GEOLOGY AND CULTURAL HERITAGE

Christaras B.[1]

ABSTRACT

In the present investigation some geological factors of failure and intervention methods are applied in four representative Greek monuments. These factors refer to the geotechnical stability analysis and geomorphological changes at the foundation site of the monuments, the origin of the building stones, their weathering conditions and protection techniques. Our examples refer to: a) the stability of the Monasteries in Mount Athos, b) the relationship observed between the ground level and the age of the monuments, in Thssaloniki, and c) the origin of the building stones, used in the construction of the Temple of Eleusis.

INTRODUCTION - GEOLOGICAL FACTORS

The monuments need protection particularly in regions like the Mediterranean basin, where the seismotectonic regime is active, and the geomechanical conditions are dangerous. The construction of works, as a result of *urban expansion or tourist exploitation* in the proximity of historical monuments is also responsible for their deterioration via geomechanical failures in the foundation area and the infra-structure of the buildings.

Phenomena like, settlement and slope movements as well as earthquakes and tectonic activity contribute to the damage of the historical buildings. The ground water activity is also an important factor, especially in cases where monuments are buried in the soil or they are founded on steep slopes. The instabilities observed at the sites of the Monasteries in Mount Athos are related both to the presence of active faults and the geometry of the tectonic discontinuities. On the other hand the flooding of the Macedonian Tombs of Leukadia, in N. Greece, during summer, is a good investigation subject having also socio-economic extension.

[1] *Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece, E-mail: christar@geo.auth.gr*

The description of building stones and degradation forms as well as the quantitative determination of stone physico-mechanical properties are necessary for estimating the deterioration of stones because no protection measures can be taken before a detailed stone description and classification is done.

SLOPE INSTABILITY (THE SIMONOS PETRA MONASTERY, ATHOS PENINSULA))

The Monastery of Simonos Petra is located on the SW coast of Mount Athos, in Northern Greece. Mount Athos peninsula is an area of great historical and religious interest, where only Monasteries for men are built. Administratively, the area belongs directly to the Patriarchate of Konstantinople. The Monastery was built in around 1257 AD by the Blessed Simon. It was burned down several times and consequently only the lower parts of the construction, close to the rock base are of that age. The western part of the present building was built in 1590 AD while the eastern part was built after the fire of 1891 AD. (Kadas, 1989). Christaras & Moropoulou (1995) studied the origin and the weathering conditions of the building stones and mortars.

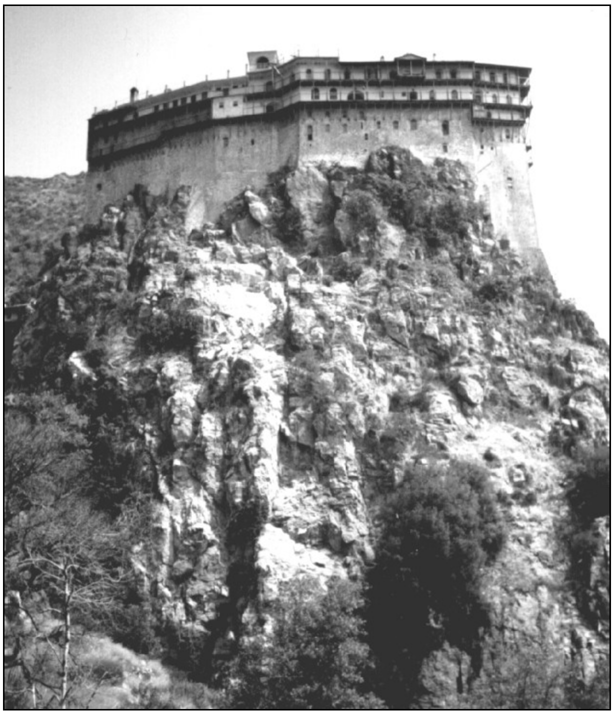


***Figure** Σφάλμα! Άγνωστη παράμετρος αλλαγής. . The Simonos Petra Monastery. An important fault of E-W direction is occurred at the western side of the rock-hill.*

The area of the Monastery consists of a typical, coarse grain, dark colour granite, which belongs to the Serbomacedonian mass (Kockel & Mollat, 1977). The material is very compact, durable and resistant to the compression.

The Monastery is built up on an isolated and uplifted rock (altitude 305 m), at the S/SW side of the mountain. The construction presents a particularity caused to the morphology of the rock-hill. The slopes of this rock are steep and the difference of altitude between the lower and higher points is more than 90 m (Fig. 1).

The area is very fractured and is traversed by joints of various directions. Many important faults cut the area studied in E-W and N-S general directions. From a first point of view, these discontinuities can cause unstable geotechnical conditions, especially at the slopes of the construction area. These instability phenomena are related to the neotectonic conditions of the broader area.

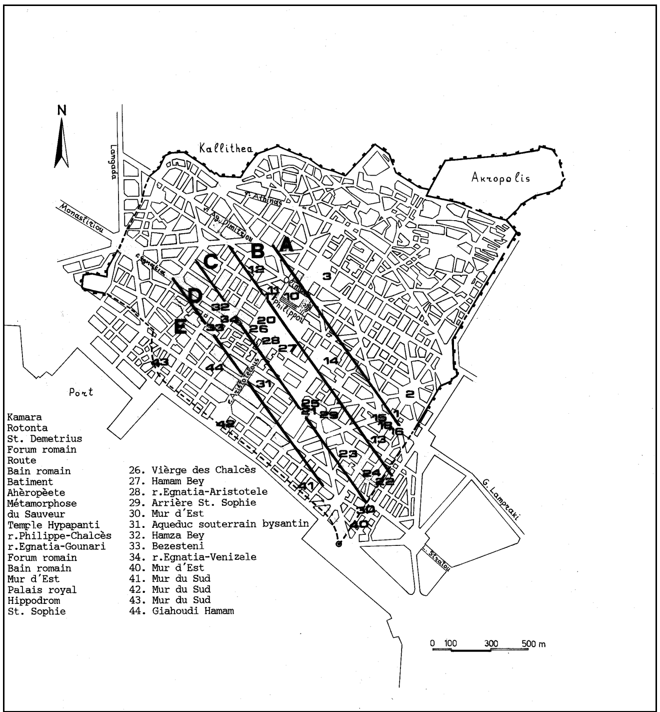
A slope stability analysis was performed with the determination of important unstable wedge and plane failures and the calculation of their factors of safety, using both field measurements and laboratory tests results (Christaras et al., 1994). Field measurements were interpreted statistically and the results were plotted in stereographic projections. The intersections of joint sets that determine probable wedge failures, were defined for representative sites, using the tests proposed by Markland (1972), Hocking (1976) and Hoek & Bray (1981). Part of our preliminary data was presented in STREMA-93 (Christaras et al., 1993), the 7th IAEG Congress in Lisboa(Christaras et al., 1994) and the IAEG Congress of Athens-97 (Dimitriou et al., 1997).

The geometry, roughness, water pressure, external forces and other characteristics of the discontinuities are not the only factors of the instability in the rock mass. The tectonic structures determined in the foundation area could also affect the foundation rock mass (Christaras et al., 1993). In this framework the presence of an important neotectonic fault or large scale joint of SW dip direction (216^o/80^o) distinguishes two sections in the rock mass at the western side of the Monastery; causing damage to the wall of the building (Fig. 1). According to our measurements, since 1993, a N-S fault that traverse the western part of the Monastery presents a creep movement of more than 0.01 mm/year. This creep rate is not important but this opening increases to some millimetres, each time an earthquake, of Ms>4, in the marine area between Mount Athos and Limnos island is recorded. Small faults and open fractures also affect the southern part of the Monastery. Two important fractures (190^o/50^o and 145^o/45^o) are observed in this side and they can give rise to sliding.

The rock mass quality was estimated at several representative sites, and a geomechanical classification was performed. The results of the data elaboration were also used for the construction plotting of rock mass quality maps of the foundation area. According to these results, the rock mass quality in the southern and western slopes of the foundation area is very low and of limited stability, causing damage to the monument (Christaras et al., 1995). In order to protect this rockmass a net bolts is necessary to be applied, in the sites where the approach is possible. Grouting could be used only in the cases where the material is very broken and the discontinuities open. All the protection techniques have to respect the environment.

GEOMORPHOLOGICAL CHANGES IN THESSALONIKI

Thessaloniki is a good example of sedimentation activity. The city, built in 315 B.C., provides many historical monuments, of different age, found today buried in the ground. The ground is composed of sediments, coming from the mountains on the NE of the city. The depth of the floors of these monuments is normal to be considered that depends upon their age, so that the more ancient buildings should be found in deeper position. According to our investigations, this consideration is not expressed by a general relationship. Nevertheless we determined three parallel zones, of NW-SE direction, where, in each one, the altitude of the ground, in the construction period of the monuments, could be related to their age. In these zones, the rhythm of soil accumulation can be represented determined linear regressions, with error ±25 years, providing useful data for archaeological dating (Fig. 2, Christaras, 1988).



Zone B: Y=0.00214X+13.34	Regr. Coef. (r) = 0.988
Zone C: Y=0.00397X+ 5.31	Regr. Coef. (r) = 0.995
Zone D: Y=0.00403X+ 3.44	Regr. Coef. (r) = 0.989

Figure ***Σφάλμα! Άγνωστη παράμετρος αλλαγής.*** *. The NW-SE parallel zones, in Thessaloniki, where the ground level of the construction period is related linearly to the age of teh*

ORIGIN AND DESCRIPTION BUILDING STONES (TEMPLE OF ELEUSIS)

The Temple of Eleusis is situated in one of the most historical and significant ancient cultural centres of Attica, the city of Eleusis, the mother country of the philosopher Aeschylus. In the Temple, the Athenians used to worship the goddess of agriculture, Ceres, and her daughter Persephone, by extraordinary ceremonies, which constituted the "Eleusis Mysteries". Recent excavations proved that this sacred centre existed during the prehistoric period and was active till the 4th AD century. In the existing ruins of the Temple, one can distinguish the traces of successive constructions, representing all the periods of antiquity, from pre-Mycenae to Roman period. The site corresponds to a typical urban-centre profile of intense and diversified industrial activity as well as that of climatic conditions favouring photochemical pollution in the presence of an atmosphere highly charged by suspended particles.

The replacement or the completion of existing blocks, in monuments, needs the investigation of their origin, by determining old quarries or, if this is not possible, the geological formation from where these stones were excavated. Furthermore these materials have to be described regarding their mineralogical and physico-mechanical characteristics in order to determine the most appropriate methods for their preservation (Moropoulou et al., 1994, 1995, 1996, Christaras et al., 1996).

All the building stones, which were used in the construction of the Temple of Eleusis, were excavated from the surrounding area, of Attica.

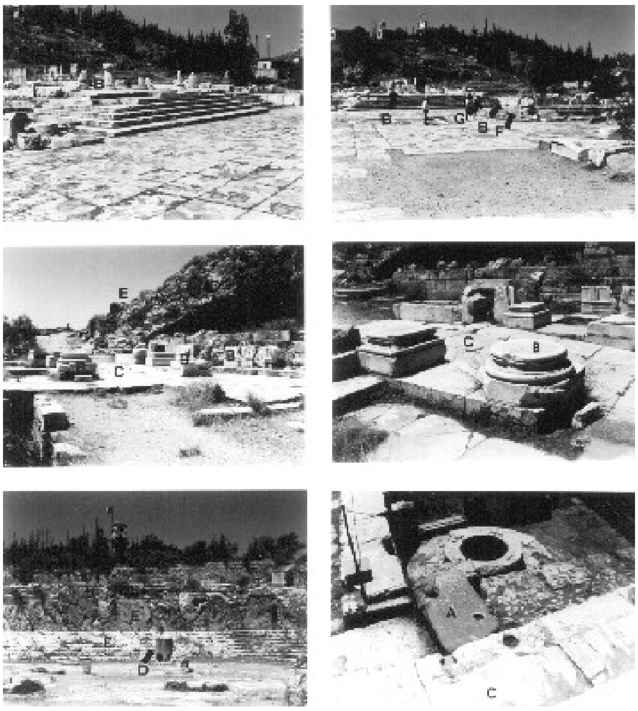


Figure ***Σφάλμα! Άγνωστη παράμετρος αλλαγής.***. *Views from the archaeological site of Eleusis. The sites of the different rock types are also figured.*

Attica is characterised by a complicated geological structure consisted of several alpine rock units forming different tectonic napes. The sampling sites of the different lithotyles, determined in the archaeological area, are shown in Figure 3 and are described petrologically in Table 1.

The geological origin of the lithotypes (samples A to G) is described as follows:

1. Sample A: Upper Triassic - Upper Jurassic neritic limestones of the Subpelagonian unit, having thickness of more than 1000 m.
2. Samples B & C: Autochthonous Attico-Cycladic crystalline complex with schists, gneiss, marbles and crystalline dolomites. Their age is Triassic to Upper Cretaceous (Marinos & Petrascheck 1956, Papadeas 1970, Katsikatsos 1976, 1977)
3. Sample D: The Upper Cretaceous limestones of Cenomanian - Maestrichtian age, with a thickness ranging from 150 m to 800 m, transgressivelly lying over the older formations.
4. Sample E: It consists of a lower unit of the Subpelagonian unit with white to white grey, massive to thick bedded, crystalline karstic limestone and dolomite, strongly connected, and fractured. The upper unit corresponds to the sample A.
5. Sample F: Corresponds to the most upper horizons, than that of the sample G. The limestone is thin bedded brown to greenish-brown alternating upwards with conglomerates and sandstones.
6. Sample G: The upper horizons of the Upper Cretaceous limestones (corresponding to the sample D). The material is greyish brown, medium to thick-plated, locally dolomitised with chert nodules.and microfossils.

Table 1. Rock types used in Eleusis Temple and samples studied

ROCK TYPE	MONUMENT
Grey micritic limestone, SAMPLE A	Kallichoron Well, Telestirion
White "Pentelic" marble, SAMPLE B	Temple of Artemis (Columns), Greater Propylaea, (Columns), Smaller Propylaea (Columns)
White grey marble, SAMPLE C	Kallichoron Well, Smaller Propylaea (Floor)
Yellow microsparitic limestone, SAMPLE D	Plutoneion, Telestirion
Grey biosparitic limestone, SAMPLE E	Smaller Propylaea

Yellow-brown oosparitic limestone, SAMPLE F	Artemides temple (Basement), Kallichoron Well, Smaller Propylaea (Walls)
Yellow-brown biomicritic dolomite, SAMPLE G	Greater Propylaea (Basement), Smaller Propylaea (Walls), Artemides temple (Basement).

CONCLUSIONS

The most common geological factors that influence the conservation of monuments and some proposed investigation methods are summarized in the following table.

GEOMECHANICAL ASPECTS - PROTECTION OF MONUMENTS	
Geological causes Foundation Stability 1) Foundation settlement, 2) Mass wasting & subsidence, 3) Slope movements - gravitation, 4) Creep, 5) Earthquake & active faults, 6)Volume change of soil, 7) Ground water, 8) Glaciers & permafrost, 9) Wind erosion in deserts, 10) Weathering - erosion, 12) Other factors	Environmental factors Building stones & mortars decay 1) Weathering (Indoor humidity, Outdoor humidity, Marine spray, Industrial pollution, Capillary, Important temperature changes, Freezing), 2) Earthquake, 3) Other factors
INVESTIGATION METHODS	
Foundation Stability 1) Rock (or soil) mass quality investigation, 2) Tectonics - Active faults, 3) Stability of geological formations - FS, 4) Laboratory & in situ tests, 5) Risk maps, 6) Seismic risk, 7) ground water activity 8) Protection measures	Building stones & mortars decay 1) Petrography, 2) Origin, 3) Physical & mechanical properties, 4) Non destructive methods, 6) Weathering estimation, 7) Protection measure

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