest of the deposit. This solution, which seems suitable for the continued extraction of the ore, was hampered by the appearance, in 2013, of new cracks at the top of the Northwest edge of the new exploitation pit. These cracks are located at the phosphate/marl interface (Fig. 2).

Monitoring device. With the objective of monitoring the movement of the unstable rock mass, in amplitude and direction and to identify the location of the sliding surface two (02) monitoring systems have been set up: control stations and inclinometer.

Control stations. This device, installed along cracking line, is used to monitor the cracks progress in terms of spacing. These are steel stakes concreted in two points located on either side of a crack in which, periodic and continuous linear measurements are made of the distance between the two stakes; this method is widely used because of their low cost and ease of implementation. The measurements taken at these stations, between April 2013 and October 2016, showed that:

- the cracks diverge with a maximum speed of 14 cm/yr, recorded at the station number three (ST-3). Therefore, this area is unstable (Fig. 3);

- the progression of the cracking line follows the advancement of the mining front of the phosphate stands on the west side of the mine (Fig. 2).

Inclinometers. In order to quantify the deformation rate and identify the exact location of the sliding surface, four (04) core drill holes equipped with inclinometers (Ic-1, Ic-2, Ic-3, Ic-4) were carried out between February and June 2014. These

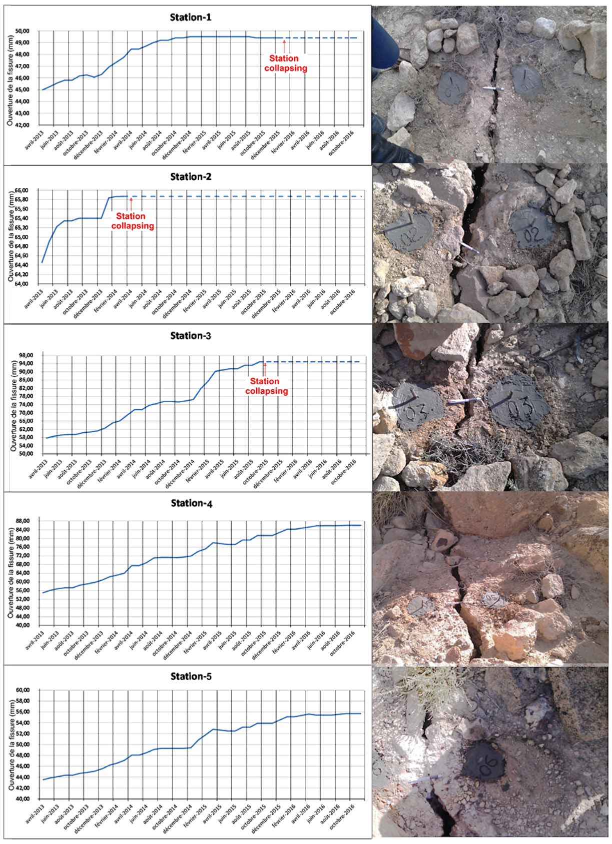


Fig. 3. Control stations from N°01 to 05 with the registration

Table 1

Location and depth of inclinometers

Inclinometer	*X*	*Y*	*Z*	Depth(m)
Inc-1	82,620.52	69,430.15	723.22	75
Inc-2	82,627.62	69,400.20	705.66	55
Inc-3	82,279.63	69,336.42	716.65	80
Inc-4	82,418.96	69,404.24	719.10	77

Table 2

Registered displacements at inclinometers

Inclinometer	Cumulative displacement to the South (mm)	Cumulative displacement East-West (mm)	Depth (m)
1nc-1	53.83	43.85	55.5
1nc-2	10.10	4.03	33
1nc-3	6.64	0	72.5
1nc-4	16.47 (Sheared)	0	62

inclinometers were installed at the lower bench of the quarry (Table 1, Fig. 5). The main results are presented in Table 2.

These measurements showed that:

1. All the inclinometers have detected deformations of different degrees that are located in the marly layers.

2. The most important deformation is of 53.38 mm towards the South, recorded at a depth of 55.5 m in the inclinometer.

3. The likely movement is oriented to the feet of the stands (to the steepest slope).

Principal factors affecting the slope stability. There are a number of factors that can contribute to slope instability and landslides during the open-pit mining. Identifying these factors is one of the main goals of the open pit slope stability study, which helps us to propose appropriate solutions. For the case of Kef Essennoun quarry, the causes influencing the stability of the slope can be divided into two groups: technical and natural.

Natural factors. These include factors linked to the natural properties of the deposits, such as:

- the stratiform structure of the deposit contributes to the edges instability and the initiation of the landslide;

- the geological structure, illustrated in Fig. 2, shows a layers dipping with an almost sub-vertical dip, resulting from the tectonic activity of the Pliocene. This structure allows the rock mass, released in the downstream part by the excavation, to detach from the mountain and trigger its downward slide following an inclined plane [12];

- the Djebel Onk region belongs to the eastern end of the Saharan Atlas, at the border of the south Atlas flexure, which corresponds to a confrontation zone between the atlas domain and the Saharan platform. This heterogeneous tectonic situation has strongly contributed to generating an intense massive fracturing, perfectly visible on the site. This fracturing confers poor geo-mechanical properties to the rock mass.

Technical factors. These factors are linked to the mining method, we find:

- the location for the mine opening has not been chosen correctly, at the foot of the mountain, without taking into consideration the stratified structure of the rocky mass and the direction of the mining operations, which progress to the inverse direction of the layers dipping. However, according to art and standards of the open-pit mining, the best mining method of this type of deposit (hillside stratified deposit) is to begin excavation from top to bottom, following the dip direction of the geological layers;

- failure to respect of the technological parameters of an open pit mining (reduced safety berms and very straightened front with a slope angles of 75 to 85° and 30 m in height);

- the effects of vibration generated by blasting activities, which contribute to the progressive structural weakening of the rocky mass.

Stability assessment of the Northwestern edge of the Kef Essennoun quarry. For confirming the results obtained by the monitoring device, we carried out a digital assessment of the Northwestern edge stability of the Kef Essennoun quarry by using the Geo-Studio 7.10 software (Slope/W, 2007) [13]. This software calculates the edge safety factor by taking into account the integration of the geometric aspect (height and inclination of the embankment) and also the geo-mechanical aspect (cohesion and internal friction angle).

Characteristics of the unstable area. Fig. 4 shows a survey plan of the Kef Essennoun phosphate mine, updated in January 2016. The unstable zone is located in the Northwestern part of the new exploitation pit and extends over a surface area of more than 20 hectares with a total volume exceeding 10 million cubic meters, which risks being in motion.

This area is bounded at the bottom by the operating benches (free surface), at the top by the cracking line and to the left and right by a few thalwegs. Therefore, the only probable direction of the slide is from the Northwest to the South-East (towards the feet of the benches).

Choice of the cross-section. The choice of such a profile for the slope stability study is justified by the characteristics of the study area, the instability indices observed in the field (observation of certain signs of sliding at the crest) and that it be representative for the different specificities, especially morphology and lithostratigraphy.

For the case of Kef Essennoun quarry, the selection of the profile location adopted for the modeling of the unstable area was made taking into account the location and direction of the cracking line, the probable direction of the slip (from the Northwest to the southeast) (Figs. 2, 4).

For this purpose, we have used the survey plan of the mine, updated in January 2016, on which, we have drawn a Northwest-southeast section.

The overall model adopted to calculate the safety factor with Geo-Studio software is an edge more than 150 m high with a spacing of 380 m, and a slope varying between 20 to 22°, consisting of five benches: two benches in the phosphate layer (H ~ 15 m and α = 75 to 85 °) and three benches in the waste rock (H ~ 10 m and α = 70 to 80 °). This heterogeneous edge is

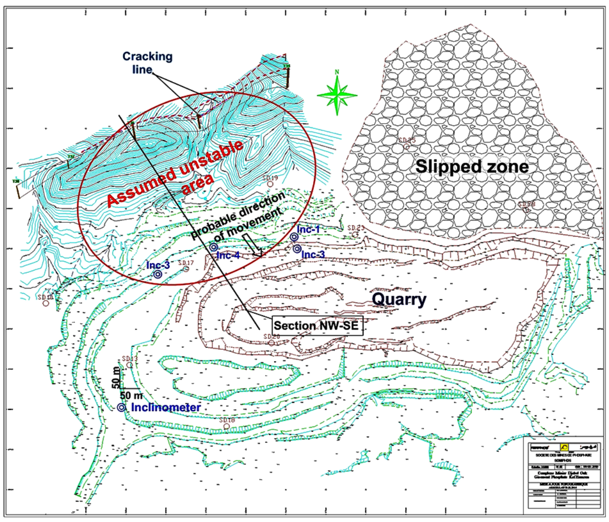


Fig. 4. Characteristics of the supposedly unstable area

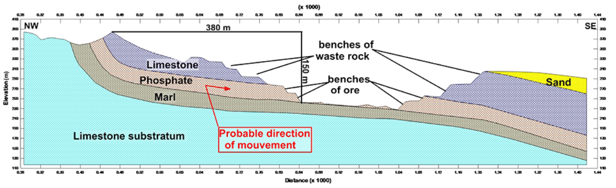
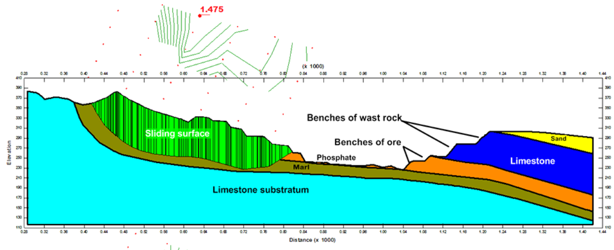
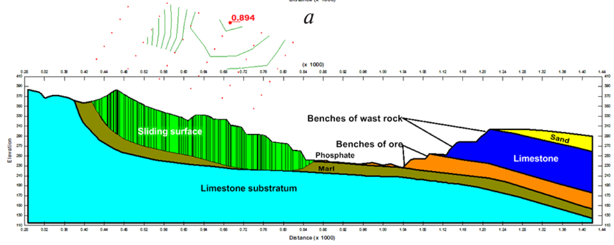


Fig. 5. Geometrical model adopted for the numerical modeling



a



b

Fig. 6. Sliding surface (hatched in green) for the minimal factor of safety for both approaches:

a — without the blasting effects; b — with the blasting effects

made up of four main layers: Limestone, Phosphate, Marl and limestone as the substratum (Fig. 5).

Results and discussion. ***Numerical calculation of the security factor.*** The calculation of the security factor (FS) of the Northwestern edge of the Kef Essennoun quarry was carried out on the basis of the geometrical model defined previously (Fig. 5). The main conditions of the calculation are the geomechanical parameters of the rocks (Table 3) and the anthropogenic seismicity due to blasting operations, represented by two horizontal and vertical components, ($kh = 0.05$ and $kv = 0.0125$). To this end, two approaches were considered, without and with the blasting effects. The obtained results are illustrated in Table 4 and Fig. 6.

According to the results obtained by the numerical modeling (Table 4 and Fig. 6), one notes that:

Table 3

Geomechanical properties of rocks

Property Layer	γ (kN/m^3)	*C* (MPa)	φ (°)
Altered limestone	22	8.24	39
Phosphate	23	7.35	39
Marl	20	1	15
Limestone substratum	26	5.6	33
Sand	18	1	27

Table 4

Simulation results

Method	Security factor FS	
	Approach-1: without blasting effects	Approach-2: with the blasting effects
Ordinary	1.475	0.895
Bishop	1.919	1.081
Janbu	1.575	0.894
Morgenstern-Price	1.704	0.931

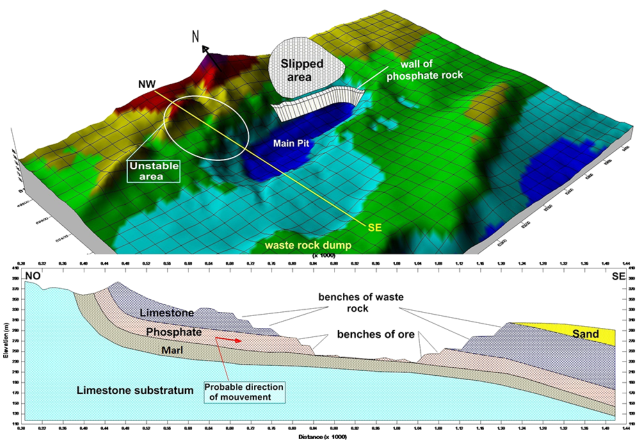
Approach-1: All security factors calculated by the different methods are greater than the minimum tolerated threshold for the slope stability ($FS > 1$), with a minimum safety factor of 1.312, obtained by the Janbu method. Thus, the edge is stable.

Approach-2: All safety factors are critical ($FS \leqslant 1$), with a minimum safety factor of 0.806, also obtained by the Janbu method. Thus, the edge is unstable.

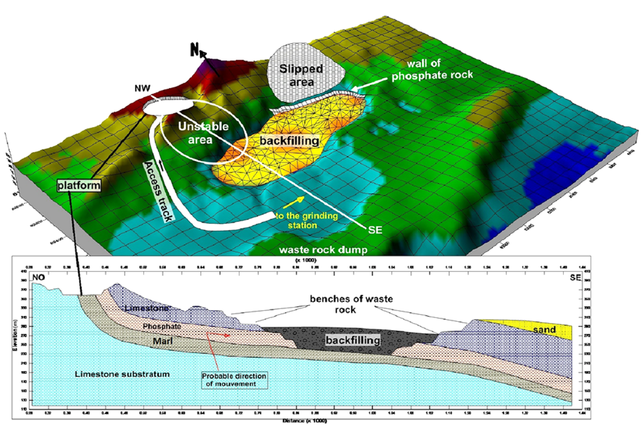
The sliding surfaces given by these two approaches have a non-circular (polygonal) shape and are located in the marly layer, with a slight difference in the volume of the unstable rock mass (Fig. 6) between the two approaches.

Reopening plan of the Kef Essennoun quarry. The results obtained previously showed that, under the current operating conditions of exploitation, the Northwestern edge of the Kef Essennoun quarry is unstable ($FS < 1$) (Table 4). This critical situation requires the proposal of a new exploitation plan for the reopening of the deposit under the required security conditions.

Current situation of the quarry. The Kef Essennoun deposit is the only one which in exploitation among the five existing in the Jebel Onk mining field (Kef Essennoun, Djemi-Djema, Djebel Onk North, Bled Hadba and Oued Betita). The quarry is made up by several benches in the shape of a pit, with an overall surface area of over 35 hectares and a mean depth of 70 meters. In the Northeastern part of the



a



b

Fig. 7. Current situation of the phosphate quarry (a) and condition of the quarry after backfilling and reopening of the initial platform (b)

pit, we have the gigantic landslide produced in 2007, estimated at 7.7 million cubic meters, blocked by a wall of phosphate rock (security barrier). In the Northwestern side, we find the unstable zone and to the south the waste rock dump (Fig. 7, *a*).

Reopening of the deposit. The reopening of the Kef Essennoun quarry will need to go through the following four main steps:

- backfilling of the pit;
- creation of an access track at the upper level;
- opening of a new platform;
- development of the mining operation exploitation from the top to bottom.

Backfilling of the pit. In order to stabilize the walls of the mine, we found it very useful to backfill the main mining pit. The economic and technical feasibility of this operation requires us to study carefully the surface and height to be backfilled, the type and volume of the backfill and the distance between the backfill and the pit. For this purpose, we recommend:

1. Partial backfilling of the pit which affects only the first two benches with a height of 30 m and a volume of 4.6 million m^3 (Table 5).
2. The use, as backfill, of the waste rock stored to the south of the quarry (dump), consisting mainly of limestones, dolomites and marly limestone.

Access track and working platform. After the backfilling work of the main exploitation pit, we will reopen the deposit by creating another access track to the upper levels and reopening a new working platform in the outcrop of the phosphates layer (Fig. 7, *b*).

Development of the mining operation. The development of the mining operation in the Kef Essennoun quarry goes through two principal steps:

- the reopening of an initial platform and the elimination of the overlying waste rock (hill), in order to reduce the load above the unstable zone (Figs. 8, 9; Phase 3);
- the continuation of the mining exploitation from the top to the bottom, level by level, in the dip direction of the phosphate layer, with bleachers not exceeding 12 m in height and an inclination βg of 70°. Regarding the security and cleaning berms (*bs*, *bn*) we take a minimum width of 8 m, these parameters give us a maximum ultimate edge which does not exceed 35° (Fig. 8, Phase 4, 5).

Stability assessment of the final edge considered. In order to prevent all critical situations of the stability of the mine walls, we carried out an assessment of the edge stability, as the work to reopen and develop the Kef Essennoun quarry progressed, the results of which are shown in Table 6 and Fig. 9.

From the results of Table 6 and Fig. 9, we notice:

- the remarkable influence of the backfill operation on the stability of the Northwestern side of the Kef Essennoun quarry, where the safety factors were increased at a rate of over 30 % after backfilling;
- after the backfilling of the pit, all the safety factors calculated by the different methods are much greater than 1 ($FS > 1$), which means that the edge is stabilized.
- for the different development phases of the deposit (Phases 3, 4 and 5) (Table 6), all the safety factors are greater than 1 ($FS > 1$). Therefore, there will be no risk of instability at during mining operations, provided that we comply with the recommended technical and technological parameters ($hg \leq 12$ m, $\beta g \leq 70°$, bs, $bn \geq 8$ m) and under current blasting conditions.

Table 5

Surface area to backfill and the necessary volume of waste rock fill

Backfilling of the pilot pit			
Level	Surface (m^2)	height (m)	Volume (m^3)
N-1(705-690)	184,286	15	2,764,290
N-1(690-675)	116,033	15	1,740,495
Total	–	–	4,504,785

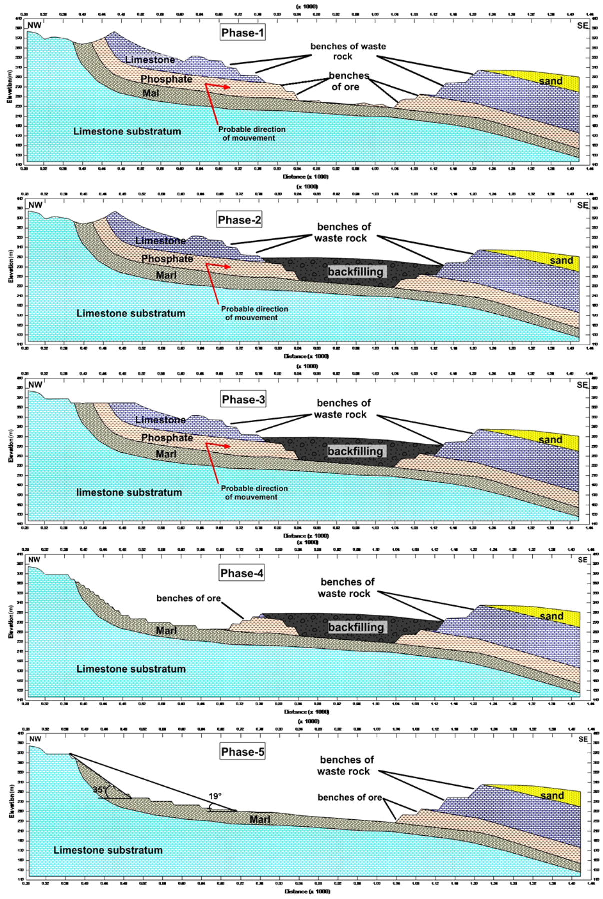


Fig. 8. Development stages of the mining exploitation of Kef Essennoun deposit

Table 6

Security factor of the different phases of development of Kef Essennoun's quarry

Method	Phase-1 (Before backfill)	Phase-2 (After backfill)	Phase-3	Phase-4	Phase-5
ordinary	0.895	1.340	1.859	4.936	4.894
Bishop	0.981	1.559	1.884	4.819	4.795
Janbu	0.894	1.289	1.714	4.738	4.534
Morgenstern-Price	0.931	1.508	1.794	4.755	4.753

Conclusions. At the end of this study, we find that:

1. The plan proposed by the company SOMIPHOS for the continuation of mining work in the Kef Essennoun deposit, after the sliding of the Northern edge was not reliable, either, because as the pit was enlarged, new cracks appeared in the upper parts of the North and Northwest of the quarry.
2. The monitoring devices used (control stations and inclinometers) were complementary to each other and they showed that the Northwest edge of the Kef Essennoun quarry is unstable, the sliding surface of which corresponds to the phosphate interface/marl.
3. Numerical modeling carried out using the Geo-Studio 7.10 software showed that the Northwest edge of the Kef Es-

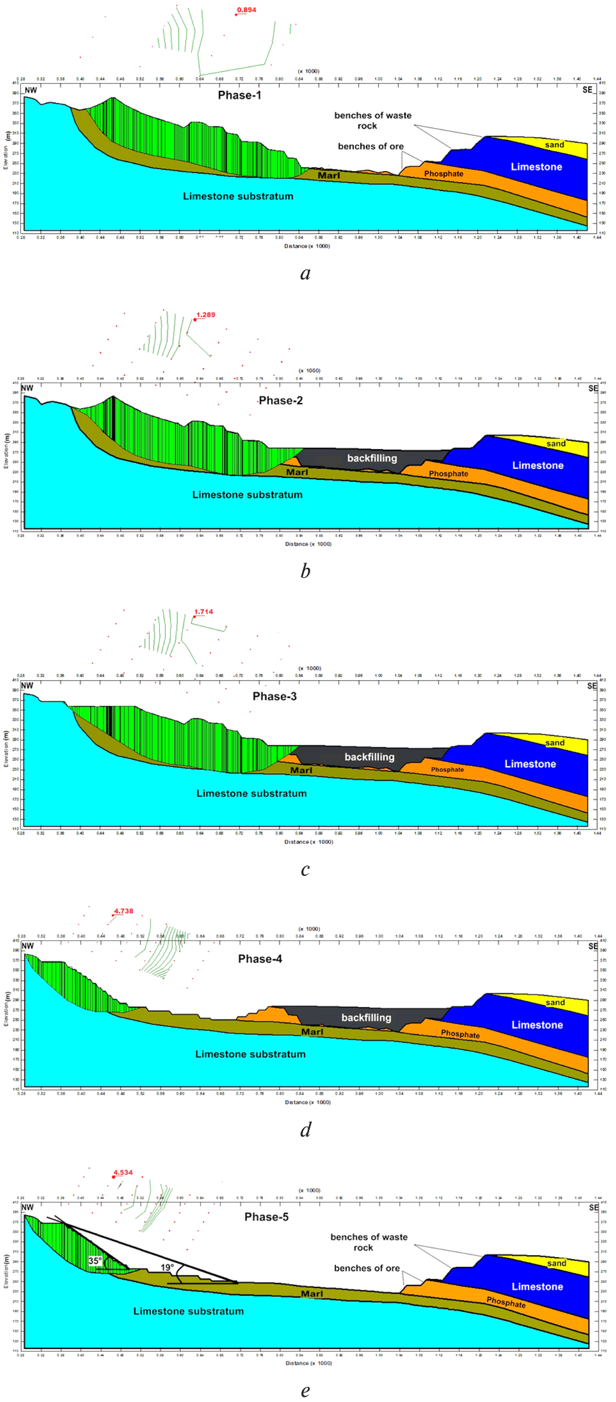


Fig. 9. Sliding surfaces for the minimum safety factor for the development phases of the Kef Essennoun quarry

sennoun quarry is sensitive to mine blasting work and stable in the opposite case.

In view of this observation, we recommend:

1. Partial backfilling of the pilot pit of the mine, up to the first two benches with a height of 30 m. This operation would lead to the assurance of stability, by increasing the values of safety factors with a rate of more than 30 %.

2. Re-studying the mining work in order to find an optimal blasting plan, which ensures both the blasting operation and the stability of the mine walls.

Resumption of top-down mining exploitation remains the appropriate method for this type of deposit, which will ensure the stability of the quarry during and after the operating exploitation mining.

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Новий метод видобутку для відновлення роботи кар'єру Кеф Ессеннун

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Мета. Вирішення проблеми стабільності фосфатного кар'єру Кеф Ессеннун у гірничодобувному регіоні Джебель-Онк, розташованому в північно-східній частині Алжиру.

Методика. Для досягнення цієї мети ми почали з моніторингу нестабільної ділянки, використовуючи дві системи моніторингу: контрольні станції та інклінометр. Потім ми провели цифрову оцінку стійкості північно-західного краю кар'єру за поточних умов експлуатації. Після цього ми запропонували новий план дій для відновлення роботи кар'єру з дотриманням необхідних умов безпеки. На завершення ми провели оцінку стійкості бортів, оскільки роботи з відновлення й розробки кар'єру Кеф Ессеннун продовжувалися.

Результати. Результати показують, що за поточних умов експлуатації північно-західний край кар'єру Кеф Ессеннун є нестійким ($FS < 1$). Засипка експериментального кар'єру сприяла забезпеченню стійкості стінок кар'єру за рахунок збільшення значень коефіцієнтів запасу міцності більш ніж на 30 %.

Наукова новизна. Засипка експериментального кар'єру й відновлення видобутку зверху вниз забезпечить стабільність кар'єру під час і після завершення експлуатаційного видобутку корисних копалин.

Практична значимість. Дослідження стійкості уступів насипів, бортів кар'єрів і облицювання шлакових відвалів при відкритій розробці родовищ корисних копалин є важливим етапом, що має виконуватися поступово відповідно до розвитку гірничих робіт, щоб гарантувати безпеку персоналу, матеріалів, запасів і навколишнього середовища.

Ключові слова: *Тебесса, Алжир, коефіцієнт безпеки, стабільність насипів, відновлення роботи кар'єру*

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