Engineering geological characteristics of İstanbul greywackes, Turkey

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Abstract: The İstanbul greywackes outcrop mainly on the 'European' side of the city where the density of the population is high. For this reason researchers have paided attention to the use of the greywackes as construction and foundation material. The İstanbul greywackes generally show sound and stiff characteristics however the engineering characteristics may vary due to the varying facies. The aim of this study is to determine the geo-engineering properties of the stanbul greywackes that have been used in areas of dense population. The geological and geomechanical data obtained from fieldwork, boreholes, field and laboratory experiments were evaluated for different purposes such as deep foundations, underground works and construction materials.

Résumé: L'affleurement de greywackes d'Istanbul principalement sur le côté Européen de la ville où la densité de la population est haute. Pour ces chercheurs de raison a paided l'attention à l'usage du greywacke comme le matériel de construction et le matériel de fondation. L'Istanbul greywackes généralement le son de spectacle et les caractéristiques raides cependant les caractéristiques d'ingénierie peuvent varier en raison du facies variable. Le dessein de cette étude sera obligé à déterminer les propriétés de geo-ingenieur de l'Istanbul greywackes qui a utilisé dans les secteurs de population dense. Les géologiques et données de geomechanical ont obtenu du travail de terrain, boreholes, les expériences de champ et laboratoire ont été évaluées pour les buts différents fondations tels que profonds, les travaux de métro et les matériels de construction.

Keywords: Sandstone, engineering geology, engineering properties, İstanbul

INTRODUCTION

İstanbul greywackes are common especially on the European side of İstanbul, and many engineering structures have been constructed or will be constructed over these rocks (Figure 1). Therefore, all engineers who are working on surface and subsurface excavations encounter these greywackes. Problems associated with them are related to the determination and recognization of the physico-mechanical and technological properties such as ripability, excavability, usability etc. (Erguvanli, 1985). These parameters have been studied by many investigators since 1895 on both sides of İstanbul, but mostly on the European side. In İstanbul, the geological characteristics of this rock have been defined by Kaya (1973). Recent detailed studies show that Trakya formation belongs to the Lower Carboniferous Period, and in the İstanbul area they consist of intercalated sequences of sandstones (the greywackes), siltstones, claystones with varying thicknesses. Experimental studies were conducted on these rocks.

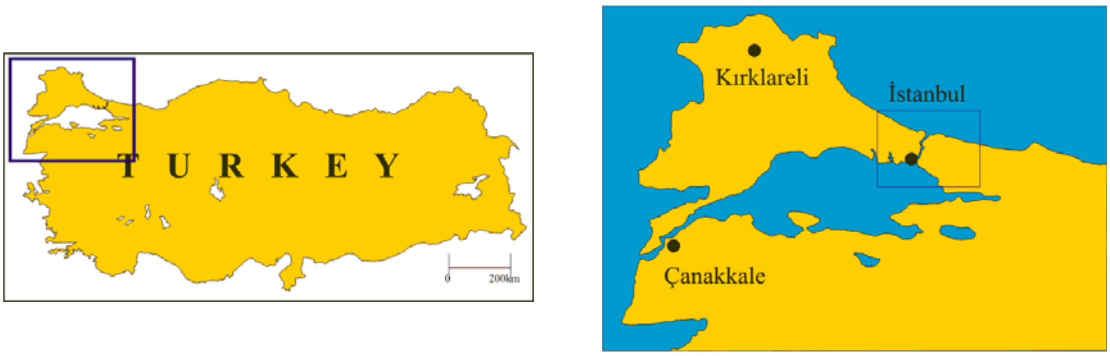


Figure 1. Location map of the studied area

This paper presents the engineering properties of the greywackes. The term greywacke is used for dark grey, firmly indurated, coarse grained sandstone that consist of poorly sorted, angular to subangular grains of quartz and feldspar, with a variety of rock and mineral fragments embedded in a compact clayey matrix and containing an abundance of very fine grained illite, sericite and chlorite minerals (Eroskay, 1985).

The interrelationships of primary textural characteristics such as grain size, shape (form, roundness, surface texture), and fabric (grain orientation and grain-to-grain relations) control other properties such as density, porosity, etc. (Boggs, 1987). The relationship between petrographical, mineralogical, chemical and geomechanical properties of this type of rock has been studied by many investigators (Bell, 1978; Fahy and Guccione, 1979; Barbour, et al., 1979; Howarth and Rowlands, 1986 and Shakoor and Bonelli, 1991; Haney and Shakoor, 1994; Ulusay, et al., 1994). They reported significant correlations between geological and geomechanical characteristics of different types of sandstones.

The initial stages of these investigation involved field description and collection of representative samples and testing the samples. The study area selected has irregular land morphology depending on the lithology and tectonics of the region. During the site investigations lithological and structural characteristics of the sandstones were determined and also sampling was carried out. The sampling was performed from deep excavations, boreholes and tunnels. The experimental work included petrographical and mineralogical analyses, physical and mechanical properties. The methods included X-Ray diffraction (XRD) analyses, and optical microscopy. In addition, during laboratory studies, dry unit weight, water absorption, porosity, uniaxial compressive strength, elasticity modulus and the poisson ratio were also determined.

GEOLOGICAL SETTING

Paleozoic, Mesozoic and Cenozoic Period formations were recognized at İstanbul. There are generally Paleozoic rocks in the city. From the Ordovician to the Carboniferous Periods, comprising several thousand metres of rock, a concordant rock sequence is observed. This stratigraphic sequence generally consists of clastic rocks and limestones in different facies (Önalan, 1981; Eroskay, 1985). This study was carried out on the Carboniferous Trakya Formation, a sequence that is unconformably overlain by Neogene sediments.

The Trakya Formation consists of intercalated sequences of sandstone (greywackes), shale, siltstone and mudstone. They are typically dark grey-green or greyish-brown due to weathering. Sandstone is the most abundant rock type in this formation, and limestone and conglomerate interbeds or lenses are found between layers. The thickness of the Trakya formation varies between 600-1700 metres (Eroskay, 1985). They are generally of marine origin and are believed to have been deposited by submarine turbidity currents (Pettijohn, 1972).

The Trakya formation is commonly exposed in the west of İstanbul, especially in İkitelli, Cebeciköy, Şişli, Beşiktaş, Levent and Gaziosmanpaşa (Figure 2). Greenish brown coloured andesite dykes, up to 10 m thick, are common in the study area, and generally follow a NW-SE direction. When they were fresh, they could be easily identified in the field. But in the highly weathered conditions, dykes which were yellowish brown coloured, could only be differentiated with difficulty from the greywackes (Eroskay, 1985).

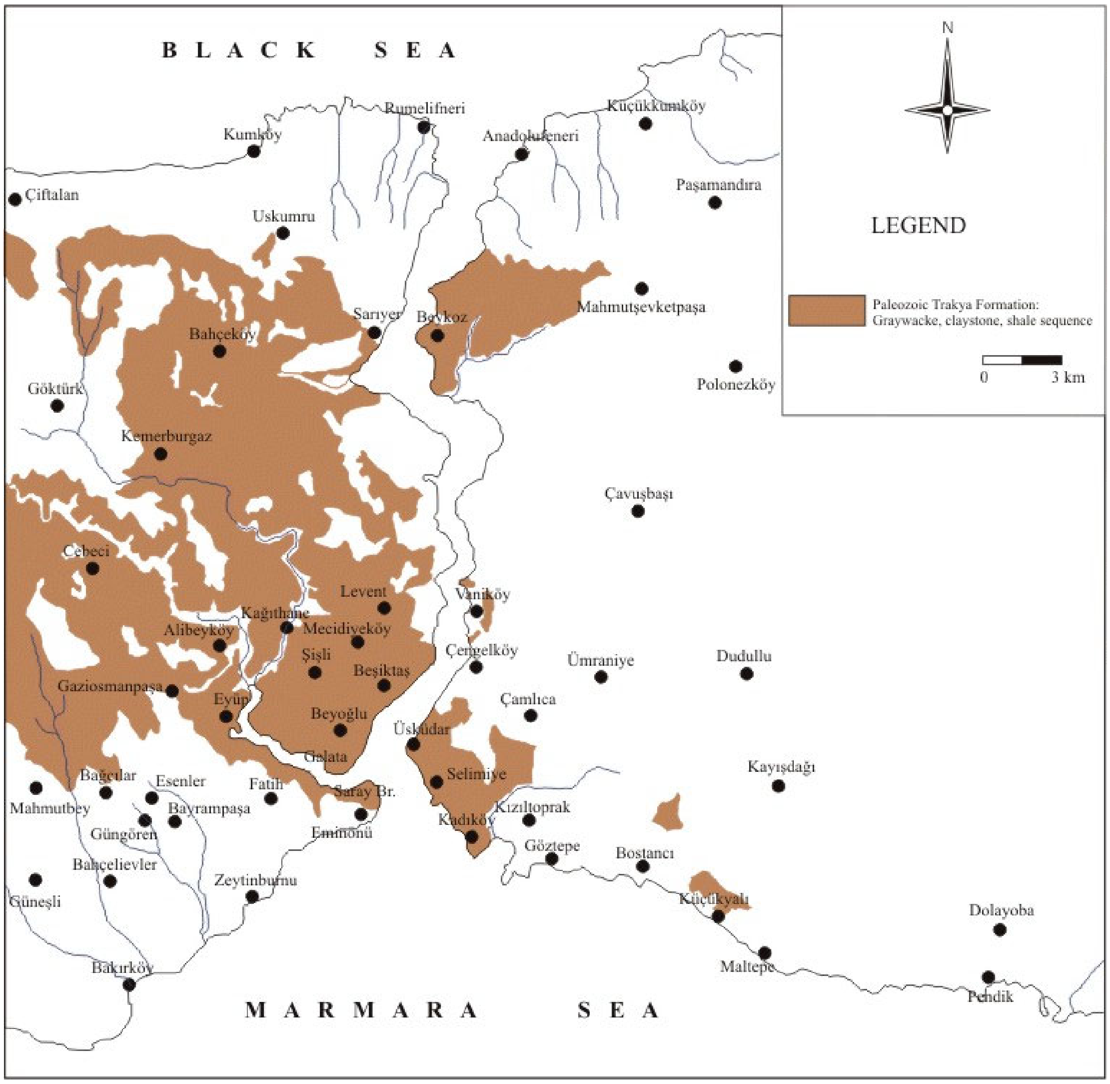


Figure 2. Map showing the location of the greywackes (Modified from Ketin, 1991)

The Trakya formation is very intensely folded, faulted, fractured, and is also weathered which is well developed along discontinuities. The major structural features of the area are NW-SE and NE-SW trending faults. Dense crack surface developments are observed and rock masses are completely fractured from place to place. Usually, three or four clearly defined major sets of joints are found. Minor sets or random joints also occur in study area. The strike directions of joints are almost NW-SE and NE-SW.

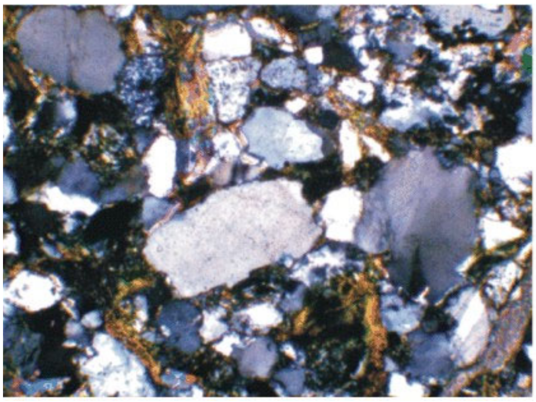
GENERAL CHARACTERISTICS OF THE GREYWACKES

The greywacke is typically a dark grey and green or brown sandstone, owing to a secondary hematite cement. Their thickness changes between 10 cm and 2.5 metres (Figure 3).

Figure 3. Alternating of shales and greywackes in Ayazağa – Maslak Region

Petrographical and mineralogical analyses have been used to document the fabric and mineralogical properties of both unweathered and weathered greywackes. Generally coarse and medium grained greywacke sandstones are dominated by angular and subangular grains of quartz, and a lesser amount of feldspars (orthoclase and plagioclase), muscovite, chlorite and hematite with a variety of dark rock and mineral fragments (Figure 4, Table 1). Average grain size is about 0.2-0.4 mm. The quartz grains range from 60 to 75%. The rock fragments are between 8-15%; the muscovite is more than 3%. The cemented materials consisted mainly of clay (sericite, chlorite and illite) and sometimes hematite. They are generally poorly cemented, but have been firmly lithified by compaction and close packing of the sand-size grains.

The above petrographic characteristics classify the rock as lithic wacke according to Dott (1964).Based on the Wentworth (1922) scale size classes, the greywackes range from very coarse to coarse sandstone.



(A)

(B)

Figure 4. General aspect of the **(A)** Slightly weathered greywacke texture showing quartz grains, other minerals and rock fragments with a few microfracture; **(B)** weathered greywacke showing mineralogy and fabric characteristics; the opening of microfractures and iron stainting of some minerals and rock fragments; feldspars show void formation; grain boundaries are open; (25X, cross-polarized light).

Table 1. Petrographical composition of the greywacke sandstones

Location	Quartz (%)	Feldspar (%)	Muscovite (%)	FeO (%)	Chlorite (%)	Rock Fragments (%)	References
Levent (Deep Excavation)	60-75	5-6	10-12	3-5	-	10-15	
Eminönü (Boreholes)	65-75	3-8	5-20	3-9	2-4	8-12	
Fatih Tunnel	70-75	2-5	3-10	5-8	-	10-12	Erguvanli (1985)
Eyüp Tunnel	60-70	2-6	8-30	3-8	-	10-15	Erguvanli (1985)
İstanbul Metro	60-70	6-8	8-10	6-8	2-3	8-10	Dalgiç (2002)

WEATHERING

Weathering is the main factor that weakens the greywacke. The thickness of the weathered sandstone is about 2-4 metres. Most of the deeply weathered sections are related to faults and fractures. Weathered greywackes are often open textured, weakly bonded and microfractured and they contain a small amount of clay matrix, commonly sericitic and iron stained. Mechanically, the rock break down by the opening of joints and the formation of new discontinuities, coupled with fracturing along grain boundaries and across individual grains (Dearman et al., 1978). The weathering of the greywackes decreases gradually and progressively with increasing depth.

XRD analyses of the samples of weathered sandstone indicated a very similar composition. The relative proportions of feldspar, mica and clay minerals were found to show some variation between samples.

ENGINERING GEOLOGICAL CHARACTERISTICS OF THE GREYWACKES

The physical and mechanical properties of the fresh and weathered greywacke sandstones were determined by a variety of laboratory tests. A number of physical test were made on the cores including, dry unit weight, water absorption, and porosity, in accordance with the ISRM (1981) suggested methods. The results of the physical tests are presented in Table 2. Both porosity and water absorption increase and dry unit weight decreases with increasing weathering grade.

Table 2. Physical properties of İstanbul Greywacke

Location	Weathering	Dry Unit Weight γ_d (kN/m^3)	Water Absorption (by weight) w_a(%)	Total Porosity (%)	References
Levent (Deep Excavation)	Unweathered	26.4-27.3	0.22-1.06	-	
Levent (Deep Excavation)	Weathered	25.6-26.1	2.23-4.12	-	
Eminönü (Boreholes)	Unweathered	26.5-27.7	0.39-1.49	0.95-3.66	Zarif and Tugrul (2002)
Eminönü (Boreholes)	Weathered	25.8-26.6	3.14-3.73	8.47-10.23	Zarif and Tugrul (2002)
Eyüp Tunnel	Unweathered	27.2	0.22	2	Erguvanli (1985)
Eyüp Tunnel	Weathered	26.0	2.8	8	Erguvanli (1985)
Haliç Tunnel	Weathered	25.9	1.90	-	Erguvanli (1985)
Dolmabahçe-Baltalimanı	Unweathered	26.5	0.97	-	Erguvanli et al. (1987)
İstanbul Metro	Unweathered-Weathered	25.2-27.4	-	-	Dalgiç (2002)

Pore size distribution was determined using the mercury intrusion technique as suggested by ISRM (1981). The mercury is forced in the specimen and its volume is determined from the displaced fluid volume. During the test, the mercury fills up the large pores under low pressure and the small ones under high pressure. The results obtained from porosimeter tests for each sample are given in Table 3 and are shown in Figure 5. The effective porosity values of weathered samples are generally higher than unweathered samples. Changes in pore geometry are caused by the dissolution of some minerals and increase in microfracture density by progression of weathering and new mineral formation (Tuğrul, 1995).

Table 3. Results obtained by mercury intrusion porosimetry.

Weathering Grade	Total Intrusion Volume (ml/gr)	Total Pore Area (mm^2/gr)	Median Pore Diameter (μm)	Effective Porosity n_{eff} (%)
Highly weathered	0,0555	3,648	0,0609	12,95
Moderately weathered	0,0192	0,870	0,0882	4,91
Unweathered	0,0076	1,086	0,0280	1,95

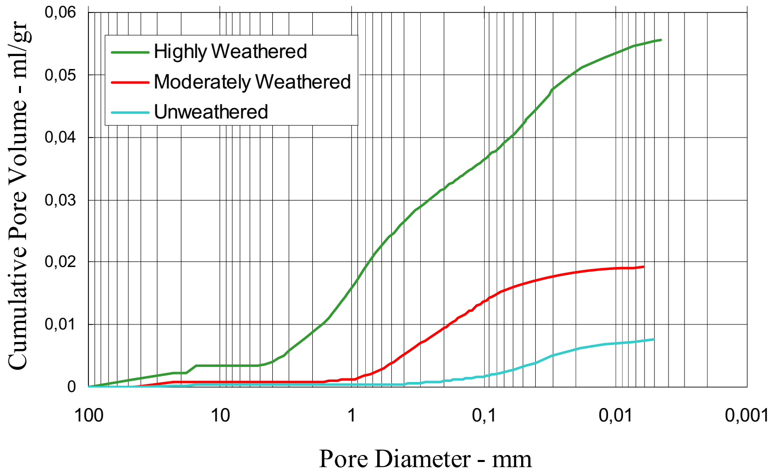


Figure 5. Pore volume versus pore diameter for the greywacke sandstone

The strength of the unweathered and weathered greywackes were determined on cores using the uniaxial compression test, in accordance with ISRM (1981) suggested method. Results of laboratory tests are given in Table 4. As seen in this Table of mechanical properties of the sandstones, the strength of the greywackes decreases rapidly with weathering.

Table 4. Mechanical properties of the sandstones

Location	Weathering	Uniaxial Comp. Strength UCS, (MPa)	Elasticity Modulus Ex10^3 (MPa)	Poisson Ratio ν	References
Levent (Deep Excavation)	Unweathered	58-64.7	10.8-48.2	-	
Levent (Deep Excavation)	Weathered	38-62	4-36	-	
Eminönü (Boreholes)	Unweathered	51.3-66.2	13.9-96.3	0.20-0.26	Zarif and Tuğrul (2002)
Eminönü (Boreholes)	Weathered	14.1-43.3	33.9-47.3	0.16-0.33	Zarif and Tuğrul (2002)
Fatih Tunnel	Unweathered	61-77.5	34.7-40.6	0.19-0.23	Erguvanli (1985)
Eyüp Tunnel	Weathered	35-60.5	4.1-9.6	0.22-0.24	Erguvanli (1985)
HaliçTunnel	Unweathered	66.9	37.5	0.19-0.21	Erguvanli (1985)
Dolmabahçe-Baltalimanı	Unweathered	118-121	22-31	-	Erguvanli et al. (1987)
Dolmabahçe-Baltalimanı	Weathered	36-62.1	1.6-18	-	Erguvanli et al. (1987)
İstanbul Metro	Unweathered-Weathered	55-136	3-59.1	-	Dalgç (2002)

According to the Deere and Miller (1966) classification; the unweathered sandstones can be classified as rock having “moderate strength” and the weathered sandstones as rock having “low strength”.

GREYWACKES AS FOUNDATION OF HISTORICAL MONUMENTS

İstanbul was the capital of the east Roman, Byzantine and Ottoman Empires. Many historical buildings such as basilicas, and other water structures, and mosques were constructed over greywackes in the historical Peninsula (Eminönü) because of their much more higher bearing capacity than the overlying Tertiary rocks (Figure 6).

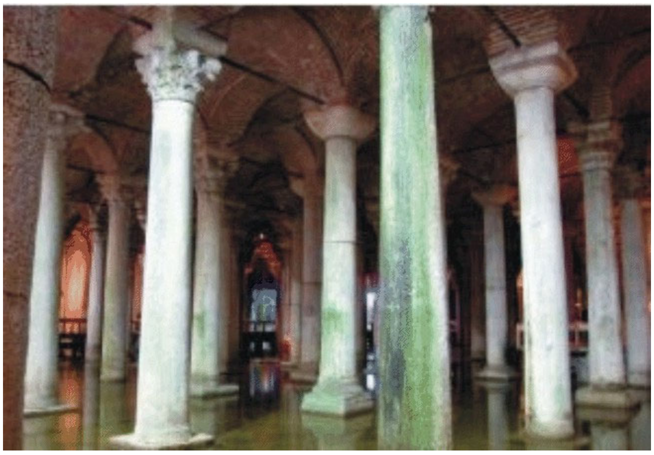


Figure 6. Yerebatan basilica constructed on greywackes

GREYWACKES IN DEEP EXCAVATIONS

The bearing capacity of the unweathered greywackes is generally high. However, deep excavations (i.e. deeper than 3 metres) should be supported, otherwise it can result in stability problems (Sağlamer, 1985). Excavations and embankments which are going to be constructed on slopes consisting of dense fractured and weathered greywackes should be investigated in detail.

GREYWACKES IN UNDERGROUND WORKS

The first and most of the second stage excavation of the İstanbul Metro is in the Trakya Formation (Köksal et al., 1996; Yildızel, 2001). According to Dalgiç (2002); the rock mass behaviour and properties of this sequence are important because the route of the metro is close to the ground surface (averaging 22 metres depth). The general investigation for the İstanbul tube tunnel and metro route included 60 boreholes. Sandstone and mudstones in some areas occur as separate units but in other areas they are interbedded (IRTC, 1988; Köksal et al., 1996).

The excavation of the tunnels was carried out in two stages, the upper half and lower half. Over-breaking that occurred during excavation was due to the discontinuity planes and particularly the fault zones and water leaking from these zones. The alignment measurements throughout the tunnel line showed that, the deformations occurred mostly in faulted and highly weathered zones (Yildizel, 2001).

GREYWACKES AS CONSTRUCTION MATERIALS

Limestones and sandstones are the main aggregate produced today. The abundance of these rocks varies in different parts of İstanbul. Unfortunately, much of the good quality limestone and sandstone has already been quarried in the most densely populated areas. In general, the İstanbul aggregates that are mainly used in concrete industry are of sufficient quality, as far as materials requirements are concerned (Tuğrul and Zarif, 2003). In addition to their use as crushed rock aggregate, limestone and sandstone have been using as the basic raw material of the construction industry.

The quality of the sandstone is often poor because there is no segregation between the sandstone and the shale. This mixture is not very good for concrete, due to the different shape, texture and hardness. Fresh rocks are used as first-class aggregate not as rubble. Lower rock grades are designated as upper course road base, sub-base and select fill as their quality decreases. Some parts of deposits especially those are very close to city in the western part of İstanbul are exploited even though it is prohibited because of environmental reasons. Most current sandstone quarries may disappear in the next few years because of urban development or lack of reserves.

CONCLUSION

A variety of petrographical and mineralogical analyses and physico-mechanical tests were carried out, in order to clarify the engineering properties of both unweathered and weathered greywackes . The results are as follows,

- Petrographical and mineralogical composition, physical and mechanical properties of greywackes are very changeable depending on their composition, texture, structures and weathering degrees.
- Bearing capacity of the unweathered greywacke is generally high. Excavation and embankment constructed on slopes that consist of greywackes should be investigated, because of their heavily fractured and weathered nature.

- The greywacke sandstone generally provides suitable conditions for underground excavations. Over-breaking that occurs during excavation are due to the discontinuity planes and particularly to the fault zones and water leaking from these zones. The deformations occurs mostly in faulted and highly weathered parts.
- Greywacke sandstone aggregates that are mainly used in concrete industry are of sufficient quality, as far as materials requirements are concerned (Tuğrul and Zarif, 2003). In addition to their use as crushed rock aggregate, the sandstone have been using as the basic raw material of the construction industry.

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