



The phosphate series of Benguerir (Maastrichtian - Ypresian, Morocco): Mineralogy and mine planning

A. Anjjar¹, Y. Driouch², F. Benjelloun¹, H. Ait Hmeid³, A. El Alami⁴

¹Laboratory of Functional Ecology and Environmental Engineering (EFGE), Department of the Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, B.P. 2202 - Imouzzar Road, Fez, Morocco.

²Laboratory of Geodynamics and Natural Resources, Department of Geology, Faculty of Sciences Dhar El Mahraz, Fez, Morocco.

³Laboratory Observatory of the Marchica Lagoon of Nador and Limiting Regions (OLMAN-RL), Multidisciplinary Faculty of Nador, Mohamed 1st University, 60700 Nador, Morocco.

⁴The OCP Group, Benguerir Morocco.

Received 22 June 2019,
Revised 05 March 2020,
Accepted 09 YYY 2019

Keywords

- ✓ Phosphates,
- ✓ Gannour Basin,
- ✓ Exploration,
- ✓ Phosphate layers,
- ✓ Reserves.

anjjar01ahmed@gmail.com ;
Phone: +212650387289;

Abstract

Morocco is the world leader in phosphates. Exploration and reserves evaluation of deposits in terms of tonnage and quality are charged to the geological service of the Office Cherifien of Phosphates (OCP). The Maastrichtian-Ypresian exploitable phosphates from the northern deposit of Benguerir, are transgressive on a Paleozoic basement. The coordinates of the samples and their physicochemical characteristics allowed building a database. The processing of these data by the ArcGIS software allowed us to propose maps of the different properties of the deposit, such as BPL (Bone Phosphate of Lime (BPL = 2, 18 * % Phosphorus pentoxide P₂O₅) and CO₂ contents, as well as structural characters such as the thicknesses and structures of the phosphate layers. This work offers a quick and efficient method for the evaluation of resources and the definition of deposit structures to assist the operator in the extraction procedures.

1. Introduction

Morocco has the largest deposits of phosphates in the world with estimations of more than three quarters of the world's reserves. Their geographical location, marketability and diversity give Morocco a special place in international market. As the world's largest exporter of phosphates in all its forms and the third largest producer behind the United States and China [1-3], its production reaches approximately 26.6 million tons per year [4,5]. It is the Cherifien Phosphates Office (OCP), which holds the monopoly of the exploitation and extracts the raw phosphates from the Moroccan undergrounds thanks to open-pit sites [6]. Almost half of the ore is exported as raw material, and the other half is delivered to the group's chemical industries for processing into marketable by-products such as basic phosphoric acid, purified phosphoric acid and solid fertilizers [7].

Beyond this very constructive work, we have assigned ourselves the task of proceeding, by our own methods; to the processing of mining data of a well-defined area, using techniques of Geographic Information Systems in order to have tools helping geologists to better visualize the structure of the phosphate deposit and evaluate its resources. The ArcGIS software has been used for this purpose.

The problem defined consists of:

- Conducting a geological study of the sector to capture the sedimentary and structural characteristics and link them to the paleogeography of the time of their deposit;
- Studying the petrography of representative phosphate layers and specifying their chemo-mineralogical properties;

- Collecting and compiling the mining data to form a database that can be processed by the software for geomineral purposes.

2. Material and Methods

2.1. Presentation of the study area

The Ganntour basin corresponds, on the surface, to a 120 Km long and 20 to 30 Km wide east-west oriented rectangle (Figure 1). In the Benguerir deposit, the phosphate series range from the Maastrichtian (last Cretaceous) to the Lutetian (Middle Eocene) with different levels in the form of either phosphate beds (layer, furrows) or sterile to slightly intercalated phosphate levels [8]. The phosphate series of the Benguerir deposit spreads from Maastrichtian to Lutetian with different levels forming phosphate beds (layers and furrows), phosphate-reduced (spacer) or sterile.

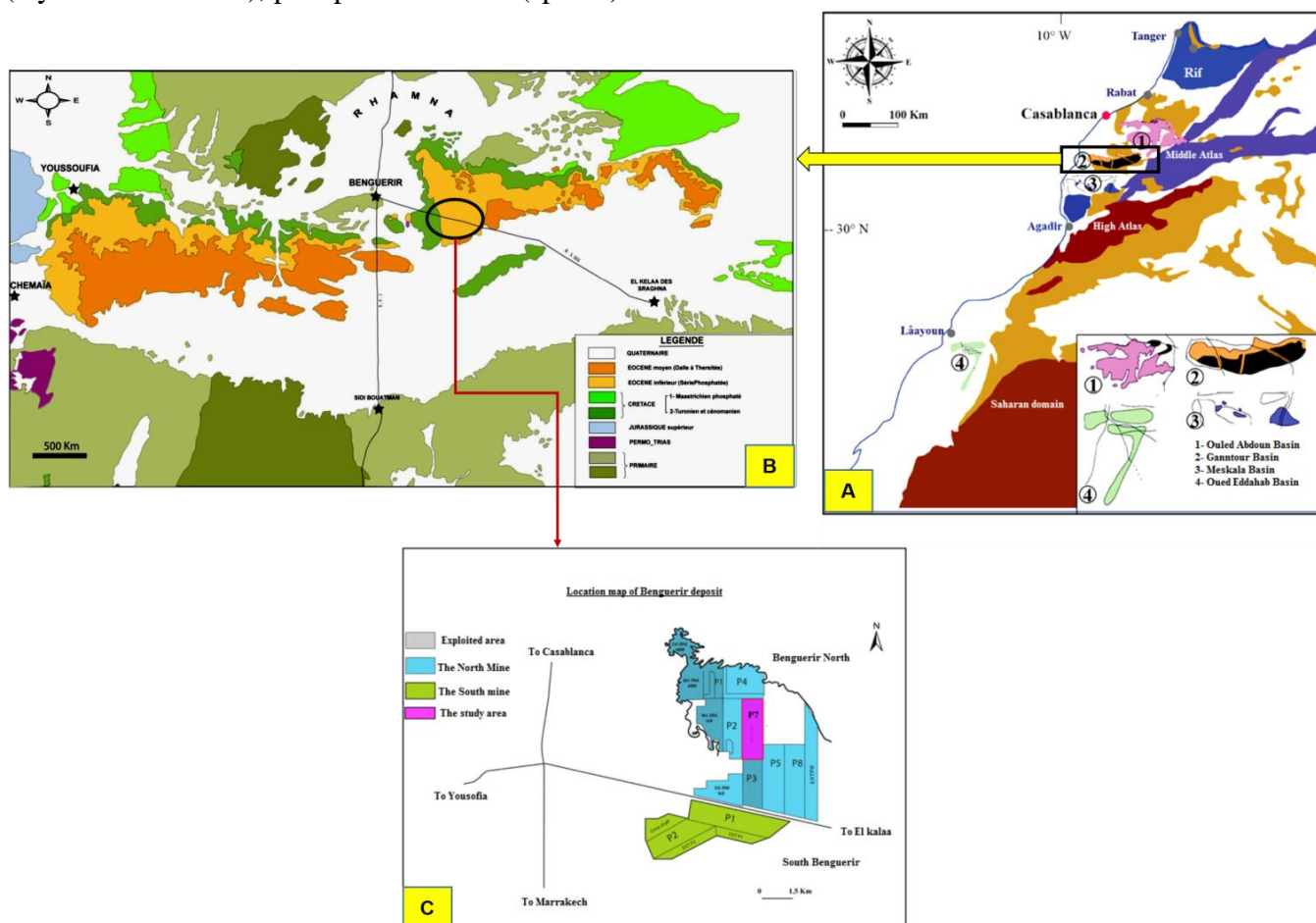


Figure 1: Situation of the study area: A- Structural scheme of Morocco and location of Moroccan phosphate basins [9] modified by EL Haddi [10, 11]. B- Geological map of the Ganntour basin extracted from the geological map of Morocco at 1:500000. [12]. C- Location of panel 7 of the Benguerir deposit [13].

2.2. Contribution of X-ray diffraction

Two samples were subject to an X-ray diffractometry mineralogical analysis. The objectives were, besides confirming and possibly completing the mineralogical study, to define the mineralogy of two reference levels: the yellow level and the C4-C3 intercalary (Spacer), both sterile. X-ray diffraction is a non-destructive analysis technique used for the determination of single-crystal structure as well as the study of qualitative and quantitative analysis of mineral phases. For X-ray diffraction, Panalytical X 'Pert Pro MPD diffractometer has been used for the identification and study of polycrystalline samples (pulverulent or solid). With the following characteristics: an X-ray tube source with copper anode of $\lambda = 1.54 \text{ \AA}$; a vertical O-O configuration goniometer; a rotating sample holder called spinner; a fast linear solid detector X 'Celerator; a 45-position autosampler.

2.3. Morphological characterization by scanning electron microscopy

These observations were made using a 20 kV voltage scanning electron microscope (Oxford ISIS 1300 ESM) coupled to a EDXA microanalysis system (Energy Dispersive X-ray Analysis) recording the X-ray fluorescence lines emitted after electronic excitation. The spatial resolution in imaging mode (secondary electrons and backscattered electrons) is less than 0.1 μm . The backscattered electron images make allow obtaining in certain cases, depending on the state of the surface, a good crystallographic contrast. The instrument also allows the analysis of elements up to uranium with detection limits as low as 1%.

2.4. Mine planning

The database is intended to be processed by ArcGIS software. It is based on data from 108 well sections and other recognition documents developed by the mining geology department of Benguerir [14]. The preparation of the database which contains the necessary information on the parameters studied by the geoprocessing on ArcGIS software is carried out according to several stages:

Identification of phosphate levels and sterile levels:

- Determination of the powers of phosphate levels (PM:the thicknesses of the phosphate layers) and sterile levels (sterile P);
- Calculation of the physico-chemical parameters (BPL: Bone Phosphate of Lime ($\text{BPL} = 2, 18 * \% \text{ Phosphorus pentoxide } \text{P}_2\text{O}_5$)), CO_2 :Carbon dioxide) of each phosphate level;
- Elimination of outliers of the studied parameters.
- Notation of the coordinates (X, Y and Z of each well).

3. Results and discussion

3.1. Benchmark level

Although the SEM study showed the existence of phyllosilicates, the results of the X-ray diffraction do not show evidence of clay mineral abundance [15]. This mineralogical study is fragmentary for it only concerned a single sample, not representative of the entire thickness of the layer and its possible lithological variations. Moreover, the resolution chosen for X-ray diffraction may not be able to reveal the peaks of these minerals. It is appropriate for an objective study to proceed with a sedimentological step of phases separation before an objective X-ray diffraction study. At this stage, this study is not considered conclusive to the mineralogy and the origin of this yellow landmark layer.

However, calcite and dolomite appear in the analysed sample (Benchmark level) as the most abundant minerals (Table 1). These minerals are often associated with, however, a clear predominance of dolomite over calcite (Figure 2), defining a dolomite or limestone dolomite for this yellow level.

Table1: The abundant minerals in the analyzed sample.

Compound Name	Chemical Formula	PDF Index Name
Dolomite	$\text{Ca Mg (C O}_3 \text{)}_2$	Calcium Magnesium Carbonate
Calcite	$\text{Ca (C O}_3 \text{)}$	Calcium Carbonate

The dolomite is characterized in this case by a broad and intense peak at 3.91 \AA ($22.87^\circ 2\theta$), while calcite is characterized by peaks with lower intensities. From a mineralogical point of view, the line (interplanar distance) of calcite is generally between 1.03 \AA and 3.86 \AA ($23.05^\circ 2\theta$), and for dolomite, its main line range between 2.89 \AA and 2.90 \AA . The yellow color, often attributed to iron oxides in clay sedimentary rocks, is in this case. The presence of these two components is not obvious at first sight; this may be related to phosphate rock leaching and carbonate impregnation. The significance of these benchmark levels remains therefore posed.

3.2. Spacer C4 - C3

X-ray diffraction analyzes show two dominant crystalline forms (Table 2), which are calcium carbonate and hydroxylapatite with lines that appear respectively at 3.02 Å (for calcium carbonate) and 3.16 Å (for hydroxylapatite) (Figure 3).

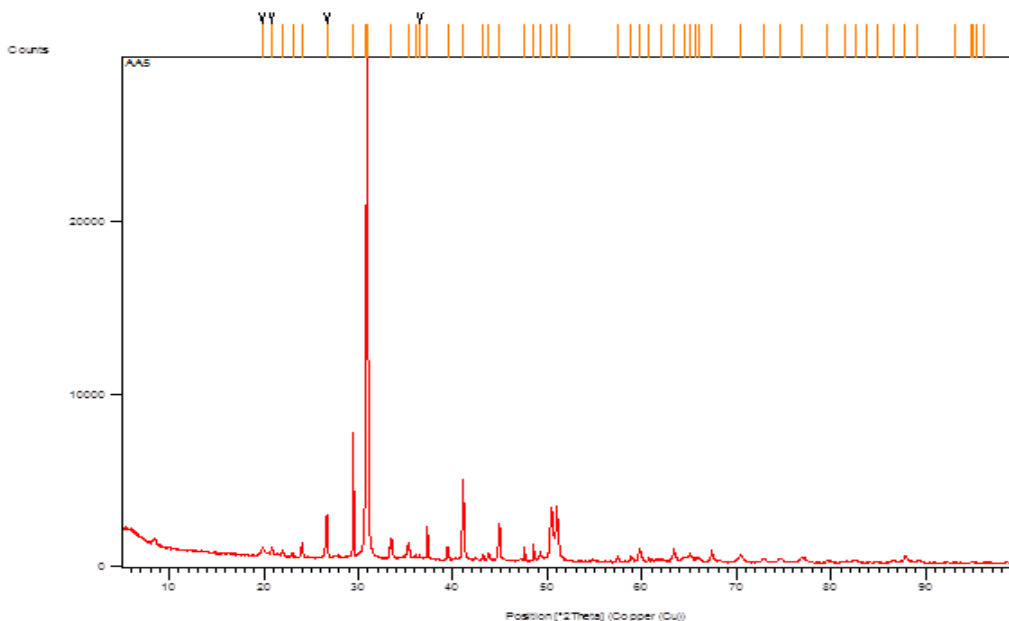


Figure 2: X-ray diagram of clay level samples from the Benguerir North phosphate series

Table 2: The abundant minerals in the analyzed sample.

Compound Name	Chemical Formula	PDF Index Name	Semi Quant [%]
Calcium Carbonate	Ca C O ₃	Calcium Carbonate	66
Hydroxylapatite	Ca ₅ (P O ₄) ₃ (O H)	Calcium Phosphate Hydroxide	34

Calcium carbonate forms 60% of the rock (Table 2); it is therefore a phosphate limestone. Petrographic and SEM studies show that these carbonates are essentially oolitic.

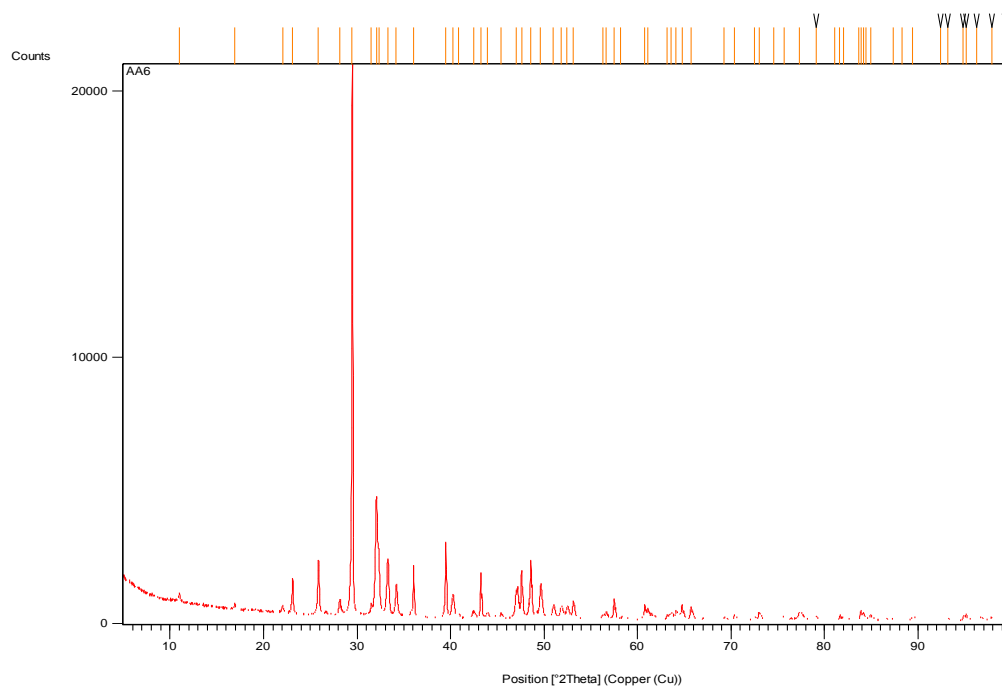


Figure 3: X-ray diagram of the spacer C4 - C3 level samples from the Benguerir Nord phosphate series.

3.3. Yellow benchmark level

The images of the sample obtained by scanning electron microscope (SEM) show four types of crystals (Figure 4 and Figure 5):

- Crystals in rhombohedral form: are the most frequent, with a size varying around $43.3\mu\text{m}$. These crystals thus correspond to dolomite and calcite already confirmed by X-ray study.
- $29\mu\text{m}$ cubic crystals which probably have to correspond to halite crystals (rock salt).
- Crystals in laminated form correspond to phyllosilicates (Clays).
- Irregularly shaped crystals that probably correspond to quartz.
- Thus, these observations, in contrast with the results of the RX, confirm the presence of clays in this reference level.
- The qualitative chemical analysis carried out with the energy dispersive micro-analyzer (EDXA) accounts for the presence of the Ca, Si, Mg, as well as Al and Fe elements (Figure 6) which enter into the compositions of all the raised minerals including clays.

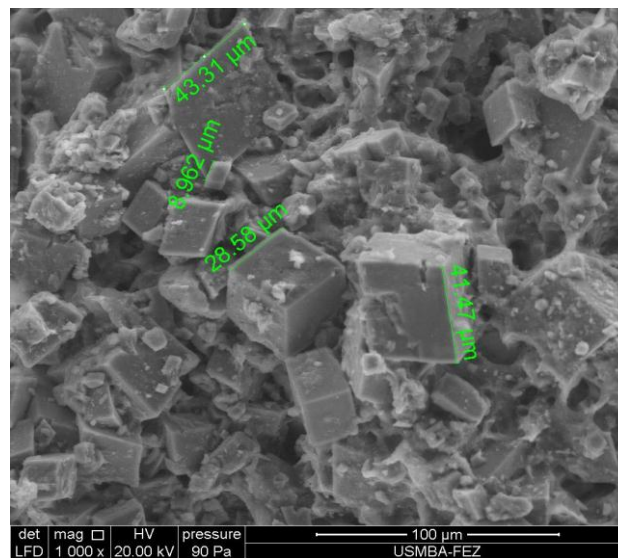


Figure 4: Images of the scanning electron microscopy of the benchmark level.

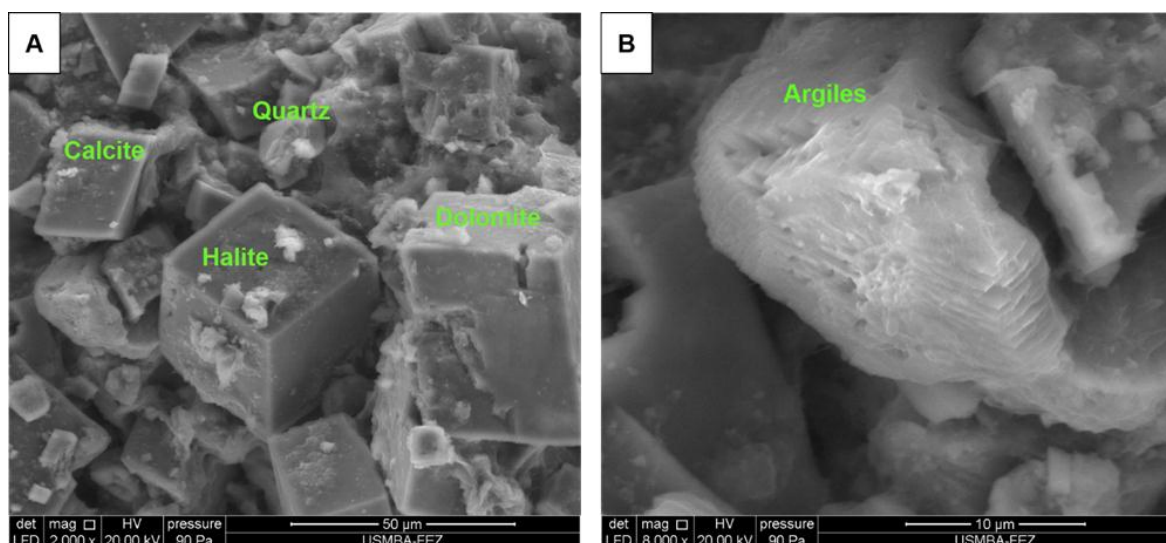


Figure 5: The different shapes of the crystals. A- Rhombohedral and cubic. B- Laminated.

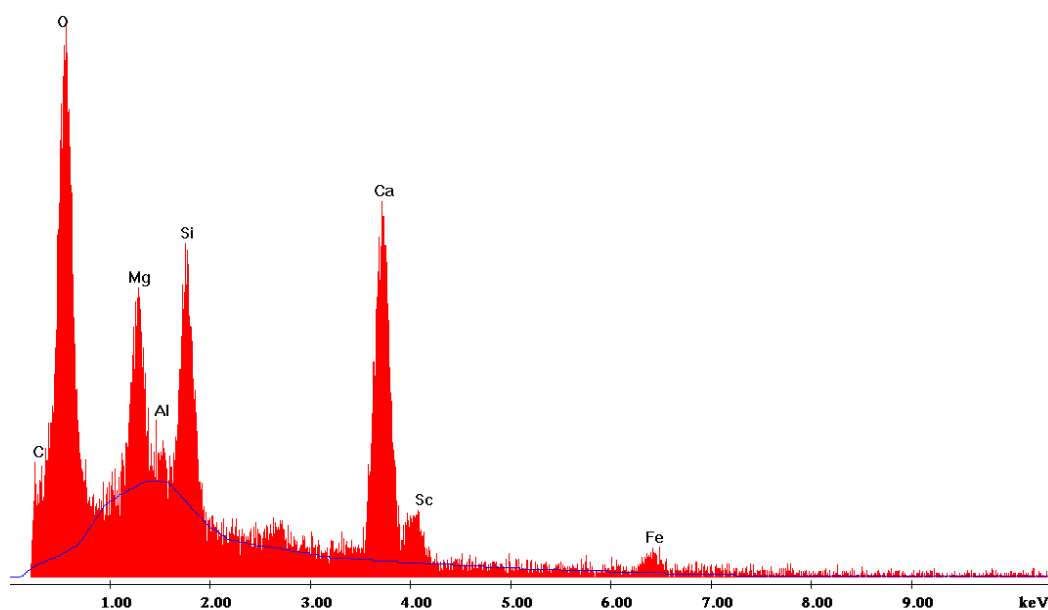


Figure 6: Spectrum of chemical elements of benchmark level (SEM).

3.4. Spacer layer 4 - layer 3

Observation under a scanning electron microscope (SEM) shows that this level consists essentially of oolites of size ranging between 396 μm and 410 μm , and of rounded or sometimes irregular shapes, bone debris, as well as quartz grains [16]. X-rays showed the predominance of carbonates and apatite in the composition of this level (Figure 7).

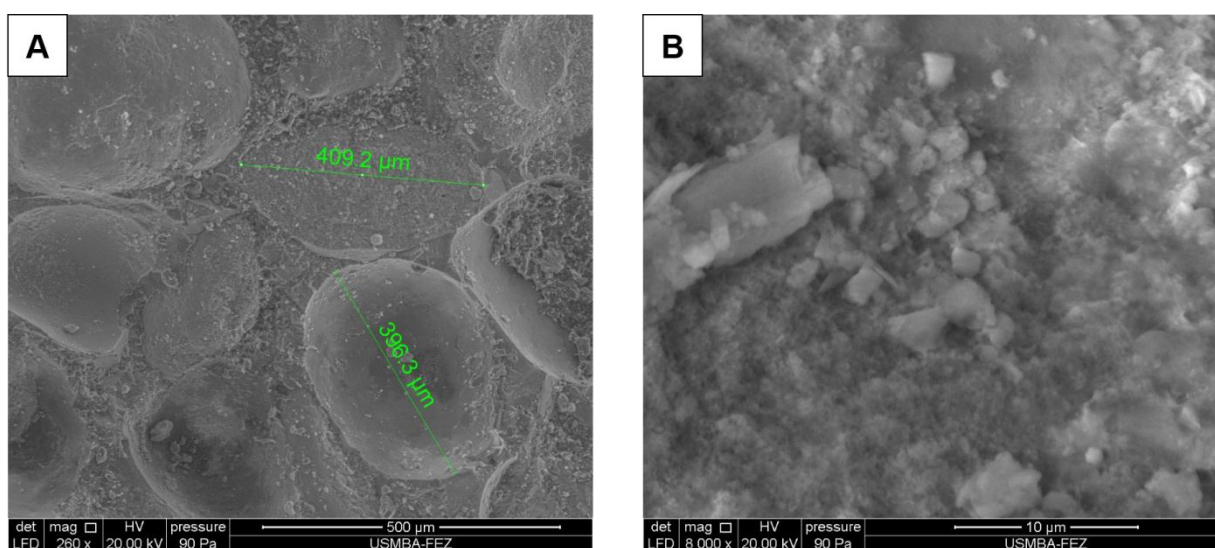


Figure 7: SEM image of the structure of phosphate constituents. A- The ooliths. B- Bone fragments.

Qualitative analyzes using a scanning electron microscope confirm that the level consists of phosphate components associated with carbonates. The presence of clay minerals is not to be excluded in this interlayer as well as organic matter. Sc (Scandium) is also a constituent element (Figure 8).

3.5. Geographic Information System (GIS)

After the data collection phase, ArcGIS software spatial interpolation methods are applied to characterize statistically the characteristics of the studied panel. We are particularly interested in the calculation of some classical statistical parameters such as the mean, the standard deviation, etc ... These statistical parameters are very determining as to the possibility of interpolation by Kriging (Kriging: denotes a set

of methods of interpolation based on mathematical and statistical models that all allow to estimate the value of a property at a point of geographical space from neighboring observations (the autocorrelation, being a function of distance).

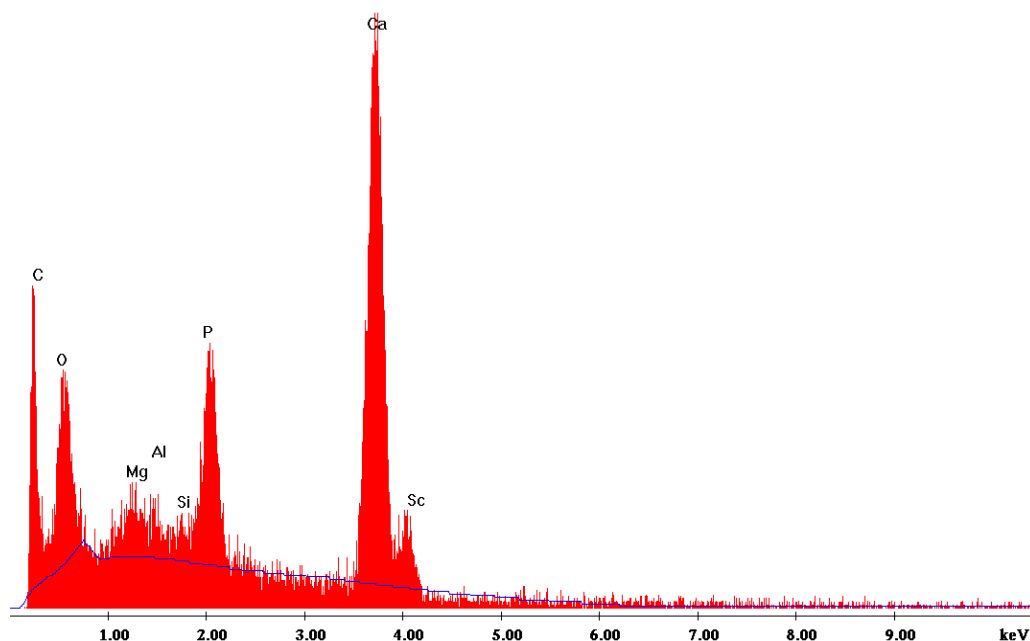


Figure 8: Spectrum of chemical elements of Spacer layer 4 (C4) – layer 3 (C3).

Subsequently, the realization of the cards is approached taking into account the objective assigned to the study and the expected results. It consists of:

- Making maps of the physical and chemical characteristics of the phosphate layers by the geostatistical method.
- The connection between the database and the GIS software through a data source that allows a dynamic link to be established so that updates of the data contained in the database are automatically taken into account in the mapping software.

3.6. Maps Creation

After the input database is developed from the well data, it is imported to the ArcMap interface of the ArcGIS geographic information system to be the subject of a geoprocessing aimed at creating iso-value maps of all the studied parameters (Figure 9).

3.7. 3D Model

The structural maps of the other layers, treated in the same way show that the general structure is practically unaffected by major structures. It is generally monoclinical with a slight dip to the northwest[17]. Some irregularities punctuate this structure, particularly in the south-west of the panel as shown by the 3D reconstitution of the panel (Figure 10). At our observation scale, no major structure of the type has been identified or folded. No disturbance has been observed either directly or indirectly in this panel.

3.8. Map listing mining boxes

Listing Cases is the mining database that links each box to its properties [18]. The establishment of the mining listing maps (Figure 11) is based on the compiled data of the physicochemical parameters obtained by the chemical analyzes of the samples taken in the phosphate series from the recognition wells. These data are then recorded on the lithological sections of these different wells for the purposes of correlation and resource evaluation.

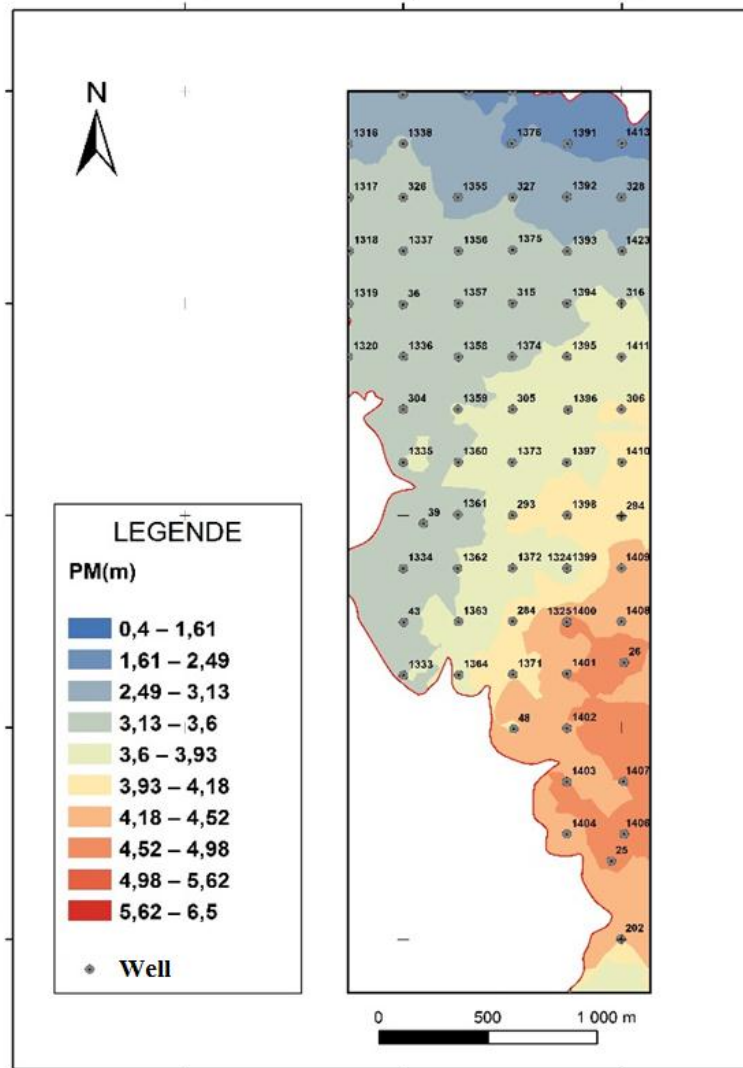


Figure 9: Example of the distribution map of global thickness.

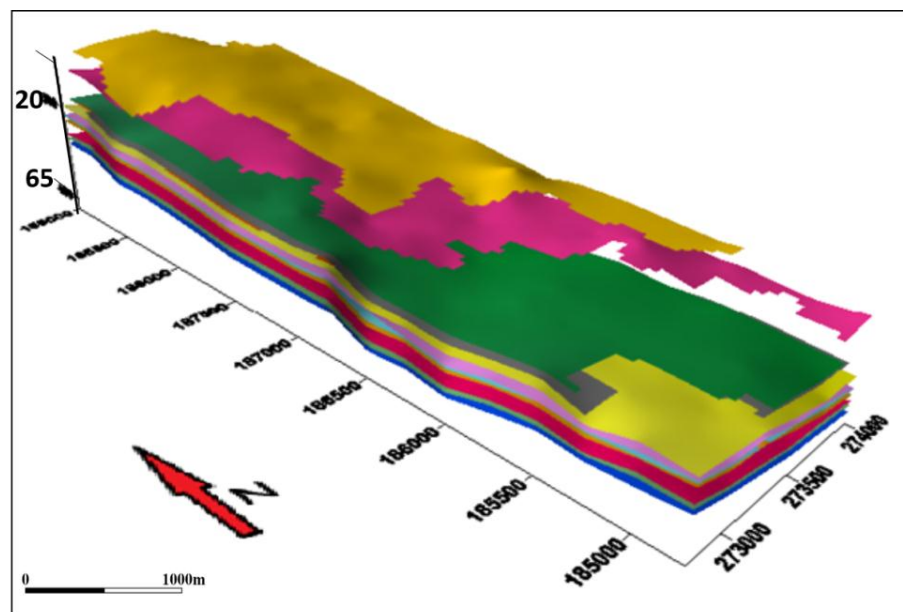


Figure 10: Presentation of phosphate layers in 3D model.

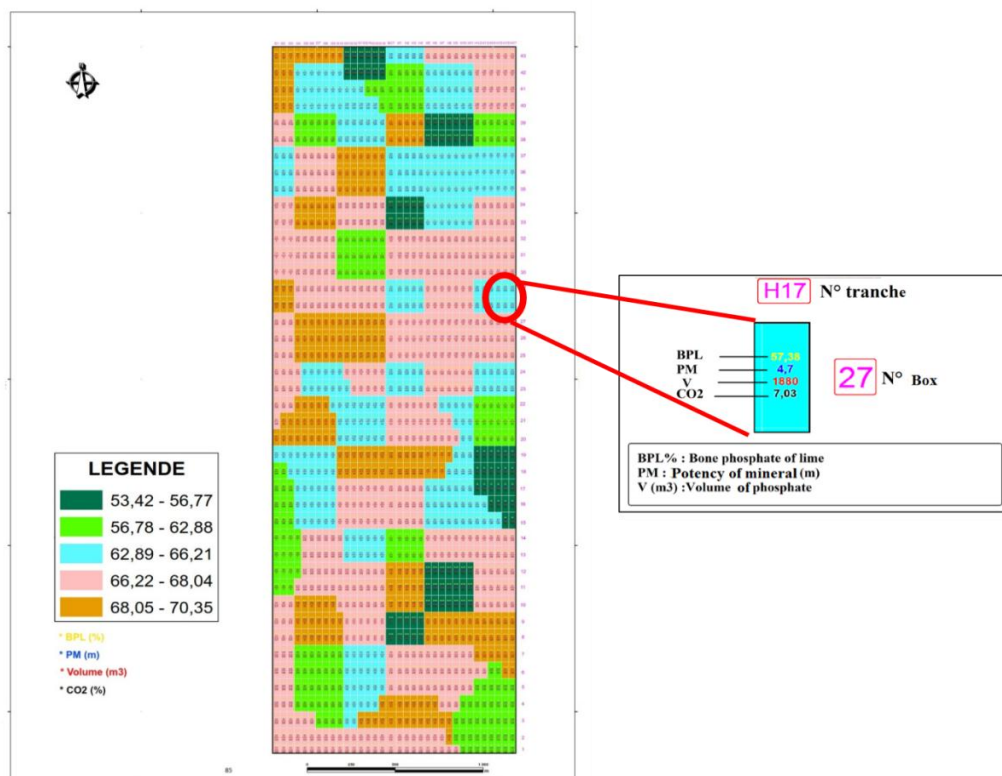


Figure 11: Example of a Map listing cases.

Conclusion

The work presented in this paper deals with a geological and mining study of the panel 7 of the exploration and exploitation zone of North Benguerir belonging to the Ganntour basin. The exploitation of phosphates, although it is done in open-pit, must be preceded by an exploration in order to reconstitute the geometry of the phosphate layers including their extension and their power; the evaluation of their mining quality based on their overall chemical composition and, particularly, their content of P₂O₅ (Phosphorus pentoxide). These data, in large numbers are obtained through direct or indirect methods based on random sampling or regularly spaced wells on exploration areas. They must be the object of an objective computerized treatment which allows to analyze and discuss the properties of the deposit and mainly to evaluate the volumes of the ore in such a way as to direct the miners towards the best exploitation methods.

In this work, a technique based on the use of ArcGIS software for the processing of data from panel 7 of the North Benguerir deposit is proposed. This technique allowed us to establish different maps showing different properties of the phosphate layers. The main ones are the BPL, CO₂; Mg concentration maps, isopach maps, structural maps and finally listing boxes that link each box to all its mining properties. This enabled us reconstruct the geometry of the layers of the entire panel with an objective 3D view of the layers and to quantify the resources of this panel.

References

1. A. Lenoble, H. Salvan, V. Ziegler, Découverte de l'uranium dans les niveaux phosphatés du Maroc. *C. R. Acad. Sci. Paris*, t. 234, No 9 (1952) 976-977.
2. O. Ouakibi, R. Hakkou, M. Benzaazoua, Phosphate Carbonated Wastes Used as Drains for Acidic Mine Drainage Passive Treatment. *Procedia Engineering*, 83 (2014) 407- 414.
<https://www.sciencedirect.com/science/article/pii/S1877705814011424>
3. S. Zouhri, A. Kchikach, O. Saddiqi, F.E. Haïmer, L. Baidder, A. Michard, The Cretaceous-Tertiary Plateaus. In: Michard A., Saddiqi O., Chalouan A., Lamotte D.F. (eds) *Continental Evolution: The Geology of Morocco. Lecture Notes in Earth Sciences*, vol 116. (2008) Online ISBN 978-3-540-77076-3 Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-77076-3_7

4. N. El Kiram M. Jaffal, A. Kchikach, D. El Azza, M. El Ghorfi, O. Khadiri, ES. Jourani, A. Manar, M. Nahim, Phosphatic series under Plio-Quaternary cover of Tadla Plain, Morocco : Gravity and seismic data, *Comptes rendus-Geoscience.*, 351(2019)420–429. doi.org/10.1016/j.crte.2019.05.002
5. OCP, Growing circular, Rapport annuel 2018 du groupe OCP sa. (2018). <https://www.ocpgroup.ma/sites/default/files/2019-12/Rapport%20annuel%20OCP%202018VF.pdf>
6. Azzouz Kchikach, Mohammed Jaffal, Tahar Aifa, Lahcen Bahi, Cartographie de corps stériles sous couverture quaternaire par méthode de résistivités électriques dans le gisement phosphaté de Sidi Chennane (Maroc), *Comptes Rendus Geoscience*, 334(6) (2002) 379-386, [https://doi.org/10.1016/S1631-0713\(02\)01767-4](https://doi.org/10.1016/S1631-0713(02)01767-4)
7. H. El Haddi, A. Benbouziane, M. Mouflih, E. Jourani, M. Amaghaz, Siliceous Forms of Phosphate Deposits of Cretaceous Age in Oulad Abdoun Basin (Central Morocco). Mineralogy, Geochemistry and Diagenetic Phenomena, *Procedia Engineering*, 83 (2014) 60-69. <https://doi.org/10.1016/j.proeng.2014.09.013>
8. A. Boujo. Contribution à l'étude géologique du gisement de phosphate crétacé-éocène des Ganntour (Maroc occidental) ". *Notes & M. Serv. Géol., Maroc*, (1976), n° 43. https://www.persee.fr/doc/sgeol_0302-2684_1976_mon_43_1
9. A. Piqué, Geology of Northwest Africa: Beiträge zur regionalen Geologie der Erde. Borntraeger, Berlin Stuttgart. (2001) p. 310. <https://doi.org/10.1017/S0016756802257118>
10. H. EL Haddi, A. Benbouziane, M. Mouflih, and M. Laadila, Silicification in the phosphate deposits of Maastrichtian-Lutetian age in the Ouled Abdoun basin (Morocco): Sedimentology, mineralogy, geochemistry. *Arabian Journal of Earth Sciences*. V: 1 (2014) 16-25. www.researchgate.net/publication/271212309_silicification_in_the_phosphate_deposits_of_maastrichtian-lutetian_of_the_ouled_abdoun_basin_Morocco_sedimentology_mineralogy_and_geochemistry
11. El Hadi H., Tahiri A., El Maidani A., Saddiqi O., Simancas F., González Lodeiro F., Azor A., Martinez Poyatos D., Tahiri M., De La J., *Bull. Inst. Sci*, 36 (2014) 55-67. [http://www.israbat.ac.ma/wp-content/uploads/2015/12/06-%20El%20Hadi%20et%20al.%20\(12.01.2016\).pdf](http://www.israbat.ac.ma/wp-content/uploads/2015/12/06-%20El%20Hadi%20et%20al.%20(12.01.2016).pdf)
12. H. Saadi, Carte géologique du Maroc au 1/500 000. *Ministère de l'énergie et des mines, direction de la géologie* (1982). <https://www.mem.gov.ma/Pages/index.aspx>
13. A. Anjjar, Y. Driouch, F. Benjelloun, A. Lahrach, A. Chaouni, R. Afgane, A. El Alami, Caractérisation pétrographique et valorisation des phosphates du gisement de Benguéir (Maroc). *Am. J. Innov. Res. Appl. Sci. Appl. Sci.* 6 (2018) 160–169. <https://www.american-jiras.com/Anjjar-ManuscriptRef.1-ajira300318.pdf>
14. Y. Daafi, Unpublished report, « Etude géologique et minière du panneau 7, Gisement de Benguéir Nord, Bassin du Gantour », *IDRV*, (2012) 48/12.
15. M. Dass Amiour, H. Mezghacheet B. Elouadi, The use of three physico- chemical methods in the study of the organic matter associated with the sedimentary phosphorites in Djebel Onk Basin, Algeria. *Arab. J. Geosci.*, 6 (2011) 309-319 <https://doi.org/10.1007/s12517-011-0381-9>
16. K. Kouraiss, K. El Hariri, A. El Albani, A. Azizi, A. Mazurier, J. Vannier, X-ray microtomography applied to fossils preserved in compression: Palaeoscolecoid worms from the Lower Ordovician Fezouata Shale, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 508 (2018) 48-58, <https://doi.org/10.1016/j.palaeo.2018.07.012>
17. A. Ayad and S. Bakkali, Interpretation of Potential Gravity Anomalies of Ouled Abdoun Phosphate Basin (Central Morocco), *Journal of Materials and Environmental Science*, 8 (2017) 3391–3397. https://www.jmaterenvironsci.com/Document/vol8/vol8_N9/358-JMES-3119-Ayad.pdf
18. Y. Daafi, A. Chakir, E. Jourani, SM. Ouabba, Geology and mine planning of phosphate deposits : Benguerir deposit. *Procedia Eng.*, 83 (2014) 70-75. <https://doi.org/10.1016/j.proeng.2014.09.014>

(2020) ; <http://www.jmaterenvironsci.com>