Geotchnical properties of Cyprus clays

CAVIT ATALAR[1]& RECEP KILIC[2]

[1] *Engineering, Near East University, Nicosia, NORTH CYPRUS. (e-mail:catalar@neu.edu.tr)*
[2] *Engineering Ankara, University, Ankara,TURKEY . (e-mail: Kilic@eng.ankara.edu.tr])*

Abstract: Cyprus Clays occurred as a result of the alteration of the Troodos ophiolite and the pelagic sedimentary cycles that followed in the post Createceous period. A large part of Cyprus is covered by clay formations with intermediate to extremely high swelling potential and high calcium corbonate content.

Cyprus Clays can be divided into five main groups; 1. Bentonitic Clays, 2. Clays of Mamonia Complex, 3. Clays of Kythrea Group, 4. Clays of Nicosia Formation and 5. Alluvial Clays. The first four groups are overconsolidated clays of high swelling potential. Geological formations containing clays of high swelling potential are significantly exposed around Nicosia and Famagusta. There is widespread damage observed to the buildings, major roads and highways all over the Island which were founded on swelling clays. Landslides occur at the steep and very steep slopes of these formations. The alluviums comprise loose-medium dense gravel and sand, and soft-firm silt and clay. Mostly contain low amounts of clay size material. The alluviums also contain high amounts of montmorillonite. These clayey soils have low to intermediate swelling potential.

Field studies, geotechnical investigations, soil mechanical properties of analysis, moisture content, specific gravity, density, liquid, plastic and shrinkage limits, permeability, consistency and shear strength, suction, swelling pressure, X-ray diffraction, and scanning electron microscopy results are presented. The semi quantitative X-ray diffraction and Scanning microprobe analyses indicated that the predominant clay mineral of the Cyprus Clays is smectite. Illite and chlorite or kaolinite are the other abundant clay minerals. Calcite is the major mineral. Quartz and feldspar are also present in high amounts. The calcium corbonate content of the clays originated from the limestones and dolomites of the Kyrenia zone, the chalks of the South Cyprus zone, and considerable parts of it are biogenic in origin.

Résumé: Les argiles de Chypre ont été formeés a la suite de dégredation des ophiolites et la deposition des sediments pélagiques pendant le period de Cretacé. La plupart de Chypre est découverte par des argiles, montrant la possibilité de gonflement moyen et elevé et possedant $CaCO_3$ en grande quantité.

On peut classer les argiles de Chypre en 5 categories: 1. Argiles bentonitiques, 2.Argiles de Complex de Mamonia, 3. Argiles de Group de Kythrea, 4. Argiles de formation de Nicosia, 5. Argiles des alluvions. Les quatres (4) premiers des argiles, qui montrent la possibilité de gonflement elevé, affleurent a Nicosia et a Gazi Magusa. Les batiments, les autoroutes et les grandes routes, construits sur ces argiles, montrent des dommages. Des glissements de terrains ont été observés dans les sheves perpendiculaires ou presque. Les alluvions tendres sont formés par des cailloux, des sables, des siltes et des argiles. Les alluvions peuvent posséder, en partie, des minéraux d'argiles. Les argiles des alluvions sont montmorillonitiques, en général, et les argiles des subasments ont une plasticité faible ou moyenne.

Dans cette étude les travaux de terrains, les études geotechniques, les propriétés mecaniques des subasments, le contenu d'eau, la densité absolue et la densité normale, la liquidité, les limites de contractions et de plasticité, la perméabilité, la consistance de gonflement, l'absorption, la pression de gonflement, les analyses de XRD et des microscopes electroniques ont été examinés. Le minéral dominant des argiles de Chypre est le smectite. Autres minéraux sont illites et chlorites. Le minéral abundant dans les argiles est la calcite. Le quartz et le feldspath se trouvent aussi en grande quantité. Les calcaires et les dolomies dans la Zone de Girne et les craies de la Zone de Chypre, considerés comme des roches- mères, et les precipitation biogeniques ont permis le conteno elevé de $CaCO_3$ dans les marnes.

Keywords: clay minerals, alluvium, silt, limestone, chalk.

INTRODUCTION

Occurrences of swelling clays are the result of the alteration of other minerals. Chemical weathering of materials such as feldspars, micas, and limestones can form clay minerals. The particular mineral formed depends on the makeup of the parent rock, topography, climate, neighboring vegetation, duration of weathering and other factors.

Clays are found in nature as a rock or soil, and clays exhibiting rock-like behaviour may transgress to soil-like within a time frame of between a few months to 70 years. The layered silicate materials, with their ability to absorb and exchange metal ions, water molecules, and other substances, strongly affect soil chemistry, biological mineralisation cycles, and weathering. Many types of plastic clays swell considerably when water is added to them and then shrink with the loss of water. These clays, due to their volume changing ability, are called swelling clays, expansive clays, or active clays. Most of the swelling clay problems occur continuously in arid and semi-arid regions due to the soil expanding in the winter and shrinking in the summer.

Attention was first paid to the damages of swelling clays in the United States in the 1930's. Brick veneer residence started to replace the light frame dwelling, which could accommodate considerable distortion without signs of damage, and the construction of large dams and major highways began in 1933. Natural landslides were not considered a major engineering problem until a major landslide in Bearpaw shale formation, before the completion of the Fort Peck Dam.

The principal minerals in a deposit of clay tend to influence its swell-shrink and engineering behaviour. The highest volume changing is the montmorillonite group (smectites). There are two types of montmorillonite, calcium montmorillonite and sodium montmorillonite (also known as bentonite). The latter is much more expansive, but less common.

Montmorillonite often forms as a result of the weathering of ferromagnesian minerals, calcic feldspars, and volcanic materials. They are most likely to form in an alkaline environment with a supply of magnesium ions and a lack of leaching. Such conditions would most likely be present in semi-arid regions. Bentonite (sodium montmorillonite) is formed by chemical weathering of volcanic ash.

Volume changing clays are extensively present all over the world and are responsible for the most costly natural hazards. Swelling clays are responsible for slope stability and foundation problems causing damage to the structures, roads, and services. Volume-changing clay subsoils constitute the most costly natural hazard to buildings on shallow foundations in Canada and the United States. The damage caused by expansive clays in the United States alone is of the order of $9 billion every year (Jones and Holtz, 1973; Jones and Jones, 1987).

Due to its geological evolution, a large part of the island of Cyprus is covered by clayey and marly alluviums and formations bearing bentonitic clays to montmorillonite group of clays (Atalar & Das 2005). Nicosia, Famagusta, Kyrenia, Kythrea, Myrtou, and Gastria are some locations of swelling clay formations in the northern part of Cyprus. Bentonitic clay deposits are found at Arsos and around Lefka. Settlements situated on clay formations containing a high amount of montmorillonite group minerals are particularly vulnerable to damage due to high swelling/shrinkage characteristics of this group of clays. Collapsible soils and gypsum bedrocks also occur in some parts of the island.

Swelling clays that have caused the greatest amount of damage in north Nicosia are contained in stratigraphic sequences ranging in age from Tertiary to Quaternary, and are exposed in an area extending along the north banks of the Pedios stream from east to west, and to the west of the Old Nicosia city.

TOPOGRAPHY AND CLIMATE

Cyprus with an area of 9,251 km², is the third largest island in the Mediterranean sea, and the biggest island in the Eastern Mediterranean region. The northern part of Cyprus covers an area of 3,299 km². The island geographically is located in the centre of the triple junction of three continents Europe, Asia and Africa.

The island is divided into three main features stretching in an almost east-west direction, namely from north to south: the Kyrenia range, the Mesaoria plane and the Troodos range. The Troodos range, which is the largest of the two mountain ranges, is located, in the central south of the island and rises to a height of 1951 metres (Olympos hill). The Kyrenia range is in the north of the island and rises to 1023 metres.

Cyprus is a good example of a country with a typical Mediterranean climate; arid and semi-arid in character. The summer periods are long and relatively hot and dry from mid-May to mid-October, and the winters are mild and short from December to February, which are separated by short spring and autumn seasons.

The Troodos range receives the highest annual precipitation of up to 1100mm, while the Mesaoria plain receives only about 300-350mm. The maximum annual precipitation in the Kyrenia range is 550mm which is slightly higher than the islands latest annual average of 489mm.

The northern part of Nicosia covers an area 7.0km in east west and 2.0-4.0km in north-south directions. Due to political and geographical conditions the city has spread to the north and west-northwest. North Nicosia is almost flat lying at about 100-150m above mean sea level and is located between the Kyrenia and Troodos ranges. The elevation of the northern part of the study area reaches up to about 180m above mean sea level. High mountains that surround the region to the north are generally rocky.

GEOLOGICAL BACKGROUND

Geologically Cyprus is situated at the triple junction of the Eurasian, Arabian, and African plates, and has played a very important role in the geological understanding of the Eastern Mediterranean region. Geological investigations in Cyprus were started in 1878 by Gaudry. The first geological map of the island was published by Bellamy in 1905. Many experts organised geological field studies to Cyprus.

It is accepted that tectonic terrains of ophiolite complexes such as Cyprus, the Hellenic Arc, the Aegean graben system, the Anatolian and Sinai microplates, and several ocean basins are produced by the separation and collision of the Eurasian, Arabian, and African plates. The Troodos massif of Cyprus is one of the largest and most studied of these complexes.

The geology of Cyprus governs the topography. Cyprus geologically is divided into three main stratigraphic and tectonical units stretching in an almost east-west direction, from north to south they are the Kyrenia range and surrounding units in the north, Mesaria Basin in the centre, and the Troodos massif in the south. The three main features stretching in an almost east-west direction, namely from north to south, are the Kyrenia range the Mesaoria plain and the Troodos range.

Clay as a geological material has been studied and discussed by different scientists. However, studies of swelling clays are merely in its infancy. The eldest rocks of Cyprus comprise all kinds of ophiolites of volcanic and plutonic rocks. Under submarine conditions, extensive occurrences of lavas, the halmyrolisis, produced extensive deposits of bentonitic clays. All sediments derived from the Troodos complex contain different quantities of the expansive clay mineral montmorillonite.

Most of the swelling clays in north Cyprus occur in geological units of the Neogene. Swelling clays that have caused the greatest amount of damage are contained in stratigraphic sequences ranging in age from Miocene to Quaternary. Therefore, the geological and geotechnical evolution of the island played an important role in the formation of swelling clays. The Troodos massif of Cyprus is one of the largest and most studied of the ophiolite complexes and contains extensive volcanic sequences, basal group pillow lavas, plutonic sequences, plagiogranites, gabbros, pyroxines etc. and mantle sequences, harzburgite and serpentinite. Most of the clays of Cyprus occurred as a result of the alteration of the Troodos ophiolite. Despite the intensive investigations carried out there is no concensus on the geological division of the island and the tectonics of the Eastern Mediterranean region. Cyprus is mainly divided into between three to five geological zones by different researchers. Cyprus may be divided into three main geological zones from north to south according to its topography (GSD, 2002); the Kyrenia Zone, Mesaoria Zone, and the Troodos Zone.

Cyprus may also be divided into six geological zones according to geological evolution and emplacement of its geological units (Atalar, 2005): (1) Troodos Zone or the Troodos Ophiolite, (2) North Cyprus (Kyrenia) Zone, (3) Mamonia Zone or Mamonia Complex, (4) South Cyprus Zone, (5) Mesaoria Zone, and (6) Alluviums (Figure 1).

Around the Kyrenia mountains outcrops Oligocene - Upper Miocene Kythrea Group, consist from bottom to top, of gravel, conglomerates, greywacke, marl, and mostly abyssal turbidites with a shallow environmental chalk, marl, limestone, and gypsum finishing. The northern part of Nicosia is covered with this formation. The marl member of this formation contains clays of intermediate-high swell potential.

The Mesaoria Group is located between the Kyrenia and Troodos ranges and consists of rocks of deep and shallow marine environment of marl, sandy marl, base conglomerates of gypsum belonging to Pliocene till to Quaternary age and fluvial deposits. They outcrop at the southern slopes of the Kyrenia range and are spread towards the Troodos mountains. Swelling clays of the Mesaoria Group occurred as a result of the alteration of the Troodos ophiolite and Kythrea Group.

Most of the sedimentary formations especially marls have a swelling potential. The Neogene sedimentary formations of north Cyprus are characterised by clayey soils.

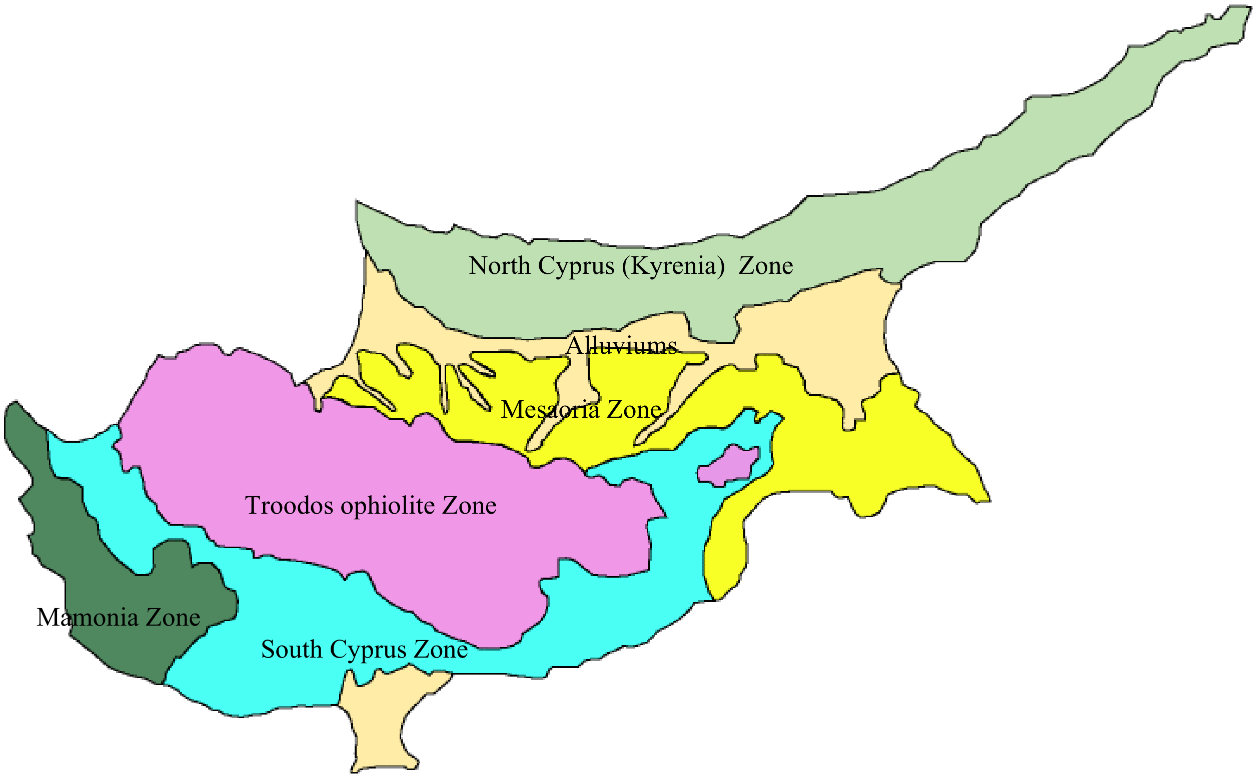

Figure 1. Geological Map of Cyprus (Revised from GSD, 1995)

Troodos Zone or the Troodos Ophiolite: The geological evolution of Cyprus started with the formation of the Troodos Ophiolite in the Upper Cretaceous due to the subduction of the African plate beneath the Eurasian plate. Troodos Ophiolite comprises of plutonic, intrusive and volcanic rocks. It covers the Troodos range in the southern central part of the island.

North Cyprus (Kyrenia) Zone: Kyrenia zone may be divided into two subzones. The first subzone is composed of autochthonous sedimantery rocks of Upper Createaceous to Middle Miocene. The Kythrea group is within this zone The second subzone is composed of allochthonous massive and recrystallised limestones, dolomites and marbles of Permian-Carboniferous to Lower Cretaceous age which have been thrust southward to their present position in the Miocene.

Mamonia Zone or Mamonia Complex: The allochthonous Mamonia Zone or Mamonia Complex comprises of igneous-volcanic, sedimentary and metamorphic rocks of Middle Triassic to Upper Cretaceous age. During the Maastrichtian the movement to Cyprus took place. It only appears near Paphos in the south west part of South Cyprus.

South Cyprus Zone: In the south of Cyprus, sedimentary rocks ranging in age from Upper Cretaceous to Miocene, are extensively exposed in an area extending between the south of the Troodos Ophiolite and the south coast from Larnaka in the east to Paphos in the west and less extensively in the north of Troodos Ophiolite. This zone is composed of mostly chalks, clays, marls and gypsum. Bentonitic Clays, Lefkara, Pakhna and Kalavasos formations are within this zone.

Mesaoria Zone: The Mesaoria Zone is located between the Kyrenia and Troodos ranges and consists of rocks of deep and shallow marine environment of marl, sandy marl, calcarenites and terraces belonging to Pliocene and Pleistocene ages. They outcrop at the Mesaoria plane, southern slopes of the Kyrenia range and are spreading towards the Troodos mountains. Nicosia and Athalassa formations are within this zone.

Alluviums: The alluviums Holocene to recent in age containing gravel, sand, silt, and clay are widespread in the Mesaoria plain, especially at Nicosia and Famagusta and at the east and west coasts as well as the stream beds all over the island.

Cyprus Clays

Clays of Cyprus occurred as a result of the alteration of the Troodos ophiolite and the pelagic sedimentary cycles that followed in the post Createceous period. The calcium corbonate content of the marls originated from the limestones and dolomites of the Kyrenia zone, the chalks of the South Cyprus zone and considerable parts of it are biogenic in origin. A large part of Cyprus is covered by alluvium of low to intermediate swelling potential and clays with intermediate to extremely high swelling potential. Nicosia is covered by extensive surficial deposits of clayey soils. The walled city and its closed surroundings are covered by fill. Alluviums (containing clays) of low bearing capacity are present around the Pedios river in the southeast, southwest, and at the old bed of the Pedios river in the northeast. Overconsolidated marl is extensively exposed in the eastern and western parts of the city. Extensive outcrop of uncemented gravel covers part of the southeast and southwest. Calcarenite, sandstone and limestone of high bearing capacity are exposed in the south and southeast (GSD, 1982).

The semi quantitative X-ray diffraction and Scanning microprobe analyses indicated that the predominant clay mineral is smectite, illite and chlorite or kaolinite are the other abundant clay minerals. Calcite is the major mineral of the marls, quartz and feldspar are also present at high amounts.

There is widespread damage observed to the buildings constructed on swelling clays, and in major roads and highways all over the country which were founded on swelling clays (Atalar, 2002).

Swelling clays of Cyprus can be divided into five groups (Figure 2):

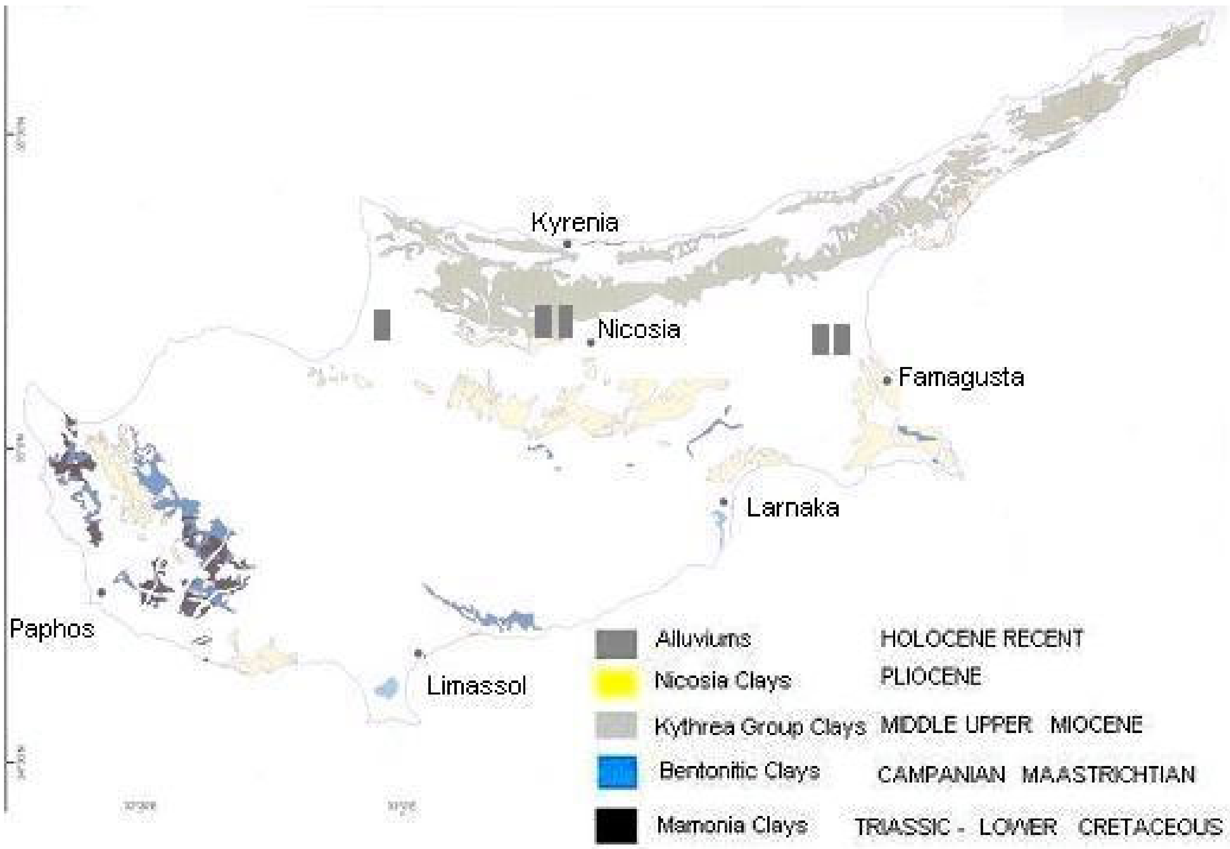

Figure 2. Cyprus Clays (Revised from GSD, 1995).

Bentonitic Clays: The bentonitic clays occurred as the first clays of Cyprus due to alteration of the pillow lavas of the Troodos ophiolite. Bentonitic clays are mainly found in Kathikas-Moni and Kannaviou formations in the south part of the Troodos ophiolite, at the boundary of the pillow lavas with the postvolcanic sediments and are widespread at Paphos in the west, less widespread at Moni near Limassol, in the south and at Paralimni at the south of Famagusta in the east. In south Cyprus it reaches a thickness of more than 300 metres. It is only found near Yi itler village in North Cyprus. Bentonitic clays contain more than 35 % low swelling potential calcium montmorillonite and no high swelling potential sodium montmorillonite. Despite that Bentonitic clays exhibit the highest swelling potential of Cyprus clays (Table 1).

Clays of Mamonia Complex: In the south western part of the island near Paphos, igneous-volcanic, sedimentary and metamorphic rocks of the Mamonia Complex of Middle Triassic to Cretaceous ages also contain clays of swelling potential; however, swelling potential is much less than in the bentonitic clays because their swelling potential is acquired from the Kannaviou formation.

Clays of Kythrea Group: The Kythrea group mostly contains turbiditic rocks. The Group, consists from bottom to top, gravel, conglomerates, greywacke, marl, and mostly abyssal turbidites with a shallow environmental chalk, marl, limestone, and gypsum finishing. Alternation of sandstone-siltstone-marl-claystone are widespread within the group. The group is only observed in TRNC and has a complete coverage of the northern and southern slopes of Kyrenia range from east to west. The Kythrea group consists Mia Milea, Skylloura, Lapatza (Pre-evaporitic) and Lapatza (evaporitic) formations. The clayey units of several metres thickness to tens of metres thickness in the different formations of the group exhibit different swelling potential. Lapatza (Pre-evaporitic) and Skylloura formations exhibit high to very high, Mia Milia intermediate to high swelling potential (Atalar, 2004).

Clays of Nicosia Formation: In the middle of the island from east to west and in the southwest and west, overconsolidated clays with high to very high swelling potential (Table 1) occur in geologic units of Nicosia Formation of Pliocene age and are extensively exposed in big settlements like Nicosia, Famagusta, Larnaka and Polis. The southern parts of Nicosia and Famagusta are completely covered by this formation. The Nicosia formation mainly contains calcarenites and marls. Gravels, limestones and conglomerates are also present in this formation. The clay minerals contained have large amounts of montmorillonite, with lesser amounts of illite and kaolinite. Some researchers describe the Myrtou formation seperate while others describe it together with the Nicosia Formation. Some units of Apolos and Athalassa formations of Pleistocene age also contain clays.

Alluvium Clays

The alluviums, Holocene to recent in age containing gravel, sand, silt, and clay are widespread in the Mesaoria plain, especially at Nicosia and Famagusta and at the east and west coasts. They comprise loose - medium dense gravel and sand, and soft - firm silt and clays. The alluviums mostly contain low amounts of clay size material. The alluviums also contain high amounts of montmorillonite (smectite). These alluviums show relatively high apparent strength in their dry state. However, with saturation their strength decreases. Most damage occurs to the buildings constructed close to the stream beds. These clayey soils have low to medium swelling potential.

Table 1. Swelling potential of Cyprus clays

Clays	Liquid Limit (LL)	Swelling Potential
Alluvium	Up to 48	Low - Intermediate
Nicosia Formation	53 - 91	High – Extremely High
Kythrea Group	47 - 73	Intermediate – High
Mamonia Complex	33 - 167	Intermediate – Extremely High
Bentonitic	55 - 210	High – Extremely High

GEOTECHNICAL INVESTIGATIONS

Detailed geotechnical investigations of the northern part of Nicosia were carried out between 2001 and 2002 (Atalar 2002). Further investigations were carried out in 2004 and 2005. Tens of boreholes were drilled to recover undisturbed and disturbed samples for laboratory testing. Several trenches were also excavated. Undisturbed and disturbed soil samples from different boreholes from all over north Nicosia, several trenches, and several cut slopes were obtained.

Laboratory Tests

More than two hundred soils were tested for various tests to determine the basic geotechnical characteristics of the marls and Quaternary deposits. The following laboratory tests were performed.

Mechanical (Grading) analysis:

Mechanical (Grading) analysis is the determination of the size range of particles present in a soil, expressed as a percentage of the total dry weight. The marls contain a sand content between 0% and 5%, a silt content between 26% and 43% and a clay content between 53% and 74%. The alluviums contain a sand content between 6% and 59%, a silt content between 29 and 65% and a clay content between 12% and 44%.

Moisture content (Anon, 1990)

The marls contain a moisture content between 18.3% and 35%, imbedded sandstone 11.4%, and alluviums between 11.6% and 28.4%.

Specific gravity (Anon, 1990)

All samples tested are in a narrow range between 2.66 and 2.70

Density, g/cm^3, (Anon, 1990)

The variation of dry and bulk densities are ranging between 1.43 and 1.70 g/cm^3 and between 1.79 and 2.09 g/cm^3 respectively.

Liquid, Plastic, and Shrinkage limits (Anon, 1990)

Fifteen soil samples from five different boreholes at five different locations were tested for all atterberg limits. More than one hundred samples were tested for liquid and plastic limits. According to their liquid limit values the clays may be classified as having: 0%-30% low, 30%-50% intermediate, 50%-70% high, 70%-90% very high, and more than 90% extremely high swelling potential.

Permeability

The coefficient of the permeability of tested soil samples from SC-1, SC-3, and SC-4 boreholes range between 10^{-5} and 10^{-7} m/s. The highest value of permeability is found to be at the SC-1 UD 2 sample which contains the largest amount of sand (33%).

The coefficient of permeability values for all specimens tested from SC-2, and SC-5 boreholes were found to be in the range of 10^{-9} to 10^{-8} cm/s. These values indicate that the clays tested are almost impermeable.

Consistency and Shear strength

The triaxial tests show that the friction angle and cohesion of the uncemented alluviums tested from SC-1, SC-3, and SC-4 boreholes range between 4º and 8º, and 0.24 and 0.44 respectively. The friction angle and cohesion of the marls are between 18º and 22º and between 0.28 and 0.40 respectively. The friction angle and cohesion of cemented alluvium is 29º and 0.24 respectively. The consistencies of the soils tested from SC-1, SC-3, and SC-4 boreholes differ between boreholes and different samples recovered from the same borehole as well. The undrained shear strength of the soils tested from SC-2 and SC-5 boreholes increases with depth as the soil gets more consolidated. SC-2 (1) is stiff - very stiff, SC-5 (1) is very stiff and SC 2 (2) and SC-5 (2) are hard.

X-ray diffraction analysis

A total of 53 samples from different formations were analysed by X-ray diffraction. The semi-quantitative X-ray diffraction analysis indicated that the predominant clay mineral is Montmorillonite (smectite) with an amount ranging between 15% and 20%. Illite with an amount ranging between 5% and 15%, and chlorite or kaolinite with an amount of 10% are the other clay minerals. Calcite with an amount ranging between 35% and 40% is the major mineral of the marls. The other minerals are Quartz ranging between 10% and 20 %, Feldspar ranging between 10% and 20% (Figure 3). The semi-quantitative X-ray diffraction analyses of a sample from SC-5 borehole contains 40% calcite, 15% montmorillonite (smectite), 15% quartz, 10% chlorite or kaolinite, and 10% feldspar.

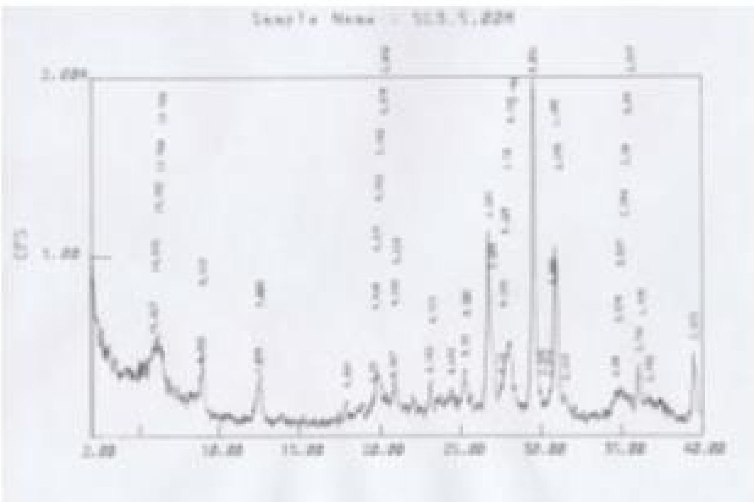

Figure 3. The semi-quantitative X-ray diffraction analyses of sample SC3 (5.00).

Suction

Water retention characteristics were derived for clay sub-soils from only four areas in Nicosia reputed for their shrink-swell potential. Suction versus depth relationship could not be established due to an insufficient number of undisturbed samples. However, suction versus water content relationship, known as soil-water characteristic curve (SWCC) is obtained for four samples. Samples below 3.50m depths have higher air-entry values.

Swelling pressure

Swell pressure is observed to range from 1000 kPa to as high as 40000 kPa. The compressibility values for all specimens tested were found to be very slightly compressible, preconsolidation stress between 70 and 300 kPa, and overconsolidation ratio between 1.1 and 11.2.

The SPT values in unconsolidated alluvium are found to be low. Whereas the values in overconsolidated marl-claystone formations and in the precompressed alluvium and alluvium cemented by secondary calcium carbonate are higher.

Scanning electron microprobe analysis

Three samples from SC-2, SC-3, and SC-5 boreholes and one sample from TR-6 trench were tested. The predominant clay mineral is found to be smectite. Illite and chlorite or kaolinite are the other abundant clay minerals.

Smectite, illite, kaolinite, and calcite are shown in figure 4.

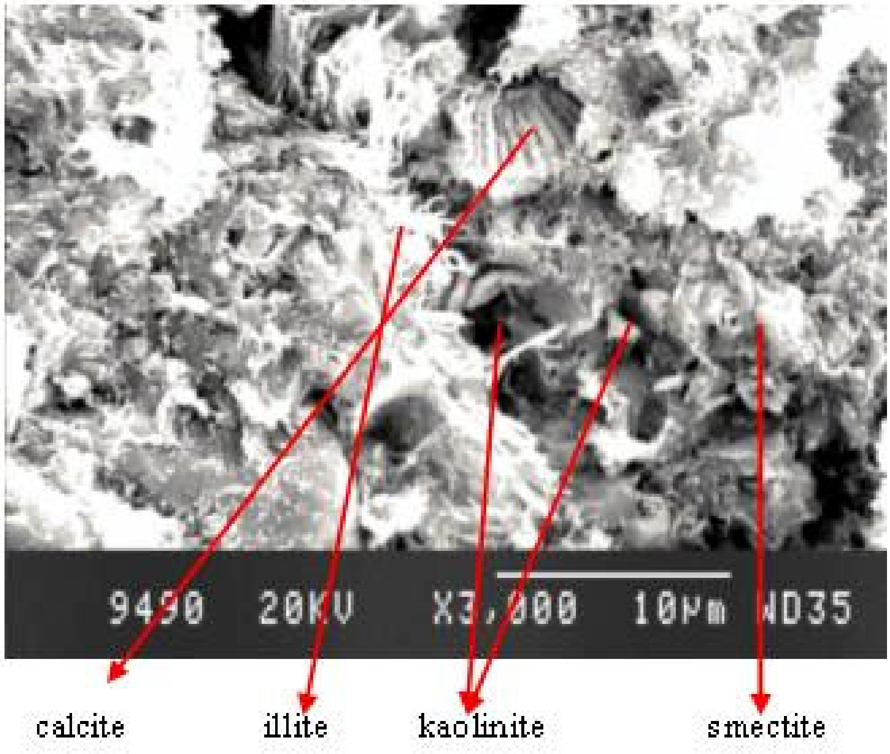

Figure 4. Scanning microprobe analyses showing smectite, illite, calcite, and kaolinite of sample TR-6 (3.00)

Chemical analysis

Fifty soil samples representing all formations in the investigated area were analysed for pH, % salt, % $CaCO_3$, K_2O ppm, Na ppm, and water absorption and some results are shown in Table 2. The older marls are darker in colour and contain less than 30 per cent calcite, while the younger ones are lighter in colour and usually contain more than 30 per cent calcite. The water absorption values of younger marls are higher than the older marls.

Table 2. Test results of chemical analysis

Formation	Water Absorption	Percent(%)	
		Clay	CaCO3
Nicosia	127-129	51-72	29-31
Myrtou	108-118	57-69	23-49
Lapatza	89-171	53-74	16-30
Skylloura	97-105	54-59	20-30

CONCLUSIONS

More than half of Cyprus is covered by clayey soils. Most of the settlements are usually on the coastline or on the flat areas of the Mesaoria plain. Therefore, most of the building sites are situated on clayey soils.

Systematic methods should be employed to classify the clays of the alluviums and the swelling clays, by identifying, testing, and evaluating their swell potential. Geotechnical investigations will be carried out to find the strength, durability and compressibility of the alluviums. If soil improvement is needed, it should be carried out before construction.

REFERENCES

ATALAR, C. 2002. Swelling Clays: A continuous threat to the built environment of Cyprus. Report of Turkish Cypriot Chamber of Mining, Metallurgical and Geological Engineers, (contributed by Tando du, Y., Acar, A., Bilsel, H., & Necdet, M.), Nicosia, North Cyprus.

JONES, D.E., & HOLTZ, W.G. 1973. Expansive soils – the hidden disaster. Civil Engineering, Vol. 43, No. 8, ASCE.

JONES, D.E., & JONES, K.A. 1987. Treating expansive soils. Civil Engineering, Vol. 57, No. 8, August 1987, ASCE.

ATALAR, C. 2004.”Foundation design for swelling clays of north Nicosia” Proceedings of the International Conference on Geotechnical Engineering, Sharjah, UAE, 121-128.

ATALAR, C. and DAS, B.M. 2005 Problematic soils of Cyprus” proceedings of the International Conference on Problematic Soils, GEOPROB2005, 3, May 2005, 1331-1338

ATALAR, C. 2005. The origin and characteristics of Cyprus clays. Extended Abstract Book of 57th Geological Congress of Turkey, Ankara, 144-148.

Geological Survey Department (GSD). 2002. Geology of Cyprus. edited by G. Petrides (Director)) Nicosia, Cyprus.

Geological Survey Department (GSD). 1995. Swelling clay occurrences in Cyprus. Scale 1:250,000. Edited by G. Constantinou (Director) Nicosia, Cyprus.

Geological Survey Department (GSD). 1982. Geotechnical map of Nicosia. Scale 1:25,000. Edited by G. Constantinou (Director) Nicosia, Cyprus.

GAUDRY, J. 1878. Geology of the Island of Cyprus. HMSO, London.

BELLAMY, C.V. 1905. Geological map of Cyprus, 1:348 480. Edward Stanford, London.

ANON. 1990. Methods of test for soils for civil engineering purposes BS1377. British Standards Institution, London.