Engineering-geological map of the wider Thessaloniki area, Greece

D. Rozos · E. Apostolidis · I. Xatzinakos †

Abstract The preparation and compilation of a 1:10,000 scale engineering geological map of the wider Thessaloniki area is discussed. This map includes the range of values of the geomechanical characteristics of the 13 engineering geological units distinguished. Greater detail was available in the inhabited and industrial areas where many of the 1,300 boreholes studied had been drilled. Particular emphasis was given to the earth fill unit, which in places is up to 20 m thick. Some of the underlying Quaternary units are aquifers and severe pumping has resulted in both a lowering of the groundwater level and surface subsidence. The subsidence was most prominent in the Sindos–Kalohori–Axios River zone and required the construction of an embankment along the coast.

Résumé On présente la préparation et l'élaboration d'une carte géotechnique à l'échelle du 1/10 000 de la région de Salonique. Cette carte rend compte des gammes de variation des caractéristiques géomécaniques des treize unités géotechniques qui ont été distinguées. Elle est très détaillée dans les zones d'habitation et industrielles, dans lesquelles sont implantés un grand nombre des 1.300 sondages étudiés. Une attention particulière a été accordée à l'unité des remblais dont l'épaisseur dépasse 20 m par endroit. Quelques-unes des unités de dépôts quaternaires sous-jacentes sont aquifères et les pompages intensifs ont provoqué à la fois un abaissement de la surface piézométrique et des phénomènes de subsidence. Ceux-ci ont surtout affecté la zone Sindos-Kalohori-rivière Axos, où une digue a dû être construite le long de la côte.

Keywords Engineering geological mapping · Greece · Lithostratigraphic units · Thessaloniki

Mots clés Carte géotechnique · Grèce · Unités lithostratigraphiques · Thessalonique

Introduction

Engineering geology developed in response to the increasing demands of various technical works that required a better understanding of the interaction between the ground, foundations and constructions, in order to build more economically and on a safer base.

In the Hellenic territory (Fig. 1), engineering geological maps have been progressively developed and, as far as practical, have incorporated information from various technical works such as roads, dams and tunnels, as well as the investigations of ancient monuments and other areas under protection and restoration. They have been produced at various scales, but are usually greater than 1:5,000.

Even a few years ago, there was lack of regional maps giving basic engineering geological information, such as for planning land use and technical works, the selection of the most appropriate types and methods of construction and the better protection of the environment. To this end, the engineering-geological map of Greece, at a scale of 1:500,000 (IGME 1993), constituted one of the first important efforts. The 1:10,000 engineering-geological map of the wider Thessaloniki area is considered to be a basic infrastructure tool for more detailed investigations, as well as a useful aid for responsible civil authorities and technical personnel during the preliminary stage of various technical works. It contributes significantly to the optimisation of land use and better planning of technical works. However, such maps cannot be considered a substitute for in-situ geotechnical investigations at the microscale for every individual construction.

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Fig. 1
Location of the wider Thessaloniki area, Greece

Engineering-geological structure of the wider Thessaloniki area

The Thessaloniki engineering-geological map distinguishes 13 main engineering-geological units (Fig. 2). As indicated below, these fall into four main lithostratigraphic divisions. More than 1,300 geotechnical boreholes as well as in-situ observations and sampling (Rozos et al. 1990; Rozos and Xatzinakos 1993) were used in the preparation of the maps. Special emphasis was given to those units that are present in inhabited/industrial areas. The brief descriptions of the engineering rocks and soils follow those prepared for Engineering Geological Mapping (UNESCO/IAEG 1976; Anon 1981); see Table 1. The range of the engineering properties of each of the units is given in Table 2.

In the Thessaloniki area, earth fills cover almost all of the downtown area, with thicknesses of from 5 to 20 m. They have a major effect on foundations and other construction works and hence, it was decided to consider this material as a discrete unit.

The next six engineering-geological units are Quaternary deposits. Most are in areas where construction has already taken place although they are still found as screes and closed basin deposits in the slopes and mountainous flat zones, respectively. The fine deposits of the river deltas are associated with extensive soil subsidence due to lowering of the groundwater level in the industrial areas as a consequence of over-pumping. These subsidence phenomena have caused serious problems, particularly in the Sindos–Kalohori–Axios River zone.

The two Neogene units occur mainly in the northern and southern parts of the city where they outcrop, whereas in the downtown area they form the geological basement. These materials are difficult to classify and may be considered as either soft rocks or hard soils.

The four pre-Neogene basement units are rocky formations found in the semi-mountainous and mountainous zone to the north-east and east of the city. In general, these materials have good geotechnical properties.

Engineering-geological problems

Historic and recent fills cover the downtown area. In the deeper horizons (historic earth fills zone), the lower material is frequently derived from the natural or artificial destruction of Roman and Byzantine buildings. The fill consists of building stones, tiles, masonry/plaster and other construction materials mixed with natural soils, which generally have a silty-sandy composition. In the central part of the city these deposits, which overlie the Neogene strata, are loose with poor geomechanical properties. Near the coast there are clayey silts with some sand, grits and gravels deposited at a time of rising sea level.

In the areas of loose earth fill material with a seismic acceleration of 0.24 g (EPPO 2001), special care should be given to the foundations of buildings in order to avoid failures, particularly after dynamic loading.

In the Kalohori–Sindos area, west of Thessaloniki town, there has been a marked increase in industrial development in recent years. Since the 1960s, the accumulation of loose and unconsolidated materials from the Aliakmonas, Loudias, Axios and Gallikos Rivers, combined with other factors such as the diversion of Axios River bed and variations in the groundwater regime, has resulted in a change in the line of the coast as a consequence of extended soil subsidence.

From a geomorphological point of view, the region in question is almost flat with elevations rarely exceeding 5 m. Structurally, this area is in a graben (attributed to the Axios zone–Paionia unit) and is covered by a significant thickness of Quaternary marine and lacustrine sediments. These deposits reach a thickness of 600–700 m in the coastal area south of Kalohori (Nikolaou and Nikolaidis 1987). Similar thicknesses are also reported for the area west of the Axios River bed (Demiris 1988). The upper 200 m of these Quaternary deposits consist of alternating fine and coarse horizons or/and mixed phases, which may be lensoid. Three subdivisions can be distinguished, units 4, 5 and 6 in Table 1.

According to the engineering-geological conditions prevailing in the broader area of Kalohori (Figs. 2 and 3), a silty to sandy horizon extends for a depth of up to 5 m with satisfactory geomechanical behaviour. Below this a sensitive silty clay horizon with lenticular intercalations of sand extends for up to 30–35 m. From between 40 and 45 m, the deposits are dominantly sands with grits and relatively thin layers of black-grey clayey-silt (extending for a maximum thickness of 14 m). Below this, the material consists of brown-yellow sands, sandy to clayey silts with grits and gravels, which generally have good geomechanical properties.

The presence of more porous materials associated with the Axios, Loudias and Gallikos Rivers has resulted in the formation of aquifers; the water table being at a depth of 3–6 m from the surface.

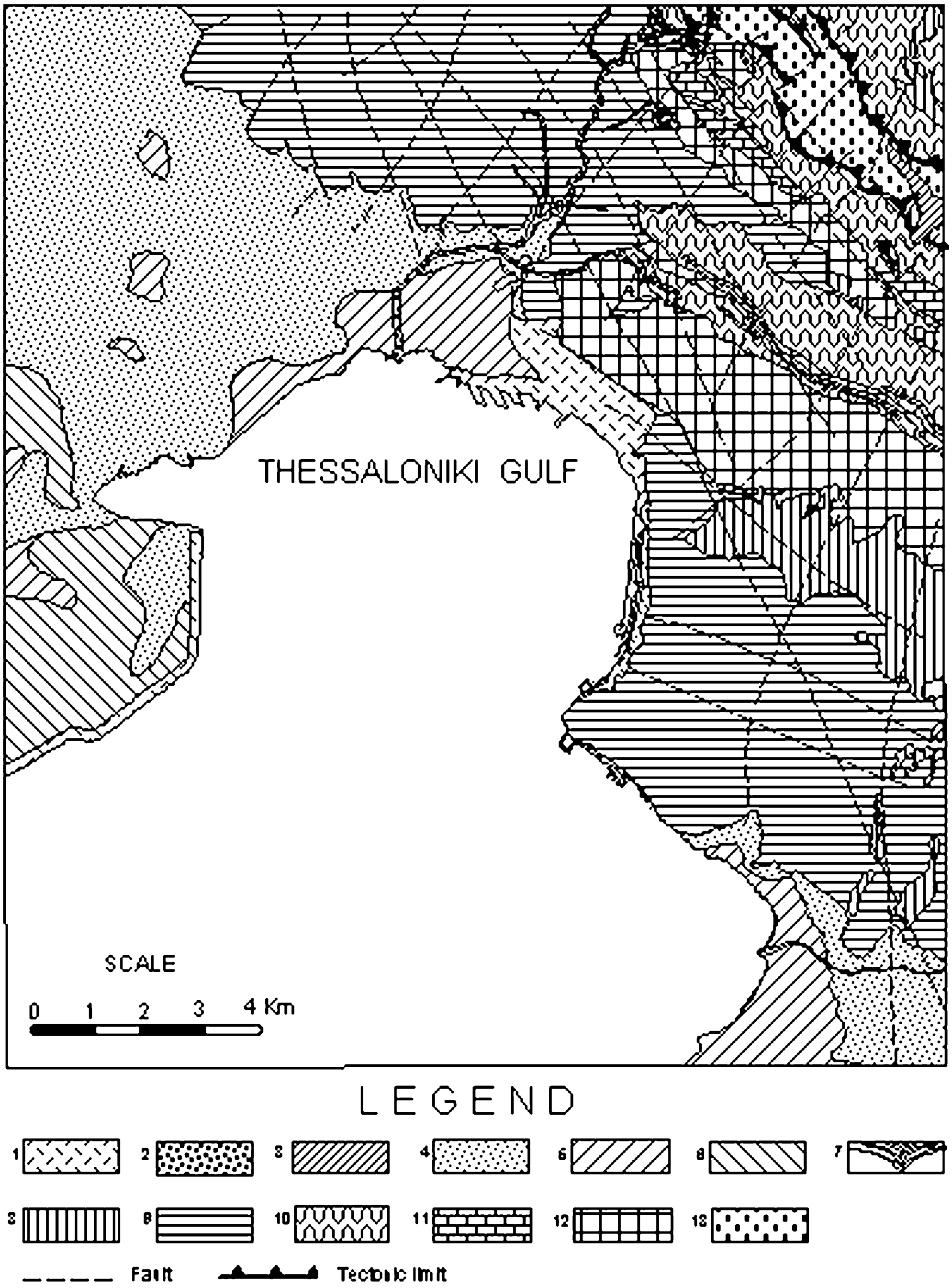

Fig. 2
Engineering geological map of the wider Thessaloniki area, Greece

Soil subsidence

Andronopoulos et al. (1990, 1991) have noted the highly compressible nature of the silty clay in the wider Thessaloniki area. The main subsidence appears to have started in 1955 with a transgression of the sea to areas close to the outer suburbs of Kalohori (Fig. 4). As a consequence, a large embankment was constructed in 1976. Pumping is now used to keep the area reasonably drained (Fig. 5). With the continuous pumping, there is an internal settlement of the soil structure with a loss of porosity and an increase in effective stress. It is considered that the main compression of the soils is related to the high mica content in the clayey-silt fraction as well as the lenticular horizons within the sandy layers.

Between 1955 and 1981, the water level in the aquifer fell to a depth of 37 m due to intensive pumping of the ground water. Unfortunately there are no records of the amount of water extracted. The drawdown of water and the resultant reduction in water pressures led to consolidation of the black-grey silty clay horizons creating a relatively uniform subsidence over wide areas. As pumping from this geological horizon has decreased, particularly since 1980, the extent of the subsidence has been arrested.

Table 1
Lithologies of the four main stratigraphic units

Earth fills	
1.	Recent and historic fills
Quaternary deposits	
2.	Coastal sands and rivers deposits
3.	Inland basins deposits
4.	Loose Quaternary deposits, with predominance of sandy horizons
5.	Loose Quaternary deposits, with predominance of silty horizons
6.	Fine loose Quaternary deposits, with organics
7.	Loose Quaternary deposits, with predominance of coarse-grained materials
Neogene sediments	
8.	Pleistocene cohesive sediments of mixed phases
9.	Neogene of mixed phases, with predominance of fine-grained particles
Formations of pre-Neogene basement	
10.	Semi-metamorphic to metamorphic rocks of Hortiati mountain and Svoula district units
11.	Metamorphic carbonate rocks of Hortiati mountain unit
12.	Metamorphic igneous rocks of Hortiati mountain and Svoula district units, including: gneiss-schists, green-schists, schist-sandstones, schist-gneisses, gneisses, schistose gabbro and ultra-basic formations
13.	Metamorphic formations of the basement

Table 2
Physical and mechanical properties of the formations encountered in the Thessaloniki area

Formation	Liquid limit	Plastic limit	Moisture content	Bulk density	Dry density	Uniaxial compressive strength	Shear strength parameters		Consolidation	Young's modulus
	w_L (%)	w_P (%)	w (%)	γ_b (kN/m^3)	γ_d (kN/m^3)	q_u (kPa)	c (kPa)	ϕ (°)	Cc	E (GPa)
Recent and historic fills				15–23		2–40				
Coastal sands and river deposits	13–35		8–15	19–23		30–190	0–85	28–49°		
Inland basins deposits	15–30		18–26	20–23		25–150	25–50	12–43°		
Loose Quaternary deposits, with predominance of sandy horizons	9–39	12–21	3–39	11.8–18.4	14.8–21.7	14–117	1–50	28–30°	0.12–0.29	
Loose Quaternary deposits, with predominance of silty horizons	21–49	17–32	23–53	12.3–15.2	16.5–19.9	17–25	5–80	7–28°	0.10–0.47	
Fine loose Quaternary deposits, with organics	18–95	10–38	4–69	8.7–18.2	14.8–23.0	4–120	3–170	0–37°	0.08–1.01	
Loose Quaternary deposits, with predominance of coarse-grained materials	17–30		18–26		20–24	30–120	0–20	25–48°		
Pleistocene cohesive sediments of mixed phases	31–53	15–21	9–16	17.4–20.3	20.1–22.4		45–135	8–29°		
Neogene of mixed phases, with predominance of fine-grained particles	20–75	8–27	8–45	13–21	17–23	44–1,340	43–170	8–38°	0.03–0.38	
Semi-metamorphic to metamorphic rocks of Hortiati mountain and Svoula district units					11–25	70–1,300	50–120	26–39°		
Metamorphic carbonate rocks of Hortiati mountain unit					25–29	600–2,000	100–300	35–45°		70–100
Metamorphic igneous rocks of Hortiati mountain and Svoula district units					17–34	200–1,800	100–550	30–50°		3.5–25
Metamorphic formations of the basement					20–26	200–1,800	100–400	30–48°		4–25

Discussion and conclusions

1. Over 1,300 geotechnical boreholes have been analysed allowing the lateral extent of individual geological units to be mapped. As most of the boreholes were in inhabited and/or industrial areas, the quality of the information allowed more detailed mapping in these areas.

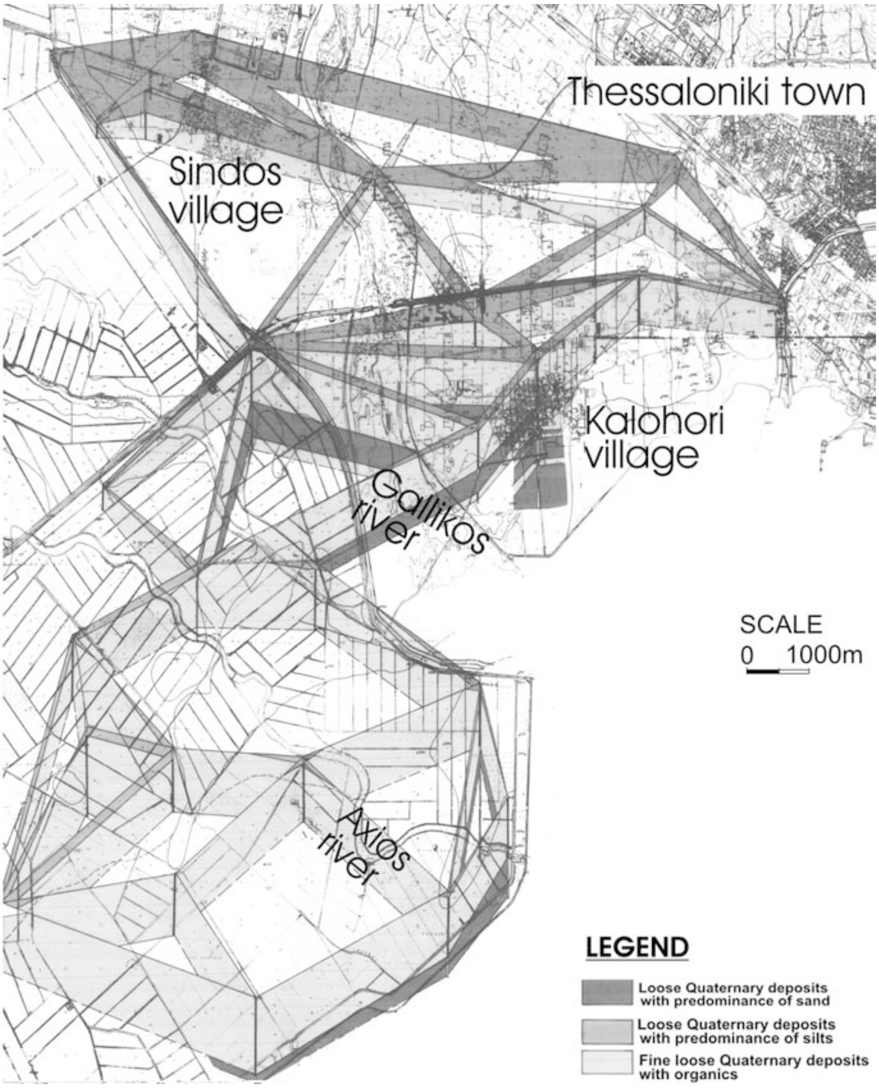

Fig. 3
Block diagram presentation of the three distinctive Quaternary deposits at Kalohori–Sindos–Axios based on an analysis of the geotechnical borehole data

Fig. 4
Small building at the Gallikos River mouth (Kalohori village), now surrounded by seawater due to ground subsidence

2. Thirteen engineering geological units have been distinguished, which can conveniently be placed into four lithostratigraphic groups. The engineering geological map of the wider Thessaloniki area shows the spatial distribution of these units.
3. The range of physical and mechanical properties is provided for each of the engineering geological units.
4. Recent and historical fills occur, particularly in the downtown area of Thessaloniki. Especially under conditions of dynamic loading, such areas are prone to severe problems and hence special care must be taken when developing on these deposits.
5. Extensive subsidence has taken place in the industrial part of the area due to the consolidation of the loose deposits and extraction of groundwater. As a consequence, it has been necessary to construct protective embankments along much of the sea coast.

Fig. 5
Embankment along the coast at Kalohori village showing the pumping stations inland of the embankment

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