Typology of Phosphate Ores in Deposits of the Djebel Onk Mining Basin (Eastern Algeria)

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Abstract
In mining basin and in some deposits, several types of ores are often formed under different physico-chemical conditions. Each of these types can contain polluting chemical elements in by-product, which need to be removed. We note also that commercial value of a sedimentary phosphate ore depends on the presence of impurities such as carbonates, silicates, iron and organic matter. So as to reply to technical, commercial and environmental demands, it is therefore necessary to proceed to the typology and the location of these different ores. In phosphate ore deposits of the Djebel Onk mining basin in Eastern Algeria, several mining and geological researches companies such as EREM and BRGM have defined this typology, use classic methods such as mineralogical and petrographic studies of rock samples collected from drilling cores. In this study, the typology has been confirmed ore specified in the four main phosphate deposits of the Djebel Onk basin using the monovariate discriminate method called “passage par zero” and the potential method (dynamic clouds method) which is a multivariate statistical discrimination method. These methods were applied using chemical data (P₂O₅, CO₂, CaO, MgO, Fe₂O₃, SiO₂ and RI) of whole rock samples collected from drilling cores during the assessment stage. Different ore types have been obtained for each of the four main deposits.

Key Words: Phosphate ores deposits, Eastern Algeria, typology, impurities, statistics method, exploitation, and pollution.

INTRODUCTION
In the different sedimentary phosphate deposits of the Djebel Onk mining basin, several types of ores coexist. To valorise these types according to commercial constraints and workability whose preservation of the environment; it is necessary to eliminate existing chemical plutants and impurities such that carbonates, silica, iron and organic matter. The determination of the typology of the different ores and their localisation is needed. This cartography allows proceeding to a selective exploitation. EREM and BRGM companies using mineralogical and petrographic studies have defined the typology of four main phosphate deposits of the Djebel Onk mining basin in Eastern Algeria (Kef Es Sennoun, Djerim Djema, Djebel Onk Nord and Bled El Hedba). However, studies are long, tedious and sometimes more subjective. Mono and multivariate statistical discrimination methods have been applied using chemical data of samples collected from drilling cores during assessment stage of the Kef Es Sennoun deposit (Mezghache et al., 2000) and the Djerim Djema deposits (Mezghache and Hani, 2000). The very satisfying results obtained on these deposits have pushed us to generalise the use of this method, which is rapid and inexpensive to other deposits. The statistical method; i. e. the monovariate method called "passage par zero" method and the multivariate method (potential method) and results obtained on each of deposits are presented here.
REGIONAL GEOLOGICAL FRAMEWORK

The Djebel Onk phosphate basin is located in eastern Algeria, on the Algerian-Tunisian border, approximately 300 km to the South of Annaba City (Figure 1). It contains some indices and four main deposits. Kef Es Sennoun and Djemi Djema deposits are situated on the Southern anticline limb of the Djebel Onk anticline, the Djebel Onk Nord deposit situated on Northern anticline limb and Bled El Hadba Deposit located at about 14 km to the East of the Djebel Onk anticline (Figure 1).

The phosphate deposits have been formed during the upper Cretaceous-Eocene period, similar to those of the Maghreb and continental margin of Arabic and African platforms.

Lithostratigraphy

The regional stratigraphy was studied by several geologists among which Kassatkine et al., (1978), Cielenski et al., (1987) and Prian and Cortial (1993).

The geological formations are composed of calcareous rocks of Maastrichtian to Quaternary age (Figure 2a). The principal phosphatic layer whose average thickness is 30 m., but sometimes exceeding 40 m., is located in the Upper Thanetian.

This principal phosphatic layer is clearly stratified and is generally subdivided in to three sublayers that are (Figure 2b):
- The basal phosphatic dolomite sublayer which is noted IIm, and thick of 2 m;
- The sublayer told "exploitable layer or productive layer 1", thick of 25m to 30m;
- And the sublayer of phosphatic dolomite which noted IIt and overlying the productive layer. Its thickness is 6 m.

Lithologically, the phosphatic mineralization is constituted by two main types of phosphate ores: the pseudolitic type where the phosphatic grains varies from 70 to 200 μm cemented mainly argillaceous matter; and the coprolitic type with grains higher than 200 μm and cemented by dolomitic carbonate. These two types of ores form alternate layers of variable thickness. The passage of one type to other is rarely net, and the combination of the different gangues gives intermediate ore types.

Lithostratigraphic column of the Djemi Djema deposit (Cielenski et al., 1988; BRGM, 1993)

Mineralogy and Petrography

The Phosphate ores are composed of a phosphatic matter and an exogangue (Duchatelle, 1975).

- **Phosphatic matter** is formed by an endogangue and the association of a carbonated fluorapatite \( [(P_{0.88}C_{0.12}O_{4})_{6}Ca_{10}F_2] \) (89%) and a sulfo-carbonate which may be hydrated \( [(S,C,O_{4})_{6}K,Na,Ca,Mg,F_2 nH_2O] \) (11%) with a very low contents of magnesium. The composition of apatite is:

\[
P_2O_5 = 37.90 \%; \quad CaO = 56.70 \%; \quad CO_2= 3.20 \% \quad and \quad F = 3.85 \%.
\]

The total content is 101.65 %. The Ratios CaO/P_2O_5 and F/ P_2O_5 are 1.50 and 0.10 respectively.

- **The endogangue** represents approximately 5% of the phosphatic matter. Mainly opal, quartz, illite, water, organic matter and accessory elements constitute it. The content of Al, Fe, Mg, Si, Na and Cl in phosphate ore is lower than 0.3% for each one.

- **The exogangue** can have three different compositions: first is carbonated mainly dolomitic, the second sulfatic very rare (Epsomite) and the third argillosiliceous.

Carbonated exogangue is mainly composed by dolomite that have formula \( \text{Mg}_{0.93}\text{Ca}_{1.07}(\text{CO}_3)_2 \) (Duchatelle, 1975). The calcite is rare.

Sulfatic exogangue is met but no often. The epsomite is rarely met in ore because it is soluble in water.

Free silica and silicates represent Arillosiliceous exogangue. There are met quartz, opal, amorphic silica, feldspar, zeolithe, glauconite and illite. This exogangue is chemically characterised by a relatively higher grade of Si and Fe.

The mineralogical constitution being relatively simple, the mineralogical modelling using chemical typology would not have to pose particular problem. For example if an ore of phosphate has a higher content in MgO, it will be deduced that its exogangue can be mainly dolomitic.

METHODS USED FOR TYPOLOGY OF ORES IN DJEBEL ONK MINING BASIN

Usually typology is made mainly on the basis of:

- Macroscopic description of drilling cores and setting up of drilling log;
- Mineralogical and petrographic studies of hundred of samples collected from drilling cores.

It is therefore an expensive work, long and tedious. In the Djebel Onk mining basin this has been made by several Geologists among which these Ciélenksi et al. (1988) and Prian and Cortial (1993). In this study, we have, in more, applied mono and multivariate statistical discrimination methods using data chemical analysis of core samples (Mezghache et al., 2000 and Mezghache and Hani, 2000). The monovariate statistical method is "passage par zero" method. The results obtained by this method are generally used for starting the iterative process of the multivariate method, which is potential, or dynamic cloud method. We remind here the principle of these methods.

The "passage par zero" method

It is based on the principle according to whether there are so much statistical subpopulations or types of ores that mode in a histogram (Sinclair, 1974; MacCammon, 1976). This method discriminate heterogeneous data in statistical subpopulations characterised each by a distinct distribution law. Each of these subpopulations would be result of a particular geological phenomenon. So as to determinate the number and parameters of each subpopulation, the graph of cumulative frequency curve is drawn using Gaussian scale in Y-axis. The curve is decomposed in a number of parts in function of the number of inflection points. Each value of inflection point represents the limit between two adjacent subpopulations (Figure 3). It in spring that the existence of k points of inflections would indicate the presence of (k+1) subpopulations.

The algorithmic bearing the name of the "Passage par zero" method (Mezghache, 1989) permits thus to calculate automatically the statistics of the subpopulations. This method consists of:

a) - Calculating the cumulative frequencies of the whole data;

b) - Calculating the Gauss reciprocals of cumulative frequencies using the Abramovitz and Stegun polynomial (1978):

Let \( Q(x) \) cumulative distribution function, and \( p \) the experimental cumulative frequency of a value and let \( Q(x) = p \) if \( p < 0.5 \) and \( Q(x) = 1 - p \) if not.
If \( P(x) = 1 - Q(x) \), we can write:

\[ Q(x) + P(x) = 1 \] and \( P(-x) = Q(x) \)

Let \( X_p \) the inverse of \( Q(x) \) and

\[ t = \sqrt{\ln\left(\frac{1}{p^2}\right)} \]

Then:

\[ X_p = t - \frac{a_0 + a_1 \cdot t}{1 + b_1 \cdot t + b_2 \cdot t^2} + \epsilon(p) \]

Where \( \epsilon(p) \) is the error of estimation and \( a_0, a_1, b_1 \) and \( b_2 \) are coefficients with: \( \epsilon(p) < 3 \times 10^{-3} \); \( a_0 = 2.30753; a_1 = 27061; b_1 = 0.99229; \) and \( b_2 = 0.04481. \)

c)- calculating the limits of each sub-population and their representative weights with the aid of the convolution method done from the remote sensing techniques:

- Using dispositif -1, +2, -1, we calculate the second derived of the Gauss reciprocals.

Let \( F''m \) the second derived function of the value \( m \) and \( F_{m-1}, F_m, F_{m+1} \) the Gauss reciprocals of values \( m, m-1 \) and \( m+1 \) then:

\[ F''m = - F_{m-1} + 2F_m - F_{m+1} \]

The limit value \( m \) between two sub-populations corresponds to that value when the second derived \( F''m \) of the Gauss reciprocals \( F \) is cancelled during its decrease (Figure 3).

The weights and the statistics of each sub-population are obtained according to the principal described by Sinclair (1974).

It is thus convenient to note that if a sub-population were to follow a lognormal, instead of a normal distribution, it would be readily detected since the average, calculates by this method, and would be negative.

However this method cannot discriminate two sub-populations which have the same mode or which the superimposition can show up a lognormal distribution (Govett and al., 1975). The drawback will be filled up by the multivariate classification.

### The potential method

The potential method enables to discriminate between different groups of data on the basis distinguish of several variables. It is the generalisation of the monovarite method.

Let to discriminate \( N \) samples \( co \) using \( K \) variables. The calculation consists of:

a)- Initialising a given number of multivariate classes starting from the results of monovariate discrimination. For example if two subpopulations are obtained for each of 2 variables A and B, four multivariate subpopulations can initialise (Figure 4). Samples, which belong to the subpopulation 1 by the variable A and to the subpopulation 1 by the variable B, would form the multivariate subpopulation 1. Samples which belong to the subpopulation 1 by variable A and to the subpopulation 2 by variable B constitute the multivariable subpopulation 2 and thus of continuation. The samples \( co \) will then be coded respectively by 1 or 0 according to whether or not they belong to the population i.

b)- We calculate the mean values \( M_i \) of the \( N \) variables, the variance-covariance matrix \( C_i \) of each population i and multivariate density function \( f_i[X(co)] \) according the formules (Mallet and Wild, 1984):
- \( m_i^k \), the mean of variable \( k \) in population \( i \):

\[
m_i^k = \frac{\sum_{\omega=1}^{n} I_i(\omega) \cdot X_i^k(\omega)}{\sum_{\omega=1}^{n} I_i(\omega)}
\]

Where \( I_i(\omega) \) is the indicatrix function of the sample \( \omega \) in \( i \) and \( X_i^k(\omega) \) is the value of \( k \) in \( \omega \).

- \( \text{Cov}(X_k, X_l) \) the covariance of variables \( k \) and \( l \) in class \( i \):

\[
\text{cov}(X_k X_l) = \frac{\sum_{\omega=1}^{n} \left[ I_i(\omega) \cdot [X_i^k(\omega) - m_i^k][X_i^l(\omega) - m_i^l] \right]}{\sum_{\omega=1}^{n} I_i(\omega)}
\]

- Calculating the multivariate density function \( f_i[X(\omega)] \) using the new values of \( C_i \) and \( M_i \) and assumed to obey a normal multivariable law.

c) - We recalculate the new indicatrix function \( I_i(\omega) \) which is:

\[
I_i(\omega) = \frac{p_i \cdot f_i[X(\omega)]}{\sum_{j=1}^{N} p_j \cdot f_j[X(\omega)]}
\]

Let \( J_i(\omega) \) to be equal:

\[
J_i(\omega) = \frac{I_i(\omega)}{\sum_{\omega=1}^{n} I_i(\omega)}
\]

d) - We recalculate the weight \( p_i \) of \( i \) in the \( r+1 \) iteration:

\[
p_i^{(r+1)} = p_i^{(r)} \sum_{\omega=1}^{n} J_i^{(r+1)}[\omega; M_i^{(r+1)}; C_i^{(r+1)}]
\]

We repeat in b) proceeding by iteration until convergence is reached.

Thus, according to indicatrix function values, the measurements are reconsidered and fictive classes vanish (Figure 4).
Figure 3: Schematic performance of monovariate discrimination by «passage par zéro» method (In Mezghache and Hani, 2000)

Figure 4: Schematic performance of multivariate discrimination by potential method in Mezghache and Hani, 2000
RESULTS OBTAINED IN THE DJEBEL ONK MINING BASIN

We resume here results obtained by Mezghache and Hani (2000) and Mezghache and al., (2000) in the Djemi Djema and Kef Es Sennoun deposits and we present results of typology in Djebel Onk Nord and Bled el Hadba deposits.

Djemi Djema Deposit

The structure of phosphate layers is simple (Figure 5). 24 exploration bore-holes have been realised by EREM in 1988 and 724 core samples were collected and analysed for P2O5, CO2, RI, CaO, MgO, Fe2O3, SiO2 and U. Elementary statistic parameters have been calculated (Table 1).

![Figure 5: Structure of phosphate layer in zone of Djemi Djema dome and drilling location (Prian and Cortial, 1993)](image)

Table 1: Elementary statistic of data chemical analysis in % safe U in ppm (Djemi Djema deposit)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>P2O5</th>
<th>CO2</th>
<th>RI</th>
<th>CaO</th>
<th>MgO</th>
<th>Fe2O3</th>
<th>SiO2</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>7.28</td>
<td>2.84</td>
<td>0.62</td>
<td>11.97</td>
<td>0.39</td>
<td>0.23</td>
<td>0.03</td>
<td>16.80</td>
</tr>
<tr>
<td>Maximum</td>
<td>29.90</td>
<td>36.30</td>
<td>8.70</td>
<td>52.22</td>
<td>14.20</td>
<td>9.74</td>
<td>8.90</td>
<td>92.15</td>
</tr>
<tr>
<td>Mean</td>
<td>23.42</td>
<td>12.29</td>
<td>3.20</td>
<td>44.18</td>
<td>4.69</td>
<td>0.61</td>
<td>1.81</td>
<td>44.18</td>
</tr>
<tr>
<td>St. deviation</td>
<td>3.94</td>
<td>5.17</td>
<td>1.80</td>
<td>3.65</td>
<td>2.72</td>
<td>0.32</td>
<td>1.46</td>
<td>10.73</td>
</tr>
</tbody>
</table>

Four ore types have been discriminate (Mezghache and Hani, 2000) (Table 2). The cross section through S52, S50 and S55 (Figure 6) shows the location of different ore types. Notice that in the ore type III, Uranium is mainly localised in the exogangue. The distribution of ore types is feebly regular (Figure 6). The type I (phosphatic dolomite) is met essentially to the apex of the main phosphate layer which is usually noted IIt. The basal sublayer of phosphatic dolomite IIIm is practically lack.
Kef Es Sennoun deposit

913 samples have been collected from 31 exploration boreholes (Figures 7 and 8). The length of samples was, in average, 1m. Using data chemical analysis of these samples (Table 3) and the statistical methods, five ore types have been determinate (Table 4; Figures 7 and 8):

- The type I has brown to black colour and a dolomitic gangue. Two ore bodies have been localised - In apex (IIt) and in basal (IIm) of the main phosphatic layer.
- The type II is a pseudoolithic ore which has brown colour. The grains of glauconite are met. Gangue is mainly argilocarbonatic.
- The type III is a friable black phosphate ore. Sometimes, it contains bituminous beds. The exogangue is mainly argillose with much organic matter.
- The types IV and V are phosphatic dolomites.

Table 2: Synthesis of results of typology in the Djemi Djema deposit (Mezghache and Hani, 2000)

<table>
<thead>
<tr>
<th>Parameters of ore types</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Associations</td>
<td>P₂O₅, CaO, U</td>
<td>P₂O₅, U(CaO,Fe₂O₃)</td>
<td>P₂O₅, CaO, U</td>
<td>P₂O₅, CaO</td>
</tr>
<tr>
<td>1ère</td>
<td>Fe₂O₃, SiO₂, RI</td>
<td>Fe₂O₃, SiO₂</td>
<td>Fe₂O₃, SiO₂, RI</td>
<td>Fe₂O₅, SiO₂, RI, U</td>
</tr>
<tr>
<td>2ème</td>
<td>MgO, CO₂</td>
<td>MgO, CO₂</td>
<td>MgO, CO₂</td>
<td>MgO, CO₂</td>
</tr>
</tbody>
</table>

Contents:
- P₂O₅ (%) 18.31 24.82 25.56 23.99
- U (ppm) 36.00 48.62 52.33 36.39
- Proportion-% 23.55 16.99 36.68 22.78
- Affinity of U Phosphatic Mat Phosphatic Matter Phosphatic Mat. Exogangue
- Principal Exogangue Carbonated dolomitic Clay-silicate Marlaceous Carbonated Calcareous

Figure 6: Cross section showing the location of the different ore types (Djemi Djema deposit)
Table 3: Elementary statistic of chemical analysis data in % (Kef Es Sennoun deposit)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>P_2O_5</th>
<th>CO_2</th>
<th>RI</th>
<th>CaO</th>
<th>MgO</th>
<th>Fe_2O_3</th>
<th>SiO_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1.19</td>
<td>0.59</td>
<td>0.26</td>
<td>3.20</td>
<td>0.01</td>
<td>0.30</td>
<td>0.02</td>
</tr>
<tr>
<td>Maximum</td>
<td>30.52</td>
<td>31.08</td>
<td>42.36</td>
<td>50.06</td>
<td>42.36</td>
<td>7.98</td>
<td>25.14</td>
</tr>
<tr>
<td>Mean</td>
<td>25.24</td>
<td>9.87</td>
<td>3.04</td>
<td>45.22</td>
<td>3.25</td>
<td>0.63</td>
<td>2.14</td>
</tr>
<tr>
<td>St. deviation</td>
<td>4.30</td>
<td>4.81</td>
<td>2.66</td>
<td>3.25</td>
<td>2.76</td>
<td>0.55</td>
<td>2.22</td>
</tr>
</tbody>
</table>

Table 4: Results of the multivariate typology (Kef Es Sennoun deposit)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Mean contents in % (Kef Es Sennoun)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type V</td>
</tr>
<tr>
<td>P_2O_5</td>
<td>17.34</td>
</tr>
<tr>
<td>CO_2</td>
<td>20.35</td>
</tr>
<tr>
<td>RI</td>
<td>2.24</td>
</tr>
<tr>
<td>CaO</td>
<td>41.72</td>
</tr>
<tr>
<td>MgO</td>
<td>8.16</td>
</tr>
<tr>
<td>Fe_2O_3</td>
<td>0.46</td>
</tr>
<tr>
<td>Effective -%</td>
<td>5.1</td>
</tr>
</tbody>
</table>

![Figure 7: Drilling location and horizontal distribution of the three main ore types (Mezghache et al., 2000).](image)

1 - Exploration borehole and its number; 2 - Outcrop of the main phosphatic layer; 3 - ore type I; 4 - ore type II; 5 - ore type III. 6 - South limit of ore type II; 7 - North limit of ore type III.
Using 160 data chemical analysis of collected samples from exploration bore holes (Figure 9), three ore types have been discriminate (Table 6): The type I corresponds to the overlying sublayer phosphatic dolomite II and basal sublayer phosphatic dolomite II. Note that thickness of this type is large near the high shoal (western limit of Djebel Onk basin) (Figs 9 and 10). The type II is argiloquartzous ore and type III is siliceous carbonatic ore.

**Djebel Onk Nord deposit**

Using 160 data chemical analysis of collected samples from exploration bore holes (Figure 9), three ore types have been discriminate (Table 6): The type I corresponds to the overlying sublayer phosphatic dolomite II and basal sublayer phosphatic dolomite II. Note that thickness of this type is large near the high shoal (western limit of Djebel Onk basin) (Figs 9 and 10). The type II is argiloquartzous ore and type III is siliceous carbonatic ore.

**Figure 8: Serial cross sections (bloc-diagram) through the Kef Es Sennoun phosphate ore deposit (Djebel Onk).** 1 - Exploration bore hole and its number; 2 - ore type I; 3 - Ore types IV and V; 4 - Ore type II; 5 - Ore type III.

**Figure 9: Geological map and drilling location in Djebel Onk Nord deposit**
1 - Quaternary and Miocene: sand and clay;
2 - Lutetian: Limestone, marl, clay and gypsum;
3 - Lutetian: Limestone with silex, Marl and dolomite
4 - Thanetian: Marl and Phosphate ore
5 - Montian: Limestone and marl;
6 - Western limit of gap of phosphate layer;
7 - Western limit of phosphate layer;
8 - Ditch on outcrop;

Table 5: Elementary statistic of chemical analysis data in % (Djebel Onk Nord deposit)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>P₂O₅</th>
<th>CO₂</th>
<th>RI</th>
<th>CaO</th>
<th>MgO</th>
<th>Fe₂O₃</th>
<th>SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>2.14</td>
<td>6.94</td>
<td>2.12</td>
<td>32.50</td>
<td>0.76</td>
<td>0.24</td>
<td>1.10</td>
</tr>
<tr>
<td>Maximum</td>
<td>29.36</td>
<td>36.20</td>
<td>19.40</td>
<td>50.86</td>
<td>11.13</td>
<td>6.37</td>
<td>27.46</td>
</tr>
<tr>
<td>Mean</td>
<td>19.52</td>
<td>15.89</td>
<td>7.84</td>
<td>42.07</td>
<td>4.09</td>
<td>0.64</td>
<td>6.72</td>
</tr>
<tr>
<td>St. deviation</td>
<td>6.00</td>
<td>6.69</td>
<td>3.50</td>
<td>3.35</td>
<td>2.06</td>
<td>0.46</td>
<td>3.65</td>
</tr>
</tbody>
</table>

Table 6: Results of the multivariate typology (Djebel Onk Nord deposit)

<table>
<thead>
<tr>
<th>Chemical Elements</th>
<th>Mean contents en %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type I</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>15.37</td>
</tr>
<tr>
<td>CO₂</td>
<td>19.88</td>
</tr>
<tr>
<td>RI</td>
<td>9.35</td>
</tr>
<tr>
<td>CaO</td>
<td>40.17</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.62</td>
</tr>
<tr>
<td>SiO₂</td>
<td>8.14</td>
</tr>
<tr>
<td>MgO</td>
<td>5.28</td>
</tr>
<tr>
<td>Effective - %</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Figure 10: Schematic lithofacies cross section AA’ through Djebel Onk Nord deposit (see Figure 9)
Bled El Hadba deposit

Data chemical analysis of collected samples from exploration bore holes (Figure 11) permit to discriminate four ore types (Table 7). Figure 12 gives comparison of results obtained several geologists in bore hole S-6H. Type I is phosphatic siliceous dolomite ore and type II is dolomitic phosphate without silica. Type III has essentially a carbonatic exogangue and type IV has a carbonatic siliceous exogangue. Note that these ore types are irregularly alternate in cross section and that the basal phosphatic dolomite sublayer IIm is lack (Figure 13).

Figure 11: Geological sketch map and location of exploration bore holes - Bled El Hadba deposit
Figure 12: Log of drilling core and ore typology in the bore hole S-6H

Table 7: Results of the multivariate typology (Bled El Hadba)

<table>
<thead>
<tr>
<th>Chemical Elements</th>
<th>Mean contents in % (Bled El Hadba)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type I</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>16.33</td>
</tr>
<tr>
<td>CO₂</td>
<td>19.65</td>
</tr>
<tr>
<td>R₁</td>
<td>7.11</td>
</tr>
<tr>
<td>CaO</td>
<td>39.03</td>
</tr>
<tr>
<td>MgO</td>
<td>7.61</td>
</tr>
<tr>
<td>SiO₂</td>
<td>5.92</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.68</td>
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<tr>
<td>Effective - %</td>
<td>25</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The typology of phosphate ores has been made in four main deposits of the Djebel Onk mining basin: Djemi Djema, Kef Es Sennoun, Djebel Onk Nord and Bled El Hadba deposits. Five ore types have been determinate and localised in each deposit:

- First type is dolomitic, second is dolomitic siliceous, third is calcareous carbonated, fourth calcareous siliceous carbonated and fifth is argillosiliceous ore.
- In the Kef Es Sennoun deposit, ore types are very regularly.
- Three and four ore types have been determinate in Djebel Onk Nord and Bled El Hadba deposits respectively.

The overlying phosphatic dolomite sublayer II has been met in the four deposits. It is sometimes subdivided in siliceous and not siliceous sublayer like in the Bled El Hadba deposit. However the basal phosphatic dolomite sublayer IIm is met only immediately near the western limit of basin, in Kef Es Sennoun and Djebel Onk Nord deposits.

Note that the total thick of phosphatic dolomite ore is less and less large and the number of alternate sublayers of ores increases towards eastern. This confirms that the centre of the phosphate paleosedimentary basin is found in Tunisia.
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