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Procedia Engineering 138 (2016) 8 – 18

Procedia Engineering

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"SYMPHOS 2015", 3rd International Symposium on Innovation and Technology in the Phosphate Industry

Characterization and Valorization of Tozeur-Nefta Phosphate Ore Deposit (Southwestern Tunisia)

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Abstract

The Tozeur-Nafta phosphate deposit is located, in the southwest of Gafsa mining basin, about 12 kilometers west of Tozeur town. Geologically, this deposit is represented by an anticline with large radius of curvature and characterized by the absence of visible outcrops.

Phosphate series show a clear analogy with the other deposits in the neighbor basin. The thickness of 6 exploitable layers is 10,61m with an average content of raw phosphate: P_2O_5: 22.67%.

The collected samples were characterized from a mineralogical, chemical and grain size distribution point of view. Data analysis was firstly used to calculate various statistical parameters, correlations between the chemical elements and secondly to determinate mineral assemblages and useful fractions.

The present study is complemented by a geostatistical analysis of geochemical data which consist of the establishment of spatial distribution maps by kriging techniques. The resulting thematic maps that can lead to the development of geochemical model assuming the spatial distribution of oxides and metals of the district

Peer-review under responsibility of the Scientific Committee of SYMPHOS 2015

Keywords: phosphates; Tozeur-Nefta district, geological ; mineralogy and grain size distribution ; mineralogical and granulo-chemical characterization, geostatistical study ; Reserves.

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Peer-review under responsibility of the Scientific Committee of SYMPHOS 2015
doi:10.1016/j.proeng.2016.02.047

1. Introduction

Phosphate ore is the principal mineral products in Tunisia. This country is the second largest phosphate producer in Africa, turning out about 8 Mt of rock on average in recent years [1]. The phosphate deposits of Tunisia are all aged Early Ypresian, found in the Chouabine Formation. The Tozeur-Nefta deposit is considered part of the Gafsa mining basin and is located in the southwest corner of the Basin. Lithologically, this deposit presents a clear analogy with the other phosphatic strata in the region (10 phosphate layers only 6 layers are economically exploitable others are considered sterile with interlayers). The deposit which completely covered by miocene sands and eocene limestone is characterized by the absence of visible outcrop. This phosphate accumulations was the subject of several mineralogical, geochemical and geostatistical investigations [2], [3], [4]. In the present study, new prospecting results are integrated (more than 3000 meters have been recently drilled). Therefore, the aims of this study are firstly to determine mineralogical and geochemical characteristics of phosphate mineralization. A second aim is to create isopach and isovalue maps. These maps can be used as decision support for the mining designer or decision maker in order to select the mining method for extraction and production control by identifying the thickness and geographic distribution of chemical elements [5].

2. Geographic and geological frameworks

The Tozeur-Nefta deposit is located in the southwest part of Gafsa mining basin, about 12km west of the Tozeur town. This deposit has a width of about 4km in the North-South direction (between Chott El Gharsa and Chott Dejrid) and a length of 10 km in the East-West direction (between Tozeur and Nefta towns) (Fig. 1).

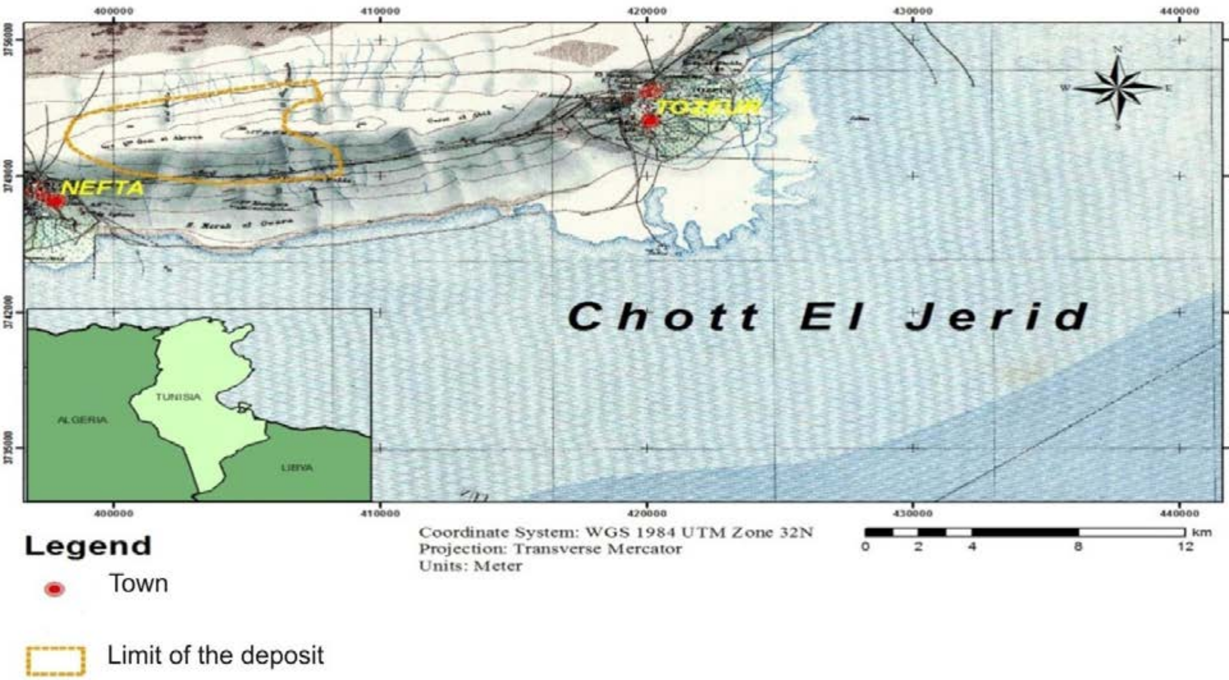

Fig. 1. Location map of the studied area

In this district phosphate deposit is marked by the absence of visible outcrops. It is completely covered by mio-pliocene sand. Reconnaissance examination showed that the deposit constitute an anticline with large radius of curvature and with low dipping strata (0° to 15°). The north limb is less sloped than the South one. The axis of the structure is oriented East-west and dipped about 5° to the West (Fig. 2).

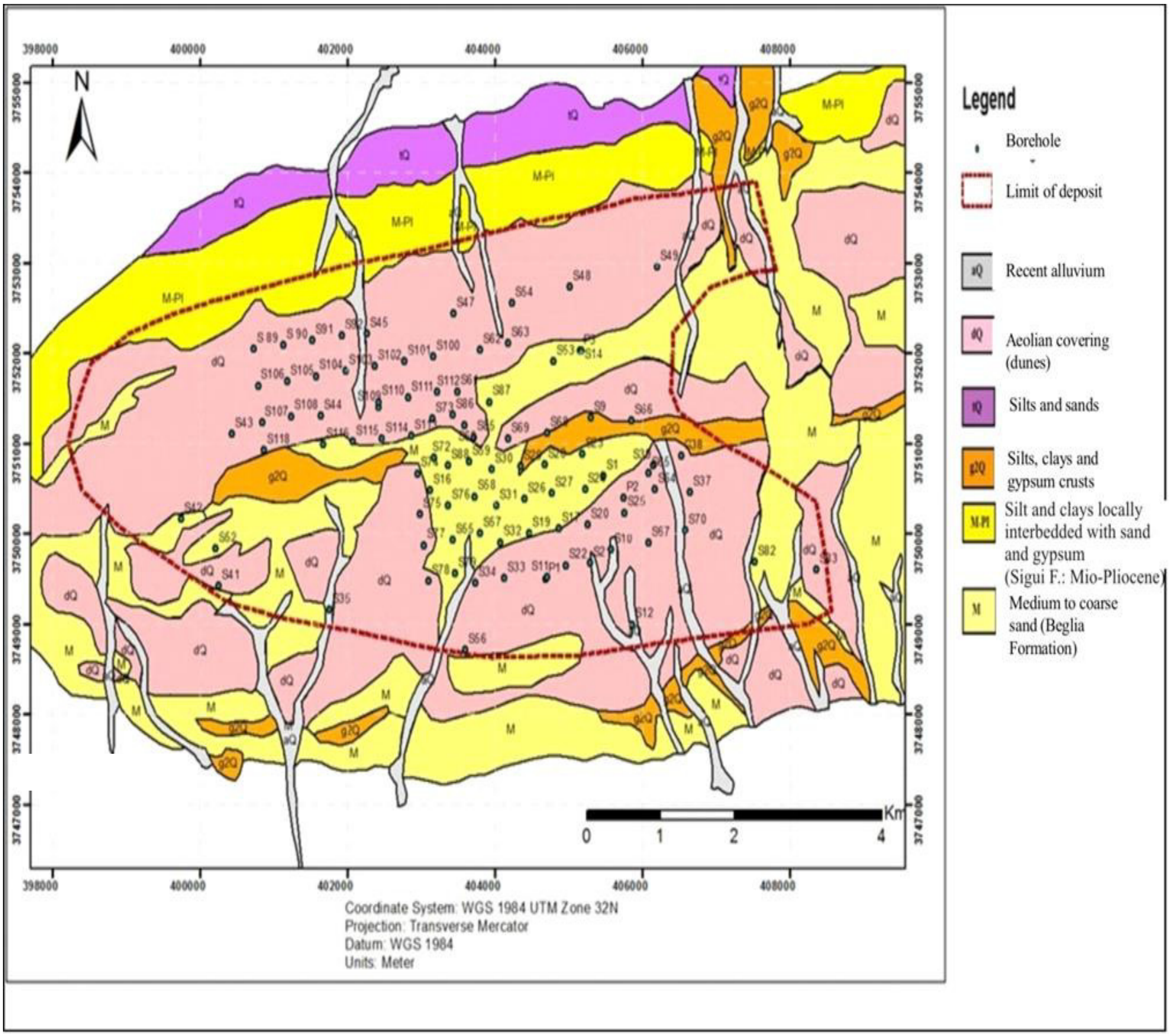

Fig.2. location of boreholes and geological map of Tozeur-Nefta deposit (after Mahjoub, 1990) [6]

The lower Eocene phosphate series are limited by the shelly lavel at the base, and by the limestone slab at the top. It consist of nine phosphorite beds designated from top to bottom (from I to IX). The layers (0, I, II, VI, VII and VIII) are exploitable however the layers (III, IV, V and IX) are eventually non productive layers because their small thickness (Fig. 3). They are separated by non phosphate materials like marl, chert and limestone. The interlayers are indicated by the letter "m" followed by two numbers of top and down layers.

3. Methodology

A representative sample was collected from the phosphate bed. X-ray diffraction (XRD), Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic absorption spectroscopy (AAS) studies were carried out to characterize the phosphate sample. The samples were characterized using mineralogical and chemical methods. Size fractionation and the separation of the particles were accomplished using wet seiving method. All the analytical work was carried out in the laboratories of Company of Phosphates of Gafsa (CPG).
To estimate the accumulated P_2O_5, Cd and C.org variables and the variable thickness, the ordinary kriging method was used. The estimation was performed using a 2D block model by ArcGis 10.1.

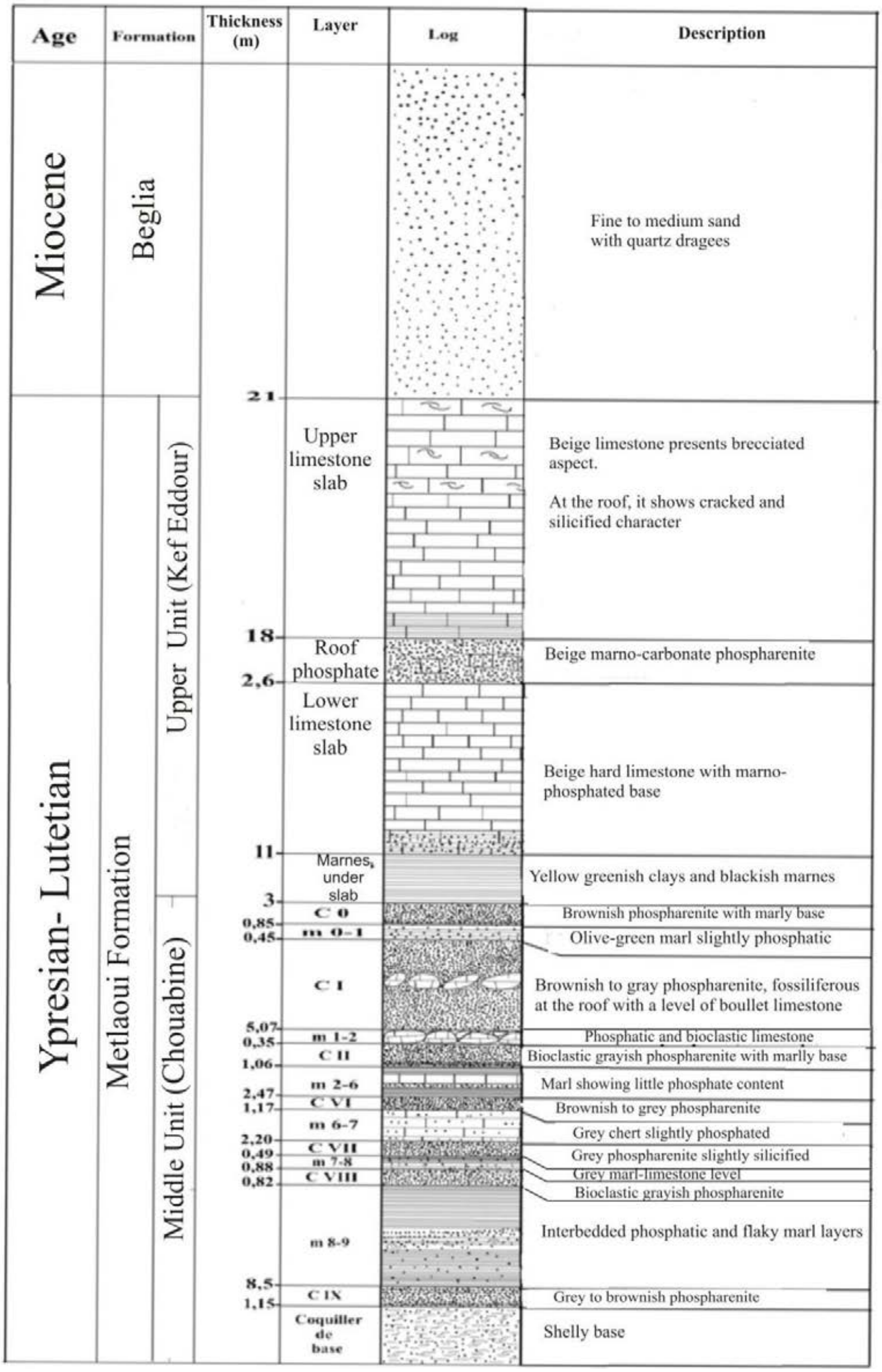

Fig. 3. Synthetic lithostraphic log of the studied area [3] and [7].

4. Results and discussion

4.1. Petrographic Analysis

The phosphorites in Tozeur-Nefta deposit are sedimentary and granular material (Fig. 4). The phosphate grains are dominated by pellets cemented with carbonaceous matter. Calcite is the major cementing material and main constituent of foraminifera (nummulites) (Fig 5a, d). Furthermore micrite and quartz are presents (Fig.5b, c). Other phosphate components are phosphoclasts including bones and shark teeth's (Fig. 4) coprolites (Fig.4 b and 5b) are dominant, in large grain size.

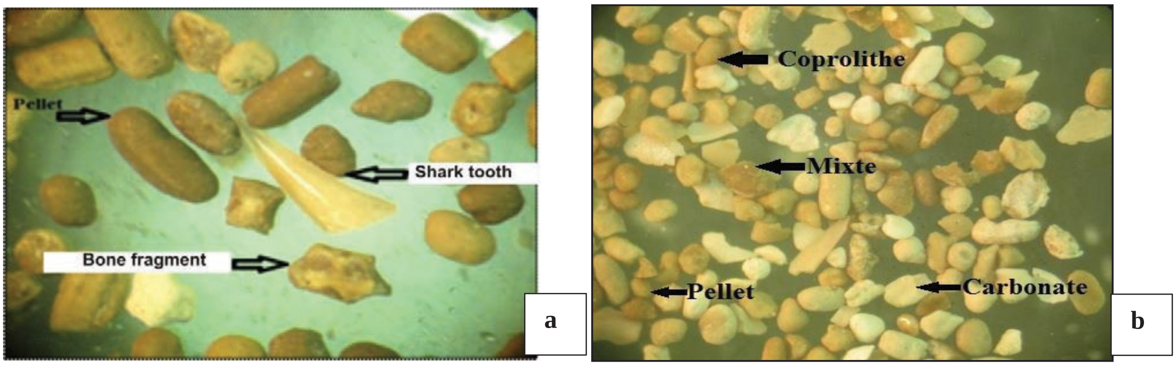

Fig. 4. Observation of phosphate materials under stereomicroscope

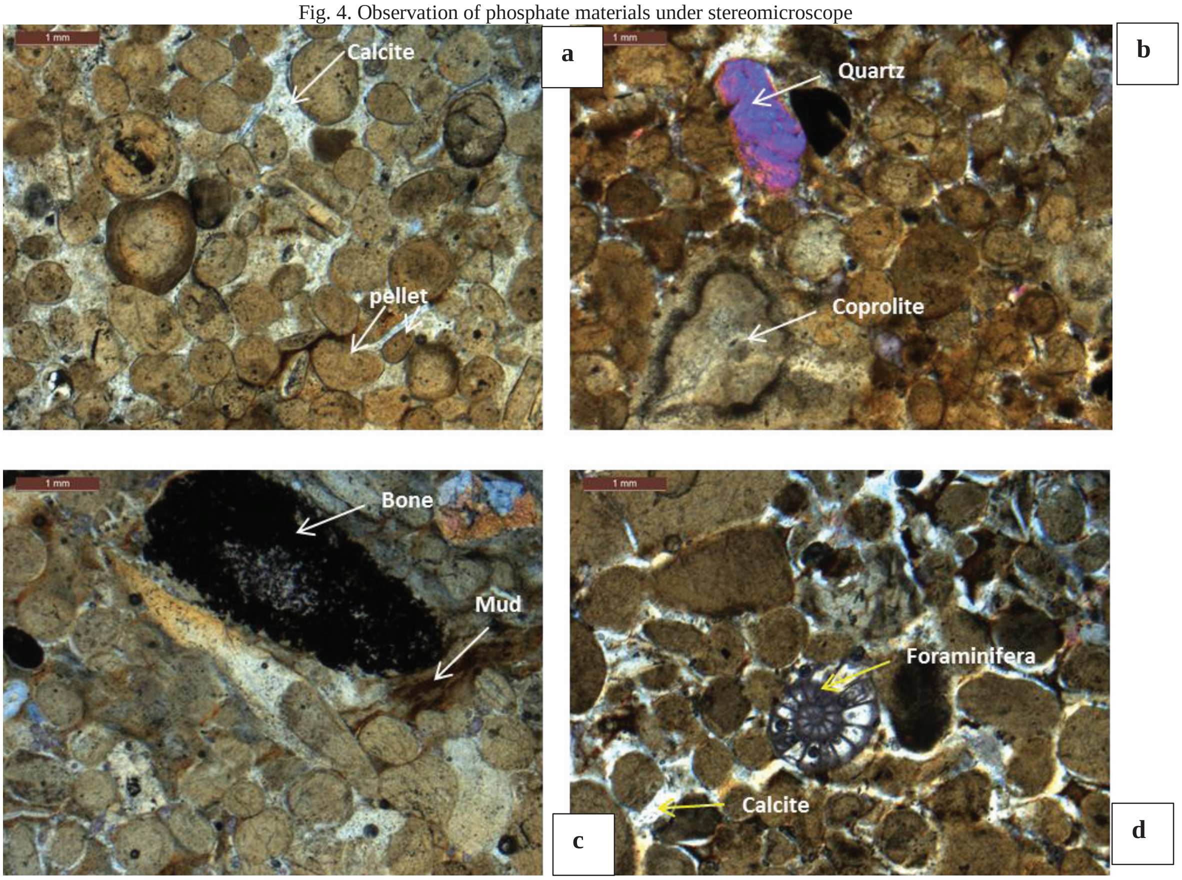

Fig. 5. Phosphate textural components in the Tozeur-Nefta deposit

4.2. Mineralogy

X-Ray diffraction (XRD) was adopted for the determination of phase composition of the specimens. This analysis showed that the phosphorite contain calcite, carbonate fluorapatite and accessorily quartz and dolomite (Fig.6). This mineralogy is repeated in all samples with different percentages (Fig.7).

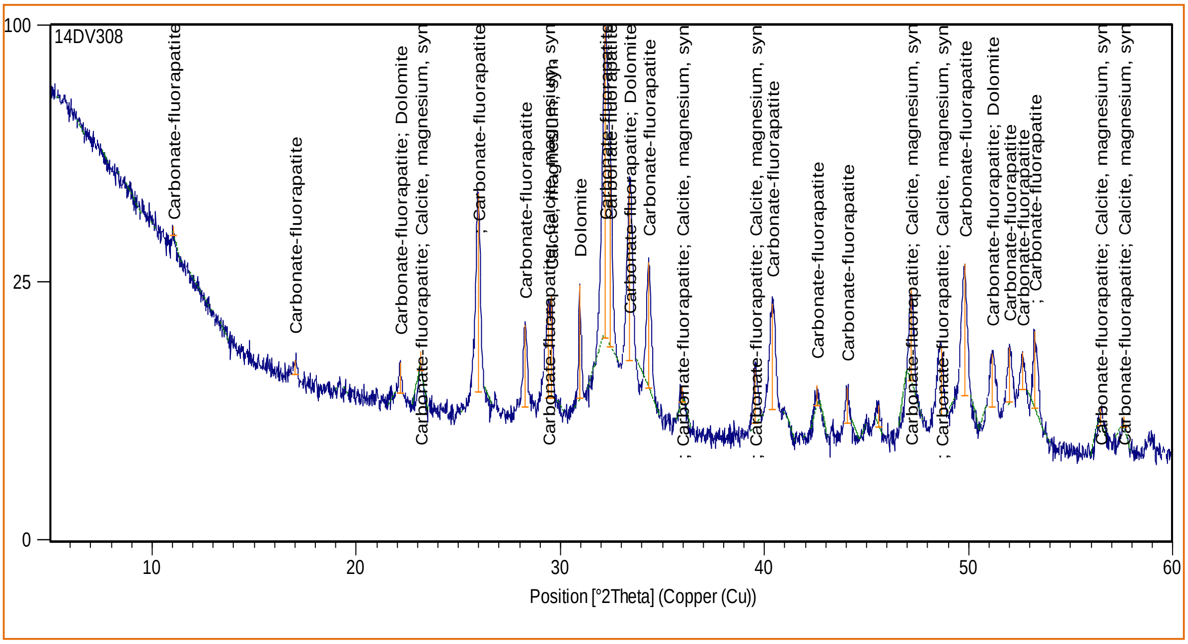

Fig. 6. Example of XRD diagram of powder

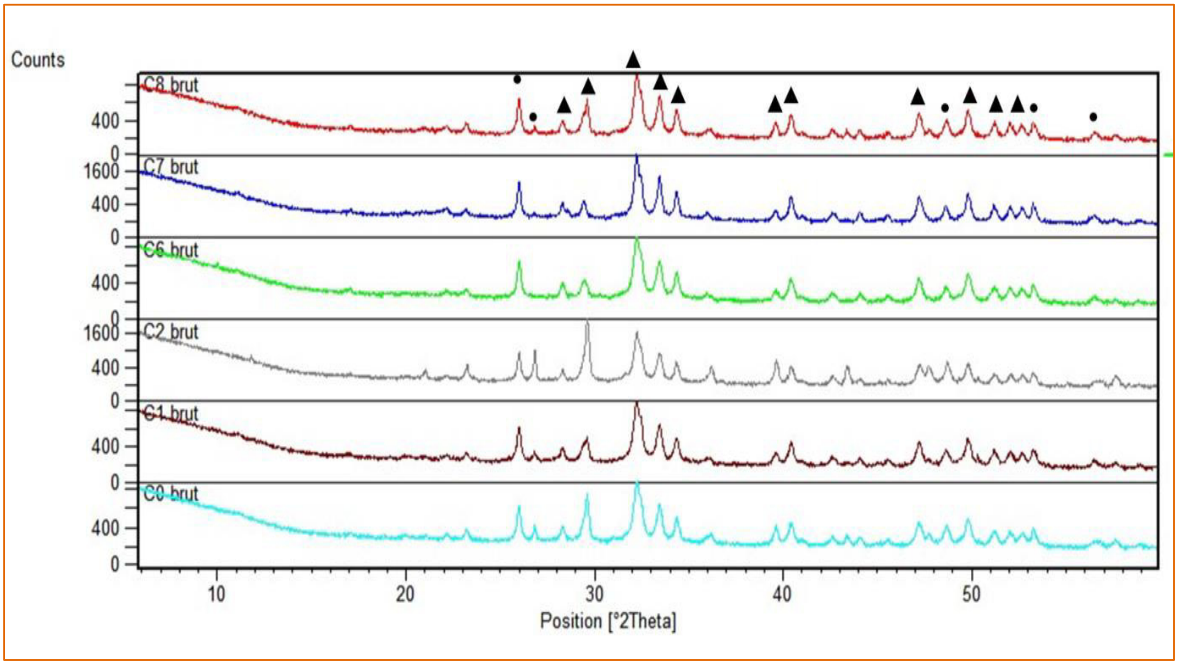

Fig. 7. XRD diagrams of powder of different layers (legend: ▲ : carbonate-fluorapatite; ● : dolomite

4.3. Chemical composition

The results of chemical analysis of representative samples for each layer are presented in Table 1. P_2O_5 content of phosphorite is between 27.7 and 30 % and CaO content oscillate from 48.5 to 50.1 %, the CaO/P_2O_5 does not exceed 1.7 slightly higher than that of 1.54 for a pure carbonate-fluorapatite. The layer CVIII is the riches layer in P_2O_5 and Cd. These elements are positively correlated.

Table 1. Major and trace elements) in the main phosphatic layers

Sample	Mass recovery (%)	P_2O_5 (%)	CaO (%)	Na_2O (%)	K_2O (%)	MgO (%)	SiO_2 (%)	C.org (%)	Fe_2O_2 (%)	Al_2O_3 (%)	Cd(ppm)	CaO/ P_2O_5
C0	62.03	29.19	50.15	1.23	0.07	0.82	2.31	2.31	0.36	0.50	23.00	1.713
CI	78.79	29.76	50.10	1.29	0.08	0.89	2.23	2.23	0.25	0.25	24.00	1.68
CII	52.88	27.71	49.13	1.25	0.07	0.76	2.74	2.74	0.25	0.26	10.00	1.77
CVI	53.25	29.16	49.06	1.30	0.09	0.99	4.16	4.16	0.31	0.20	18.00	1.68
CVII	85.44	29.82	48.51	1.27	0.07	0.92	2.52	3.02	0.30	0.51	25.00	1.62
CVIII	78.76	30.44	49.79	1.30	0.08	0.83	3.02	2.52	0.46	0.23	45.00	1.63

4.4. Geostatistical study

4.4.1. Thickness

The data used throughout this study are collected from 48 boreholes. For each sampling borehole; thickness and P_2O_5%, were measured and reported to the Company of phosphates of Gafsa , which in turn provided all the data used throughout this study.
Maps have been created by ARCGIS.10 as shown in Figure 8; from this figure one can conclude that the eastern part has high thickness and the small region in the west of area, save for the other places have low thickness relatively. The lowest thickness is represented using green color. Moreover, the covering layers, considered as tailing, have also the lowest thickness in eastern part (Fig.9).
Consequently, the development of this deposit could be started with layers located in the East.

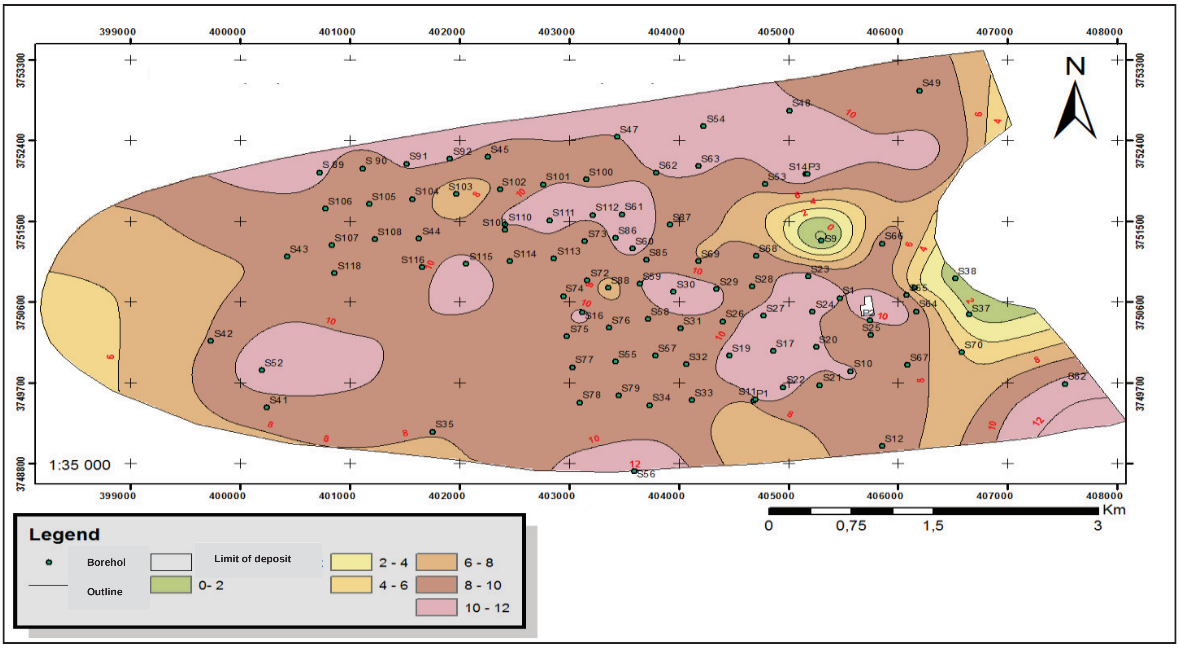

Fig. 8. Thickness of cumulated phosphate layers

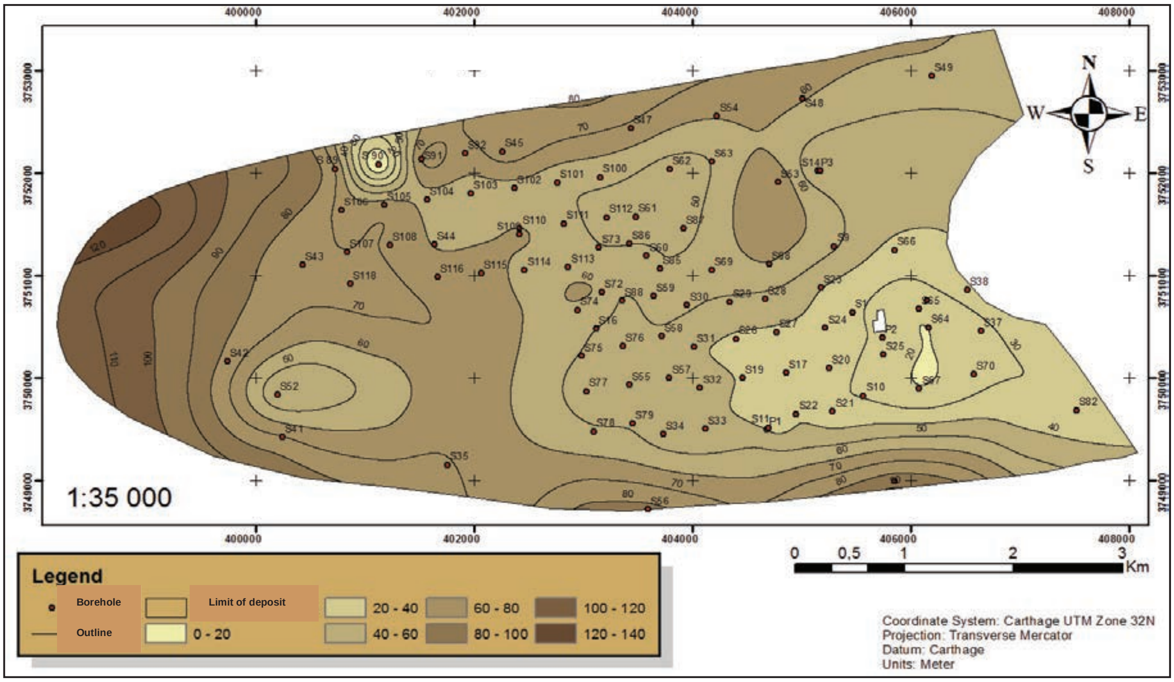

Fig.9. Thickness of covering layers

4.4.2. P_2O_5 distribution

P_2O_5 content in the raw phosphate shows a great variation between different phosphate layers with median values between 20.5 % and 25.34% (Table 2). The maximum is registered in the layer CVI. This layer shows the most rich phosphate level. The weakest layer is presented by CII.

Table2. Summary statistics of the P_2O_5

Layer	Min	Max	Mean	Standard deviation	Kurtosis	Mediane
C 0	17,25	24,29	21.63	1.99	-0.69	21,44
C I	20 ,00	27,47	24.19	1.67	0.20	24,07
C II	9,60	24,67	20.68	3.30	2.51	20,50
C VI	20,53	27,64	25.48	1.57	2.30	25,34
C VII	17,03	26,70	23.23	2.1	0.29	22,90
C VIII	15,02	26,72	22.24	2.69	0.38	21,78

- The productive layers which includes above 25% P_2O_5 content. Only the layer VI is classed in this category. This layer shows a maximum content in the central portion of the deposit and specifically at S.74 borehole.
- The lower productive layer which includes less than 25% P_2O_5 content. In this category in the rest of the layers 0, I, II, VII and VIII is class with an average content varies between 20.5% and 24.07% .The mapping the P_2O_5 content in the phosphate levels, showed that the blocks around the S47, S74 and S107 are the richest separated by blocks with medium grade or even poor especially at S29 borehole (Fig.10).

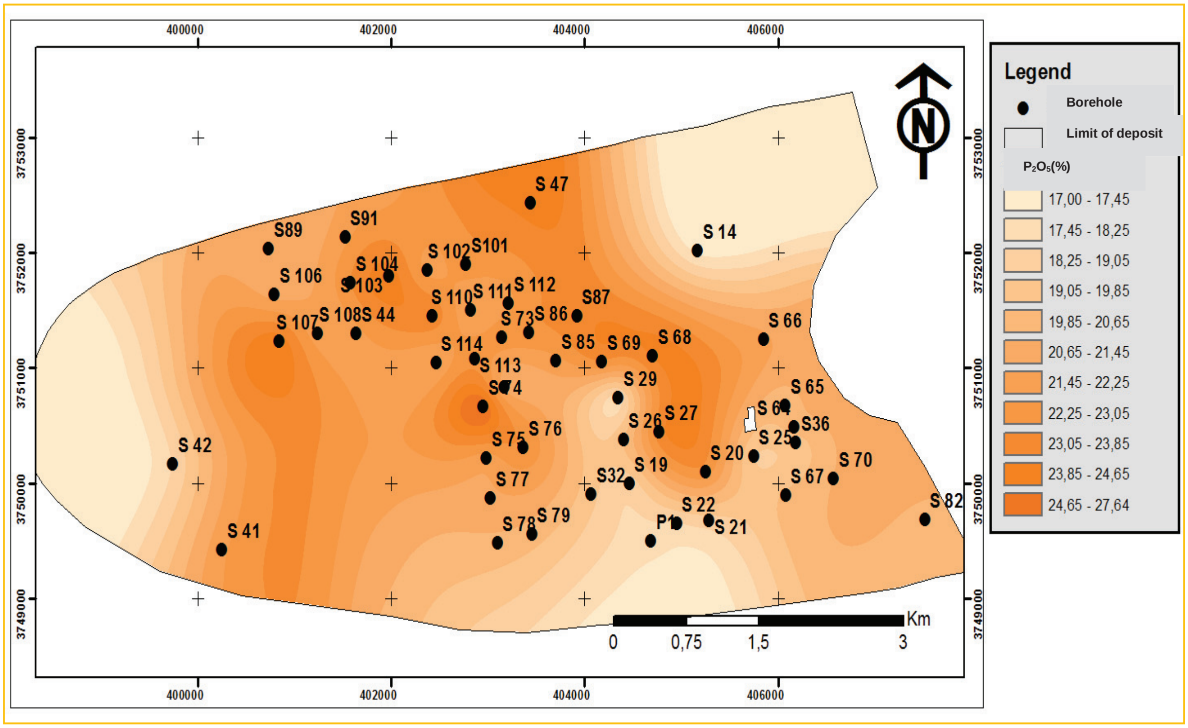

Fig. 10. The distribution of P_2O_5 % data (raw phosphate)

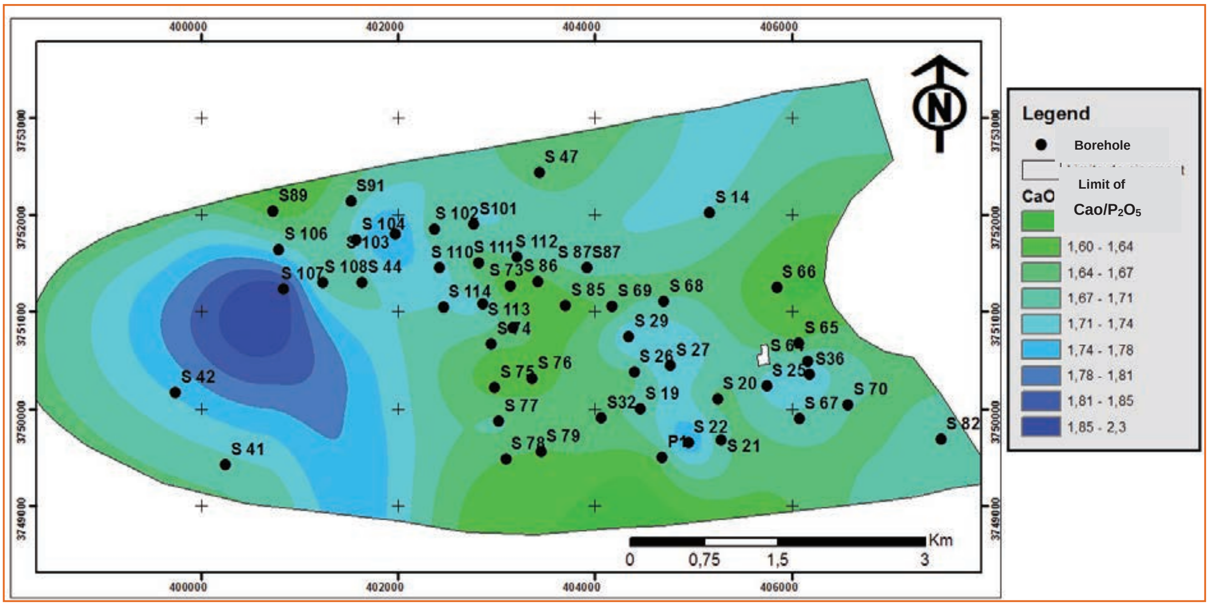

Fig.11. The distribution of CaO/P_2O_5 data (raw phosphate)

CaO/P_2O_5 ratios are generally constant (Standard Deviation between 0.8 and 1.2 %). This ration doesn't exceed 1.7 in all parts of deposit (Fig; 11). The higher ratio is due to the substitution of (PO_4).

4.5. Reserve calculation

The reserves were estimated depending on the thickness of the phosphatic layers in each borehole. The reserve was estimated using geostatistical method as Ordinary Kriging Method.
The formula adopted for the reserve determination is as follows:

$$\boxed{\mathbf{B.T.S\ (T) = S \times P \times T_r \times T_s \times T_h \times d}}$$

BTS: Raw phosphate, sorted and dried (in tons)
S: real area (m2)
P: mean thickness of phosphate layers between two consecutive isopacks curves (m)
Tr: recovery rate, it is considered a loss of 5 cm in the wall and 5 cm in the Roof of each layer.
Ts: fouling rate which depend on the estimated thickness of limestone balls or marl existing within each layer.
Th: humidity equal to 12%.
d: density of the phosphate equal to 2.

BTS reserves, in the Tozeur-Nefta deposit determined until hydrostatic level, give 264 MT. The deposit contains an estimated volume of sterile 489 MT (table 3) which constitute a handicap during open pit mining.

Table 3. Ore reserves estimations of the phosphate by Kriging method

	Volume (m^3)	**reserve (tons)**	
C0	26 144 511 660	41 831 218. 652	
CI	107 340 038 648,68	171 744 038 868,40	
CII	30 527 483 920	49 778 268. 952	
CVI	93 509 850 ,998	149 615 .760	
CVII	44 047 100	70 475. 360	
CVIII	76 677 030	122 685. 248	
TOTAL	164 056 081 329	263 353 526. 472	
Interbedded layer			117 503 751. 200
Recovering layer			371 932 693. 620

Conclusion

The Paleocene-Eocene phosphate series constitute the continuity and the equivalent series in the Gafsa mining basin. It exists in the subsurface undercover. The covering layers have an average thickness of about 78 m consisting essentially of sands of Beglia Formation and carbonates of Metlaoui Formation.
This phosphate series are represented by phosphate levels alternating with marl levels. The thickness generally increases in the EW direction.
The phosphate layers consist of into pellets, rounded predominantly between 10 and 500 microns with a clay-carbonate matrix. Petrographic identification is complemented by XRD. The minerals identified are carbonate fluor-apatite, calcite, dolomite, quartz. The chemical analysis by XRF, ICP-AES and ICP-MS show the following chemical composition.

- raw phosphate: P_2O_5: 22.67%
- washed phosphate, P_2O_5: 28.15%
- Yield weight: 68.72%
- CaO: 47.48%
- MgO: 0.66%
- CaO / P_2O_5 ratio: 1.70
- Cd: 36.5 (ppm)
- C.org: 1.09%

The comparison between the layers shows that the layer VI is the richest (P_2O_5 median: 25.3%) and layer II is the weakest (P_2O_5 median: 20.5%).The highest content is recorded at S75 in the Layer VI.

Acknowledgements

The authors owe a great appreciation to Phosphate Company of Gafsa for providing the borehole data.

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