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TEXTURE OF THE MAIN GENETIC TYPES OF CLAY ROCKS (ACCORDING TO DATA OBTAINED BY MAGNETIC ANISOTROPY)

TEXTURE DES PRINCIPAUX TYPES DE ROCHES ARGILEUSES (D'APRES LES RESULTATS OBTENUS AU MOYEN DE L'ANISOTROPIE MAGNETIQUE)

OSIPOV Yu.B., All-Union Scientific Research Institute of Hydrogeology and Engineering Geology, Moscow, USSR.
SOKOLOV B.A., Geological faculty of the Moscow State University, USSR.

Summary:

The principles of the genetic classification of clay rock textures of different genesis which has been made on the data obtained by magnetic anisotropy method are presented. A qualitative evaluation of clay rock textures of marine, lacustrine, alluvial, talus and eluvial genesis is described. According to the mechanism of their formation the textures are distinguished as follows: coagulative, uncoagulative, accumulative and hypergene. A given geometric model and quantitative indices of texture are correlated with qualitative characteristics of texture ascertained from lithology and sedimentary petrography.

Résumé:

Les auteurs proposent les principes d'une classification génétique des textures des roches argileuses de diverses origines, établie à partir des résultats de mesures d'anisotropie magnétique. Ils présentent une description qualitative des textures des roches argileuses de genèse marine, lacustre, éluviale, alluviale, et des formations de pentes. Ils distinguent, d'après le mécanisme de formation des textures, les classes suivantes: coagulante, non coagulante, accumulative et hypergène. Ils établissent une corrélation entre un modèle géométrique de texture (correspondant à certains indices quantitatifs) et les caractéristiques qualitatives de textures connues en lithologie et en pétrographie sédimentaire.

During the past 10 – 15 years in engineering geology attention has been particularly given to texture analysis of clay rocks. It is very important to teach engineer-geologists to describe quantitatively the texture of a rock so as later to evaluate quantitatively the contribution of the texture to strength and deformation of rocks either by strict theoretical solutions or by correlation relationships. Qualitative description of texture made by lithologists and petrographers cannot completely satisfy engineer-geologists.

At present, as yet there is no common texture classification of sedimentary rocks. There exist several classifications of stratified textures suggested by L.V.Pustovalov (1940), N.B.Vassoevich (1948, 1958), M.S.Shvetsov (1961), L.N.Botvinskaya (1965) and others, the basis for which was the first USSR genetic (facial) classification of bedding types suggested by Yu.A.Zhemchuzhnikov in 1926 (2, 4, 6, 12, 14). Five genetic types of bedding are distinguished in this classification:

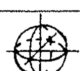
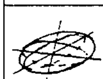
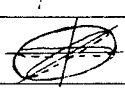
Genesis of clay rock	Model of texture	Type of texture by mechanism of its formation		Qualitative characteristics of texture	Qualitative characteristics	
					Coefficient of volume orientation $A = \frac{X_{xx}+X_{yy}}{2X_{zz}}$	Angle of inclination of orion ted texture to level φ
Marine	 (a) sphere  (b) ellipsoid elongated along the vertical line	Sedimentation	Coagulative	(a) isotropic (random) (b) oriented (axial vertical)	1 <1	- >45°
	 Ellipsoid compressed along the vertical line	Sedimentation	Uncoagulative	Medium to highly oriented	1.2-1.5	0-30°
Lacustrine	 Plane ellipsoid	Sedimentation	Uncoagulative	Plane highly oriented	2 -3	0-10°
Alluvial	 Ellipsoid elongated along one axis (in the direction of flow)	Accumulative		Axial	< 1	0-90°
Talus	 (a) ellipsoid compressed along the vertical line  (b) ellipsoid elongated along one axis	Accumulative		(a) oriented inclined (b) axial vertical	>1 <1	30-90°
Eluvial	 Sphere	Hypergene		Random	1	-

Table 1 : Genetic classification of textures of the main genetic types of clay rocks (according to data obtained by magnetic anisotropy)

aeolian, stream, river, deltaic and coastal-marine. It is necessary to note that this classification has been made mainly for sandy rock textures. The classification of clay rock textures was suggested by M.F.Vikulova (1, 5). This classification is not virtually genetic but morphologic and it describes textures, in particular, qualitatively. The genetic classification of textures suggested concerns only clay rocks (Table 1). It has been made as a result of generalising the factual material obtained by a new method which enables the evaluation of a texture of any clay rock quantitatively. The classification takes account of the genesis of clay rock and the mechanism of texture formation. Each type of texture is characterized by quantitative indices, geometric model and description in the early terminology ascertained. The objective of the classification suggested is to favour a quantitative description of textures in engineering geology. The procedure of measurements and estimates is published in the works (11, 15). Each type of texture is characterized by quantitative indices as a characteristic of the classification of volume particle orientation $(A) = \frac{\kappa xx + \kappa yy}{2\kappa zz}$ where κ are basis values of magnetic susceptibility, and in geometric interpretation lengths of ellipsoid semi-axis and angular characteristics (φ) describing the arrangement in space of axis or plane of predominant particle orientation relative to a horizontal plane (Table 1).

I. Clays of marine genesis
(a) Old marine deposits

It has been shown by the magnetic anisotropy method (16) that a texture of Cambrian clay (Cm, m, Leningrad), cannel clay (N_2 kn, m, Povoljye), spondyl clay (Pg_2, m, Kiev) can be described by ellipsoid-disk typical of a sedimentation texture of uncoagulative type (Table 1). In this case it is ascertained that the degree of particle orientation in the bedding plane may be two or five times as high that in a perpendicular direction and the plane of the best particle orientation is commonly inclined 20 – 30° to level.

Some samples of Jurassic clay (Moscow) have an ideal-isotropic texture (A= 1) but most samples are of the value A a little more than 1 which is indicative of a tendency to particle orientation in a horizontal direction. As a whole, according to the data obtained by magnetic anisotropy, it is possible to say that the isotropic coagulative texture of the Jurassic clay may be associated with intensive coagulation of particles at sedimentation stage due to much content of organic matter (~ 3%) and soluble salts (~ 1%) (10). This conclusion is in agreement with the results obtained by us as well as from a great deal of literature data on the structure-texture of Jurassic deposits of the Russian platform.

As a result of compressive stress of these clays to 6 kgp/cm² loads the orientation of particles in horizontal direction increases and the texture of samples becomes more oriented. With sandy clay this tendency is not observed. Within the depth of occurrence under study (10 to 30 m from the surface) any essential differences in clay texture are not recorded, although a more isotropic texture is marked in the samples selected at the top of Jurassic deposits. It is possible to assume that this situation is connected with the processes of weathering and erosion in post-Jurassic time.

(b) Recent marine deposits

A typical sedimentation texture of uncoagulative type (A= 1.13) is recorded on samples of the Caspian marine deposits ($N_{ap} - Q_1$ bak). This texture is due to the relatively small salinity of the Caspian sea, mainly due to the hydromica composition of sediments and the content of clay fraction of about 30%. With increase of the depth of occurrence to 420 m the coefficient A increases as much as 1.19 despite the fact that the content of clay fraction decreased by 10%. Hence, it may be concluded that with increase of the depth of occurrence a sedimentation texture of uncoagulative type becomes more oriented (coefficient A varies from 1.13 to 1.42) that may be associated with pressure increase as well as with increase of hydromica content in clay fraction of 41% to 57% (according to the data obtained in the marine geology laboratory of the Moscow State University).

Holocene marine deposits
($Q\frac{1-2}{4}$, m, Murmansk area)

The estimated coefficient A for many samples of these deposits proved to be the same as for Jurassic clays, that is less than 1. This fact, however, cannot be accounted for by rapid coagulation of sediments as water suspended matters proved to be very stable, and it is also known that the basin was fresh-water. Distribution of the values of coefficient A and the data on the presence of cross macrobedding show that the type of deposits under consideration may have a texture oriented in space in any possible direction. These data are correlated with the results obtained by G.L.Koff (8) who distinguished three types of texture in vertical section according to the results obtained by electron-microscopic studies. These are as follows: random (2 – 3 m), vertical (6 – 7 m), vertical and inclined (9 – 10 m). According to our data in the interval of depths 5.6 to 10 m both vertical and horizontal textures (A= 0.90 – 1.11) may be encountered. However, in the lower part of this interval (8 – 10 m) a tendency to transition from vertical to horizontal texture is clearly marked. Such a result was gained by us in collaboration with A.S.Polyakov from the study of recent deposits of the Black sea.

II. Clay rocks of lacustrine genesis
(Novgorod)

Banded lacustrine clays are typical of the deposits of Quaternary period of the North-West of the European part of the USSR, overlying Paleozoic bedrocks. According to the data of B.D.Vasiljev (3), M.N.Kagner (7) and others banded lacustrine clays have well-defined anisotropy of physico-mechanical characteristics. Thus, the value of the permeability coefficient in banded clays is ten thousand times as high in horizontal direction as in vertical direction; swelling is accompanied by the increase in sample height by 40 – 50%; the value of lateral pressure is always by 30 – 40% more in horizontal layer location than that in vertical one.

The texture of clays is studied in bands, intercalations separated from bands as well as in levels where a microtexture is not visually marked.

The texture of banded clays in section changes as follows:

Interval 1 – 2 m. Oriented texture in clay bands 2 cm thick is not visually observed. Clay beds are characterized by highly oriented, horizontally occurring texture. The coefficient A of orientation ranges within 2.5 and 3.08. The angle of planar dip of orientation to the level is 5 – 10°.

Interval 2 – 4 m. The degree of orientation in wide bands including silty (summer) and clay (winter) beds is different. It is evidenced by the change in the coefficient A 1.28 – 1.41 in silty intercalations and 1.59 – 1.62 in clay intercalations respectively. The angle of planar dip of orientation to the level is 5 – 10°.

Interval 4 – 8 m. No macrobedding has been found at a given level. The rock texture is isotropic. The results of measurements, however, showed that the clay rock within this interval has an oriented texture with the coefficient 1.2 and the angle of inclination to the level a little more than that in the overlying levels, that is 10 – 23°.

Thus, as the depth of occurrence increases the degree of particle orientation $(A)_o$ decreases from 3.08 to 1.42 and the angle φ increases to 23°. Such a decline in particle orientation with depth seems to be explained by change in granulometric composition from thin-dispersed to coarser-dispersed which is stressed by M.N.Kagner (7).

III. Clay rocks of eluvial genesis

Loessial rocks are widely distributed both in the European and eastern regions of the USSR. According to the ideas of A.V.Minervin and E.M.Sergeev (9) these rocks are of eluvial genesis in the upper part of section. The main features of changes in natural texture of loessial rocks with depth can be considered using the examples of several sections of the south of East Sibiria. In the first case the section is confined to watershed plain with absolute altitudes of 400 to 410 m. The entire section 8 m thick has essentially random texture which through the mechanism of formation, according to the classification suggested (Table 1) is known as a hypergene texture so far as in consequence of weathering of sedimentary rocks of different genesis a primary texture is necessarily changed into a random texture.

The alternative section of loessial rocks to 55 m thick is confined to IVth terrace above the flood plain of the Tuba river. The major part of the section is represented by the deposits typical of alluvial genesis; however, as in the above case, within the upper eight meters the rocks have practically random texture unlike the lower levels where

Sample number	Initial data: stress of magnetic field H_3	magnetic susceptibility κ	Mechanic rotative moment Mx	My	Mz	Electronic computer results: Principal axes of ellipsoid κxx	κyy	κzz	Direction cosines of principal axes κxx	κyy	κzz	Coefficient of volume orientation $A = \frac{\kappa xx + \kappa yy}{2\kappa zz}$	Rock genesis
			24.00	-35.00	8.00				0.94	-0.32	-0.14		marine (uncoagulative) type
									0.33	0.94	0.04		
152	8650	11.9				13.16	13.38	9.32				1.42	
			-143.00	143.00	11.00				0.12	-0.08	0.99		
			4.80	-0.79	0.00				1.00	0.04	-0.04		
												1.06	marine (coagulative) typ
15	8650	4.08				4.11	4.19	3.90	-0.03	0.97	0.23		
			-10.70	6.0	1.58				0.05	-0.23	0.97		
			63.60	-63.60	3.20				0.70	-0.66	-0.26		
128	8650	5.50				7.14	6.91	2.28	0.69	0.73	0.01	3.08	lacustrine type
									0.18	-0.18	0.97		
			-163.60	156.00	-4.60								
			-5.1	3.40	- .34								
									0.84	0.54	-0.05		Alluvial type
159	8650	4.90				4.90	4.83	5.00	-0.38	0.65	0.66	0.97	
			1.7	-0.17	0.50								
									0.39	-0.53	0.75		
			7.93	0.00	-6.40				0.61	0.61	-0.50	1.00	Eluvial type
109	8650	18.0				17.81	18.09	17.91	-0.33	0.78	0.53		
			-6.36	-6.36	-1.40				0.71	-0.16	0.68		

Table 2 : Results of quantitative evaluation of textures obtained by electronic computer computation

from the depth of about 30 m the texture is not only well oriented but even axial (Table 2).

Loessial rocks in exposures of the IInd terrace above the flood plain also show a change in texture with depth from random to poorly oriented vertical texture (A= 0.97 – 0.91). For loessial rocks high susceptibility to external loads is typical. They can radically change a texture of rocks particularly in the moist state. It is of interest to note that the value of subsidence is well correlated with the texture characteristics, in particular, with the angle of inclination of oriented texture to the level.

Well-known bentonite clays (Makharadze) with a well-defined hypergene texture are the other representative of eluvial genesis. It is natural that the texture of these clays is always random (A = 0.99 – 1.0); in this case it is possible to say about the approximation to the maximum possible under natural conditions ideal-isotropic random texture.

IV. Clay rocks of alluvial genesis

Texture description of typical alluvium represented by loess-like rocks is partially described in the above section. Alluvial clay rocks (Naberezhnye Chelny) along with them have been studied. They are subjected to hypergene processes to a lesser degree so far as they are overlapped by aeolian-talus deposits of Quaternary age. Their thickness is 10 m; they are represented by silty heavy and middle loams (by V.V.Okhotin). Throughout the entire section the soils have a random texture with the coefficient 0.98 – 0.99. Consolidation of these soils as much as 6.0 kgp/cm² did not change the texture in samples which is accounted for by their coarse-dispersed composition and semi-solid hard-plastic state (B < 0). One of the most typical features of clay alluvium texture is the wide range of its variability from random to axial or even plane. In this case the angle of inclination of the axis or plane of the best particle orientation to the level may be from 0° to 90° which is associated with the existence of well-known cross bedding in alluvium (2). On the other hand, the texture quality of alluvial deposits as well as of marine and lacustrine deposits depends on their granulometric composition so far as relatively coarse-dispersed composition of sedimentary material prevents the formation of highly oriented textures. Thus, as pointed out by us previously, a highly oriented texture is typical of the soils which according to the granulometric classification are related to the interval: clay-heavy loam, and for the interval middle loam – sand a more random texture is typical. The existence of axial texture occurring in alluvial deposits seems to be associated with the main direction of water flow in the period of sediment formation.

V. Clay rocks of talus genesis
(d Q, Bereznyaki, West Urals)

Clay soils of talus genesis are widely spread in the Pre-Urals where their thickness ranges within 3 and 8 m. Talus deposits of the section are represented mainly by silty heavy and middle loams. A study of talus texture showed that some types of texture are formed in these deposits. So, within the interval of depths 1.0 – 2.6 m the oriented texture (A = 1.15 – 1.06) is observed to incline to the level at angles of 34 – 49°. The deposits at a depth of 4.0 m have weak vertical orientation (A = 0.89) with the angle of inclination about 80°, and even below along the section the texture becomes random. Such a variability in the degree of particle orientation and the angle of inclination of oriented textures to the level is characteristic of the deposits of talus genesis.

Conclusions

1. Qualitative and quantitative characteristics of clay rock texture, mechanism of its formation and geometric model characterizing the texture from quantitative aspect are defined by its genesis.
2. Quality of clay rock texture within a single genetic type depends on: the hydrodynamic regime, salinity and temperature of water in a basin; granulometric and mineralogical composition; rates of sedimentation; level of stressed state of rock masses, epigenetic changes and other factors.
3. Variability in texture characteristics is also defined by genesis of clay rocks. It is negligible for coagulation and to a lesser degree for hypergene textures and very important for uncoagulative and accumulative textures.
4. A preliminary scheme of the genetic classification of textures of the main clay rock types is suggested; it enables the description of a texture quantitatively taking into account the mechanism of formation.

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