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Petro-Mineralogical and Geotechnical Analysis on the Clays of Constantinois Province (Mila North-East Algeria)

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ABSTRACT

This work was realized for 5 years. It consists to study a ground located on the Northwest of Mila city. The soil of this region is characterized by marl and clays with gypsum of Mio-Pliocene age. These trainings constitute a seat of a lot geotechnical problems such as swelling, who's engenders damages in the constructions. This study has done to contribute and to solve this problems. Therefore, we have preceded a petrographic analysis according to the model of Czerminski, a mineralogical analysis by diffraction the X-rays and a geotechnical study by analysis of the various parameters. The petrographic analysis revealed a clear evolution of marland clay dominated in the formations. The mineralogical analysis show a variety of minerals dominated by calcite, quartz and interstratified minerals. The geotechnical tests carried out showed clay with high plasticity and medium to high swelling potential. In view of this, we propose adequate solutions to solve this problem.
KEY WORDS: Petrographic analysis, Mineralogical analysis, Geotechnical analysis, Clay, swelling, Mila, Algeria.

1. INTRODUCTION

In the world, the soil is exposed to various natural hazards or risks such as erosion [1], contamination[2], salinity [3], slips [4], settlements [5], swelling [6]…etc.

Algeria has been the subject of a lot research's, we quote the effort of Azzouz [7] on Tlemcen region, Benaissa [8]on Constantine, Bellatrache [9]on Ain Aminas region and Athmania [10, 11], Afes [12], Afès &Didier [13] and Khellaf &*al.*[14] on Mila region…etc.

Mila region is a part of the Constantinois basin. It's characterized by clays overlying marl Moi-Plio-Quaternary age [15]. These clays exhibit a significant shrinkage during drying period and swelling in the presence of water [12, 13, 16]. These phenomena cause significant variations in the volume of soils which causes damages to buildings [14, 19, 17, 5, 18].

The aim of this work is to solve this problem. For that, we have done petrographic analysis, mineralogical analysis (XRD) and geotechnical analyzes of this soils.

Therefore, two profiles are taken into consideration and a systematic sampling was conducted with care.

2. MATERIAL AND METHODS

2.1. Study Riding

The studied area is a part of the Mila-Constantine Neogene basin that belongs to the Constantinois post slick basin [15]. It's located about fifty kilometers in west of Constantine and it's limited on the north by Oued El Kebir, on the east by the cities of Mila and Sidi Merouane, on the south by the mountainous ridge of Marechou and on the west by the hill of Redjas (Fig.1).

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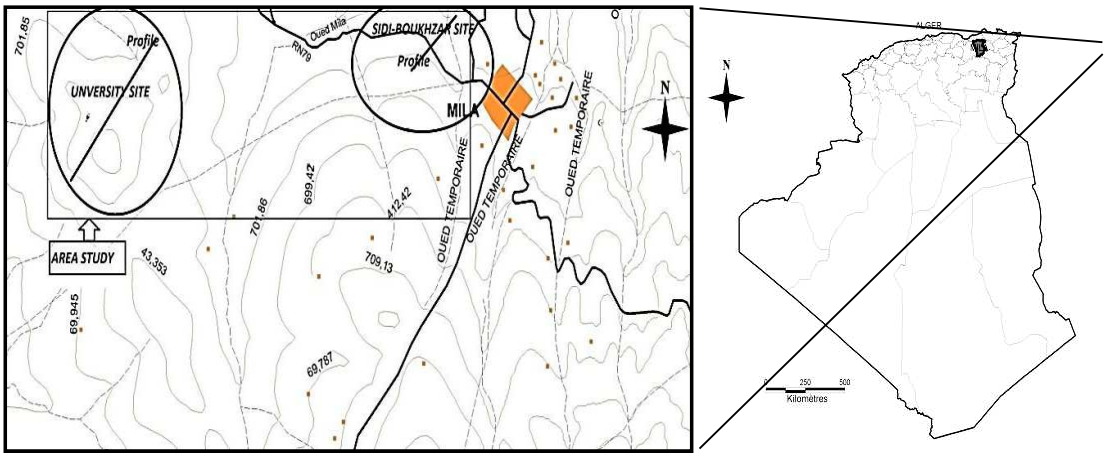


Figure 1: Map of geographical location, studied area and position of the studied profiles.

2.2. Sampling

Clays examined have been taken from different depths. These clays have been chosen according to the problems encountered in this region specially the instability of the area.

2.2.1. Samples Analysis

The analysis of samples has been performed as follows:

1. Petrographic or chemical-weight analysis, which determines the percentages of carbonates, clays and sands, for a specific weight of fine soil with a diameter less than 0.063 mm [19].
2. Diffractometric analysis with X-ray powder diffraction (XRD): is done by interpreting the diffractograms obtained of the samples examined.
3. Geotechnical analysis: This analysis is performed by determining various geotechnical parameters to soil of the two studied sites [20].

The interpretation of the results obtained is from the international bibliography.

2.3. Description of profiles

2.3.1. Profile of Sidi Boukhzar

This profile is located at 1.5 km on north-west of Mila city (Fig.1) with a thickness of 150 m. In this point, the section has been performed from bottom to top (Fig.2):

- Formation (15 to 20 m) of marly clay and sandy, gray to greenish. It contains sandstone and fibrous gypsum.
- A powerful series (thickness 10 m) clay-sandy little marly to gypsum brown to greyish.
- Heterometric and polygenic Conglomerate (100 m) with red cement clay.

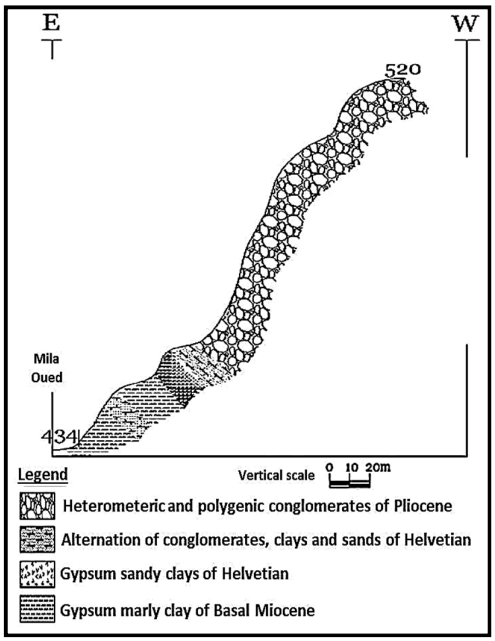


Figure 2: Geological section of the Sidi Boukhzar site.

2.3.2. Profile of the University (200m)

This profile (Fig. 1) is located at about 5 km towards the north-western part of Mila town. The section (Fig. 5) made at this point contains clays or marly clays, gray to blackish with traces of gypsum and fossil debris. This basic alternation is surmounted by a clay entity black (20m) not very marly and little sandy.

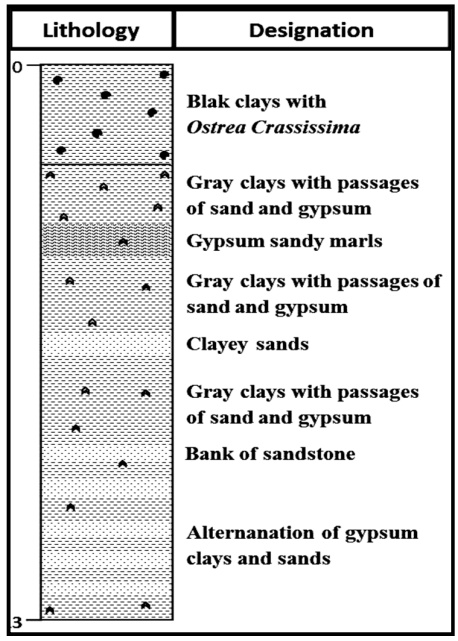
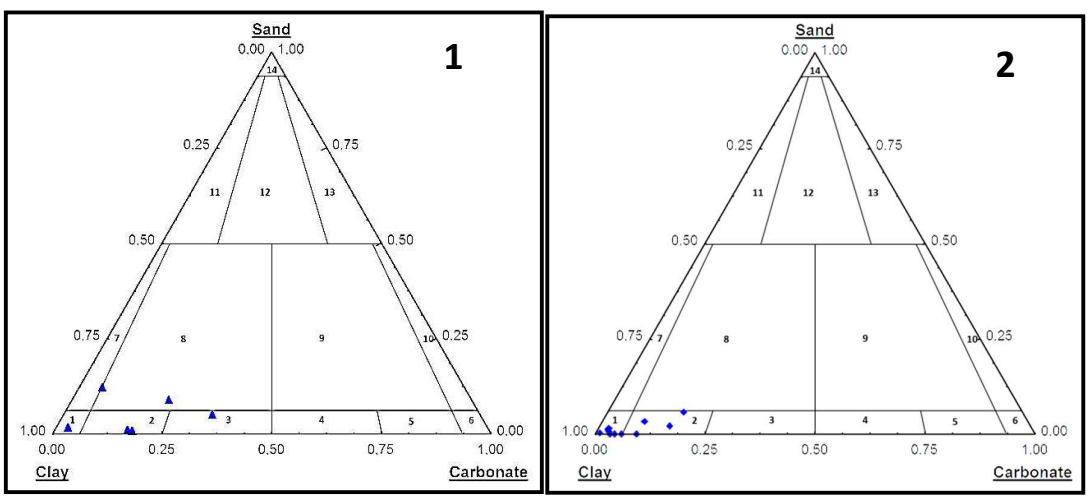


Figure 3: Geological section of the university site.

3-RESULTS AND DISCUSSIONS

3.1. Petrographic (chemical-weight) analysis and classification of rocks

The results obtained from this test are represented on the diagrams below:



1: Sidi Boukhzar site, 2: University site, (1) Clay, (2) Marly Clay, (3) Clayey Marl; (4) Marl; (5) Marly Limestone; (6) Limestone; (7) Sandy Clay; (8) Marl-Sandy Clay; (9) Marl-Sandy Limestone; (10) Sandstone Limestone; Clayey Sandstone (12) Marly Sandstone (13) calcareous Sandstone (14) Sandstone.

Figure 4: Ternary presentation of chemical-weight analysis and classification of sedimentary rocks according to the method of Czerminski.

According to these results, we note the predominance of clay and marl rocksthan sand rock (Fig. 4).

Sidi Boukhzar profile: the group of clay rocks contains 2 to 34% carbonates, 61 to 95% clays and 0.5 to 4.7% sands; the group of marly and sandy clay rocks presents 30 to 82% clay content, 5 to 30% carbonates and 8 to 40% sand.

University profile: the analyzed sediments encountered are presented by clays, marly clays, marl-sandy clays and rarely clay marl (Fig. 3). The group of clay rocks contains 73 to 98% clays, 0.8 to 27% carbonates and 0.1 to 3.4% sands; and the group of marly or sandy clay rocks contains 32 to 74% clay, 6.7 to 20.5 carbonates and 9.2 to 49% sands.

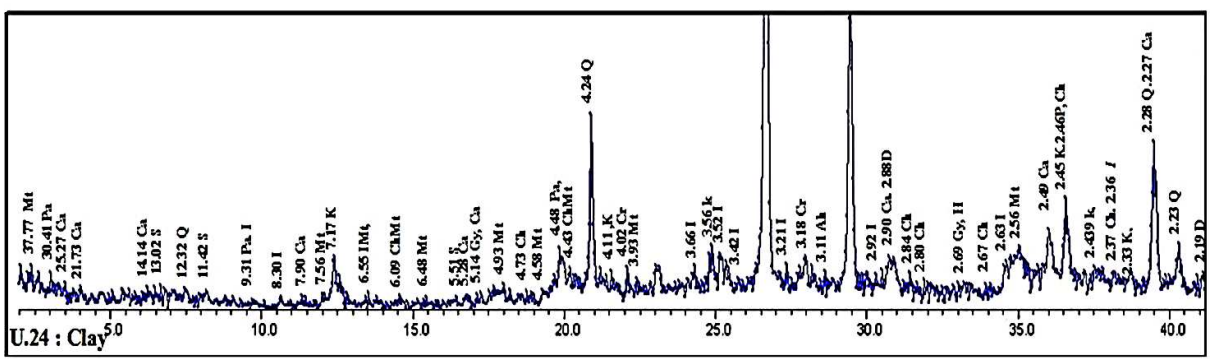
Therefore, referring to the work of [10, 11, 21, 16, 22, 23] clay contents are higher than 75%, which makes it's possible to classify these soils as clays or marl and sometimes sandy clays. The Silica (SiO_2) contents are below than 80%. This percentage is the border between swelling and non-swelling soils [24, 25]. The low to medium calcium carbonate grades (0 to 30%); which is a good mechanical index for the soil resistance [26].

The petrographic analysis of the samples proved different varieties of clayey rocks. For both profiles, these varieties are presented by clays or marly clays and marl-sandy clays with a high rate of clays, a less rate of silica and low carbonate content.

3.2. Diffractometric analysis

The analysis of diffractograms (Fig. 5) reveals that: Calcite is presented in the all samples with it's main peak 3.3 Å. The siderite and ankerite are shown as traces. Quartz is presented in the samples with it's characteristic peak of 3.34 Å. The α-cristobalite (4.5 Å) and α-tridymite (4.8, 3.7 and 2.75 Å) forms are found in most samples. Montmorillonites are mainly calcitic with characteristic peaks between 21.7 Å and 9.7 Å. Chlorites are ferriferous (chamosite). Kaolinite is also present by it's characteristic peaks of 7.14; 4.43Å. The interstratified represented mainly by montmorillonite-illite and montmorillonite- chlorite. Vermiculite and palygorskite traces. Illite is crystallized in small peaks (8.8, 19.8 and 26.97 Å). Gypsum is represented by it's characteristic peaks 11.71; 29.19; 20.60; 33.45; 31.20; 23.47 Å and it's reported sometimes with small peaks. Iron Oxides and Hydroxides are represented as traces by the hematite (3.69 Å), pyrite and iron hydroxides (goethite 4.18Å).

For that, it's noted on Mila region that the calcite is abundant, dolomite and siderite are traces [16], quartz manifests a lot with rate of 49% [17], montmorillonite is the type 2/1 [27] and by attention when carrying out projects [17], Kaolinite is a mineral typical of emerged and altered soils; it's presence in these environments proves the tendency to temporal immersion [27]but the smectite which is very sensitive to the phenomenon of shrinkage-swelling which can manifest itself by differential settlements [10], Chlorite have more than 15% ; so, it's can be swelling [17],Saponite and Vermiculites are likely to fix water therefore, they can swell and also they are capable to lose and to retract giving variations in volume [28]. Illite is reported in traces.



(Ca) calcite (Cha) chamosite (Ch) chlorite (ChMt) chlorite-montmorillonite (ChV) chlorite-vermiculite; (Cr) cristobalite (D) dolomite; (H) Hematite; (I) illite, (IMt) illite-montmorillonite, (Go) goethite, (Gy) gypsum, (K) kaolinite, (Mt) montmorillonite, (Pa) palygorskite, (P) pyrite, (Q) quartz, (S) siderite; (Tr) tridymite

Figure 5: Diffractogram of samples from the University profile.

3.3. Geotechnical analyzes

The study of these clays has been performed as follows:

3.3.1. Determination of the physical and mechanical parameters of the two sites soils

3.3.1.1. Determination of physical parameters

The tables below (Table 1 and 2) summarize the physical parameters results of the examined clays:

Table 1: Physical parameters of Sidi Boukhzar clays [29]

Parameters	Sidi Boukhzar site					
	Site 1	Site 2	Site 3			
	SC1	SC3	SC1	SC3	SC5	SC1
Depth (m)	2.00-3.00	2.00-3.00	4.00-4.50	2.00-3.00	2.00-3.00	2.00-3.00
w (%)	29	31.90	20.50	18.60	21.25	19.90
Sr (%)	100	100	98.50	99.20	98.64	98.76
$\gamma h(N/m^3)$	1.54	1.56	1.40	1.36	1.49	20.9
e_0 (%)	78.30	86.13	55.4	53.54	65.08	0.54
n	0.44	0.46	0.35	0.35	0.39	0.5

Table 2: Physical parameters of University clays [30].

	University Site					
Parameters	**SC1**	**SC3**	**SC4**	**SC5**	**SC6**	**SC8**
Depth (m)	3.10-8.00	2.30-8.00	1.30-7.20	1.00-4.50	0.65-.50	2.50-8.00
w (%)	17.29	27.76	25.30	18.16	23.19	42.88
Sr (%)	95.11	93.28	88.77	99.11	96.38	90.84
$\gamma h(N/m^3)$	2.12	2.09	2.15	1.75	2.07	2.20
e_0 (%)	54.60	35.60	54.21	69.68	70.9	45.89

These results show a very high soil saturation degree (Sr)(88.77 to 100%), average water content (w) from 17.29% to 42.88%, a dry density (γd) from 1.36 to 1.82 KN/m^3, a wet density (γh) from 1.74 to 2.20 KN/m^3 and a significant vacuum index (e) reached 70% which reflects porosity (n) of 30%.

According to these results we can classify the materials analyzed as medium to stiff clay very saturated with water [26, 31], with a slightly humid to humid hydric state, present a more compact behavior and sometimes more or less loose [32].

3.3.1.1.1. Atterberg limits

The results obtained from this test are summarized on the Casagrande diagram and abacus (Fig.8 and 9).

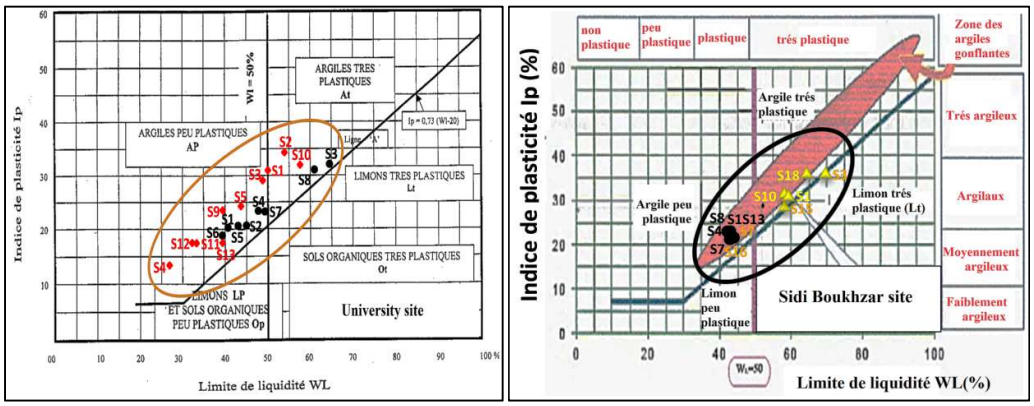


Figure 6: Position of Mila clays on the Casagrande diagram.

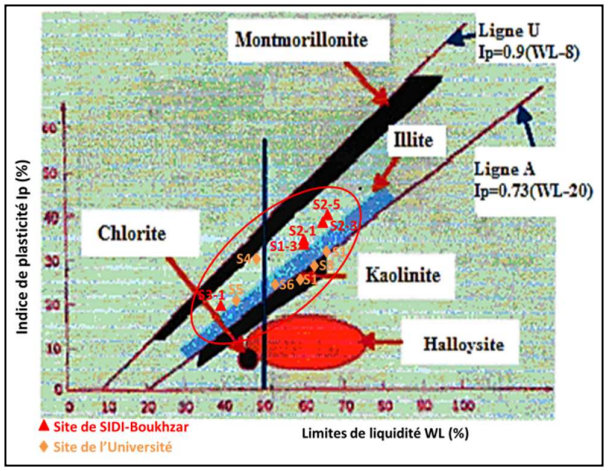


Figure 7: Position of Mila clays on the Casagrand plasticity abacus.

The representation of values Ip and WL obtained from Atterberg limitstest, on the Casagrande diagram and abacus above show that these clays are on the one hand, positioned above the line A on Casagrande diagram, on the other hand, these clays are between the line A and U, on Casagrande abacus. So, Mila clays ranges from slightly plastic (AP) to highly plastic (AT) and belongs to the three major families of clay minerals (montmorillonite, kaolinite and illite) (Fig. 7).

So, referring to the works of Dakshanamurthy & Raman [33], Komornik & David [34], Afès & Didier [13], Afes [12], Sebaai & Aziz [35], Hazmoune[23], Khellaf & *et al.*[16], Khellaf & Bitat[20], Khellaf[14], these clays are swelling because the values of the Atterberg limits obtained are quite large as standards.

3.3.1.1.2. Sedimentometric analysis and clay activity

The results obtained (Fig.8) are represented on Seed diagram and Wiliam and Donaldson diagram.

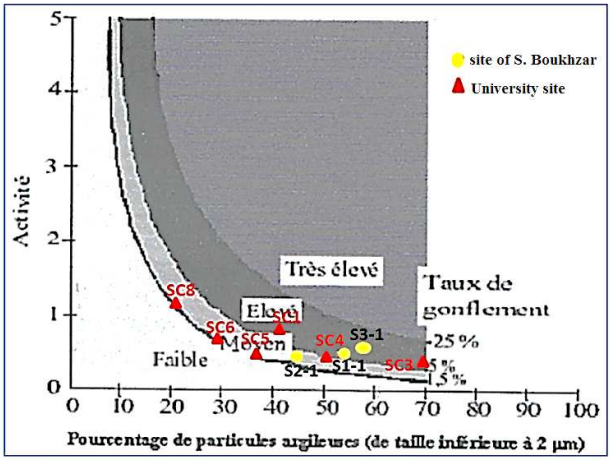


Figure 8: Position of Mila clays on the classification diagram of the swelling potential.

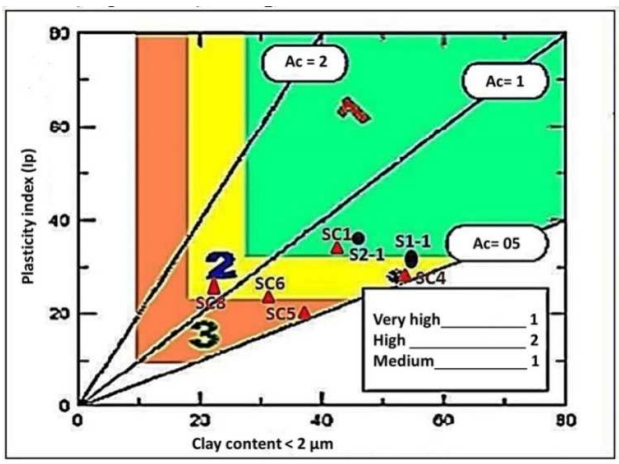


Figure 9: Position of Mila clays on the abacus of William & Donaldson, 1980.

The results obtained from this analyzes carried out on the clays show that the most part have a medium to high swelling potential [14, 16, 35].

3.3.2. Determination of the mechanical parameters for the studied clays

3.3.2.1. Oedometric and straight shear tests

The results obtained are summarized in the tables below (Table 3 and 4).

Table 3: Compressibility characteristic's of Sidi Boukhzar site [29].

Parameters	Site 1		Site 2			Site 3
	SC1	SC3	SC1	SC3	SC5	SC1
Depth (m)	2.00 - 3.00	2.0 3.00	4.00-4.50	2.00 - 3.00	2.00 - 3.00	2.00 - 3.00
Cc (%)	0.21	0.23	0.23	0.24	0.20	0.08
σ'_c (bars)	1.15	1.20	2.00	2.10	1.97	3.10
σ'_{v_0} (bars)	1.43	1.35	2.40	1.97	1.20	3.53
Cg (%)	0.005	0.01	0.03	0.03	0.03	-
Cu (bars)	0.44	0.5	0.40	0.60	0.60	0.40
φ (°)	15	22	8	5	3	16.4

Table 4: Compressibility characteristics of university Site [30]

Parameters	SC1	SC3	SC4	SC6
Depth (m)	3.10-8.00	3.80-800	2.30-8.00	1.30-7.20
Cc (%)	0.20	0.16	0.16	0.13
σ'_c (bars)	2.06	1.95	1.40	1.42
Cg (%)	0.004	0.01	0.008	0.006
Cu (bars)	0.75	0.83	0.69	0.75
ϕ(°)	3.38	2.72	3.38	5.20

The clay samples submitted to the triaxial and oedometer compressibility tests show that all the samples subjected with the undrained and unconsolidated triaxial test (UU) have a low to medium internal friction angle (φ), it's from 2° to 22°, cohesion values (C) less than 1 bar (0.4 to 0.83 bar), the constraint of pre consolidation (σc) has values between 1.20 to 3.10 bar; the coefficient of compressibility (Cc) reveals remarkable variations; it's from 0.13 to 0.24 and the swelling index (Cg) shows high values; it's between 0.05 to 0.1.

Therefore, the results obtained from the triaxial test (C, φ),on the one hand, are weak cohesion and internal friction angle for (UU) test, this is due to low percentage of the fine elements and to high percentage of sand. On the other hand, a weak cohesion and an average angle of internal friction, which due to high proportion of fine sand compared with clays [14, 16,36,37, 23] which proves that all the analyzed facies are medium to stiff and consistent clays [32, 38, 39]. The oedometric test results show a stiff clay consisting of over consolidated, moderately to highly compressible and medium to high swelling potential [14, 16,35, 40, 31, 23, 22]. The variations of these parameters confirm the heterogeneity of area soil[23].

3.3.2.2. Free swelling test

This test has been done only on Sidi-Boukhzar clays; after the determination of the optimum water content "w_{op} = 20.30%" and the maximum dry density "= 1.79g / cm³", the results obtained are summarized in the following figure (Fig. 12)

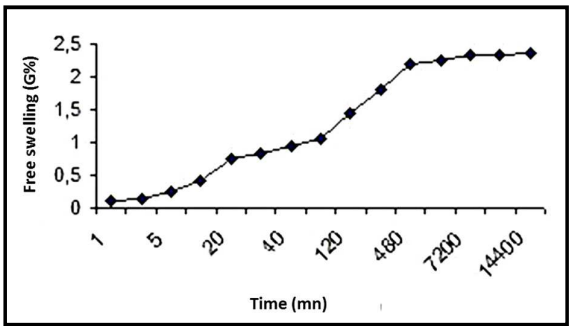


Figure 12: Evolution of free swelling [35]

From the figure, we note that at the beginning of saturation, the soil swells quickly and evolves from 1 to 480 minutes where the swelling rate reaches to 2.5%. After 480 minutes, the swelling stabilizes at 2.5%, which proves the swelling character of examined clays [14,35, 16].

So, the tendency of the sample to swell is neutralized by the application of an increasing load as soon as the vertical displacement reaches 1/100 mm. The value of the load when the sample is stabilized named the swelling pressure [41, 14, 35].

3.3.2.3. Chemical analysis

This analysis allows determining the clays chemical characteristics of Sidi-Boukhzar site. The results are summarized in the table below (Table 5).

Table 5: Results of Chemical analysis for Mila clays [29].

Chemical composition (%)	Site 1	Site 2	Site 3
SiO_2	40.51	43.67	46.30
Al_2O_3	11.13	15.54	13.46
FeO_3	5.03	7.73	6.51
CaO	16.54	10.93	11.77
SO_4	1.64	-	-
Na_2O	Trace	Trace	trace
M.O	0.20	0.15	0.20

The samples selected for the chemical analysis have been taken from various depths which are from 1 to 5 m (depth of foundation anchorage). The results obtained reveal mainly for the important parameters that the soil is clayey with low to medium sulphates content (1 to 3%) and low organic matter contents witch is from 0.15 to 0.20%.

These results show that Sidi Boukhzar soils are less rich in sulphates. Consequently are weakly aggressive to concrete [12, 42, 29]and the presence of these sulphates may have several origins, for example gypsum formation dissolution [43, 23, 44, 45]. Depending on the organic matter contents, these soils can be classified as weakly organic clays (less than 3%) with low to no aggressiveness [46].

4- CONCLUSION

The study area located on the northwest of Mila city is characterized by clays surmounting marl. The various analyzes carried out have given remarkable results.

The petrographic analysis of the samples proved different varieties of clayey rocks for both profiles. These varieties are presented by clays or marly clays and marl-sandy clays with a high rate of clays, better than 75%, a low rate of silica, less than 80% and low carbonates content.

The mineralogical analysis revealed that the Mio-Pliocene serie of Mila region shows abundance of calcium carbonates (calcite), quartz and gypsum (49%). Phyllitous minerals are mainly found in smectite (montmorillonite, vermiculite), relatively more crystalline kaolinite, interbedded (illite-montmorillonite, illite-chlorite and chlorite-montmorillonite) and the chlorite especially magnesian.

Sometimes the presence of fibrous minerals (palygorskite) is a good testimony of a relatively salty sedimentary environment. The presence of these swelling minerals makes the soil constructible with conditions.

All the geotechnical tests (Atterberg limits, water content ...etc.) show a medium to high swelling potential and a high plasticity of the clays. These parameters confirm that the soil of Mila region is building with conditions.

5. RECOMMENDATIONS

In the case of large swellings, it is recommended to treat clays in order to minimize or eliminate the swelling phenomenon. So, we have to minimize water in the soil to keep the foundations stable and protect structures under the repeated effect of this phenomenon driven by temperate climate type of the region.

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