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RESEARCH ARTICLE

Oltu clay deposits (Erzurum, NE Turkey) and their possible usage areas

Ekrem KALKAN[1,*]

[1] *Ataturk University. Oltu Faculty of Earth Sciences Department of Geological Engineering Applied Geology Division, Erzurum, TURKEY.*

**Corresponding author E-mail: ekalkan@atauni.edu.tr*

HIGHLIGHTS

> Clay deposits are developed in two clastic-evaporitic sedimentary sequence.
> Clay deposits are defined as highly compressible inorganic silt and organic clays.
> Oltu clay deposits are suitable for utilization in geotechnical applications and clay-related industries.

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ABSTRACT

Oltu clay deposits known Oligocene-Miocene Formations in the Oltu-Narman Basin (NE Erzurum, Turkey) are concentrated in two different stratigraphic horizons namely the Late Oligocene and the Early Miocene sequences. Clay minerals originated by the alteration of Eocene calcalkaline island-arc volcanic, preferably from pyroclastics (trachyte and andesite flow) which form the basement. In this study, these clay deposits have been studied for chemical, mineralogy, and physical properties to decide the most proper industrial use. The industrial significance of the clay deposits depends on the type and the chemical properties of minerals (montmorillonite) in different layers. Physical, mineralogical, and chemical properties of this clay deposits are convenient to use in constructing barriers, filtering layers, and liners in landfills. Some industrial areas are suitable for use of kaolinite and serpentine clay group such as the ceramics and related refractory. Paligorskite and sepiolite group clay mineral are utilized in drilling applications. Mica group clay materials are suitable for manufacture of kiln wares and in red or firing pottery products.

Contents

1. Introduction

On the basis of stratigraphic data, clay sediments represent about 50% of volume of known sedimentary lithosphere [1]. Clay deposits, i.e. residual or hydrothermal argillaceous accumulations, plastic clays and loams of all possible mineral or organic-mineral compositions and semi-plastic or non-plastic clay stones, shales and slates are often accompanied by other important raw materials. Conversely, clay raw materials accompany coal seams, ore deposits or other industrial materials [2]. Clay deposits are principally composed of fine

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quartz and clay minerals. The principal minerals in clay deposits tend to influence its engineering behavior. Expansive soil or swelling soil is a highly plastic soil that typically contains clay minerals such as montmorillonite that attract and absorb water [3]. Reaction of an expansive soil to changed environmental conditions is to swell or exert large pressures against non-yielding structures; but it may also exhibit a high degree of shrink-swell reversibility with changes in moisture content, leading to deformation and damage to buildings [4]. In the past decades, many studies were done providing helpful information of expansive soil properties, which may be applicable to engineering practice [5–16].

Early use of clayey materials including high amount of certain clay minerals goes back to pre-historical times. First scientific clay researches were started at early fifties by Robertson and Ward [17], and Winkler [18]. Following the 1970's, works on clay have increased and varied rapidly. Last 40 years, rich countries have achieved enormous progresses in industrial use of clay, particularly in the disposal of domestic and industrial waste, in landfill projects. There is currently growing interest in the more sophisticated and advanced technologies in montmorillonite processing which include their use as impermeable and containment barriers in landfill areas and other environment-related applications [19], surface modifications and development of organo-clays for use as components in organic systems [20], and other utilization.

The basic objectives of this research was to propose possible utilization areas of Oltu clay deposits using chemical, mineralogical and index properties. To achieve this goal, the laboratory tests and field observations were carried out.

2. Experimental Study

2.1. Materials

Oltu-Narman Basin is located at 100 km northeast of Erzurum, NE Turkey. Clay deposits are developed in two clastic-evaporitic sedimentary sequences formed different time intervals during Late Oligocene-Early Miocene (Figure 1).

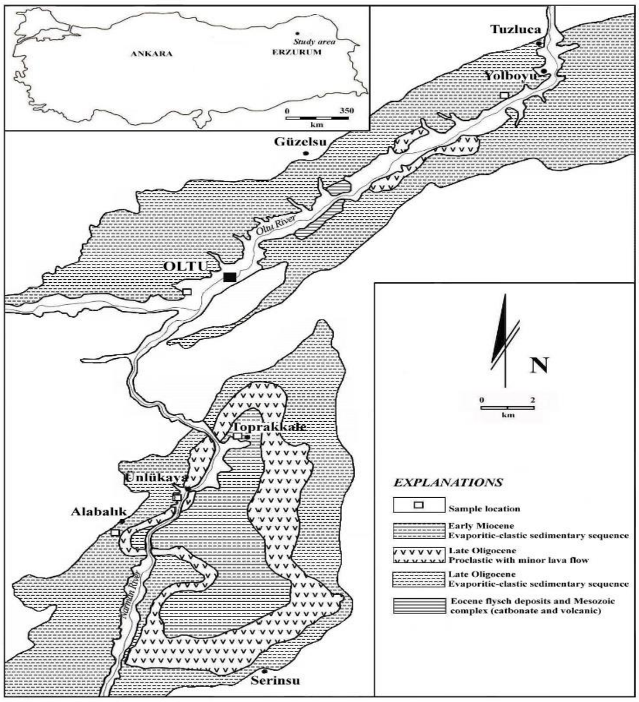

Figure 1 Simplified geological map with samples locations [16].

Oltu clay deposits used in this study are obtained from five different stratigraphical levels at five different locations.

Three locations were selected from Late Oligocene sedimentary sequence named Alabalık Village, western Oltu, and Yolboyu Village, and two locations were selected from Early Miocene sedimentary sequence named Ünlükaya Village and Toprakkale Village. Undisturbed samples were collected by digging investigation pits at depths of 70-80 cm, to exclude cover-highly disturbed by agricultural activity.

2.2. Methods

The chemical compositions were determined by X-ray fluorescence (XRF) using a Philips 1400 spectrometer using methodology of Franzini et al. [21] and Leoni and Saitta [22]. The mineralogical compositions were determined by X-ray powder diffraction (XRPD) using Philips PW 1010/80 diffractometer with graphite-filtered CuKα radiation.

Grain size distributions of samples were carried out accordance with the procedure suggested by ASTM D 421 and ASTM D 422. Standard compaction tests have been made to determine the compaction properties of samples in accordance with the ASTM D 698. Liquid limit and plastic limit tests were conducted in accordance with ASTM D 4318.

The compressive strength was determined from unconfined compressive tests (ASTM D 2166). Odometer tests were performed to obtain pre-consolidation pressure and swelling pressure (ASTM D 2435). The hydraulic conductivity was calculated by fallen-head permeability tests performed in according to the ASTM D 5084.

3. Results and Discussion

3.1. Chemical and mineralogical properties

Al_2O_3, CaO_3, CaO, Fe_2O_3, MgO, $SO_3$and SiO_2 compositions of soil samples were determined by XRF analyses. Table 1 shows the results of chemical analysis. CaO_3, Fe_2O_3, and MgO contents of clayey beds are comparatively higher in the Late Oligocene sequence, whereas Al_2O_3, CaO_3, SO_3 and SiO_2 content of clayey beds higher in the Early Miocene sequence.

Lack of correlation between the SiO_2% and the other major elements, indicating that the SiO_2% content is mainly related to the abundance of quartz [23]. Increase in content of SiO_2 of clay deposits reflects high quartz content, and that of CaO reflects calcite content. As mentioned above, quartz and calcite contents in the upper sedimentary sequences are higher than those of the lower sedimentary sequences.

It is observed in examined samples that there is a linear relationship between loss of ignition and CaO content. In other words, the loss of ignition increases with increase in CaO content. High percentage of SiO2, Fe_2O_3, Al_2O_3 and MgO indicates the presence of smectite clay minerals, and therefore, the swelling of the soil samples from Oltu clay deposits are likely to be high.

Table 1 Chemical composition of samples

Sample Name	Late Oligocene sequence			Early Miocene sequence	
	Alabalık Village	Western Oltu	Yolboyu Village	Ünlükaya Village	Toprakkale Village
Al_2O_3	8.74-13.68	9.87-14.02	9.26-13.35	14.78-19.69	11.31-20.02
CaO_3_a	-	27.27-28.98	23.09-27.08	23.75-29.87	23.18-28.21
CaO_3_b	-	23.88-29.79	18.74-23.63	22.24-25.01	17.81-25.28
CaO	10.20-18-50	10.23-12.62	8.26-14.46	7.18-11.93	7.48-16.59
Fe_2O_3	6.40-7.98	5.51-6.21	6.02-7.63	4.91-8.03	4.80-7.04
MgO	4.17-8.21	3.45-7.59	6.15-7.72	2.38-3.18	2.90-6.42
SO_3	-	0.12-0.27	0.02-0.44	0.01-0.31	0.02-0.54
SiO_2	39.58-48.81	39.46-51.04	34.71-47.40	44.27-51.35	36.91-54.67
LOI	11.85-17.92	11.80-17.92	13.05-19.76	8.32-12.07	9.00-20.04

LOI: Loss in ignition

The XRPD results are given in Table 2. The XRPD results of whole sample mineralogy indicated that the samples are comprised clay minerals, quartz, calcite, and anortite. Clay minerals are montmorillonite, palygorskite, halloysite, natrolite, and hydrobiotite. As shown in Table 2, the results of types of XRPD analyses consist of clay and none clay minerals. Clay minerals represented by simectite group (montmorillonite, nontronite), kaolinite and serpentine group (halloysite), paligorskite and sepiolite group (paligorskite), and mica group (hydrobiotite). None clay minerals are silicate group (quartz, anortite) and carbonate group (calcite).

Table 2 The distribution of clay and none clay minerals

	Clay minerals				
	Smectite group		Kaolinite and serpentine group	Paligorskite and sepiolite group	Mica group
	montmorillonite	nontronite	halloysite	palygorskite	hydrobiotite
Sample location					
Late Oligocene sequence					
Alabalık Village	x				
Western Oltu	x	x	x	x	x
Yolboyu Village	x		x		x
Early Miocene sequence					
Ünlükaya Village	x				
Toprakkale Village	x				

	None clay minerals		
	Silicates		Carbonates
	quartz	anortite	calcite
Late Oligocene sequence			
Alabalık Village	x		x
Western Oltu	x		x
Yolboyu Village	x		x
Early Miocene sequence			
Ünlükaya Village	x	x	x
Toprakkale Village	x		x

3.2. Engineering properties

The results of experimental studies are given in Table 3. The natural moisture content varies from 12 to 17% with an average value of 13.7%.

The porosity values of samples are given in Table 3, which reveals variation from 32 to 39%. The average value of porosity is 35.9%. The void ratio values are 64, 47, and 56.2% for the highest, the lowest, and the average, respectively. The specific gravity and unit weight values change in the interval of 25.8-27.8 kN/m^3 and from 18.3 - 20.4 kN/m^3, respectively.

The average values are 26.7 kN/m^3 and 19.5 kN/m^3 for specific gravity and unit weight value, respectively. Samples contain 15%-41% clay and 41%-75% silt. Frequently the silt+clay fraction exceeded %98. The liquid limit of samples ranges between 50% and 72%, averaging 64.12% and plastic limit range between 21% and 42%, averaging 30.48%. As shown in the Figure 2, samples from clay deposits have fallen (CH) and (MH) areas on the plasticity chart. According to the USCS (Unified Soil Classification System), all samples are inorganic clays of high plasticity (CH) and highly compressible inorganic silt and organic clays (MH).

The highest value of activity recorded was 0.96 the lowest being 2.43 with an average of 1.33. Samples were classified using activity values according to limits suggested by Skempton [24] as normal and active clays. As shown in Figure 3, samples have generally high and very high swelling potential, but only three samples have medium swelling potential.

According to test results, maximum dry unit weight values of samples range between 13.6 kN/m^3 and 11.1 kN/m^3, with the average of 14.05 kN/m^3 and optimum water content values range between 21% and 42%, average of 24.72% (Table 3).

Table 3 Engineering properties of samples

Properties	Locations of soil samples				
	Late Oligocene sequence			Early Oligocene sequence	
	Alabalık Village	Western Oltu	Yolboyu Village	Ünlükaya Village	Toprakkale Village
	Natural field condition				
Water content, %	12-15	13-17	12-14	12-17	12-16
Unit weight, kN/m3	19.1-20.2	18.6-19.9	19.7-20.4	19.6-19.9	18.3-19.1
Void ratio, %	54-59	56-64	52-56	47-56	54-61
Porosity, %	35-37	36-39	32-36	32-36	35-39
Specific gravity, kN/m3	26.8-27.8	25.9-27.5	26.5-27.4	26.0-27.0	25.8-26.6
	Grain size				
Gravel (> 2000 μm), %	0-7	0-2	0-2	0-5	0-2
Sand (2000-75 μm), %	8-29	2-9	7-20	8-29	2-26
Silt (2-75 μm), %	48-61	57-81	55-68	41-61	55-67
Clay (<75 μm), %	16-31	19-41	16-28	15-31	17-32
	Atterberg limits				
Liquid limit, %	61-67	62-72	50-72	58-71	58-68
Plastic limit, %	25-31	25-36	23-35	25-42	21-38
Plasticity index, %	25-39	36-40	27-38	23-33	22-41
	Clay activity and expansion degree				
Activity	1.00-2.43	1.00-1.95	0.96-1.90	1.00-1.19	0.97-1.78
Degree of expansion	high	high-very high	high	medium-high	high
	Compaction parameters				
Optimum moisture content, %	25-27	24-26	23-27	23-26	23-26
Max. dry unit weight, kN/m^3	13.9-14.6	13.6-14.4	13.7-14.5	13.7-15.1	13.6-14.3
	Unconfined compressive strength				
Compressive strength, kPa	69.78-97.68	72.63-103.89	80.56-94.67	84.64-101.51	62.35-87.65
	Permeability				
Compacted permeability (cm/s)	1.65-2.01x10^{-7}	1.35-2.16x10^{-7}	1.54-1.98x10^{-7}	1.99-2.32x10^{-7}	1.70-2.25x10^{-7}
	Swelling behavior				
Swelling pressure, kPa	207	230	239	169	146
	Consolidation				
Consolidation state	over-consolidated	over-consolidated	over-consolidated	over-consolidated	over-consolidated
Pre-consolidation pressure, kPa	186-223	172-220	175-215	173-216	170-212
	Soil classification				
USCS	CH-OH or MH	CH-OH or MH	CH-OH or MH	CH-OH or MH	CH-OH or MH-CL

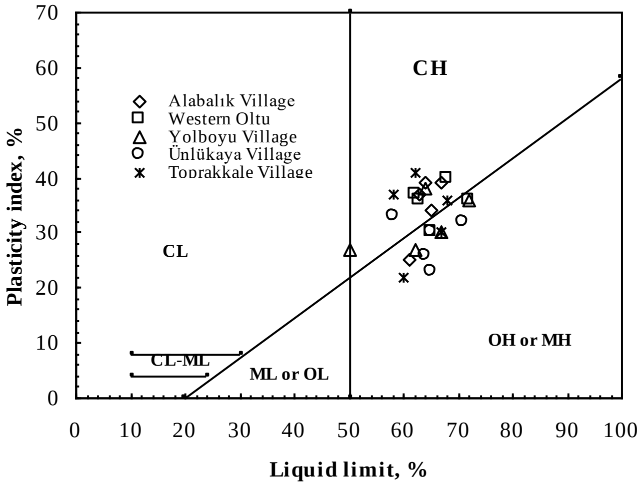

Figure 2 Plasticity chart showing the samples

The unconfined compressive values range from 62.35 to 103.89 kPa, averaging 83.85 kPa. Hydraulic conductivity values of compacted samples ranged from 2.32x10^{-7} cm/s to 1.35x10^{-7} cm/s, averaging 1.86x10^{-7} cm/s. The swelling pressure values ranged from 146 to 239 kPa, averaging 189.2 kPa. According the test results, pre-consolidation pressure values vary between 170 and 223 kPa (Table 3).

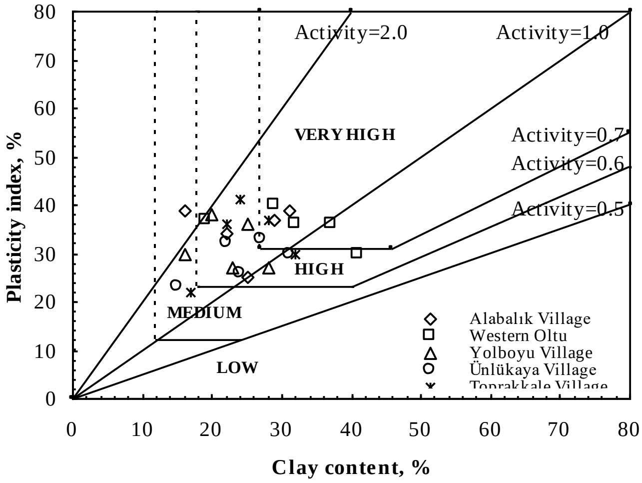

Figure 3 Activity and swelling potential chart proposed by Van der Merve [25].

3.3. Possible utilization

Clay and clayey soils, having a number of utilization, are not desirable to have present in the ground underlying foundations for buildings due to their negative effects on bearing capacity, swelling pressure, and settlement of soils. Clay minerals and clayey raw materials are commonly used in industry and other areas of human activities. The plastic limit and liquid limit of clay deposits were placed on clay workability chart suggested by Bain and Highly [26] which is shown in Figure 4. The results indicated on clay workability chart, scattered by differences in composition of samples. This leads to differences in the plastic behavior of such samples. Because of variations in the plastic behaviors, samples were located at different areas on the clay workability chart. Most samples located in sticky consistency area on clay workability chart, while five of twenty-five samples fall in optimum and acceptable molding areas. Also, it is shown from Figure 4 that some samples have increasing shrinkage behavior. Grouping of points (representing consistency) around sticky character in the chart proves the preferable use of clayey deposits in solution of the geo-environmental problems.

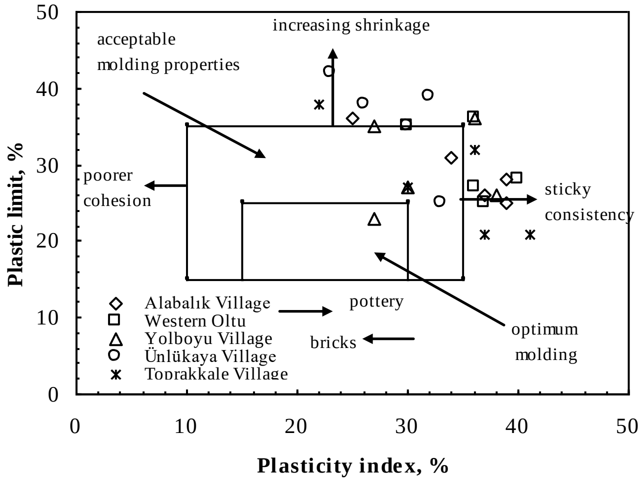

Figure 4 Clay workability chart, (after Bain and Highly [26]) for samples

Clay deposits are commonly used as containment barriers in landfills and other environmentally-related applications and other utilizations [19, 27]. Compacted clay liner materials are generally, required to have a hydraulic conductivity of $k \leq 10^{-7}$ cm/sn, weight passing sieve number 200≥39 to 50 percent, plasticity index (in accordance with ASTM 4318) ≥7 to 10 percent, gravel ≤20 to 50 percent, and maximum particle size 20 to 50 [28, 29]. Clay deposits have suitable properties for using as clay liner in landfill areas according to results of laboratory tests.

According to classification suggested by Konta [27], Oltu clay deposits content of smectites, kaolinite and serpantinite, paligorskite and sepiolite, and mica group clay minerals. These clay deposits can be utilized in clay industries due to clay mineralogy. Smectite group clay minerals are used acid-activated smectites for oil balancing and other uses [30, 31] and as containment barriers in landfills and other environmentally-related applications [19] and other utilizations [27]. Some industrial areas are suitable for use of kaolinite and serpentine clay group such as the ceramics and related refractory [30]. Paligorskite and sepiolite group clay minerals are utilized in drilling applications [27, 30, 32, 33]. Mica group clay materials are suitable for manufacture of kiln wares [18, 34, 35] and in red or firing pottery products [36, 37].

4. Conclusions

Although clay deposits include of smectites, kaolinite and serpantinite, paligorskite and sepiolite, and mica group clay minerals, the most common clay mineral is montmorillonite. Results provide an indication for the potential expansion and suggest high to very high degree of expansion. From the values of hydraulic conductivity, it can be seen that clayey deposits are impermeable or/and low permeable with the average value of 1.86x10^{-7} cm/s. The results, indicated on clay workability chart, scatter reflecting differences in composition of samples. Most of samples located in sticky consistency area on clay workability chart, while some samples fallen in optimum and acceptable molding areas. Oltu clay deposits can be used as impermeable materials for barriers in geotechnical applications and liners in landfill areas. These clay deposits can be utilized in clay industries depending on clay mineral content such as montmorillonite, palygorskite, halloysite, natrolite, and hydrobiotite.

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