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Shrink-swell potential of flood-plain soils in Nigeria in relation to moisture content and mineralogy

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Abstract. The shrink-swell hazard is an important soil factor that affects infrastructural development of the soil. The shrink-swell potential of some flood-plain soil profiles was determined using the coefficient of linear extensibility (COLE). Most Nigerian soils under investigation have slight to moderate shrink-swell potential. Clay content, plastic limit (PL), moisture contents, mineralogy and total forms of soil elements contribute significantly to the shrink-swell hazard. The principal component analysis reduced 28 soil factors relating to COLE to only 4 components, out of which the total forms of Fe_2O_3, Na_2O, moisture content at 0.1 MPa and liquid limit (LL) are properties which could be used to predict COLE. These are the component defining variables (CDV).

Keywords: coefficient of linear extensibility, mineralogy, principal component, flood-plain soils of Nigeria, moisture content

INTRODUCTION

Shrink-swell behaviour is that quality of the soil which determines its volume change with change in moisture content. Building foundations, roads and other engineering structures such as lined irrigation canals and embankments may be severely damaged by the shrinking and swelling of the soil (Olson, 1973). Simon *et al.* (1987) therefore observed that these shrink-swell related soil properties should be routinely estimated and determined prior to designing building foundations, septic tank subsurface absorption systems, roads, dams and other structures in contact with the soil.

A number of researchers (McCormack and Wilding 1975; Smith *et al.*, 1985; Simon *et al.*, 1987; Mbagwu 1992) have associated the soil volume changes associated with shrink-swell phenomena to changes in water content, mineralogy, type of cation present on the cation exchange complex (CEC), clay content, structure, aluminum and iron oxide concentrations, soil organic matter, over-burden pressure, density and interactions of these properties. Franzmeier and Ross (1968) reported that soils with predominantly kaolinitic, micaeous or vermiculitic mineralogy had low COLE values of less than 0.03. Soils in which montmorillonite was a major component had a wide range of COLE values, indicating that differences in clay content may be the primary factor controlling the degree of shrinkage. On the other hand, soils having equal amounts of kaolinite and montmorillonite behave like montmorillonitic soils. However, Thomas *et al.* (2000) showed that the shrink-swell potential in kaolinitic and mixed mineralogy soils and acid montmorillonitic soils is often more difficult to predict.

Although shrink-swell potential is recommended for inclusion in soil survey reports, this important parameter is absent in all existing survey reports for areas where very intensive agricultural operation is on-going. The objectives of this study are (i) to determine the coefficient of linear extensibility (COLE) and the shrink-swell severity of the soils (ii) to determine the influence of mineralogy and moisture content on the shrink-swell potential of soil.

MATERIALS AND METHODS

Field study

The soil samples used for this study were collected from pedogenetic horizons of five soil profiles located on an east-west chrono-sequence at different depositional stages of the River Niger in eastern Nigeria. The oldest deposition, furthest from the present riverbed, which also includes colluvial material from the upland, was identified as profile 1,

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followed by profile 2. The intermediate stages are represented by profiles 3 and profile 4 while profile 5 represented the most recent materials and are closest to the present riverbed. The intervals between the soil profiles were 2 km apart. The soil profiles sited in areas with no recent history of cultivation were described using the FAO (1977) guidelines. The soil samples collected were air-dried, sieved through a 2 mm mesh and analysed as described below.

Laboratory methods

Particle size distribution of less than 2 mm fine earth fractions was measured by the hydrometer method as described by Gee and Bauder (1986). Bulk density was determined by the clod method (Blake and Hartge, 1986). The coefficient of linear extensibility (COLE) being a measure of the shrink-swell behaviour of soil was calculated as follows (Schafer and Singer, 1976):

$$\mathrm{COLE} = (\mathrm{Lm} - \mathrm{Ld})/\mathrm{Ld}, \tag{1}$$

where: Lm – length of moist soil, Ld – length of dry soil.

Volumetric shrinkage (VS) was calculated from the COLE as:

$$\mathrm{VS} = [(\mathrm{COLE} + 1)^3 - 1]\ 100. \tag{2}$$

The moisture contents at different retention levels were determined by the Klute (1986) method while the total available water (TAW) was calculated as the difference between moisture retained at 0.1 and 1.5 MPa.

Atterberg limits were determined by the Cassagrande method described by Sowers (1965).

Soil pH was measured in 0.1 M KCl suspension using a soil: liquid ratio of 1:2.5 (i.e., 20 g air-dried soil to 50 ml 0.1 M KCl). Soil organic carbon (OC) was analysed by the Walkley and Black method (Nelson and Sommers 1982).

Cation exchange capacity (CEC) was determined by the method described by Rhoades (1982) and the percentage base saturation (BSAT):

$$\mathrm{BSAT} = [\mathrm{TEB}/\mathrm{CEC}]\ 100, \tag{3}$$

where TEB is total exchangeable bases.

Clay minerals were determined by X-ray diffractometry (XRD) with a SIEMENS D500 diffractometer, using Ni-filtered CuKα-radiation. Oriented clay samples were analysed after various pre-treatments while the semi-quantitative evaluation of the mineral fractions was determined using the 'DIFFRAC AT V3.3 SIEMENS 1993' computer package. The chemical composition of the fine-earth fractions was determined using SIEMENS SRS 200 X-ray fluorescence (XRF) equipment.

Principal component analysis (PCA) was performed on the data with the aid of the SPSS/PC Package. Eigen-values and factor loadings or coefficients of the components were obtained using SPSS procedures. The components selected were those that explained at least 100/P percent of the total variance, where P is the number of variables in each data set (Afifi and Clark, 1984). Factor loadings for each component were selected on the basis of having a value larger than the value calculated using the relationship:

$$\mathrm{SC} = 0.5/(\mathrm{PC\ Eigenvalue})^{0.5}, \tag{4}$$

where SC is selection criterion.

The correlation coefficient between the components and the soil properties was computed with the equation

$$\gamma_{ij} = a_{ij}\ (\mathrm{VAR\ PC})^{0.5}, \tag{5}$$

where: γ_{ij} – correlation coefficient, a_{ij} – factor loading and VAR PC – principal component Eigen-value.

Soils

The soils are mainly loamy fine sand to sandy clay loam and slightly acidic in reaction. They are poorly drained with most soils being waterlogged during the high peak of the rainy seasons in July to September. Often the soil profiles show orange to brown mottles below the topsoil with the main soil being gleyed. The soil puddles when wet but are dusty when dry.

The soils are low in CEC, organic carbon and available nutrients (Table 1). The soil mineralogy is mixed though kaolinite dominated the other clay minerals. The soils are mostly classified as fluvisols and gleysols.

RESULTS AND DISCUSSION

Coefficient of linear extensibility (COLE) and volumetric shrinkage (VS)

Table 2 presents the values for COLE within the soil profiles. The values of COLE generally ranged from 0.006 to 0.082. Schafer and Singer (1976) outlined the categories of COLE and their ratings of shrink-swell hazard as follows:

COLE	VS	Shrink-swell hazard rating
0.00–0.03	0–10	Slight
0.03–0.06	10–20	Moderate
0.06–0.09	20–30	Severe
>0.09	>30	Very severe

If the values of COLE in the soils studied are evaluated alongside the ratings above, it will be observed that the topsoil of profiles 1, 2 and 4 fall within the slight shrink-swell hazard category. However, soils of profiles 3 and 5 fall into the severe and moderate shrink-swell hazard category. The values of COLE in the topsoil are reflected on the subsoil of the profiles studied except for some few exceptions like in Bg2 of profile 2 (Table 2).

Table 1. Selected properties of the representative soil profiles

Horizon	Depth (cm)	Clay	Silt	Sand	OC (%)	pH H_2O	CEC (cmol(+) kg^{-1})	BSAT (%)
		(%)						
Profile 1 (Dystric Fluvisol)								
Ap	0–15	12	8	80	2.11	5.1	2.8	59
Bg1	15–30	20	6	74	0.76	4.9	3.5	41
Bg2	30–60	30	6	64	0.76	4.7	6.0	37
Bg3	60–93	22	4	74	0.32	5.1	6.9	26
BCg	93–130	20	4	76	0.32	4.9	3.9	38
Profile 2 (Dystric Gleysol)								
Ap	0–16	14	4	82	1.32	5.0	3.4	50
Bg1	16–37	18	6	76	1.08	5.2	5.7	30
Bg2	37–64	18	4	78	0.32	5.4	5.5	33
Bg3	64–108	16	4	80	0.24	5.5	5.4	36
Cg	108–175	6	2	92	0.12	6.0	2.5	68
Profile 3 (Dystric Gleysol)								
Ap	0–12	26	14	60	1.52	5.3	3.8	47
Bg1	12–27	34	10	56	0.68	5.5	3.0	54
Bg2	27–60	32	10	58	0.40	5.8	3.0	51
Bg3	60–80	34	12	54	0.28	5.8	4.1	39
Bg4	80–125	36	14	50	0.32	5.8	6.1	24
Profile 4 (Eutric Gleysol)								
Ap	0–20	18	20	62	1.52	5.6	6.2	82
Bg1	20–43	24	16	60	0.56	5.4	6.9	84
Bg2	43–79	24	16	60	0.32	5.6	8.0	50
Bg3	79–106	20	14	66	0.12	5.8	6.8	50
Bg4	106–160	24	10	66	0.20	6.1	6.7	52
Profile 5 (Eutric Fluvisol)								
Ap	0–23	12	18	70	1.12	5.7	6.1	80
AB	23–56	22	18	60	0.92	5.4	8.2	70
Bg1	56–84	22	20	58	0.12	5.6	7.8	86
Bg2	84–123	24	18	58	0.52	5.9	9.4	92
Bg3	123–170	16	16	68	0.28	6.0	6.7	88

OC - organic carbon.

Also the volumetric shrinkage (VS) reflects the absolute values of COLE. The VS values for all the soils of the five profiles are presented (Table 2). In line with the classification of Schafer and Singer (1976), the soils of profiles 1 and 2 have a slight shrink-swell shrinkage rating except soils of horizon Bg2 of profile 2. As in COLE, the VS of soils of profile 3 and 5 are mainly of the severe category while it is either moderate or slight in profile 4.

Atterberg limits and moisture contents

The Atterberg limits present the values of plastic limits (PL), liquid limits (LL) and the plasticity index (PI) for the soils (Table 2). Generally the values for the liquid limits are higher than those of the plastic limits. However, in the Cg horizon of profile 2, the Atterberg limit values were zero, indicating that at that depth there is no shrink-swell hazard anticipated.

Table 2. COLE, volumetric shrinkage (VS), bulk density (BD) and Atterberg limits for the representative soil profile

Depth (cm)	COLE	VS	BD (Mg m^{-3})	PL	LL	PI
					(%)	
			Profile 1			
0–15	0.018	5.50	1.53	2.2	6.4	4.2
15–30	0.031	9.59	1.11	2.0	2.7	0.7
30–60	0.021	6.43	1.40	2.5	8.7	6.2
60–93	0.027	8.32	1.62	3.1	37.5	34.4
93–130	0.027	8.32	1.31	2.0	7.6	5.6
			Profile 2			
0–16	0.020	6.12	1.54	3.9	33.3	29.4
16–37	0.020	6.12	1.34	4.2	37.1	32.9
37–64	0.063	20.11	1.68	4.5	20.5	16.0
64–108	0.006	1.81	1.38	4.5	19.0	14.5
108–175	0.011	3.34	1.87	0	0	0
			Profile 3			
0–12	0.070	22.50	1.70	1.0	12.0	11.0
12–27	0.071	22.85	1.54	11.9	22.0	10.1
27–60	0.076	24.58	1.38	1.1	25.0	23.9
60–80	0.055	17.42	1.50	2.3	14.6	12.3
80–125	0.067	21.48	1.81	35.1	43.9	8.8
			Profile 4			
0–20	0.017	5.19	1.33	1.0	13.9	12.9
20–43	0.050	15.76	1.66	9.9	28.2	18.3
43–79	0.047	14.77	1.38	4.2	36.6	32.4
79–106	0.027	8.32	1.79	1.0	47.7	46.7
106–160	0.021	6.43	1.63	9.2	11.0	1.8
			Profile 5			
0–23	0.031	9.51	1.78	8.0	22.0	14.0
23–56	0.068	21.82	1.85	26.6	44.2	17.6
56–84	0.082	26.67	1.84	9.9	54.1	44.2
84–123	0.082	26.67	1.78	15.1	22.0	6.9
123–170	0.027	8.32	1.85	2.3	6.4	4.1

COLE – coefficient of linear extensibility, PL – plastic limit, LL – liquid limit, PI – plasticity index.

Table 3 presents the volumetric moisture contents at 0.1, 1.0, 1.5 MPa and the total available water (TAW) for the soils. Apart from soil profile 5, the values of soil moisture contents seem to be higher on topsoil than the horizons below. The reason for this may be the combined retention capabilities of clay and organic materials on topsoil. However, as the clay content increases, the moisture content also begin to increase with the soil profile.

Relationship between COLE, Atterberg limits, moisture contents and soil properties

Table 4 presents the values of clay minerals and the total elements of those soil samples of less than 2 mm. Rampazzo *et al.* (1993a, 1993b) emphasized the relevance of mineralogical information for the assessment of soil structural status. The coefficient of linear extensibility (COLE) correlated positively with clay contents, plastic limit (PL), moisture

Table 3. Volumetric moisture contents (%) at different retention levels of representative soil profiles

Soil depth (cm)	0.1	1.0	1.5	TAW
	(MPa)			
		Profile 1		
0–15	41.4	26.5	19.7	21.7
15–30	29.6	17.9	14.0	15.6
30–60	33.0	29.5	22.1	10.9
60–93	45.0	31.8	23.5	21.5
93–130	34.8	22.1	16.5	18.3
		Profile 2		
0–16	57.0	39.6	29.7	27.3
16–37	42.1	28.0	20.9	21.2
37–64	45.4	28.9	21.5	23.9
64–108	38.1	24.4	18.2	19.9
108–175	29.7	14.6	10.5	19.2
		Profile 3		
0–12	64.6	45.2	33.8	30.8
12–27	54.5	37.4	28.0	26.5
27–60	47.6	32.7	24.4	23.2
60–80	50.1	33.9	25.4	24.7
80–125	67.5	47.0	35.1	32.4
		Profile 4		
0–20	39.7	25.9	19.3	20.4
20–43	38.5	23.2	17.3	21.2
43–79	35.4	21.9	16.3	19.1
79–106	39.7	23.4	17.3	22.4
106–160	35.1	20.6	15.2	19.9
		Profile 5		
0–23	49.3	31.7	23.7	25.6
23–56	54.1	35.2	26.3	27.8
56–84	52.6	34.2	25.6	27.0
84–123	47.5	30.1	22.4	25.1
123–170	51.5	33.3	24.8	26.7

TAW – total available water.

contents at 0.1, 1.0 1.5 MPa and total available water (TAW), MgO, Al_2O_3, CaO, TiO_2, MnO, Fe_2O_3, illite and smectite (Table 5). Also, the negative correlation coefficients were obtained between COLE and SiO_2, Si/Al ratio and interlayer-vermiculite. Several researchers (Mbagwu and Abeh, 1998; Thomas *et al.,* 2000) have shown the magnitude of the contribution of mineralogy and PL to shrink-swell hazards. Mbagwu and Abeh (1998) obtained strong linear relationships between COLE and PL, including clay content. As in this study, a weak relationship existed between COLE and PI. Therefore, it will be concluded that total clay content, PL, moisture content, elemental concentration and mineralogy, contribute significantly to the COLE and eventually the shrink-swell hazard of these soils. This finding is in support of the earlier assertion that Al and Fe oxides including water contents and mineralogy and also their interactions play very significant roles in shrink-swell phenomena (Anderson *et al.*, 1973; McCormack and Wilding, 1975; Smith *et al.*, 1985).

The PL has linear positive relationships with MgO, Al_2O_3, Fe_2O_3, smectite and bulk density while a negative relationship existed between PL, SiO_2, Si/Al ratio, interlayer-vermiculite and kaolinite (Table 5). Again it will be observed that the moisture retention characteristics depended on the clay contents and total elemental concentration such as MgO, Al_2O_3, SiO_2, TiO_2, MnO, Fe_2O_3 and Si/Al ratio (Table 5). The implication of this result is that moisture retention is greatly affected not only by the clay content but the total mineral and elemental reserve in the soil. Therefore, it is possible that clay content and total elemental reserve could be used to predict moisture retention characteristics of these soils, which in turn can be used to predict COLE and shrink-swell potential. Igwe *et al.* (1995)

Table 4. Summary of clay minerals and the total elements of the soils

Soil property	Minimum	Maximum	Mean	CV
	(%)			
Kaolinite	38.00	57.00	46.84	41
Smectite	4.00	29.00	15.40	426
Illite	2.00	7.00	4.60	37
Inter. Vermicul.	10.00	36.00	20.64	201
Ill/Smectite	6.00	19.00	12.44	121
Na_2O	0.08	0.89	0.47	12
MgO	0.30	1.12	0.78	7
Al_2O_3	6.13	19.57	14.10	84
Fe_2O_3	1.13	8.68	4.62	103
SiO_2	54.71	77.23	65.65	59
K_2O	1.02	3.16	2.38	20
CaO	0.09	0.85	0.44	12
TiO_2	0.49	1.73	1.26	11
MnO	0.01	0.33	0.076	9
ZrO_2	0.03	0.14	0.081	1
Si/Al	2.80	10.99	4.63	72

Inter. Vermicul. – interlayer vermiculite; Ill/smectite – illite/smectite interlayer; Si/Al – silica/alumina ratio.

used similar indices in predicting potential soil loss in some other soils within the same ecological zone.

Principal component analysis of shrink-swell soil factors

Principal component analysis was also used to reduce the 28 variables – which are thought to relate to shrink-swell potential – to 4 orthogonal components having Eigenvalues greater than unity. These four components together accounted for 80% of the total variance within the variables (Table 6).

Component 1 explained 33.2% of the total variance and has a significant loading greater ±0.90 on the total Fe_2O_3, Al_2O_3, SiO_2 and MgO. This first component confirms the earlier correlation coefficients on these elements. Component 2 explained 21.7% of the total variance and has a significant loading on Na_2O and K_2O. These are alkali elements suggest also that these elements contribute to the shrink-swell phenomena in the soil. Moisture contents at 0.1, 1.5, 1.0 MPa and TAW loaded significantly on component 3 explaining 16.1% of the total variance. The implication of this confirms the contribution of moisture content in the COLE shown earlier by correlation analysis. Finally the 4th component has high loading on LL and PI while explaining 9.1% of the total variance.

To obtain the relationship between the COLE or the shrink-swell potential and these components, the variables defining each component were extracted. These component-defining variables (CDV) are those variables that have the highest loading on each component. They have the highest regression weights. These variables are Fe_2O_3, Na_2O, moisture content at 0.1 MPa and LL (Table 6). These are properties associated with mineralogy, moisture content and the Atterberg limits. To some extent this confirms the results of the correlation coefficients of COLE and Fe_2O_3 (r=0.75). Again the results confirm the findings of Simon *et al.* (1987); Rampazzo *et al.* (1993a); Thomas *et al.* (2000). It also supports the claim of Thomas *et al.* (2000) that acid smectite and mixed mineralogy showed a weak correlation with COLE. Although Carstea *et al.* (1970) observed that Al and Fe in montmorillonite inhibit swelling, in this study, the total forms of Al and Fe were found to encourage swelling. This should not be taken in isolation of clay contents and the dominating effects of these elements in these soils.

CONCLUSIONS

1. Shrink-swell potential using the COLE index indicate that from the 5 investigated flood-plain soils of Nigeria, 3 of them fall under the slight shrink-swell category and 2 fall under the severe and moderate shrink-swell category.

2. The clay content plastic limits, moisture contents, total forms of elements and mineralogy such as illite, interlayer vermiculite and smectite correlated significantly with COLE. It is evident that total elements and clay content could be used to predict moisture content. This is significant because moisture content can be used as a good estimator of COLE.

Using principal component analysis, 28 variables relating to shrink-swell characteristics can be reduced to only 4 components. The component defining variables are Fe_2O_3, Na_2O, moisture content at 0.1 MPa and liquid limits. These are properties relating to mineralogy, moisture contents and the Atterberg limits. These factors influence the shrink-swell potential of these soils.

Table 5. Correlation coefficients of COLE, Atterberg limits, moisture contents with soil properties

Variables	COLE	PI	PL	LL	0.1 MPa	1.0 MPa	1.5 MPa	TAW
COLE	–	0.15	0.49*	0.35	0.40*	0.40*	0.39*	0.41*
CLAY	0.62*	0.03	0.40*	0.14	0.56*	0.56*	0.56*	0.55*
OC	–0.16	–0.17	–0.11	–0.27	0.37	0.36	0.36	0.39*
CEC	0.24	0.35	0.42*	0.48*	–0.23	–0.21	–0.22	–0.24
BSAT	0.18	–0.07	0.05	–0.002	–0.31	–0.32	–0.33	–0.26
PI	0.15	–	–0.07	0.81*	0.08	0.11	0.09	0.04
PL	0.49*	–0.07	–	0.47*	0.24	0.24	0.23	0.25
LL	0.35	0.81*	0.47*	–	0.07	0.10	0.09	0.05
0.1 MPa	0.40*	0.08	0.24	0.07	–	0.99*	0.99*	0.99*
1.0 MPa	0.40*	0.11	0.24	0.10	0.99*	–	0.99*	0.98*
1.5 MPa	0.39*	0.09	0.23	0.09	0.99*	0.99*	–	0.98*
TAW	0.41*	0.04	0.25	0.05	0.99*	0.98*	0.98*	–
Na_2O	0.03	0.19	0.14	0.24	–0.20	–0.22	–0.23	–0.16
MgO	0.77*	0.15	0.48*	0.31	0.40*	0.39*	0.38*	0.43*
Al_2O_3	0.74*	0.16	0.47*	0.29	0.52*	0.51*	0.50*	0.53*
SiO_2	–0.75*	–0.20	–0.46*	–0.34	–0.51*	–0.51*	–0.50*	–0.53*
K_2O	0.23	0.27	0.17	0.30	–0.01	–0.02	–0.04	0.05
CaO	0.38*	0.16	0.31	0.29	0.02	0.01	–0.01	0.06
TiO_2	0.69*	0.20	0.36	0.28	0.51*	0.49*	0.48*	0.55*
MnO	0.55*	0.12	0.09	0.11	0.43*	0.43*	0.42*	0.45*
Fe_2O_3	0.75*	0.14	0.41*	0.28	0.49*	0.48*	0.48*	0.51*
ZrO_2	–0.19	0.24	0.04	0.25	–0.32	–0.34	–0.35	–0.27
Si/Al	–0.61*	–0.30	–0.36	–0.30	–0.50*	–0.49*	–0.49*	–0.50*
ILL/SM	–0.05	–0.12	0.04	–0.05	–0.28	–0.29	-0.30	–0.24
ILLITE	0.43*	–0.06	0.18	0.06	–0.03	–0.04	-0.05	0.01
INTVE.	–0.43*	0.07	–0.43*	–0.20	0.28	0.29	0.30	0.25
KAOL.	-0.31	–0.19	–0.40*	–0.38*	–0.02	–0.01	0.01	–0.06
SMECT.	0.47*	0.07	0.51*	0.37	–0.08	–0.08	-0.09	–0.06
BD	0.31	0.08	0.41*	0.37	–0.18	–0.15	-0.17	–0.18

*significant $p<0.05$. BD – bulk density, SMECT. – smectite, KAOL. – kaolinite, INTVE. – inter-layered vermiculite, ILL/SM – illite/smectite, Si/Al – silica/alumina ratio, 0.1,1.0 and 1.5 MPa – moisture contents retained at 0.1, 1.0 and 1.5 MPa, PI – plasticity index, PL – plastic limits, LL – liquid limits, BSAT – percent base saturation, CEC – cation exchange capacity, OC – soil organic carbon.

T a b l e 6. Principal component analysis of shrink-swell soil factors after varimax rotation

Variables	Components			
	1	2	3	4
Fe_2O_3	0.968	0.082	0.126	0.032
SiO_2	–0.958	–0.088	–0.141	–0.159
Al_2O_3	0.931	0.092	0.152	0.170
MgO	0.914	0.347	0.064	0.119
CLAY	0.863	–0.337	0.186	0.037
TiO_2	0.806	0.388	0.301	0.085
MnO	0.784	–0.033	0.162	–0.139
Si/Al	–0.764	–0.218	–0.258	–0.277
SMECT.	0.677	0.210	–0.478	0.229
INTVE.	–0.647	–0.261	0.639	–0.021
ILLITE	0.604	0.492	–0.190	-0.281
PL	0.476	0.097	–0.038	0.357
Na_2O	0.015	0.946	–0.092	0.183
K_2O	0.252	0.894	0.054	0.179
ZrO_2	–0.240	0.864	–0.108	0.254
CaO	0.355	0.841	–0.055	0.177
KAOL.	–0.391	–0.829	0.049	–0.195
ILL/SM	–0.099	0.772	–0.057	–0.126
BSAT	0.080	0.721	–0.245	–0.171
BD	0.231	0.424	–0.370	0.257
0.1 MPa	0.433	–0.168	0.860	0.066
TAW	0.450	–0.112	0.857	0.019
1.5 MPa	0.421	–0.198	0.854	0.092
1.0 MPa	0.425	–0.186	0.852	0.099
OC	–0.334	0.166	0.672	–0.295
LL	0.208	0.110	–0.049	0.895
PI	0.011	0.079	0.113	0.811
CEC	0.205	0.448	–0.294	0.552
Eigen-value	9.640	6.313	4.673	2.650
% of Variance	33.243	21.769	16.113	9.137
% Cum. Variance	33.243	55.012	71.125	80.261

For explanations see Table 5.

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