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Practical charts to identify the predominant clay mineral based on oxide composition of clayey soils

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ABSTRACT

This study proposes some useful practical charts representing the relationships between oxide composition and the type of predominant clay mineral present in clay soils. In order to produce the charts, the data set are collected from published literature. Some useful classification schemes for predominant clay mineral type were obtained by using binary and ternary graphs of oxide composition data. The most successful relations indicating the type of clay mineral have been found on SiO_2 versus $Al_2O_3 + Fe_2O_3 + FeO$, SiO_2 versus $MgO + CaO + Na_2O + K_2O$ binary plots, $SiO_2 - Al_2O_3 -$ Others and $SiO_2 - Al_2O_3 - K_2O$ ternary plots.

1. Introduction

Mineral type is one of the most important properties of fine-grained soils. The colloidal particles of soils are mainly composed of clay minerals that occur in all type of sediments and sedimentary rocks as a result of weathering and hydrothermal alteration. All the clay minerals are layered crystalline hydrous aluminosilicates, and the arrangement and the chemical composition of the layers determine the type of clay mineral (Holtz and Kovacs, 1981; Craig, 1994; Terzaghi et al., 1996; Weaver and Pollard, 1973).

Clays are defined as soils which have particles smaller than 2 μm and cohesive effects. The influence of the electrical forces acting at the surface of each particle is significant. It is very complicated and difficult to classify the mineral types. However, various groups exist based on mineralogical and chemical structures in the literature. In terms of geotechnical engineering, clay minerals are mainly classified as kaolinite group, micalike minerals group and Smectite group (Lambe and Whitman, 1979; Mitchell, 1993). It is so difficult to find pure clay mineral composing of only one mineral on earth. However, it is possible to estimate behavior of clays from geotechnical point of view as the predominant mineral existing in clay is known.

For geotechnical engineers the mineralogical composition of clays may be useful as a notice of their characteristic behavior, and as an indication of the difference from the other materials (Holtz and Kovacs, 1981). Sizes, shapes and surface characteristics of the clay particles as well as their interactions with fluids are governed by the mineralogy. Therefore, mineralogical characterization is essential for understanding of geotechnical properties of clayey soils such as plasticity, swelling, compression, strength, and permeability. It also gives us good estimation about the consistency limits and grain size distribution reflecting both composition and engineering properties (Mitchell, 1993).

The consistency limits are very useful for soil identification and classification. In addition, they are widely used as a means of estimating the plastic properties of clay materials. The liquid limit (w_L) and plastic limit (w_p) are in the order montmorillonite > illite > kaolinite for common clay minerals belonging to smectite group, mikelike minerals group and kaolinite group, respectively (Mitchell, 1993; White, 1949; Bain, 1971). Susceptibility of clays to swelling and shrinking increases with increasing activity (A_c). Therefore, the swelling and shrinking potential is in the order montmorillonite > illite > kaolinite for clay minerals. For clay minerals compared at the same water content, the permeability is in the order montmorillonite < illite < kaolinite. The compressibility of saturated clay minerals decreases in the order montmorillonite > illite > kaolinite (Mitchell, 1993). The angle of shear strength decreases in the order by kaolinite, illite and montmorillonite for clay minerals (Olson, 1974).

One of the most important issues for geotechnical engineers is to estimate behavior of clayey soils, which is mainly governed by the dominant clay type. Although identification of mineralogical composition of clay samples by XRD analysis is an easily applicable technique for clay scientist, the specimen preparation and assessment of XRD patterns to determine the available minerals in clay soils is a complicated methodology for

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geotechnical engineers. Therefore, assessment of predominant clay type in soils and their engineering properties, by using practical charts prepared based on chemical composition, could be more attractive when compared to sophisticated XRD analyses for geotechnical engineers.

In this study, some practical charts have been prepared for use in estimation of dominant clay type in fine-grained soils from their chemical composition. The general idea presented in this study is to provide practical charts for geotechnical engineers to assess dominant clay type in soils and thus to evaluate their related engineering properties based on their chemical compositions, instead of complicated X-ray diffraction methods utilized by clay scientists.

2. Materials and methods

In this study, it is aimed to produce practical charts that can be used for identification of major type of clay minerals in clay soils based on their oxide composition. For this purpose, the oxide composition data of 40 clay samples for each of three common clay mineral types (kaolinite as a mineral in kaolinite group, illite in micalike group and montmorillonite in smectite group) from published literature are collected. Types of dominant clay mineral in clay soil samples had been reported as determined by powder XRD analyses in published literature. Their chemical compositions had been reported as determined by means of X-ray fluorescence (XRF) or conventional wet chemical method or inductively coupled plasma emission spectrometry (ICP) by fusion/dissolution technique using the bulk or powdered samples which had grain size <20 μm. In order to produce practical charts representing the relations between oxide composition and dominant clay mineral type in clay soils, some binary and ternary graphs were plotted and they are assessed analytically to identify the regions representing each dominant clay mineral type.

3. Results and discussion

3.1. Relationships between SiO_2, Al_2O_3, Fe_2O_3 contents of clays and their type of dominant mineral

The data sets clay soil samples of kaolinite, illite and montmorillonite and their statistical parameters are determined (Table 1, Table 2 and

Table 1
Chemical contents and statistical parameters of kaolinites used in the study.

	Chemical composition (%)												
Data number	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	TiO_2	Na_2O	K_2O	LOI	H_2O^-	Total	References
1	46.20	39.20	0.23		0.06	0.07	0.09	0.09	0.21	13.80		100.0	Jepson and Rowse (1975)
2	45.2	39.2	0.17		0.06	0.08	1.21	0.03	0.02	13.3		99.3	
3	46.40	39.52	0.09		0.23	0.15		0.09	0.01	13.90		100.4	Nemecz (1981)
4	44.06	39.44	0.80		0.06	0.26				14.16	1.06	99.8	
5	45.10	37.70	0.70				1.40			13.90	0.90	99.7	
6	44.59	38.12	1.43		0.10	0.06	1.38	0.12	0.08	13.91	0.71	100.5	
7	44.84	40.36	0.30		0.31					13.99		99.8	
8	44.15	38.99	1.06			0.14	0.62			12.96		97.9	Weaver (1989)
9	46.86	38.22	1.19				0.41			13.59		100.3	Weaver and Pollard (1973)
10	45.84	38.30	1.50		0.06		0.01	0.03	0.31	14.08		100.1	Çelik et al. (1997)
11	46.30	34.80	0.65		2.33			0.45	0.18	14.40		99.1	Karakaya et al. (2001)
12	45.10	37.50	0.60		0.10	0.02	0.03		0.10	14.70		98.2	
13	46.51	39.62			0.11				0.03	13.74		100.0	Bauer and Berger (1998)
14	44.6	38	0.2		0.01	0.02		0.01	0.04			82.9	Heller-Kallai and Lapides (2007)
15	44.1	37.8	1.08		0.02	0.04		0.01	0.04			83.1	
16	47.6	38	1.1		1.1	0.5		<0.1	1			89.3	
17	44.4	37.9	0.68		<0.02	0.11		<0.15	0.29			83.4	
18	42.8	37.2	1		<0.1	<0.1		<0.1	<0,1			81.0	
19	46.7	33.8	2		1.1	0.26		0.28				84.1	Kamiyango et al. (2009)
20	48.15	38.36	0.43		0.09	<0,02	0.5	0.13	0.5	11.5		99.7	Kılıç and Hoşten (2010)
21	48	37	0.75						2.5			88.3	Mergen and Aslanoğlu (2003)
22	47.2	35.75	2.86		0.17		0.9			12.23		99.1	Saikia et al. (2003)
23	47.05	36.98	0.34				0.53	0.12	0.08	14.31		99.4	Suraj et al. (1998)
24	46.01	34.27	1.26				2.2	0.15	1.45	14.4		99.7	
25	45.5	38.1	0.3				1.4			13.8		99.1	Sanchez et al. (2003)
26	51.3	32.6	1.1		0.1	0.3	1.1	0.2	0.3	13		100.0	Jaarsveld et al. (2002)
27	51.4	31.2	3.8				0.6		3.1	10		100.1	Sei et al. (2004)
28	51.8	28.8	4.4				1.7		2.6	10.5		99.8	
29	51.6	31.3	3.5				2.3		0.3	11.1		100.1	
30	47	36	3.08		0.16	0.32		0.42	0.74	12.31		100.0	
31	45	34	7.38		0.23	0.24		0.12	0.5	13.1		100.6	
32	48	33	6.13		0.19	0.19		0.08	0.62	12.41		100.6	
33	49	34	4.13		0.25	0.22		0.19	0.7	10.02		98.5	
34	49.72	33.85	0.96		0.03	0.3	0.04	0	3.02	11.9		99.8	Steudel et al. (2009)
35	44.72	36.34	1.58		0	0.08	1.58	0	0.47	14.2		99.0	
36	45.69	35.98	0.97		0.16	0.33	1.39	0	0.27	15.1		99.9	
37	43.98	38.54	1.12		0.01	0.03	2.34	0.01	0.01			86.0	Volzone and Ortiga (2006)
38	45.5	35.15		1.54	0.06	0.47	0.83	0.63	1.01	12.12	0.63	100.0	Ekosse (2001)
39	44.12	35.71		1.64	0.04	0.46	0.83	0.14	1.15	12.84	0.95	99.9	
40	51.4	34.5	0.45		0.15	0.3	0.41	0.15	0.58	11.9		99.8	Ferrari and Gualtieri (2006)
Statistical parameters													
Max.	51.80	40.36	7.38	1.64	2.33	0.50	2.34	0.63	3.10	15.10	1.06		
Min.	42.80	28.80	0.09	1.54	0.00	0.02	0.01	0.00	0.01	10.00	0.63		
Avrg.	46.59	36.38	1.60	1.59	0.26	0.21	0.99	0.14	0.72	13.04	0.85		
Median	46.11	37.10	1.06	1.59	0.10	0.21	0.87	0.12	0.31	13.45	0.90		
Std dev.	2.39	2.67	1.70	0.07	0.49	0.15	0.71	0.16	0.90	1.36	0.18		

LOI: Loss of ignition from 110° to 1000 °C.
H_2O^-: Ignition loss below 110 °C.

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