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République algérienne démocratique et populaire
وزارة التعليم العالي والبحث العلمي
Ministère de l'enseignement supérieur et de la recherche scientifique
جامعة الشهيد شيخ العربي التبسي – تبسة
Université Echahid cheikh Larbi Tebessi – Tébessa
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Institut des mines
قسم المناجم والجيوتكنولوجيا
Département des mines et de la géotechnologie

MEMOIRE

Présenté en vue de l'obtention d'un diplôme de Master académique

Filière : Génie minier

Option : Géotechnique

Stability analysis and safety factors prediction of an open pit mine

(Kef Essnoun case study)

Présenté et soutenu par

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جامعة الشهيد الشيخ العربي التبسي - تبسة
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(Kef Essnoun case study)

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Chapitres réalisés	Signature de l'encadreur
Chapter I :Generality and review on the stability In open pit mines.	
Chapter II: general settings and description of the study area.	
Chapter III: -part I: stability analysis and prediction of safety factor. -part II: Geotechnical hazards of the Kef Essnoun open pit.	

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Stability analysis and safety factors prediction of an open pit mine

(Kef Essnoun case study)

أصرح بشرفي أني ألتزم بمراعاة المعايير العلمية والمنهجية ومعايير الأخلاقيات المهنية والنزاهة الأكاديمية المطلوبة في انجاز البحث المذكور أعلاه.

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إمضاء المعني (ة)

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وزارة الشهيد الشيخ التعليم العالي و البحث العلمي

جامعة العربي التبسي- تبسة

مقرر رقم: مؤرخ في: 2023/05/30

يتضمن الترخيص بمناقشة مذكرة الماستر

إنّ مدير جامعة العربي التبسي بتبسة،

- بموجب القرار الوزاري رقم 318 و المؤرخ في 05 ماي 2021 المتضمن تعيين السيد "قواسمية عبد الكريم" مديرا لجامعة العربي التبسي - تبسة،

-و بمقتضى المرسوم التنفيذي رقم : 12- 363 مؤرخ في 8 أكتوبر 2012، يعدل و يتمم المرسوم التنفيذي رقم 09 - 08 المؤرخ في : 04 جانفي 2009 و المتضمن إنشاء جامعة العربي التبسي بتبسة،

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- وبموجب القرار رقم 362 المؤرّخ في 09 جوان 2014 الذي يحدّد كيفيات إعداد ومناقشة مذكّرة الماستر، لاسيما المادة 7 منه،

- وبموجب القرار رقم 1080 المؤرّخ في 13 أكتوبر 2015 والمتضمّن تأهيل ماستر الفروع ذات تسجيل وطني بجامعة تبسة.

- وبموجب القرار رقم 375 المؤرّخ في 15 جوان 2020 المعدل لملحق القرار 1080 المؤرّخ في 13 أكتوبر 2015 والمتضمّن تأهيل ماستر الفروع ذات تسجيل وطني بجامعة تبسة، اختصاص جيوتقني

- وبموجب المقرّر رقم .... المؤرّخ في 2023/05/29 والمتضمّن تعيين لجنة مناقشة مذكّرة الماستر،

- وبعد الاطّلاع على مقرر تعيين لجنة مناقشة مذكر ة الماستر المؤرّخ في ....

يقرّر ما يأتي:

المادة الأولى: يُرخّصُ للطالب(ة) **براكني هبة الرحمان**، المولود (ة) بتاريخ **2000/12/13** بـ **تبسة**، بمناقشة مذكّرة الماستر والموسومة بـ

Stability analysis and safety factors prediction of open pit mine (Kef Essnoun case study)

المادة 2: يكلّف رئيس قسم **المناجم والجيوتكنولوجيا** بتنفيذ هذا المقرّر الّذي يسلّم نسخة عنه إلى الطّالب المعني بالمناقشة وأعضاء لجنة المناقشة فور توقيعه، وبضمان نشره عبر فضاءات المؤسّسة المادية والرقمية.

المادة 3: تُحفظ نسخة عن هذا المقرّر ضمن الملفّ البيداغوجي للطّالب المعني وينشر في النّشرة الرّسمية لجامعة العربي التبسي.

حُرّر ب تبسة، في: 2023/05/30

عن المدير، وبتفويض منه

مدير معهد المناجم

د. عزلمي زوبير

مدير معهد المناجم

جامعة العربي التبسي - معهد المناجم - المدير

الجمهورية الجزائرية الديمقراطية الشعبية
وزارة التعليم العالي والبحث العلمي
جامعة الشهيد الشيخ العربي التبسي- تبسة

مقرر رقم : مؤرخ في : 2023/05/29

يتضمن تعيين لجنة مناقشة مذكرة الماستر

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- وبموجب القرار رقم 362 المؤرّخ في 09 جوان 2014 الذي يحدّد كيفيات إعداد ومناقشة مذكّرة الماستر، لاسيما المادتان 10 و11 منه،

- وبموجب القرار رقم 1380 المؤرّخ في 09 أوت 2016 والمتضمّن مواءمة التكوينات في الماستر بعنوان جامعة تبسة في ميدان "علوم وتكنولوجيا".

- وبموجب القرار رقم 375 المؤرّخ في 15 جوان 2020 المعدل لملحق القرار 1080 المؤرّخ في 13 أكتوبر 2015 والمتضمّن تأهيل ماستر الفروع ذات تسجيل وطني بجامعة تبسة، اختصاص جيوتقني

- وبعد الاطّلاع على محضر المجلس العلمي لمعهد المناجم المؤرّخ في.................................... ،

يقرّر ما يأتي:

المادة الأولى: تُعيّنُ بموجب هذا المقرّر لجنة مناقشة مذكّرة الماستر المحضّرة من طرف الطّالب (ة):

براكني هبة الرحمان، المولود (ة) بتاريخ **2000/12/13** بـ **تبسة** ،

والموسُومة بـ **Stability analysis and safety factors prediction of open pit mine (Kef Essnoun case study)**

والمسجّل (ة) بمعهد **المناجم**

المادة 2: تتشكّل اللجنة المشار إليها في المادة الأولى من الأعضاء الآتي ذكرهم:

رقم	الاسم واللّقب	الرتبة	مؤسّسة الانتماء	الصّفة
1	زياد بن غازي	أستاذ محاضر - ب	جامعة العربي التبسي - تبسة	رئيسا
2	براح ياسين	أستاذ محاضر - ب	جامعة العربي التبسي - تبسة	مشرفا
3	سرحان براهمي	أستاذ محاضر - ب	جامعة العربي التبسي - تبسة	ممتحنا

المادة 3: يكلّف رئيس قسم **المناجم والجيوتكنولوجيا** بتنفيذ هذا المقرّر الّذي يُسلّم نسخةً عنه إلى كلّ من الطّالب المعني والمشرف على المذكّرة وأعضاء لجنة المناقشة فور توقيعه.

المادة 4: تحفظ نسخة عن هذا المقرّر في الملفّ البيداغوجي للطالب المعني، وينشر في النّشرة الرّسمية لجامعة العربي التبسي.

حُرّر بـ تبسة، في: 2023/05/29

عن المدير، وبتفويض منه

مدير معهد المناجم

د. عولمي ... مدير معهد المناجم

جامعة العربي التبسي بتبسة - معهد المناجم - المدير

Dedication

This work is sincerely dedicated to my loving parents, who have supported me throughout my life. They gave me strength and hope to continue my journey.

To my hero, the one who sacrificed his life for me and provided me with a great life mentally and financially, my father, you will always be my source of inspiration. To my angelic soul, you are the candle that lights up in my darkest moments. To the source of my efforts, to you, my mother, words could never describe my deep love to you. To the pure soul who taught me the value of kindness, to you, Khawla, the best sister in the world,

To the unique one in the family, to you, El Maamoun, thank you for being the best brother a sister would ask for.

To my little princess, the joy of the family, Eline, and to the prince, Issef Mohamed Nibras

To my little monsters, Amane and Ahmed Yanis I love you so much.

And to my sister from another mother, Takwa

Without forgetting the coolest person faycel

Hiba

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First, before anything, thanks to Allah, who guides, helps, and gives me the capacity to do this work.

I would like to express my infinite gratitude and respect to my supervisor, Mr. BERRAH Yacine, for his constant help, precious suggestions, and valuable advice.

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I will not forget, of course, to express my gratitude to my colleagues, who have provided me with moral and intellectual support throughout my process.

Finally, I also deeply thank all the people who have helped and supported us from near or far.

Abstract

This research focuses on the geotechnical challenges associated with open-pit mining in the Djebel Onk deposit located in the Tebessa region of Algeria. The study area contains substantial untapped reserves of phosphates, estimated to exceed 2 billion tons. The dissertation is divided into three chapters, covering a literature review, site description, and geotechnical analysis. A comprehensive dataset on the Djebel Onk deposits, including historical, geological, subdivision, and tectonic information, the second chapter discusses the Kef-Essnoun site and introduces slope stability concepts. When focusing on the physical and mechanical characteristics of the rock massifs and conducting stability analysis using Geostudio software. Additionally, hazard and risk mapping related to landslides within the mine pit is performed using Surfer software .The research highlights the importance of considering water effects in slope stability analysis, as the inclusion of water in numerical models impacted the safety factors. By digitizing the open pit, potential risks and sliding areas were identified. The findings contribute to the understanding of geotechnical evaluations and slope stability analysis, demonstrating the value of advanced software tools like Geoslope and Surfer in mining projects. Leveraging Algeria's mineral resources, particularly the Djebel Onk phosphate deposit, can drive economic development while prioritizing safe and sustainable mining practices. The research emphasizes the significance of stability analysis, numerical modeling, and scenario prediction for effective decision-making and risk mitigation in mining operations.

Keywords: geological condition, geotechnical parameters, open pit, stability analysis, geotechnical hazard mapping.

ملخص

ويركز هذا البحث على التحديات الجيوتقنية المرتبطة بمنجم سطحي في جبل عنق الواقع في منطقة تبسة في الجزائر. وتحتوي منطقة الدراسة على احتياطيات كبيرة غير مستغلة من الفوسفات تقدر بما يزيد على بليوني طن. وتنقسم الأطروحة إلى ثلاثة فصول، تشمل استعراضا للأدبيات، ووصفا للموقع، وتحليلا جيوتقنيا.

ويتضمن الفصل الثاني مجموعة بيانات شاملة عن رواسب جبل عنق ، بما في ذلك المعلومات التاريخية والجيولوجية و التقسيمية الفرعية و التكتونية، ويناقش الفصل الثاني موقع كاف السنون ويعرض مفاهيم استقرار الميل. وعند التركيز على الخصائص الفيزيائية والميكانيكية للمدللات الصخرية وإجراء تحليل استقرار باستخدام برامجيات Geostudio. وبالإضافة إلى ذلك، يجري رسم خرائط الأخطار والمخاطر المتصلة بالانهيارات الأرضية داخل حفرة المنجم باستخدام برامجيات " Surfer".

يسلط البحث الضوء على أهمية النظر في آثار المياه في تحليل استقرار المنحدرات، لأن إدراج المياه في النماذج الرقمية يؤثر على عوامل السلامة. و برقمنة الحفرة المفتوحة، تم تحديد المخاطر المحتملة ومناطق الانزلاق. وتسهم النتائج في فهم التقييمات الجيوتقنية وتحليل استقرار المنحدرات، مما يدل على قيمة أدوات البرمجيات المتقدمة مثل Geoslope, Surfer في مشاريع التعدين.

من شأن تعزيز الموارد المعدنية للجزائر، ولا سيما رواسب الفوسفات في جبل عنق ، أن يدفع عجلة التنمية الاقتصادية مع إعطاء الأولوية لممارسات التعدين المأمونة والمستدامة. و تشدد البحوث على أهمية تحليل الاستقرار، ووضع النماذج الرقمية، والتنبؤ بالسيناريوهات من أجل اتخاذ قرارات فعالة والتخفيف من المخاطر في عمليات التعدين.

الكلمات الرئيسية: الحالة الجيولوجية، الخصائص الجيوتقنية، والحفرة المفتوحة، وتحليل الاستقرار، ورسم الخرائط الجيوتقنية للمخاطر.

Résumé

Cette recherche met l'accent sur les défis géotechniques associés à l'exploitation minière dans le dépôt de Djebel Onk situé dans la région de Tebessa en Algérie. La zone d'étude contient d'importantes réserves inexploitées de phosphates, estimées à plus de 2 milliards de tonnes. La thèse est divisée en trois chapitres, couvrant une revue de la littérature, une description du site et une analyse géotechnique. Un ensemble complet de données sur les dépôts de Djebel Onk, y compris les informations historiques, géologiques, de sous-division et tectoniques, le deuxième chapitre aborde le site de Kef-Essnoun et introduit les concepts de stabilité de pente. Lors de la concentration sur les caractéristiques physiques et mécaniques des massifs rocheux et de la réalisation d'analyses de stabilité à l'aide du logiciel Geostudio. En outre, la cartographie des dangers et des risques liés aux glissements de terrain dans le puits de la mine est effectuée à l'aide du logiciel Surfer. La recherche souligne l'importance de considérer les effets de l'eau dans l'analyse de la stabilité de la pente, car l'inclusion de l'eau dans les modèles numériques a eu un impact sur les facteurs de sécurité. En numérisant le puits ouvert, des risques potentiels et des zones de glissement ont été identifiés. Les résultats contribuent à la compréhension des évaluations géotechniques et de l'analyse de la stabilité de la pente, démontrant la valeur des outils logiciels avancés tels que Geoslope et Surfer dans les projets miniers. Utiliser les ressources minérales de l'Algérie,

Mots clés : condition géologique, paramètres géotechniques, trou ouvert, analyse de la stabilité, cartographie des risques géotechniques.

Notation list

α_T	general angle of the slope
α_g	tier angle
h_g	tier height
H	depth of the pit
b	width of the bench
τ	shear stress
C	Soil cohesion
σn	The inclination of the sliding surface in the middle of section n
θi	The angle formed by the resultant and the horizontal
λ	A constant that must be evaluated for the calculation of the safety factor
$f(xi')$	The function of variation in relation to the distance along the sliding surface
xi':	The linear normalization of the xi coordinates
Fs	Safety factor

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Part I

General introduction

General introduction

Algeria, boasts abundant mineral resources encompassing a wide array of substances such as iron, zinc, copper, clays, marble, and phosphates. However, a significant portion of these resources remains untapped, including a substantial deposit of phosphates located in the east of the country known as (Djebel Onk) in Tebessa region. The proven reserves of this deposit are estimated to exceed 2 billion tons of phosphates [7] and are currently being exploited by the phosphate mining company, SO.MI.PHOS.

For the purpose of mining investigation and exploitation, a geotechnical study ensures the natural unfolding of all different exploitation operations. This final graduation thesis is elaborated and composed of three main chapters as follows:

In the first chapter, we have conducted an extensive literature review and collected on-site data to construct a comprehensive dataset on the study sites. This dataset provides a comprehensive overview of the Djebel Onk deposits, encompassing their historical significance, geological characteristics, subdivision, and tectonic context.

The second chapter entails a detailed description of the Kef-Essnoun site, rather than introduces slope-related concepts, enabling us to address the geotechnical challenges associated with open-pit mining. We discuss methods and calculations pertaining to slope stability and factor of safety.

The third chapter is divided into two main parts:

Part one focuses on the physical and mechanical characteristics of the rocky massifs within the Kef Essnoun open pit, and the stability analysis studied and a factor of safety calculations are performed using Geostudio software.

Part two involves the elaboration of the geotechnical hazard and risk mapping related to the landslides movement within the mine pit, attempt to the creation of various maps and digitization the open pit by collecting data and using Surfer software.

Generality and review on the stability

In open pit mines

I.1. Introduction

Mining is one of humanity's oldest activities. Almost since the beginning of the Stone Age, 2.5 million years ago or more, it has been the main source of materials for the manufacture of tools. But there are many disasters that happen in the mine; one of them is ground movement (landslide).

Landslides, which originate from the displacement of the fracture and movement of the soil and affect any part of the world, are one of the most common natural hazards They impact both natural and artificial slopes and cause significant losses in lives and assets every year. Therefore, slope stability is a crucial factor to take into account when managing various mining activities.

I.2. Slope stability in an open pit mine

From a stability standpoint, the size of the pit slopes is important for the analysis of an open-pit operation.

A pit's dimensions consist of determining the angles of these slopes in order to assure overall stability. A pit has multiple slopes that have varied orientations and frequently encounter ground that may have different geotechnical properties. [1].

Figure I.1: an open pit mine of diamonds Nyurbinsky, in Russia (Alexander Nemenov Agency France-Press).

- A mining slope is defined by the parameters shown in the figure I.2

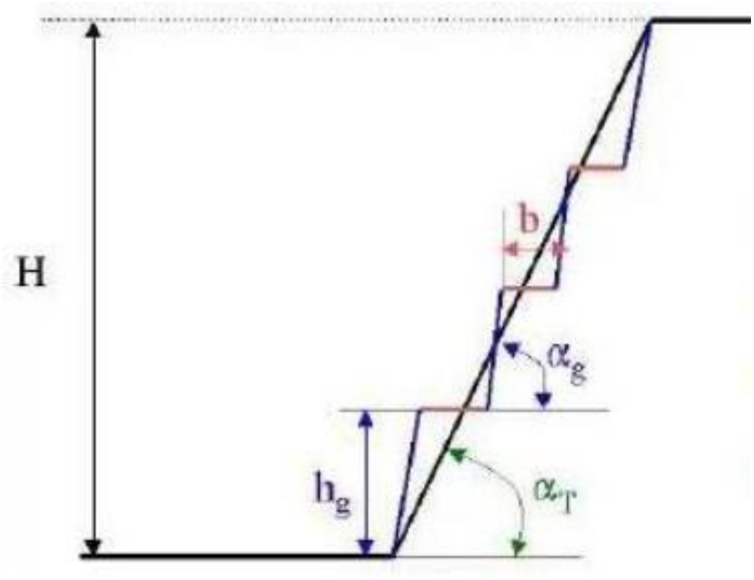


Figure I.2: definition of a mining slope (H: depth of the pit;

αT: general angle of the slope; αg: tier angle, hg: tier height; b: width of the bench). [1].

First of all, the dimensions of a slope consist of the general angle (α) for the ultimate depth of the pit (H). Once the angle is defined, the parameters of the slope (tier, bench, and ramp access) will be chosen by the general angle. [1].

A tier is analyzed as a low-height slope, and its angle (αg) is defined as a slope. The height of the tier (hg) is determined by taking mainly technical considerations into account (available equipment; selectivity criteria). [1]

For a given slope; there's a geometric relationship between depth H, the general angle α, (hg), the angle (αg), width of the bench (with the ramp). [1]

The width of the benches is generally defined in the last place; it allows the circulation and crossing of the used machines in the explorations. [1]

I.2.1. General Angle of the slope:

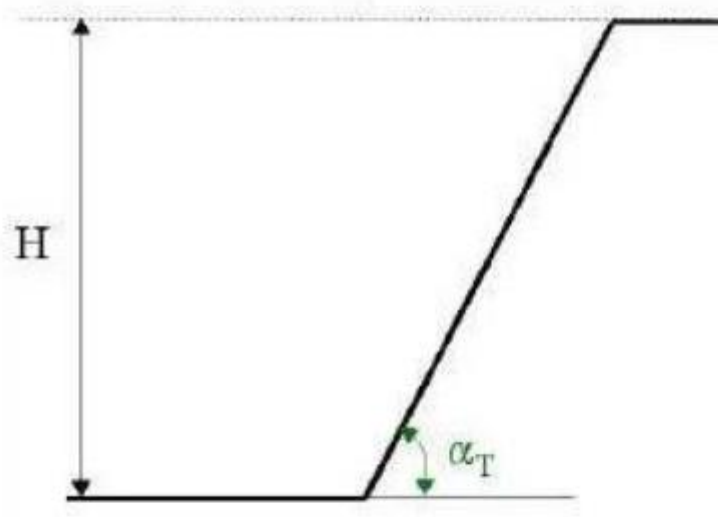
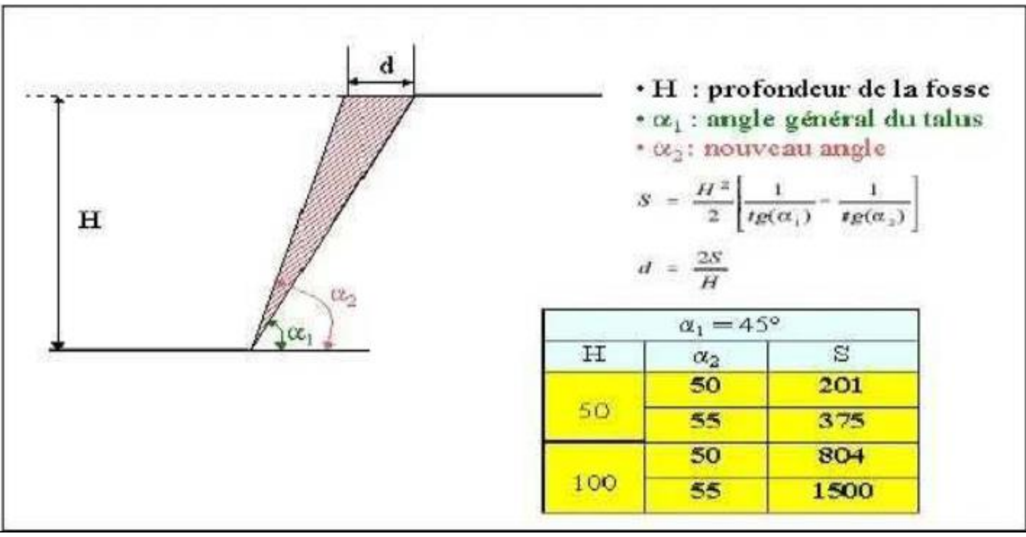


Figure I.3: general angle of the slope. [1]

The maximum depth of the pit is generally defined according to technical and economic criteria (deposit shape, cost of extraction in open pit mining versus underground mining, overdraft rate, etc.). [1]

Once the ultimate depth has been selected, the angle of the slope must be defined to ensure the stability of the exploitation. Moreover, the condition of the angle will largely determine the overdraft rate. There's a trend among engineers to increase this angle in order to reduce the tonnage of the extract sterile (FigureI.4) [1] .



$\alpha_1 = 45°$		
H	α_2	S
50	50	201
	55	375
100	50	804
	55	1500

(The volume of saved land per unit by doing the angle 45°, to 50°and to 55°)

Figure I.4: influence of general angle on the volume of the extract sterile. [1]

I.3. Description of the potential rupture modes

To study stability, it is important to understand the mechanisms of these rupture modes and the conditions of their occurrence. [2]

I.3.1. Landslide definition

Landslides are gravitational movements; they are the rapid collapse of the earth or a mass of rock from a mountain or cliff. Material will be pulled by gravity and pushed downward, which may result in rock falls, topples, debris flows, and sliding. This definition said that landslides usually happen in tropic zones because the rainfall accelerates the mass movement. The climate is one of the causes of landslides (wet tropics) [2]

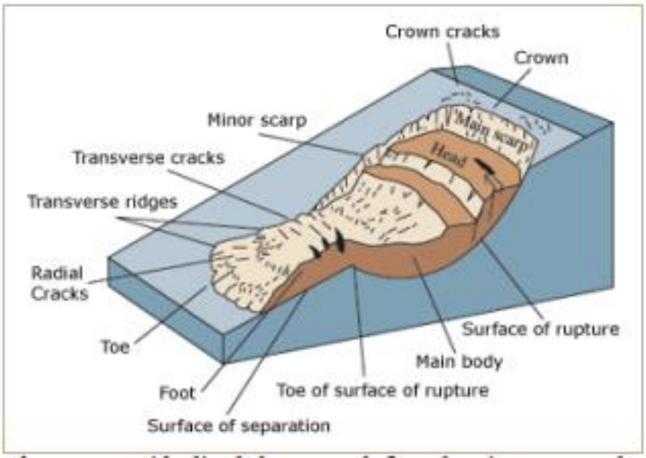


Figure I.5: parts of the landslide [2]

I.3.2. Types of landslides

The types of material involved and the way of movement can be used to distinguish between the many types of landslides. Table I.1 displays a classification scheme based on these criteria. Other classification systems take into account further factors including the rate of movement and the amount of water, air, or ice in the landslide debris. [2]:

Table I.1: Types of landslides Abbreviated version of Varnes' classification of slope movements [3].

Type of movements		Type of material		
		Bedrock	Engineering soils	
			Predominantly Coarse	Predominantly Fine
	Falls	Rock fall	Debris fall	Earth fall
	Topples	Rock topple	Debris slide	Earth slide
SLIDES	Rotational	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
	LATERAL SPREADS	Rock Spread	Debris spread	Earth spread
	FLOWS	Rock flow	Debris flow	Earth flow
		(deep creep)	(soil creep)	
	COMPLEX	Combination of two or more principal types of Movement		

Despite being generally associated with sloped locations, landslides can also happen in places with low relief. Landslides can take many different forms in low-relief locations, including cut-and-fill failures (roadway and building excavations), river bluff failures, lateral spreading landslides, the collapse of mine-waste piles (particularly coal), and a variety of slope failures connected to quarries and open pit mines. Figures I.6, I.7, and I.8 exhibit the following description of the most typical landslide types. [2]

a. Slides:

The more specific application of the term "landslide" only refers to mass movements where there is a clear zone of weakness that separates the slide material from more stable underlying material, despite the fact that many other types of mass movements fall under the general definition of "landslide." Rotational slides and translational slides are the two main categories of slides. Rotational slide: This type of slide has a concave upward surface of rupture, and it moves roughly in a rotation about an axis that is parallel to the ground and runs transverse to the slide (fig. I.6A). A translational slide is one that moves along a surface that is roughly planar with little rotation or tilting backward (fig. I.6B). A block slide is a translational slide in which the mass traveling down slope is made up of just one unit or a small group of closely linked components. (fig.I.6C)[2]

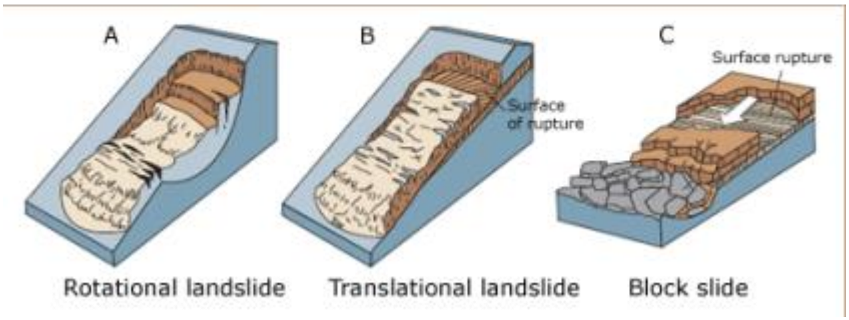


Figure I.6 (A,B,C): These schematics illustrate the major types of landslide movement [2]

b. Falls:

Falls are sudden movements of geologic material masses, such as rocks and boulders, that separate from cliffs or steep slopes (fig. I.7D). Movement happens through free-fall, bouncing, and rolling, and separation happens at discontinuities like fractures, joints, and bedding planes. Gravity, mechanical weathering, and the presence of interstitial water all have a significant impact on falls. [2]

c. Topples

The forward rotation of a unit or units about a pivot point that is below or low in the unit, under the influence of gravity, forces from neighbouring units, or fluids in fissures, distinguishes toppling failures.(fig. I.7E)[2]

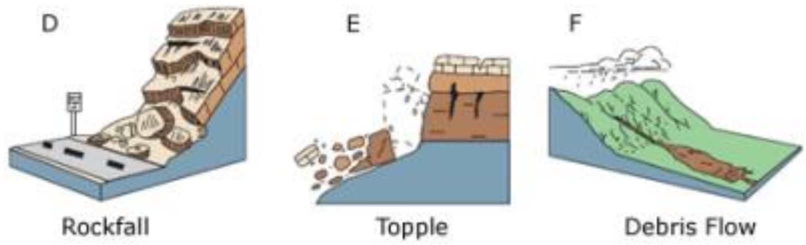


Figure I.7 (D,E,F): These schematics illustrate the major types of landslide movement [2]

d. Flows:

There are five basic categories of flows that different from one another in fundamental ways [2]

- **Debris flow**

When loose soil, rock, organic matter, air, and water mobilize to produce a slurry that runs down slope, it is referred to as a debris flow (fig. I.7F). About 50% of debris flows are fines. Debris flows are frequently created by high surface-water flow that erodes and mobilizes loose soil or rock on steep slopes as a result of heavy precipitation or quick snowmelt. [2]

Other forms of landslides that happen on steep slopes, are almost saturated, and contain a significant amount of silt- and sand-sized material frequently mobilize debris flows as well. Steep gullies are frequently found near debris-flow source locations, and the presence of debris fans at gully mouths typically indicates the existence of debris-flow deposits. Slopes that have been burned down become more vulnerable to debris flows because the vegetation has been destroyed. [2]

- **Debris avalanche**

This is a variety of very rapid to extremely rapid debris flow (fig. I.8G) [2]

- **Earth flow**

The "hourglass" shape of earth flows is a defining feature (fig. I.8H). The material of the slope pours out and liquefies, creating a bowl-shaped depression at the top. It typically happens in fine-grained materials or rocks that contain clay, on moderate slopes, and in saturated conditions. The flow itself is elongate. Granular material flows can, however, also occur dry. [2]

- **Mudflow**

A mudflow is an earth flow that comprises at least 50% of sand, silt, and clay-sized particles and is sufficiently moist to move quickly; in some cases, such as in many newspaper stories, mudflows and debris flows are usually referred to as "mudslides." [2]

- **Creep:**

The gradual, steady descent of slope-forming soil or rock is known as creep. Shear stress that is large enough to create permanent deformation but not enough to cause shear collapse is what causes movement. In general, there are three different kinds of creep: (1) seasonal, where movement occurs within the depth of the soil and is influenced by seasonal variations in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the material's strength; and (3) progressive, where slopes are approaching the point of failure along with other types of mass movements. Curved tree trunks, twisted fences or retaining walls, tilted poles or fences, and minor soil ripples or ridges are all signs of creep. (fig. I.8I) [2]

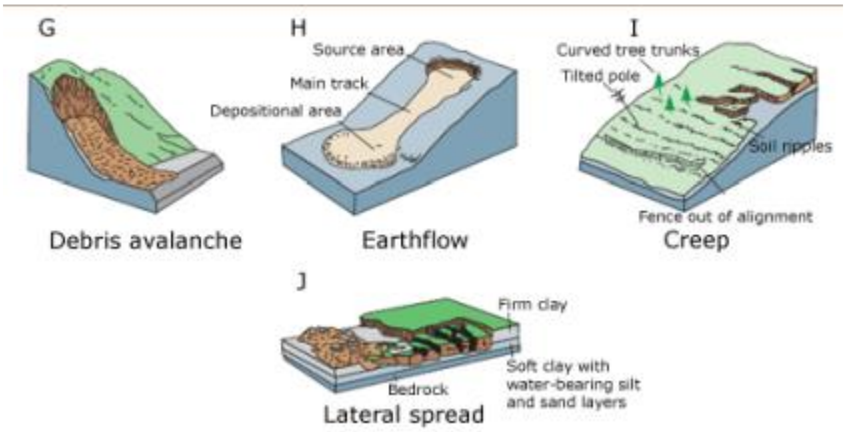


Figure I.8 (G, H, I, J) : These schematics illustrate the major types of landslide movement. [2]

Lateral spreads

Because they typically occur on flat terrain or extremely gentle slopes, lateral spreads stand out (fig. I.8J). With shear or tensile fractures, lateral extension is the predominant mechanism of movement. Liquidification, the process by which saturated, loose, cohesion-less sediments (often sands and silts) are changed from a solid to a liquefied condition, is the cause of the failure can be purposely generated but is typically brought on by sudden ground motion, such as that encountered during an earthquake. The top units may fracture and extend, subside, translate, rotate, disintegrate, or liquefy and flow when cohesive material, such as bedrock or soil, rests on materials that liquefy. Progressive lateral spreading typically occurs in fine-grained materials on shallow slopes. A tiny area experiences an abrupt start to the collapse, which spreads quickly. Although a slump is frequently the first failure, certain materials shift for no apparent reason. Complex landslides are made up of two or more of the aforementioned kinds. [2]

I.4. Rupture causes

Table I. 2: Rupture causes [2]

➢ **Geological causes**
• Weak or sensitive materials • Weathered materials • Sheared, jointed, or fissured materials • Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth) • Contrast in permeability and/or stiffness of materials
➢ **Morphological Causes** • Tectonic or volcanic uplift • Glacial rebound • Fluvial, wave, or glacial erosion of slope toe or lateral margins • Subterranean erosion (solution, piping) • Deposition loading slope or its crest • Vegetation removal (by fire, drought) • Thawing • Freeze-and-thaw weathering • Shrink-and-swell weathering
➢ **Human Causes** • Excavation of slope or its toe • Loading of slope or its crest • Drawdown (of reservoirs) • Deforestation • Irrigation • Mining • Artificial vibration • Water leakage from utilities

I.5. Stability study in an open pit

A slope must be constructed to avoid all potential rupture modes in the exploitation. The geotechnical characteristics of the rock mass that will dictate the rupture that could occur in a slope (natural cracking, mechanical resistance of the ground); the important role of discontinuities in the stability of open pit exploitation All rupture modes are due to shear stresses: sliding along cracks or the absence of oriented cracking. With all these conclusions, it becomes obvious that the stability study of an open pit requires a good geotechnical characterization of the massif rock. [1]

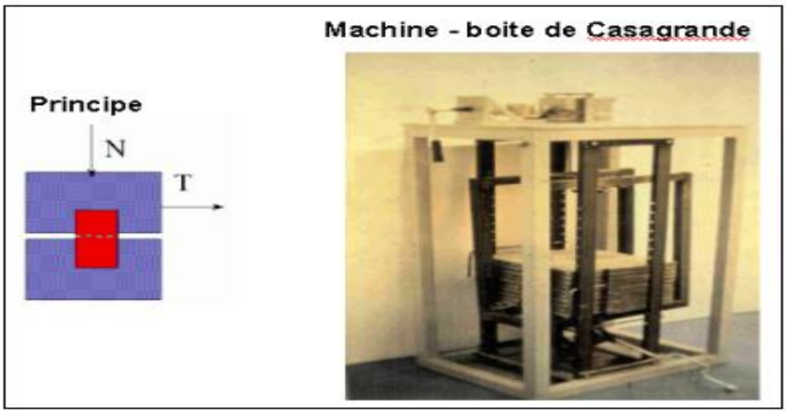
I.5.1. Characterization of the rock mass

The main parameters involved in the stability study of open pit exploitation are:

- The shear strength characteristics of the soil (rock or soil) and natural cracks
- Orientation of the cracks [1]

I.5.1.1. Shear strength

A simple lab-based shear strength test performed in a ‘shear box" A soil sample is positioned in a shear box on a predefined horizontal plane. The specimen is placed under different normal stresses, and the tangential (shear) stress is determined in each case (the consolidation stage). Next, during the shearing stage, a shear stress is applied along the predetermined horizontal plane to work out the shear strength of the sample. [1]



FigureI.9: the casagrande principle test [1]

I.5.1.2. Orientation of the cracks

The orientation of discontinuity is defined by the azimuth and the dip direction; the azimuth is the angle between the horizontal of the plane and the magnetic north clockwise. Instead of the azimuth, the direction of dip is often used, which is the angle between the horizontal projection of the plane normal and the magnetic north, always in the sense of the clockwise direction. Between the azimuth and the dip direction, there is an angle of 90°.. [1]

FigureI.10: Orientation of a discontinuity and measuring equipment. [1]

The banding of the plane is the angle between the horizontal and the line of greatest slope; these two parameters are measured by means of a compass and an inclinometer. . [1]

From a practical point of view, the measurement of the orientations of the cracks in a rock mass consists in defining in a fixed reference mark compared to the zone concerned gallery steps and to take note of the azimuths and the dip of the cracks indicated by their trace on the exposed surface (siding, roof). . [1]

For a more precise characterization of the natural cracking, other parameters can be taken into account.

Once the survey is done, several techniques can be used to identify the main orientation that characterizes the natural cracking of a rock mass. The most common method is stereographic projection. . [1]

I.5.2. Principle of dimensioning

The sizing of embankments in an open-pit operation must be done in such a way as to avoid all potential failure modes. The calculation is different in each case, but the general principle remains the same. To illustrate the principle, the example of the plane break is treated below.

The data of the problem are illustrated in figureI.11. The ultimate depth of the pit is known, and the general angle of the slope must be defined to ensure safety. The massif rock is cut by a main discontinuity parallel to the slope and has unfavourable banding. . [1]

As an example, the discontinuity passes through the foot of the slope. [1].

- The shear strength of the discontinuity is given by the Coulomb criteria:

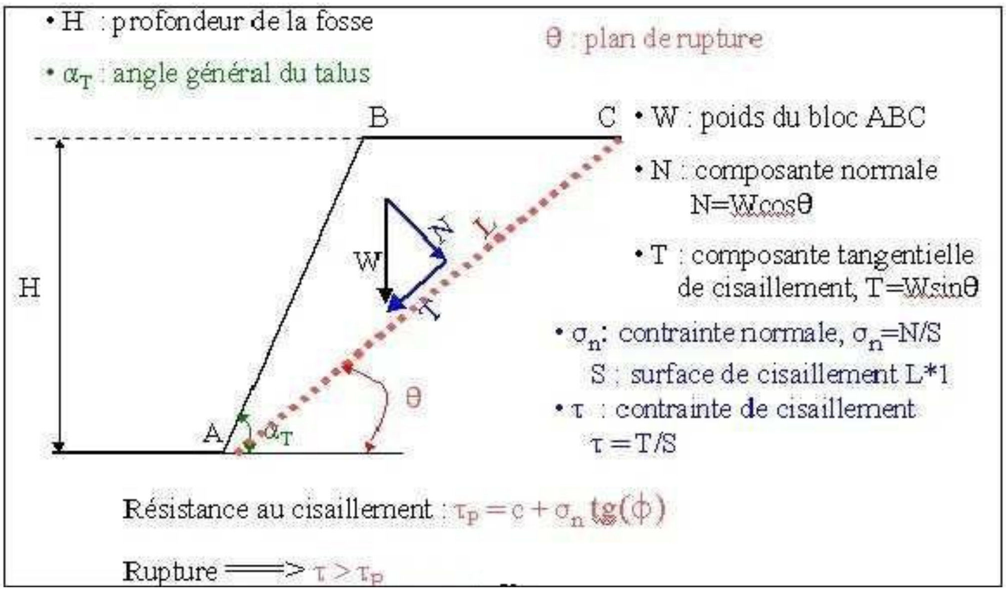
$\tau = C + \sigma n. \, Tan\upsilon$ (1)

In this case, cohesion C is taken into account.

With the following assumption, the case of the rupture by sliding a magnifying glass is treated in the same way; but the equation becomes a little more complicated since the line of the break is not straight but circular. . [1]

The stability study comes down to the establishment of equilibrium equations along the AC slip line; the division of the forces by the sheared surface considering a unit slice leads to the following constraints: . [1]

- Shear and slip occur when the active stress exceeds the shear strength.

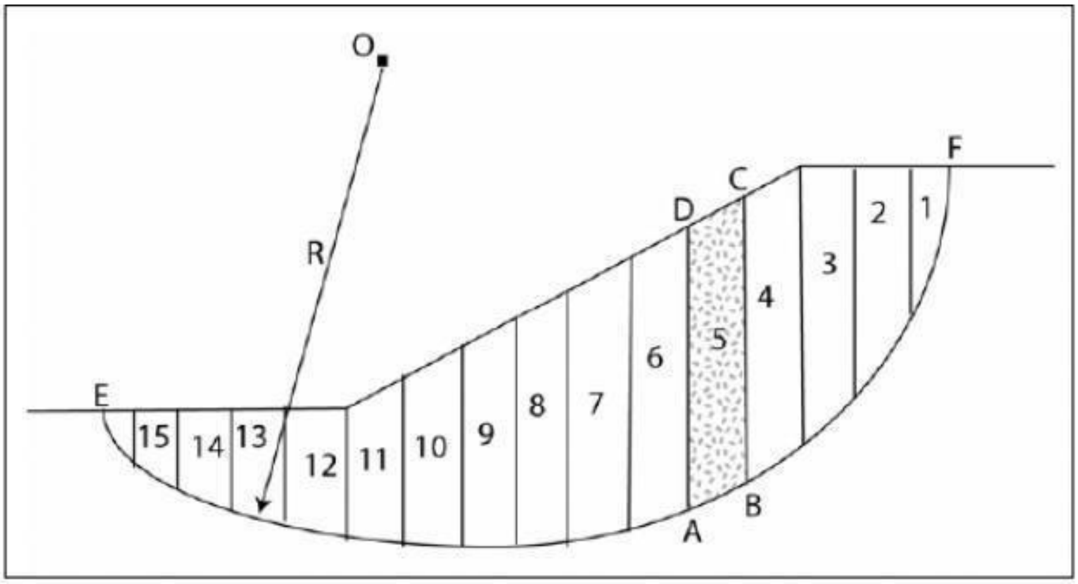


FigureI.11: equilibrium equation along the discontinuity [1].

I.5.2.1. Slice Method

This approach takes into account the forces that tend to hold a specific volume of land, which is defined by the free forces of the slope and a potential fracture surface, as well as the forces that cause it to move [4].

a-



FigureI.12: Cutting of a bank into slices and forces acting on a slice [5].

I.5.2.3. Morgenstern and Price Method (1965)

This method introduces an arbitrary mathematical function to represent the fluctuation of the direction of the forces between the units. Morgenstern and Price develop a function that gives the inclination of the inter-unit forces.

$$\tan\theta i = XE/ = \lambda . f(xi') \qquad \textbf{(2)}$$

Where:

- $\theta \boldsymbol{i}$: is the angle formed by the resultant and the horizontal, and, it varies systematically from one slice to another along the sliding surface;
- λ**:** is a constant that must be evaluated for the calculation of the safety factor;
- $f(xi')$: is the function of variation in relation to the distance along the sliding surface;
- xi': is the linear normalization of the xi coordinates, with the values of the two ends of the fracture surface equal to zero a π.

This method satisfies all the static equilibrium conditions for each slice, as well as the equilibrium of moments and the equilibrium of forces in the horizontal direction, for the whole mass that slides along a circular or non-circular fracture surface [6].

I.5.3. Safety factor calculation

The safety factor is defined as the ratio between the resistance forces and the active forces.

$$\mathbf{Fs}=\frac{\boldsymbol{\Sigma}\ \textbf{resistance strength}}{\boldsymbol{\Sigma}\ \textbf{active strength}} \qquad \textbf{(3)}$$

- In this case the expression of the safety factor becomes:

$$\boldsymbol{fs}=\frac{\boldsymbol{\tau}\mathbf{p}}{\boldsymbol{\tau}}=\frac{\mathbf{c}+\boldsymbol{\alpha}\mathbf{ntg}(\boldsymbol{\varphi})}{\boldsymbol{\tau}}>\mathbf{1} \qquad \textbf{(4)}$$

To ensure security, this factor must be greater than 1. In the case of dimensioning slopes (general stability), a factor of 1.5 is often used.

If we replace the different parameters of the safety factor by their values:

The result is either a component that depends on the friction angle or a component that depends on the cohesion.

Graphs can easily be established to study the influence of the characteristics of the ground (cohesion C, angle of friction, and volume weight). [1]

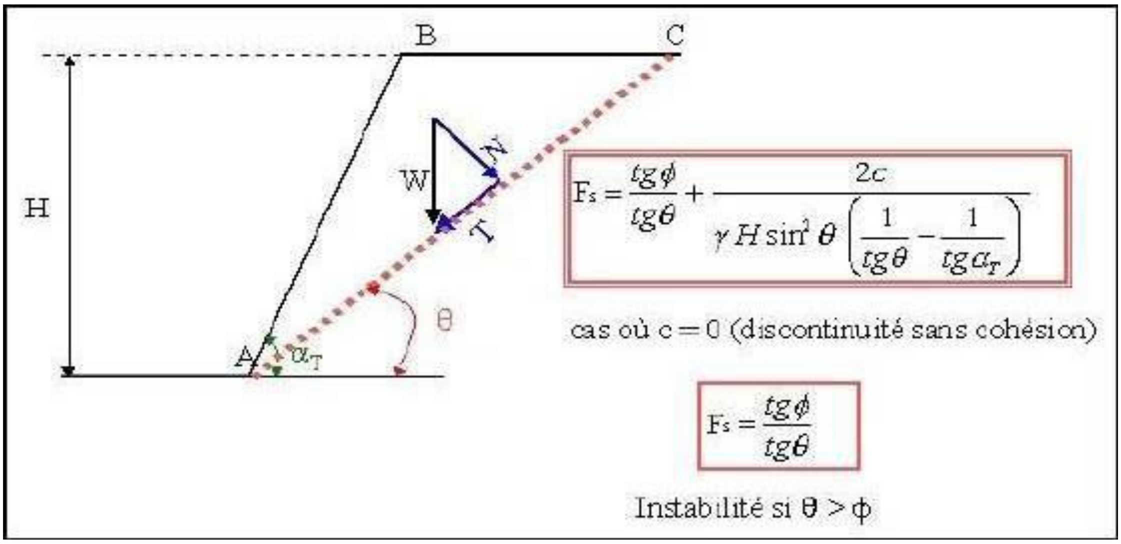


Figure I.13: condition of stability [1]

In practice; we do the opposite calculation: the safety factor is fixed, and the angle of slope is sought to obtain this factor. [1]

It is very easy to see that when the cohesion is zero, the stability conditions are simplified and the criteria are reduced to a comparison between the friction angle and the inclination of the discontinuity figureI.13. [1]

I.4. Conclusion

There are several helpful methods that have been suggested by various searches for the calculation of the stability and safety factor of a landslide and that are still being used the limit equilibrium method of forces.

Stabilizing a landslide is a difficult and delicate task.

From this brief presentation of the stability aspects of open pit mining, the following highlights can be noted:

- The possibility of landslide affects the stability of an open pit operation performs.
- Shear strength and fracture orientation are two geotechnical factors that affect easily the ground to slide.
- The overall angle that must be established for the final depth of the pit controls the stability of the pit principally.

General settings and description of the study area

II.1. Introduction

Algeria is a country rich in mineral resources and various substances (iron, zinc, copper, clays, marble, and phosphates). The majority of its resources are not yet developed; among those resources is a deposit of phosphates in the region of Tebessa (Djebel Onk) in north-east Algeria. The proven resources of this deposit are estimated at more than 2 billion tons of phosphates [7]. They are exploited by the phosphate mining company (SOMIPHOS).

In this chapter, based on the literature review and data collected in the field, we develop a data unit on the study sites, which gives us a general review of the deposits of Djebel Onk (historical, geological, subdivision, and tectonic situation).

II.2. History and methodology of geological research at Djebel Onk

According to the report by [10] written by Cieslinski et al. from 1985 to 1987 [9]

- Algerian phosphates were discovered in Boughari by Thomas Ph. in 1873.
- In the period of 1907–1908, Joleau discovered the deposit of Djebel Onk; more complete information was presented by Dussert.
- In 1924, Dussert D. Provided an ethologic details of the phosphates deposits in the Djebel Onk.
- In 193, the Djebel Onk phosphates were the subject of a first concession by the Constantine phosphates company; which was the main producer in Algeria. Subsequently; a subsidiary was founded by the Djebel Onk Society (S.D.O.) in 1936.
- In 1951 and 1952, the study for the (S.D.O.) phosphate deposit of Djebel DjemiDjema, of which it takes again, with many details, the stratigraphy to evaluate the reserves in all the zones of Djebel Onk.
- From 1961 to 1963, airborne radiometric prospecting tests were carried out over the Djebel Onk deposit.
- In 1963; the geological and mining studies preceding the exploitation of DjemiDjema deposit were carried out by the SERMI Company; for the (S.D.O). At the same time; the French company SOFREMINES drafted a preliminary project for the exploitation of the deposit of Kef Essnoun.
- In February 1965; the exploitation of the DjemiDjema deposit was started.
- From 1971 to 1974, research and prospecting work on phosphates in eastern Algeria was relaunched by SONAREM based on an aeradiometric survey. Then by a

prospecting and evaluation campaign in the Djebel Onk mining district in order to identify additional reserves and better characterize the known deposits.

- In 1986, the Kef Essnoun deposit was recognized in detail by EREM thanks to 32 core holes made with a mesh size of 250 x 300 m and 22 trenches made in the dressers.
- In November 1989, FERPHOS announced its specifications for the development studies of the Djebel Onk mining complex.
- In 1993, BRGM provided a report of geological expertise on all the deposits of Djebel Onk in April 1992. Signature of the contract between Ferphos Company and BRGM Consultant concerning the resemblance of technical and economic elements allowing the stopping of a project for the development of Djebel Onk phosphate deposits

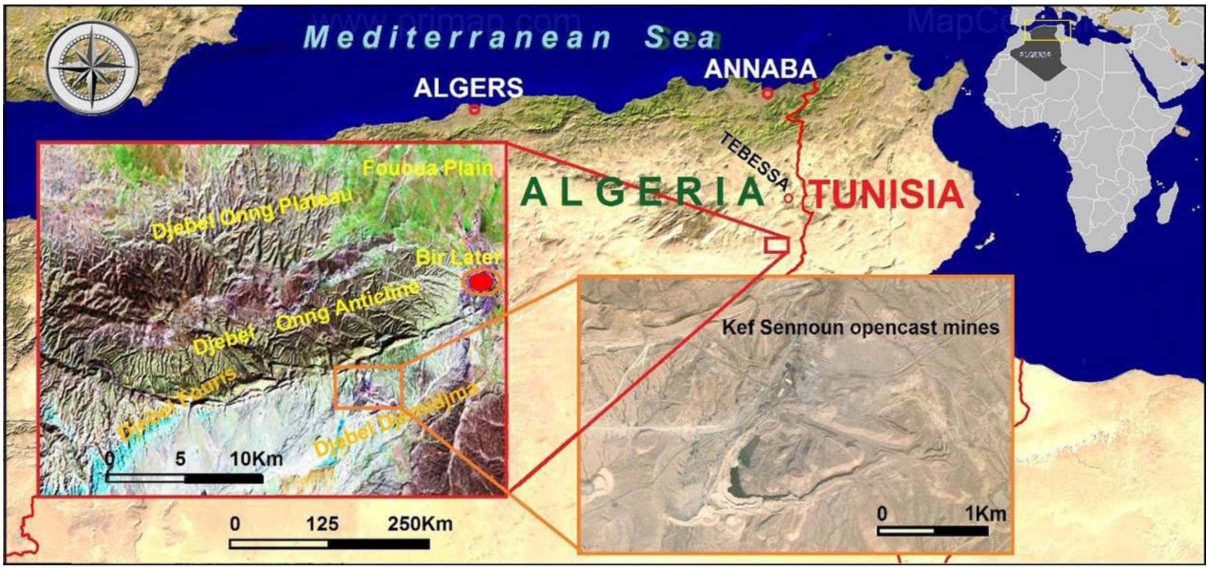
II.3. Geographic location

II.3.1. Geographic location of Jebel Onk

Djebel Onk is located in the north-east of Algeria, at the eastern end of the Nememcha Mountains, the last chains of the Saharan Atlas. It constitutes the natural geographical limit between the Constantinian high plateaux and the Saharan domain. The terrain is semi-desert with a low population [9] [11].

From an administrative point of view, the region belongs to the wilaya of Tebessa, about 100 km to the south and 20 km from the Algerian-Tunisian border, linked to Bir El Ater (Daïra) by road (RN 16).

Topographically and geomorphologically, the Djebel Onk massif forms a 20km-long limestone ensemble that culminates at 1198m (Djebel Tarfaya); the lowest altitudes at the foot of Djebel Onk are around 635m. The terrain is cut by numerous wadi valleys that originate on the northern flank of the area and join up further south. In general, these wadis are dry, except in winter [11].



FigureII.1: Geographical location map of Djebel-Onk [8]

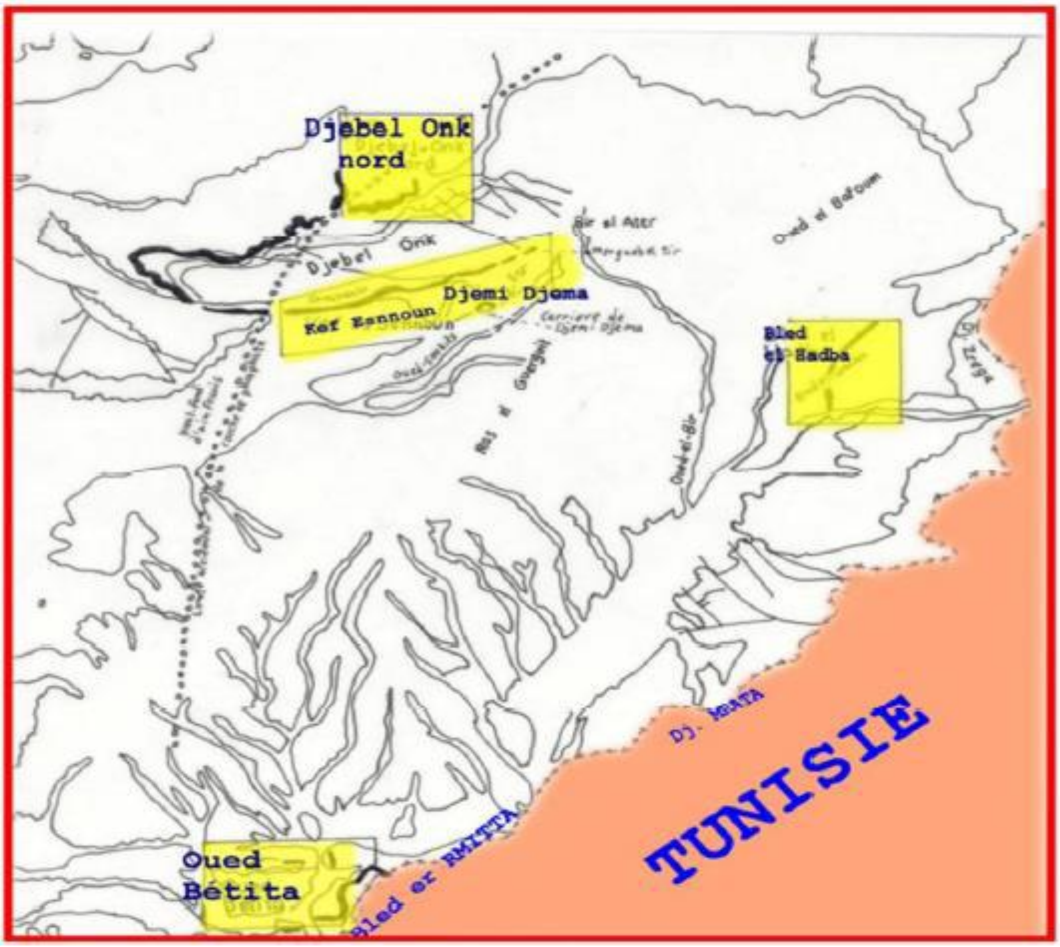
The Jebel Onk basin belongs to the sub-desert climate zone, characterized by two very distinct seasons: a cold and harsh winter and a hot summer where temperatures can exceed 45°.[12]

Rainfall is very low, and the water system is rarely used. The major disadvantage lies precisely in the brutality of the stormy showers that unleash the valleys descending from Jebel Onk. The violence of the periodic rains causes torrential run-off, which floods and can change the former course of some ravines. [12]

Sandstorms are frequent in the dry season. The population is sparse. The economic situation of the region has improved thanks to the installation of the phosphate mining complex at Bir El-Ater, which has contributed to the expansion and development of the town. [12]

The Djebel Onk region is subdivided into 5 mining sectors (Figure II.2):

- DjemiDjema deposit, (South of the Djebel Onk massif) ;
- Kef Essnoun deposit, (South of Djebel Onk massif);
- Djebel Onk Nord deposit, (North of the DjemiDjema mining centre);
- Oued Betita deposit, (South-East of the DjemiDjema mining centre) ;
- Bled El Hadba deposit, (South-East of Djebel Onk).



FigureII.2: Map of the geographical location of the phosphate deposits in the Djebel Onk region [13]

II.3.2. Genesis of phosphate formation

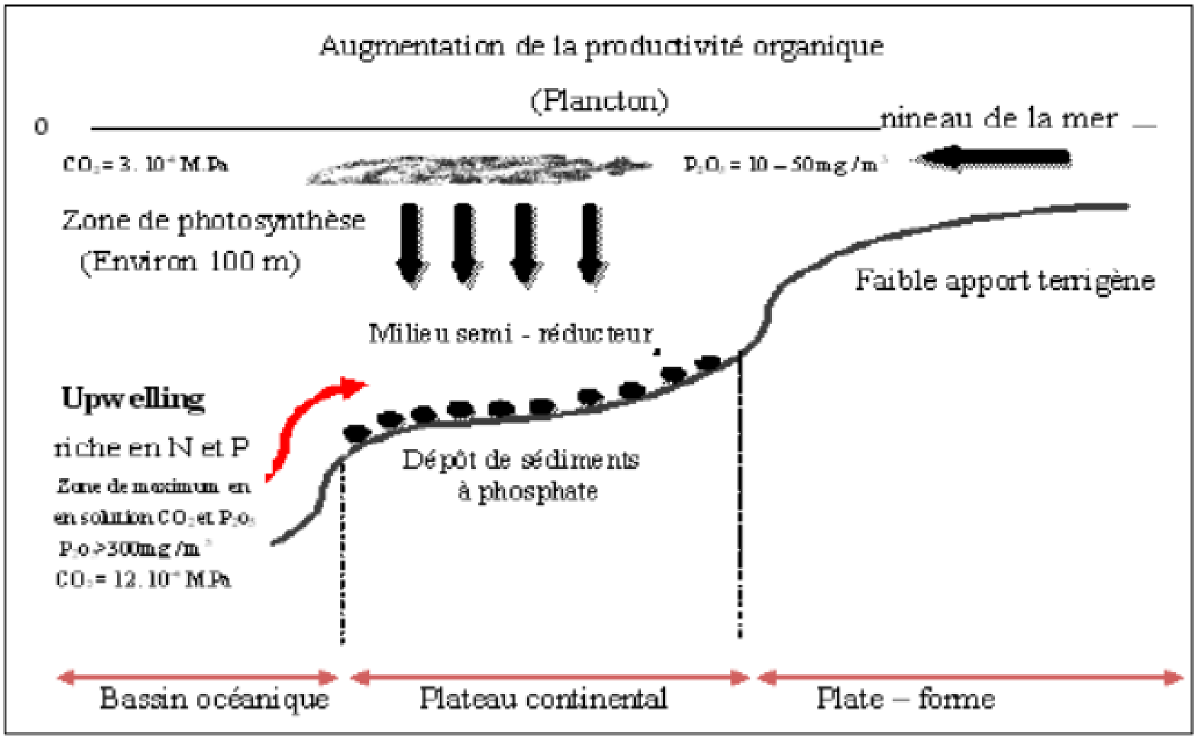
The formation of phosphate deposits is not yet fully understood. There are various theories: some adopt an organic origin, others a non-organic origin, each of which has its own organic origin and has its supporters.

Some researchers suggest that bottom waters are supplied with phosphorus that is mainly released during the putrefaction processes of organisms (biogenetic hypothesis). Others believe that organisms are not the source of phosphate but that it is transported by water. Others believe that organisms are not the source of phosphate but that it is transported by rivers from the continent to the ocean.

There is still a theory linking the volcanic origin of phosphorus to the phases of submarine volcanism [9]. One of the most suitable, hypotheses is that of Kazakov, 1930. This is based on the results of the oceanographic campaign. This work showed that the P2O5 content of seawater increases with depth. The minimum is in the photosynthesis zone, where phosphorus is consumed, while the maximum is at depths of around 500 m. According to this theory, the following stages of phosphate formation can be distinguished:

1. Phosphorus precipitates chemically on the edges of the continental shelf after being brought there by cold updrafts (FigureII.3).

2. Geosynclinal margin deposits provide dark-colored ores with a pseudo-olite structure, a pseudo-olithic structure, a generally clayey exo-gang, and important siliceous and important siliceous formations. This type of deposit would be rather regressive.



FigureII.3: Diagram of phosphato-genesis, [12].

II.3.3. Stratigraphy [12]

The stratigraphy of the Jebel Onk area was established by Visse (1952). The outcropping sedimentary series is expressed by a stratigraphic succession going from the Upper Cretaceous (Maestrichtian) to the Middle Eocene (Lutetian). This series is unconformity by a thick continental sandy-clay series of Miocene age, then by the Quaternary (alluvial deposits and scree). [16].

- **Cretaceous:**

Represents the oldest sediments in the heart of the Jebel Onk anticline, on the Onk anticline, which is tectonically very uneven, only the Maestrichtian deposits outcrop here, the latter is characterized by massive white limestones with marl intercalations [16]

- **Palaeogene:**

These are marine sediments represented by lime stones, phosphates, and gypsum in the region; the Palaeogene reaches quite large thicknesses of 350 m; the lithological variations and the remains of organisms have the following stratigraphic subdivisions: [16]

- **Danian:**

It is conventionally adopted in the Maestrichtian limestone, clay, and marl series. This lithological difference is presented by a subdivision into two distinct series, where we note the separation between the upper and lower Danian, And the Lower Danian. The total thickness of the Danian is about 100 m. [16]

-Lower Danian It is represented by marly schistose clays, dark grey to greenish brown in color, interspersed with grey to greenish brown, interspersed with hard and irregular marls. The whole is crossed by gypsum seams of different orientations.

-Upper Danian Formed by alternating lime stones and calcareous marls, In the upper part of the Danian, we note the presence of a characteristic bench of 1 to 2 m thick, formed of beige limestone with lumachelic overlaid by white marl in white platelets. It is in this layer that the first thin levels (10 to 30 cm) appear. Thin levels (10 to 30 cm) of phosphate marl appear**.**

- **Montien**

This stage is marked by the presence of a series of lime stones, detrital lime stones with lumachelic with intercalations of marl and dolomite; these sediments are characterized by the absence or small quantity of flint. The oysters are abundant, on gray to black banks. [16]

- **Thanetian**

This is the horizon that carries the mineralization. It is visible on the flank of the Djebel Onk anticline with a thickness of 72m. It is subdivided into two parts: [16]

- Lower Thanetian Represented by schistose marl, In the upper part of the Lower Thanetian appear phosphate intercalations up to 2 m thick and very rich in organic matter, surmounted by lime stones and marls with large gastropods. The thickness varies from 30 to 40 m.

-Upper Thanetian presents pseudo-lithic and cupro-lithic phosphates, It begins with a dolomite level with gastropods, underlying a phosphate layer 30 m thick on average at Djebel Onk and at Bled El Hadba, which decreases until it disappears towards the north, west, and south of the deposit. This deposit generally ends with a lumachelic level. [16]

- **Eocene:**
  - **Ypresian**

It rests directly on the Thanetian deposits and outcrops in the DjemiDjema quarry and to the north of Djebel Onk. It is 32 m thick.

-Lower Ypresian It is represented by limestone with flint lenses and phosphate-bearing limestone. The average thickness of the Lower Ypresian is 30 m at its maximum.

-Upper Ypresian It is made up of alternating limestone, dolomite limestone and marl. Dolomite and marl, its thickness is 2 to 3 m. [16]

- **Lutetian**

The formations of this stage cover in concordance the Ypresian series; they are widespread in the region of Djebel Onk. We distinguish: [16]

-Lower Lutetian is characterized by limestone and dolomite with quartz geodes.

-upper Lutetian is characterized by the presence of gypsum with inter bedded marl. Its thickness can reach 100 meters.

- **Neogenous**

The Neogene is characterized by a sandy-clay facies of continental type with a thickness of about 600 m. [16]

- **Miocene**

The dating of the Miocene rocks has been done thanks to the discovery of rare fossils (Helix Tissiti). Fossils (Helix Tissiti) are formed essentially by sediments, represented by terrigenous rocks and sandy shale, while the sediments of the region of Bled El Hadba are composed of numerous solidified fragments [16]

The Miocene is subdivided into three units, from bottom to top:

- **Lower Miocene** is represented mainly by conglomerates and sands; with thin beds of siliceous clay, its thickness reaches more than 200 m.

-**Middle Miocene** is essentially clayey, sometimes shaly, with intercalations of fine and medium-grained sands. The thickness is about 100m.

-**Upper Miocene** a sandy-clay-conglomeratic series.

- **Quaternary**

It is essentially represented by slope scree, sandy deposits, eolian deposits, gravels, and alluvial and fluvial deposits. [16]

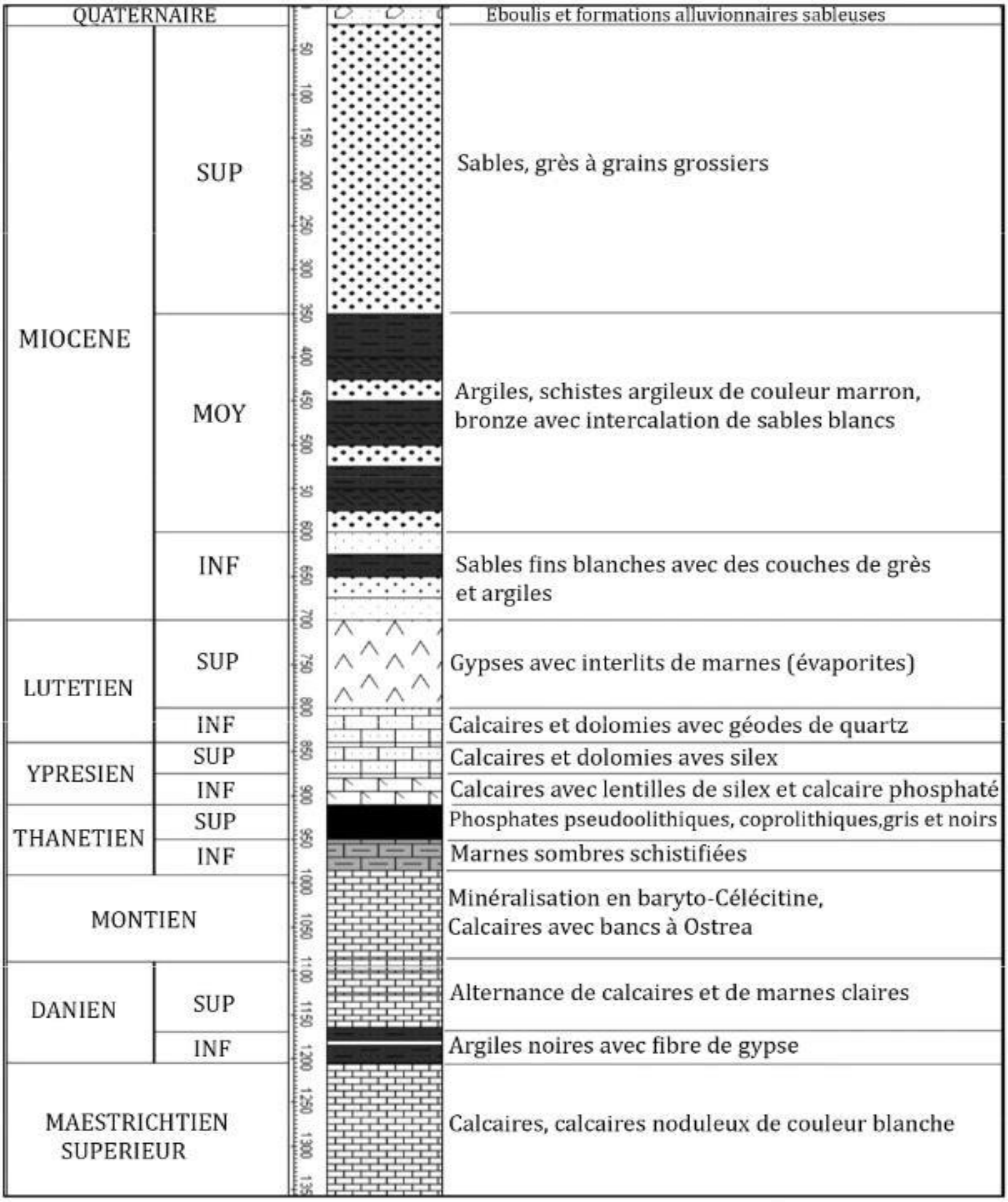


Figure II.4: Stratigraphic column of the Jebel Onk region [9]

II.3.4. Tectonic

Ranchin (1963-a, and 1963-b) deduced that the Djebel Onk region belongs to the eastern end of the Saharan Atlas. The upper series of Eocene age in the Djebel Onk-Gafsa-Metlaoui basin is structured in a series of asymmetrical anticlines and synclines, generally faulted in their flanks, with a most often SW-NE axis, and unhooked by transverse accidents from N 120° to N 140° E.

The anticlines of Djebel Onk, Djebel DjemiDjema, and Oued Betita are located at the edge of the South Atlas flexure, which corresponds to an outcrop zone between the mobile Atlas domain and the stable Saharan platform. They belong to the northern branch of the South Atlas flexure with an E-W direction. The Djebel Onk anticline extends from the Nememcha Mountains to the east as a pericline under the Miocene formations in an E-NE direction.

This anticline is asymmetrical on the southern flank, with a dip of 80° and a northern flank of 10°. [14].

II.4. Geographical location of Kef Essnoun

According to the EREM (Entreprise de Recherches et d'Exploitation Minières) report by Cieslinski et al., from 1985 to 1987, the Kef Essnoun deposit was located in the south of the Djebel Onk massif, 4 km from the town of Bir El Ater, and the administrative headquarters of the region (Daïra) was 2 km west of the DjemiDjema deposit between the Djebel Fouris and the Djebel Tarfaya. Its surface area, circumscribed by reconnaissance drilling, is 2.1 km2, i.e., 2.7 km in length and 0.8 km in width. [10]

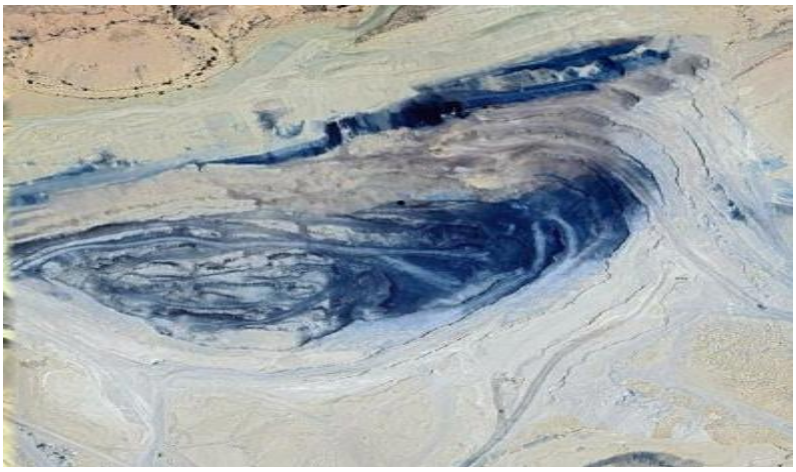


Figure II.5: kef Essnoun open pit (Google earth. 2023)

Topographically, the area of the deposit, located at the foot of Djebel Kef Essnoun, constitutes a plateau sloping gently towards the South-West. The topographic heights vary from 720m in the south-west to 810m in the north-east (north side). The deposit is located at the following coordinates: x = 951.500 and y = 168.0 to 170.0.

The geology of the Kef Essnoun deposit was summarized by Cieslinski et al., 1985–1987. Kef Essnoun is located in the southern extension of the antiformal flexure of Jebel Onk, whose major structuring is due to post-Miocene tectonics.

The geology of the Kef Essnoun deposit is relatively simple. The total geological reserves of this deposit have been estimated at 317 million tons of ore, consisting of 26.53% P2O5 and 2.61% MgO. Proven reserves are 168 million tonnes, probable reserves are estimated at 50Mt (slope break zone, south of the table) and 99Mt possible in the deeper parts of the deposit. [10]

II.4.1. History of the Kef Essnoun deposit search

The deposit of Kef Essnoun was recognized in detail by EREM during the year 1986. Thanks to 32 cored drillings carried out with a mesh of 250 x 300 m, the depth of the recognition work reached 250m in the right of drilling number 7. In addition to the drillings, the company carried out, on the flanks of the deposit, 22 trenches whose depth varies from 1 to 2m and whose width is 1m (figureII.6). [10]

Older data comes from research carried out by G. Ranchin in 1963. We also note the realization of three drillings and some trenches in the slopes of Kef Essnoun by SONAREM (Société Nationale de Recherche ET d'Exploitation Minières). [13]

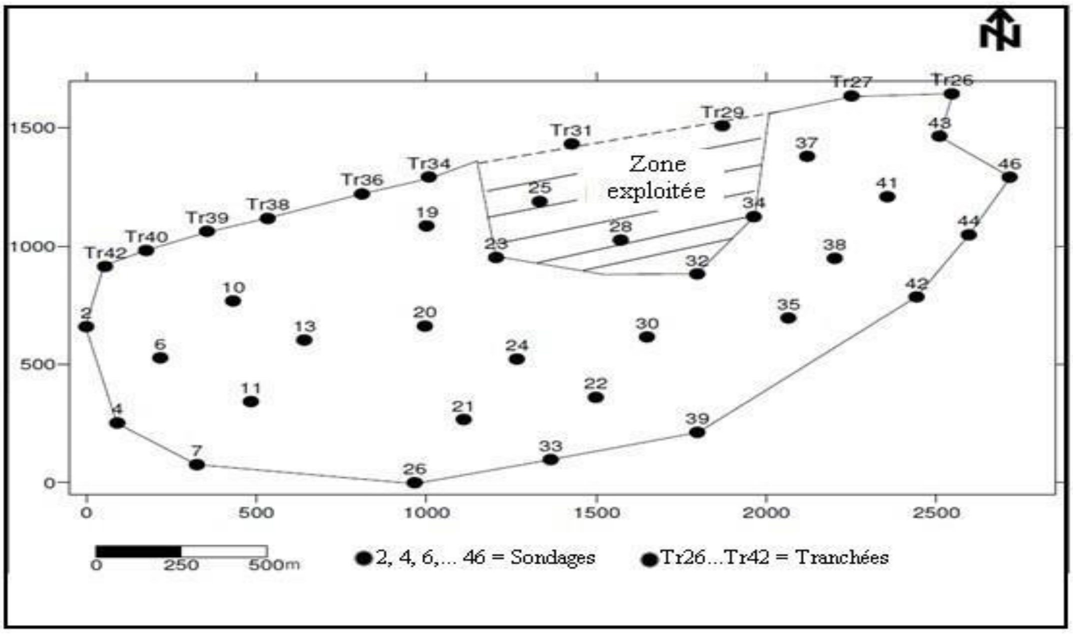


Figure II.6: Situation of the boreholes and trenches of the Kef Essnoun deposit - Djebel Onk - Eastern Algeria – [15].

II.4.2.Stratigraphy

The lithological succession encountered at Kef Essnoun is practically the same as that of Djebel Onk, but it differs by a greater vertical thickness of the phosphate beam, which varies up to 53 m in certain drill holes. According to Cieslinski et al. (1985, 1987) and Prian and Cortiel (1993),

- The Lower Thanetian formations, which form the wall of the phosphate cluster, are represented by dark, laminated marls in which two sub-meter thick levels of dolomite phosphates are locally intercalated in the lower part; [11]

- The phosphate beam, belonging to the sedimentations of the Upper Thanetian, is constituted by a homogeneous layer of phosphate without sterile intercalation;

- The Ypresian flinty calcareous-dolomite series appears at the top of the phosphate bundle, above which the Lutetium lime stones are deposited locally, followed by Miocene sands and, lastly, recent Quaternary deposits consisting essentially of alluvium. The total thickness of the barren overburden varies from 40 m in the north to 198 m in the south. [11]

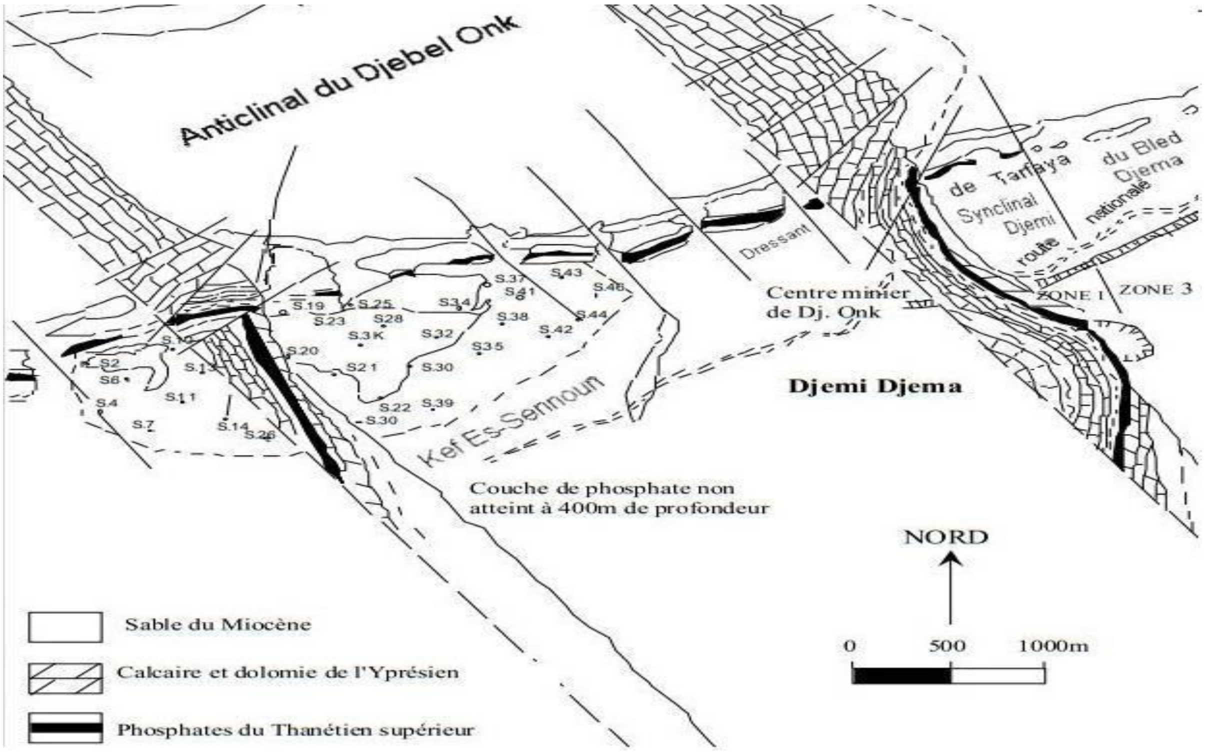


Figure II.7: Structure of the phosphate layer in the Kef Essnoun area and location of core holes [11].

II.4.3. Tectonic

The structure of the Kef Essnoun deposit is due to post-Miocene tectonics. It is simple and presents itself in the form of a monoclinal table with a regular dip, at an angle of 5 to 10° towards the south. To the south of the table, there is a slope break zone where the dip of the layers reaches 20°. A series of three major NNO-SSE steering faults, cross the deposit but do not cause major deformations in the geometry of the phosphate layer. On the other hand, the soft, brittle tectonics on the slopes of the steep deposit caused a sudden change in the dip of the outcropping phosphate layer, where the dip angle is very strong towards the southeast or northwest. These flanks are represented by the Paleocene (Danien-Montien and Thanétien) and Lower Eocene (Ypresian) formations corresponding to the flexure fault zone of the Djebel Onk anticline inverse flank [7]. In the north-east of the dressants, the series is reversed, and the phosphate layer dives at an angle of 30° to 60° towards the northwest. On the other hand, in the central part of the steep slopes, the phosphate layer is in a normal series and sinks southward [7].

II.4.4. Hydrogeological overview

From a hydrological point of view, according to the National Resources Agency Hydraulic (ANRH), the Kef Essnoun field is located in the large basin Chott Melrhir, whose area is around 68751 km2 and where there are several hydrometric stations.

II.4.5. Surface water

The surface waters of the Kef Essnoun region, which is part of the Saharan waters, mark their presence only during the rainy period by small wadis (Tarfaya, Abiod, El Bir, Regou, etc.), which flow from the north to the south. The study of the chart of the river system allows us to confirm, with the exception of a few wadis that originate in the neighbouring regions of the North, which the sources of all wadis come from the steep. The flow rate and velocity do not become significant until after the confluence of all the wadis in the south-western part of the region at the level of the EI-Abiod wadi as it drains the waters southward to the final discharge Chott Melrhir [9].

II.4.6. Groundwater

The Hydrogeological study of the Bir El Ater region highlighted the following aquifers [9]:

- The alluvium of the quaternary

- The sands of the Miocene
- The marly gypsiferous lime stones of Lutetian;
- The Ypresian flint lime stones;
- Lime stones of the Dano-Montien;
- Compact, cracked lime stones of the Mæstrichtian.

These aquifers are fed by the infiltration of atmospheric precipitation and the drainage of neighbouring aquifers. Their water importance is low overall. Near Djebel Onk in the Kef Essnoun area, these formations are devoid of water and have no aquifers. In 1986, the E.R.E.M. carried out 32 boreholes ranging in depth from 76 m to 250 m, and no borehole reported the presence of water. [9].

II.5. Conclusion

The richest pole of Algerian phosphates is the region of Djebel Onk, which is situated in the country's northeast. L. Joleau made the discovery in the years 1907–1908. Since its discovery, multiple prospecting operations including the mining boom; which has gained enormous international popularity have been conducted out by several mining research departments.

Phosphate minerals in the Djebel Onk area date back to the Thanetian age. Near Kef Essnoun, where the exploitable phosphates are thicker, the maximum vertical thickness of the phosphate beam ranges up to 53 m. The phosphates that can be exploited have a thickness of around 30m.

The Djebel Onk region is separated into five mining sectors: the Oued Betita deposit, the Djebel Onk North deposit, the DjemiDjema deposit, and the Bled El Hadba deposit.

Chapter III

PART I: stability analysis and prediction of safety factor

III.1. Introduction

In this chapter, we build a comprehensive analysis of the study site based on documentary analysis and data gathered in the field.

In part one; Slope stability is important in various applications of mining engineering, such as excavated slopes; We use Limit equilibrium (LE) methods with a Mohr Coulomb collapse criteria are frequently used in routine geotechnical study to analyze the failure initiation of slopes using a 2D approximation that as closely as possible matches the worst possible scenario. It involves analytic and numerical analyses; the purpose of slope stability is to calculate the factor of safety using geometric models and to predict different scenarios at the site of an open pit.

In part two; With the use of data gathered from society for all the different levels of coordination and the three geological layer formations consolidated from the bore hole, the topographic plane of the mine has been digitalized. We can create designs for several maps with the aid of the program surfer; the first one is a contour map, 3D mine, geological profile, and digitized map.

III.2. Stability analysis

III.2.1. Overview of the Kef Essnoun Field

The phosphate deposit at Kef Essnoun is significant. The exploitation and processing of its ore are given priority and strategic character by its closeness to existing processing facilities, the quality of its ore, its industrial grade reserves, and its technological opening criteria.

III.2.2. Geo-mining characteristics of Kef Essnoun

The geo-mining characteristics have been determined by CERAD and are summarized in:

- Presence of significant tectonics in the North (dressants area);
- Good ore quality (an average of 26.53% P205 and low in MgO with an average grade of 2.61%;
- Its operational simplicity (depth less than 100 m, high power of (25 to 35 m);
- Easy access to other parts (extension and advancement).

III.2.3. Open pit methods and parameters

The Kef-Essnoun mine is an open pit mine that resembles a pit by way of multiple bleachers; the recovery factor is one to two; therefore two grades of waste rock must be removed for every grade of ore that is removed. The ore steps in the centre of the pit and the waste rock steps on the sides are there for this purpose.

III.2.4. Exploitation parameters

The operating parameters chosen for F21 are shown in the table III.01, taking into account the geomorphologic conditions of the deposit and the suggestions from DMT.

Table III.01: exploitation parameters summary table of parameters operating. [17].

DESCRIPTION	Marl	sterile	Phosphate
STEP HEIGHT IN (m)	15	15	15
SLOPE ANGLE IN (degree)	30	70	70
SAFETY BERM IN (m)	/	Mini6	Mini6
WORKING PLATFORM IN (m)	≥ 40	≥ 40	≥ 40
THE WIDTH OF THE SLICE IN (m)	20	20	20
THE CHANGING OF THE SLICED MAXIMUM IN (m)	/	300	300
MAXIMUM SLOPE IN %)	10		

III.3. Physical and mechanical properties

In our case study, the parameters used were taken from the database available and communicated by the company. They come from previous tests carried out at a laboratory.

The physical-mechanical properties of the flank of Kef Essnoun are presented in the tables

III.3.1. Uni-axial compressive strength

According to the results, the limestone and marl layers are classified as moderate strength; the phosphate layers are classified as weak.

Table III.2: Results of uni-axial compression tests. [18]

Type of sample (each layer)	**Uni-axial compressive strength (MPa)**
Layer1: Limestone	**34.1**
Layer2: Phosphates	**10.2**
Layer3: Limestone/ conglomerate	**34.1**
Layer4: Marls	**21.6**

III.3.2. Tensile strength

The data shown on the table III.3 simultaneously leads us to categorize the limestone and marl layers of phosphate as having moderate resistance.

Table III.3: Results of Tensile strength tests [18]

Type of sample (each layer)	**Tensile strength (MPa)**
Layer1: Limestone	**2.5**
Layer2: Phosphates	**1.8**
Layer3: Limestone/ conglomerate	**2.5**
Layer4: Marls	**2.9**

III.3.3. shear strength

The results of the shear strength lead us to deduce that limestone, phosphate and marl are resistant

TableIII.4: Results of shear strength tests [18]

Type of sample (each layer)	Shear strength(MPa)
Layer1: Limestone	**64.4**
Layer2: Phosphates	**78.3**
Layer3: Limestone/ conglomerate	**64.4**
Layer4: Marls	**83.6**

III.3.4. Point loading index

Table III.5: Point loading index of the samples [18]

Type of sample (each layer)	Point loading index (MPa)
Layer1: Limestone	**2.2**
Layer2: Phosphates	**1.0**
Layer3: Limestone/ conglomerate	**2.2**
Layer4: Marls	**1.6**

III.3.5. Sample cohesion

Table III.6: Sample cohesion [18]

Type of sample (each layer)	Sample cohesion (KPa)
Layer1: Limestone	**1800**
Layer2: Phosphates	**1150**
Layer3: Limestone/ conglomerate	**2700**
Layer4: Marls	**0**

III.3.6. Angle of internal friction of the sample

Table III.7: Angle of internal friction of the sample **[**18]

Type of sample (each layer)	**Angle of internal friction of the sample**
Layer1: Limestone	**37 °**
Layer2: Phosphates	**37 °**
Layer3: Limestone/ conglomerate	**37°**
Layer4: Marls	**15°**

III.3.7. Young modulus

Table III.8: Young modulus of samples [18]

Type of sample (each layer)	**Young modulus (MPa)**
Layer1: Limestone	**5200**
Layer2: Phosphates	**4600**
Layer3: Limestone/ conglomerate	**5200**
Layer4: Marls	**3600**

III.3.8. Poisson's ratio

Table III.9: Poisson's ratio of samples [18]

Type of sample (each layer)	**Poisson's ratio**
Layer1: Limestone	**0.21**
Layer2: Phosphates	**0.24**
Layer3: Limestone/ conglomerate	**0.21**
Layer4: Marls	**0.14**

III.3.9. Specific gravity

Table III.10: Specific gravity of samples [18]

Type of sample (each layer)	**Specific gravity**
Layer1: Limestone	**2.19**
Layer2: Phosphates	**2.21**
Layer3: Limestone/ conglomerate	**2.19**
Layer4: Marls	**2.06**

Tables on cohesion, unit weight, and friction angles present the different geotechnical parameters that describe the different layers that compose the open pit. These Characteristics are the main input parameters to analyze the stability of different.

Suggested models that were obtained from different cross sections from the top to the bottom of the open pit along a slope of manmade using the exploitation method of benches and cuts

III.4. Classification of the rock massifs in the flank of the mine of Kef Essnoun

III.4.1. Evaluation of joints, bedding plane and cracks

- **Limestone**

The limestone has massive bedding with direction 70E/40S and strength R5 with good surface conditions; weathered slightly category is III; it has a high roughness surface; and the joint direction is 45E/45N.

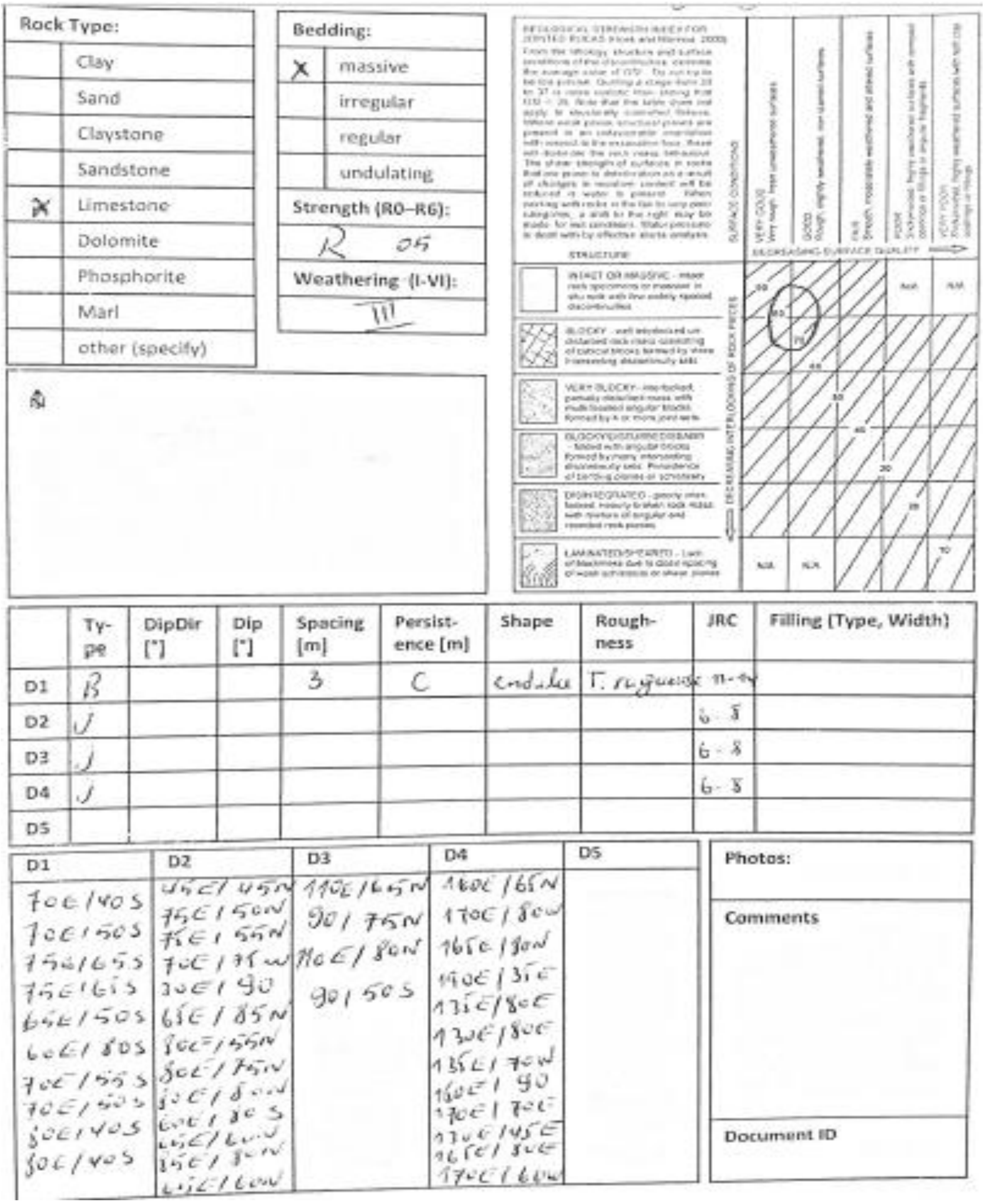
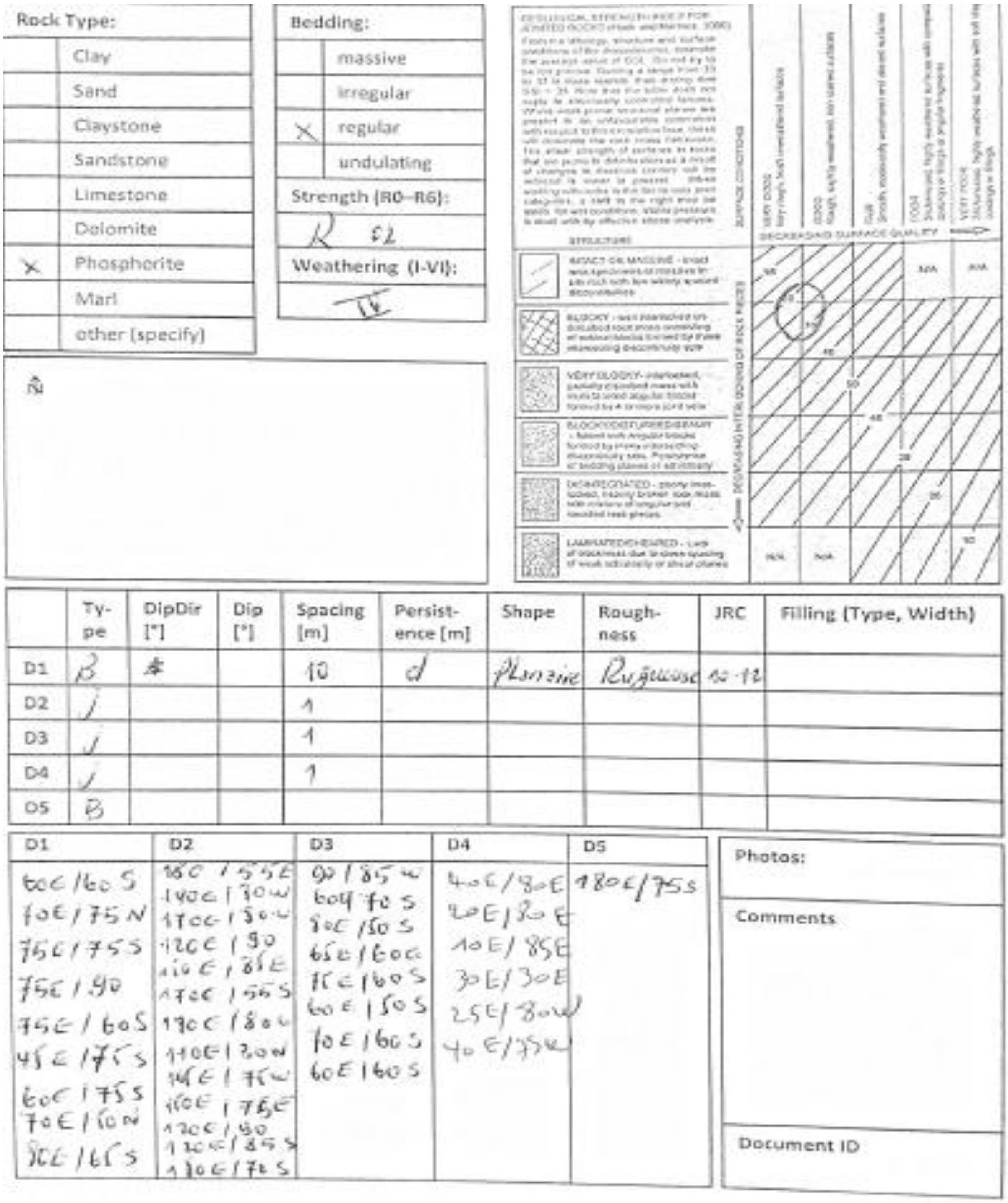


Figure III.1: Observation and characterization of discontinuities [18]

- **Phosphate**

The phosphate has a regular bedding plane with direction 70E/60S and strength R2 with good surface conditions; the weathering category is IV; it has a high roughness surface, and the joints direction is 140E/70W.



Rock Type:	
	Clay
	Sand
	Claystone
	Sandstone
	Limestone
	Dolomite
X	Phosphorite
	Marl
	other (specify)

Bedding:	
	massive
	irregular
X	regular
	undulating
Strength (R0–R6):	R2
Weathering (I-VI):	IV

	Type	DipDir [°]	Dip [°]	Spacing [m]	Persistence [m]	Shape	Roughness	JRC	Filling (Type, Width)
D1	B	*		10	d	Planaire	Rugueuse	10-12	
D2	J			1					
D3	J			1					
D4	J			1					
D5	B								

D1	D2	D3	D4	D5
60E/60S	180/55E	90/85W	40E/80E	180E/75S
70E/75N	140E/30W	60W/70S	20E/80E	
75E/75S	170E/30W	90E/50S	10E/85E	
75E/90	120E/90	65E/60E	30E/30E	
75E/60S	110E/85E	75E/60S	25E/80W	
45E/75S	170E/55S	60E/50S	40E/75W	
60E/75S	190E/80W	70E/60S		
70E/60N	110E/30W	60E/60S		
90E/65S	140E/75W			
	160E/75E			
	170E/90			
	130E/85S			
	130E/75S			

Photos:

Comments

Document ID

Figure III.2: Observation and characterization of discontinuities [18]

It has been divided into two categories based on the characteristics of the structural discontinuities:

Those of a geometric nature that control the dimensions, shapes, and locations of the rock fragments or blocks, and which have an impact on the direction and distance between the discontinuities

Hard rock massifs, which have to do with the persistence of the discontinuities, the apertures, the filling of the discontinuities, and the resistance from the wall, dictate the resistance along the discontinuities.

III.5. Safety Factor Calculation

In order to assess slope stability, the safety factor (Fs) is commonly utilized. This aspect refers to the interaction between the driving force and the resisting force. The values of the safety factor can be used to assess the stability of the slope, as shown in Table III.11 below. **[19]**

Table III.11: Slope balance based on theoretical safety factor value [19]

Safety factor Fs	State of the work.
Fs<1	Danger.
Fs=1	Limit stability
Fs є] 1, 1.25 [	Questionable security.
Fs є] 1.25, 1.40 [	Satisfactory safety for minor works but by Against this is questionable security for the slopes of open quarries.
Fs >1.4	Satisfactory security

At the end of the experiments a classification was proposed by the International Society of Rock Mechanics in Table III.12 below

Table III.12: Slope equilibrium based on experimental safety factor values [19]

Fs < 1	**Unstable slope**
1 < Fs < 1.5	**Possible slippage.**
Fs > 1.5	**Generally stable**

III.6. Slope stability analysis using Geostudio (Geo-slope software)

III.6.1. Presentation of the geo-slope software

A tool called GEO-SLOPE that calculates slope stability enables modelling of geotechnical and geo-environmental issues. The safety factor of sloping masses made up of one or more layers of soil, with or without the presence of a water table or suction, etc., can be calculated using the slice approach using this computer-aided design application.

SLOPE: safety factors of a slope can be calculated using traditional analysis techniques (Bishop, Janbu, Spencer, Morgenstern-Price, etc.).

III.6.2. Stability modelling by Geostudio (Geo-slope software)

- **topographic update**

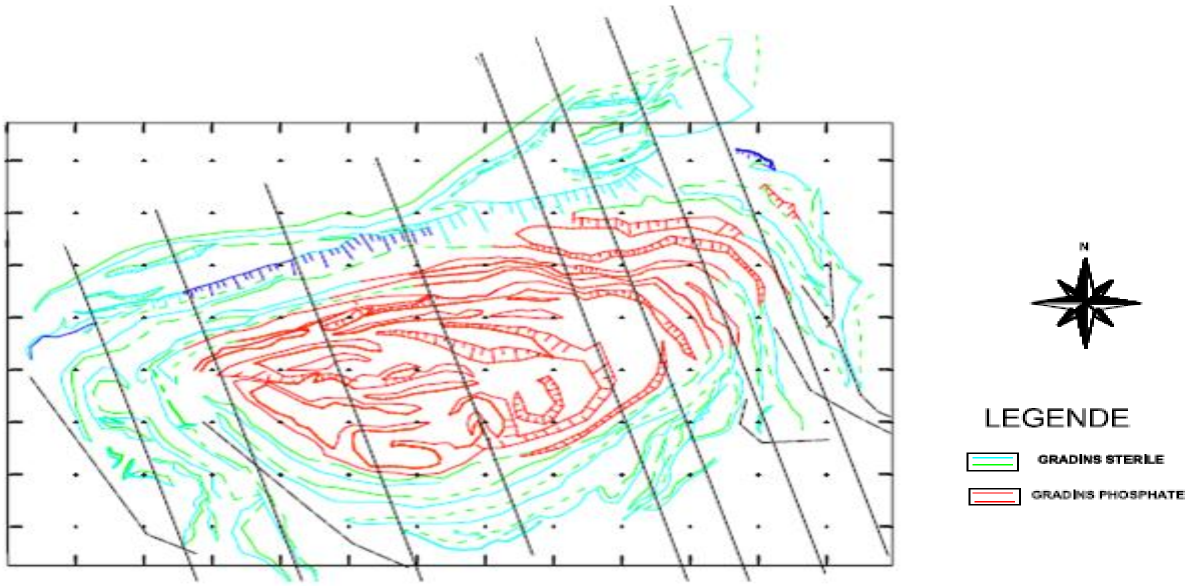


Figure III.3: topographic update kef Essnoun

III.6.3. Geological cross-section KEF ESSNOUN

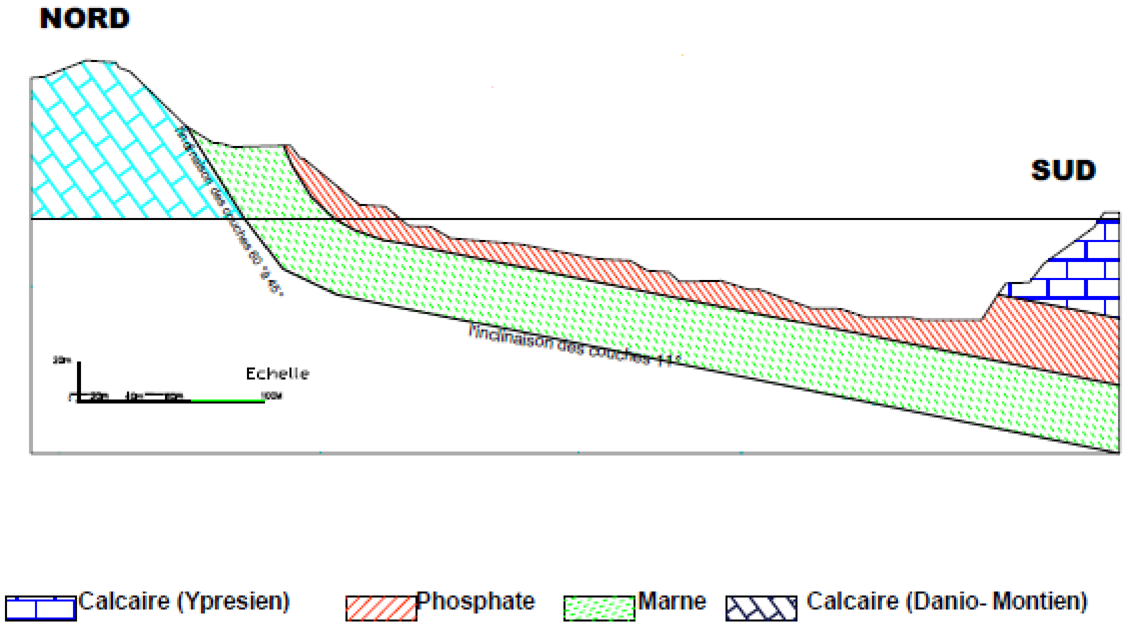


Figure III.4: geological cross-section KEF ESSNOUN [17]

III.6.4. Calculation of safety factor KEF ESSNOUN

With the use of the Geostudio program and the limit equilibrium methods, the safety coefficient (Fs) was calculated. With the physico-mechanical properties of the rock mass and the coordinates (X, Y), the geometrical parameters of the model to be investigated as well as the level of the water table (the model studied is unaffected by the water table).

- **Parameters of calculation**

- **Geological parameters**

In the calculation, four geological formations were taken into account:

-Upper Ypresian limestone;

- Phosphate of the Upper Thanetian;

- Lower Thanetian marl;

- The lower limestone of the Montian.

Table III.13: Geotechnical parameters of the different geological formations.[17]

Geological formation	Unit weight (KN/m3)	Angle of internal friction (o)	Cohesion (KN/m2)
Upper Ypresian limestone	26.5	37	1.800
Phosphate	20.6	37	1.150
Marl	22.6	15	0
Lower limestone of the Montian.	26.5	37	2.700

- **Geotechnical parameters**

The geotechnical parameters established by the DMT specialists and listed in table are those that were taken into consideration for the determination of the safety factors of the Kef Essnoun quarry.

III.6.5. Different model scenarios KEF ESSNOUN

- **Numerical model N°1**

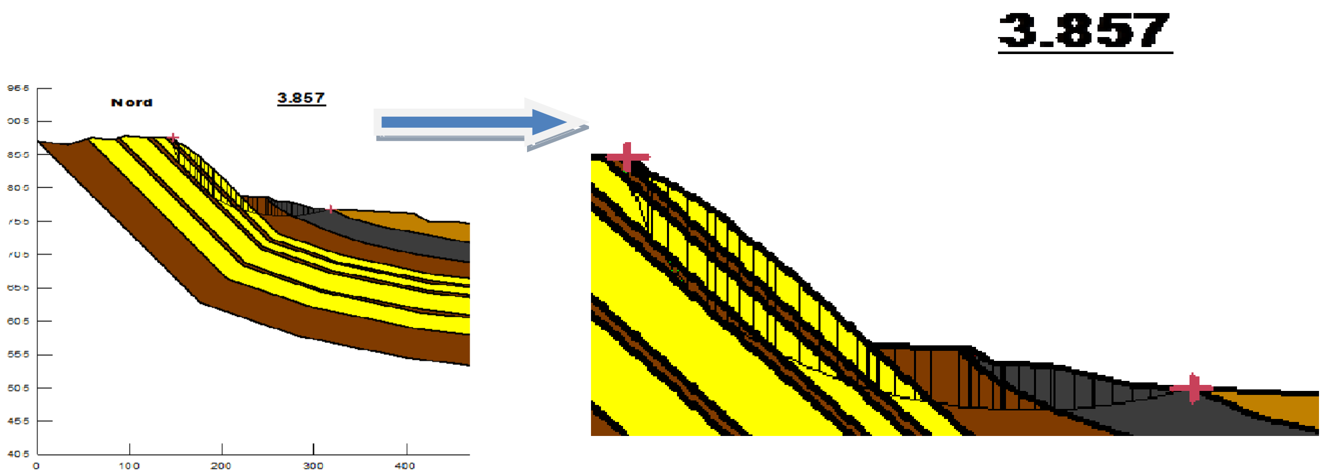


Figure III.5: Numerical model 1

➢ **Numerical model N°2**

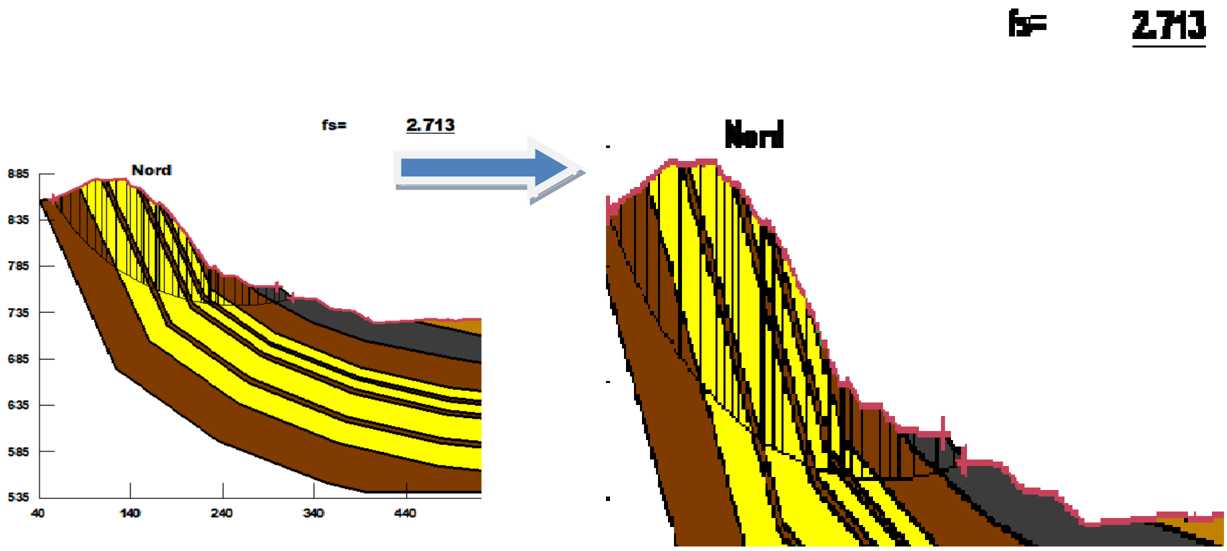


Figure III.6: Numerical model 2

➢ **Numerical model N°3**

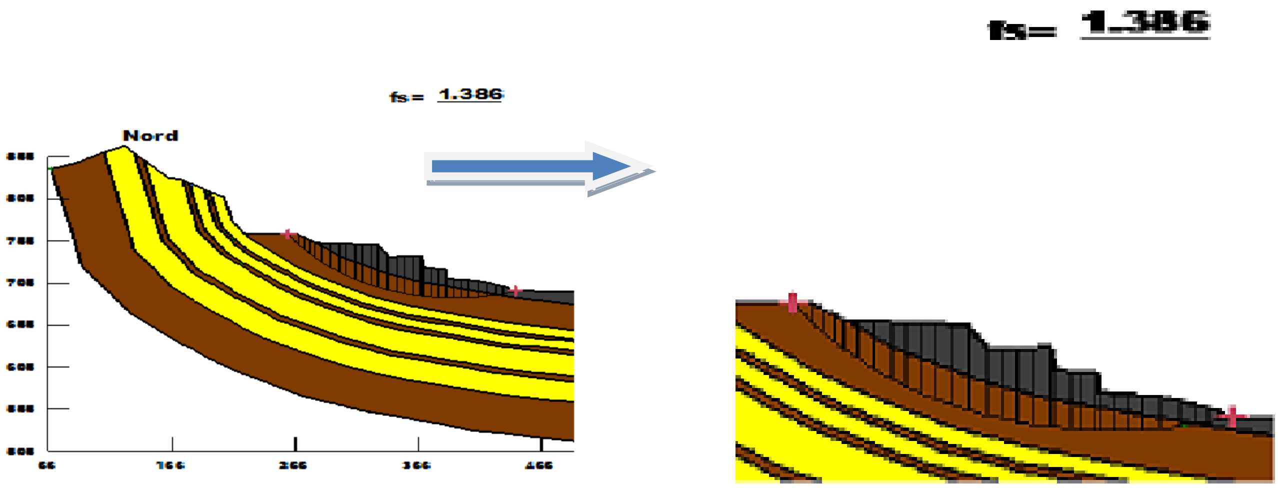


Figure III.7: Numerical model 3

- **Numerical model N°4**

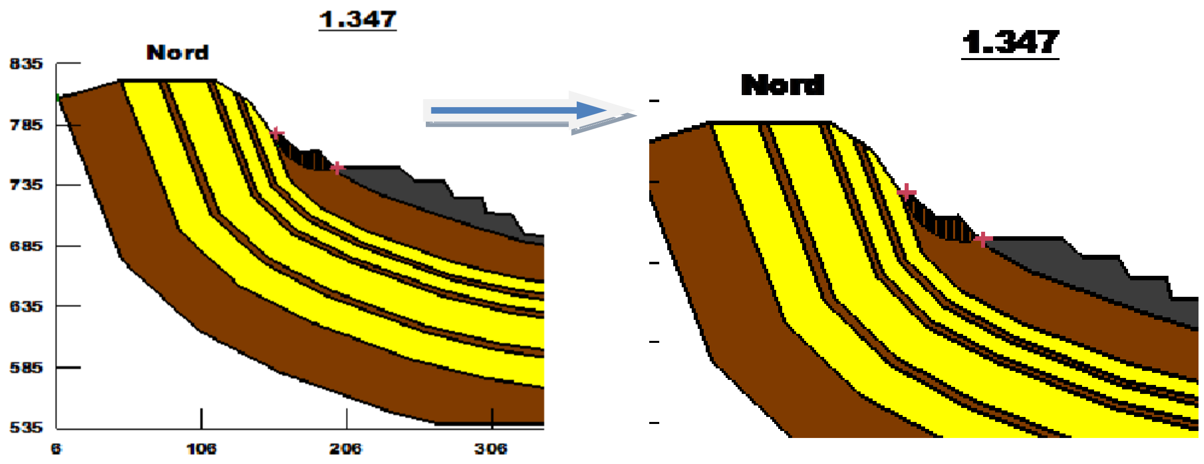


Figure III.8: Numerical model 4

- **Numerical model N°5**

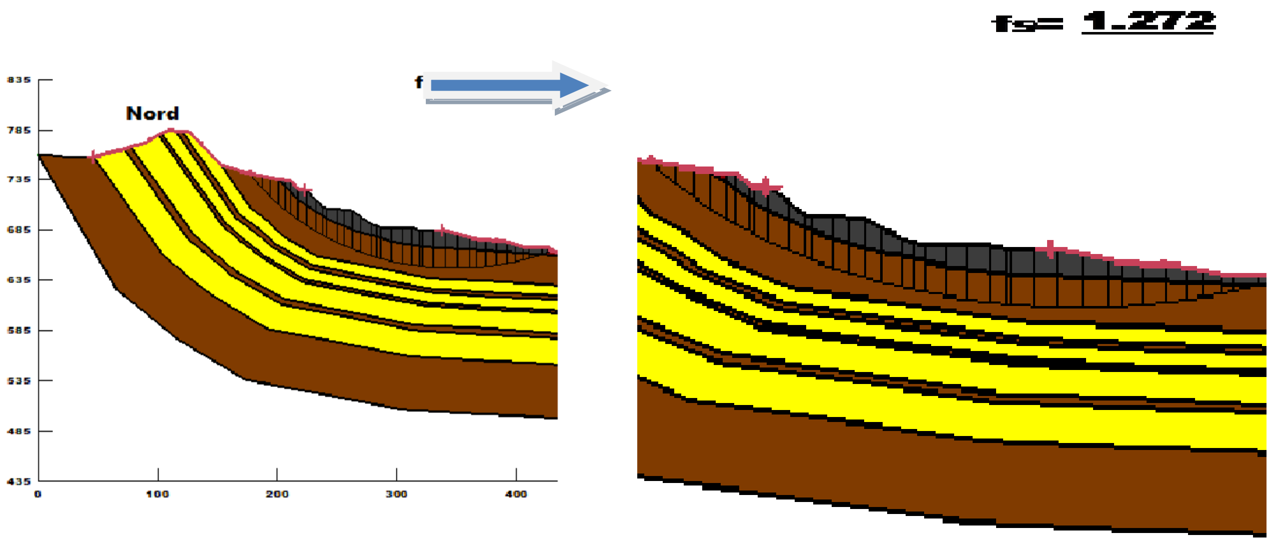


Figure III.9: numerical model 5

➢ **Numerical model N°6**

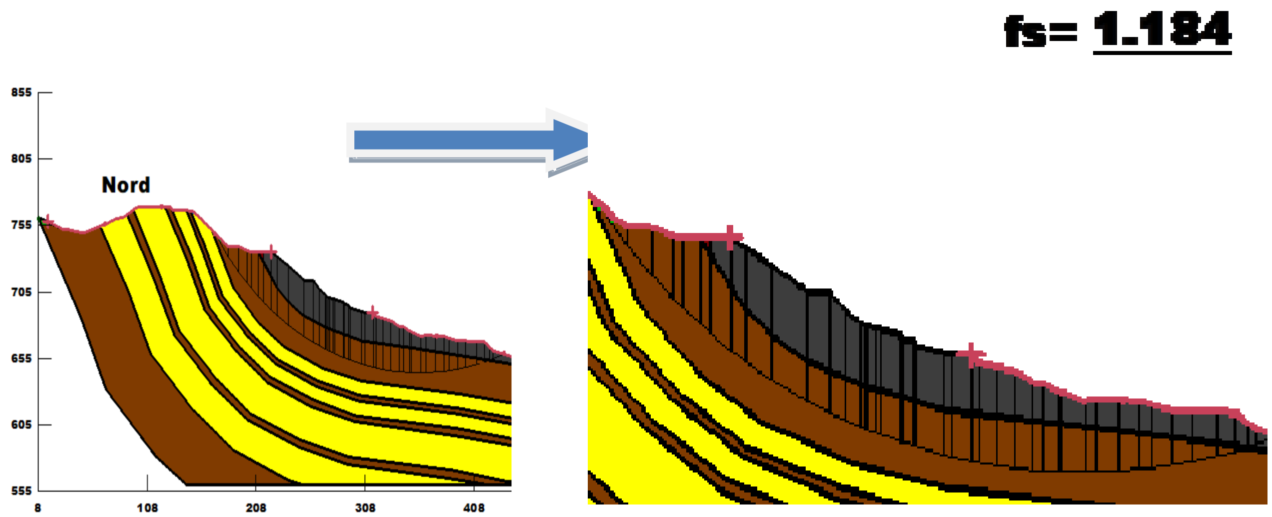


Figure III.10: Numerical model 6

➢ **Numerical model N°7**

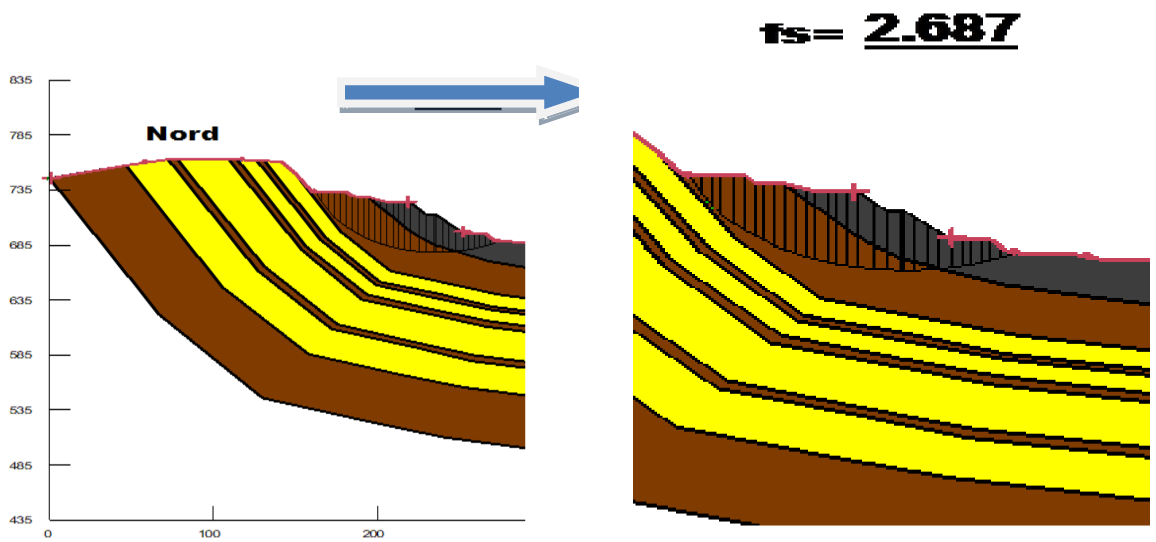


Figure III.11: Numerical model 7.

➢ **Numerical model N°8**

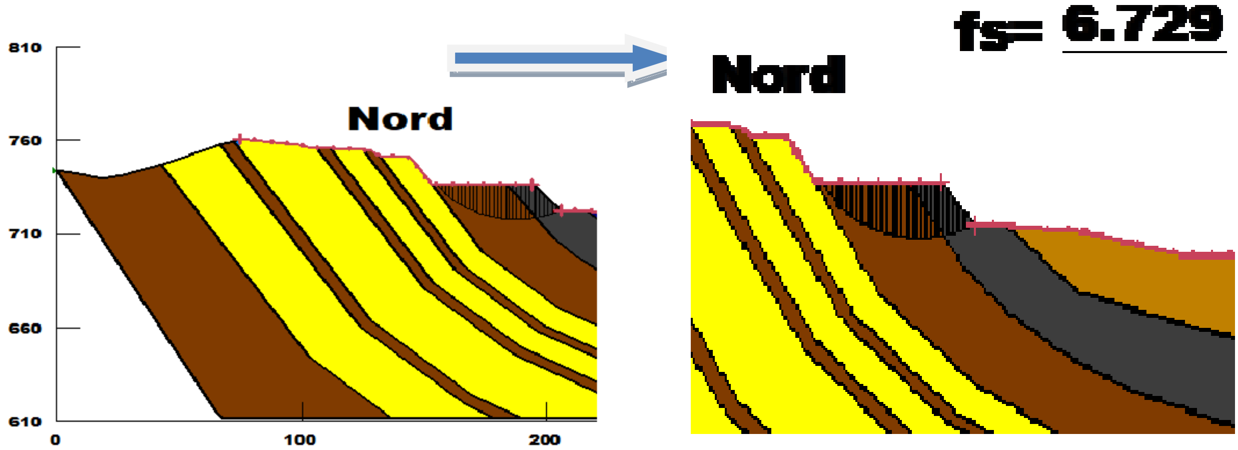


Figure III.12: Numerical model 8

III.6.6. Results of the calculation of the safety factor

Table III.14 shows the safety factor values for the eight (08) studied cases in the kef Essnoun north west; The (Fs) values of numerical models 1, 2, 7 and 8 (6.729; 3.857; 2.712; 2.687) describe a state of stable slopes and the other Fs values (1.386, 1.347, 1.272, 1.184) of numerical model (3, 4, 5, 6) present a high risk and possibility of sliding if the geotechnical parameters changes grammatically.

The results of the calculation of the safety factor are presented in the table TableIII.14

Table III.14: Values of the safety factor.

Designation	Safety factor
Numerical model N°1	**3.857**
Numerical model N°2	**2.712**
Numerical model N°3	**1.386**
Numerical model N°4	**1.347**
Numerical model N°5	**1.272**
Numerical model N°6	**1.184**
Numerical model N°7	**2.687**
Numerical model N°8	**6.729**

III.6.7.Another scenarios (water table) KEF ESSNOUN

With the use of the Geostudio program and the limit equilibrium methods, the safety coefficient (Fs) was calculated. It is the physico-mechanical properties of the rock mass, the coordinates (X, Y), and the geometrical parameters of the model to be investigated as well as the level of the water table.

- **Numerical model N°1**

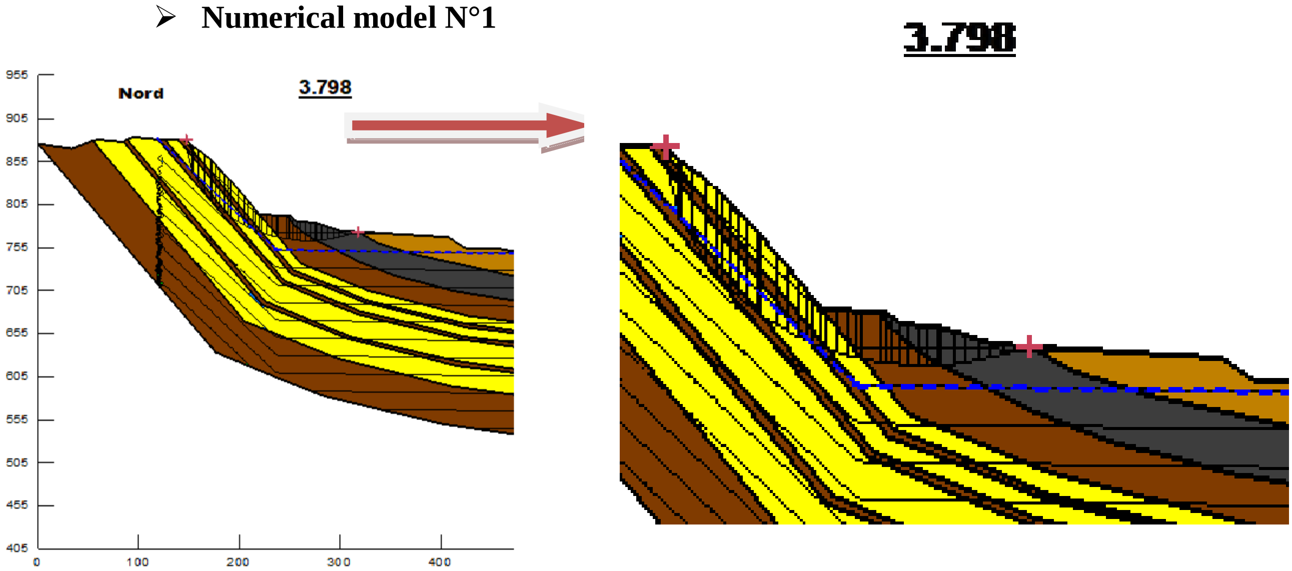


Figure III.13: Numerical model 1

- **Numerical model N°2**

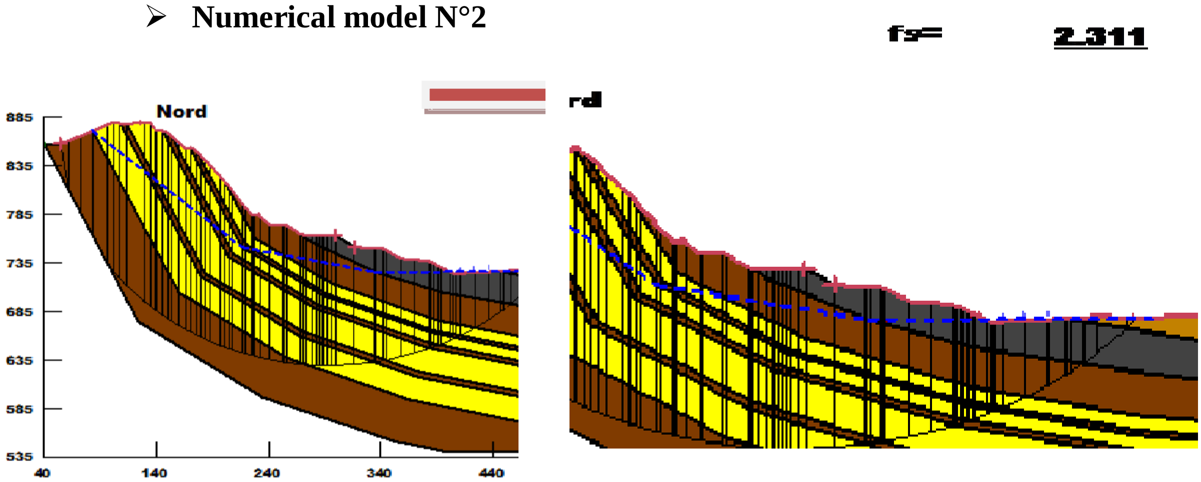


Figure III.14: Numerical model 2

- **Numerical model N°3**

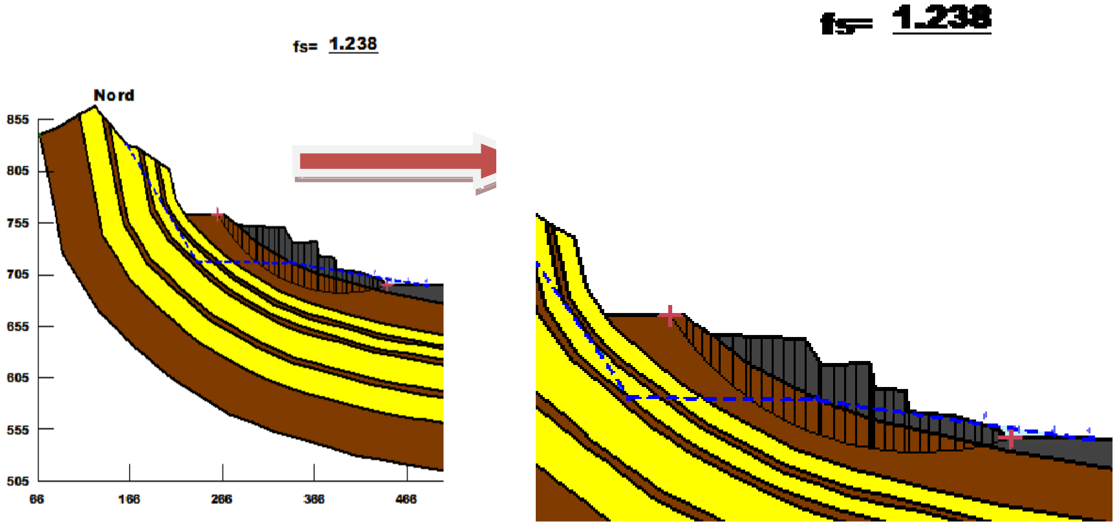


Figure III.15: Numerical model 3

- **Numerical model N°4**

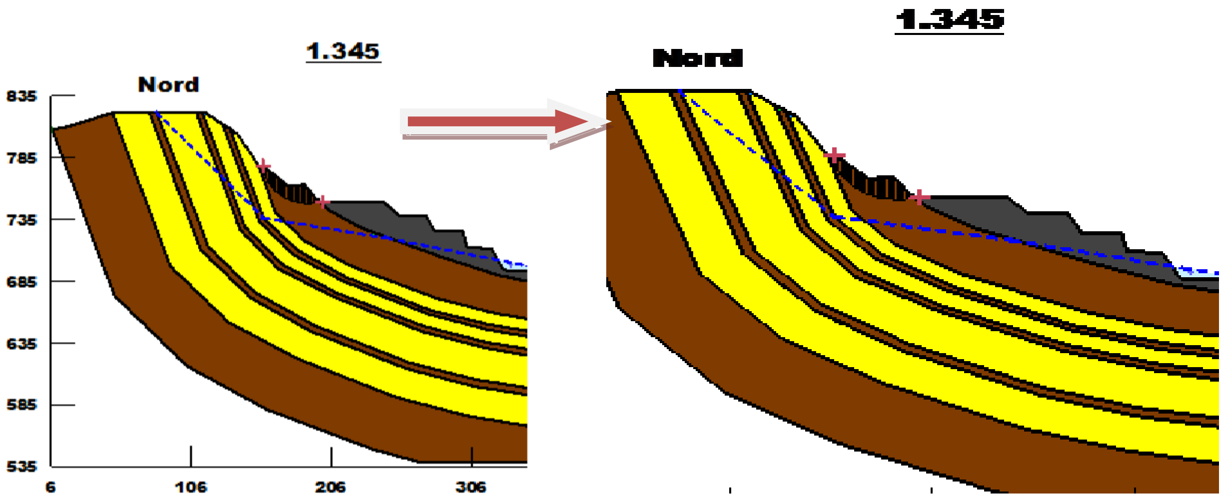


Figure III.16: Numerical model 4

➢ **Numerical model N°5**

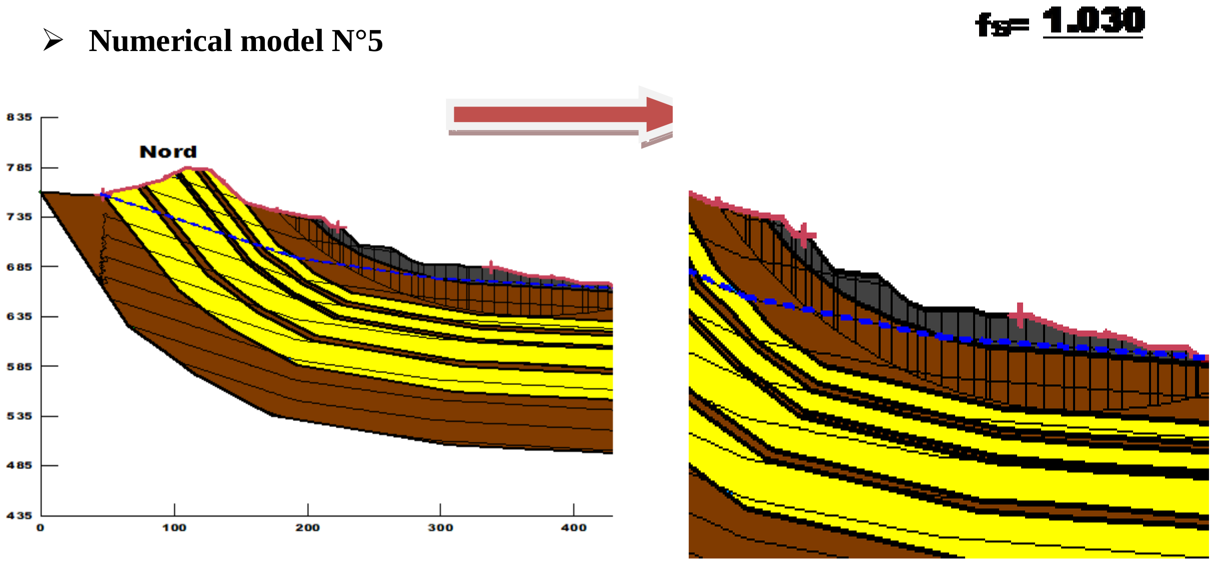


Figure III.17: Numerical model 5

➢ **Numerical model N°6**

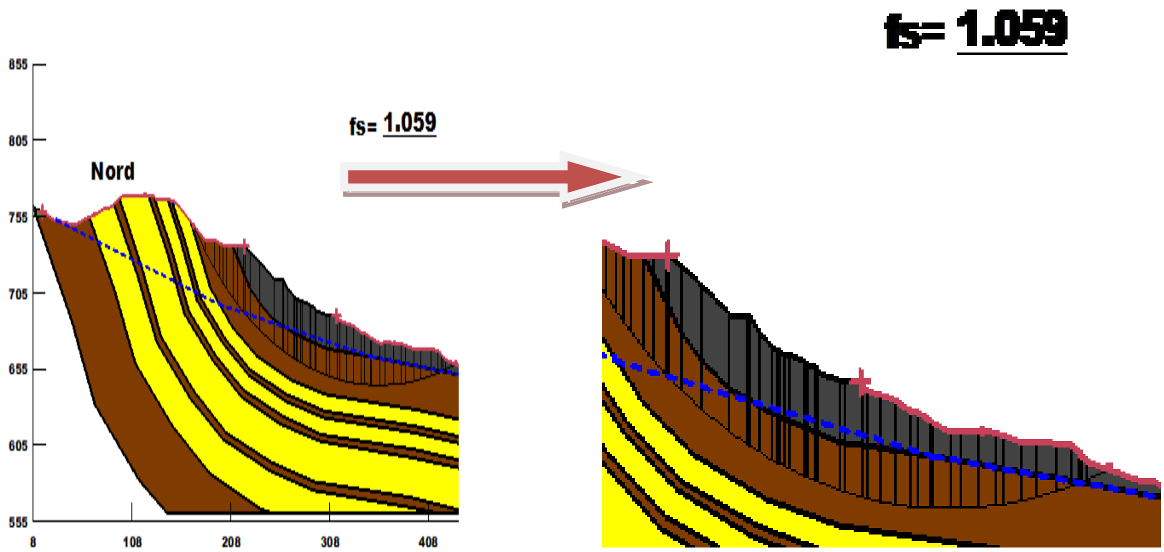


Figure III.18: Numerical model 6

➢ **Numerical model N°7**

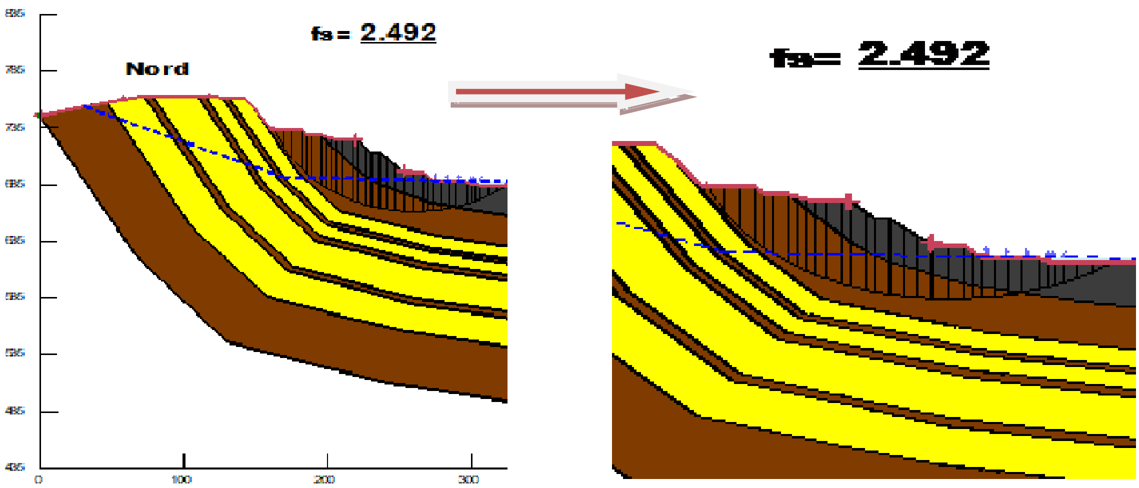


Figure III.19: Numerical model 7

➢ **Numerical model N°8**

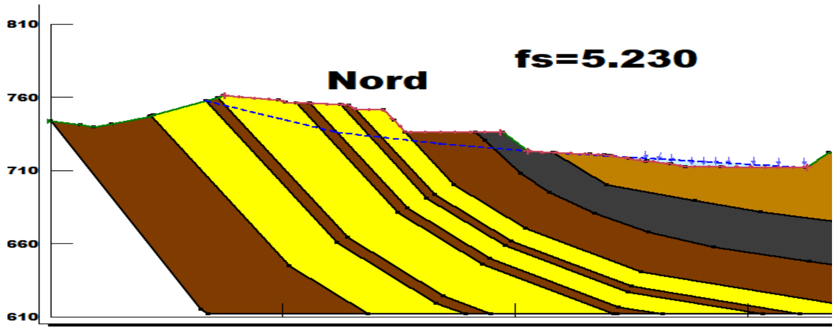


Figure III.20: Numerical model 8

III.6.8. Results of the calculation of safety factor

Table III.15 shows the safety factor values for the eight (08) studied cases in the North West of kef Essnoun. We can see right away that there is a relation between the input variables and the Fs; the water table has an effect on factors of safety and stability. In general, all the Fs in the table are decreased, especially numerical models number 5 the Fs value is decreased to

(1.030) and model 6 Fs values is deceased to (1.059) There's a high possibility of sliding, and the Fs values of numerical model 3 and 4 (1.238;1.345) present a high risk and possibility of sliding if the geotechnical parameters changes; and the rest of the Fs values of numerical model (1,2,7,8) describe a state of stable slopes.

The results of the calculation of the safety factor are presented in the table TableIII.15

Table III.15: Values of the safety factor.

Designation	Safety factor
Numerical model N°1	**3.798**
Numerical model N°2	**2.311**
Numerical model N°3	**1.238**
Numerical model N°4	**1.345**
Numerical model N°5	**1.030**
Numerical model N°6	**1.059**
Numerical model N°7	**2.492**
Numerical model N°8	**5.230**

III.7. conclusion

In the studied massif rock, there are four formations: upper Ypresian limestone; phosphate of the Upper Thanetian; lower Thanetian marl; and lower limestone of the Montian.

- The presented discontinuities (cracks and joints) have an influence on behaviour and rock quality.
- The three geotechnical parameters (unit weight, cohesion, and frictional angle) are the inputs in the Geoslope software they describe the different layers that compose the open pit
- The rain fall in the area of kef Essnoun effect the stability of slope, in some scenarios has been decreased so the value of Fs present us a high risk
- The different Geoslope modelling scenarios show that the massif rock of Kef Essnoun is generally stable.

PART II: Geotechnical hazards of the Kef Essnoun open pit

III.8.Geotechnic mapping of the open pit mine and landslides hazard

III.8.1. Presentation of the open pit mine geometrical, geological model

The topographic plane of the mine has been digitized using data obtained from society for all the different levels of coordination, as well as the three geological layer formations consolidated from the bore hole. With the help of the software surfer, we can make designs for different maps; the first one is contour map, 3D mine, geological profile, and digitized map.

III.8.2. Maps modelling using surfer

Gathering data from all resources by SOMIPHOS and Google Earth

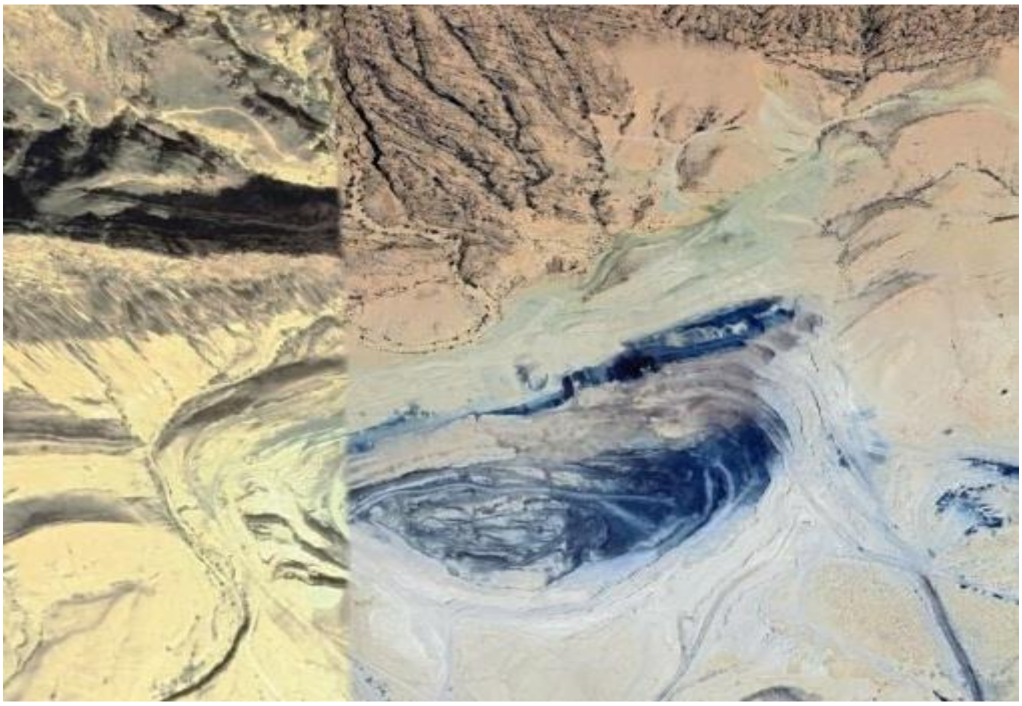


Figure III.21: kef Essnoun open pit (Google earth,2023)

III.8.2.1.Contour map

The figure III.22 shows us the contour map of Kef Essnoun open pit; this map allows us to design other different maps.

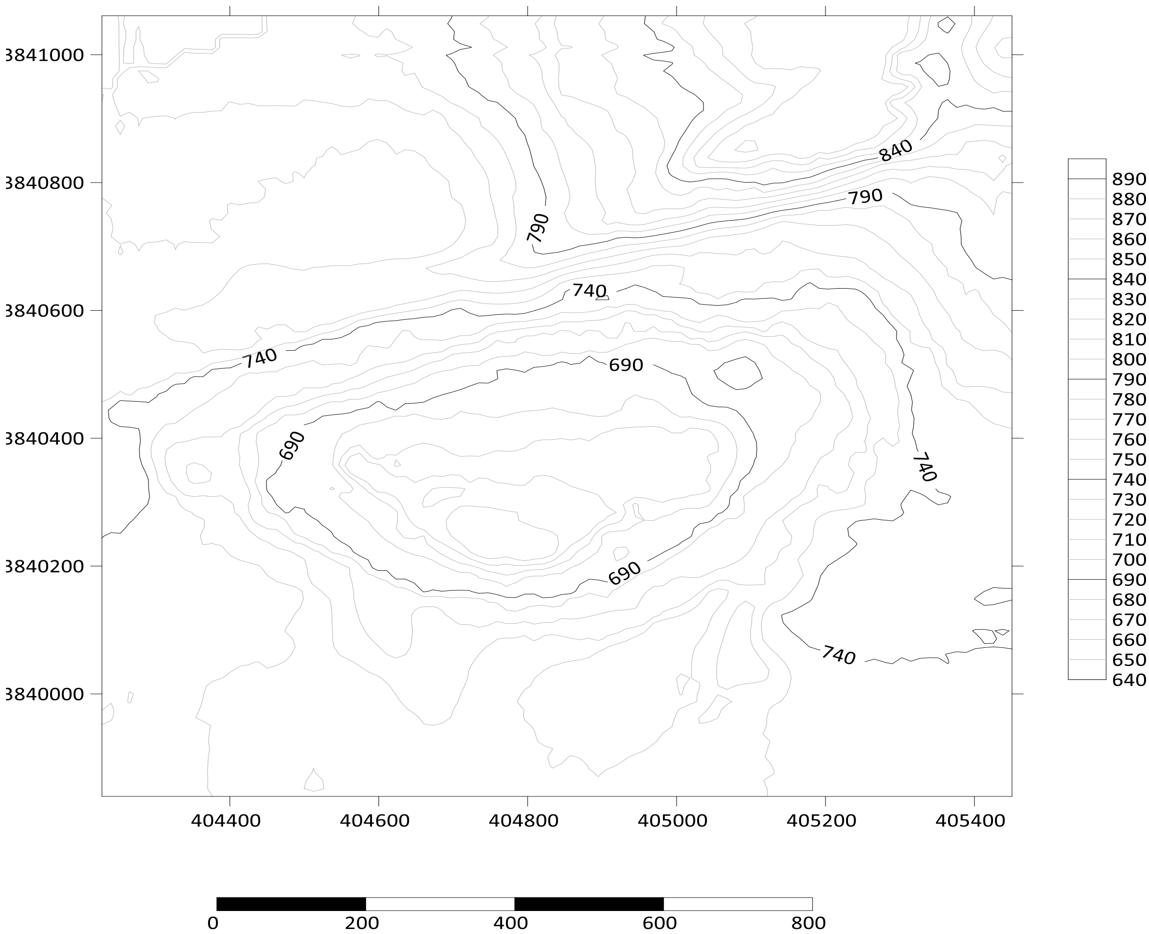


Figure III.22: contour map kef Essnoun open pit

III.8.2.2.Color relief map

This map shows us the relief of the Kef Essnoun open pit, as it shows that the color scale is from 650m to 880m and the map scale is from 0 to 800 m.

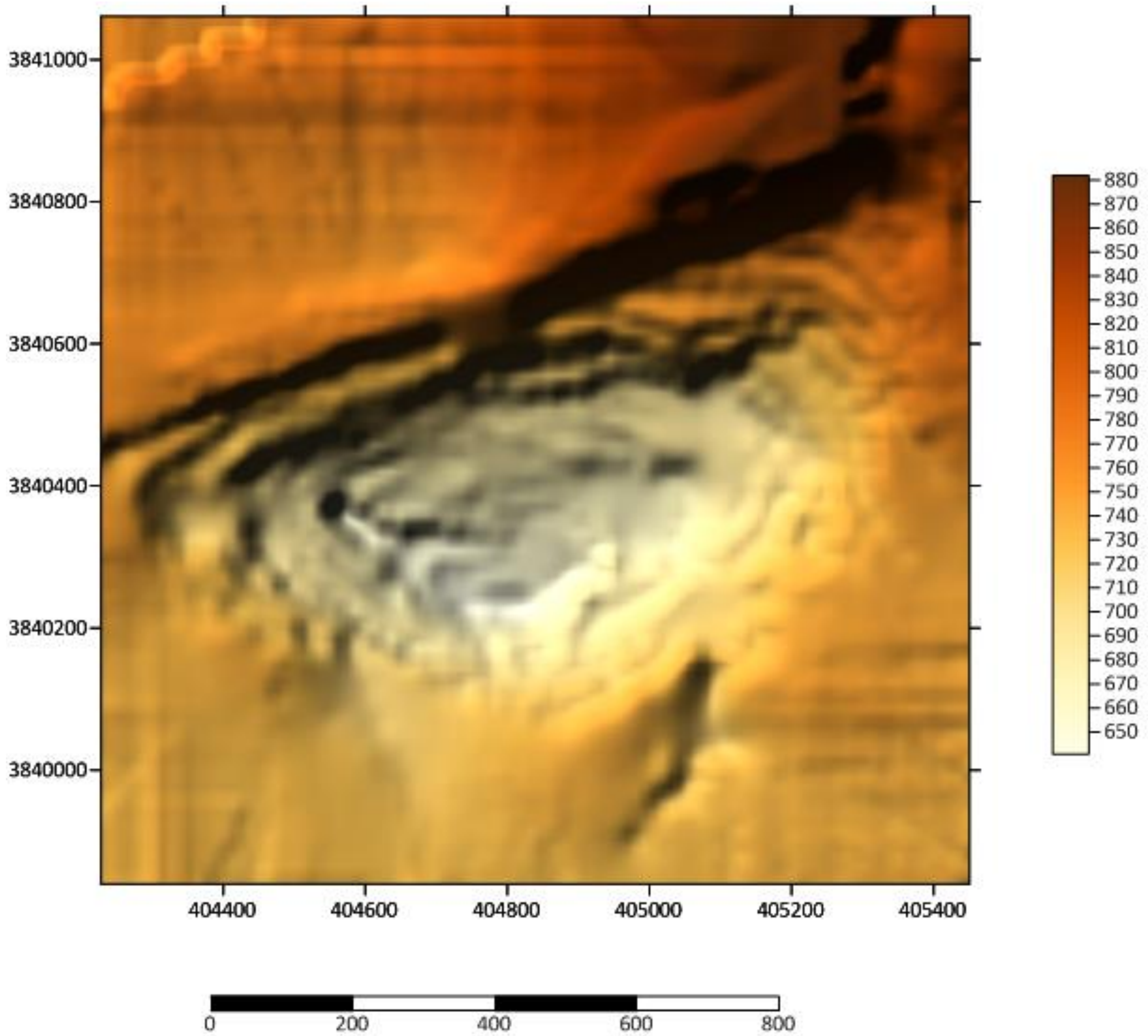


Figure III.23: Color relief map of kef Essnoun open pit.

III.8.2.3. grid values map

This map shows us the grid values layer, which is overlaid with a filled color relief layer and has the same scale as the first maps. A grid values map displays symbols and labels to show the positions and values of the grid nodes.

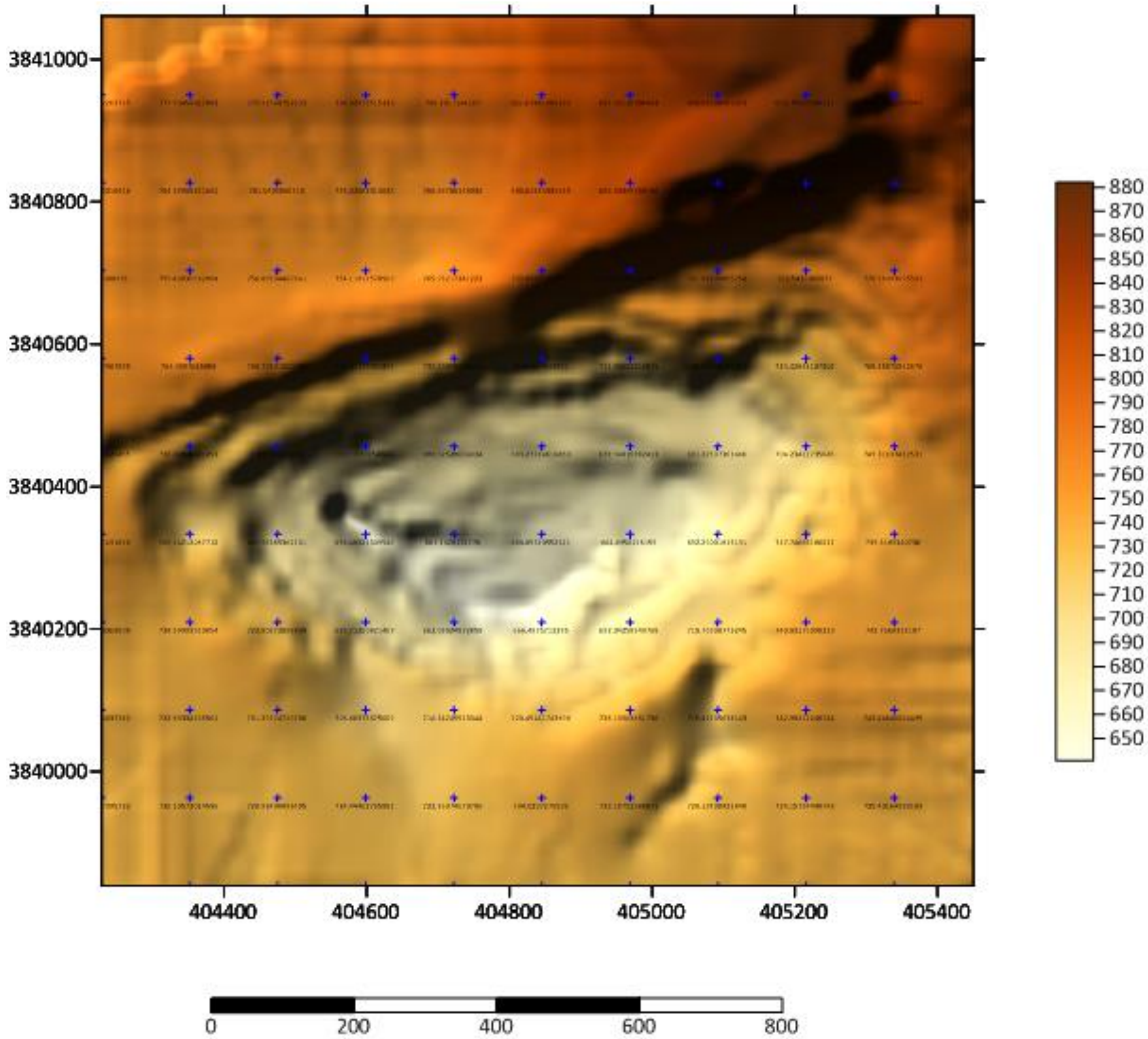


Figure III.24: grid values map of kef Essnoun open pit

III.8.2.4. Grid vectors map

This map shows us the grid vector map overlaid with a filled contour layer; the arrows show us the direction of water flows from low elevation to high elevation.

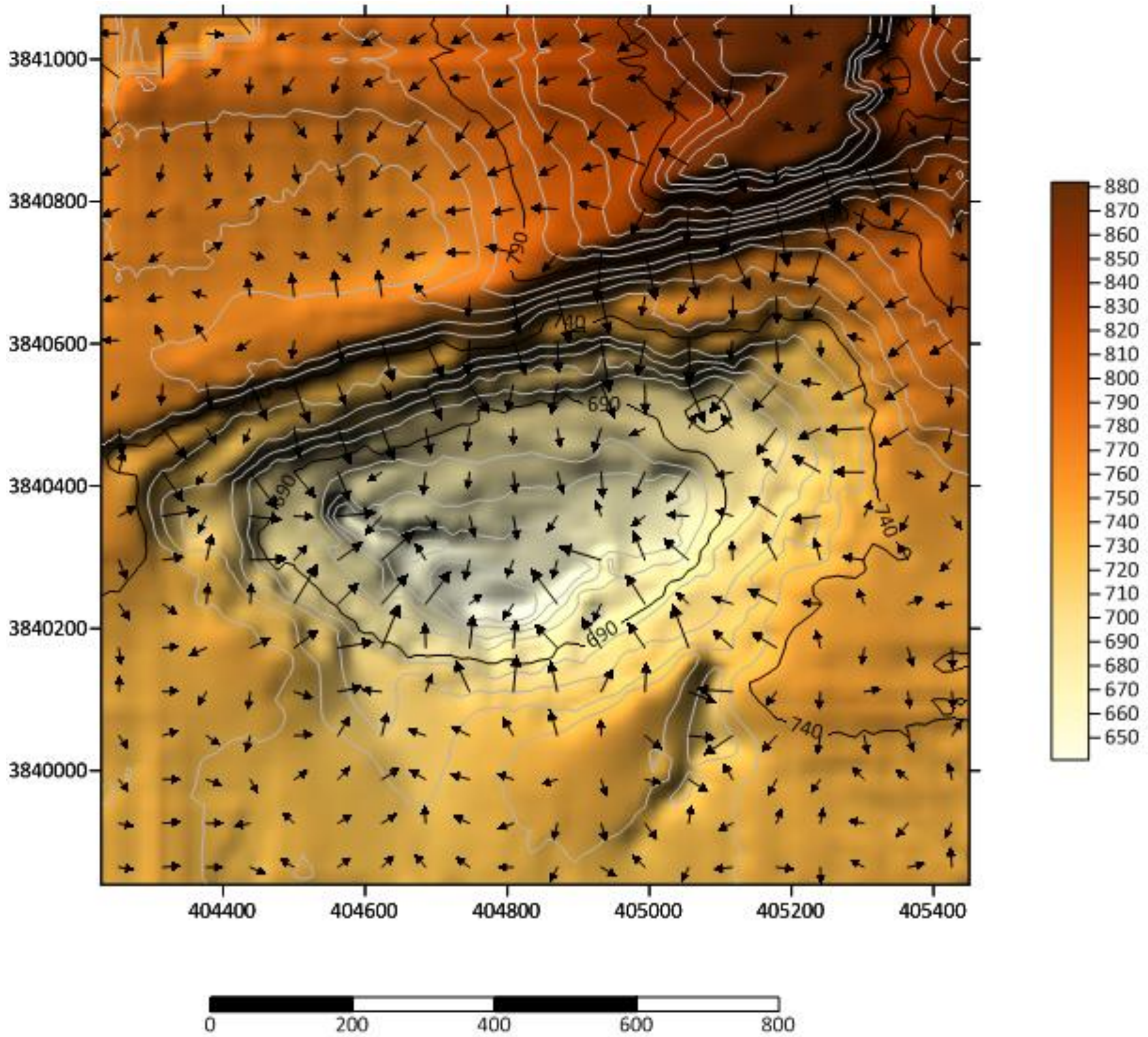


Figure III.25: vectors map of kef Essnoun open pit

III.8.2.5. Kef Essnoun open pit mine in 3D surface

This figure shows a 3D view of the open pit of Kef Essnoun with the three formation layers of phosphate, marl, and limestone.

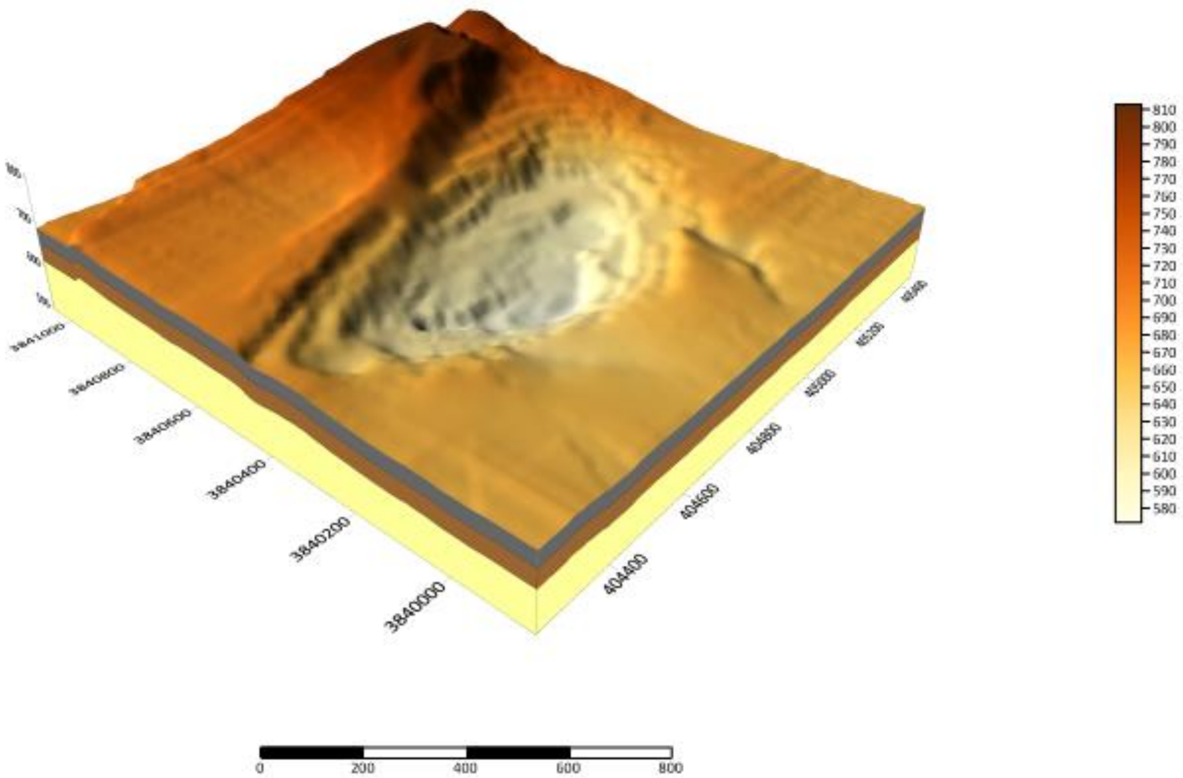


Figure III.26: 3D surface of kef Essnoun open pit

III.8.2.6. Geological profile using surfer

As shown in the figure, a color relief map, we did a profile to see how the 3-layer formation in the open pit from phosphate, marl, to limestone.

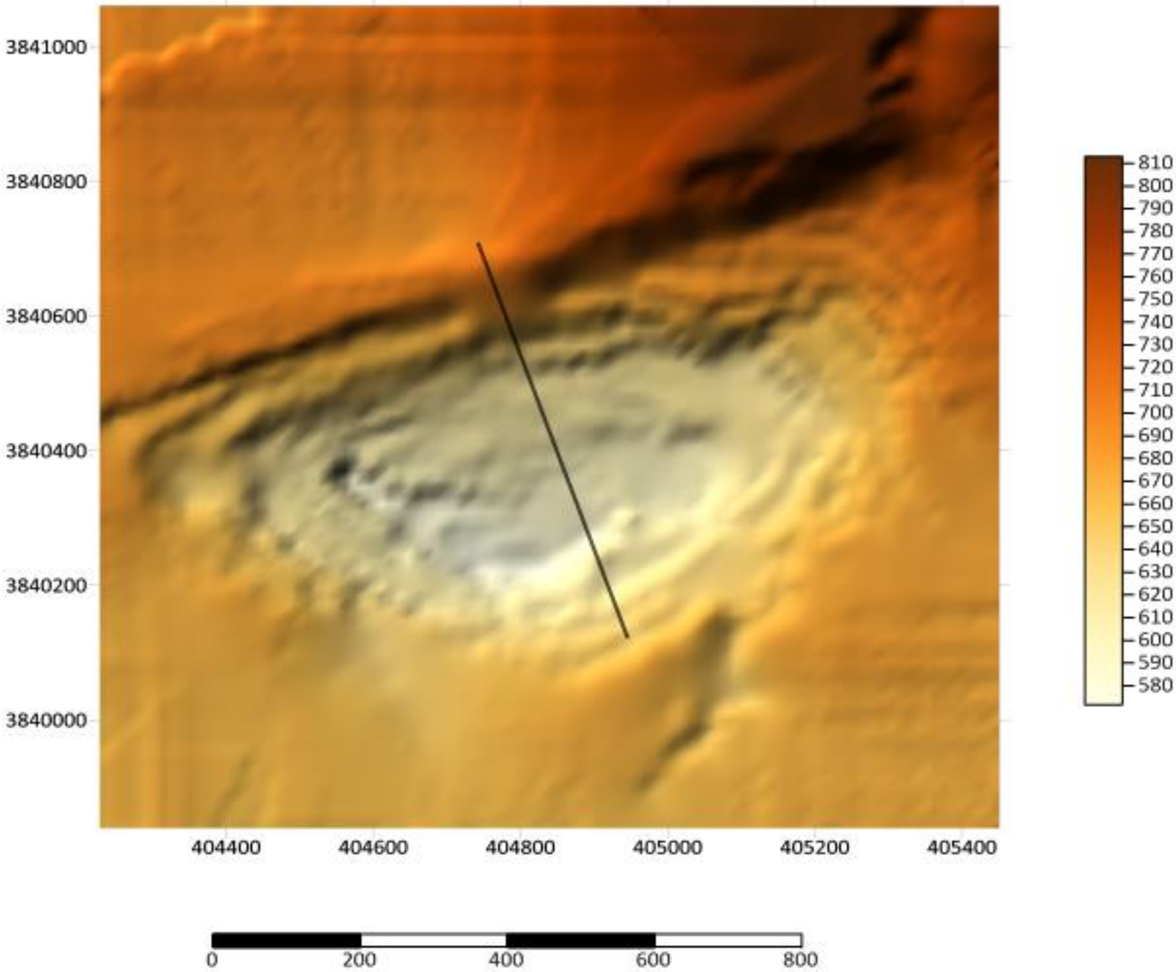


Figure III.27: color relief map of kef Essnoun open pit.

- **Profile N°1:**

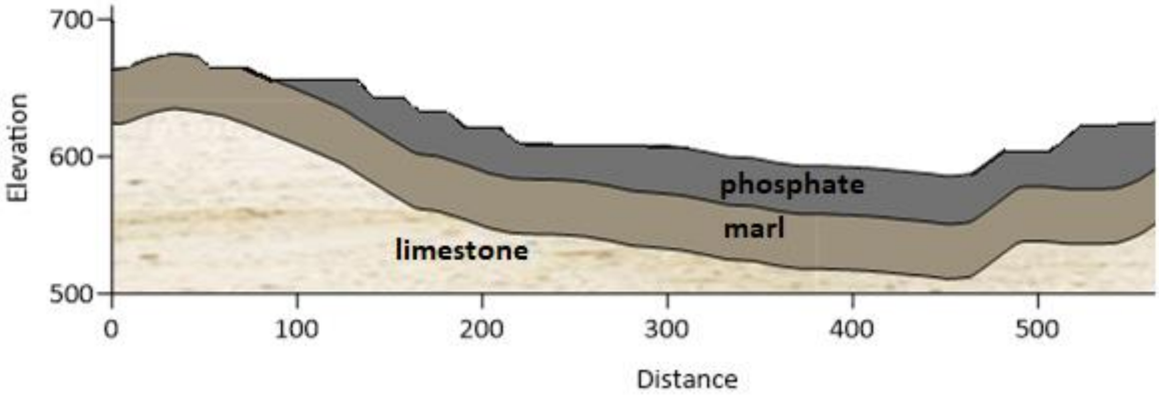
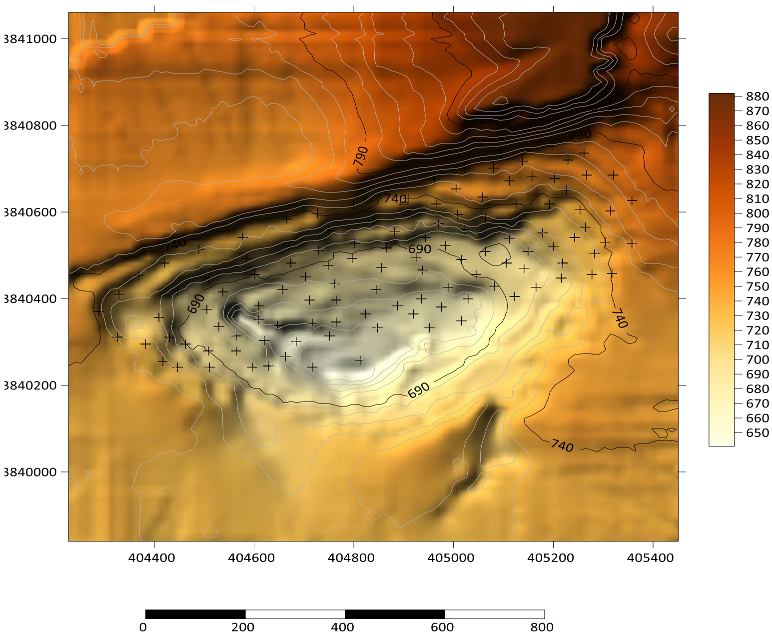


Figure III.28: geological layers profile of KEF ESSNOUN

III.8.3. Digitizing a map using surfer

III.8.3.1.post map

A color relief map laid on a contour map with safety factor marks, as shown in the figure III.29



FigureIII.29: safety factor post map.

III.8.3.2. safety factor contour map

We can see in the safety factor contour map that the area in the red color of safety factor it represent ranges from 1 to 1.5 has high risk and possibility of sliding; on the site this area present a slope with high angle ; they should treat it better to maintain the slide that can happen in the future; the green color of safety factor from 1.5 to 6 describe a state of stable slope or massif rock.

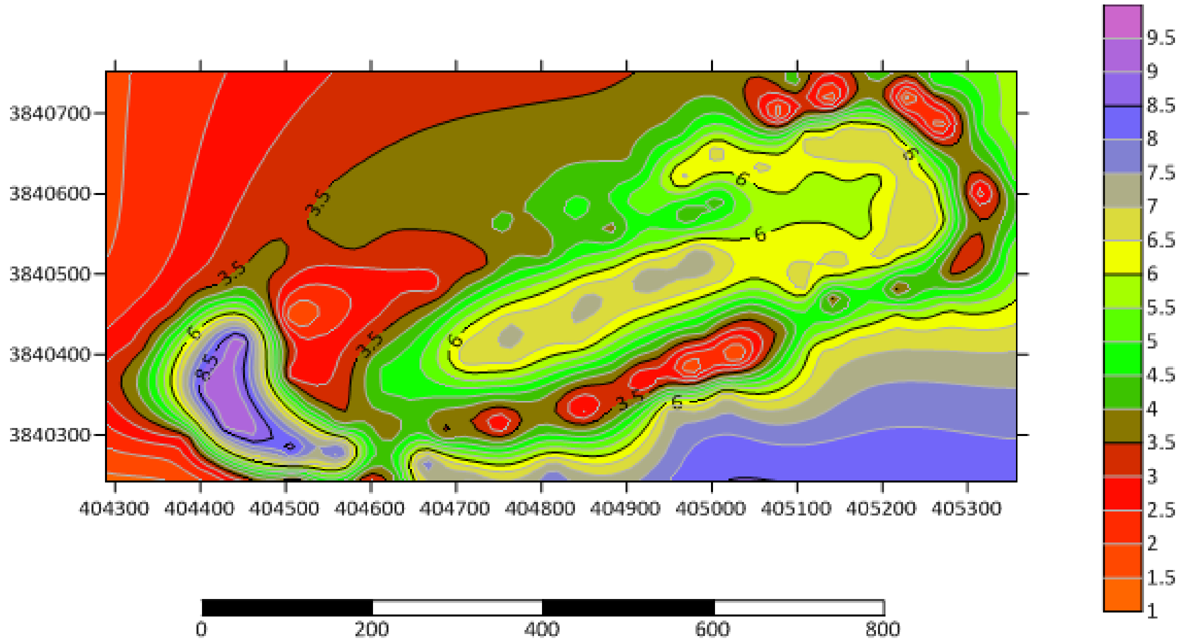


Figure III.30: safety factor contour map

III.8.3.3. Final descriptive 3D model of the stability in the Open pit mine of Kef Essnoun

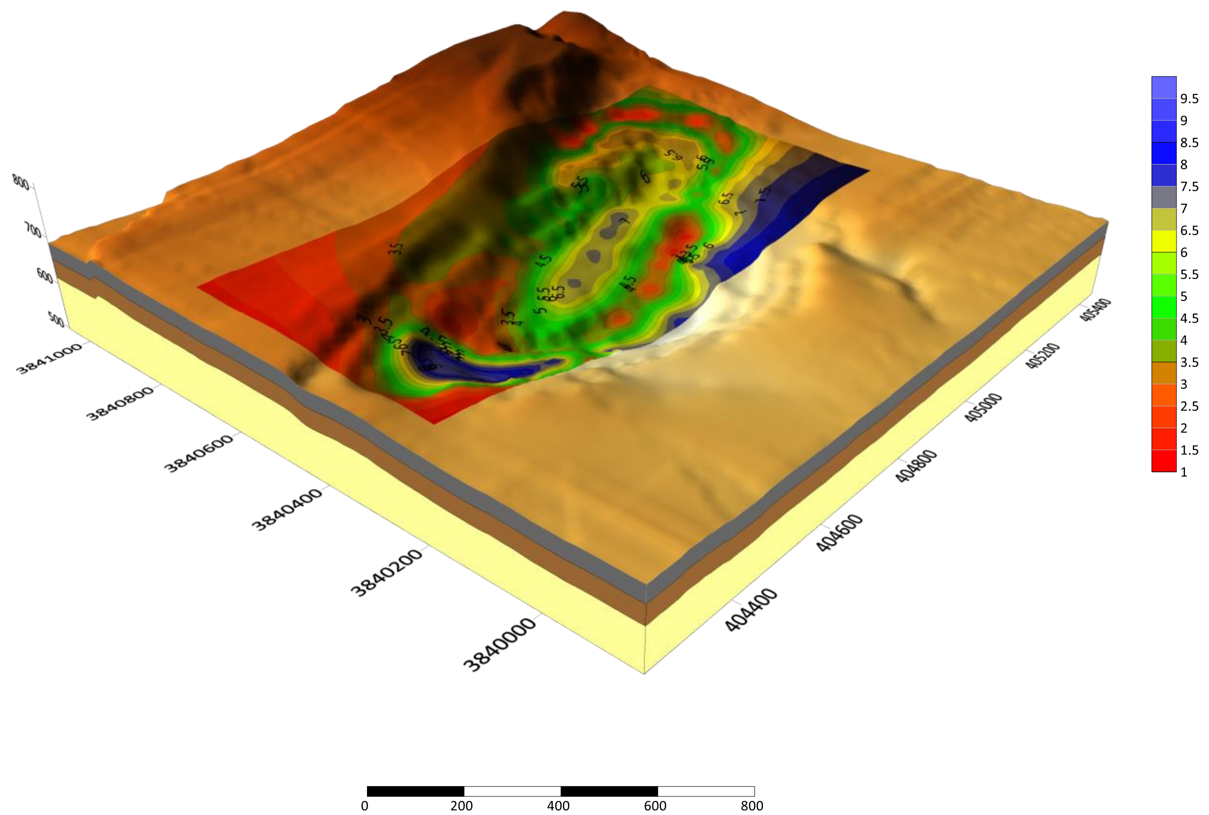


Figure III.31: 3D view map present the Fs of kef Essnoun

III.9. Conclusion

Investigation in geotechnical hazard with the use of software surfer and the data, we can make designs for different maps; the first one is contour map, 3D mine, geological profile, and digitized map.

- the grid value map showed us positions of the area and values of grid nodes
- direction of water flows from low elevation to high elevation with grid vector map
- Simulation of kef Essnoun open pit in 3d view surface with the three formation layers phosphate, marls and limestone.
- By digitizing a map helped us to simulate the safety factor in 3D surface map and predication the position of risk and possibility of sliding slopes or massif rocks.

General conclusion

Through the present dissertation research, we have addressed the geotechnical challenges associated with open-pit mining, particularly in the north western part of the Kef Essnoun deposit (Djebel Onk-Tébessa), which presents several geotechnical issues. The rock mass in the study area is composed of four distinct formations, with vertical and fractured contacts resulting from tectonic and manmade activities. the collected physico-mechanical characteristics of the rock mass, providing essential insights into its geo-mechanical behavior and quality. To assess slope stability and the potential for sliding, we employed the Geoslope software to calculate the safety coefficient (Fs) using various scenarios.

Furthermore, we examined the influence of water by incorporating it into the numerical models, observing changes in the safety factor that indicated the impact of water on slope stability. As a result, all safety factor results decreased, highlighting the significance of considering water effects in slope stability analysis.

To enhance the reliability of our findings, we utilized Surfer software to design multiple maps, including a 3D surface representation with layers. By digitizing the open pit and incorporating safety factors into the 3D map positioned on the mine's surface, we gained valuable insights into the identification of risks and potential sliding in slopes and rock masses.

Moving forward, it is crucial for plan implementers to prioritize the continuity of phosphate extraction while gradually removing the marl layer and reducing explosive consumption in the outcrop zone. Additionally, ensuring ultimate stability requires the gradual reduction of the north side dome until it reaches the topographically permissible height.

The knowledge gained from this study contributes to the broader understanding of geotechnical evaluations, slope stability analysis, and the use of advanced software in mining projects. By harnessing Algeria's rich mineral resources, especially the significant phosphate deposit in Djebel Onk, the country can drive economic development and capitalize on its mineral wealth while maintaining safe and sustainable mining practices.

In conclusion, our work emphasizes the importance of stability analysis, numerical modeling, and scenario prediction in assessing slope stability and identifying potential risks in mining operations. The integration of advanced software tools, such as Geoslope and Surfer, has enabled us to obtain accurate and comprehensive information for effective decision-making and risk mitigation strategies.

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