Proceedings Paper:

Flieger-Szymanska, M, Machowiak, K, Krawczyk, D et al. (1 more author) (2019) Characterisation of mineral composition and strength parameters of varved clays. In: Proceedings of the 17th European Conference on Soil Mechanics and Geotechnical Engineering (ECSMGE 2019). XVII ECSMGE 2019, 01-06 Sep 2019, Reykjavik, Iceland. International Society for Soil Mechanics and Geotechnical Engineering . ISBN 978-9935-9436-1-3

https://doi.org/10.32075/17ECSMGE-2019-0172

Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 17ecsmge-2019-Y-XXXX

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Characterisation of mineral composition and strength parameters of varved clays

Caractérisation de la composition minérale et des paramètres de résistance des argiles varvées

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ABSTRACT: Varved clays from the valley of Junikowski Stream (Poznan area, Poland) are investigated in this paper. Such clays are characterised by an anisotropic structure, in a form alternate occurrence of thick summer (light) layers and thin winter (dark) layers. Soils forming the light and dark layers have different granulometric compositions. Light layers are built mainly of clays with silt and clays with silt and sand (siCl, sasiCl) while dark ones are composed mainly of clays (Cl). The light and dark layers were tested separately in a direct shear apparatus. The test results revealed differences in strength parameters for soils forming the light and dark layers.
The X-ray diffraction analysis was also used to determine the mineral composition of the clay fraction. It is interesting to note that the set of identified clay minerals does not differ very much in both layers. The dominant mineral is illite with presence of kaolinite, smectite and chlorite. A detailed analysis of northern rock pebbles from the terminal moraine of the Poznan glaciation phase and from the outwash plain, which could have been a sourcing area for varved clays, confirmed the largest content of acid igneous rocks in them. Decomposition of the igneous rocks resulted in the dominant presence of illite in the mineral composition of the studied clays.

RÉSUMÉ: Dans cet article, on étudie les argiles varvées de la vallée du ruisseau Junikowski (région de Poznan, Pologne). Ces argiles sont caractérisées par une structure anisotrope, se présentant alternativement en couches épaisses d'été (claire) et en couches minces d'hiver (foncé). Les couches claires sont principalement constituées d'argiles à limon et d'argiles à limon et de sable (siCl, sasiCl), tandis que celles foncées sont principalement composées d'argiles (Cl). Les sols prélevés des couches claires et foncés ont été testées respectivement dans un appareil de cisaillement direct. Les résultats experimentaux ont démontré des différences dans les paramètres de résistance pour les sols formant les deux couches. L'analyse par diffraction des Rayons-X également été utilisée pour déterminer la composition minérale de la fraction d'argile. Il est intéressant de noter que l'ensemble des minéraux argileux identifiés ne diffère pas beaucoup dans les deux couches. Le minéral dominant est illite avec la présence de kaolinite, smectite et chlorite. Une analyse détaillée des cailloux rocheux du nord de la moraine terminale de la phase de Poznan et de la plaine de outwash, qui aurait pu être une zone d'approvisionnement en argiles varvées, a confirmé la plus grande teneur en roches ignées acides existant dans cet zone. La décomposition des roches magmatique a entraîné la présence dominante d'illite dans la composition minérale des argiles étudiées.

Keywords: varved clays, strength parameters, mineral composition, northern rock pebbles

1 INTRODUCION

Varved clays are characterised by anisotropic structure with periodically occurring light and dark sediment layers. They are commonly present in many regions of the Northern Hemisphere, affected by Pleistocene glaciations. Varved clays are formed in lake basins during cyclic changes in temperature and sedimentation environment caused by advances and retreats of glaciers. In Poland, including the area investigated in this study, the mineral composition of clay fraction is determined mainly by the parent rocks of Scandinavian origin, transported by a glacier from Fennoscandia and the Baltic basin (Czubla 2004). Therefore, the northern regions of Poland are considered to be the primary outwash plain of the weathered and transported rocks, affecting mineralogy of the varved clays analysed in this study. The content, distribution and chemical composition of clays minerals in the varves have significant effects on their physical properties and strength parameters.

2 RESEARCH AREA

The research area is located in Poland. The varved clays, investigated in this paper, are deposited in the Junikowski Stream Valley, which occupies parts of two cities, Poznan and nearby Luboń (Fig. 1), in the Greater Poland region. The study is focused on the central part of the Junikowski Stream, which includes more than 40 water reservoirs (Fig. 1), created due to dredging of tills and varved clays for civil engineering construction.

3 RESEARCH METHODOLOGY

Petrographic analysis of the outwash plain pebbles was carried out on two representative samples of coarse gravel (20-60mm) collected from exploratory pits in the town of Przeźmierowo. Each sample included over 300 individual pebbles.

Granulometric and mineral analyses of varved clays were carried out separately on light and dark layer samples. Particle distributions of the varved clays were determined with the use of hydrometer. Mineral compositions of the clay particles were determined by a high-resolution powder X-ray diffractometer (model ARL X'tra) with the use of WinXRD software.

All the clay samples were separated into two fractions, (1) <0.2μm, and (2) < 2μm. XRD analysis was performed on each fraction in three different states, (1) natural, (2) soaked in ethylene glycol, and (3) calcinated at the temperature of 550°C.

Shear strength parameters of varved clay were determined in the direct shear box. The tests were carried out on undisturbed specimens (class A, category 1) according to the Polish standard PKN-CEN ISO/TS 17892-10. All the specimens were trimmed directly from the block samples collected from the investigation site. The light and dark layer samples were tested separately.

4 CHARACTERISTICS OF VARVED CLAYS

Varved clays investigated in this paper were formed in the North Polish Glaciation, which was the youngest one in Poland. The area of Poznan was affected by two phases of this glaciation, the Leszno phase and the slightly younger Poznan phase.

Stratigraphic and morphologic positions of the varved clays in the in the catchment area of the Junikowski Stream and the outwash plain sands in the Warta River basin suggest that the dead-ice from the Leszno phase was still present in the Poznan phase, obstructing the Junikowski Stream basin. The thickness of the lacustrine deposits in the basin reaches approximately 12m and their outcrops cover relatively large areas.

In terms of granulometry, lacustrine deposits including varved clays, are highly anisotropic in the vertical direction. They are characterised by a lamellar structure, which is related to different sedimentation environments in glacial summers and winters. A single varve (an annual layer of sediment) consists of the light (glacial summer) layer (typically sandy silt or silt) and the dark (glacial winter) (silty clay or clay). A highly anisotropic structure of the varved clay deposits results in a large variability of their physical and mechanical properties, which poses significant difficulties in accurate determination of geotechnical parameters (e.g. Gradziński et al. 1976; Myślińska 1967, 2004, Florkiewicz et al. 2015).

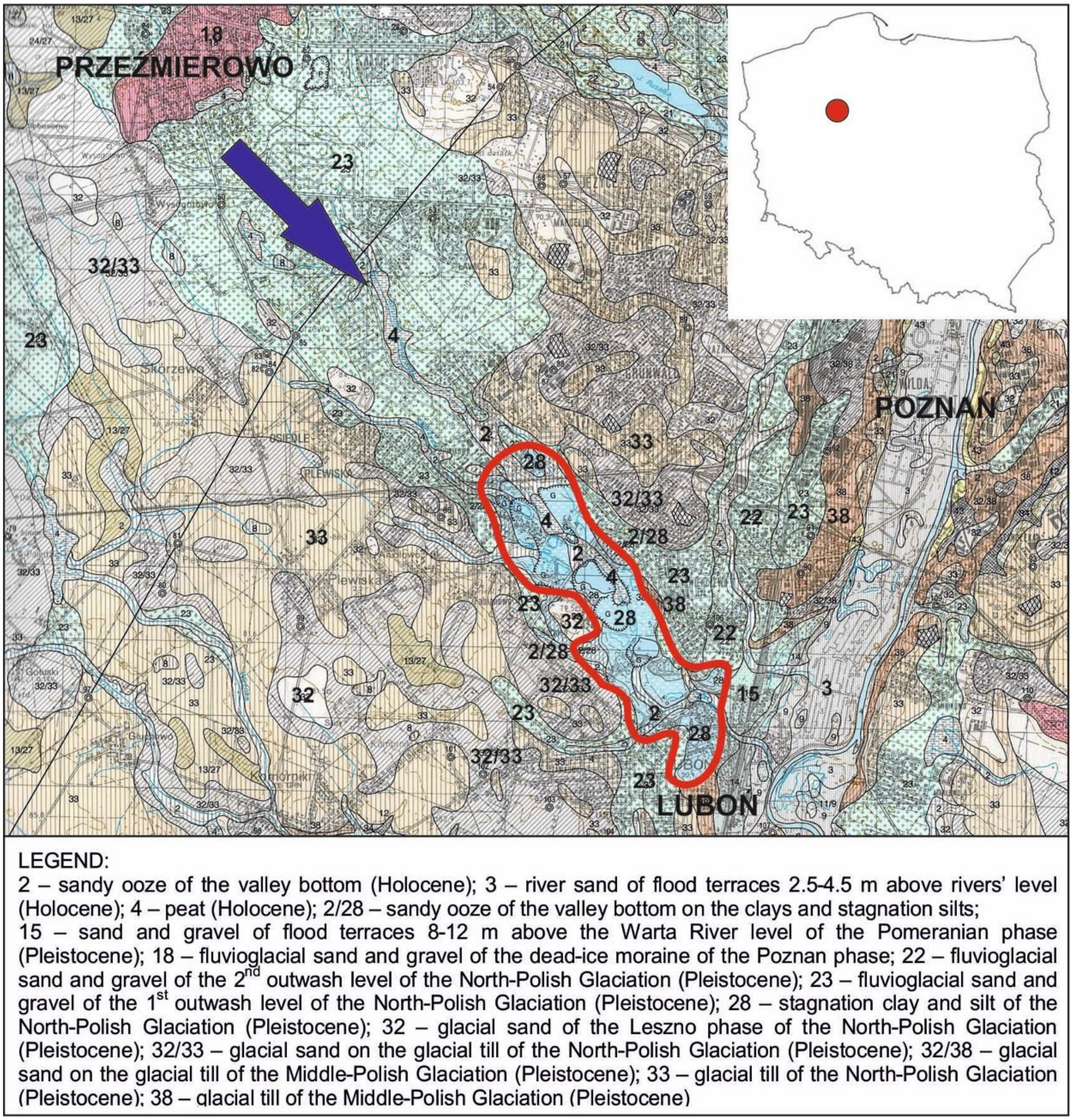

Figure 1 Location and geology of the research area in the Junikowski Stream Valley (Geological map on the scale 1:100 0000) (Chmal, 1996)

5 SOURCE ROCKS

The most probable sediment supply areas of the varved clays studied in this paper are the push moraine and outwash plains in the vicinity of the towns of Przeźmierowo and Baranowo situated a few to ten-odd km northwest of the outcrops of the varved clays (Fig. 1). Those sediments are related to the Poznan phase of the North Polish Glaciation, which is the subject of frequent debates in the literature (Kasprzak, Kozarski 1984; Krzyszkowski 1994; Wysota, Molewski 2011). It is hypothesised (Chmiel 1997) that the varved clays might have been deposited in between the older (Leszno) and the younger (Poznan) phases of the North Polish glaciation. During this glaciation, the ice sheet has advanced to the north regions of Poland, stopped at so-called Leszno line (Leszno phase) and then retreated forming a sequence of terminal moraines in the vicinity of Poznan (Poznan phase). Furthermore, recent theories of the north sediments and glacial streams (Czubla 2015) suggest that the sediments formed in the older (Leszno) glaciation phase were incorporated into the younger (Poznan) phase without any significant supply of new sediments. In addition, the mixing process of the investigated sediments was related to subglacial drainage in the area. (e.g. Piechota 2010; Sobiech i Wysota 2014). It can be concluded that the pebbles collected from the research site are the most probable source material of the varved clays.

Following a detailed petrographic analysis, most pebbles were classified as crystalline rocks (66%) with dominant presence of acid igneous rock of the northern origin (53%), both intrusive and extrusive. Smaller amounts of neutral and alkaline rocks (8 out of 66%) and metamorphic (mainly gneiss 5 out of 66%) were identified within the main group. Remaining pebbles were classified as sandstones (13%), flints (7%), limestones (6%), dolomites (3%), shales (3%, and quartz (2%) (Fig. 2).

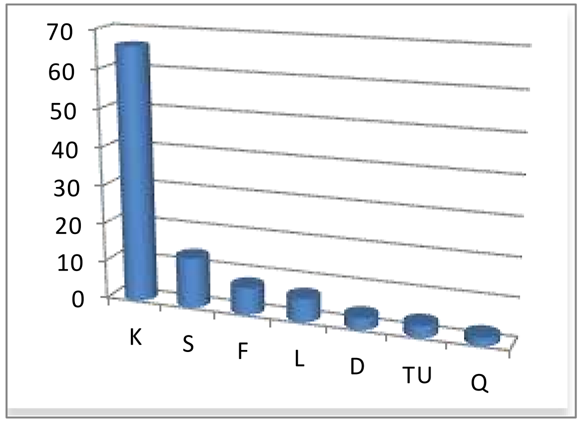

Figure 2. Petrographic groups of gravel fraction (20-60 mm): K- crystalline rocks, S – sandstones (included Jothnian), L – limestones, D – dolomites, TU – shales and claystones, Q – quartz, F - flints

6 GRANULOMETRIC AND MINERAL COMPOSITION OF VARVED CLAYS

A detailed granulometric analysis of varved clays confirmed variable clay and silt fraction contents in light and dark layer samples. In the light soil samples the silt fraction f_π is dominant with the silt content in the range of 54-74%, and the clay content f_i of 24-42%. On the other hand, the dark soil samples are predominantly composed of clay, with the clay fraction f_i in the range of 54 to 82%, and silt fraction f_π in the range of 18 to 48%, as shown in Fig. 3.

Light layers are composed mainly of clays with silt and clays with silt and sand (siCl, sasiCl) while dark ones are composed mainly of clays (Cl) (Fig. 3).

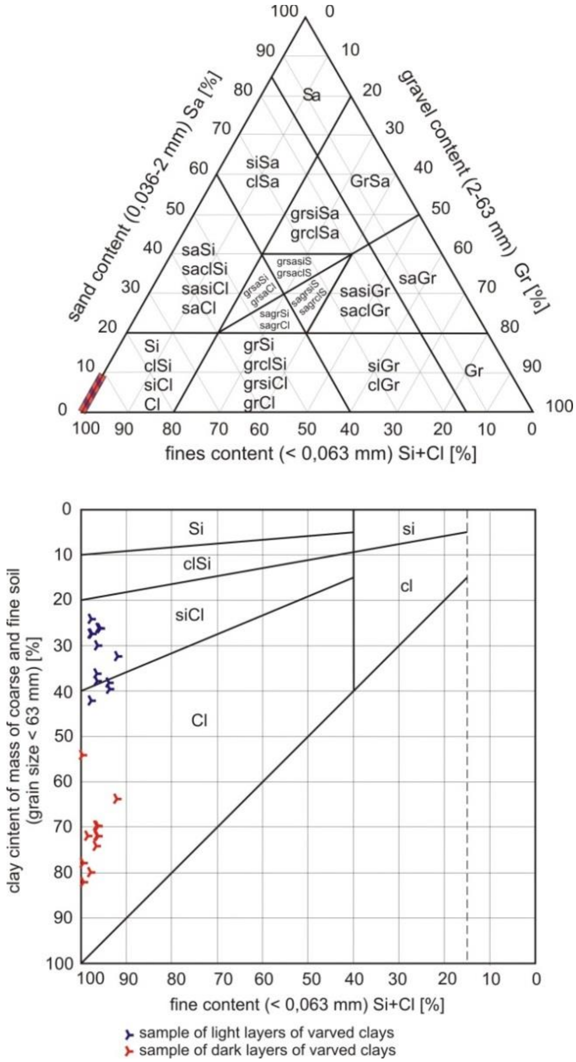

Figure 3. Granulometric composition of varved clays from the Junikowski Stream Valley according to the standard PN-EN ISO 14688-2 (Flieger-Szymańska, 2018)

Based on the detailed X-ray diffraction analysis of 10 varved clay samples and the available literature (Stoch 1974; Myślińska 1965), it was determined that hydrous micas (illites) were the main clay minerals present in the tested samples. In addition, smaller amounts of kaolinite, smectite and chloride could also be detected.

The illite group of clay minerals detected in the XRD analysis suggests that they are originated from the decomposition of acid igneous rocks, which was verified by petrographic analysis of pebbles from the sediment supply area. The origin of illite is related mainly to chemical weathering of feldspars, including potassium feldspar, which is widely present in the northern rock pebbles. Mixed-layered minerals from the illite-smectite group as well as chlorites were probably created by secondary metamorphism and further decomposition of primary micas. The presence of kaolinite can also be related to the weathering of acid igneous rocks.

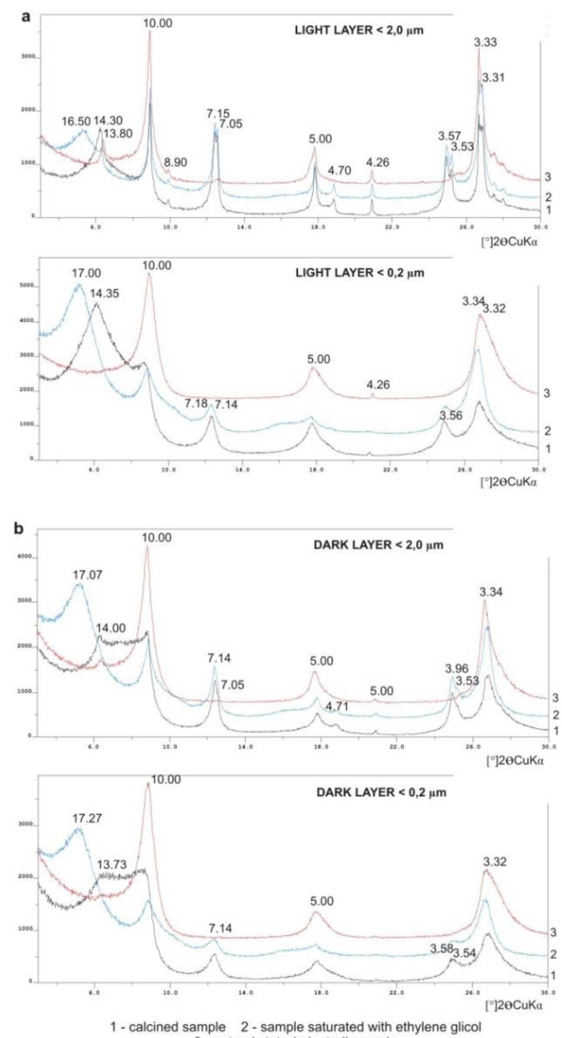

Figure 4. X-ray diffraction patterns of varved clay samples: a – light layers, b – dark layers (Flieger-Szymańska, 2018)

7 STRENGTH PARAMETERS

The shear strength parameters were determined separately for the light and dark layers in the direct shear box. The cohesion values of the light layers (c_{w-j}) are in the range of 21.9 do 55.7 kPa (average of 34.7 kPa), while the cohesion values of the dark layers (c_{w-c}) are in the range of 33.2 do 75.7 kPa (average of 53.4 kPa). The friction angles determined for the light layers (ϕ_{w-j}) were in the range of 11.0 to 20.7° (average of 16.2°), while the values of the dark layers (ϕ_{w-c}) varied from 6.0 do 14.9° (average of 9.8°).

It should be noted that all the strength parameters were determined on the samples with similar average water content values *(w)*, i.e. 27.6% for the light layers and 32.1 %, for the dark layers. However, the light and dark layers are characterised by different average values of plastic limit, w_p (22.6% for the light layers and 30.9% for the dark layers) and liquid limit, w_L (42.2% for the light layers and 80.6% for the dark layers). Consequently, their plasticity indices (I_L) are also different (0.23 for the light layers and 0.05 for the dark layers) The average values of the parameters determined in this study are summarised in Tab. 1 (Flieger-Szymańska, 2018).

Table 1. Average values of water content (w), plasticity index (I_L), cohesion (c), and friction angle (ϕ) determined for the varved clays from the Junikowski Stream Valley (Flieger-Szymańska, 2018)

Type of sample	w [%]	I_L [-]	c [kPa]	ϕ [°]
light layer (undisturbed)	27.6	0.23	34.7	16.2
dark layer (undisturbed)	32.1	0.05	53.4	9.8

8 CONCLUSIONS

1) The mineral compositions of clay fractions in dark and light layers are similar with dominant presence of illite. Smaller quantities of kaolinite, smectite and chlorite are also found in both layers.
2) Decomposition of the igneous rock pebbles from the terminal moraine and from the outwash plain of Poznan phase, is the main cause for the dominant presence of illite in the varved clays.
3) The shear strength parameters determined separately for the light and dark layers are different. The cohesion values of the light layers (c_{w-j}) are in the range of 21.9 do 55.7 kPa (average of 34.7 kPa), while the cohesion values of the dark layers (c_{w-c}) are in the range of 33.2 do 75.7 kPa (average of 53.4 kPa). The friction angles determined for the light layers (ϕ_{w-j}) were in the range of 11.0 to 20.7 ° (average of 16.2 °), while the values of the dark layers (ϕ_{w-c}) varied from 6.0 do 14.9 ° (average of 9.8 °).
4) The differences in strength parameters of the light and dark layers may be related not only to the variability in the clay fraction in two layers but also to the differences in swelling properties of clay minerals present in the two layers, which are related to variable sedimentation environments of the light and dark layers.

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