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Effects of swelly pressure on changes in pore space morphology in Miocene clays from Warsaw: preliminary results and open questions

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Miocene clays of the Poznań series from Warsaw were analysed by scanning electron microscope. The influence of swelly pressure causes soil porosity to decrease slightly together with a reorientation of pores. They become more anisometric, while their original matrix microstructure acquires properties of matrix-turbulent microstructure.

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INTRODUCTION

One of the most important features of clay microstructure is the nature of pore space, whose morphology (e.g. measurements, shapes and configuration) has a substantial influence on possible migration of water, oil, gas or liquid impurities. The influence of pore-size on permeability in clays has been widely recognised, while resulting changes in the internal morphological structure of pores under the influence of water (or any liquid) depend on the amount of pressure exerted on the soil. This paper attempts to provide a qualitative analysis of those changes.

The Miocene Poznań clays (Dyjor, 1970; Piwocki and Ziembińska-Tworzydło, 1995) of Warsaw were selected for these analyses (Fig. 1). These deposits, on account of their mineral and granulometric composition as well as their sorptive properties (Rowe *et al*., 1998), can be used as geological barriers. Table 1 presents the results obtained for two samples, both of which were prepared in different manners. Further experiments of this kind, currently being carried out, aim to confirm the initial results reported here.

METHODS AND MATERIALS

Scanning electron microscopy (SEM) provides the most information of current methods regarding the nature of pore space. In addition, it provides real images of microstructural changes. Imaging of pore space was conducted in the Institute of Geological Sciences of the Polish Academy of Sciences and the analysis of the images obtained was made using the *STIMAN* program in the Institute of Hydrogeology and Engineering Geology, Warsaw University (Kaczyński and Trzciński, 1997).

The following procedure was applied successively:

— samples with undisturbed structure (NNS) were collected;

— swelly pressure was examined in a sample with undisturbed structure (NNS) in a *Geonor* apparatus by the C method according to ASTM D 4546-90;

— hydraulic conductivity was examined in a sample with a *Geonor* consolidometric adapter for hydraulic conductivity determination, with a constant hydraulic gradient equal to 30;

— the same clay samples were used in swelly pressure studies, and subsequently in hydraulic conductivity measurements under a pressure equal to the swelly pressure.

Fig. 1. Distribution of Miocene clays in Poland after Wichrowski (1981)

Cubes 2 × 2 × 2 cm each were cut out of the undisturbed clay sample (NNS) 20 × 20 × 20 cm. Cubes of 1.8 × 1.8 × 1.8 cm were cut out of the samples that had undergone the tests for the swelly pressure, hydraulic conductivity and both the swelly pressure and hydraulic conductivity. Samples prepared similarly were analysed by SEM.

RESULTS AND DISCUSSION

Analysis of the results obtained shows significant differences in the parameters of the clay cubes possessing an intact structure (NNS), compared with cubes which had previously undergone testing for swelly pressure and hydraulic conductivity (Table 1):

— the porosity of clay which normally ranges from 48–52% slightly decreased, and reached the lowest level (39–45%) in samples that had undergone the test for swelly pressure;

— a similar tendency was observed for the diameter of mediumsize-pores, which decreased from 1.16 μm for NNS to 0.81 μm for the samples that had undergone tests for both swelly pressure and hydraulic conductivity;

— the average pore area decreased from 5.9–3.5 μm^2;

— the circumference of the average pore decreased from 8.7–6.3 μm.

To evaluate structural elements the form index of pores was used. This parameter describes the proportion of circle perimeter equal to the observed square pore to true pore perimeter. The form index of pores is accounted for in the following equation:

$$K_f = 3.354 \frac{\sqrt{S}}{P}$$

where: K_f — form index of pores; S — pore area [μm^2]; P — pore perimeter [μm].

Table 1

SEM analysis of pores

Parameter	Green clay			
	Sample with undisturbed structure	Sample after swelly pressure experiment σ_{sp}	Sample after measurement of hydraulic conductivity coefficient (k)	Sample after measurement of σ_{sp} and k
Porosity n [%]	48.55–52.66	45.58–50.48	39.51–45.85	41.97–48.03
Number of pores $N \times 10^3$	30506–33793	27964–29438	47618–54564	40703–41144
Average diameter of pores D_{av} [μm]	0.924–1.161	0.875–0.988	0.714–0.884	0.694–0.819
Total pores area $S_t \times 10^3$ [μm^2]	151651–180025	154600–160817	136828–170118	155175–171139
Average area of pores S_{av} [μm^2]	4.488–5.901	5.252–5.751	2.507–3.572	3.772–4.2459
Total pores perimeter $P_t \times 10^3$ [μm]	182512–265933	210689–283418	268650–298614	222010–257298
Average perimeter of pores P_{av} [μm]	5.401–8.717	7.157–7.939	4.923–6.271	6.321–6.888
Average form index of pores K_{fav}	0.463–0.527	0.533–0.581	0.485–0.538	0.474–0.55803
Microstructure anisotropy index K_a [%]	15.9–26	26.9–28.9	31.7–33.6	24.1–28.8
Dominating orientation direction of pore α [°]	4.5–10.8	1.2–27.5	147.1–173.6	163.0–177.0
Swell pressure σ_{sp} [kPa]	–	–	120–150	100–143
Hydraulic conductivity coefficient k [m/s]	–	5.71×10^{-11}	–	4.69×10^{-11}

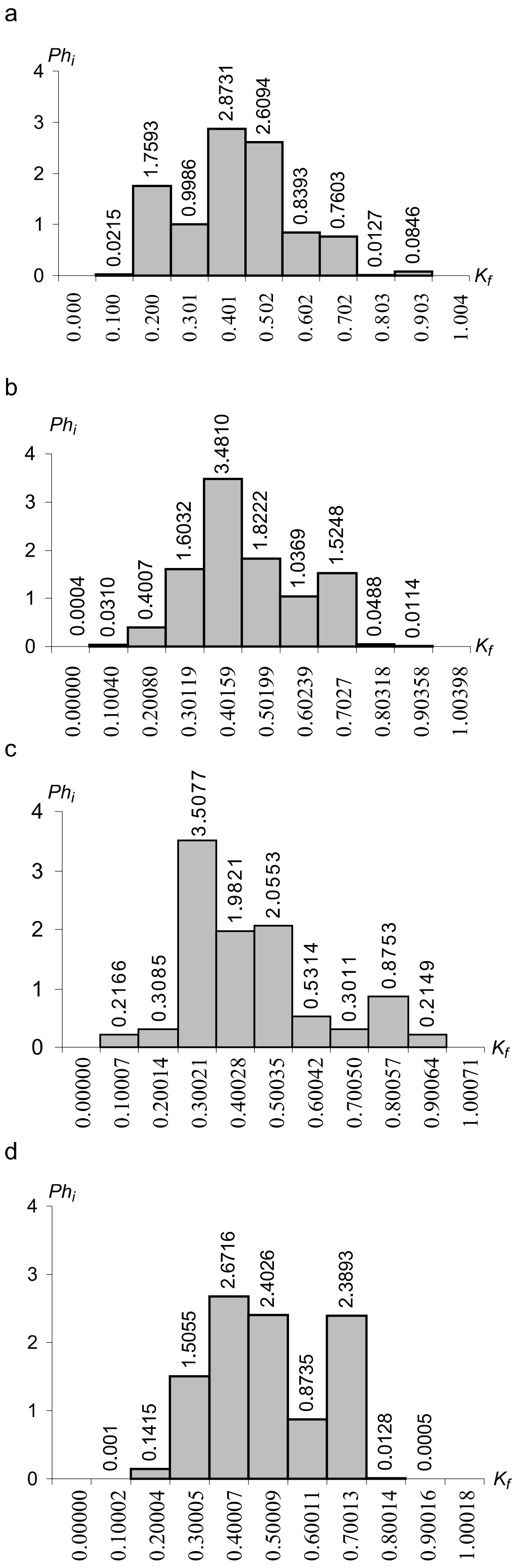

Fig. 2. Distribution histograms of the form index of pores (K_f) for Miocene clay

a — with undisturbed structure; b — after examination of hydraulic conductivity; c — after examination of swelly pressure; d — after examination of swelly pressure and hydraulic conductivity; Ph_i — density distribution in *i*-range

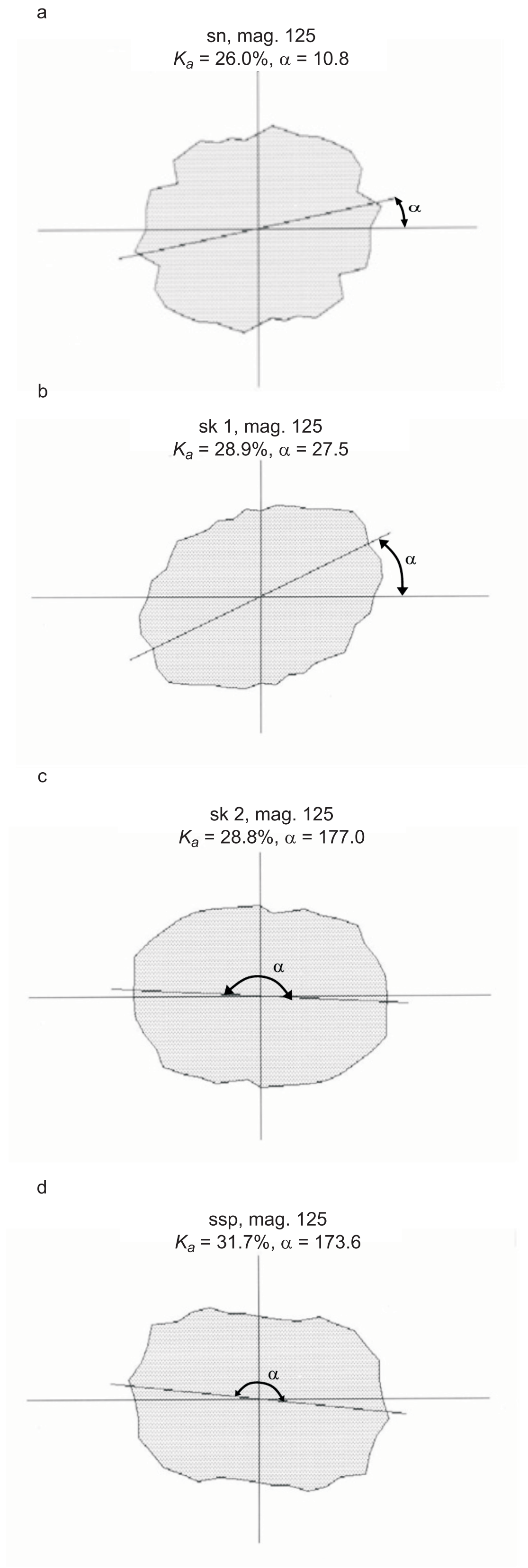

Fig. 3. Rose diagram of pore orientations

a — sn sample with undisturbed structure; b — sk 1 sample after examination of hydraulic conductivity; c — sk 2 sample after examination of swelly pressure and hydraulic conductivity; d — ssp sample after examination of swelly pressure; K_a — degree of anisotropy of microstructure [%]; α — dominant orientation direction of pores [°]; mag. — enlargement

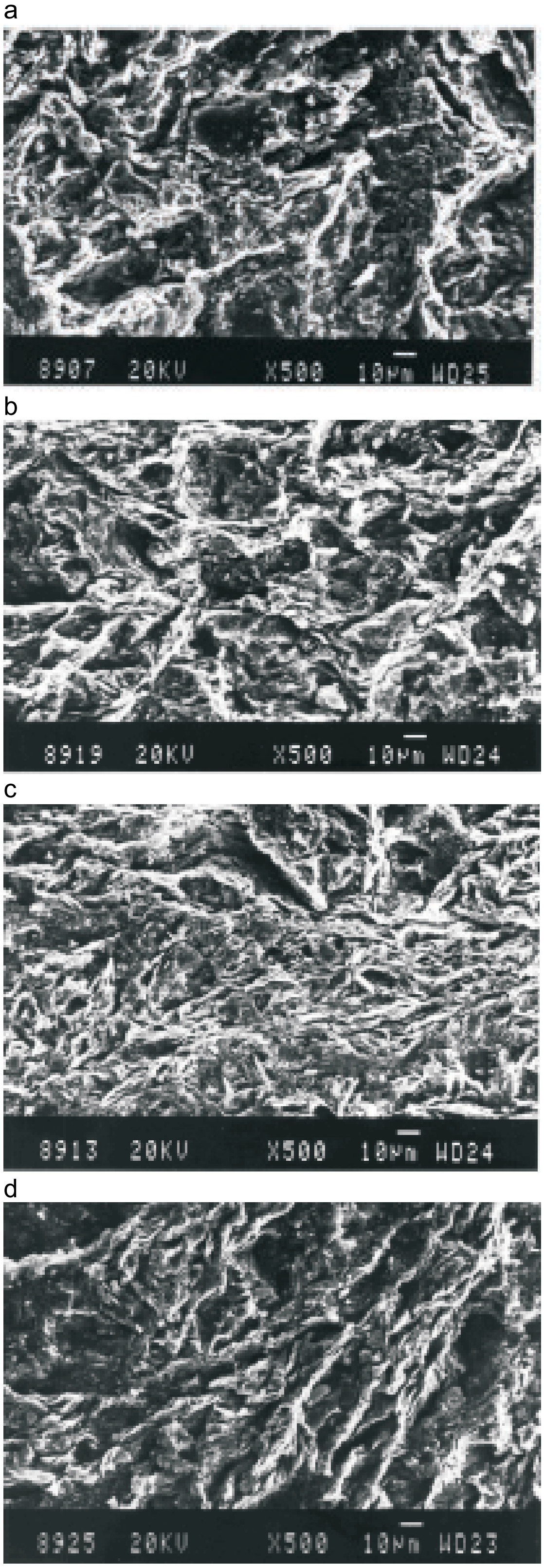

Fig. 4. Microstructures of Miocene clay, magnification × 500

a — with undisturbed structure; b — after examination of hydraulic conductivity; c — after examination of swelly pressure; d — after examination of swelly pressure and hydraulic conductivity

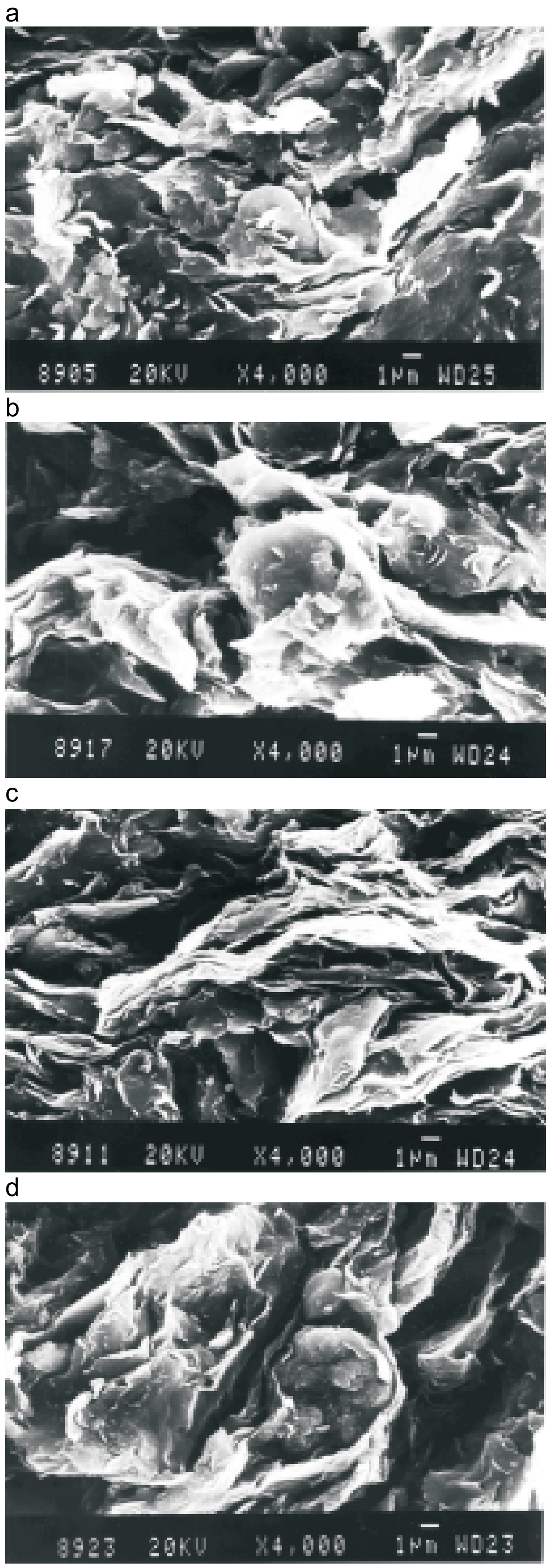

Fig. 5. Microstructures of Miocene clay, magnification × 4000

a — with undisturbed structure; b — after examination of hydraulic conductivity; c — after examination of swelly pressure; d — after examination of swelly pressure and hydraulic conductivity

The values of K_{fav} (average form index of pores) do not show conspicuous differences, although the values for the sample which had undergone swelly pressure testing are somewhat higher. An analysis of histograms of K_f (form index of pores), which describe the pore shape, shows significant differences (Fig. 2). They show that there is an increase in the number of pores (in relation to the NNS sample) between values of 0.3–0.4 K_f, and a decrease between the values of 0.5–0.6. This means that the number of pores which are anisometric in shape rises because the value of the index K_f tends to approach whole units for more isometric pores, and tends to approach zero for anisometric pores.

Similar patterns were observed in samples that were subjected to tests for hydraulic conductivity and swelly pressure (Fig. 2b, c). In the first case the number of pores (histogram b) increases in the intervals 0.4–0.5 and 0.6–0.9, but decreases between 0.3–0.4 and 0.5–0.6. This may indicate that testing for swelly pressure causes, pores to become anisometric.

One of the most important geometrical parameters of the nature of the pore space is pore orientation. The orientation of pores in undisturbed samples of clay (NNS), and following testing is shown on the pore orientation rose diagrams (Fig. 3). This shows that the hydraulic conductivity has a significantly weaker influence on reorientation of pores than the swelly pressure.

The pore orientation rose diagram enables to calculation of a geometrical index, namely the degree of anisotropy of microstructure (K_a). The formula for this parameter is:

$$K_a = \left(1 - \frac{S_1 + S_1^{'}}{S_2 + S_2^{'}}\right) \times 100$$

where: K_a — degree of anisotropy of microstructure; S_1, S_1', S_2, S_2' — pore orientation in a rose segment.

Considering these values the following classification of types of soils has been proposed (Sokolov, 1990):

— soils with poorly oriented microstructure: K_a = 0–7%;
— soils with medium microstructure orientation: K_a = 7–22%;
— soils with highly oriented microstructure: K_a > 22%.

According to this classification, the clay under consideration may be classified as possessing a highly oriented microstructure since the K_a index for the undisturbed samples (NNS) is 26%, while it is 31% for the samples that had been subjected to the swelly pressure test (Figs. 4 and 5).

SEM analysis showed that the original matrix microstructures (Fig. 4a, b), do not have a distinctly different orientation (Grabowska-Olszewska *et al*., 1984). The intermicroaggregate micropores are regularly distributed and have irregular shapes and sizes, from 2–20µm. This matrix microstructure also dominates the samples that were subjected to the test for hydraulic conductivity. However, the microstructure was slightly rearranged when it was subjected to saturation since micropores of parallel arrangement appeared (Figs. 4b and 5b). Those structural changes, recognised as osmotic swelling, are related to double layer repulsion (Grabowska-Olszewska, 2001).

The samples which had been subjected to swelly pressure changed their matrix microstructure into a matrix-turbulent one (Figs. 4c, d and 5c, d), with elongated micropores, whose crosswise measurements ranged from 0.5–3 µm. However, these changes in microstructure, which resulted from the saturation with water of the samples subjected to the swelly pressure test, decreased the size of pores so substantially that the migration of water was made practically impossible.

PRELIMINARY CONCLUSIONS

These studies showed that the swelly pressure examination resulted in:

— reduction in clay porosity and in average pore diameter,
— pore reorientation towards more anisometric pores,
— decreases in average pore area,
— decreases in average pore perimeter.

As regards microstructure anisotropy, the clay samples under examination can be classified as soils with highly oriented microstructure.

In clay samples with undisturbed structure (NNS) and in samples examined for hydraulic conductivity, matrix microstructures have been found, and in clays examined for swelly pressure, matrix-turbulent microstructures.

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REFERENCES

ASTM D 4546-90 — Standard test methods for one-dimensional swell or settlement potential of cohesive soils.

DYJOR S. (1970) — Seria poznańska w Polsce Zachodniej. Kwart. Geol., **14** (4): 819–835.

GRABOWSKA-OLSZEWSKA B. (2001) — An influence of swelling on microstructural changes of bentonites stadium with ESEM (in Polish with English summary). Prz. Geol., **49** (4): 299–302.

GRABOWSKA-OLSZEWSKA B., OSIPOV W. and SOKOLOV V. (1984) — Atlas of the microstructure of clay soils: 10–220. PWN. Warszawa.

KACZYŃSKI R. and TRZCIŃSKI J., 1997 — Ilościowa analiza miktostrukturalna w skaningowym mikroskopie elektronowym (SEM) typowych gruntów Polski. Prz. Geol., **45** (7): 721–726.

PIWOCKI M. and ZIEMBIŃSKA-TWORZYDŁO M. (1995) — Lithostratigraphy and spore-pollen zones in the Neogene of Polish Lowland (in Polish with English summary). Prz. Geol., **43** (11): 916–926.

ROWE K. R., QUIGLEY R. M. and BROKER J. R. (1998) — Clayey barrier systems for waste disposal facilities: 108–119. F and FN Spon. London.

SOKOLOV W. N. (1990) — Engineering-geological classification of clay microstructures. Proc. 6th, International IAEG Congress, **1**: 753–760.

WICHROWSKI Z. (1981) — Mineralogical studies of clays of the Poznań series (in Polish with English summary). Arch. Mineral., **37** (2): 93–196.