ENGINEERING GEOLOGICAL CHARACTERIZATION OF THE TUFFITE MEMBER OF HANÇİLİ FORMATION, ÇAYYOLU, ANKARA

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ÇAĞLA FERSOY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
GEOLOGICAL ENGINEERING

DECEMBER 2008

Approval of the thesis:

ENGINEERING GEOLOGICAL CHARACTERIZATION OF THE TUFFITE MEMBER OF HANÇİLİ FORMATION, ÇAYYOLU, ANKARA

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ABSTRACT

ENGINEERING GEOLOGICAL CHARACTERIZATION OF THE TUFFITE MEMBER OF HANÇİLİ FORMATION, ÇAYYOLU, ANKARA

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December 2008, 87pages

Along NS trending road cut between Çayyolu and İncek, relatively thick tuffite layer of the Hançili formation has been exposed. It is alternating with other lacustrine deposits such as clayey limestone, marl, siltstone and mudstone. These units unconformably overlie the Mesozoic basement limestones of Akbayır formation. The illite rich tuffite consists of glass shards tridymite, biotite, quartz and plagioclase. It has a persistent areal extend and forms the foundation of the residential buildings at several localities.

In this thesis, it is aimed to assess the engineering geological properties of the tuffite layer and to investigate its suitability as a foundation material. In order to accomplish this task, field studies and laboratory tests were conducted. Field studies involve detailed site geological observation.

Laboratory studies include tests to investigate mechanical, physical and mineralogical properties of the tuffite.

Analyses revealed very weak nature of tuffite with strength values ranging between 0.1 MPa and 1.00 MPa. The tuffite is characterized with very high effective porosity (43.3%) and very low dry and saturated densities (1.19 Mg/m^3 and 1.62 Mg/m^3, respectively). The slake-durability tests yield medium durability. The durability index of tuffite is rated as very poor.

Considering index properties and the durability assessment it is concluded that tuffite serves as a poor foundation material.

Keywords: Tuffite, Hançili formation, Engineering Geological Properties, Çayyolu, Ankara,

ÖZ

HANÇİLİ FORMASYONU TÜFİT ÜYESİNİN MÜHENDİSLİK JEOLOJİSİ ÖZELLİKLERİ, ÇAYYOLU, ANKARA

FERSOY, Çağla

Yüksek Lisans, Jeoloji Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. Vedat Doyuran

Aralık 2008, 87 sayfa

Kuzey-Güney yönelimli Çayyolu-İncek yol kazısı sonrası Hançili formasyonuna ait kalın bir tüfit seviyesi yüzeylenmiştir. Bu seviye gölsel killi kireçtaşı, marn, silttaşı ve çamurtaşları ile ardalanmalıdır. Tüm bu birimler Mesozoik yaşlı Akbayır formasyonuna ait kireçtaşları üzerine uyumsuzluk ile gelmektedir. Tüfit illit, volkan camı parçaları, tridimit, biyotit, kuvars ve plajiyoklasdan oluşmaktadır. İnceleme alanında yaygın yayılıma sahip olup bazı binaların temel kayasını oluşturmaktadır.

Bu tez kapsamında tüfitin mühendislik jeolojisi yönünden özelliklerinin belirlenmesi ve temel malzemesi olarak uygunluğu araştırılmıştır. Bu amaçla saha ve laboratuvar araştırmaları yapılmıştır. Saha çalışmaları ayrıntılı saha gözlemlerini içermektedir. Laboratuvar çalışmaları sırasında tüfitin mekanik, indek ve mineralojik özellikleri araştırılmıştır.

Analiz sonuçları tüfitin çok zayıf (0.1 MPa-1.00 MPa) kaya sınıfında olduğunu göstermektedir. Yüksek gözenekliliğe ve çok düşük kuru ve doygun (sırası ile 1.19 Mg/m^3 ve 1.62 Mg/m^3) yoğunluğa sahiptir. Suda aşınma deneylerine göre orta duraylılığa sahip olan tüfitin duraylılık indeksi çok düşük olarak sınıflandırılmıştır.

Gerek indeks özellikleri ve gerekse duraylılık sınıflaması dikkate alındığında tüfitin zayıf bir temel malzemesi olduğu anlaşılmaktadır.

Anahtar Sözcükler : Tüfit, Hançili formasyonu, Mühendislik Jeolojisi Özellikleri, Çayyolu, Ankara.

This thesis is dedicated to loving memory of my precious father Mehmet Emin FERSOY with yearning and honour...

ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude to my supervisor Prof. Dr. Vedat Doyuran and send my special regards to him for his guidance and encourage on me to complete this thesis.

In addition, I would like to express indebted thanks to Prof. Dr. Reşat Ulusay for technical equipments and academic advice.

I would like to thank Prof. Dr. Kadir Dirik and Prof. Dr. Ali Koçyiğit for their informative advices about the site geology.

Thanks also go to Assoc. Prof. Dr. Yusuf Kaan Kadıoğlu for his sincere behaviour and caring motivation on my uneasy times during my study.

I am grateful to Burcu Ertaş with whom the laboratory hours were incomparable and to Gülfem Alsan for her kind friendship.

Endless thanks are due to my beloved M.İlkkan Kılıç affectionately for his backup in all ways of my life and his patience during this study.

Finally, my dear mother, Meser Fersoy, as any plentiful phenomenon that created me or that I created till now, this thesis is a product of your labour and reliance on me.

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CHAPTER 1

INTRODUCTION

1.1 Purpose and Scope

Ankara is one of the most densely populated cities of Turkey with its 4.007.860 citizens according to census data in 2000. This number still continues to increase rapidly and new allocation units are more needed to be constituted day by day (Turkish Statistical Institute, 2008). Regarding to this fact, Çayyolu is a presently developing neighborhood on the west of Ankara due to growth of population in the city center and increase in need of new settlements (Figure 1.1).

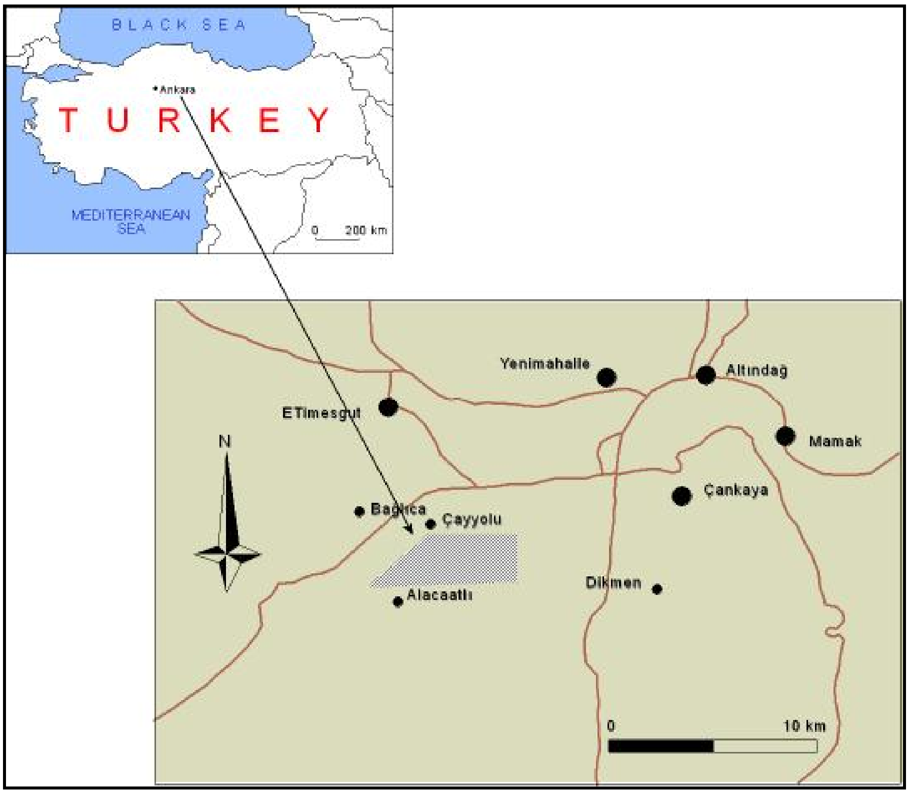

Figure 1.1 Location map of Çayyolu quoted from 1/100.000 scale Ankara map of Akyürek *et al.* (1997).

In this enclave, a great number of constructions still progressively continue. These constructions, excavations and road cuts aid in clear observation of once concealed units in the Çayyolu district. Tuffite is one of those units realized in an outcrop created at the N-S aligned Çayyolu-İncek road excavation in 2005 along the İncek Boulevard (Figures 1.2 A and B).

Figures 1.2 (A) Road construction in Çayyolu (B) Tuffite exposure along the road cut.

Tuffites are volcanoclastic (pyroclastic) rocks formed of rock fragments ('clast', from the Greek klastos, broken in pieces), that are flungout of volcanoes.

In other words, tuffite is a tuff containing both pyroclastic and detrital material but predominantly pyroclasts (Bates and Jackson, 1980). In practice, pyroclastic and volcaniclastic rocks include all the products of extrusive volcanic activity except lava flows. A volcaniclastic rock is one containing volcanic material in whatever proportion and without regard to its origin or environment of deposition.

The term ‘pyroclastic’ is used for classic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent. The distinction between tuff and tuffite is based on volcanic origin but sedimentary characteristic of tuffite. Moreover, on account of its engineering geological and physical parameters that will be explained afterwards, tuffite is a transition material between soil and rock.

The tuffite member of Hançili formation is evident under Bircan houses in the western side of the İncek Boulevard (Figure 1.3). The tuffite exposed in this area forms the foundation of many houses. Just across this location, in the east bank of the boulevard, this member identically exists in the same sequence (Figure 1.4).

The purpose of this thesis is to determine the index, mineralogical, and material properties of the tuffites of the study area, and to evaluate the engineering characterization of the tuffite member of the Hançili formation by means of laboratory tests and field study since they form the foundation of several buildings either completely or partially.

Figure 1.3 A view of Hançili tuffite exposure under Bircan Houses (Looking west).

Figure 1.4 A view of Hançili tuffite exposure on the east bank of the road.

1.2 Location of the Study Area

The study area is located on the west of Ankara and is approximately 14 km away from the city centre. The accessibility of the site is provided by asphalt paved Eskişehir-Ankara E90 highway.

This area is included in the 1/25.000 scale topographic map sheets of Ankara i29-a2. A contemporary Google Earth view of the area and vicinity is presented in Figure 1.5 for introducing the location of tuffite member of the formation and the surrounding locations with roads.

Figure 1.5 Google earth view including the study area and its vicinity.

In the western part of the area, Ümitköy and centre of Çayyolu are located and on the east of the area there is Kocabayır Hill. In addition, Beysukent is located in the northeast and İncek is located further south of the thesis area.

1.3 Climate

The study area is located in the Central-Anatolian region of Turkey which is characterized by continental climate which exhibits cold and rainy winters and arid and hot summers.

Based on the records of Turkish State Meteorological Service, average annual rainfall in Ankara for the last 33 years is 382 mm and the average annual temperature is 11, 8 °C. The meteorological data of Ankara for the last 33 years is listed in Table 1.1.

Table 1.1 Average monthly data for Ankara for the last 33 years (Turkish State Meteorological Service, 2008)

Months	*Average Temperature (°C)*	*Average Maximum Temperature (°C)*	*Average Minimum Temperature (°C)*	*Average Insolation Time (hours)*	*Average Number of Rainy Days*
January	0.4	4.3	-2.9	2.6	11.5
February	1.9	6.5	-2.2	4.0	10.2
March	6.0	11.6	0.8	5.6	10.2
April	11.2	17,0	5.7	6.4	12.6
May	15.9	22.0	9.6	8.6	12.4
June	19.9	26.3	12.9	10.4	9.3
July	23.4	30.0	16.0	11.4	4.0
August	22.9	29.8	15.8	10.9	3.3
September	18.5	25.9	11.7	9.4	3.7
October	12.9	19.7	7.3	6.6	7.3
November	6.6	12.3	2.2	4.4	9.0
December	2.3	6.1	-0.8	2.4	11.1
Average	**11.8**	**21,6**	**6.3**	**6.9**	**8.7**

1.4 Methods of the Study

The study comprises five main stages. The initial stage involves project conception and site reconnaissance. The literature survey includes collection of 1/100.000 scale topographical and geological maps of the study area and its vicinity, and gathering both published and unpublished reports, papers and supplementary documents.

In the second stage, field studies were performed in order to determine uniformity and characteristics of the tuffite member of the Hançili formation in the study area. Lithological boundary of the tuffite with other units of the sequence was also investigated.

The third stage involves rock mass characterization. The discontinuity survey was performed on account of representing discontinuity spacing, apertures, discontinuity persistence and asperities.

The fourth stage comprises preparation of samples for laboratory tests. In this stage, rock blocks taken from the field were first prepared for the tests. Despite of the restriction to get representative specimens with current drilling equipments and techniques, preparation of the specimens for testing was carried out in the laboratory by manual and mechanical cutting in a very sensitive manner and representative samples could be handled. Upon completion of this stage, a set of physical and mechanical tests have been performed on these samples. The engineering properties of the tuffite investigated comprises; effective porosity, unit weight, water absorption, uniaxial compressive strength, point load strength index, needle penetration value, sonic velocity, slake durability index and jar slake index.

Mineralogical and petrographical studies were carried out through thin-sections in optical microscopy, scanning electron microscopy, X-ray diffraction, X-ray fluorescence and methylene blue adsorption.

The fifth stage covers the final evaluation of the overall gathered data.

1.5 Previous Works

Literature survey on engineering geological properties of tuffite was an intricate task in view of the fact that mechanical behavior and/or index properties of tuffite that are closely associated with engineering characterization are not present.

Creating the matrix of the Hançili tuffite, a relevant research of Fisher and Schiminke (1984) on volcanic glass is taken into consideration in this section since this study states that volcanic glass is thermodynamically unstable and decomposes more readily than nearly all associated mineral phases.

There exist several approaches that are mainly focused on tuff to be correlated with tuffite member of the Hançili formation in Çayyolu region since mechanical and physical properties somehow resemble each other. Besides, approaches regarding origin and chemical characterization of tuff are readily available in literature. On the other hand, previous studies on the geotechnical characterization of tuffite are not as widespread, nearly none. In this section, a summary of investigations on engineering properties of tuff is documented in a way to support meaningful and acceptable results of the test of this thesis.

Topal (1995) studied formation and deterioration of the Kavak tuff in Ürgüp-Göreme area and revealed that the Kavak tuff has poor durability. Based on his test results, the Kavak tuff has a very high effective porosity and a very low dry unit weight. Its water absorption averages around 21.60 % under atmospheric pressure and 28.06 % under pressure. Topal (1995) states that, these tuffites are moderately weak to weak and have point load strength indices ranging between 0.12 MPa and 0.50 MPa. The Kavak tuff has low sonic velocities.

Baba (1995) studied engineering geology of the Ürgüp-Göreme tuffs and revealed that fairy chimneys in the area are developed in Neogene sequences consisting of tuff, tuffite, ignimbrite, lahar, volcanic ash-flow and marl intercalations. Resultant to chemical analyses, SiO_2 and Al_2O_3 existence in the composition is also noted. Water absorption, unit weight and porosity of the Kavak tuff showed similarities with those obtained by Erguvanlı & Yüzer (1977), Erdoğan (1986), METU Research Team (1987), and Topal and Doyuran (1995).

Sözmen (2000) examined the very weak to weak Yazılıkaya tuffs in Midas Monument, Eskişehir, and pointed out the likely values with the Hançili tuffite such as effective porosity of 38.82%, dry unit weight of 12.22 kN/m^3 and saturated unit weight of 16.03 kN/m^3 (for white tuffs in his study area). In addition, dry indirect tensile strength value of Yazılıkaya white tuffs is 0.71 MPa. Saturation coefficient of this material is also quite near to that of the Hançili tuffite saturation with 0.74 (by weight) and 0.79 (by volume). Weakness of Yazılıkaya white tuff is also revealed by point load strength index test with 0.80 MPa and 0.25 MPa in dry and saturated states, respectively. The slake durability indices after two test cycles are nearly approximating with 91%.

Sölpüker (2002) reviewed the measurements of Yazılıkaya, Elmadağ, Orta and Karacadağ in an engineering geological manner and noted parallel values of strength, effective porosity and unit weight, water absorption under atmospheric pressure and water absorption under pressure with Hançili tuffite in Çayyolu region, Ankara. Besides, in this study, the nearest values of uniaxial compressive strength are those of Mamak tuffs with values ranging between 0.2 and 0.7 MPa.

There are a great number of geological studies carried out previously in the study area and its vicinity. The geological information given here is a compilation of the previous studies conducted by several researchers on tuffite and/or Hançili formation.

Akyürek *et al.* (1997) prepared 1:25.000 scaled geological maps of Ankara and compiled them on 100.000 scale with brief description of various lithological units. Field investigations and personal discussions with Koçyiğit (2008) clearly reveal that the tuffite member in the study area is included in the Hançili formation overlying limestone basement, which was named as Akbayır formation by Akyürek *et al*. (1995).

Karadenizli *et al*. (2003), at the Çankırı-Çorum basin, revealed that tuffite member of the formation consists of plagioclase crystals set in the volcanic ash matrix. More to the point, due to high amount of epiclastic material income, tuffite is thought to be reworked.

The Hançili formation is additionally focused on by Savaşçı and Seyitoğlu (2004) regarding syn-sedimentary tectonic structures in the Kumartaş and Hançili Formations in Çankırı basin. Among to this research, the Kumartaş formation is mentioned to laterally and vertically grading into the overlaying the Hançili formation and normal faults observed within these units indicated existence of extensional tectonics in Early - Middle Miocene in the Çankırı basin. The Hançili Formation was first named by Akyürek *et al.* (1980). Kaymakçı (2000) determined the age of the formation as Early- Middle Miocene. In Hançili Formation, alternation of gray and beige sandstone, siltstone and mudstones are observed at the base. Other members of the formation include silty mudstone, gray-to-green claystone, marl, beige clayey limestone and tuff (Savaşçı and Seyitoğlu, 2004).

Dirik *et al.* (2005) performed studies in Çayyolu, Ankara with a view to introduce Ankara duplex which is stated to be a new evidence of Post-Miocene contractional regime around Ankara in consequence of their evaluation. With respect to this research, the age of the Hançili formation units exposed in the study area was determined as Post-Miocene. The Neogene rocks consist of an alternation of multicolored siltstone, claystone, sandstone, and thick, white to cream limestone deposited in a lacustrine environment. Folds and faults in the limestones constituting the upper levels of the Mesozoic basement suggest WNW- to NW-trending compressional tectonics. A characteristic duplex structure, named herein Ankara Duplex, was observed in the Neogene rocks having different competence.

The Hançili formation is additionally taken into account by Bağırgan (2007) in her master thesis in which the age of this formation is accepted as early-middle Miocene. Nevertheless, Akyürek *et al.* (1980) have assigned an age of Middle-Late Miocene. The field investigations reveal creamy to beige colors and gastropoda fossil fragments typical for the Neogene lacustrine environment.

CHAPTER 2

GEOLOGY

2.1 Geology of the Study Area

Areal distribution of the units is exposing in the study area are given Figure 2.1 and the stratigraphical column is presented in Figure 2.2.

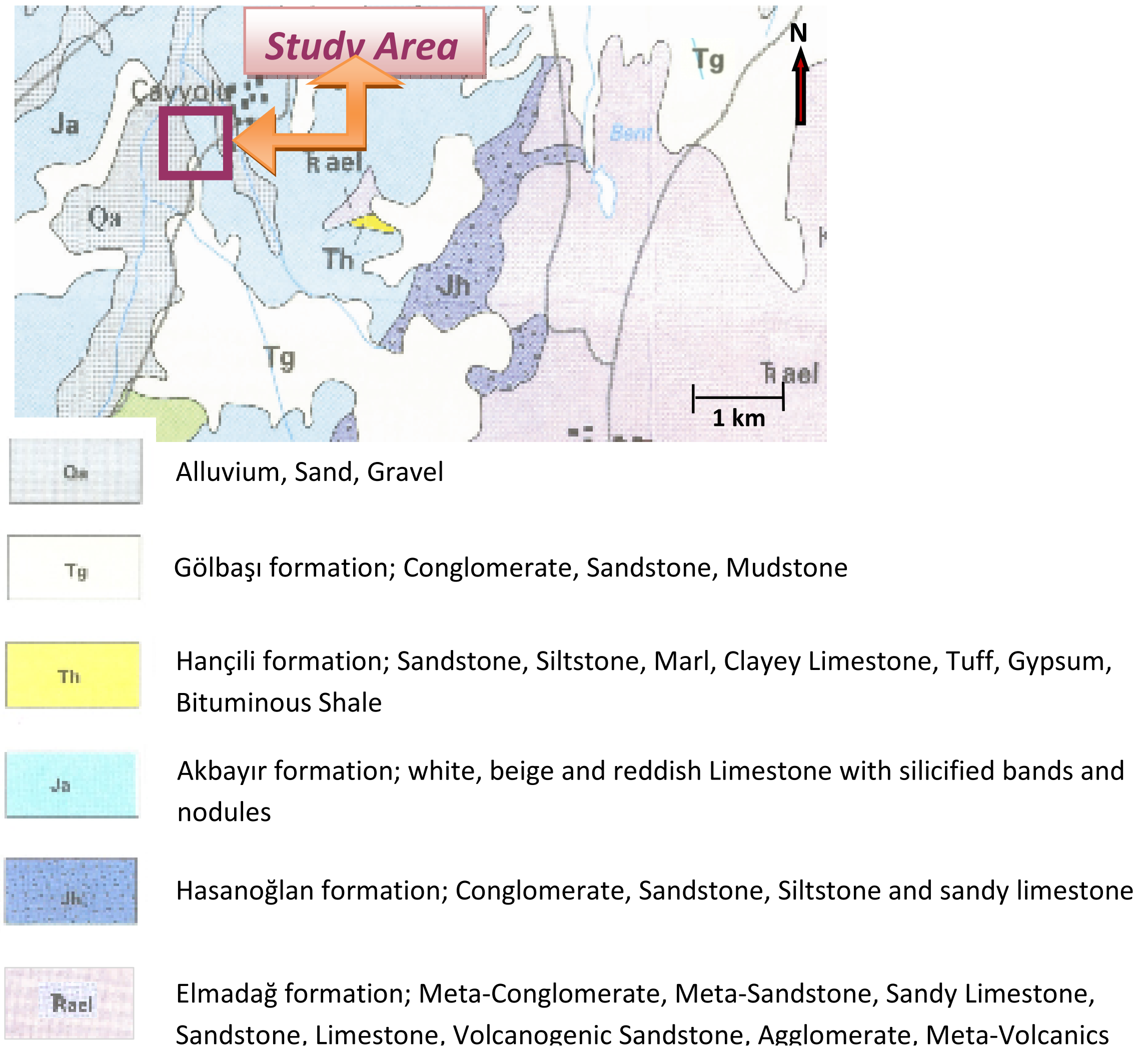

Figure 2.1 Simplified regional geological map of the study area (modified from 1/100.000 geological map of MTA, Ankara sheet, 1995).

The units exposing in and at close vicinity of the study area include; Quaternary alluvial deposits, Gölbaşı, Hançili, Akbayır, Hasanoğlan and Elmadağ formations (Akyürek *et al.* 1997)

The Elmadağ formation is of Triassic and is mostly composed of metamorphosed sandstone-shale sequence and gravelstone. In course of the deposition of the Elmadağ units, volcanism was additionally in process (Akyürek *et al.*, 1995).

The Hasanoğlan formation is composed of sandstone, mudstone, sandy limestone and gravels deposited within alluvial fan environment. The age of the Hasanoğlan formation was assigned as Liassic (Bilgütay, 1960; Ketin, 1962; Akyürek *et al.,* 1982).

The Akbayır formation is transitional to the Hasanoğlan formation (Akyürek *et al.,* 1982). The Akbayır formation is formed during Dogger-Malm and equivalent to Jurassic Limestone (Bilgütay, 1960) and the Lalelik formation (Batman, 1978). This formation is generally represented by medium to thin bedded, hemipelagic biomicritic limestone and was first introduced by Akyürek *et al.,* (1982).

The geology of the road cut slope in the study area is rather complex. It comprises an alternating sequence of limestone, tuff, marls, mudstones and tuffite of the Hançili formation deposited within a lacustrine environment during Neogene. Within the study area, the Hançili formation is exposed along 200 meters long segment of the road cut and is underlain by the white to cream limestone of the Akbayır formation.

The Hançili formation is composed of argillaceous limestone, marl, siltstone, sandstone, conglomerate and tuffite, and includes bituminous gypsum and shale in some places. This formation is deposited within streams and lakes (dominantly in the environment of lakes) of a terrestrial environment by which alluvial fans were developed and gradually this basin was entirely wrapped into lacustrine character. During this depositional process, active volcanism intercalated tuffite in deposition of this sequence (Akyürek *et al*., 1997).

White to yellowish-white, thin-to-medium bedded clayey limestone is underlain by white-to-creamy white tuffite and these units alternate yellowish-white to light green, thin-to-medium bedded mudstones.

Siltstone-marl in the formation is grey, weakly cemented, laminated and thinly layered. This alternation exhibits complexity and rock types show local variations.

The Hançilli formation is equivalent to Middle-Lower Miocene Lacustrine limestone (Erol, 1956), Lower-Pliocene deposits (Çalgın *et al,.* 1973) and Kavaklı formation (Akyürek *et al.*, 1982, 1984).

The Gölbaşı formation initially termed by Akyürek *et al.* (1984), within Pliocene epoch and comprises conglomerates, sandstone, and mudstone. It is generally free of laminations and composed of alluvial fan and fluvial deposits.

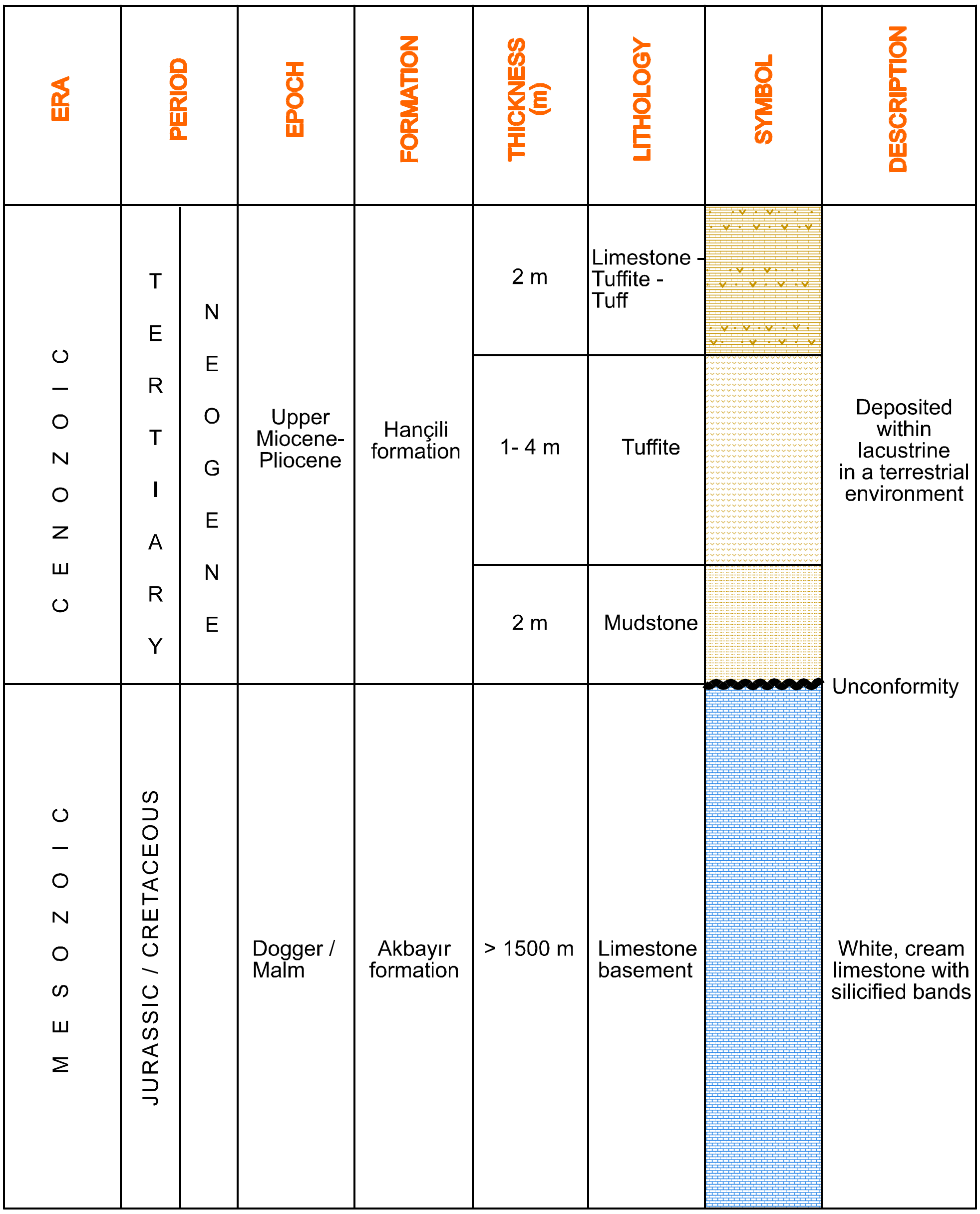

Figure 2.2 Generalized stratigraphic column of the Hançili Formation in the study area.

2.2 Description of the Material

The tuffite of the study area is white to cream, medium-to-thick bedded, fine grained, slightly weathered and soft (Figure 2.3). Under the microscope glass shards, pumice, tridymite, illite, biotite, quartz and albite crystals are recognized within a glassy matrix.

The tuffite layers are alternating with limestone-tuff, mudstone and marl layers. Above the tuffite layer limestones of 1.5-2 m thick are observed. The limestones are light beige to light brown, slightly weathered and include gastropod in sparitic calcite matrix with beige fresh surface color. Light green to light brown mudstone layers underlie 1-4 m thick tuffite on the top of the excavation. Mudstone layers are underlain by 1.1-2 m thick marls of light gray in color. This complex sequence of tuffite, marl, mudstone and limestone clearly reveals the deposition within lacustrine environment.

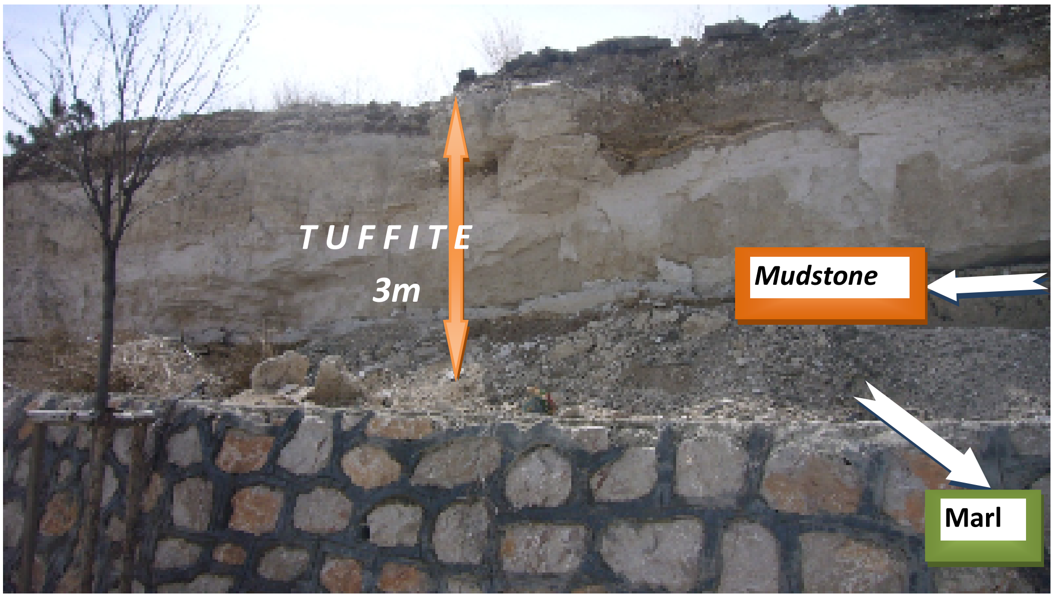

Figure 2.3 Close-up view of the tuffite member with other units in the sequence.

2.3 Structural Geology

The faults in the study area are locally developed during and/or after the volcanism. They are normal faults and no deformation at the top soil is observed. Persistence of these faults in younger units (post Pliocene) is not observed as well. Regarding to these facts, a statement on these as they are active or inactive would not display consistency. On the other hand these normal faults are not an extension of north Anatolian fault zone and they are not thought to create potential earthquakes.

In the geological cross-section of the west bank of the road (Figure 2.4), the positions and orientations of the normal faults encountered under the buildings are signified and in the cross-section of the eastern bank of the road (quoted from Dirik et al., 2005) are presented (Figure 2.6). Figure 2.5 illustrates the geological units and positions of normal faults on the east bank of the Çayyolu-İncek road.

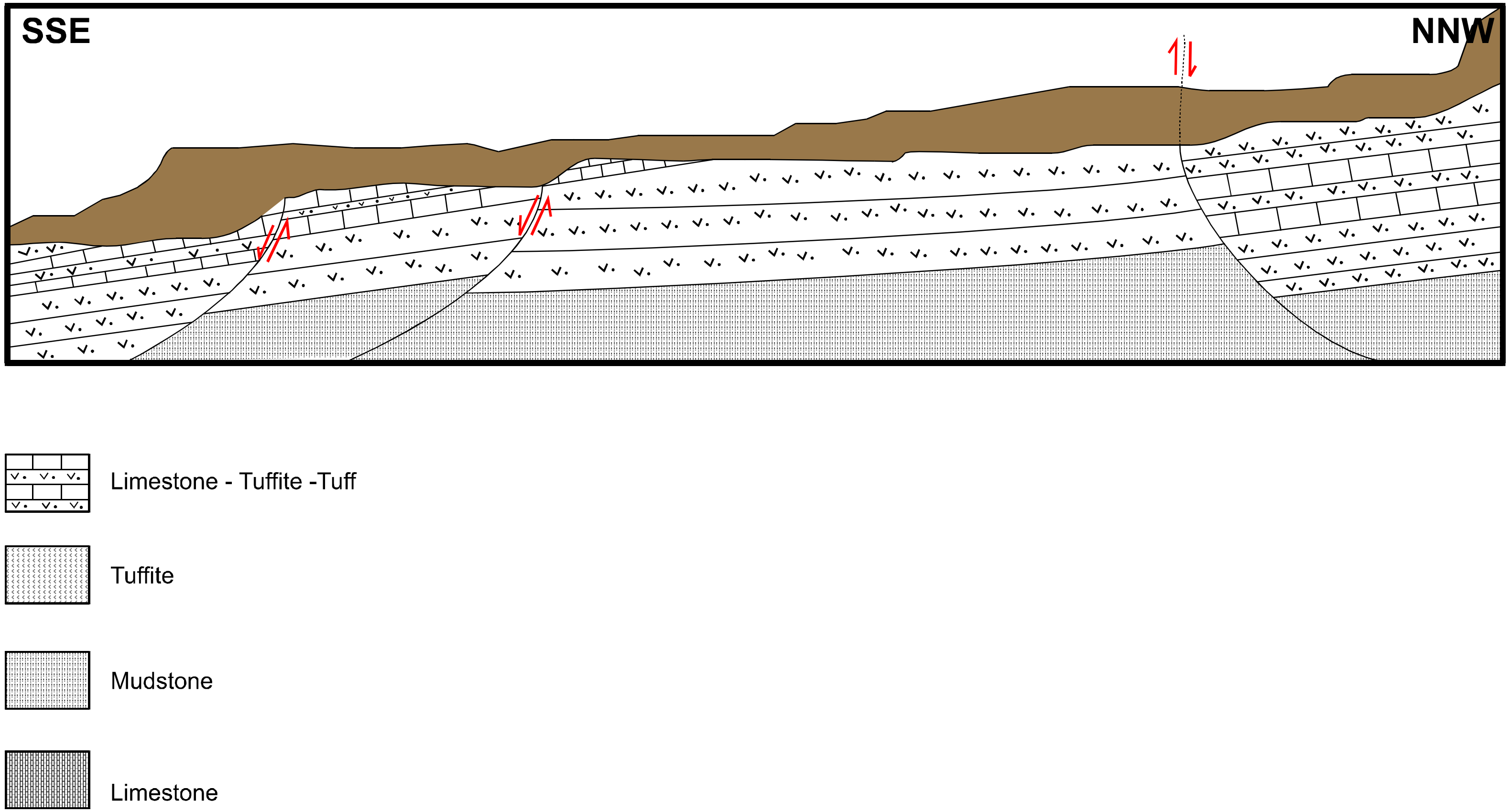

Figure 2.4 Geological cross-section of the west bank of the road within a horizontal length of 200 m (under the Bircan buildings)

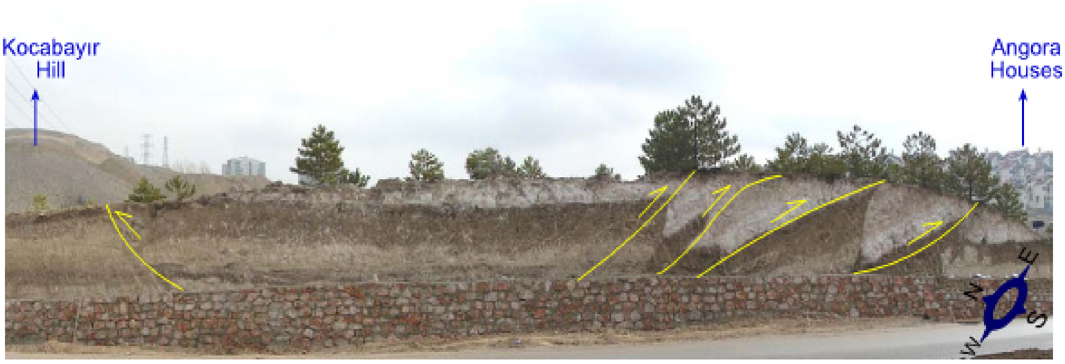

Figure 2.5 Photograph illustrating the geological units and positions of normal faults on the east bank of the road.

Dirik *et al.* (2005) performed an investigation on the west bank of the Çayyolu-İncek road with a view to introduce Ankara duplex which is stated to be a new evidence of Post-Miocene contractional regime around Ankara in consequence of their evaluation. With respect to this research, folds and faults in the limestone constituting the upper levels of the Mesozoic basement suggest WNW- to NW-trending compressional tectonics. A characteristic duplex structure, named herein Ankara Duplex, was observed in the Neogene rocks having different competence (Figure 2.4)

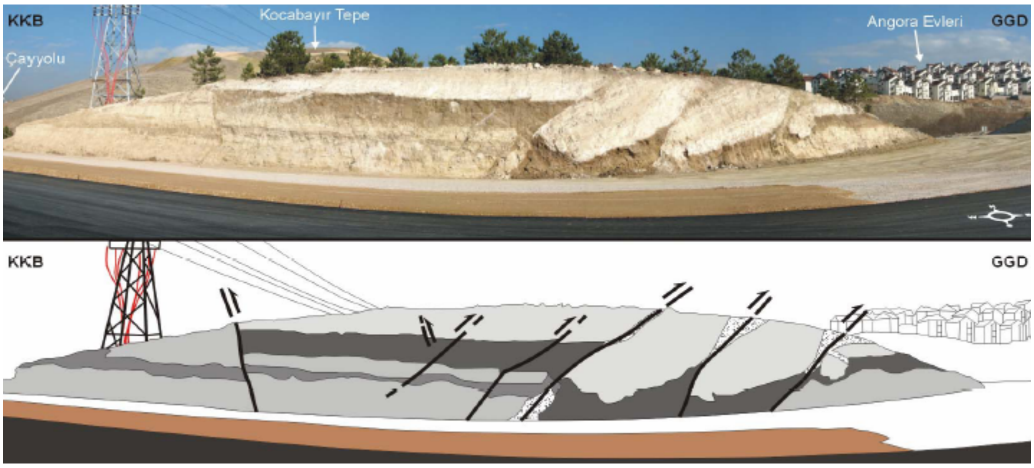

Figure 2.6 Illustration of Ankara Duplex with the faults and photograph of the location by Dirik *et.al* (2005).

The mass properties of the tuffite units were studied during the field studies. No survey on the joints of other units in the sequence is considered since the alternating units are clayey and fractured and since tuffite member is the focus of this thesis**.**

Two joint sets and a bedding plane are the main discontinuity sets observed within the tuffite member of the Hançili formation under Bircan Houses. The bedding plane is measured to have an orientation of 62^{o}/246 (dip /dip direction). The dip and dip direction of the two joint sets are nearly 52^{o}/155 and 80^{o}/052 .Even though close sight observation is obligatory to investigate the joints; bedding is clearly noticeable from a considerable distance.

The tuffite member is underlain by dry and highly fractured mudstones. Upper limestone units including tuff fragments are also difficult to measure concerning this fractured nature. Consequently, continuity of the joints of the tuffite cannot be possible to observe neither along the underlying unit nor in the limestone (Figure 2.7).

However, joints of the tuffite member are locally well-developed. Due to this fact, the tuffite unit is determined as bed confined. The joints of nearly 90^{o} are additionally shown in Figure 2.7. In the study area, no extensive exposures of tuffite were available. In addition, Çayyolu-İncek road cut slope does not exhibit a smooth surface due to detached blocks.

Figure 2.7 Photograph showing the tuffite unit with nearly 90^{o} units and the underlying fractured mudstone layer.

CHAPTER 3

GEOMECHANICAL PROPERTIES OF THE TUFFITE MEMBER

The laboratory tests were carried out at the Engineering Geology Laboratory of the Department of Geological Engineering of METU and Engineering Geology Laboratory of the Department of Geological Engineering of Hacettepe University. These tests and analysis were performed by following the methods suggested by ISRM (2007), RILEM (1980) and TS699 (1987).

The index properties of the rocks were determined through laboratory tests comprising the determination of dry and saturated unit weights, effective porosity, water absorption, saturation coefficient, slake durability index, jar slake index, needle penetration resistance, point load strength index, sonic velocity and dry and saturated uniaxial compressive strengths.

The average test values of the tuffite member of the Hançili formation are presented within the text. On the other hand, the detailed presentation of the test results is included in the Appendix.

In order to achieve this goal, block samples of the Hançili tuffite were collected from a total of 4 locations either at the eastern (Figure 3.1) and western sides of the study area (Figure 3.2).

Figure 3.1 Photograph showing the locations on the west bank of the road from which block samples were collected.

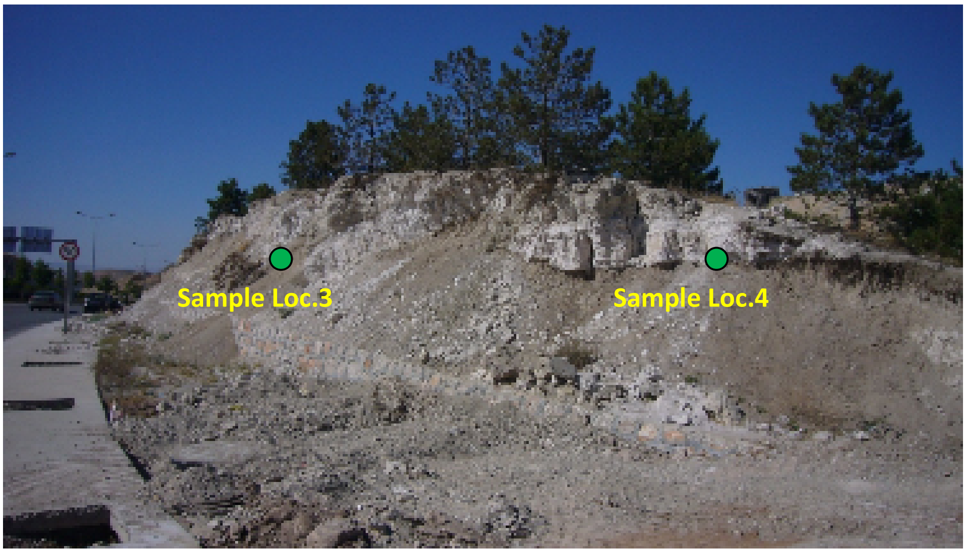

Figure 3.2 Photograph showing the locations on the east bank of the road from which block samples were collected.

The engineering geological characteristics of the tuffite samples were evaluated by means of field observations and laboratory tests. To obtain representative specimens of the Hançili tuffite, 15 block samples were gathered. Current drilling equipments and techniques tend to damage weak rocks; as a consequence, it was not possible to obtain high quality samples. Since the road cut in the study area is the unique available fresh excavation, block sampling could be carried out.

The preparation of the specimens for testing has then been carried out in laboratory by manual and mechanical cutting. Blocks were transformed into minor dimensions at first by using ribbon saw to be trimmed with fret saw in the second step. Subsequently, these tuffite lumps were rasped and filed for the purpose of matching the dimensions, shape, regularity and uniformity of those prepared via machines and/or equipments suggested for stronger rocks by international standards.

Finally, a keen-edged knife is used to sharpen the surfaces and corners of cubic samples and smooth away the snags of NX core sized cylindrical samples. Thin-section preparation device was used for mechanical cutting for circumstances in which it was arduous to divide the lumps. Using these techniques, 20 cubic samples with 5cm x 5cm x 5 cm dimensions were acquired (Figure 3.3).

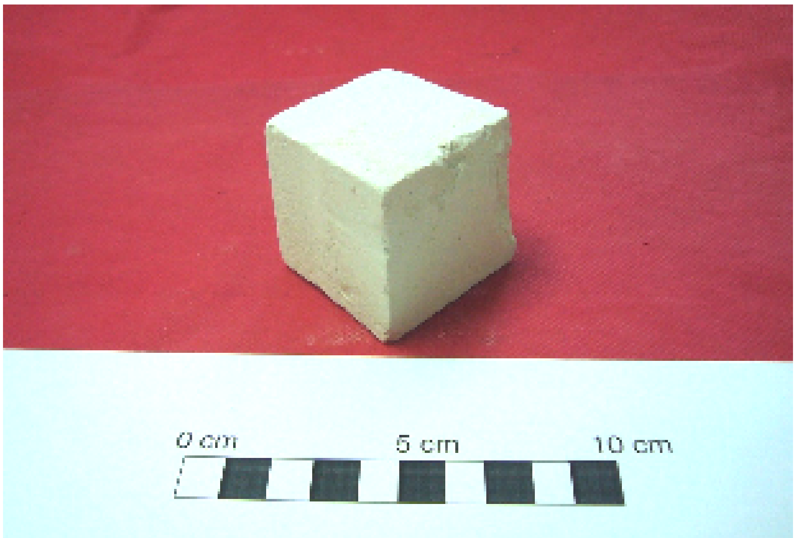

Figure 3.3 Photograph of a 5cm x 5cm x 5cm cubic sample manually cut for testing.

In addition to cubic samples, the preparation of cylindrical and NX sized core samples was carried out by trimming of the blocks. This was a very tedious task. Otherwise, there was no possibility in obtaining core samples since the tuffite becomes disintegrated upon contact with water. 10 NX core sized specimens are prepared by manual cutting and trimming of the blocks (Figure 3.4).

Nevertheless, even using great care, intact cylindrical samples could not be achieved to assess accurately most of the relevant properties. The shape and dimension of these samples were not possible to fix the standards when prepared manually (Figure 3.5).

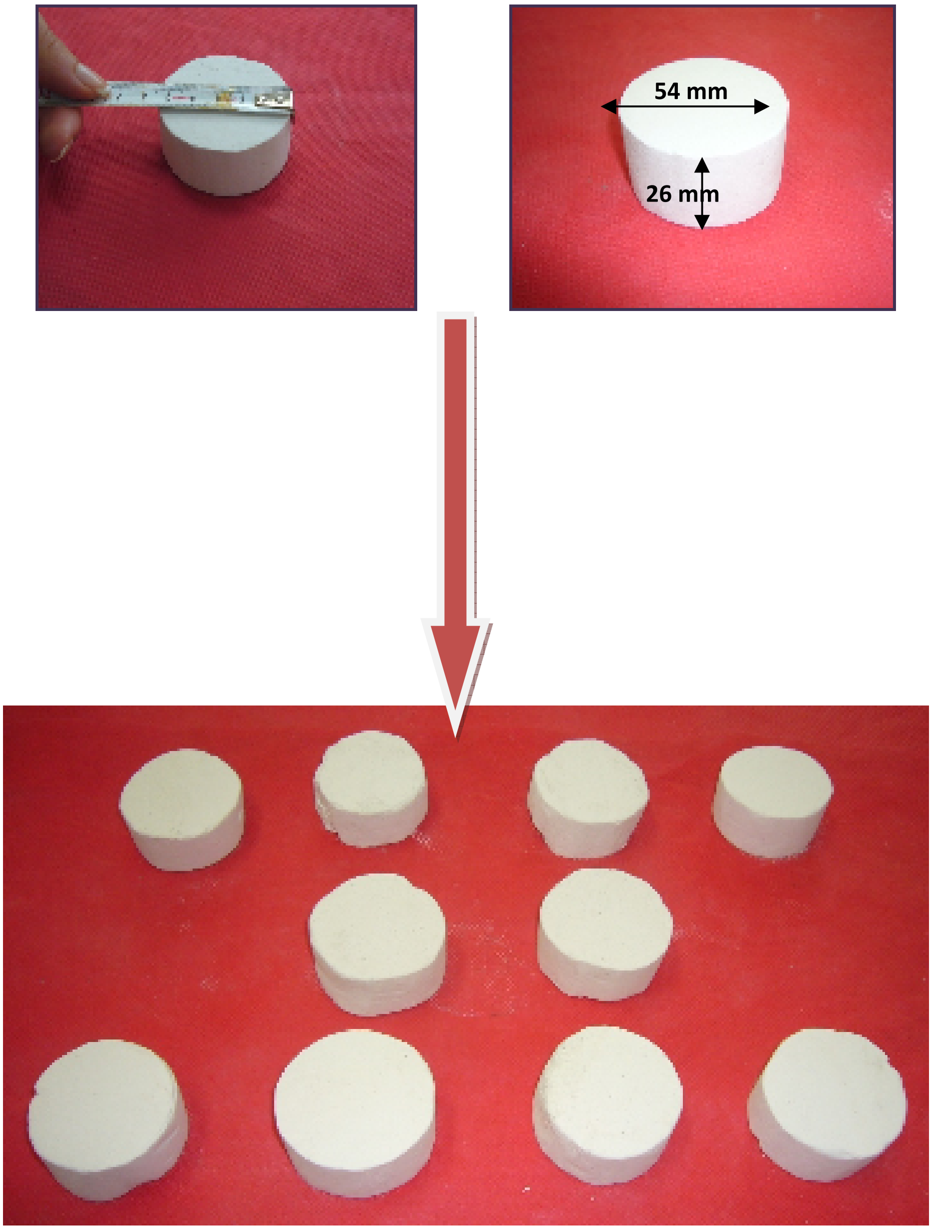

Figure 3.4 Photograph of 10 NX core sized specimens prepared by manual cutting and trimming of the blocks.

Figure 3.5 Photograph of cylindrical samples trimmed of the blocks inappropriate for testing.

3.1 Physical, Index and Mechanical Properties of the Tuffite

3.1.1 Effective Porosity and Unit Weight

Considering the fact that pores in the fabric of a rock material result in a decrease in its strength, and increase in its deformability, effective porosity and unit weight are two significant index properties of a rock. The presence of pores creates a direct relationship with the unit weight. A low density rock is usually highly porous. Effective porosity, dry and saturated unit weight of the Hançili tuffite were determined by using suggested method for determination with saturation and buoyancy techniques (ISRM, 2007). For this test; 10 tuffite samples were used.

The average values of effective porosity, dry and saturated unit weights of the Hançili tuffite are given in Table 3.1 and the general effective porosity and unit weight test results is given in the Appendix.

Table 3.1 Average effective porosity and unit weights of the tuffite.

HANÇİLİ TUFFITE	***VALUES***	***Engineering Classification ANON (1979)***
The average effective porosity (%)	43.33	Very high
Dry unit weight (kN/ m^3)	11.68	Very low
Saturated unit weight (kN/m^3)	15.93	Very low

In relation to Anon (1979), the Hançili tuffite is concluded to have very high porosity and very low density. Considering this very high porosity value, it is accepted to have high water absorption.

3.1.2 Water Absorption under Atmospheric Pressure

This test is intended to measure the amount of water absorbed by a rock under atmospheric pressure and expressed in percentage. The tests were performed according to TS699 (1987). A total of 10 samples were subjected to this test with a view to calculate water absorption values by weight and volume individually. Under atmospheric pressure, the average water absorption by weight and the average water absorption by volume values are 36.52(%) and 43.33(%) respectively. The overall water absorption under atmospheric pressure test results is given in the Appendix.

3.1.3 Water Absorption under Pressure

Water absorption under pressure test was performed on the same samples used for the water absorption under atmospheric pressure test according to ISRM (2007). Throughout the test, the water absorption percentages by weight and volume were determined.

The average value of water absorption by weight under pressure is 40, 93(%) and the average value of water absorption by volume under pressure is 49, 26(%).

Saturation coefficient (S) of a stone is the ratio between the natural capacity of a stone to absorb water after complete immersion under atmospheric pressure for a definite time, and its total volume of the pores that is accessible to water.

The average water absorption values of the tuffite member of Hançili Formation under pressure and the saturation coefficient by weight and volume are presented in Table 3.2 and the test results are tabulated in the Appendix.

Table 3.2 Average water absorption values of the tuffite member of the Hançili formation under pressure.

HANÇİLİ TUFFITE	*VALUES*
Water absorption by weight (%)	40,93
Water absorption by volume (%)	49,26
Saturation coefficient by weight	0,89
Saturation coefficient by volume	0,89

Derived from the test results, it is apparent that, Hançili tuffite considerably exhibits higher water absorption under pressure than it does under atmospheric pressure.

3.1.4 Uniaxial Compressive Strength

The uniaxial compressive strength (UCS) test is mainly used for the strength classification and characterization of an intact rock (ISRM, 2007). The UCS value is also employed in design. 10 cubic samples (5cm x 5cm x 5cm in size) are used for first dry and following saturated conditions of the test.

During the tests, a motorized hydraulic compression machine with a loading capacity of 1500 kN was used. The pace rate of hydraulic compression machine was so adjusted that failure takes place in about 5 minutes.

According to ISRM (2007), the tuffite has very low strength both in dry and saturated states. The UCS is constantly higher in dry state rather than in saturated state. The ISRM classification for intact geotechnical materials has made a distinction between rocks and clays by upper strength for hard clay and the overlap between extremely weak rock and very stiff and hard clays, regarded as materials on the fringe of the two main sciences. The guideline of ISO (International Standards Organization), classifies a geological material with strength values less than 0.6 MPa as ‘soil’ (Singh and Goel, 1999).

According to ANON (1979), the tuffite member of the formation is very weak in dry and saturated state. Moreover, another comprehensible statement is that the tuffite has a strength, which corresponds to ‘very weak’ class in all engineering classification systems. The tests to this point indicate that tuffite has relatively low strength and high moisture sensitivity as a typical soft rock.

The average UCS values of the Hançili tuffite in dry state and saturated states are presented in Table 3.3 and the general test results are tabulated in the Appendix.

Table 3.3 Average UCS values of the Hançili tuffite in dry state and saturated states.

HANÇİLİ TUFFITE	*VALUES*	*Engineering Classification ANON (1979)*	*Engineering Classification ISRM (2007)*
Dry UCS*(MPa)	0.40	Very weak	Very low
Saturated UCS*(MPa)	0.07	Very weak	Very low

* UCS- Uniaxial compressive strength

3.1.5 Point Load Strength Index

The point load strength test is intended as an index test for the strength classification of rock materials. It may also be used to predict other strength parameters with which it is correlated, for example uniaxial tensile and compressive strength. (ISRM, 2007) The point load strength of the samples was determined according to ISRM (2007) on 10 irregular lumps.

Within the test results, the highest and the lowest values are omitted. The average point load strength index for tuffite member of the Hançili formation, average Is $_{(50)}$ is 0.05 MPa, and according to Broch and Franklin (1972), this value corresponds to 'very low strength rock'.

Weak rocks generally yield low correlation coefficient (k) while assessing UCS from $Is_{(50)}$. In this study, correlation factor is attained as 11.2. This figure is in good agreement with the correlation factor for the Cappadocia tuffs given by Topal (2000). The correlation between $Is_{(50)}$ and UCS is given in Figure 3.6 and the overall point load strength index test results for tuffite member of the Hançili formation are tabulated in the Appendix.

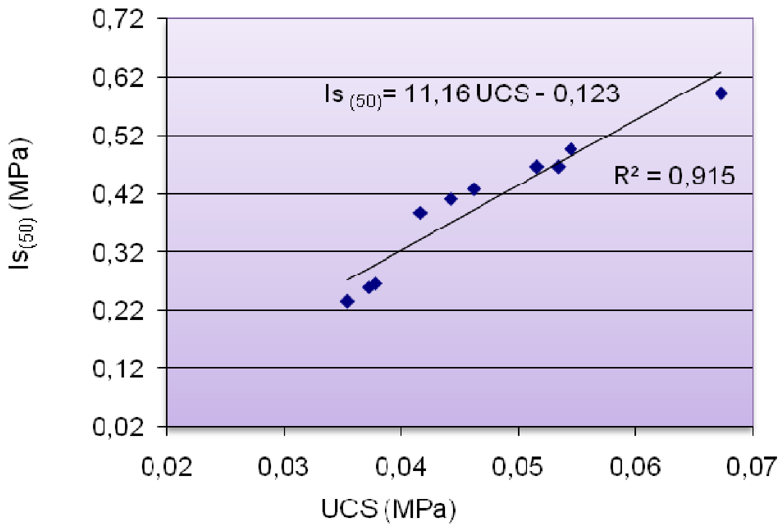

Figure 3.6 The correlation between $Is_{(50)}$ and UCS.

3.1.6 Needle Penetrometer Test

High quality core samples recommended by testing standards or suggested methods for uniaxial compressive strength (UCS) determinations cannot always be obtained particularly from weak, thinly bedded and clay-bearing rocks. Due to this difficulty, some simple index test methods have been developed in order to indirectly estimate the UCS. However, preparation of small specimens from such rocks for these simple index tests is also difficult (Ergüler & Ulusay, 2007). In recent years, a new and portable testing device called needle penetrometer has been developed. By means of UCS, test results the tuffite member of the Hançili formation is classified as a very weak rock and hence the tuffite samples are vey suitable for the needle penetration test.

In rock mass classification systems such as RMR (Bieniawski, 1989) and in rock engineering applications the most significant parameter is agreed to be the UCS of rock materials. On account of the problems and limitations in obtaining regular samples from weak, stratified and clay-bearing rocks, a new and non-destructive portable testing device called needle penetrometer has been developed by a manufacturer in Japan (Maruto Corporation, 2006) to be another alternative besides the point load test for determining uniaxial compressive strength (Ergüler and Ulusay, 2007).

The needle penetrometer is applied on weak and soft rocks to measure a resistance either in laboratory and field which is called needle penetration resistance (NPR). This value is assessed from the test through the following steps:

1) Sample surface should be smooth and cleaned up before performing the test.

2) For the samples which are being carried out to test in the laboratory, the specimen should be fixed to prevent its movement during penetration as shown in Figure 3.7.

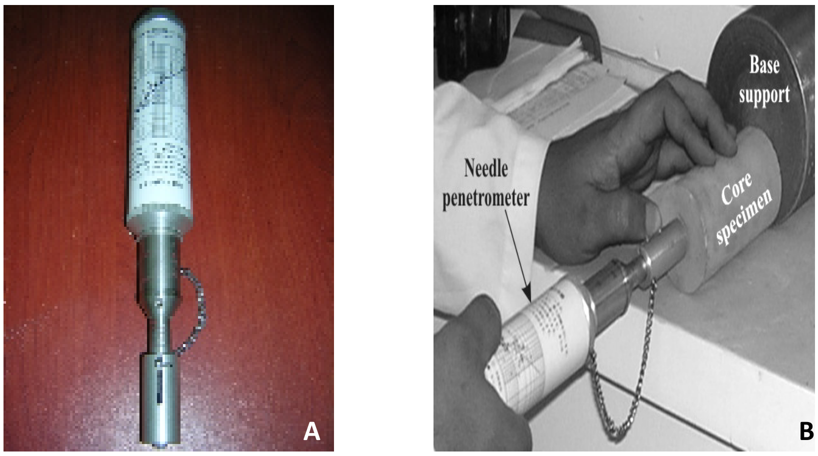

Figure 3.7 (A) Photograph of needle penetrometer equipment (modified from Maruto Corporation, 2006), (B) the needle penetration test carried out in laboratory (taken from Ergüler & Ulusay, 2007).

The uniaxial compression value is estimated from the following equation introduced by Ergüler and Ulusay (2007):

$$\mathbf{UCS = NPR * ^{0.8575}}$$

Where;

UCS: Uniaxial compression value (MPa)

NPR: Needle penetration resistance (N/mm)

The application of this test was achieved by collecting four block samples from the four locations shown in Figure 3.1 and Figure 3.2. A total of 10 measurements are performed on each block in the Soil and Rock Mechanics Laboratory of the Geological Engineering Department of the Hacettepe University. The average UCS values estimated from needle penetration test is given in Table 3.4 and the general test results are tabulated in the Appendix.

Table 3.4 The average UCS values estimated from Needle Penetration test.

HANÇİLİ TUFFITE	***NPR (N/mm)***	***UCS (MPa)***
Sample 1	5.68	2.25
Sample 2	6.21	2.44
Sample 3	6.74	2.62
Sample 4	6.82	2.64

3.1.7 Sonic Velocity Test

In order assess to the intact strength of the rock and detect incipient flaws, sonic or ultrasonic sound wave propagation through large rock samples are intensively used. The method is very sensitive to the degree of saturation, and the test specimens require careful preparation.

The sonic velocity test is intended as a method to determine the velocity of propagation of elastic waves in rocks (ISRM, 2007). The test also provides useful information about the degree of fissuring and porosity of a rock material.

Manually prepared cubic samples of Hançili formation were tested in both dry and saturated states. For the testing, longitudinal (P) velocities were measured by using ultrasonic pulse method. In this method, an impulse is imparted to a specimen and the time for the transient pulse to traverse the length of the specimen is used to calculate the velocity of the waves.

Based on the sonic velocity test results, the average dry and saturated sonic velocities of the Hançili tuffite are 966,70 m/sec and 1056,76 m/sec, respectively, and both correspond to 'very low' class regarding to Engineering Classification of ANON (1979).

The general sonic velocity test results are tabulated in the Appendix.

3.1.8 Slake Durability Index Test

Natural weathering of rock is generally a very slow process, susceptibility to which can, to some extent, be characterized by the Slake Durability Index (ISRM, 2007).

The deterioration of weak rock subject to wetting impacts upon excavation and foundation is a crucial concept. Thus, weak rock is needed to be classified into durable and non-durable rock to wetting. The classification can be made by carrying out slake durability test. In this test, tuffite as a soft rock was assessed whether to be able to stand wet and dry test cycle without disintegration. The material resistant to collapse potential was determined by repeating the wetting and drying cycles.

This test is intended to assess the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting (ISRM, 2007).

A total of 60 representative lumps, each with a mass of 40-60 g, and roughly spherical in shape were selected to be placed in drum. In the event, slake durability test has been repeated for 6 times applying the test procedures.

For the purpose of designating the resistance offered by the samples obtained from the study area to weakening and disintegration, slake durability index test have been performed on a total of 60 samples grouped under 6 sets have been subjected to two standard cycles of drying and wetting. Six-cycle slake durability testing appears to offer an acceptable indication of the durability of the tuffite samples. Since this test aids in evaluating the durability of in association with engineering behavior such as the interaction between rock and weathering, it is considered to continue observing after second cycle.

Nevertheless, not a significant amount of loss within the total lump weight Id (%) was pointed out after two test cycles. The larger the Id, the greater the loss in the weight of rock due to deterioration after soaking. The changes in slake durability indices of the Hançili tuffite for various test cycles is given in Figure 3.8.

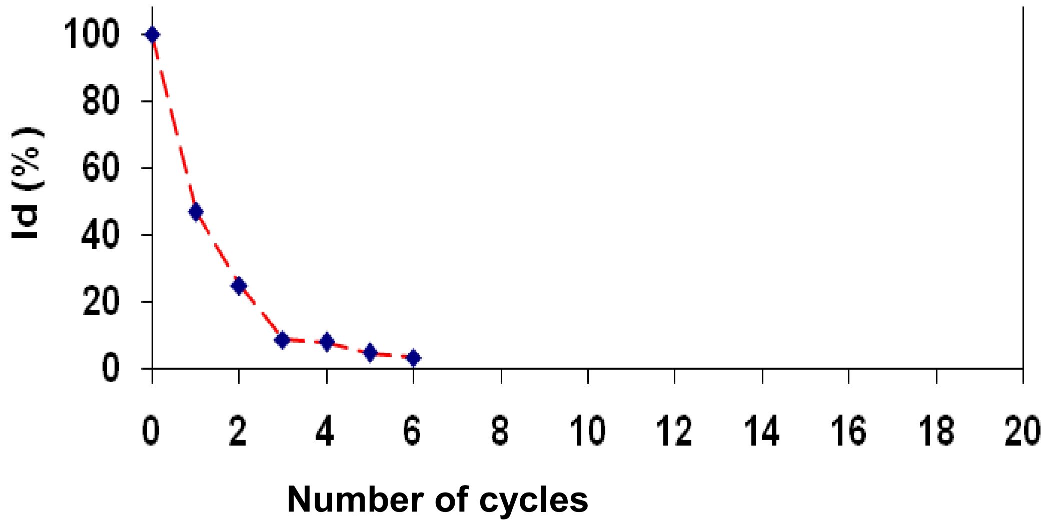

Figure 3.8 The variations of slake durability indexes of the Hançili tuffite for different test cycles.

Soaking with water for a comparatively short duration is known to significantly reduce rock strength. This is influenced by many factors, operating in a complex manner; these are inherently multivariate, and exhibit time-dependent characteristics (Anwar *et al.*, 1998; Guo, 1998).

According to Gamble's slake durability classification for each test cycles is presented in given in Goodman (1989), the Hançili tuffite exhibits medium durability. The average weight loses for each test cycles and the corresponding classes of Gamble to each these losses are presented in Table 3.5.

Table 3.5 The average weight loses for each test cycles and the corresponding classes of Gamble (1989).

HANÇiLi TUFFITE	***VALUES***	***Gamble's Engineering Classification (1989)***
Weight loss, (%) 1st cycle	88,25	Medium durability
Weight loss, (%) 2nd cycle	83,42	Medium durability

Additionally, modification in the shapes of the lumps due to this loss during the test is shown in Figure 3.9.

The slake durability, especially for the weak rocks such as tuffs, tuffite, mudstones, clay bearing sandstones and altered pyroclastic rocks, is an important engineering parameter in relation with slope stability, underground openings stability and foundation problems. Furthermore, the nondurable behavior of the rocks come from the long- and short-term influence of weathering on a rock indicating the necessity for the assessment of weathering process and slaking property. In this study, number of cycles is increased to more than 2, suggested by standards, with a view to observe and assess the behavior of weak tuffite upon decomposition with water.

Figure 3.9 Alteration in shape and size of the tuffite lumps after the 4th test cycle of slake durability test in distilled water.

3.1.9 Jar Slake Test

This test is performed on samples with a view to provide a visual observation of the weathering potential of the sample. This test is commonly used along with the results of Slake Durability Index tests to help visual determination.

The suggested jar slake test procedure is outlined in Wood and Deo (1975). This is a qualitative test to assess durability of weak rocks such as shales, mudstones, tuff and tuffites, when exposed to atmospheric conditions. Performance of oven dried (at 110 C^0 for 16 hours) rock sample, 30-50g, determines if this rock is relatively nondurable.

The sample was immersed in 250 ml distilled water and described at specified intervals until 30 minutes has elapsed, and then again after 24 hours. The categories based on the result of the jar slake description are (Wood and Deo, 1975):

Jar Slake Value Behavior

1 Degrades to a pile of flakes or mud

2 Breaks rapidly, forms many chips, or both

3 Breaks slowly, forms few chips, or both

4 Breaks rapidly, forms several fractures, or both

5 Breaks slowly, develops few fractures, or both

6 No visible change

The tuffite member of the Hançili formation behaviour corresponds into Category 4, that represents body or block slaking. After 24 hours elapsed in distilled water, tuffite sample exhibited rupture of small blocks, especially from the edges and yielded disintegration products at the base of the jar. The behavior of the sample under suggested time intervals are presented in Figure 3.10.

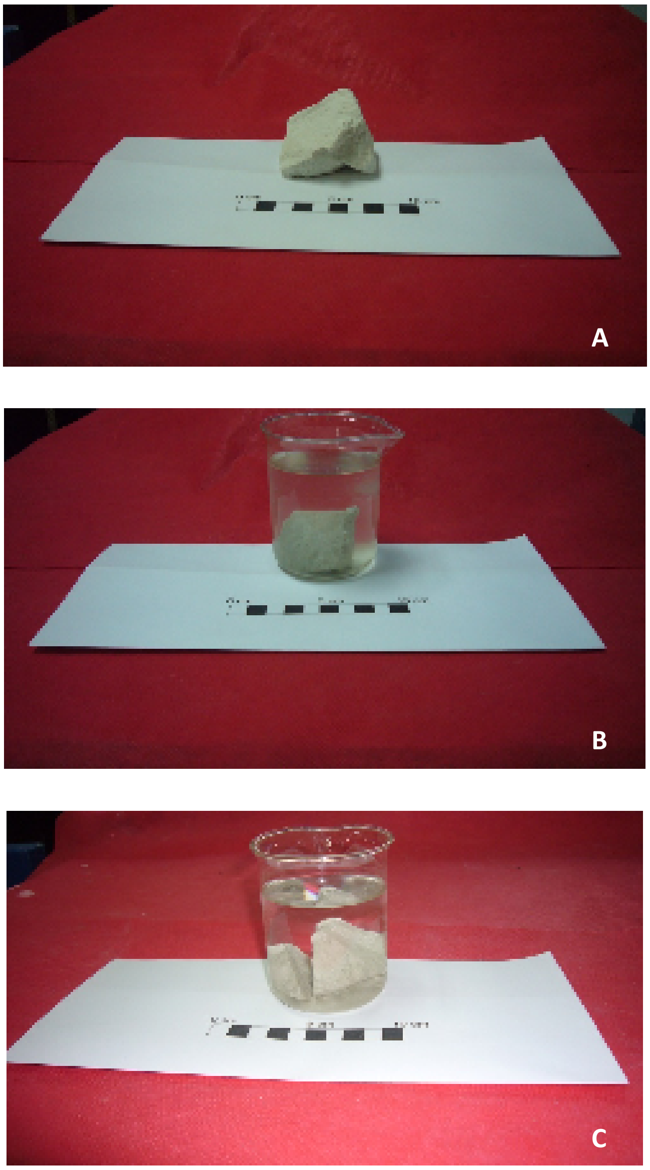

Figure 3.10 Photographs presenting physical view of Hançili tuffite before the test (A), after ½ hours (B), and after 24 hours in Jar Slake Test (C).

CHAPTER 4

MİNERALOGİCAL AND PETROGRAPHİCAL PROPERTIES OF THE TUFFITE MEMBER OF THE HANÇİLİ FORMATION

To facilitate assessing the mineral and chemical composition of the tuffite, X-ray diffraction (XRD), X-ray fraction (XRF) and optical microscopy analysis were interpreted with Assoc. Prof. Dr. Y.K.Kadıoğlu at the Petrography Laboratory of Ankara University aside from scanning electron microscope (SEM) at Electron Microscopy Laboratory of the Department of Geological Engineering of Hacettepe University and methylene blue adsorption test at the Engineering Geology Laboratory of the Department of Geological Engineering (METU).

4.1. Mineral Composition Analysis

Mineralogical constitution always directly affects many engineering properties of rocks such as swelling. A mineralogical study, therefore, was carried out to determine type of the minerals present in the Hançili tuffite.

4.1.1. Optical Microscopy

Tuffite samples have been investigated for their mineralogical constitution by means of a polarizing optical microscope at the Mineralogy and Petrography Laboratory of the Department of Geological Engineering of the University of Ankara.

A number of polished thin sections were systematically prepared from the block samples in order to represent mineralogical and petrographical consistence of the tuffite member of the Hançili formation and to identify the mineral composition and texture of the rock samples. Photomicrographs of the tuffite samples under plane polarized light (PPL), x5 and cross polarized light (CPL), x5 reveal that samples primarily consist of pumice, glass shard, quartz, biotite and plagioclase (Figures 4.1 and 4.2). Biotite, a silicate mineral within the mica group, is found in a wide variety of igneous and metamorphic rocks, for instance, commonly in the lavas.

From alteration point of view, volcanic glass of the tuffs is the most unstable component and decomposes more readily than the other associated mineral phases because it has a poorly ordered internal structure consisting of loosely linked tetrahedra with considerable intermolecular space (Topal, 1995).

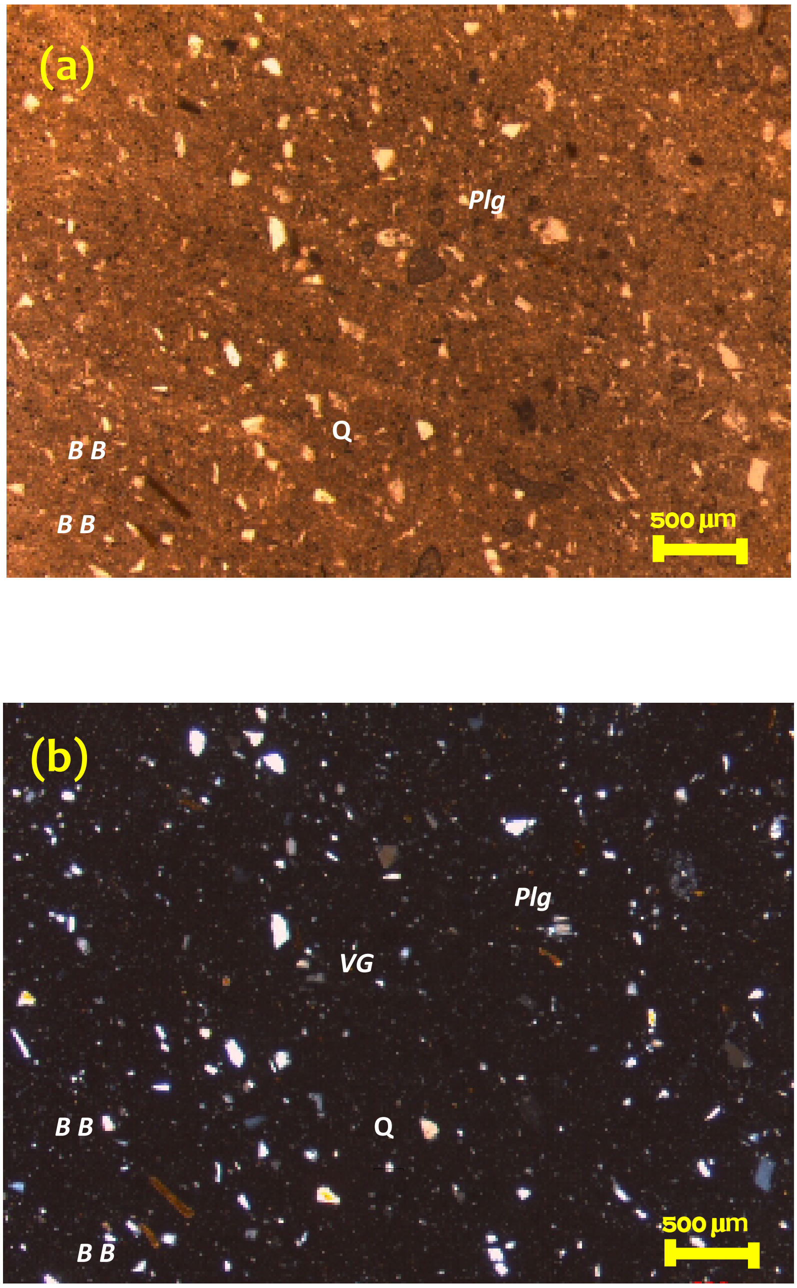

Figure 4.1 Photomicrographs of the Hançili tuffite sample. (a) Plain polarized light (PPL), x5 (b) Cross polarized light (CPL), x5 (thin section 1) (BB: baked biotite, Q: quartz, Plg: plagioclase, VG: volcanic glass).

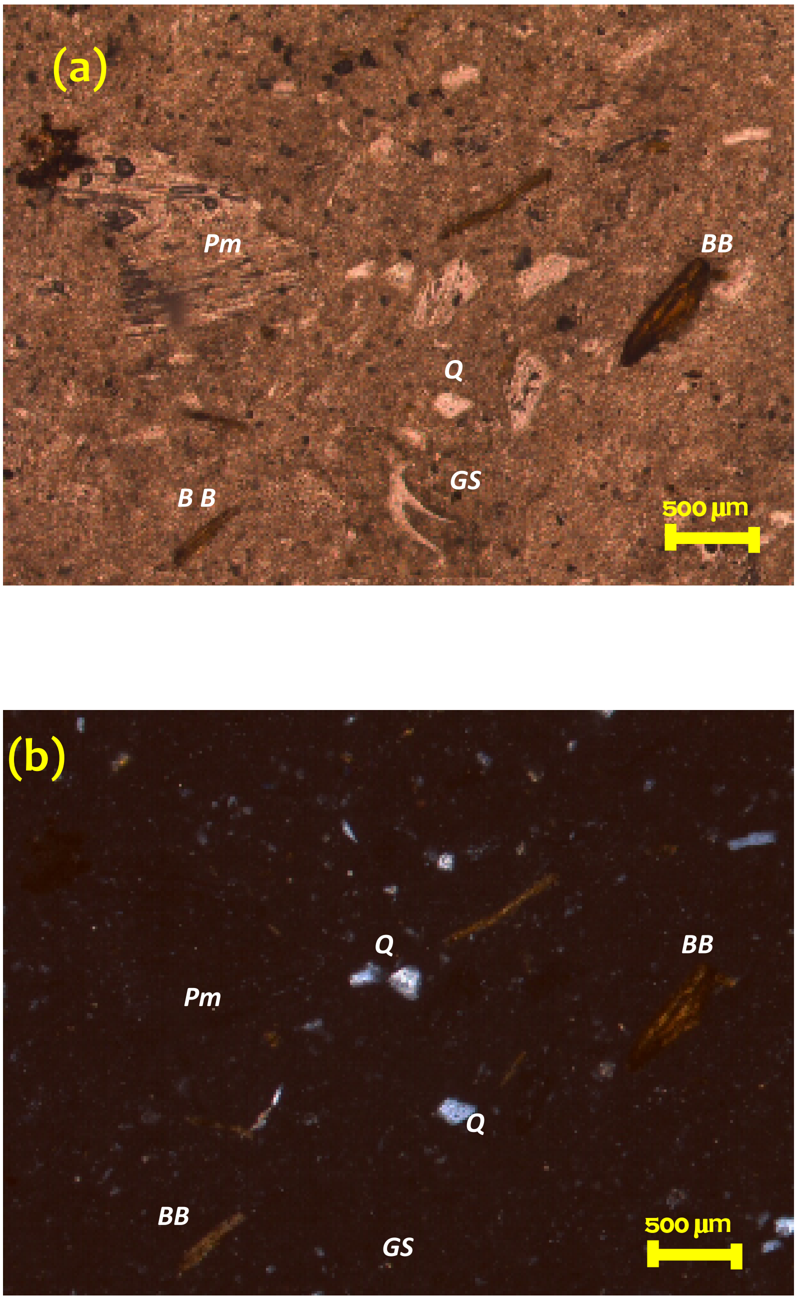

Figure 4.2 Photomicrographs of the Hançili tuffite sample. (a) Plain polarized light (PPL), x5 (b) Cross polarized light (CPL), x5 (thin section 2) (BB: baked biotite, Pm: pumice, GS: glass shard, Q: quartz).

4.1.2. X-Ray Diffraction Analysis

XRD (X-Ray Diffraction) analysis was performed at the Petrography Laboratory of Ankara University on three tuffite samples to assess the abundance of the minerals present. Interpretation on XRD diagram revealed that tuffite additionally includes illite, tridimite, volcanic glass and pumice (Figure 4.3). Illite and tridimite are expectedly taking place in the tuffite samples as regards its formation is a result of volcanic glass decomposition. As well, tridymite is defined as a high-temperature polymorph of quartz.

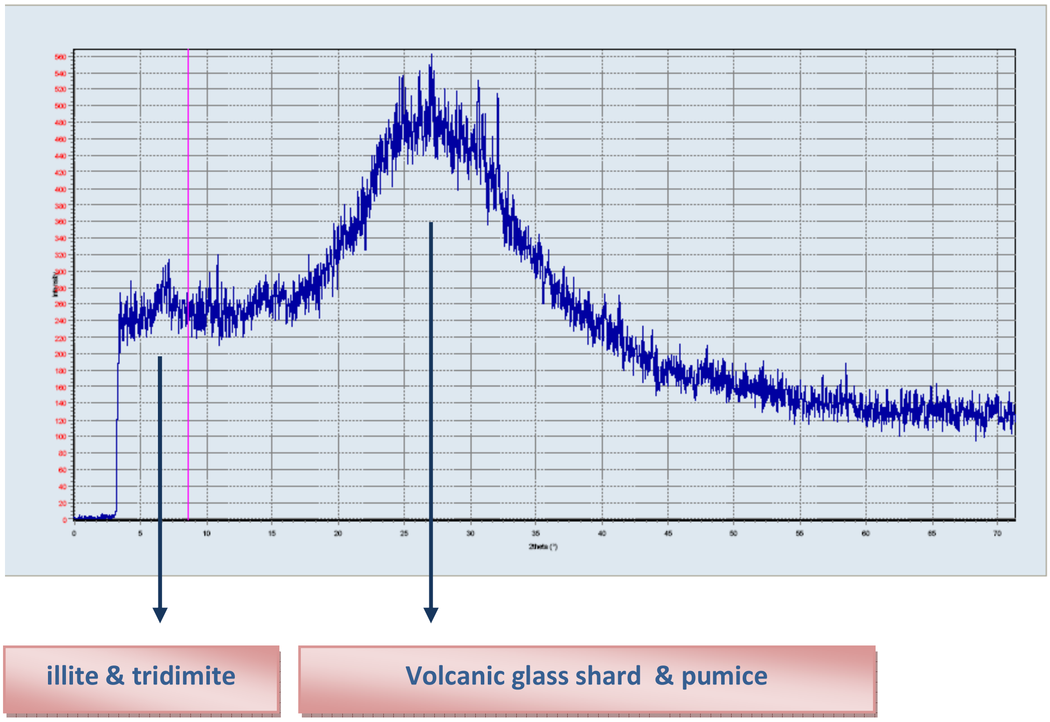

Figure 4.3 XRD diagram of the Hançili tuffite.

Subsequent to determining illite mineral in the composition of the Hançili tuffite, another sustaining analysis of clay minerals, ethylene glycole method, is considered to be performed and the picks below are obtained from the air dried, ethylene glycolated, heated at 300^0 and heated at 550^0 illites suspended from tuffite (Figure 4.4).

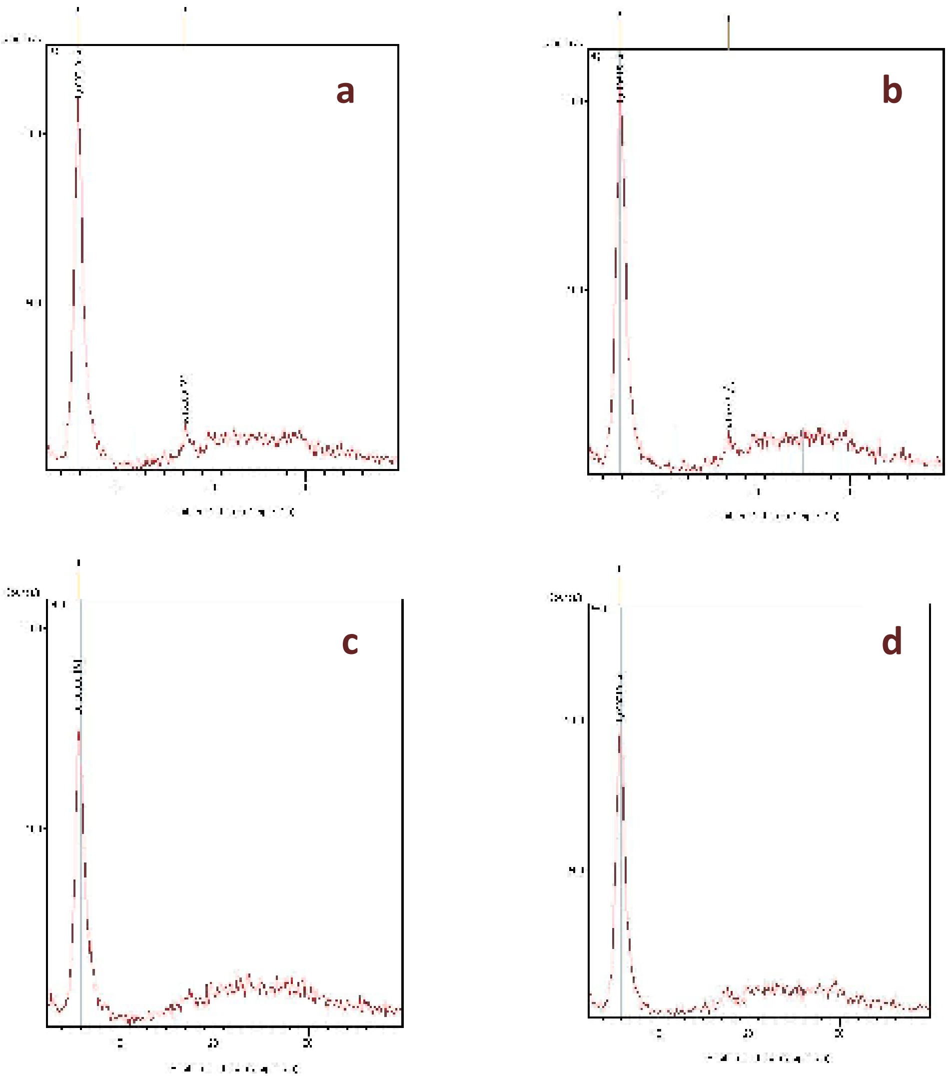

Figure 4.4 XRD difractogram of illite within the Hançili tuffite (a: air dried, b: ethylene glycolated, c: heated at 300^0 and d: heated at 550^0).

The tuffite member of the Hançili formation was chemically analyzed with the intention of appointing the main chemical composition of this unit and to interpret the mineral and amorphous content of this unit.

4.2 X-Ray Fluorescence (XRF) Analysis

X-ray Fluorescence (XRF) spectroscopy is a consequential technique in determining elemental composition of materials. The analysis was carried out at the Mineralogy and Petrography Laboratory of the Department of Geological Engineering of the University of Ankara. The samples were sieved to pass through of 200 µm, and then pressed into thick pellets of 32 mm diameter. USGS standards, GEOL, GBW 7109 and GBW-7309 Sediment equally pressed into pellets in a similar manner as the samples, and these used for quality assurance (Timothy and La, 1989; Johnson et al., 1999). Multi-element concentration was determined by using polarized energy dispersive XRF. The spectrometer used in this study was Spectro XLAB 2000 PEDXRF spectrometer which was equipped with a Rh anode X-ray tube, 0.5mm Be side window. The detector of spectrometer is Si (Li) by liquid N_2 cooled with resolution of < 150eV at Mn Kα, 5000 cps. Total analysis time for each addition element was 30 min.

Subjecting Hançili tuffite samples to XRF analysis major oxides and trace elements in tuffite are specified and listed in table 4.1. The dominant major element, SiO_2, is supporting indicator for the presence of silicates where tridimite is an amorph silicate and illite is composed mainly of silicate.

High quantity of K, Al and Si elements indicate the illite type of clay mineral present. On the other hand, poor amount of CaO and Sr represents trace amount of carbonate mineral context.

Table 4.1 XRF values of the Hançili tuffite

Major Oxides	***Weight %***
SiO_2	73,49
$Al2O_3$	10,91
LOI	6,84
K_2O	4,251
Na_2O	2,5
Fe_2O_3	1,1
CaO	0,7108
MgO	0,241
MnO	0,106
Cl	0,07574
TiO_2	0,0475
Cr_2O_3	0,00877
SO_3	0,00285
P_2O_5	0,0023
V_2O_5	0,0018
Total	**100,28776**

Trace Elements	***ppm***
Rb	350,2
Zr	137,6
As	103
Pb	84,8
Nb	72
Y	59,8
Ba	56,5
Ce	49,4
Zn	45,5
Th	39,4
Sr	34,8
U	27,6
Ga	19,5
Sn	18
Cs	17,3
W	16,2
Co	15
Ta	10,5
Ni	8,5
La	7,3
Tl	4,2
Sb	4,1
Hf	3,6
Mo	3,5
In	3,2
Cd	2,7

The complete geochemical results ascertain that Fe, Mg, Ti and CaO are observed in small quantities concluding that this composition belongs to poor amount of ferromagnesian (mafic mineral) content. The concentrations of the trace elements in this rock do not have any conclude in the interpretation of anomalous rock units.

The data gathered from these compositions reveals clearly the silicification of pyroclastic material with poor amount of mafic minerals.

4.3 Scanning Electron Microscope (SEM) Analysis

The chemical properties of the tuffite are studied by EDX within the SEM at the Electron Microscopy Laboratory of the Department of Geological Engineering of Hacettepe University by using Carl Zeiss EVO 50 EP SEM machine under an accelerating voltage of 10 kV in the SE (secondary electron) mode . The EDX mode (Energy Dispersive X-ray) of the analysis aid in clear determination of the elements in the composition with quantities. Moreover, photomicrographs of the illite mineral above are typical for that mineral.

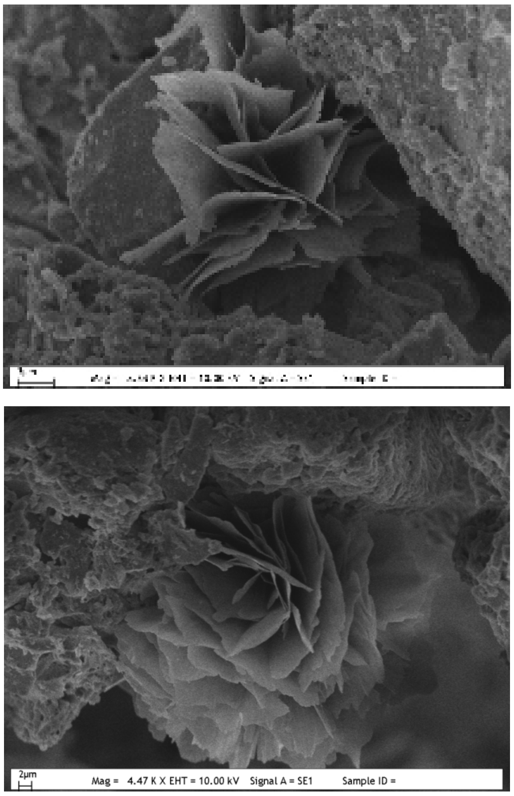

Figure 4.5 SEM view of the illite in the composition of the tuffite.

4.4 Methylene Blue Adsorption Test

This test is intended to quantify the presence and properties of clay minerals in soils and rocks. If a significant amount of methylene blue is adsorbed by the soil or rock, this may indicate the presence of swelling clay minerals (Verhoef, 1992). Low values of adsorption generally indicate low swelling activity (Stapel and Verhoef, 1989).

In the spot method, the total amount of methylene blue solution adsorped is used for the calculation of methylene blue adsorption (MBA) value and cation exchance capacity (C.E.C) (Stapel and Verhoef, 1989; Çokça, 1991; Verhoef, 1992).

The Methylene blue adsorption test, spot method was performed in order to determine MBA and C.E.C. of the Hançili tuffite in suggestion with AFNOR (1980).

Table 4.2 MBA and CEC values of the Hançili tuffite

HANÇİLİ TUFFITE	***VALUES***
MBA (gr/100 gr)	2.20
CEC (meq./100g)	5.05

The CEC value indicates the existence of illite mineral in Hançili tuffite. Illite is a non-expanding, clay-sized, micaceous mineral. It is a silicate or layered alumino-silicate. The interlayer space is mainly occupied by poorly hydrated potassium cations responsible for the absence of swelling. The cation exchange capacity of illite is smaller than that of smectite but higher than that of kaolinite.

CHAPTER 5

ASSESSMENT OF DATA

5.1 General Test Results

In this section, an overall evaluation of the tests conducted on the tuffite samples both in the laboratory and in the field is presented. The evaluation is predominantly based upon the engineering behavior of tuffite member of the Hançili formation as a foundation material since currently in the study area under Bircan buildings and potentially will be in other constructions as a foundation. With this respect, problems encountered in contact with water, comparison between wet and dry conditions of the material especially for strength were studied. Under these complications it is complex to define this material as a rock. Furthermore, various strength values for different strength tests are numerically interpreted.

Data required to determine nature of the tuffite in the outcrop are acquired by conventional site investigation processes and summarized as; the tuffite is white to cream, medium-to-thick bedded, fine-grained and slightly weathered. Geological description of the tuffite with alternating rock succession from published MTA (1997) Ankara map gave an indication of the Hançili formation and apparent nature of the outcrop. As a result of the impossibility to take and preserve samples whether from cable tool boreholes or rotary core drillhores block samples were preferable because they were likely to have been disturbed less during sampling.

Under the microscope, glass chards, pumice, tridimite, illite, biotite, quartz and plagioclase crystals are observed within a volcanic glass matrix of hypocristaline texture. The total thickness of the Hançili tuffite level ranges between 1-4 m.

3 dominant joint sets (one bedding and two joints) and one minor random set of joints are verified on the tuffite member of the Hançili formation along the Çayyolu-İncek road cut. Resultant to tests, the Hançili tuffite has very high porosity (43.33 %) and very low dry and saturated density (11.68 and 15.93 kN/m^3, respectively). The average water absorptions under atmospheric pressure and pressure are 36.52 % and 40.93 %, respectively. The tuffite has very low uniaxial compressive strength (0.40 MPa). Medium durability is indicated after two tests cycles derived from the slake durability index test.

The dry (966.70 m/sec) and the saturated sonic velocities (1056.76 m/sec) correspond to very low class. As well, MBA value of the Hançili tuffite is 2.20 gr/100 grams, indicating insignificant amount of clay percent for an engineering point of view, but the alteration of tuffite units with clayey rocks in the sequence should always be taken into account with this respect. The general index properties of the Hançili tuffite are given in Table 5.1.

Table 5.1 Index Properties of the Hançili tuffite

Properties	*Standard used for testing*	*# of tests*	*Test results*	
			Dry	*Saturated*
			*Mean±SD**	*Mean ±SD**
Unit weight (kN/m³)	ISRM (2007)	10	11.68±0.46	15.93±0.24
Effective porosity (%)	ISRM (2007)	10	43.33 ± 2.77	
Water absorption under atmospheric pressure-by weight (%)	TS 699 (1987)	10	36.52 ± 3.60	
Water absorption under atmospheric pressure-by volume (%)	TS 699 (1987)	10	43.33 ± 2.77	
Water absorption under pressure-by weight (%)	ISRM (2007)	10	40.93 ± 2.71	
Water absorption under pressure-by volume (%)	ISRM (2007)	10	49.26 ± 5.88	
Saturation coefficient	TS 699 (1987)	10	0.89 ± 0.39	
Uniaxial compressive strength (MPa)	ISRM (2007)	10	0.40± 0.12	0.07± 0.05
Point load strength index, $I_{s(50)}$ (MPa)	ISRM (2007)	10	0.05± 0.01	
Methylene blue adsorption value, MBA (g/100g)	AFNOR (1980)	2	2.20 ± 0.06	
Cation exchange capacity, CEC δ (meq./100g)	AFNOR (1980)	2	5.05 ± 0.21	
Wet – dry loss (%)	ASTM (1992)	5	0.57± 0.16	
Sonic Velocity ‡ (m/sec)	ISRM (2007)	10	966.70± 39.09	1056 .76±81.32

(SD*) standard deviation**, (δ)** determined from methylene blue adsorption test,

(‡) Pundit-plus 54-kHz transducers are used,

5.2 Quality Assessment of the Hançili Tuffite

Tuffite can be characterized as a transition material between conventional soils and conventional rocks, with regard to very high sensitivity to sample disturbance, low degree of accuracy and to tedious sampling. Thus, the border line is very difficult to draw and various researches are descriptive in creating different limits to reach a quantifiable data beneficial to engineer. The most common name seems to be 'weak rocks' and 'soft rocks', where some others use the term 'low strength rocks'.

The most common way to define the weak rock is the assesment of the geological properties of the rocks. Rocha (1977) evaluated the results of a series of tests conducted on diffrent soils and rock samples (sands, clays; mudstones, shales, limestones, granites, schists, etc.) and concluded that the cohesion and the uniaxial compressive strength serve the best for definition of the boundary between soils and rock. According to these results, materials with cohesion above 0.3 MPa and a uniaxial compressive strength above 2 MPa are considered as rocks. However in this study there was no opportinuty to perform triaxial test and cohesion (c) and internal friction angle (ø) values could not be reached. As a consequence, the uniaxial compressive strength is the simply strength value for interpretation. This value of uniaxial compressive strength was used as the lower limit of the rock strength in the BGD (Basic Geotechnical Description) published by ISRM (2007).

Classification of the Hançili tuffite in accordance with different descriptions of unconfined compressive strengths is given in Table 5.2

Table 5.2 Characterization of tuffite according to diffrent classifications.

Strength of the tuffite (MPa)	*ANON (1970)*	*ISRM (2007)*
Less than 1.25 Under 6	Very weak	Very low

As an interpretation of the high porosity values of the Hançili tuffite, it is an agreeable and consequential statement that, this material cannot be determined to have good quality as a stone when compared with the other types of rocks. By the time of progress, it can be very porous and these pores may generate fractures within the rock on the occasion of physical changes. Furthermore, this unit possesses extremely low strength which is again a confirmation for its low quality. In addition, evaluating water absorbtion and uniaxial compressive strength values; one can declare that, higher the amount of water absorption, higher the degree of weathering and lower the strength.

Regarding those low values which tuffite exhibits in terms of strength, it is significantly difficult to draw the borderline and assign tuffite as a soil or a rock. This unfavorable situation is also a factor to be limited in classifying tuffites according to standards in literature.

5.3 Durability Assessment of the Hançili Tuffite

The durability of a stone is measure of its ability to resist weathering and so to retain its original size, shape, strength and appearance over an extensive period time (Sims, 1991; Bell 1980 and 1933 b). There are several approaches suggested by numerous authors. Within the frame of this thesis, saturation coefficient and wet-to-dry strength ratio methods are discussed. The situation is interpreted to be an indicator of easily disintegration upon exposure to atmospheric effects. In this sense, relevant tests are executed to verify.

Saturation coefficient (S) of a stone is the ratio between the natural capacity of a stone to absorb water after complete immersion under atmospheric pressure for a definite time, and its total volume of the pores that is accessible to water.

S = (water absorption / effective porosity)

A stone with very high saturation coefficient may be deteriorated by freeze-thaw activity (RILEM, 1980). Therefore, this value is an indicator to evaluate the durability of the stone in freeze-thaw situation. The value of saturation coefficient can mostly vary between 0.4 and 0.95 (BRE, 1983). A saturation coefficient greater than 0.8, indicates low durability "susceptible to frost activity" (Hirschwald in Schaffer, 1972 and TSE, 1977).

However, many stones have saturation coefficients within the range of 0.66 to 0.77. In this range, the saturation coefficient gives an unreliable guide (Anon, 1975b and BRE, 1983).

Saturation coefficient of the Hançili tuffite; 0.89, is greater than 0.8, indicating low durability "susceptible to frost activity" (Hirschwald in Schaffer, 1972 and TSE, 1977).

Wet-to-Dry Strength Ratio; swelling and non-swelling clays in a stone tend to attract water when exposed to moisture. The strength of the stone can be reduced significantly due to the presence of moisture.

Winkler (1986) suggested that the wet-to-dry strength ratio based on the modulus rupture or the uniaxial compressive strength or the tensile strength is a good and rapid method of testing the durability of a stone in use as a durability index. Approximate evaluation of the stone durability as a function of the wet-to-dry strength ratio is given in Figure 5.1.

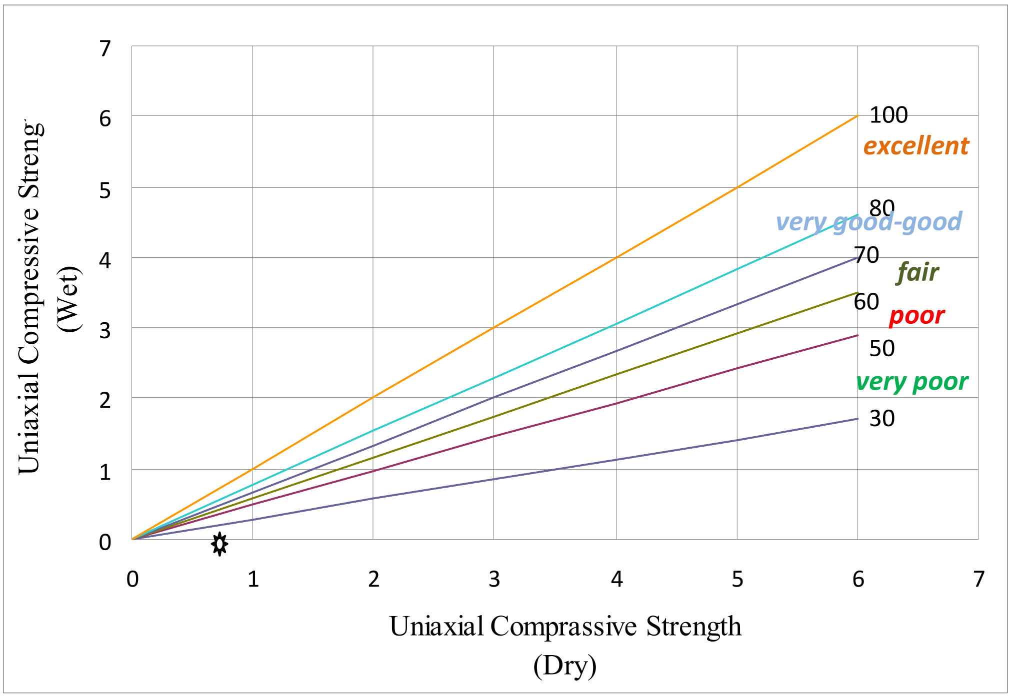

Figure 5.1 Durability evaluations of stone based on the wet-to-dry strength ratio (After Winkler, 1986).

The general stone qualities depending on the wet to dry strength ratios given by Winkler are (1986) as follows:

80-90 good and safe

70-80 further testing required

60-70 unsafe, for frost and hygric forces

< 60 very poor quality, clay present

In this study, the durability index of the Hançili tuffite is evaluated based on the saturated and dry uniaxial compressive strengths of the tuffite. Wet to dry ratio (%) of the Hançili tuffite is 18. In keeping with Winkler classification, tuffite samples correspond to very poor quality.

In addition to above mentioned classification, another assessment of classification regarding the strength of the tuffite depending on various researches is presented in Figure 5.2 and it is revealed that the average strength value of the tuffite in the area corresponds to the lower limit in each of these classifications.

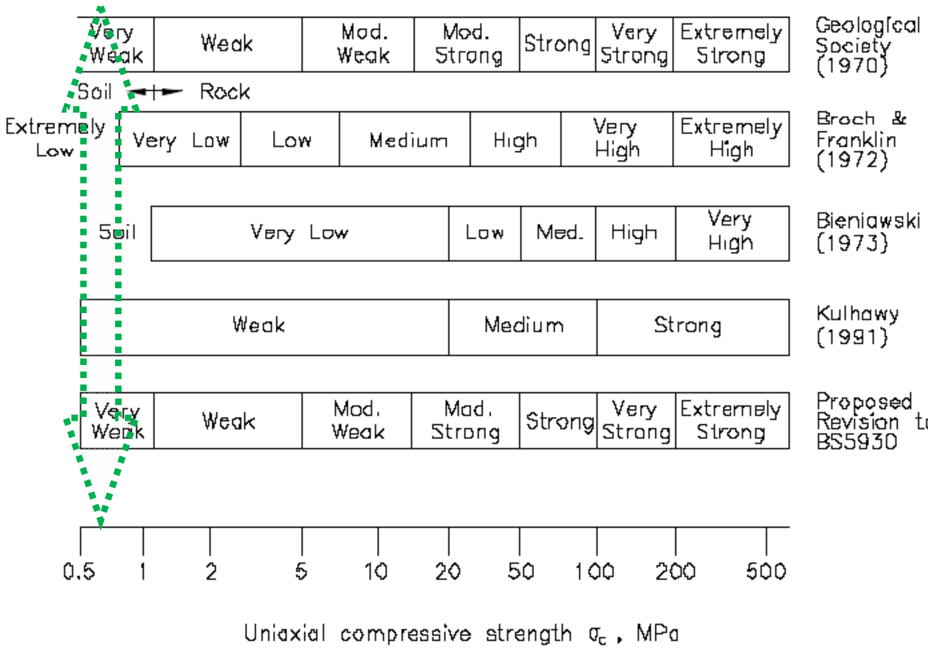

Figure 5.2 Classifications of rock material strength (after Kulhawy and Phoon, 1993) quoted from Gannon *et al*. (1999).

In general, extreme values of properties such as very low relative density (such as 1.19 mg/m^3 in Hançili tuffite) or high porosity (such as 43.33 % in Hançili tuffite) give an indication of the sensitivity of the rock and its susceptibility to reduction in its strength and stiffness brought about by changes in water content and effective stress. For rock materials composed largely of clay minerals (clayey limestone and shale and weathered volcanic rocks such as tuff and ash), behavior is highly dependent on these external influences (Gannon *et al*. 1999).

The processes in the formation of the tuffite member in Çayyolu region and the engineering significance is summarized in Table 5.3.

Table 5.3 Processes in the formation of tuffite member in Çayyolu region:

Geological Information	*Rock Type*	*Formational processes & characteristics*	*Potential engineering significance*
Neogene volcano-sedimentary rock	Tuffite	Deposited within lacustrine environment	Low intact strength. Can be expansive. Very susceptible to alteration, softening and weathering depending on moisture content. Suitability as a foundation material requires individual investigation and study.

In addition to above mentioned test procedures, another alternative approach was to employ e-SSC Test Kit that is also geological engineering laboratory equipment (Zainab, 2005). It quantifies and characterizes real time strain of soft rocks propensity to swell, shrink and collapse, prediction of in-situ behavior. This advantageous method tests on fresh samples instead of remolded samples, therefore original material texture and fabrics are preserved. With regret, this kit is not started to be applied in Turkey nowadays and cannot be able to perform on the tuffite on the location although it was considered since soft rock has high propensity to swelling and it usually generates higher risk to geotechnical hazard.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The site investigation techniques and engineering characterization methods used are generally standard methods developed for soils or hard rock masses, thus, investigation on weak rock results in poor quality sampling and, in some cases, unreliable test results. Very few large projects and researches have presently been developed in weak rock masses (Dobereiner, 1990).

Soft rock is defined as a geotechnical material having the upper strength of soil, named as ‘weak’ and ‘weathered’ in relation to rock terminology or ‘hard’ and ‘indurated’ in soils terminology (Hudson, 1993). Soft rock is also known as a generic term covering those materials which could be described as ‘hard clays, extremely weak rock, very weak rock and weak rock’.

The material has been traditionally characterized in a conservative manner owing to limited testing and limited engineering classification.

Due to the low uniaxial compressive strength values ranging between 1 and 0.1 MPa (for dry and saturated states, respectively) and medium durability of the tuffite in the study area, it is in the ‘soft rock’ group of geotechnical materials guideline suggested by the ISRM (2007) classification, which has a very broad uniaxial compressive strength ranged from 0.5 MPa to 25 MPa.

Furthermore, not all of the weak rock types have been characterized in engineering terms. There is currently much debate on how best to predict axial capacity of soft rock and to determine strengths of weak rocks of which suggested sampling methods do not work.

However, in the future, several new sites on those materials seem to be developed in Turkey and any field on account of the fullness of hard rock fields as foundation grounds. The occurrence of tuffite may be widely spread around the vicinity, but in most projects those materials were avoided. Hence the study of weak rocks, especially tuffite, that are the target of this thesis, has not been greatly developed enough.

The weak strength and tendency to disintegration upon contact with water contribute significantly to the complexity of its engineering behavior. So far, none of the buildings in the study area are problematic due to cracks, settlements or any other engineering phenomena. Nonetheless in this study, it is clearly revealed and proved that tuffite units have a potential to create troubles since:

- The alternation of tuffite unit in the study area with argillaceous units such as marl, mudstone, siltstone and clayey limestone.
- The presence of tuffite unit in the foundation not completely but partially together with the above mentioned units.
- The well-bedding of tuffite units with a nearly horizontal trend in the foundation but the above alternating units' various amount of dips and dip directions.

These are the key points in the process of field investigation, another concept as a guide behind the process of laboratory testing on Hançili tuffite is:

- The very weak nature and low strength of that material in addition to lower strengths in saturated state. Bedsides, this material has a big potential to yield upon contact with water by any means.

These are among the alarming phenomenon that promotes risk to geotechnical failure. Soft rock has relatively low strength and high moisture sensitivity. For weak foundations such as tuffite under Bircan Houses in Çayyolu restrict, foundation strengthening, or excavation of undesirable material may be more economical than forfeiting time and money for fixing problems like wall cracks, damages on pipes or any undesirable deformation on the structure. Before constructing, early recognition of the presence of weak rock is significant for an effective site investigation to be planned and carried out. During this investigation, the essential concepts are nature, properties and behavior of the rock.

The resistance of a rock to short-term weathering is described through a durability parameter called the slake durability index. As durability is an important engineering parameter, particularly for weak rocks, it was assessed by slake durability tests. The durability of weak rocks is one of their most important engineering properties hence weathering can stimulate a rapid change of rock material from initial rock-like properties to soil-like properties and can decrease its strength. Subjecting our samples to slake durability test was in order to assess the degree of degradation and the resistance of our samples against drying and soaking, which is called slaking.

This data is used to help develop recommendations and establish guidelines. The results provide an indication of how tuffite may behave when exposed to weathering agents such as snow or rain.

To overcome the weakness and drawbacks of the prior arts of ascertaining the real time behavior of soft rock, such as tuffite, more applicable methods are needed to be created for accurately testing and characterization. The measurement of these properties of tuffite is a practical basic task to predict the pre and post construction performances of geotechnical structures in it against the potential mode of real time in-situ behaviors, especially upon contact with water in wet environment. However, the need for that systematic geotechnical characterization of tuffite unit in Çayyolu district was equally critical despite its potential problems.

As well, the alternation with soft rock especially of argillaceous type such as mudstone, marl, clayey limestone etc. is taken into consideration for its slaking behavior. This phenomenon is among the most alarming outcomes of tuffite in geotechnical engineering which involves destructive stresses, deformations and loss of strength that normally be observed months after construction.

The contact with water is among the key factor that induces degradation, disintegration and mass strength reduction of soft rock thus promotes risk to geotechnical failure. Understanding the mechanics and the negative impact of tuffite failure and the ability to measure response to the change in water content will obviously assist us to make better predictions on the tuffite under Bircan Houses and the respective post construction stability. The high sensitivity to moisture changes is the key factor in this research, as to how tuffite changes its behavior with water by qualitative and observational characterization techniques.

During this thesis, site study reports on the site and its vicinity have been investigated in details but tuffite member is neglected in the related sequences. Generally most of the weak rocks are difficult to investigate, sample and test, their behavior is not well understood and are not given sufficient attention of the geological controls on their formation.

Though, attempting to save money and time by neglecting this weak rock or inadequate solutions invariably lead to even costlier failures. In other cases, where the presence of tuffite in foundations are not avoided, an alternative solution to get rid of the potential problems they will cause is to remove this layer by excavation, however, economics demand that they cannot always be removed.

If possible, the following in-situ tests are appropriate for the investigation of the strength, deformability, permeability and other characteristics of tuffite:

- Permeability tests,
- Geophysical measurements; such as electrical resistivity survey, aids in clear determination of the areal distribution of the tuffite layer.
- Plate loading test

Determination of the structural instability or modes of failure were beyond the conception of this thesis. As a result, future investigations must focus on the type of foundations and piles through a perspective of above mentioned factors.

Identification of the need for a piled foundation in tuffite, assembling the geotechnical model, analyzing the structure loads and idealized foundation load, selection of pile types at approximate dimensions and layout, and finally considering likely behavior of tuffite before contraction are subjects that additional researches should handle.

In this thesis, likely behavior of tuffite member of the Hançili formation in Çayyolu district is examined since this material had not been investigated neither in any of the previous works at the area nor at the close proximity. Over and underlying layers, moisture (saturation) sensitivity and strength were inspected in this respect.

Without near-full recovery of tuffite by high quality core drilling, bearing capacity assessment and/or foundation type suggestion would be based on incomplete information. No deformation in the buildings noted is noted so far but the potential problems and the very weak nature of the unit is documented in an important engineering point of view.

Since disintegration or any deformation on foundation material is a crucial phenomenon, the tuffite member of the Hançili formation, as a foundation material, is seriously recommended to taken into account by means of weak strength and assessment of the foundation type should be considered in this manner. However, the challenges in testing and scarcity of geotechnical data in the literature are among the intricacies to be faced in this respect.

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APPENDIX

LABORATORY TEST RESULTS OF THE HANÇİLİ TUFFITE

Table 1. Porosity and water absorption under atmospheric pressure data of the Hançili Tuffite.

Sample No	Porosity %	Dry. Unit Weight (kN/m^3)	Sat. Unit Weight (kN/m^3)	Wabs-weight (%)	Wabs-volume (%)
1	45,68	11,07	15,55	40,49	45,68
2	38,15	12,41	16,15	30,15	38,15
3	44,36	11,39	15,74	38,21	44,36
4	45,53	11,28	15,75	39,58	45,53
5	43,38	11,54	15,80	36,88	43,38
6	43,83	11,57	15,87	37,18	43,83
7	45,60	11,47	15,94	39,00	45,60
8	46,01	11,61	16,12	38,89	46,01
9	39,76	12,43	16,33	31,38	39,76
10	41,03	12,02	16,05	33,48	41,03

Table 2. Porosity and water absorption under pressure data of the Hançili Tuffite.

Sample No	Porosity (%)	Dry Unit W. (kN/m^3)	Sat. Unit W. (kN/m^3)	Wabs By weight (%)	Wabs By volume (%)	S.COEF. BY WEIGHT	S.COEF. BY VOLUME
1	46,14	11,03	15,56	41,02	46,14	0,99	0,99
2	45,35	11,57	16,01	38,46	45,35	0,78	0,84
3	48,67	11,29	16,07	42,28	48,67	0,90	0,91
4	49,78	11,34	16,23	43,06	49,78	0,92	0,91
5	47,49	11,20	15,86	41,58	47,49	0,89	0,91
6	45,32	11,41	15,85	38,97	45,32	0,95	0,97
7	63,87	15,10	21,36	41,50	63,87	0,94	0,71
8	54,45	11,48	16,82	46,53	54,45	0,84	0,85
9	44,74	11,49	15,88	38,21	44,74	0,82	0,89
10	46,77	12,16	16,75	37,72	46,77	0,89	0,88

Table 3. Uniaxial compressive strength of the dry Hançili tuffite.

Sample No	Area (mm^2)	F (kN)	UCS (MPa)
1	2575,36	1,20	0,47
2	2553,55	0,60	0,23
3	2029,20	1,20	0,59
4	2675,96	1,10	0,41
5	2575,50	1,10	0,43
6	2575,36	1,00	0,39
7	2625,66	0,70	0,27
8	3080,00	0,80	0,26
9	2575,50	1,20	0,47
10	2418,08	1,20	0,50

Table 4. Uniaxial compressive strength of the saturated Hançili tuffite.

Sample No	Area (mm^2)	F (kN)	UCS (MPa)
1	3025,00	0,10	0,03
2	2678,00	0,40	0,15
3	3080,00	0,30	0,10
4	3025,00	0,40	0,13
5	2524,50	0,10	0,04
6	3036,00	0,10	0,03
7	3164,00	0,10	0,03
8	3080,00	0,30	0,10
9	3844,00	0,10	0,03
10	2550,00	0,20	0,08

Table 5. Point Load Strength Index of the Hançili tuffite.

Sample No	W (mm)	D (mm)	Failure Load (P)	Point Load Index (I_s)
1	36,00	26,00	0,05	0,04
2	44,00	20,00	0,05	0,04
3	44,00	48,00	0,10	0,04
4	38,00	23,00	0,10	0,05
5	55,50	31,00	0,10	0,05
6	53,00	26,00	0,10	0,05
7	42,00	24,00	0,10	0,06
8	55,00	60,00	0,20	0,05
9	40,00	72,00	0,25	0,05
10	50,00	49,00	0,20	0,06

Table 6. Needle penetration test data of the Hançili tuffite (Sample Location 1).

Sample No	F, Load (N)	NPR (N/mm)	UCS (MPa)
1	39,00	3,90	1,64
2	41,00	4,10	1,71
3	45,00	4,50	1,85
4	53,00	5,30	2,13
5	55,00	5,50	2,20
6	60,00	6,00	2,37
7	62,00	6,20	2,44
8	70,00	7,00	2,71
9	71,00	7,10	2,74
10	58,00	7,16	2,76

Table 7. Needle penetration test data of the Hançili tuffite (Sample Location 2).

Sample No	F, Load (N)	NPR (N/mm)	UCS (MPa)
1	60,00	6,00	2,37
2	61,00	6,10	2,40
3	61,00	6,10	2,40
4	61,00	6,10	2,40
5	62,00	6,20	2,44
6	62,00	6,20	2,44
7	62,00	6,20	2,44
8	63,00	6,30	2,47
9	64,00	6,40	2,51
10	65,00	6,50	2,54

Table 8.Needle penetration test data of the Hançili tuffite (Sample Location 3).

Sample No	F, Load (N)	NPR (N/mm)	UCS (MPa)
1	63,00	6,30	2,47
2	65,00	6,50	2,54
3	65,00	6,50	2,54
4	65,00	6,50	2,54
5	67,00	6,70	2,61
6	67,00	6,70	2,61
7	67,00	6,70	2,61
8	70,00	7,00	2,71
9	70,00	7,00	2,71
10	75,00	7,50	2,87

Table 9. Needle penetration test data of the Hançili tuffite (Sample Location 4).

Sample No	F, load (N)	NPR (N/mm)	UCS (MPa)
1	90,00	7,10	2,74
2	80,00	6,50	2,54
3	100,00	6,70	2,61
4	75,00	6,70	2,61
5	100,00	6,70	2,61
6	85,00	7,00	2,71
7	50,00	6,40	2,51
8	87,00	7,30	2,80
9	70,00	7,40	2,84
10	78,00	6,40	2,47

Table 10. P-wave velocity measurements of the dry Hançili tuffite.

Sample number	Average Velocity µsec
1	913,37
2	1008,35
3	964,83
4	970,97
5	975,99

Table 11. P-wave velocity measurements of the saturated Hançili tuffite.

Sample number	Average Velocity µsec
1	1094,75
2	1050,26
3	1145,32
4	1067,13
5	926,32