

THE EFFECT OF INORGANIC AMORPHOUS CONSTITUENTS ON THE ATTERBERG VALUES OF CLAYEY SOILS

G. BIDLÓ

Department of Mineralogy and Geology,
Technical University, H-1521 Budapest

Received 28 May 1987

Abstract

In order to show the effect of amorphous, inorganic constituents amorphous aluminium silicate hydrates have been prepared by different methods. The amorphous particles have been added to different clay minerals and it has been established that the liquid limit and plasticity index of illite and kaolinite are increased, whereas those of bentonite is decreased by the aluminium silicate added.

When elaborating the soil-physical characteristics used in geotechnique, soil mechanics and pedology Atterberg showed (1911, 1913) that the various minerals occurring in soils behave differently under the effect of water in contact with them. Part of them become plastic under the influence of an appropriate amount of water, another part keep their non-plastic property even when disintegrated to a suitable particle size. After the identification of clay minerals occurring in soil, their plastic properties have also been determined. Simultaneously, attempts were made to derive correlations between the mineral composition and the physical properties of soils. Detailed investigations were carried out in this respect by Skempton (1953), Rosenquist (1953, 1961) the most detailed by Bottero (1971). This latter was summarized by Giroud and Bottero (1972).

Correlations between the mineral composition and rock-physical characteristics have also been sought by Hungarian experts by studying the properties of pure clay minerals: J. Pakó—Hegyi (1965), SzilvÁgyi (1970), Kovács (1971), and on the other hand by clearing up the mineralic composition of soils with known physical characteristics. In this respect a linear correlation has been found between the clay mineral content of the soil and its Atterberg limits by JÁray and Bidló (1967), Bidló (1971), Simon and Bidló (1975, 1976) and Farkas (1982).

In the course of studies it was often observed that the physical properties of soils with identical crystalline phases differed significantly. This observation and the fact that by X-ray diffractography it is often not possible to find well-defined "base reflections", and only diffuse, unidentifiable reflections are present, lead to the conclusion that the amorphous components of soils should also be taken into consideration (Bidló et al. 1971).

The subject was of interest for the Scientific Research Center of Water Economics (VITUKI), hence they supported financially the studies concerning the effect of amorphous components in rocks.

The first step in the study was to investigate the decomposition of soil minerals and the formation of the amorphous phase. Clay minerals and feldspars were the objects of studies. Quartz has not been studied as it disintegrated only in soil, but does not become amorphous, neither does it decompose chemically. Structure changes due to mechanical disintegration were studied in detail by Juhász (1982), thus we restricted our studies to amorphous materials formed by chemical decomposition.

It is well known that the dissolution of silicates is an incongruent process; the composition of the solution is not identical with that of the starting material.

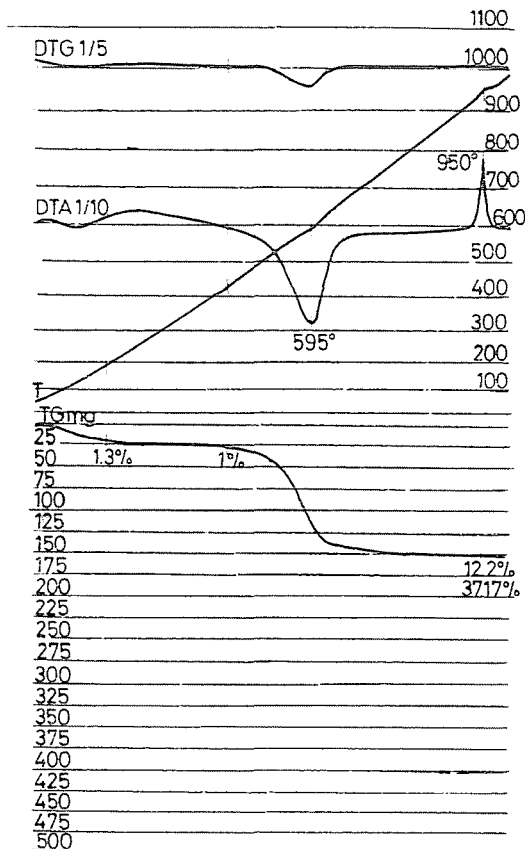


Fig. 1. Kaolinite from Szegi

Acid and basic dissolution of silicates is known from earlier studies (Vendl, Takács, 1933, Vendl 1957, Bidló 1964, 1976), thus the composition of solutions was known. However, there was no information available concerning the composition and crystal structure of the precipitates forming by the neutralization of solutions. The first objective of our work was to clarify these questions.

As starting materials, three kinds of clay minerals and a plagioclase feldspar of the albite type have been chosen:

1. Kaolinite (Fig. 1)
2. Illite (Fig. 2)
3. Bentonite (montmorillonite) (Fig. 3).

All three samples were taken from the Zemplén Mountains in Northern Hungary.

4. Plagioclase feldspar (albite) (Sweden).

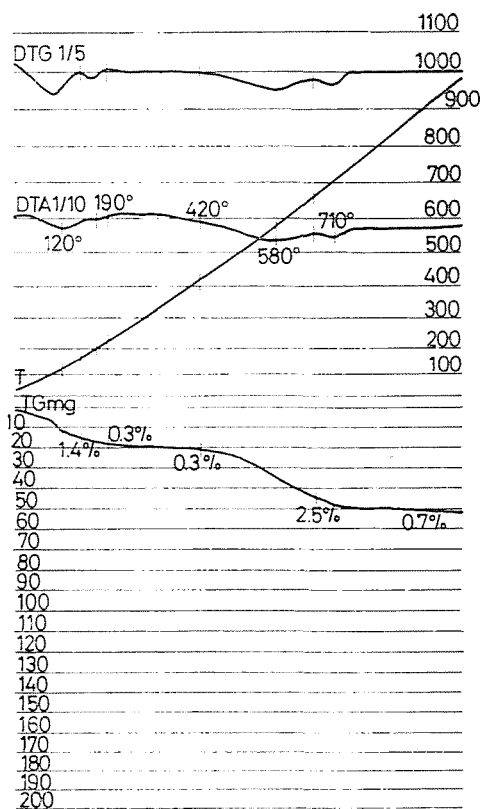


Fig. 2. Illite from Füzéradvány

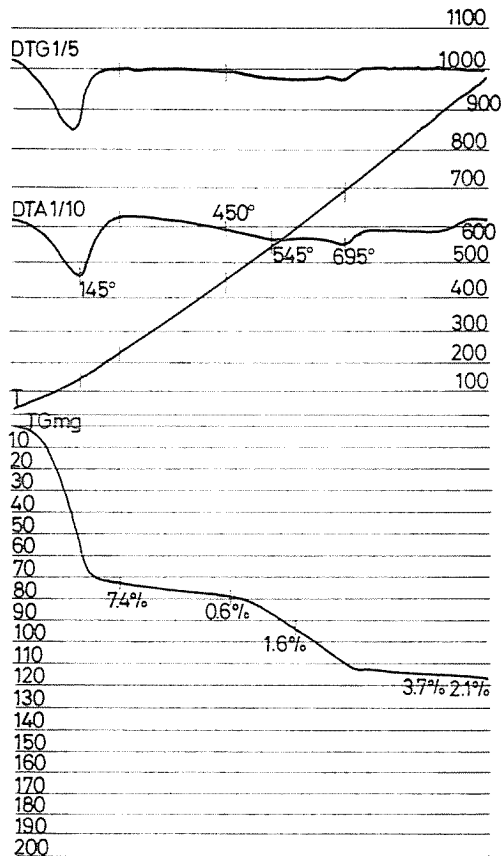


Fig. 3. Bentonite from Mád

The composition of kaolinite:

Crystalline kaolinite	87.17%
Quartz	5.91%
H ₂ O	1.80%

According to the chemical analysis, about 4% of non-identifiable amorphous aluminium silicate hydrate is also present.

Illite was a commercial product of Füzérradvány with a crystalline illite content of about 65% and a significant amount of quartz.

According to the thermogravimetric analysis, the bentonite sample contained 42% montmorillonite and 15% kaolinite.

In the albite feldspar, chemical analysis and X-ray diffraction measurements showed in addition to the 94.49% albite, also 5% of anortite.

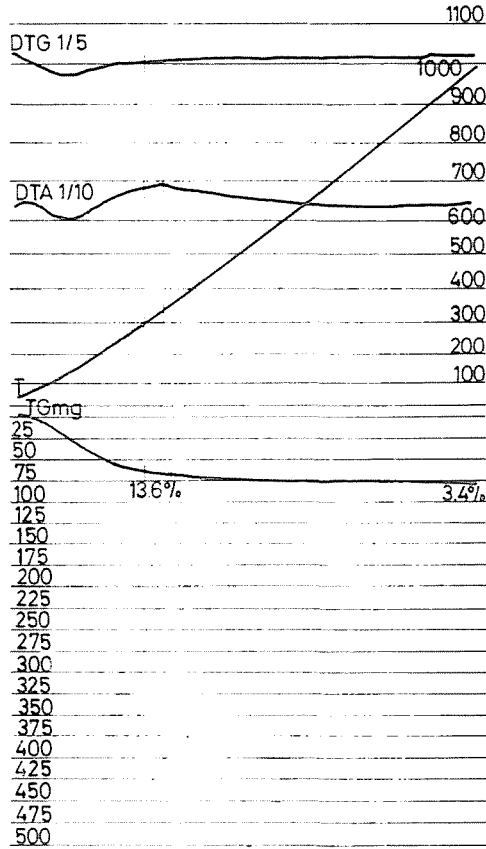


Fig. 4. Amorphous aluminium silicate hydrate precipitated from the kaolinite solution

Preparation of amorphous aluminium silicate hydrate

Two methods have been applied for the preparation of amorphous aluminium silicate hydrates from the four samples. In the first method, the samples were boiled in a 3.5% hydrochloric acid solution for 30 min, the solutions filtered and neutralized to pH = 7. In the other method, the samples were boiled in a 4% sodium hydroxide solution for 30 min, then filtered and neutralized. The precipitates formed by neutralization were filtered, washed salt-free and dried. The precipitates proved to be X-ray amorphous, by thermogravimetry they could be identified as aluminium silicate hydrates (Figs 4 and 5).

Their chemical composition is summarized in Table 1.

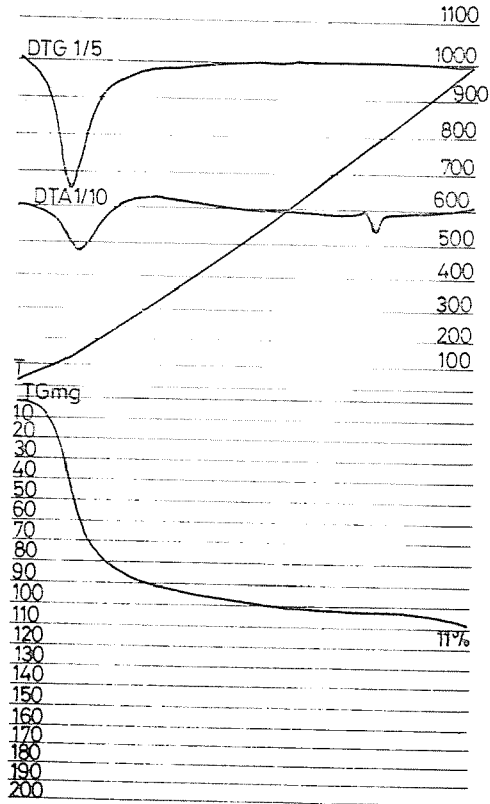


Fig. 5. Amorphous aluminium silicate hydrate precipitated from the bentonite solution

Table 1

Chemical composition of precipitates from acid dissolution

	From kaolinite	From illite	From bentonite	Feldspar
SiO ₂	75.89	44.05	13.84	30.84
Al ₂ O ₃	24.11	41.49	23.11	52.25
Fe ₂ O ₃	—	—	—	—
CaO	—	14.03	11.02	14.87
MgO	—	0.43	14.35	—
Ignition loss	×	×	21.50	×
H ₂ O	×	×	26.50	×

Note: × = ignited samples were investigated

The precipitate from the alkaline dissolution significantly differed from that characterized in Table 1 as is seen in Table 2.

Larger amounts of amorphous aluminium silicate hydrate for studying the physical properties were prepared from sodium silicate solution and aluminium chloride solution by mixing them at constant stirring. According to literature data, various precipitate compositions can be obtained by mixing the solutions in different ratios. This was proved also by our experiments (Table 3).

In the first phase of experiments, in order to study their effect, amorphous components had been mixed mechanically to the pure clay minerals after their physical properties were determined. For a better mixing and in order to be able to carry out experiments with materials of different compositions, the solution obtained by the dissolution of clay minerals were neutralized in the presence of clay minerals, precipitating thus the amorphous aluminium silicate hydrate onto the clay mineral. By this method, natural processes can be modelled better. As a consequence, the chemical composition of the material has changed, but at the same time, the mass decrease at 550 °C also increased which is the measure of the amount of clay minerals in thermogravimetric experiments (Table 4, Figs 6, 7, 8, 9 and 10).

Thus for the determination of soil physical characteristics the original clay mineral, a mechanical mixture of clay mineral and amorphous aluminium

Table 2

SiO₂ and Al₂O₃ content of precipitates formed by a 30 min boiling of the clay minerals in a 4% NaOH solution

	Kaolinite	Illite	Bentonite
	%		
SiO ₂	39.59	14.21	56.39
Al ₂ O ₃	28.55	85.78	1.51
Ignition loss	20.66	×	13.41

Note: × = ignited sample was studied

Table 3

Chemical composition of the precipitates formed on the mixing of sodium silicate and AlCl₃

	Equal ratio	Excess water glass	Excess AlCl ₃
SiO ₂	21.31%	63.48%	49.63%
Al ₂ O ₃	21.92%	12.13%	23.83%
Ignition loss	33.89%	19.16%	26.54%
Alkali	22.88%	5.23%	0.58%

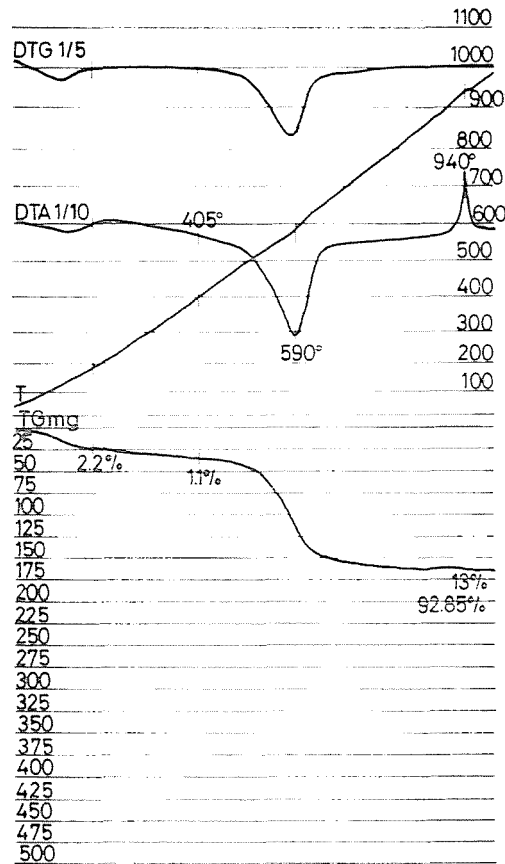


Fig. 6. Kaolinite dissolved in dilute HCl and neutralized

Table 4

Change in the composition of clay minerals as the result of precipitation of amorphous aluminium silicate hydrate onto them

	Kaolinite (%)		Illite (%)		Bentonite (%)	
	original	plated	original	plated	original	plated
SiO ₂	45.95	45.51	58.69	58.32	47.09	53.48
Al ₂ O ₃	37.64	37.49	30.31	30.48	25.06	21.13
CaO	—	—	0.91	1.01	3.83	3.18
MgO	—	—	1.73	1.11	3.17	6.02
Ignition loss	12.20	14.10	3.50	4.30	6.40	4.40
Min. cont.	87.14	92.85	70.00	86.00	72.00	76.00

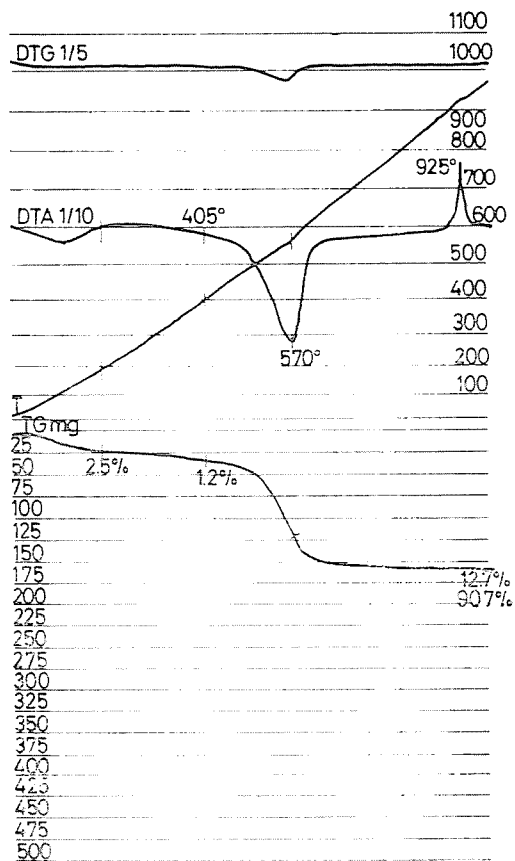


Fig. 7. Kaolinite dissolved in dilute NaOH and neutralized

silicate hydrate, a mixture prepared by the precipitation of the amorphous aluminium silicate hydrate onto the clay mineral and the amorphous aluminium silicate hydrate were available.

Soil-physical studies

Soil-physical studies have been carried out in the laboratory of the Scientific Research Center of Water Economics (VITUKI) under the leadership of G. Vastagh (1982). An additional sample, a mixture of amorphous and crystalline material has also been prepared so that aluminium silicate hydrate has been formed from sodium silicate and aluminium chloride in the presence of clay mineral at constant stirring. This material is called in Table 5 "plated", whereas the one obtained by the dissolution of kaolinite is called "precipitated". From the data in the Table 5 it is seen that in the case of kaolinite, the

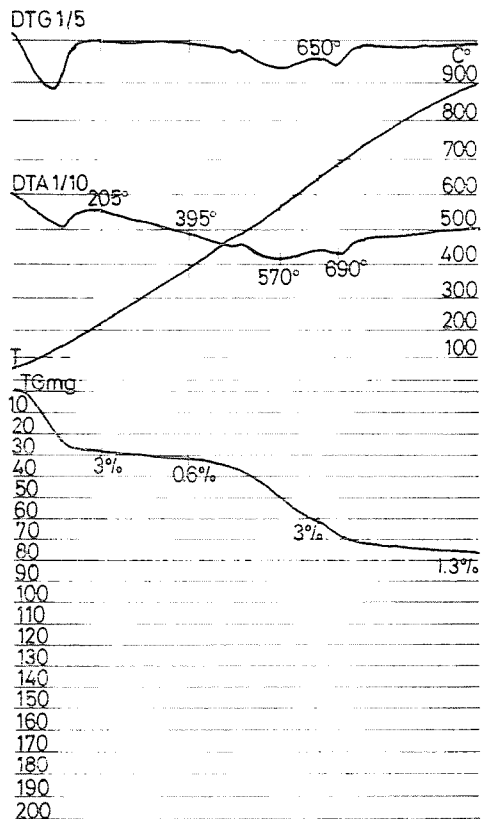


Fig. 8. Illite dissolved in dilute HCl and neutralized

amorphous material increases the liquid limit and the plasticity index, for illite the effect is only a change in the plasticity index. It is especially interesting that the presence of the amorphous material *decreases* the liquid limit and the plasticity index for bentonite.

It has also been clarified that amorphous aluminium silicate hydrate can be detected by thermogravimetric measurements. The appearance of amorphous material can be observed on all the derivatographic curves. On the DTA curve of kaolinite a water desorption peak appears at a low temperature otherwise not detectable and the temperature of lattice destruction is also reduced (Figs 6 and 7). The curves for illite (Fig. 8) and bentonite (Figs 9 and 10) also change significantly, which change refers to the presence of amorphous material.

As it has already been mentioned, the amount of amorphous silicate hydrate cannot be determined unequivocally from the mass decrease, as at the temperature of lattice destruction a larger decrease is measured than in

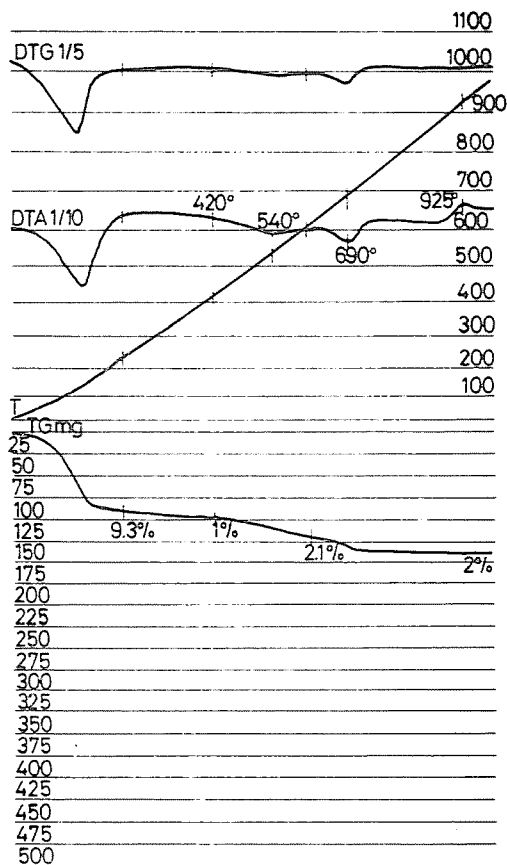


Fig. 9. Bentonite dissolved in dilute HCl and neutralized

Table 5
Atterberg values of the mixtures from clay minerals
and amorphous aluminium silicate hydrate

	W_L (%)	I_p (%)	s (g/cm ²)
Kaolinite from Szegi	47.2	14.2	2.64
+ precipitated AlSi-ate	50.8	17.0	2.60
+ mixed AlSi-ate	54.8	18.5	2.61
Illite original	85.0	59.4	2.73
+ precipitated AlSi-ate	87.9	59.4	2.75
+ mixed AlSi-ate	86.4	82.9	2.76
Bentonite	434.4	400.4	2.88
+ plated AlSi-ate	297.5	244.2	2.63
+ mixed AlSi-ate	339.6	297.3	2.66
AlSi-ate hydrate	251.8	30.3	—
After drying	153.1	14.6	2.50

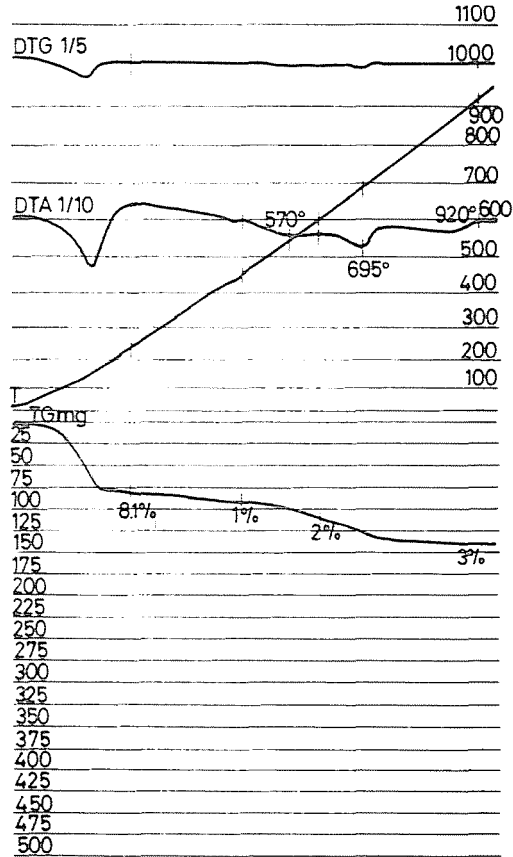


Fig. 10. Bentonite dissolved in dilute NaOH and neutralized

the original material. This is especially striking if the amorphous material is prepared from the mineral itself, which fact may be explained by the phenomenon that the chemical processes bring hydroxy-groups into the lattice which decreases the stability of the lattice and increases the mass decrease.

The presence of amorphous material plays an important role in near-surface motions. Farkas has established (1982) that an about 0.5 cm thin layer formed on the top of clay layers, initiates this motion and serves as a gliding plane. In a sample from Gyöngyösvisonta we succeeded in separating and studying this layer (Bidló 1983). It could be established that its clay mineral content determined by thermogravimetry is significantly higher than that in the underlying clay, despite the almost identical DTA curves of the two materials (Figs 11 and 12).

Summarizing, it can be established that amorphous aluminium silicate hydrate — depending on its amount — influences the Atterberg values of

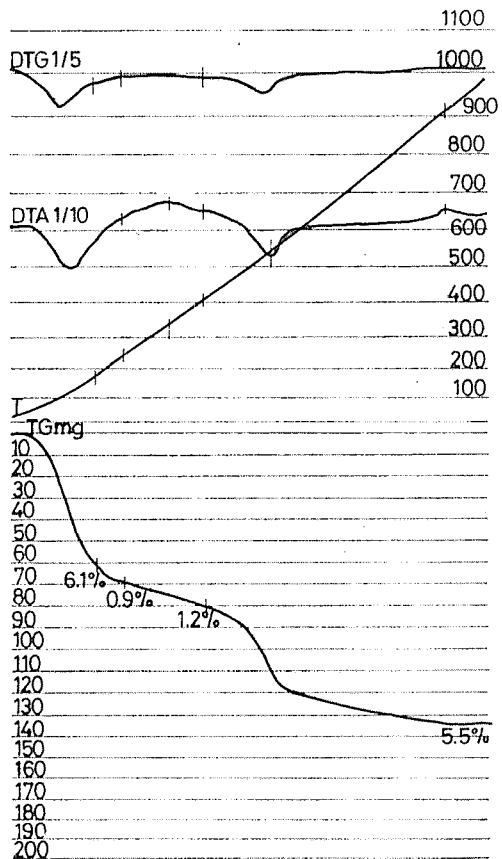


Fig. 11. "Gliding plane" from Gyöngyövisonta

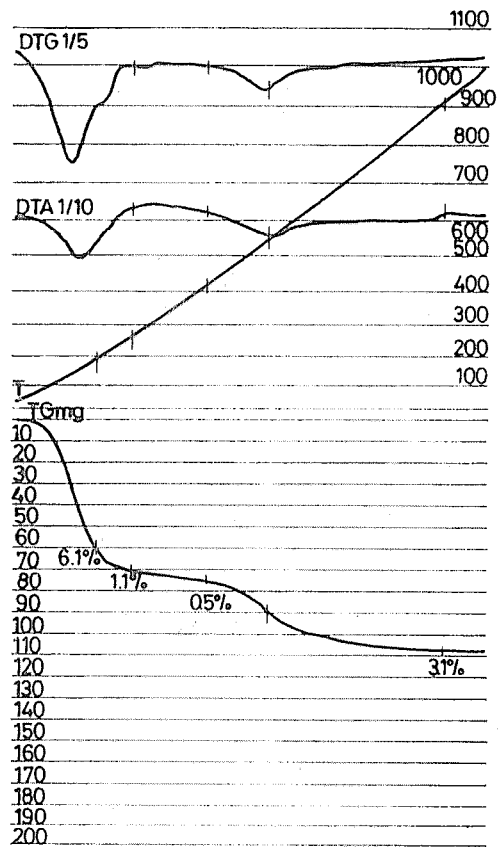


Fig. 12. Grey clay under the gliding plane from Gyöngyövisonta

clay minerals and thus the stability of constructions as well. The minerals in the soil decompose to amorphous aluminium silicate hydrates under the effect of various chemical processes, hence these processes should be followed by special care for environmental protection reasons.

References

1. ATTERBERG, A.: Die Plastizität der Tone Internationale Mitteilung für Bodenkunde. I pp.34—38, 1911.
2. ATTERBERG, A.: Die Plastizität- und Bindigkeitliefernde Bestandteile der Tone. Internationale Mitteilung für Bodenkunde 3, pp. 291, 1913.
3. BIDLÓ, G.: Veränderung der Zusammensetzung von Eruptivgesteinen unter Einwirkung verschiedener chemischer Stoffe. ÉKME Tudományos Közlemények 10, pp. 47—69, 1964.
4. BIDLÓ, G.: Die Wirkung organischer Säuren auf Tonmineralien. Schriftenreihe für Geologische Wissenschaften Berlin, 5 pp. 47—57, 1976.
5. BIDLÓ, G.: The influence of mineral composition on some near-surface motions. Földtani Kutatás, 26 pp. 47—49, 1983. (in Hungarian.)
6. BIDLÓ, G., CSAJÁGHY, G., NÁRAY-SZABÓ, I., PÉTER, É.: The mineral composition of Hungarian soils. II. Acta Mineralogica-Petrographica Szeged, 20, pp. 41—56, 1971.
7. BOTTERO, A.: Étude des propriétés mécaniques des matériaux argileux en fonction de leurs propriétés physicochimiques. Thèse de doctorat de spécialité Université de Grenoble 1971.
8. FARKAS, J.: The role of anomalies at layer boundaries of clays in the development of layer glidings in Hungary Dissertation, Budapest, (1982) (in Hungarian)
9. GIROUD, J. P., BOTTERO, A.: Influence des propriétés physico-chimiques des argiles monominérales sur leur comportement mécanique. Bull. Liaison Labo. P. et Ch. 62, pp. 105—116, 1972.
10. HEGYI-PAKÓ, J.: The significance of clay minerals in water construction. Hidrológiai Tá-jékoztató 1965. June pp. 19—23, 1965. (in Hungarian)
11. JÁRAY, J., BIDLÓ, G.: Correlation between soil-physical characteristics and the mineral composition of soils. Földtani Kutatás 20, pp. 20—29, 1967. (in Hungarian)
12. JUHÁSZ, A. Z.: Mechanical activation of silicates by fine grinding. Akadémiai Kiadó Budapest, 1982. (in Hungarian)
13. KOVÁCS, GY.: Connection between the plasticity of soils and their clay mineral content. Agro-kémia és Talajtan, 20, pp. 51—62, 1971. (in Hungarian)
14. ROSENQUIST, T., MOUM, J.: Considerations on the sensitivity of Norwegian quick clay. Geotechnique 3, pp. 193—200, 1953.
15. ROSENQUIST, T., MOUM, J.: The mechanical properties of montmorillonite and illite clays related to the electrolytes of the pore water. 5th International Congress on Soil Mechanics and Foundation Engineering, 1 pp. 263—267, 1961.
16. SIMON, A. B., BIDLÓ, G.: On the Black Cotton Soils of North-Cameroon. Engineering Geology, 9, pp. 351—357, 1967.
17. SIMON, A. B., BIDLÓ, G.: Correlation between mineral content and Atterberg limits in the soils from South-Cameroon. Proc. 3rd Conf. on Soil Mechanics and Foundation Engineering, Budapest, pp. 161—166, 1976.
18. SKEMPTON, A. W.: The colloidal "activity" of clays. Proc. 3rd Int. Conf. on Soil Mechanics and Foundation Engineering 1, pp. 57—61, 1953.
19. SZILVÁGYI, I.: Correlations in the rheological and soil mechanical studies of illites. Földtani Kutatás 13, pp. 24—27, 1970. (in Hungarian)
20. VASTAGH, G.: The role of amorphous soil components in constructions. Vízgazdálkodási Tudományos Kutató Központ 721/4/5 Subject report 1982. (in Hungarian)
21. VENDL, A.: Study of the weathering of eruptive rocks. MTA Műszaki Tud. Oszt. Közleményei, 20, pp. 201—233, 1957. (in Hungarian)
22. VENDL, A., TAKÁTS, T.: About the weathering of the andesite of Csódi Hill. MTA Mat. Term. tud. Értesítő, 50, pp. 589—616, 1933. (in Hungarian)

Dr. Gábor BIDLÓ H-1521, Budapest