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Expansiveness of selected basaltoid weathering products in Lower Silesia, Poland

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Abstract The weathering products of Tertiary basaltic rocks in Lower Silesia comprise clays that contain various amounts of smectite-group minerals, illite, kaolinite, quartz and coarser fragments of non-weathered rock. Deposits of weathering products whose volume is of economic importance occur in Krzeniów near Złotoryja, Męcinka near Jawor and Dunino near Krotoszyce. The expansiveness of these weathering products is evaluated using laboratory analyses of swelling and shrinkage and the empirical nomograms of van der Merwe and Seed. The measured results of swelling of products dominated by smectite-group minerals, and of halloysite weathering products, indicate that the swelling depends on mineral composition. The smectite clays (Krzeniów and Jawor-Męcinka) display swelling strain ε_p in the range 20.3–31.8% whereas, for the halloysite products (Dunino), the range is 10.0–18.3%. The lowest linear shrinkage characterised the samples from Jawor-Męcinka and the highest, the weathering products with 79–81% clay fraction from Dunino. Most of the basaltic weathering products fall in the van der Merwe nomogram fields of low and medium potential expansiveness. High and very high potential expansiveness is shown by the Dunino weathering products. On the Seed nomogram, the weathering products plot within the field of low expansiveness except for some high and very high expansiveness values from the uppermost halloysite horizons at Dunino.

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INTRODUCTION

In Lower Silesia, basaltoid weathering products related to Tertiary volcanic activity are represented by clays containing varying amounts of smectite-group minerals, illite, kaolinite, quartz and coarser fragments of non-weathered rock. Deposits of economic importance occur in Krzeniów near Złotoryja, Męcinka near Jawor and Dunino near Krotoszyce.

Clay minerals are hydrous aluminosilicates composed of tetrahedral and octahedral sheets bonded into layers. Various structural types are distinguished depending on the arrangement of sheets in separate layers. In kaolinites, characterised by layers comprising one tetrahedral and one octahedral sheet (1:1), strong hydrogen bonds between the individual layers explain their very low affinity to water and their low sorption and swelling capacities. In smectite group minerals, e.g., montmorillonite, beidellite and nontronite, with a structure comprising an octahedral sheet sited between two tetrahedral sheets (2:1), weak inter-layer bonding explains their high water affinity, high sorption and considerable swelling capacity. This type of 2:1 structure also characterises illites – mica-group clay minerals that contain more potassic ions and less water than mica. A strong net negative charge due to substitution within tetrahedral sheets is compensated by potassium ions forming strong ionic bonds between 2:1 layers. Thus, illites are relatively stable with properties between those of kaolinites and smectites.

An important quality, specific to clay minerals, is their moisture sensitivity. Most significantly, rocks rich in clay minerals become plastic with addition of water – they deform without cracking and retain deformed shapes afterwards. On interaction with water; clay minerals increase in volume with moisture gain, and shrink with loss.

Even in small concentrations, clay minerals influence volume changes in rocks – a matter of primary importance in practice as rocks, especially Cainozoic sediments, often serve as building foundations and as material for earth constructions. Rock volume changes in foundations can pose severe geotechnical problems. Processes that may be modelled on a laboratory scale, i.e., swelling or shrinking, are evaluated in terms of free swelling, swelling pressure, swelling moisture, shrinkage limit and linear shrinkage. Field-scale, water induced volume changes are evaluated in terms of the expansiveness of compacted soils. Expansiveness is estimated on the basis of nomograms and factors such as clay-mineral composition, percentage of clay fraction, consistence limits, colloidal activity, swelling potential and linear shrinkage (Chen, 1988).

SMECTITE AND HALLOYSITE WEATHERING PRODUCTS OF BASALTOIDS

Three stages of intensive Upper Oligocene–Pliocene volcanism related to the final tectonic movements of the Alpine orogeny have been distinguished in the Sudetes and in the Fore-Sudetic Block in SW Poland (Dyjor & Kościówko, 1986). Late Oligocene and early Miocene basaltoids and pyroclastics related to the Savian tectonic phase are widespread in Lower Silesia. Middle Miocene volcanic rocks, correlated with strong tectonic movements of the Styrian phase, crop out primarily between Legnica, Chojnów, Jawor and Świerzawa. The youngest Late Miocene– Pliocene basaltoids, occurring between Legnica, Jawor and Złotoryja, relate to the Attican and Wallachian phases.

Basaltoid lava flows, and considerable quantities of associated pyroclastics, were subjected to weathering in the warm and humid Neogene climate. The weathering was driven by volcanic and hypergene processes. Appropriate climatic conditions were crucial to the formation of thick weathering profiles. The Palaeogene and Early Miocene climate especially favoured hypergene weathering. Decomposition of the volcanic material commenced with extrusion and has continued to the present. In general, due to their greater porosity and abundance of volcanic glass, pyroclastic rocks suffered the most intensive alteration giving rise to predominantly smectite-type products (Kaczmarek, 1997). The colder Middle- and Late Miocene climate also facilitated chemical weathering that led to the development of thick weathering covers on both acid and basic rocks. Later, in a less favourable climate, alteration was of local character affecting only thin near-surface zones (Dyjor & Kościówko, 1986). Smectite, smectite-kaolinite and kaolinite weathering products may be distinguished among the basaltoids weathering products (Kościówko & Morawski, 1986).

Fig. 1. Location of sampling points.

The strongly-weathered pyroclastics are argillaceous rocks with trace amounts of coarser material. Tuffs, lapilli tuffs, tuffites and breccias may be recognised as protolithic materials. Typically the alteration products contain smectite group minerals (Stoch *et al.*, 1977). Quartz, kaolinite and illite occur in negligible amounts only in the uppermost parts of the weathering profile. Basaltoid weathering products, more uniform than those of the pyroclastics, commonly preserve macroscopic traces of primary texture and structure; they are typically composed of kaolinite, kaolinite-smectite or, in rare instances, smectite exclusively.

Near Legnica and Złotoryja, these weathering products are mined as a by-product in the Krzeniów and Jawor-Męcinka deposits and as a main product in the Dunino deposit (Fig. 1). It is from these deposits that the material described in this paper was selected.

The Krzeniów deposit is located 7 km south of Złotoryja where Tertiary volcanic breccias, tuffs and tuffites overlie Triassic sandstones. The weathering cover is bounded by steep structural elements to the west, north and, in part, to the east which serve to define a tectonic trough that developed contemporaneously with the volcanic activity and was successively filled with ashes and tuffs. The trough has an elongated trapezoid shape widest to the north and thinning southward (Teisseyre, 1964). The weathering cover is thickest along the axis of greatest subsidence. Later tectonism resulted in fracturing of massive basalts that, in turn, facilitated weathering. Smectite weathering products of original tuffs outcrop in a depression at the margin of the deposit where lava flows do not occur. The basalts and vent breccias were altered to kaolinite and kaolinite-smectite clays.

Three types of weathering products can be distinguished:

1. Smectite weathering products derived from volcanic ashes with variable amount of lappilli and basaltic bombs. Kaolinite is $<10\%$. They are usually brown or grey with a weak stratification marked by grain-size differences. Blocks and bombs form apparent layers. The blocks range in size from 10–20 cm, occasionally to 1 m. The dried clay is of paler colour with white and brown-yellow patches of weathered primary minerals. This material was sampled for expansiveness investigation.
2. Alteration products of tuffs mixed with Triassic material are beige-pink and consist of ash with discrete basaltic blocks and numerous sandstone and mudstone blocks. This type contains ca 50% smectite, 25% kaolinite, negligible quartz and other minerals.
3. Weathering products of massive and fractured basalt are a light grey rock preserving some of the structural

and textural features of basalt. The rock consists of kaolinite and illite or, in some cases, smectite only.

The Jawor-Męcinka deposit lies by the Jawor-Złotoryja road ca 6 kilometres west of Jawor (Fig. 1). It is situated ca 4 km from the Sudetic Marginal Fault on the downthrown side in the Fore-Sudetic Block. The area was a tectonic depression when intense Late Miocene and Pliocene volcanic activity occurred (Dyjor & Kościówko, 1986). Tuffs and tuffites near Męcinka reach a thickness of 40 m. They crop out in the Nysa Szalona valley and in a basalt quarry. As it is mostly pyroclastic rocks that are weathered, the products are smectite-rich. The samples taken for laboratory tests were compact grey clays or sandy clays, some with grains of weathered olivine.

The Dunino deposit lies on the east side of the Nysa Szalona valley, by the Dunino-Święciany road in the Krotoszyce commune (Fig. 1). It comprises weathering products of Late Miocene and Pliocene basalts. Blocky lava, with brecciation that facilitated deep weathering, was the probable protolith for the halloysite-rich material (Dyjor & Kościówko, 1986). The 10–20 m thick deposit crops out over an 800–900 m interval. The weathering cover is composed of halloysite and kaolinite products (Sikora, 1986). The samples selected from Dunino show great variation in their degree of weathering. In the lower part of the outcrop, the original basalt structure is discernable. In the uppermost parts, the more intensely altered rocks contain a high clay fraction.

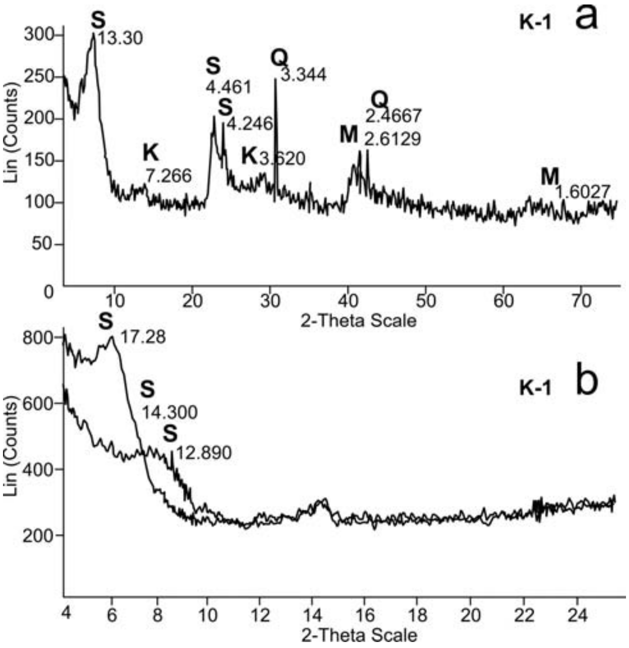

Fig. 2. Diffraction pattern of sample K-1. a – total sample in its natural state; b – clay fraction $< 2\ \mu$m both in natural state and after glycol treatment.

METHODS

Mineral compositions were determined by X-ray diffraction (D-5005 SIEMENS diffractometer with CoK_α radiation; room temperature; 2θ range – 4–75°; steps – 0.04°; counting time – 2 s/step). The analyses were performed on whole-rock samples and on clay fractions – both in their natural state and after glycolysation to enable unequivocal identification of smectites.

Granulometric analyses involved the pipette method (Myślińska, 2002) though, instead of boiling, the suspension was stirred with a magnetic mixer for >60 minutes at room temperature (19–21°C). Sodium pyrophosphate was used as a stabilizer. 3–5 preparations were measured for each sample.

Swelling and swelling pressure was measured in an edometer for samples with no remaining primary structure and compressed to their natural volumetric density. A 1:1 mixture of distilled and drinking water was used. The value of ε_p was calculated following the formula of Madsen and Müller-Vonmoos (1989):

$$\varepsilon_s = \Delta h / h_o \text{ x } 100$$

where ε_s – swelling strain, Δh – height increment and h_o – initial height of sample. In the Polish literature, swelling strain is referred to as ε_p (Drągowski, 1981; Kaczyński, 1992).

Swelling pressure (P_c) was determined for samples compressed to their natural volumetric density according to the standards of Polish Norm PN-88/B-04481. Shrinkage was estimated using the method for soil pastes at the liquid limit given by Head (1992).

Consistency limits W_L and W_p, determined following the standards of Polish Norm PN-88/B-04481, were used to calculate the plasticity index (I_p). The results were used to evaluate the expansiveness of the basaltoid weathering products using the nomograms of Seed (Seed *et al.*, 1962) and of Van der Merwe (Van der Merwe, 1964).

MINERAL AND GRANULOMETRIC COMPOSITION

The weathering covers at Krzeniów and Jawor- Męcinka are altered tuffs containing mainly high-charge Fe-smectites with a dioctahedral structure and a low cation-exchange capacity. The main phase is montmorillonite with a high layer tetrahedral charge and containing mostly Ca and Mg as interlayer cations (Dyjor *et al.*, 1991).

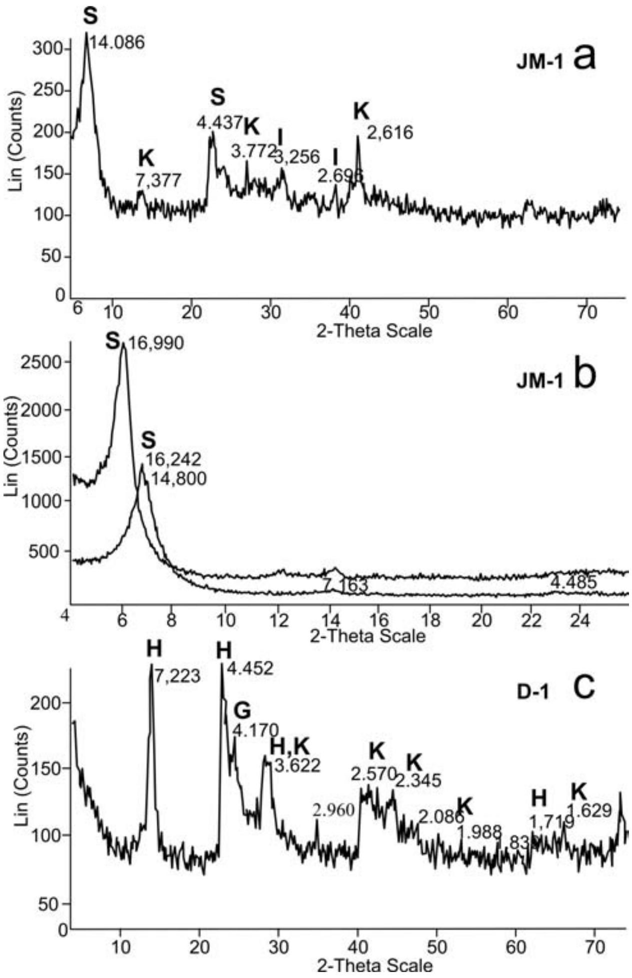

Fig. 3. Diffraction patterns of samples JM-1 and D-1. a – total sample (JM-1) in its natural state; b – JM-1 clay fraction $<2\ \mu$m both in natural state and after glycol treatment; c – total D-1sample in its natural state.

Table 1

Grain-size distribution of basaltoid weathering products

No.	Sample	Fraction			
		$>2000\ \mu$m %	2000-50 μm %	50-2 μm %	$<2\ \mu$m %
1	K1	-	43.0	35.0	22.0
2	K2	-	33.0	41.0	26.0
3	K3	-	40.0	41.0	23.0
4	K4	1.0	42.0	42.0	15.0
5	K5	-	44.0	39.0	17.0
6	K6	2.0	39.0	43.0	16.0
7	K7	-	38.0	48.0	14.0
8	K8	2.0	41.0	45.0	12.0
9	K9	2.0	47.0	38.0	13.0
10	JM1	1.0	47.0	38.0	17.0
11	JM2	1.0	46.0	38.0	15.0
12	JM3	2.0	54.0	32.0	12.0
13	JM4	3.0	50.0	35.0	12.0
14	JM5	3.0	46.0	37.0	14.0
15	D1	-	40.0	40.0	20.0
16	D2	-	29.0	48.0	23.0
17	D3	-	46.0	34.0	20.0
18	D4	-	39.0	41.0	20.0
19	D5	-	27.0	39.0	34.0
20	D6	-	24.0	46.0	30.0
21	D7	-	36.0	35.0	29.0
22	D8	-	31.0	37.0	32.0
23	D9	-	8.0	11.0	81.0
24	D10	-	7.0	14.0	79.0
25	D11	-	6.0	18.0	76.0

Halloysite is the main constituent within the documented part of the Dunino deposit. Ordered kaolinite predominates in the northern part. Halloysite with kaolinite constitute ca 65% of minerals in the weathering products. Fe oxides are present as magnetite, hematite and noncrystalline hydroxides (Sikora, 1986).

The clays from Krzeniów contain quartz, smectites, kaolinite, magnetite and goethite (Fig. 2). The weathering products from Jawor-Męcinka consist mainly of smectites with minor kaolinite (Fig. 3). The lack of kaolinite in the fraction $<2\ \mu$m suggests that it is concentrated in larger aggregates in the Krzeniów material. Smectites dominate in the clay fraction from the two deposits. The mineral composition of the weathering products at Dunino is dominated by halloysite with minor kaolinite and goethite (Fig. 3).

Investigation of the granulometric composition of the weathering clays shows that the clay fraction is $<20\%$ in most of the samples of halloysite weathering products. Only in one type of soil from Krzeniów does the clay fraction reach 24% (Tab. 1). The content of silt and sand ranges from 30–54%. Strong aggregation of the material is indicated. This is typical of basaltoid weathering products in Lower Silesia. The aggregates are strongly bonded and do not soften in water. Neither do they disintegrate under the influence of stabiliser or on stirring. Their formation is related to the presence of non-crystalline aluminosili- cates or non-crystalline iron-bearing compounds. Resistant aggregates also were observed in the Leśna-Miłoszów region (Kaczmarek, 1997).

The halloysite weathering products from Dunino display the widest range (20–78%) of clay fraction volume of all the soils investigated. The highest clay fraction values characterise the uppermost levels of weathering material showing little trace of original basalt structure.

EVALUATION OF EXPANSIVENESS BASED ON LABORATORY SWELLING AND SHRINKAGE TESTS

Swelling and shrinkage result from the interaction between clay minerals and water. Swelling, the consequent increase of soil volume, is a two-stage process involving crystalline swelling followed by osmotic swelling.

Crystalline swelling is induced by the gradual hydration of interlayer cations in clay minerals due to adsorption of consecutive molecular layers of water. Consequently interlayer spacing increases. As shown by Kraehenbuehl *et al.* (1987), crystalline swelling of dry sodium montmorillonite results in an increase of interlayer spacing by >2.5 nm and sodium cations surrounded by four molecular layers of water. Initially the swelling pressure reaches ca 400 MPa before falling back to ca 30 MPa at the end of the process.

Osmotic swelling is driven by a difference in ionic concentration between pore and interlayer water. This type of swelling leads to a further increase in interlayer distances – an effect of electric double-layer repulsion. Ultimately, a complete separation of elementary clusters of mineral layers may occur (Grabowska-Olszewska, 1998). Osmotic swelling pressure never exceeds 2 MPa.

Soil shrinking, a volume decrease due to loss of water, is a process that counteracts swelling. It is a complex physical-chemical process leading to changes in structural bonding between crystal units. As a result, soil becomes denser, less compressible and displays higher resistance to strain. However, shrinking is always accompanied by the formation of fractures and microcracks. This induces changes in many physical parameters, e.g., permeability.

The magnitude of the deformation processes driven by mineral-water interaction depends on many factors. The most important are: mineral and granulometric composition, exchangeable cation compositions, initial moisture content, amounts of organic substances and carbonates, compaction and microstructure, chemical composition of hydrating fluids, hypergenic conditions and flora types.

The analyses of swelling of the Silesian basaltoid weathering products composed mainly of smectites and of the halloysite clays establish that the intensity of the process depends on mineral composition. The weathering products from Krzeniów and Jawor-Męcinka show markedly higher ε_p values than the clays from Dunino (Tab. 2). The smectite weathering clays display ε_p values in the range 20.3–31.8%. Among weathering products of similar mineral composition, no simple correlation between the degree of swelling strain and clay fraction was detected. Nonetheless, the highest ε_p value (31.8%) was recorded from material with the highest percentage of clay (24%).

The low initial moisture contents of the Jawor-Męcinka samples should be noted. During the initial stages of their hydration, crystalline swelling occurred at a moisture content of 4.0–6.0% which, for pure sodium montmorillonite, corresponds to adsorption of the first water layer surrounding the exchangeable cations (Kraehenbuehl *et al.*, 1987). Though the Jawor-Męcinka montmorillonite is not pure montmorillonite, and contains Ca^{2+} in exchangeable sites, the swelling probably commenced with crystalline swelling. Only after hydration of the cations sited between the clay mineral layers did osmotic swelling begin. The initial moisture contents of the Krzeniów samples suggest osmotic swelling only.

The Dunino weathering products do not show a simple correlation between swelling and clay content either. In the upper parts of the deposit (clay fraction – 78%), swelling strain reaches a maximum ε_p value of 18.3% while, for other samples (clay fraction – 20–28%), it ranges from 10.0–14.5%. Initial moisture contents (12–15%) may suggest that only osmotic swelling was involved, especially as halloysite is the dominant mineral.

Table 2

Swelling strain (ε_p), swelling pressure (P_c), initial moisture content (W_i) and linear shrinkage (L_s) of the basaltoid weathering products

No.	Sample	< 2μm %	ρ Mg/m^3	W_i %	ε_p %	P_c kPa	L_s %
1	K1	22.0	1.37	19.0	30.5	75.0	7.5
2	K2	26.0	1.40	20.0	34.0	75.0	10.5
3	K3	23.0	1.40	21.0	29.5	75.0	12.0
4	K4	15.0	1.32	22.0	26.0	75.0	11.0
5	K5	17.0	1.35	24.0	27.0	62.5	12.0
6	K6	16.0	1.34	23.0	26.0	50.0	9.0
7	K7	14.0	1.46	25.0	25.5	37.5	10.0
8	K8	12.0	1.44	24.0	22.0	50.0	8.0
9	K9	13.0	1.45	23.0	23.5	65.5	10.5
10	JM1	17.0	1.12	4.0	25.0	37.5	6.0
11	JM2	15.0	1.11	5.0	29.5	50.0	8.0
12	JM3	12.0	1.10	6.0	20.5	50.0	6.0
13	JM4	12.0	1.09	4.0	18.0	50.0	5.0
14	JM5	14.0	1.11	5.0	28.5	37.5	6.0
15	D1	20.0	1.43	10.0	12.5	75.0	10.0
16	D2	23.0	1.45	12.5	14.0	62.5	12.0
17	D3	20.0	1.44	14.0	12.0	75.0	12.0
18	D4	20.0	1.44	16.0	10.5	75.0	14.0
19	D5	34.0	1.52	13.0	12.5	62.5	12.0
20	D6	30.0	1.54	16.0	10.0	75.0	10.0
21	D7	29.0	1.55	14.0	15.0	75.0	13.5
22	D8	32.0	1.56	15.0	14.0	75.0	13.0
23	D9	81.0	1.48	15.0	19.5	62.5	14.5
24	D10	79.0	1.40	13.0	16.0	75.0	15.0
25	D11	76.0	1.46	11.0	18.5	75.0	12.0

Table 3

Atterberg's limits analyses
liquid limit – W_L; plastic limit – W_P; plasticity index – I_P;
colloidal activity according to Skempton (1953) – A;
modified colloidal activity – A'

No	Sample	<2μm %	WL %	Wp %	Ip %	A	A'
1	K1	22.0	55.0	22.0	33.0	1.50	1.94
2	K2	26.0	58.0	26.0	32.0	1.23	1.52
3	K3	23.0	60.0	25.0	35.0	1.52	1.94
4	K4	15.0	49.0	24.0	25.0	1.66	2.50
5	K5	17.0	50.0	26.0	24.0	1.41	2.00
6	K6	16.0	48.0	21.0	27.0	1.68	2.45
7	K7	14.0	46.0	23.0	23.0	1.64	2.55
8	K8	12.0	48.0	25.0	23.0	1.92	3.28
9	K9	13.0	51.0	26.0	25.0	1.92	3.12
10	JM1	17.0	50.0	25.0	25.0	1.47	2.08
11	JM2	15.0	48.0	27.0	21.0	1.40	2.10
12	JM3	12.0	41.0	21.0	20.0	1.66	2.85
13	JM4	12.0	45.0	22.0	23.0	1.91	3.28
14	JM5	14.0	52.0	27.0	25.0	1.78	2.78
15	D1	20.0	53.0	32.0	21.0	1.05	1.40
16	D2	23.0	64.0	37.0	27.0	1.17	1.50
17	D3	20.0	55.0	30.0	25.0	1.25	1.67
18	D4	20.0	61.0	32.0	29.0	1.45	1.93
19	D5	34.0	71.0	36.0	35.0	1.03	1.21
20	D6	30.0	58.0	27.0	31.0	1.03	1.24
21	D7	29.0	65.0	30.0	35.0	1.21	1.46
22	D8	32.0	68.0	32.0	36.0	1.12	1.33
23	D9	81.0	84.0	31.0	53.0	0.65	0.70
24	D10	79.0	71.0	21.0	50.0	0.63	0.67
25	D11	76.0	78.0	27.0	51.0	0.67	0.72

Since all the weathering clays contain mainly calcium ions in exchangeable sites, are devoid of organic substances and were hydrated with water of similar chemical composition, it may be concluded that the amounts of swelling depend on mineral composition more than on granulometric composition.

Swelling pressure of the weathering products is low and ranges from 50–75 kPa. The highest values (50 kPa) typify Jawor-Męcinka samples with the highest initial-moisture contents.

Linear shrinkage shows a dependence on the granulometric composition. The lowest L_s values characterise samples from Jawor-Męcinka (Tab. 2) with low clay contents. The greatest linear shrinkage was observed in the weathering clay from Dunino (clay fraction – 78%). This probably reflects the strong aggregation of the smectite clay.

EVALUATION OF EXPANSIVENESS BASED ON NOMOGRAMS

The expansiveness of clay units consisting of rock and soil may be evaluated by using empirical nomograms based on simple relations between selected soil properties. Van der Merwe and Seed charts are examples of such nomograms. Both are based on analyses of consistency limits and clay fractions in soil.

The Van der Merwe nomogram (Van der Merwe, 1964) enables evaluation of potential expansiveness based on the relationship between the whole-sample clay fraction and the plasticity index. The plasticity index is the difference between the liquid limit and the plastic limit and corresponds to the range of water content in which the soil exhibits plastic properties. The potential expansiveness of a soil depends on the clay fraction and on the moisture range within which the soil behaves in a plastic manner. The Van der Merwe nomogram allows the evaluation of potential expansiveness ranging from low to very high, and of colloidal activity.

The Seed nomogram (Seed *et al.*, 1962) based on the relation between clay fraction and colloidal activity, allows differentiation between low, medium, high and very high expansiveness. This nomogram places more emphasis on mineral composition than does that of van der Merwe. In using the Seed chart, the colloidal activity should be estimated according to the formula:

$$A' = I_p/f_i - 5$$

where: A' – modified colloidal activity, I_p – plasticity index and f_i – percentage of clay fraction. The colloidal-activity recalculation reflects a difference in the liquid limit as determined according to the British and American standards (Grabowska-Olszewska, 1998).

Colloidal activity strongly depends on soil mineral composition (Skempton, 1953). It increases with the plasticity index I_p. The plasticity index has a much higher value for soils dominated by smectite-group minerals than for kaolinite soils. The high hydrophility of smectites is the reason. For soils consisting of sodic montmorillonite, the plasticity index reaches extreme values of several hundred percent and the colloidal activity is very high. Colloidal activity <0.75 corresponds to low soil activity, 0.75–1.25 to medium or normal activity and >1.25 to high activity. The higher the colloidal activity of a soil the greater is its ability to absorb water. This is a reflection of smectite-group contents in the main.

The Van der Merwe chart places the potential expansiveness of most of the basaltoid weathering products in the fields of medium and high expansiveness (Fig. 4). All samples from Krzeniów and Jawor-Męcinka fall into these categories. High and very high potential expansiveness is indicated for some of the Dunino weathering products – a consequence of greater dispersion of these clays. Samples D9-D11 from the uppermost horizons of the exposure are characterised by particularly high clay fractions (76–81%); these show very high potential expansiveness. However they fall into the field of low colloidal activity (Fig. 4) due to their halloysite mineral composition.

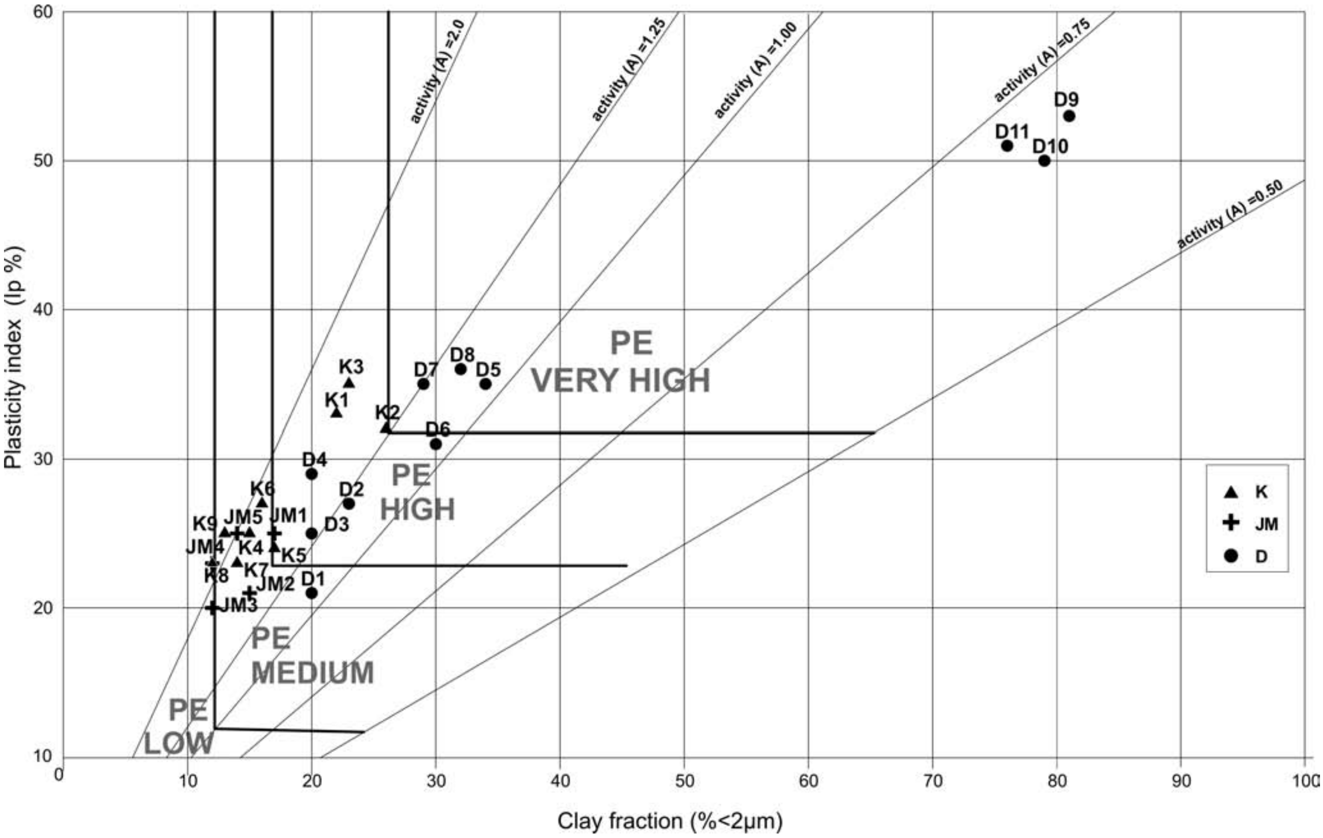

Fig. 4. Potential expansiveness (PE) of basaltoid weathering products, nomogram according to Van der Merwe (1964).

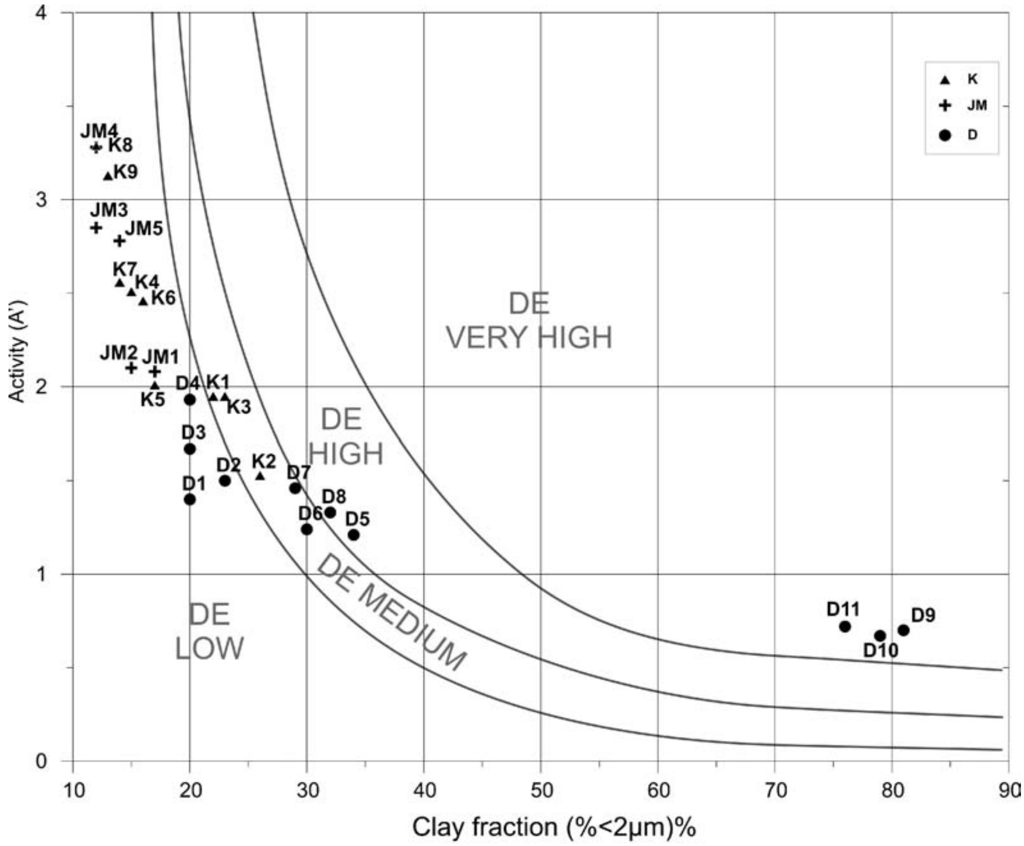

Fig. 5. Degree of expansion (DE) of basaltoid weathering products, nomogram according to Seed *et al.* (1952).

On the Seed nomogram, all samples from Jawor-Męcinka, and some from Krzeniów and Dunino, locate in the field of low potential expansiveness. Some Krzeniów and Dunino samples are characterised by medium expansiveness. High and very high expansiveness is again a feature of the uppermost horizons of the halloysite rocks at Dunino (Fig. 5).

SUMMARY AND CONCLUSIONS

Expansiveness is one aspect of deformation that occurs in soils due to changes in moisture conditions. Evaluation of possible results of the process is by no means unequivocal. In standard soil testing for geoengineering and geotechnical purposes, expansiveness is generally regarded as a negative influence. Building on expansive soils requires special treatment of the ground, in particular, security against moisture variations. In practice, dewatering of the ground, the installation of a drainage system and the construction of an isolating system around the building foundations, are all required. Commonly, in the case of roads, motorways and airport runways, expansive soils must be replaced. Erroneous soil assessment prior to a construction undertaking could have serious consequences.

The problem of expansive soils has been appreciated since the middle of the 20th century. Recurring conferences held in countries such as the USA, Israel and Spain where expansive soils can pose serious construction-industry problems, underscore their importance. Losses due to expansive soils can match those of floods and hurricanes (Chen, 1988).

In Poland, the problem of expansive soils is generally centred on areas where the Poznań clay formation occurs at shallow depths. Consequent building damage in Bydgoszcz has been documented (Fortunat, 1964; Kumor, 1992) and similar damage is known in the western and south-western parts of Wrocław where the Poznań clay formation also lies below at shallow depths. Some cases particularly emphasise the role of changes in soil moisture caused by environmental factors, e.g., varying annual rainfall and tree growth.

A different approach is adopted to evaluate the expansiveness of soil in the context of its use as a natural liner, particularly for landfills. In this case, the focus of interest is the increase in soil volume with moisture gain. The ability to swell is also key to sealing communal-waste dumps and radioactive-waste depositories. The use of highly compacted Na bentonites for lining containers with radioactive wastes, disposal and transportation tunnels is widely discussed (Pusch, 1994; Grabowska-Olszewska, 2000; Komine, 2004)

Apart from properties such as low hydraulic conductivity, adequate diffusion coefficients and sorption ability, the ability of Na bentonites to swell also plays an important role in their use as isolating material. No synthetic substance is able to fill fractures and microcracks as hermetically as swollen bentonite (e.g., Pusch, 1994). Details of the processes that occur during the swelling of smectites were presented by Laird (2006) and many have drawn recent attention to the swelling characteristics of bentonite-sand mixtures (Alonso *et al.*, 2005 and to the multifacetted role of water (Al-Homoud *et al.*, 1994).

In their comprehensive study on expansiveness of Polish soils, Grabowska-Olszewska & Kaczyński (1994), Grabowska-Olszewska (1998), Kaczyński & Grabowska-Olszewska (1997) generally focused on the Cainozoic sediments that form most of the building ground in Poland. Apart from sedimentary rocks, Grabowska-Olszewska (2001) provided a thorough assessment of the Carboniferous bentonites from Radzionków – a weathering product of volcanic ash. On van der Merwe and Seed nomograms, these rocks classify as having medium-high or high-very high potential expansiveness and medium, high and very high degrees of expansion (Kaczyński & Grabowska-Olszewska, 1997).

The basaltoid weathering products from Lower Silesia show the lowest swelling, shrinkage and expansiveness when compared with other rocks of this type in Poland. They also show the lowest clay fraction contents, liquid and plastic limits, and colloidal activities. However, the mineral compositions of the bentonites from Krzeniów and Radzionków are comparable. In both cases, the major constituent is calcic montmorillonite.

Swelling strain ε_p reaches the highest values for the bentonites from Krzeniów and Jawor-Męcinka. However, the Dunino halloysite weathering products show much lower ε_p values despite their higher clay fraction. The evaluation of expansiveness using the nomograms based on clay fraction content and consistency limits indicates higher potential expansiveness (Van der Merwe) and degrees of expansion (Seed) for these halloysite clays.

The main reason for these results appears to lie in the strong aggregation of the bentonite weathering products in Lower Silesia (see Dyjor, 1986; Kaczmarek, 1997). During laboratory swelling tests, water interacting with samples for as long as 3–5 days may penetrate the aggregates, infiltrate interlayer space and cause repulsion of electric double layers leading to the volume increase. Estimation of liquid limits using the Casagrande method involves water interacting with samples for too short a time (24 hours) to allow infiltration of the aggregates. Consequently, estimated liquid limits are low as is reflected in the plasticity index and colloidal activity. It seems clear that liquid limits in such soils should be estimated using a modified method involving a longer period of interaction with water.

Although the Van der Merwe and Seed nomograms may be used to evaluate the expansiveness of sedimentary rocks, they appear to yield estimates lower than the real volume changes in the case of the weathering products not entirely altered and dispersed.

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REFERENCES

AL-HOMOUND, A.S., BASMA, A.A., HUSEIN MALKAWI, A.I. & AL BASHABSHEH M.A., 1995. Cyclic swelling behaviour of clays. *Journal of Geotechnical Engineering*, 7: 562–565.

ALONSO, E.E., E., HOFFMANN, C. & GARCIA-ESCUDERO, E., 2005. Expansive bentonite-sand mixtures in cyclic controlled-suction drying and wetting. *Engineering Geology*, 81: 213–226.

CHEN, F.N., 1988. Foundations on expansive soils. Elsevier, Amsterdam: 281 p.

DRĄGOWSKI, A., 1981. Inżyniersko-geologiczna charakterystyka niszczenia skał mastrychckich Wyżyny Lubelskiej w wyniku pęcznienia i skurczu. Engineering-geological characterizaton of Maastrichtian rocks destruction in the Lublin Upland by swelling and shrinkage. *Biuletyn Geologiczny Uniwersytetu Warszawskiego*, 29: 5–104.

DYJOR, S. & KOŚCIÓWKO, H., 1986. Rozwój wulkanizmu i zwietrzelin bazaltowych Dolnego Śląska. Lower Silesian Volcanism and Development of Basalt Weathering Wastes. *Archiwum Mineralogiczne*, 61: 11–120.

DYJOR, S., KOŚCIÓWKO, H. & SIKORA, W., 1991. Zwietrzeliny bazaltowe Dolnego Śląska. Sytuacja geologiczna i charakterystyka mineralogiczna. In: Żabiński, W. (Ed.), *Sorbenty mineralne Polski*, pp. 65–80.{In Polish only}

FORTUNAT, W., 1960. Charakterystyczne cechy fizyczne trzeciorzędowych iłów Warszawy, Bydgoszczy i Tarnobrzegu. Characteristic physical properties of Tertiary Clays of Warsaw, Bydgoszcz and Tarnobrzeg. *Biuletyn Instytutu Geologicznego*, 163: 125–161.

GRABOWSKA-OLSZEWSKA, B. & KACZYŃSKI, R., 1994. Metody badania pęcznienia gruntów spoistych. Methods of cohesive soils research. *Gospodarka Surowcami Mineralnymi*, 10: 125–161.

GRABOWSKA-OLSZEWSKA B., 1998. Właściwości gruntów nienasyconych. Wydawnictwo Naukowe PWN Warszawa, 217 p. {in Polish only}

GRABOWSKA-OLSZEWSKA, B., 2000. Rola bentonitów w składowaniu odpadów radioaktywnych. Sesja Naukowa z okazji Jubileuszu 70-lecia prof. dr hab. inż. Zbigniewa Grabowskiego. Warszawa: 81–85. {In Polish only}

GRABOWSKA-OLSZEWSKA, B., 2001. Wpływ pęcznienia na zmiany mikrostrukturalne bentonitów badanych metodą ESEM. An influence of swelling on microstructural changes of bentonitem studied with ESEM. *Przegląd Geologiczny*, 49: 299–302.

HEAD, K.H., 1992. Manual of soil laboratory testing.vol.1. Soil classification and compaction tests. London, 417 p.

KARCZMAREK, B., 1997. Zwietrzeliny bazaltowe obszaru Leśna-Miłoszów (Dolny Śląsk) oraz próba ich wykorzystania. The study on basalt wastes from the Leśna-Miłoszów area (Lower Silesia) and on utilisation of them. *Gospodarka Surowcami Mineralnymi,* 13: 55–99.

KACZYŃSKI, R., 1992. Anisotropic swelling and shrinkage of Miocene Carpathian Foredeep clays. *Proceeding 7 International Conference on Expansive Soils*, Dallas, 2: 251–255.

KACZYŃSKI, R. & GRABOWSKA-OLSZEWSKA., B., 1997. Soil mechanics of the potenially expansive clays in Poland. *Applied Clay Scence*, 11: 337–355.

KOMINE, H., 2004. Simplified evaluation on hydraulic conductivities of sand-bentonite mixture backfill. *Applied Clay Science*, 26: 1–19.

KOŚCIÓWKO, H. & MORAWSKI, T., 1986. Charakterystyka litologiczna zwietrzelin skał bazaltowych Dolnego Śląska i możliwości ich wykorzystania. The lithological features of basaltic wastes of Lower Silesia and the possibilities of their utilisation. *Archiwum Mineralogiczne*, 61: 10–110.

KRAEHENBUEHL, F., STOECKI, H.F., BRUNNER, F.K., HAR G. & MÜLLER-VONMOOS, M., 1987. Study of the water-bentonite-system by vapour adsorption, immersion calorimetry and X-ray techniques. *Clay Minerals*, 22: 1–9.

KUMOR, M., 1992.Charakterystyczne parametry geotechniczne serii poznańskiej rejonu Bydgoszczy. Typical geotechnical parameters of the Poznań suite of the Bydgoszcz area. *Prace Geologczno-Mineralogiczne*, 26: 67–90.

LAIRD, D.A., 2006. Influence of layer charge on swelling of smectites. *Applied Clay Science*, 34: 74–87.

MADSEN, F.T.& MÜLLER-VONMOOS, M., 1989. The swelling behaviour of clays. *Applied Clay Science*, 4: 143–156.

MYŚLIŃSKA, E., 2002.Laboratoryjne badania gruntów. Wydawnictwo Naukowe PWN Warszawa, 278 p.

PUSCH, R., 1994. Waste disposal in rock. Elsevier, Amsterdam, 460 p.

SEED, H., WOODWARD, R. & LUNDGREN, R., 1962. Prediction of swelling potential for compacted clays. *Journal Soil Mechanics Foundation Division*, 3: 53–88.

SIKORA, W., 1986. Skład mineralny zwietrzeliny bazaltowej z Dunina. Mineral composition of basaltic weathering waste from Dunino near Legnica. *Archiwum Mineralogiczne*, 61: 43–56.

SKEMPTON, A., 1953. The Colloidal “Activity” of Clays. *Proceedings of Third International Conference on Soil Mechanics and Foundation Engineering*, Zurich, 1: 57–61.

STOCH, L., DYJOR, S., SIKORA, W. & KALMUS, M., 1977. Zwietrzeliny bazaltowe Dolnego Śląska. Weathering crusts of basaltic rocks of Lower Silesia. *Prace Mineralogiczne* 56: 7–64.

TEISSEYRE, H., 1964. Uwagi o ewolucji strukturalnej Sudetów. Some remarks on the structural evolution of the Sudetes. *Acta Geologica Polonica*, 4: 459–499.

VAN DER MERWE, D.H., 1964. The prediction of heave from the plasticity index and percentage clay fraction of soils. *Transactions South Africa Institute of Civil Engineers*, 6: 403–422.