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Bentonite's reserves Geometry of Trebia deposit in Nador region (North eastern Morocco); Contributions of geophysical surveys and core drilling campaign

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Abstract

Aiming to study the bentonite of Trebia deposits in the region of Nador, two methods were used to evaluate them;

- Geophysics; which allows visualizing the geometry and the lateral limits of the deposit. The geophysical method used is that of the dipole-dipole electric resistivity. Due to the lithological contrasts of the different geological units within the deposit and taking into account the presence of heterogeneous zones on surface a fairly clear picture of the bentonite body, which has a very low resistivity was produced. This low resistivity is due both to the mineralogical composition of bentonite and interstitial water contents facilitating the current flow. This method also highlights the resistivity contrasts of the subsurface and allows us to recognize discontinuity zones such as faults, dikes and magmatic intrusions.
- Drilling allowed the confirmation of the underlying formations and the limits of the deposit in depth.

The interpretation of the geoelectric profiles obtained allowed us to map discontinuities within the deposit is also supported by geological mapping conducted previously. The highly resistant body at depth was interpreted as a rhyolitic dome. Core drilling data covering the deposit of Trebia, combined with those of geophysics, have enabled us to develop a general outline of the shape of the bentonite body. The main bentonite layer encountered below the massive rhyolite was only partially detected by geophysics.

Finally, a three-dimensional model of the orebody was developed as the result of a correlation between the two methods used in this study. In addition and as result of this study, an overall estimate of the Trebia bentonite reserves is given at the end.

Keywords: Bentonites, Geophysics, Drilling, Easternal Rif, Morocco

1. Introduction

Most Moroccan bentonite deposits are situated in the region of Nador in northeastern of Morocco (Figure 1). This natural resource is related to the Neogene age Gourougou volcanism and its satellites (Figure 2 (A)). The Trebia bentonite deposit, belongs to NAIMEX company, is located 18 km west of the Nador city on the western flank of the Tidiennit volcanic massif, it is associated with the rhyolitic pyroclastics, lavas and perlites of this region [1] (Figure 2 (B)) .

In the exploration of useful substances, several geophysical methods can be used [2] [3] [4] [5] [6].

In the work that we present in Trebia sector insofar to quantify the perlite and bentonite reserves, we used two complementary methods: geophysics and diamond drilling.

The aim of this study was to correlate the core drilling results with the geophysical profiles to find a relationship between the two methods. Geophysics will allow us to visualize the extension and the approximate boundaries of the deposit, while the drilling will allow the confirmation of the underlying formations in more detail, while presenting the results in three dimensions.

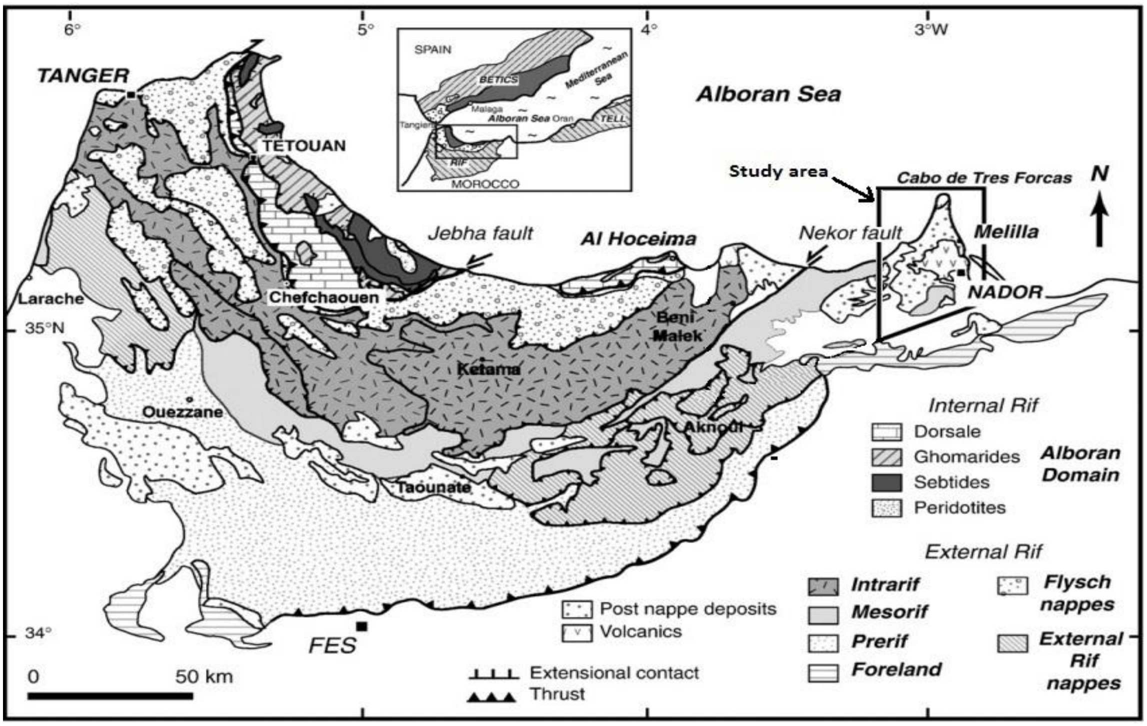

Figure 1: Geological map of the Rif belt [8-9], with the location of the study area.

In its geological setting, the Trebia area is situated in the Neogene basin of Kert ([10-11-12]. The latter consists of a complete sedimentary cycle that reflects an open, normal salinity environment [13] showing lateral intercalations of proximal volcanic products between marly marine facies (Figure 2).

The first facies deposited in the Messinian basin are calcareous marls (calcareous clays), occasionally interrupted by the arrival of pyroclastic material derived from the Gourougou volcanism and its satellites.

It should be noted that the eastern Rif is the region of intense volcanic eruptive activity since the Tortonian to Quaternary (10 to 2 Ma) [14-15-16-17]. The volcanism of Nador area is variable. The main strato-volcano of gourougou (25 Km long, 15 Km wide and 887 m high) is shoshonitic in nature, while it is calc-alkaline to potassic in its satellites such as Tidiennit, Amjar and Boutouil [14] [18].

The known bentonite deposits in the region are intimately related to the volcanic formations of the Melilla-Nador and Kert basins and are contained in the sedimentary marine series of these Messinian basins or in 'pockets' within the periphery of the volcanoes [19].

The passage from the sedimentary into the volcanoclastic formations is either gradual or more often sudden, with steep contacts.

The Trebia deposit of our study is linked to the Tidiennit acid volcanism of Messinian age. The latter consists largely of banded rhyolitic flows on the flanks and of a massive rhyolite plug at the top of the massif.

The Messinian marine formations contain discordant pyroclastic layers surrounding the volcano. At the base of the volcano and the foot-wall of the banded rhyolite, quite significant flows of gray to light-gray perlite is outcropping forming sub-horizontal layers. These flows, have sometimes the appearance of perlitic tuffs, and are overlain unconformably by brecciated layers with vitreous elements. In places, massive perlites are observed, going over gradually to fine-grained rhyolites. Some effusiva are fully made up by massive perlite and dark gray obsidians of rather characteristic columnar prism forms.

Jbel Tidiennit is affected by fracture tectonics generating a radial system of faults including NNE-SSW, WNW-ESE, NE-SW and NW-SE trends.

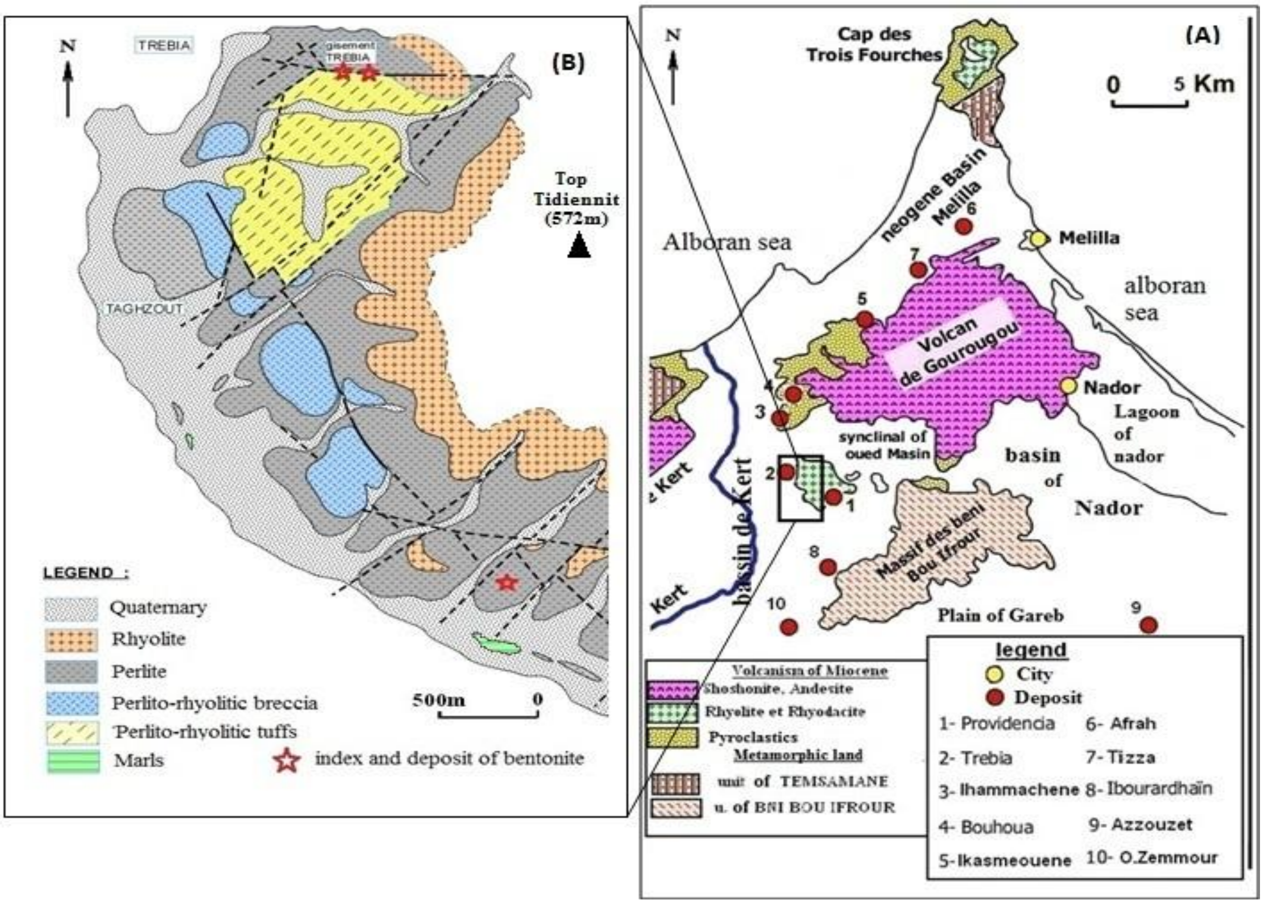

Figure 2: (A), Geology and locations of important bentonite deposits in the region of Nador; (B), the Geological Survey western flank of Jbel Tidiennit [20].

2. Materials and Methods

We carried out a geophysical survey as well as a drilling campaign [2] [3] over the region that covers the entire deposit, to confirm and calculate the reserves of bentonite and its quality. So, the geophysical survey was conducted by 'SAGAX Maghreb' company, to allow us to visualize the extension of the deposit, in meantime we can use the results map to position the drill-holes. This method will also allow us to highlight the electric resistivity contrasts in the substrata and to recognize the discontinuity zones such as faults, dikes and magmatic intrusions.

The method used in this work is based on the study of the resistivity (dipole-dipole) [4] [5] [6] [7] contrasts of the different geological units of the deposit. This method gives a fairly clear picture of the bentonite body which has a very low resistivity ($\leq 5\ \Omega$m). This last is due to both the mineralogical composition of bentonite [1] and the presence of interstitial water guarded by bentonite (between 15-30%) which facilitates the flow of current. This method measures the apparent electrical resistivity corresponding to the resistivity of a volume of soil when applying a direct current.

The procedure of this method is based on the emplacement of four electrodes in the ground, connected to the apparatus for measuring the electrical resistance. The Dipole-Dipole array method, also called Beta Wenner method (Figure 3) is the method chosen for this study. The nominal value ***'a'*** of the spacing between the electrodes was set at 20 meters and 7 dipoles were read (n = 1-7). The injection electrodes are on the same side relative to the measuring point. ($k = 6\pi.a$); ***a***: is the distance between two electrodes.

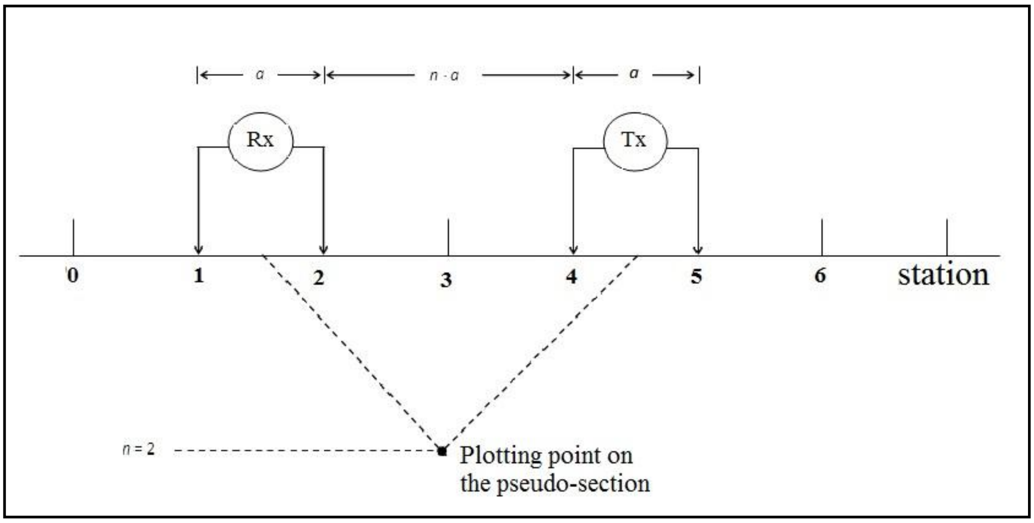

Figure 3: Diagram of dipole-dipole electrodes array

The equipment for Induced Polarization consists of:
-Apparatus for transmission and reception of an alternating signal (a commuted signal).
-An IRIS Instruments generator: VIP 3000 transmitter, capable of generating 3.0 kW DC.
-Stainless Steel Electrodes to inject a stable current into the soil.
To calculate the apparent resistivity 'ρa', the following formula is used [21]:

$$\rho_a = \pi \; n\,(n+1)\,(n+2)\; a \; VP/I \quad \text{(en ohm*m)}$$

a = spacing between electrodes (a = 20 meters)
n = multiple dipoles (n = from 1 to 7)
VP = primary voltage (mV)
I = transmitted current (mA)

For surveying the position and elevation of the geophysical profiles on the surface (Figure 4), a GPS Ashtech ProMark2 system was used.

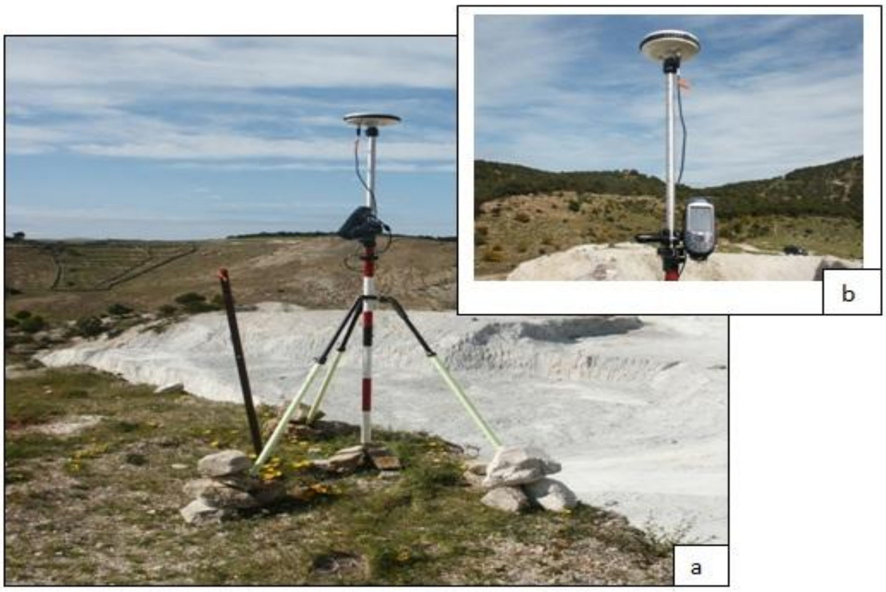

Figure 4: Station Ashtech ProMark2 GPS, a; Base tripod, b; close-up view

The data collected by the GPS mobile units were corrected in post-processing each day, using data from a base station. GPS uses the WGS84 coordinate systems and stored data were finally converted to the Lambert coordinate system. 17 geophysical lines covering the entire deposit were completed (Figure 5).

For drilling, a diamond drilling campaign over an area covering nearly 53.000 m^2 totaling a meterage exceeding 1500 m and averaging 41m per hole was carried out.

For this study, different types of machines were used all working with the rotary core barrel principle. We used the Mobile Drill, a drill mounted on a UNIMOG 1250 truck and SILEA 45 crawler rigs.

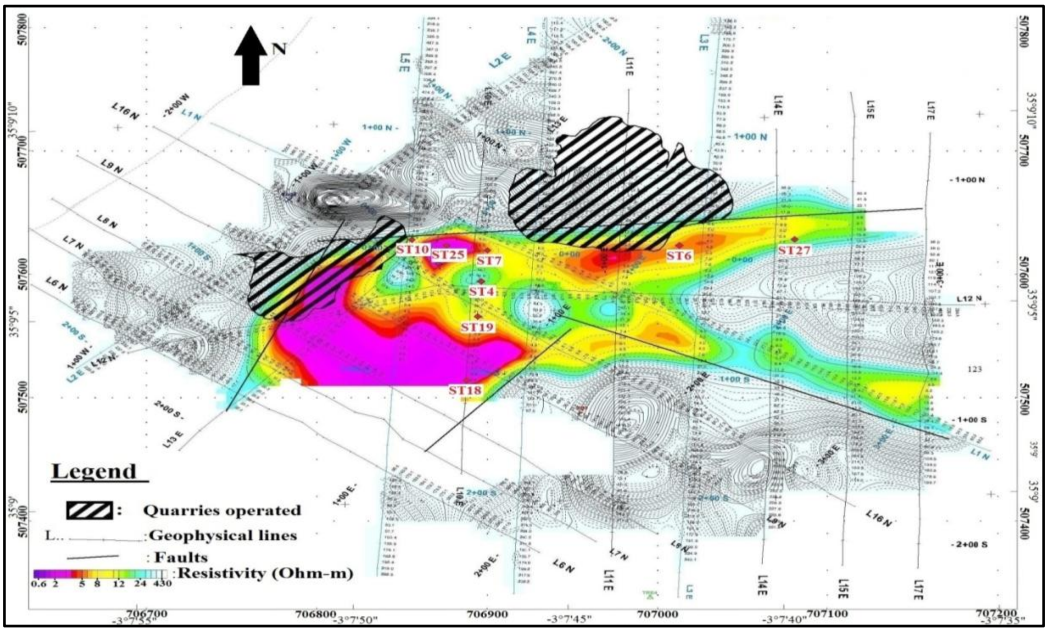

Figure 5: Map showing the electrical resistivity plan at 180m elevation above sea level.

3. Results

3.1. Geophysics

The results of the 17 geophysical lines allowed us to determine the general shape of the deposit and to highlight the main structures that were observed in the region. Of the three profiles taken as references (Figure 6), we see distinct resistivity values (equipotential), represented by different colors. The lowest resistivity is shown in violet and red, while the highest resistivities are shown in light blue to yellow.

It should be noted that the bentonite clays in general are good conductors of electricity, especially when they contain high humidity (interstitial water) as in the case of the Trebia area, where we have a bentonite humidity ranging between 15 and 30% which explains its low resistivity.

By studying the overall picture of the different profiles, we find that the mineralization is concentrated in the heart of the deposit; this is explained by the low resistivity present in the center of the deposit while the most resistant rocks are found in the periphery (blue clear). We also encounter in the deeper parts of the deposit very high resistivity (as shown in the profile 10 Figure 6). It is usually in the form of a dome, but differs in the volume (length and height) depending on the location and direction of the intersection of geophysical lines.

The interpretation of the profiles obtained (Figure 6) allowed us to map out discontinuities in the deposit. The very tight equipotential lines we interpreted as normal faults steeply dipping (65° to 85°). This interpretation is also confirmed by the cartographic study of the region. In addition, we have interpreted the deep resistant bodies as a rhyolitic dome, confirmed later through drilling.

By combining the geophysical data lines on a plan, (Figure 6) horizontal equiresistivity sections at different elevations were plotted. At the center of the grid a low resistivity zone was interpreted as a bentonite body. The latter has a length of 240 meters length in the east-west direction and a width of 130 meters in the North-South direction.

Through the study of the various geophysical sections, we have identified other faults crossing the mineralized orebody (plotted in Figure 6); these are faults in the ENE-WSW, NNE-SSW, NW-SE and NE-SW directions.

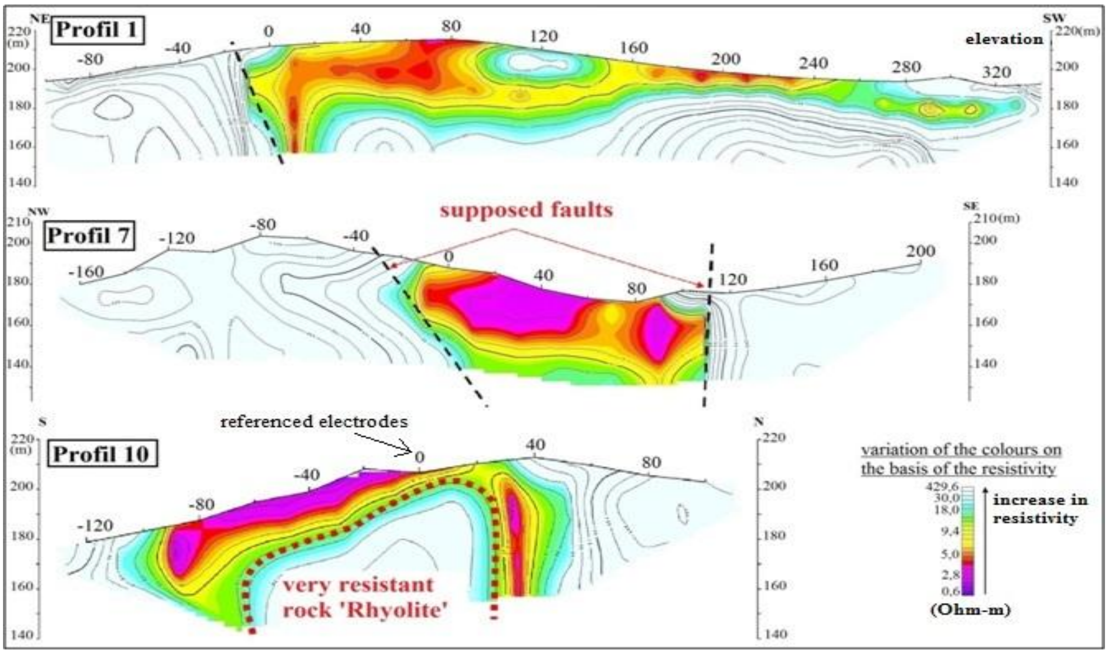

Figure 6: Interpretation of resistivity contrasts of some electrical profiles

This study carried out over the deposit of Trebia, has confirmed the existence of a low resistivity body, which is possibly bentonite. Together with the mapping, this information serves as a base for the next step which is the phase of core drilling. We relied on this info to position drill-holes on the map, determine the drill pattern as well as estimate the depth of the holes.

3.2. Drilling

After the geophysical survey, a preliminary image of the deposit was constructed, but to confirm the extension and quality of the deposit, a diamond drilling campaign was carried out on this deposit. These drillings have shown the existence of the same formations that were found outcropping on the surface such as; the rhyolitic breccia, rhyolite, the bentonite layer and perlite.

The detailed study of drill-cores has allowed us to observe the following sequence of formations (from top to bottom);

- The rhyolitic breccia formation

This formation was intersected by drill-holes: ST4, ST18, ST19 and ST25 (see location surveys Figure 5). It comes on top of the series, in the form of volcanic debris of any size and shape generally angular, dispersed in a matrix of tuffaceous bentonite. This facies shows an inclined stratification to the south-west of a 30 ° dip, covering the southern part of the deposit. We can interpret this as the final phase that covered the region and is the result of a fast, muddy flow ('Lahar').

- The bentonite layer 1

This is a less substantial layer concerning extension and reserves; It has an average thickness of 6m, is concentrated in the southwestern part of the deposit (ST4, ST18 and ST19) and it is “sandwiched " between the rhyolitic breccia above and the massive rhyolite bellow. Its color varies from white to light yellow.

- The rhyolite formation

This rhyolite rock was intersected by drilling has a variable thickness of up to 25m (ST4) and shows intense "flow banding".

- The bentonite layer 2

The bentonite of this layer is white to light yellowish. has an average thickness of 25m and a large extension. Given the large volume of this layer, we also call it the main bentonite layer. it is found generally below the rhyolite.

Geophysical data show that, in depth, the low resistivity rocks trend to the Southwest. This proves that this layer has a dip to the southwest (Figure 5).

- Perlite

It is present at the bottom of most of the drill-holes, has a gray color and a texture either amorphous or as small millispheres. This formation continues deeper, beyond the -100 m. It constitutes the footwall of the bentonite layer which is controlled by normal faults of different directions, forming horsts and grabens on the periphery of the volcanic cone of Tidiennit.

The recovered cores are preserved in boxes; we took the description by details for each core, then we sent the bentonite to the laboratories to be analyzed. So, according to the lab results we found a homogenous quality of bentonite. The mineralogical study on Trebia bentonite shows an assembly of; calcium and sodium montmorillonite, feldspar, rare cristobalite and mica [1] [22].

3.3. Correlation of the drilling logs

In Figure 7, we present the synthetic Log of the Trebia deposit, based on the study of all drill-holes carried out over this site.

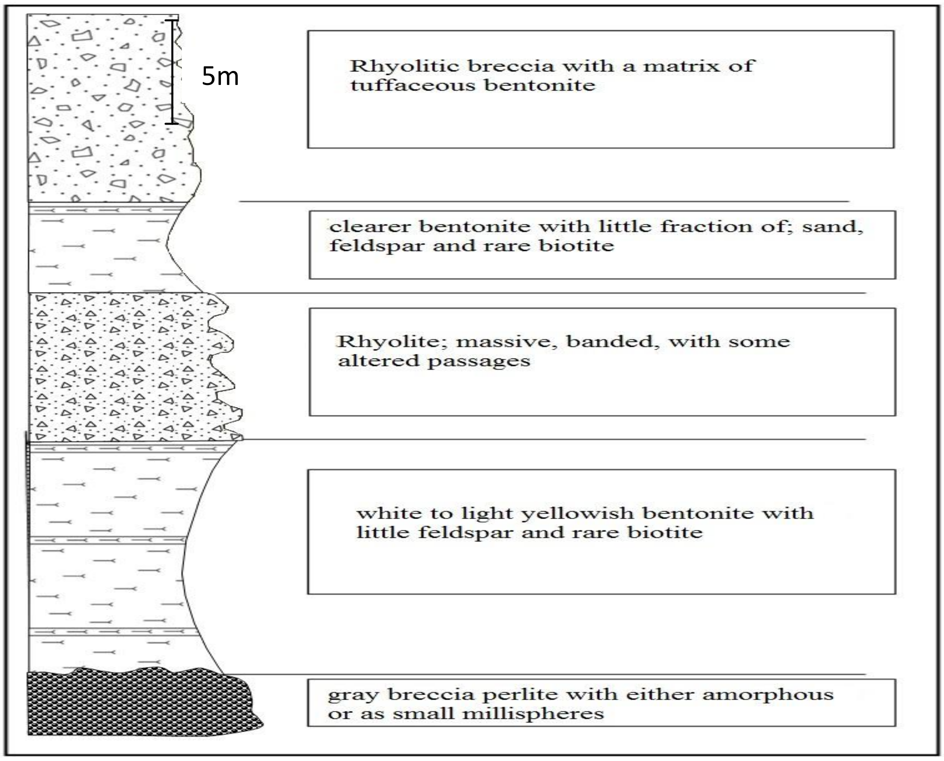

Figure 7: synthetic stratigraphy of the TREBIA deposit

Given the homogeneity encountered on most drill-holes, eight of them were taken as representative for the whole deposit (Figure 8). Therefore, two geological sections were drawn through correlation between these drill-holes allowing us to show the deposit in the North-South the East-West direction.

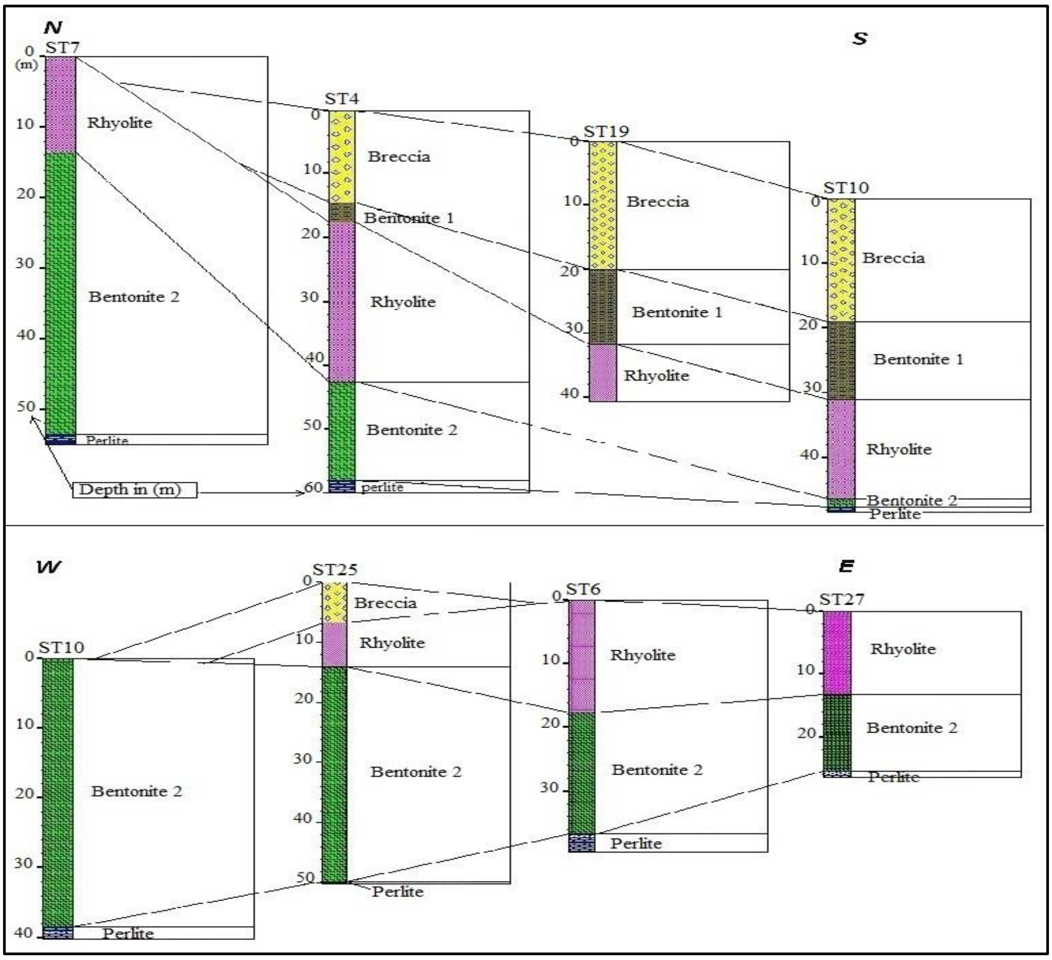

Figure 8: correlation between different drill-holes of the TREBIA deposit.

3.4. The correlation between drill-holes and geophysical profiles

Core drilling data, covering the deposit of TREBIA, coupled with those of geophysics (Figure 9) allowed us to develop a general outline of the shape of the bentonite deposit. Therefore, there is a concordance between the two methods regarding the location of faults and limits of the deposit. However, the main bentonite layer drilled under the massive rhyolite was detected only partially by geophysics.

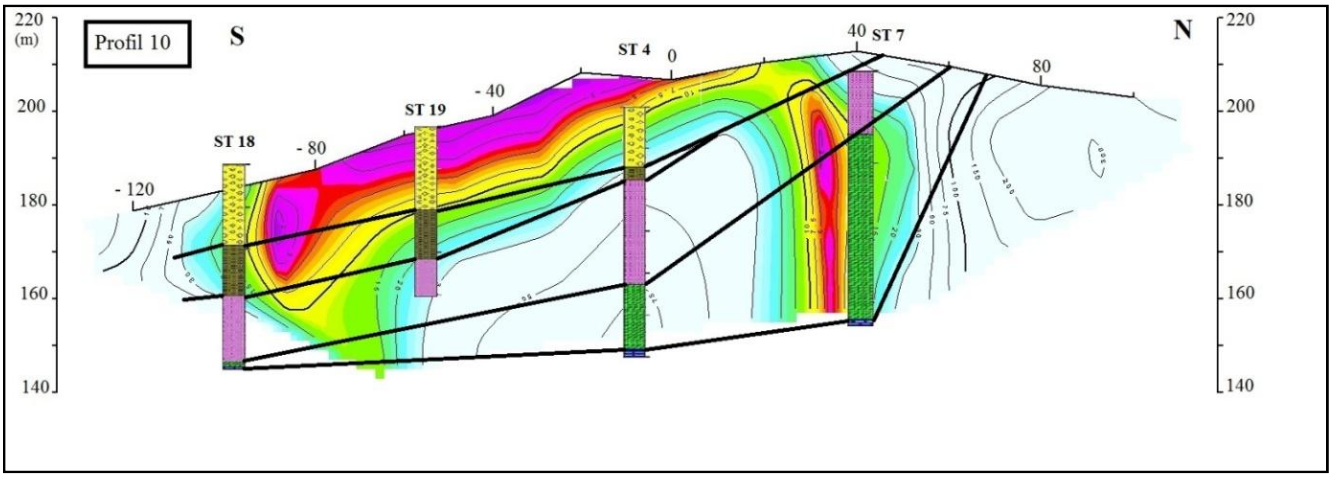

Figure 9: correlation of geophysical profiles and drille-holes in northe-south direction

Conclusion

The geophysical study on the deposit of Trebia, based on the study of the resistivity of rocks through induced current (dipole-dipole method), allowed us to have a first overview of the types of underlying rocks and the associated structures such as faults and dykes. An elongated ore body (low resistivity) was also detected trending in the East-West direction controlled by normal faults of different directions. This body is 240 meters long and 130 meters wide, with an apparent thickness of 20-35 meters, plunging deeper toward the Southwest. We also found the existence of a resistive body at the center of the deposit in the form of a dome. This information has been confirmed by core drilling.

Based on the results of these two study methods, we were able to produce a simplified model (without faults) of the deposit in three dimensions following the results of the drill-holes on the one hand and the correlation between the drill-holes and geophysical profiles on the other. As shown in Figure 10 below, we find that the mineralization dips to the south-west where we also find the concentration of the Bentonite 1 'layer 1'.

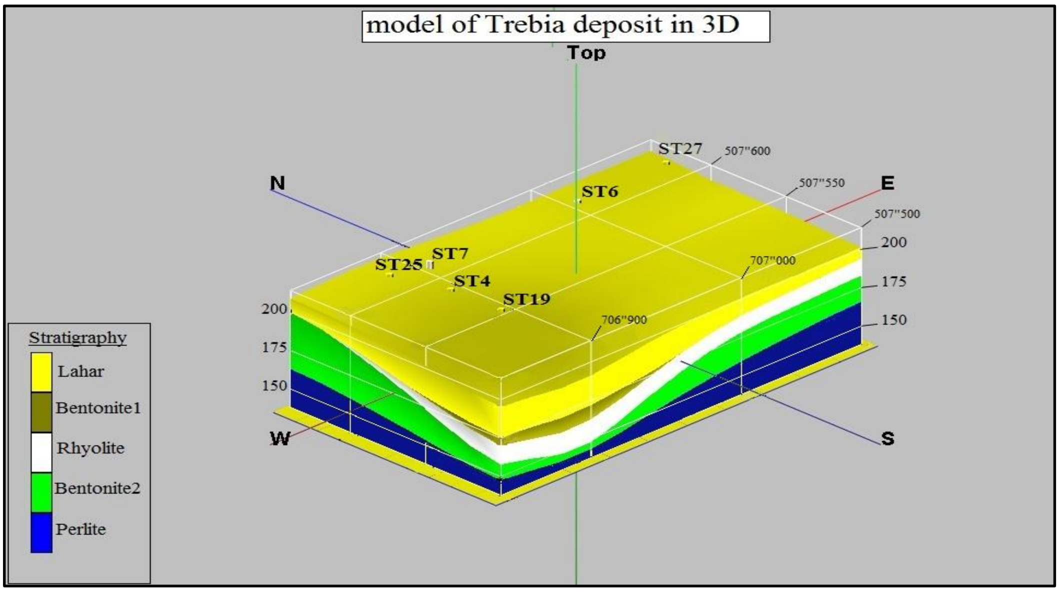

Figure 10: simplified 3D model of TREBIA deposit

Finally, we can estimate the reserves of Trebia deposit according to the previous study. We know already the dimension of the ore body (240 meters long, 130 meters wide, 25 meters in thickness) and we calculated the density of bentonite, is around 1.6 ton/m^3.

Total estimated reserves = 240*130*25*1.6 = 1.248.000 tons

These reserves are very important compared to different deposits of Morocco. This deposit increases the potentiel reserves of this substance in the region. Given the current rate of bentonite exploitation of Morocco, which is around 120.000 tons/month. And if we estimate a preliminary exploitation in our deposit of 4.000 tons/month, the life expectancy of Trebia deposit exceed 25 years.

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