

Clay and Marl Formation Susceptibility in Mila Province, Algeria

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Abstract In Mila Province, Algeria (a.k.a Mila Wilaya), sensitive clays presenting shrinkage-swelling phenomena are widespread, covering large areas. Due to this, constructions and infrastructures sustainability built on such soils is questionable. Such clays sensitivity is amplified by seasonal rainfall deficits which reaches extreme magnitudes. In order to develop disasters' prevention measures, we present in this work, areas mapping susceptible to shrinkage-swelling phenomenon by adopting a French method

developed by B R G M. This method takes into account three measurable characteristics: i.e. lithological, mineralogical and geotechnical, of clayey formations identified in the studied sector. Based on these characteristics, three scores are attributed for each formation. Then, the susceptibility index is the obtained score average for each clayey formation. The susceptibility map is established on this index basis with three classes: low, medium, high.

Keywords Clay · Shrinkage-swelling · Susceptibility · Cartography · Mineralogy · Foundation

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1 Introduction

Most the Northern Algerian territory is in quite unfavourable “Geotechnical-climate” conditions where the shrinkage-swelling phenomenon affects clayey formations.

This is mainly due to, at least, the following reasons:

- The seasonal rainfall deficits for which the maximum magnitudes are recorded, (Mebarki 1982). Consequently, the water content of soil varies in significant proportions and the resulting swelling that occurs on surface is maximum;
- Clays mineralogically sensitive to these phenomena are permanently encountered, because, very

often, these extreme climate changes are causing clay minerals formation which is swelling clays.

Unfortunately in Algeria, the parameters governing the shrinkage-swelling soils are not usually taken into account in geotechnical campaigns conducted for construction projects: their determination is not of common practice.

The shrinkage-swelling of some geological formations are likely to cause differential settlement that can be accompanied by disorders which mainly affect buildings and infrastructure projects.

The aim of the present research is to provide useful recommendation for Algerian makers when constructor on swelling soils.

Indeed, experiments throughout the world show that when simple cost effective construction regulations are respected, most of disasters scenarios are avoided. In this view the susceptibility map in Algerian Mila Province is intended for clayey and marl formations.

Observation serial has been carried out concerning the relevant to problems caused by the development projects implementation on these lands.

It is especially focused on sites where geotechnical investigations have been performed and recorded data are available at several laboratories.

The present work considers the methodology adopted and published recently by the Bureau of Geological and Mining Research (BRGM, France). This methodology provides a qualitative susceptibility of shrinkage-swelling, based on a hierarchical classification of clay formations primarily identified from the geological map, and taking into account three quantifiable characteristics (rated from 1 to 4) namely: lithologic characterization of each formation; mineralogical characterization of the induced clay phase and the geotechnical characterization of each formation. The susceptibility index is the score average selected for each clay formation. The susceptibility map is based on this index with three levels: low, medium, high.

First the geography and the geological context of Mila Province are presented. Second, a characterization of marl and clay formations is proposed based their hierarchy, lithology mineralogy and geotechnical criteria. Then a map of shrinkage-swelling susceptibility is elaborated by the implementation of a numerical model.

2 Mila Province Geographical and Geological Context

Mila Province, located in the North-East of Algeria, is North bordered by Jijel Province, West by Setif Province and Constantine Province at East (Fig. 1). It covers an area of 3,550 km² composed by five communes: Ferdjioua, Chelghoum Laid, Grarem Gouga, Oued Naja, Rouached and 32 municipalities.

The studied area is part of the Alpine chain foreland at eastern north of Algeria. It is a hinge zone between, north, allochthonous internal matters, characterized by thrust sheets, in connection with a compressive Cenozoic polyphase tectonic and south the field parautochthone field which settles the Neogene post-Constantine slicks basin.

The geological formations essentially include a set of carbonate, bedrock, of Cretaceous to Eocene age and discordant coverage which consists of Mio-Pliocene and Quaternary continental deposits (Fig. 2).

As shown in Fig. 3, these Mio-Pliocene formations cover the major part of Mila's basin. They are mainly represented by detritus deposits (conglomerates, gravel, sand, clays, evaporate deposits (gypsum, anhydrite and rock salt) and lagoon lime stones.

The Quaternary formations occupy the Rhumel and Endja Wadis valleys. These gravels and rolled blocks covered by flaky crust limestone, in silt matrix.

The Triassic is essentially represented by clayey evaporitic deposits. These formations outcrop in Sidi Merouane and Teleghma areas. The Jurassic is a very thick carbonate serial exceeding 600 m surrounding Mila basin. Table 1 illustrates statistical outcrop distribution of the main geological formations within Mila Province limits.

3 Marl and Clay Formation Susceptibility Characterization

3.1 Marl and Clay Formation Synthetic Map

These areas identification and mapping susceptible to shrinkage-swelling is intended. The 1/50,000 scaled geological map of the studied area represents the main data base. The aimed work is to refine the clayey soils contours based on lithological criteria

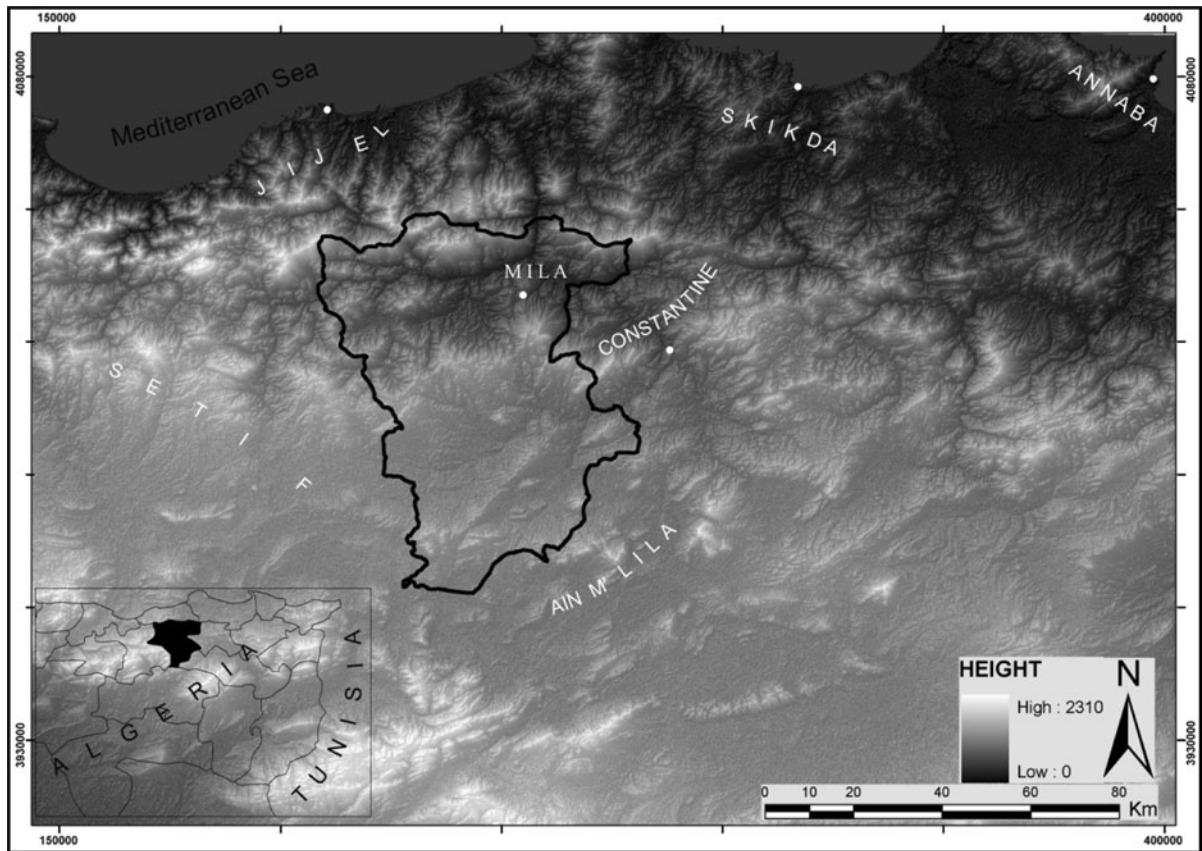


Fig. 1 Geographical location of Mila Province

and taking also into account clay thickness and continuity formations (Le Roy et al. 2007; Platel et al. 2004). Figure 4 illustrates the elaborated synthetic map. Then these formations have been classified in terms of their assumed susceptibility with respect to shrinkage-swelling by means of three main characteristics: lithology type, clay phase mineralogical composition and geotechnical behaviour.

3.2 Clay and Marl Hierarchy with Respect to Shrinkage-Swelling Susceptibility

Based on BRGM's method the shrinkage-swelling clays susceptibility is characterized successively by three main criteria which are the lithology, the mineralogy and the geotechnical one.

3.3 Lithology Criterion

Two elements are involved in the lithology criterion, first is the clay elements fraction i.e. with dimensions

less than $2\ \mu\text{m}$. Second, with less importance, is the clay formation especially when located in surface with continuous and thick geometry (Bernon et al. 2009).

The attribution of susceptibility rate for clayey formations as a lithology criterion function is given in Table 2. While Table 3 presents the attributed rate for the studied marl and clay herein.

3.3.1 Mineralogy Criteria

The term clay refers to both a grain size class $<2\ \mu\text{m}$ and mineralogical nature corresponding to the phylum silicates family (Caillere et al. 1982a, b; Thorez 1976). The shrinkage-swelling phenomena is preferably expressed in clayey minerals belonging to the smectites group and, with less extent, to the vermiculite group and interstratified minerals like swelling chlorite type C–V (chlorite vermiculite) or V–Cs (vermiculite swelling chlorite), (Moore and Reynolds 1989).

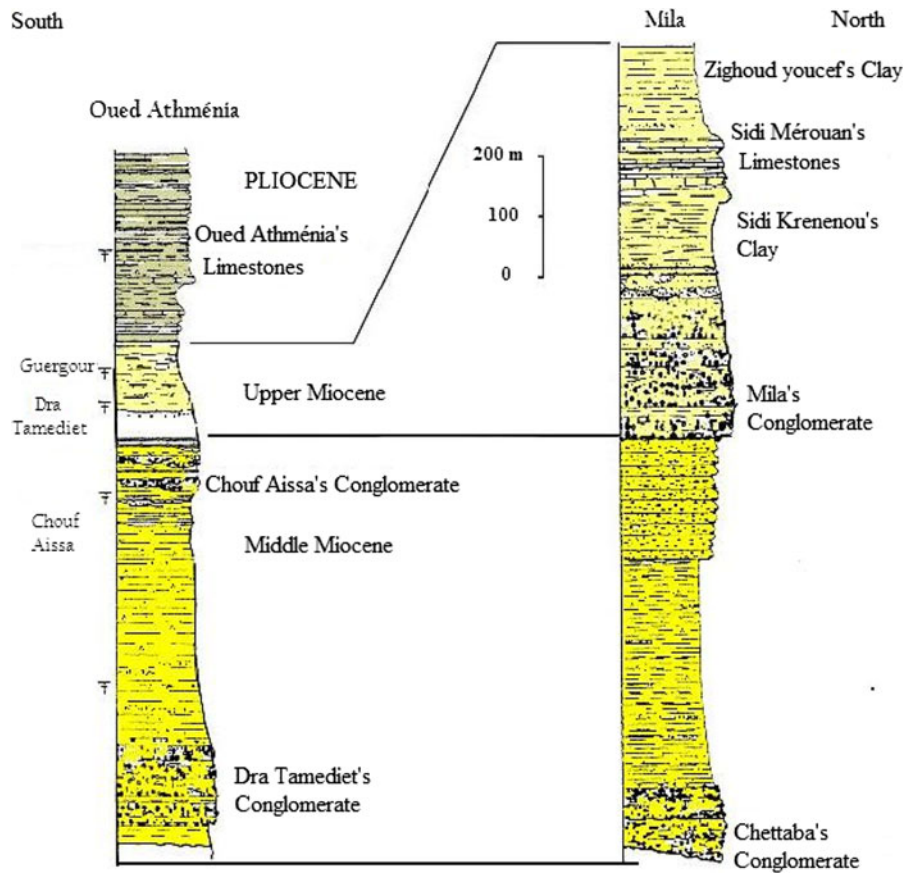


Fig. 2 Mila's basin lithology

Thirty samples (30) extracted from different Mila Province sites were subjected to various microscopic observations performed at Liege University Geology and Paleoclimate laboratory in Belgium, and in the Mineral Resources and Environment laboratory at the University of Sciences, Tunisia.

From the polarizing microscope observations, porosity matrix modification comes out due to the biogenic structures presence, (Tucker 1988). These latter induce geotechnical properties significant changes as the void ratio.

From the scanning electron microscopy observations (SEM), it has revealed that clay structure is essentially formed by kaolinite minerals represented by hexagonal shape of 2 to 5 microns layers. Such clays interlayer space may contain secondary minerals with different mineralogical and mechanical properties of those main minerals.

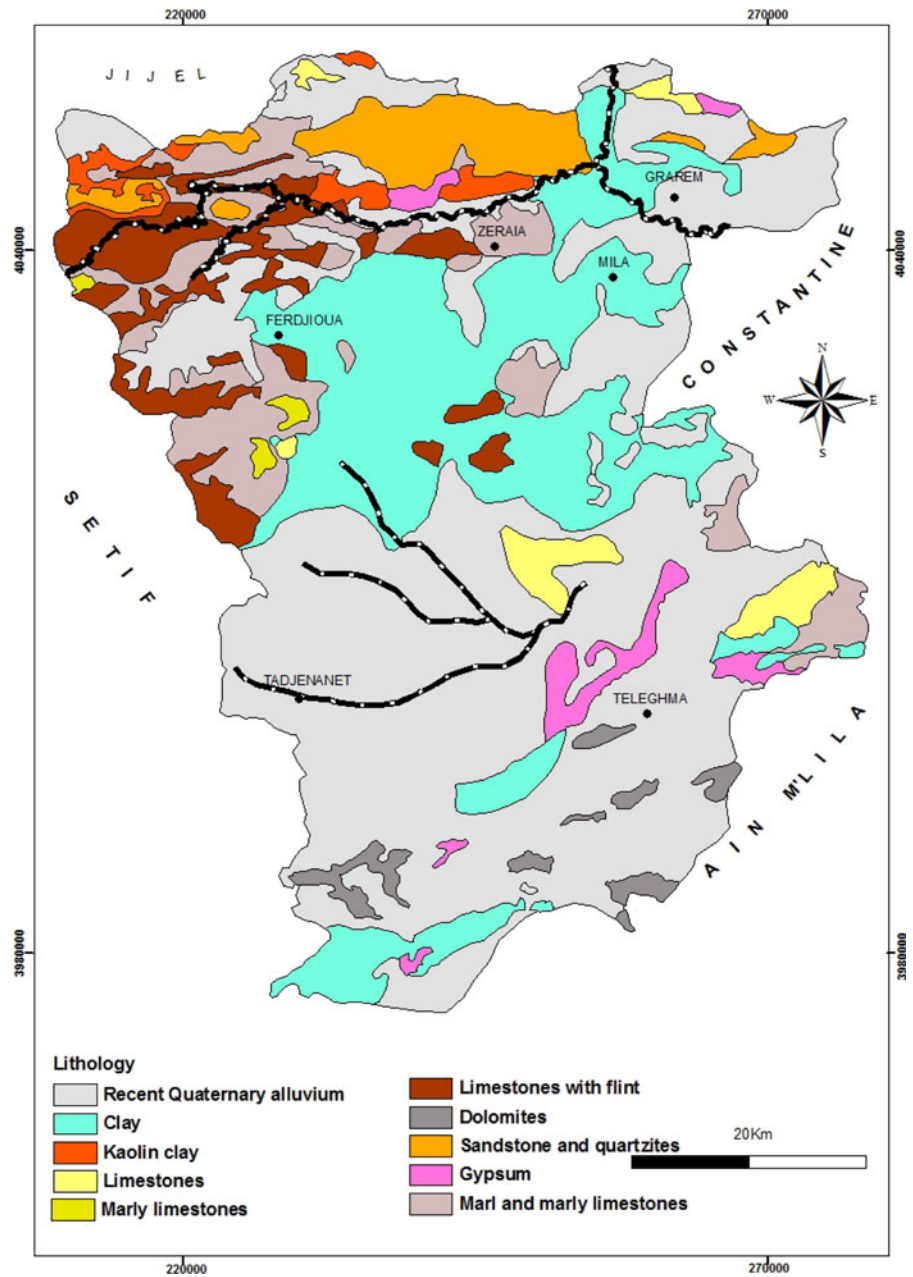
The X-ray method showed that the clayey composition, in its natural state, is mainly dominated by

the quartz, calcite, feldspar and anhydrite presence whose mineral proportions are given in Table 4.

The clay fraction XRD analysis is less than 2 microns performed under oriented aggregates form, pre extracted from initial material, provides a good estimation both qualitative and semi quantitative of various clay components (Velde 1995), either simple minerals or (and) interstratified via three standard diagnostic tests application namely: oriented aggregate drying (transition from diffracted condition called natural or normal, N); *after treatment with ethylene glycol, EG, or glycerol, Gl* and finally after post heating at 500°C. Table 5 shows different minerals proportions.

The limits for the mineralogical classification in Table 6 were adopted on the swelling minerals percentage basis (smectites and interstratified) are respectively 25, 50 and 80%. A mineral mark has been allocated for clay and marl formation according to the presented scale in Table 7.

Fig. 3 Principal geological formations Outcrop inside Mila Province



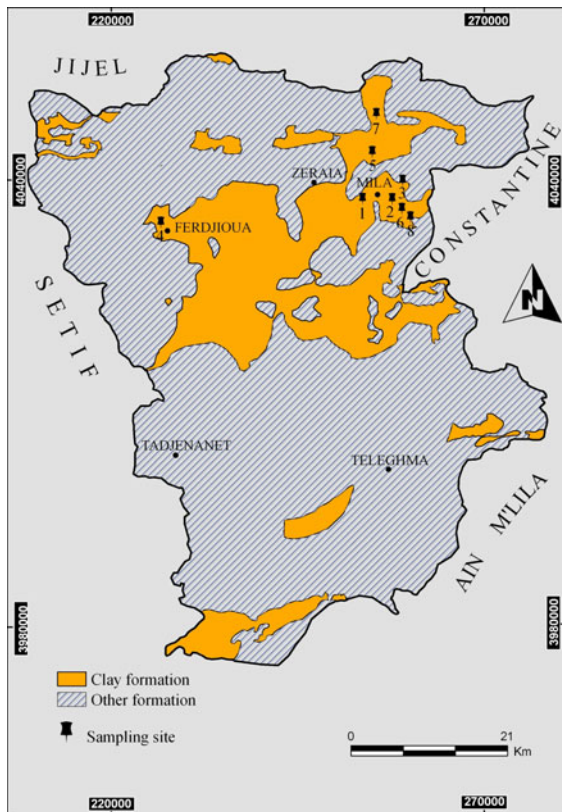
3.3.2 Geotechnical Criterion

Atterberg limits and VSB values have been determined for thirty specimens extracted from several sites in Mila’s basin (Table 8). Additional data have been collected from literature (Afès 1996; Aïssa Mamoune 2002) and data from laboratories involved previously in geotechnical surveys conducted in these sites.

In this study, these two characteristics have been determined on thirty samples. We also collected data from the literature, and from laboratory geotechnical working in the study area. Analysis and comparison with prior results (Benaïssa and Bellouche 1999) have been made. Table 9 indicates the geotechnical marks attributed to geological formations based on the VBS value and plasticity index. Table 10 presents the adopted susceptibility classes.

Table 1 Geological formations outcrop statistical distribution inside Mila Province

Lithology	Area (km ²)	%
Kaolin clay	53.49	1.53
Alluvium	1756.48	50.14
Clay	764.54	21.83
Marly limestones	12.99	0.37
Flint limestones	226.92	6.48
Sandstones and quartz	169.68	4.84
Gypsum	73.27	2.09
Dolomite	58.43	1.67
Limestones	80.77	2.30
Shale	306.10	8.74
Total	3502.69	

**Fig. 4** Clayey and marl formations distribution in Mila Province and sampling sites. Sampling sites: 1 Site 185 Homes; 2 Highway RN 79; 3 Kherrouba Site; 4 Ferdjioua Site; 5 CW 52 Site; 6 Azeba Site; 7 Sibari Site RN 27 (Ben Haroun Dam water); 8 El Malha Site RN 79

Appropriate treatment starts with the geological maps geo references at 1:50,000 of Leafs No. 50, 51, 72 and 73 corresponding to Sidi Merouane, Sidi Dris,

Table 2 Clay formations susceptibility award rating principle based on lithological criteria

Type of geological formation	Susceptibility	Lithological rate
Deposit not clay, but containing locally placed pockets or clay (e.g silt with clay lenses, with limestone karts pockets...	Low	1
Formation with a term not predominant clay calcareous clay or sandy clay Training with a term not predominant clay calcareous clay or sandy clay	Average	2
Formation mainly clay, with a term or past non clay (e.g alternating marl limestone or sandy clay) or very thin (less than 3 m)	High	3
Formation mainly clay or marl, thickness greater than 3 m and continues	Extremely high	4

Table 3 Notes attributed to lithological formations

Name of the geological formation	Lithological rate
Recent Quaternary alluvium	1
Clays	4
Kaolin clay	4
Marly limestone	2
Gypsum	1
Marls and marly limestones	3

Table 4 Initial specimen mineralogical proportions counting

Mineral	Percentage average relative (%)
Total clay	53
Quartz	30
Calcite	11
Feldspars-K	4
Anhydrite	2

Redja El-Ferada and Constantine respectively. This numerical treatment was performed by using the Geographical Information System ArcGIS 9.3. This treatment, first, uses the Mercator's universal projection that is followed by the outcrops borders scan and is completed by the different criteria coding.

Table 5 X-ray clay fraction analysis

Mineral	Average percentage
Kaolinite	36
Vermiculite	29
V-Cg	35

Table 6 Clay formations susceptibility award ratings principle depending on the mineralogical criteria

% Average percentage of mineral blowing	Susceptibility	Mineralogical rate
<25%	Low	1
25 à 50%	Average	2
50 à 80%	High	3
>80%	Extremely high	4

Table 7 Notes attributed to mineralogical clay and marl formations

Name of the geological formation	Mineralogical rate
Recent Quaternary alluvium	1
Clays	3
Kaolin clay	1
Marly limestone	1
Gypsum	1
Marls and marly limestones	2

Table 8 Clayey formations susceptibility geotechnical rate attribution

Blue of methylene value	Plasticity index	Susceptibility	Geotechnical rate
<2.5	< 12	Low	1
2.5 to 6	12 to 25	Average	2
6 to 8	25 to 40	High	3
>8	≥40	Extremely high	4

4 Map of Shrinkage-Swelling Susceptibility

The French BRGM methodology (Bernon et al. 2009) considers four criteria of susceptibility: namely the lithology, the mineralogy and two geotechnical properties i.e. the blue of methylene value and plasticity index. Related to these criteria, for a given geological formation, four marks are attributed. The average score is used to identify the susceptibility

Table 9 Geotechnical ratings attributed to clay and marl formations

Geological formation	Geotechnical rate based in plasticity index	Geotechnical rate according Blue of methylene value
Recent Quaternary alluvium	1	1
Clays	4	3
Kaolin clay	2	2
Marly limestone	1	1
Gypsum	1	1
Marls and marly limestones	2	2

degree as detailed in Table 10 for geological formations of Mila Province.

The susceptibility degree is classified in three levels: low, medium and high (Table 11). Input data for Arcgis 9.3 software: ArcMap is the main application in ArcGIS and is used for all mapping and editing tasks as well as for map-based query and analysis. It is the primary application for all map-based tasks including cartography, map analysis, and editing.

Figure 5 represents the shrinkage-swelling susceptibility map that has been drawn from the synthetic clayey and marl formation map with respective susceptibility degrees of Mila Province. The shrinkage-swelling susceptibility map calls for the following comments:

- 21.8% of total area (close to 765 km²) are classified with high susceptibility; that corresponds to clays;
- 12.4% (close to 432 km²) are classified with average susceptibility corresponding to clays, marl, kaolin and gypsum;
- 50.1%, approximately 1,756 km²) in low susceptibility area; corresponding to alluvium;
- 15.7% of total area which approximates 549 km² is classified with negligible susceptibility.

These statistics clearly highlight that by 22% of total area of Mila Province is classified with high susceptibility with respect to shrinkage-swelling. In parallel average susceptibility is expected for only 12% of Mila Province total area. This second average class is essentially encountered in superficial layers which overlay the high shrinkage-swelling susceptible clay and marl formations. It is then estimated that

Table 10 Clayey and marl formations susceptibility degree evaluation

Name of the geological formation	Lithological rate	Mineralogical rate	Geotechnical rate		Average score
			IP	VBS	
Recent Quaternary alluvium	1	1	1	1	1
Clays	4	3	4	3	3.5
Kaolin clay	4	1	2	2	2.25
Marly limestone	2	1	1	1	1.25
Gypsum	1	1	1	1	1
Marls and marly limestones	3	2	2	2	2.25

Table 11 Clayey and marl formations susceptibility classification

Average rate	Degree of susceptibility
Value ≤ 2	Low
$2 < \text{Value} \leq 3$	Average
Value > 3	High

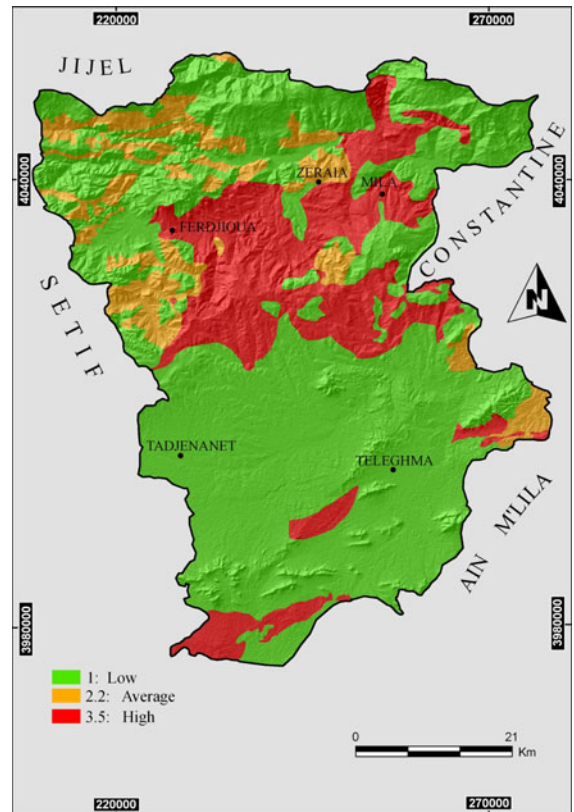
by 35% of Mila Province total area that approximates 3,550 km² is exposed to sinister shrinkage-swelling phenomena which may result from projected constructions in this area. As the water table level is located between 10 and 15 m depth the shrinkage-swelling potential is favoured due to the partially saturated clay and marl formations condition and the area semi arid climate as well.

The results here presented should be confirmed by planning much more investigation to be projected on other parcels in Mila Province.

5 Conclusions

In this paper a characterisation methodology of the shrinkage-swelling potential has been suggested for clay and marl formations that mainly constitute the geotechnical profile identified in Mila Province located in the East-North of Algeria. A 1/50,000 scaled geological map has been drawn to show the shrinkage-swelling susceptibility degree classified with high, average and negligible potential. Such classification was obtained on the VBS basis and plasticity index values, clay minerals practical identification by X-ray diffraction and mineralogical observations.

A clay and marl hierarchy with respect to shrinkage-swelling susceptibility has been proposed on the basis on the French BRGM's method.

**Fig. 5** Mila Province «swelling-shrinkage» susceptibility map

It has been appeared that about 35% area total presents may be exposed to sinister favoured by the partial clay and marl formation saturation in semi arid climate condition if constructions are projected in Mila Province.

As many Mila Province cities (Mila, Grarem, Ferdjioua, Zraïa, Sidi Méroune, etc.) are located close to the investigated zones it is obvious that subsequent measures should be decided for the potential damages prevention which may result from novel construction

projects. In parallel other geotechnical campaigns are encouraged to give other substantial highlights for a better clay characterization and marl formations of Mila Province.

References

- Afès M (1996) Contribution à la détermination des paramètres de gonflement des sols et étude de l'argile de Mila (Algérie) traitée à la chaux. Thèse de doctorat, INSA, Lyon, p 300
- Aïssa Mamoune SM (2002) Contribution à la mesure, prévision et modélisation du comportement des sols expansifs. Thèse de master. Faculté des Sciences de l'Ingénieur, Université Aboubakr Belkaïd, Tlemcen, Algérie
- Benaïssa A, Bellouche MA (1999) Propriétés géotechniques de quelques formations géologiques propices aux glissements de terrain dans l'agglomération de Constantine. *Bull Eng Geol Environ* 57(3):301–310
- Bernon N, Chrétien P, Dècle B, Imbault M, Vincent M (2009) Cartographie de l'aléa retrait—gonflement des sols argileux dans le département de l'Oise, Rapport BRGM/PR-57154—FR, p 129. <http://www.argiles.fr/Files/AleaRG60.pdf>, <http://www.argiles.fr/Files/AleaRG44.pdf>
- Caillere S, Henin S, Rautureau M (1982a) Minéralogie des argiles 1—Structure et propriétés physicochimiques. Masson Paris (France), p 184
- Caillere S, Henin S, Rautureau M (1982b) Minéralogie des argiles. 2—Classification et nomenclature. Masson Paris, p 189
- Le Roy S, Odent BE, Vincent M (2007) Actualisation de la carte d'aléa retrait—gonflement des sols argileux dans le département de l'Yonne, Rapport BRGM/PR-55546—FR, p 37
- Mebarki A (1982) Hydrogéologie de surface et aménagement des ressources en eau, thèse de doctorat de 3ème cycle Nancy II (France), p 304
- Moore DM, Reynolds RC Jr (1989) X-Ray diffraction and the identification and analysis of clay minerals. Oxford University Press, Oxford, p 332
- Platel JP, Estève A, Tomera L (2004) Cartographie de l'aléa retrait-gonflement des argiles du département de la Gironde, BRGM/RP-53382, p 223
- Thorez J (1976) Practical identification of clay minerals. In: Lelotte G (ed) A handbook for teachers and students in clay mineralogy. Belgique, p 99
- Tucker M (ed) (1988) Techniques in sedimentology. Blackwell Scientific Publications, London, p 349
- Velde B (1995) Origin and mineralogy of clays and the environment. In: Bruce (ed) XV, 356, p 182. ISBN: 978-3-540-58012-6