# *Environmental effects on the Monasteries of Mount Athos; the case of Symonos Petra Monastery*

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**Abstract**

The Monastery of Symonos Petra, located in Athos mountain (Greece) was studied geotechnical site investigation and building materials weathering conditions.

The site investigation comprises rockmass description and rock slope stability analysis. The interpretattion of the collected data determined the probable surfaces of sliding that can be activated under specific conditions.

Building stones and different types of mortar, used as cementing material, were collected from the older parts of the Monastery (13o, 16o century). These samples were examined regarding their origin so as the most proper measures for preservation to be taken.

## Introduction

Construction materials weathering, and foundation rock stability conditions are of particular interest, especially in regions like the Mediterranean Basin, where climatic and active geotechnic conditions are favourable.

Building stones are susceptible to various atmospheric factors causing their destruction. The presence of harmful soluble salts in pore water, as a result of reaction of atmospheric gases with rock minerals, is one of the main factors of stone decomposition, especially in coastal areas.

On the other hand, most of the historical buildings were built without the geomechanical particularities of the construction area having been taken in mind, in advance. Furthermore, the active neotectonic and seismotectonic conditions, in Mediterranean Basin, change the stability conditions of the area where the monument is built.

Mount Athos is located in Northern Greece and belongs administratively directly to the Patriarchate of Konstantinople. It is an area of great historical and religious interest, where only Monasteries for men are built. Many, pobably active, neotectonic faults, of N-S and E-W directions, traverse the area, causing damage to the Monasteries.

The Monastery of Symonos Petra was selected for investigation as a pilot monument in the area, because it can be considered as a good example of great scientific interest (fig. 1). It was built up around 1257 AD, on an isolated and uplifted rock (altitude 305 m) at the S/SW site of the mountain. It was burnt down several times, so as only the lower parts of the construction, near the rock

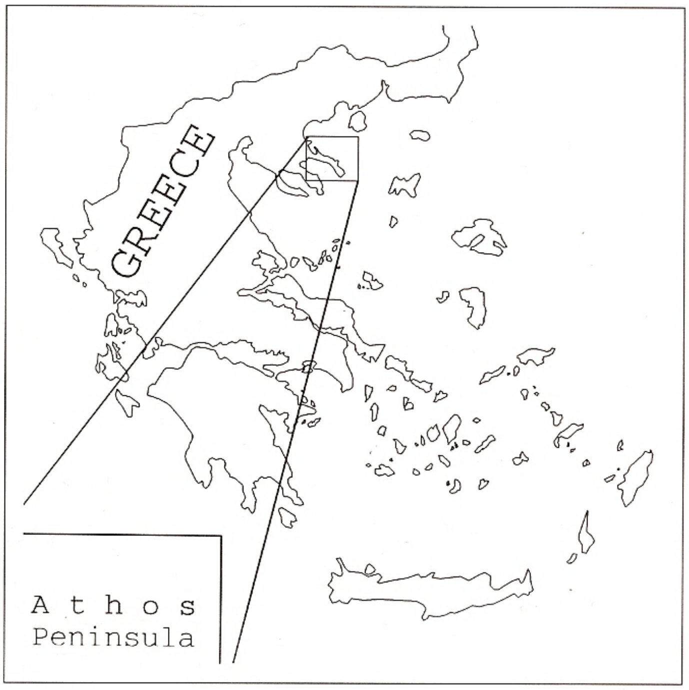



*Fig. 1 - Location of Athos peninsula.*

base is still of that age. The western part of the present building was built in 1590 AD while the eastern part in 1890 AD. The tower at the shipyard of the Monastery was built in 1563 and no restoration activities have been done until today (Xygopoulos, 1963, Kadas, 1989)

The Monastery was investigated, regarding the slope stability of the construction area as well as the weathering conditions of the older mortars, that consist the cementing material of the building stones and the critical factor of masonry strength. A part of data, used in the interpretation was presented in STREMA-93 (Christaras et al., 1993).

The foundation area was investigated by means of rockmass classification and slope stability analysis. The interpretation of the collected data determined the probable surfaces of sliding that can be activated under specific conditions and loading. The activity of important discontinuities was also investigated, with in situ measurements, using specific instruments, such as strain meters and extension meters, so as to determine their probable relationship with the existed neotectonic faults.

Building stones and different types of mortar, used as cementing material, were collected from the older parts of the Monastery and the arsenal (13°, 16° century, Table I). These samples were examined regarding their origin, hydraulic characteristics and resistance to weathering.

All data were interpreted, so as the most proper measures for preservation to be taken.

**Site investigation**

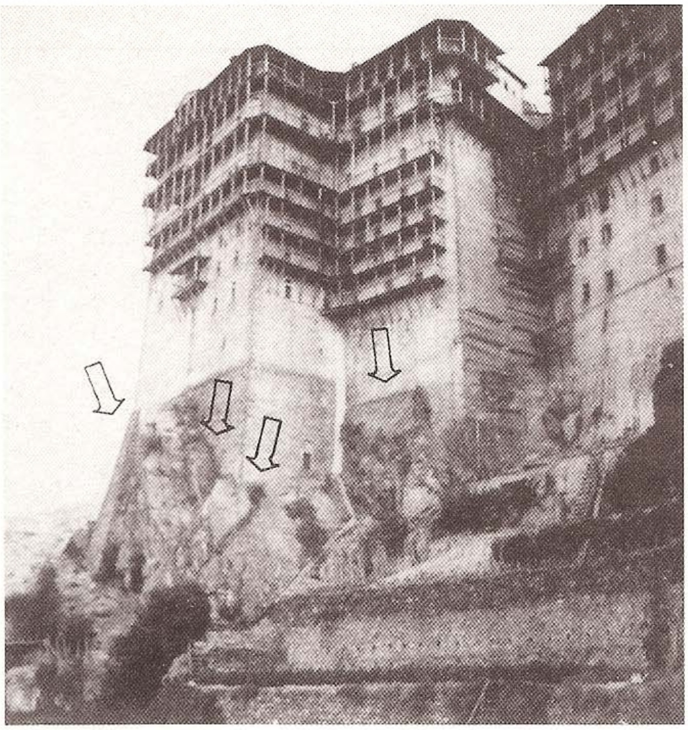
The area where the Monastery is built, is consisted of a typical, coarse grain, dark colour granite, that belongs to the Serbomacedonian mass (Kockel et al., 1977). The material is very compact, durable and resistant to the compression.

The Monastery is built on a very impressive isolated rock. The slopes of this rock are steep and the difference of altitude between the lower and higher points is more than 90 m.

The area is totally fractured and is traversed by joints of various directions. Many important faults of E-W and N-S general directions are occured. From a first point of view, these discontinuities can cause unstable geotechnical conditions, especially at the slopes of the construction area (fig. 2).

Joints are generally medium to closely spaced with routh surfaces. Widely spaced joints, of eastern dipdirection, are occurred too. Their aperture is usually narrow. Joints are usually unfilled. Although some individual fractures are filled with breccia of granite or rather with clay.

Field measurements were interpreted statistically and the results were ploted in equatorial stereonets (fig. 3). Slope direction as well as daylight envelope (DE) of joints that rise on the corresponding slope face are given in the stereonets in order to determine planar failures. The



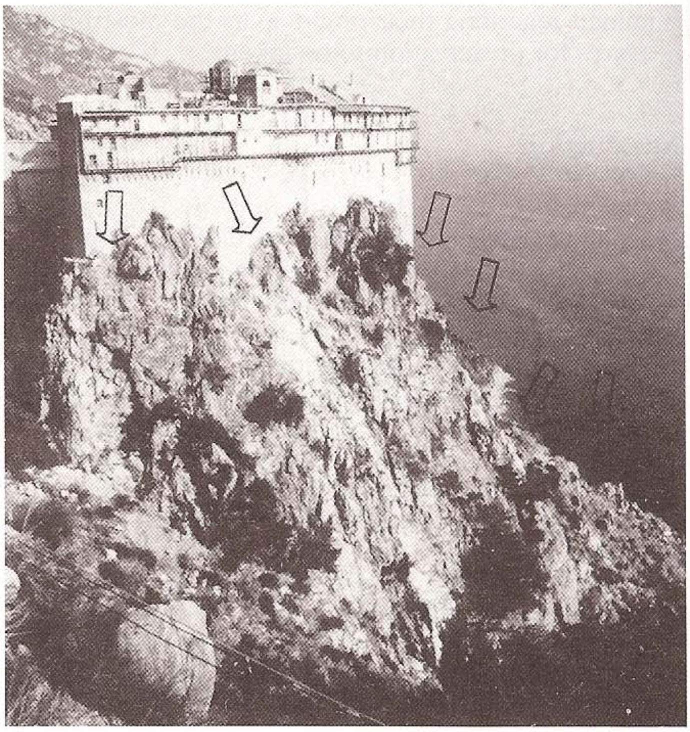


*Fig. 2 - Simonos Petra Monastery. They area is totaly fractured/ Above: western part, below: southern part.*

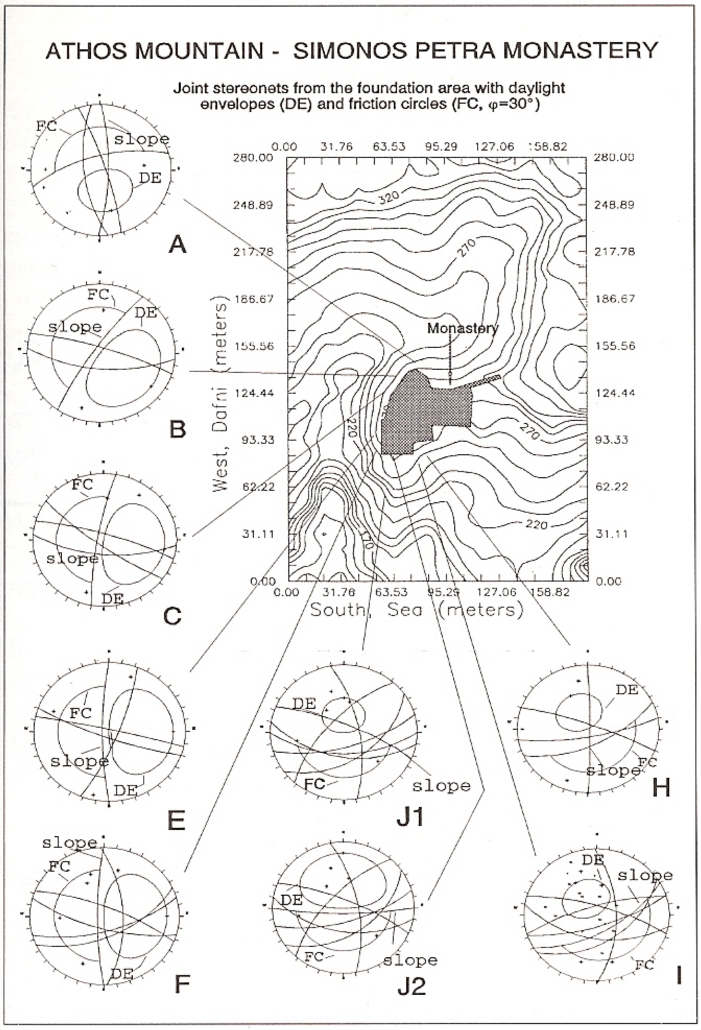



*Fig. 3 - Geotchnical at the site of Simonos Petra Monatery.*

intersections of joint sets that determine probable wedge failure conditions, are also given using the tests proposed by Markland (1972) and Hocking (1976). A friction circle (FC) with =30° was also ploted in every stereonet, for this purpose.

A probable fault of SSW dipdirection, traverse the rockmass at site E, causing damage to the foundation of the Monastery. Furthermore, an important N-S discontinuity, parallele to the N-S faults, cut the building near by its western wall, causing also damage both to the building and the foundation rockmass.

The ellaboration of the collected field data showed that the discontinuities of SSW or SE dipdirection in the southern part of the studied rock-hill, presents probable planar or wedge failures. The factors of safety determined at the area comprise a wide range of values, some of which are lower to 1.

At the southern part of the Monastery, joints of SSW or SE dipdirection cause probable wedge or planar failures.

| Sample | Sampling location | Composition |
|---|---|---|
| | Monastery | |
| 2 stone | Church, eastern wall | Talc, chlorite, calcite, spinel |
| 3 mortar | Southern wall old construction | Quartz, plagioclase, calcite, feldspars, chlorite, halite, micas. |
| 5 mortar | Church, internal | Calcite, quartz, plagioclase, chlorite, dolomite, micas. |
| | Arsenal | |
| 7 mortar | Northern wall | Calcite, quartz, chlorite, micas, plagioclase, dolomite, talc. |
| 8 mortar | Southern wall | Calcite, quartz, chlorite, dolomite |
| 9 mortar | Eastern | Calcite, quartz, feldspars, chlorite, hornblend, micas. |

*Table I - X-Ray difraction data of the construction materials.*

## Construction materials

Three types of different building stones are observed as follows:

a. Granite, petrographically characterized as biotite granite to granodiorite containing also hornblende (kockel et al, 1977). It is superficially weathered, but compact and durable inner.

b. Talc schist, composed by talc, chlorite, calcite and spinell, according to XRD analysis, (Table I), poor in calcite (content up to 2,18% , according to TG analysis).

Optical microscopic observations show a finely grained mass with oriented fine grains of muskovite and chlorite. Fe oxide veins are transpassing the mass. A substrate susceptible to serious soluble salts decay problems is indicated. However electron microprobe analysis does not reveal any Cl or S content (MgO: 30,16% ,$Al_2O_3$: 13,35% ,$SiO_2$: 45,02% ,CaO:0,70% ,$Cr_2O_3$: 0,60%, $Fe_2O_3$: 10,17%) nor any crystallized salt formation is observed by SEM.

c. Amphibol, mica schist. By polarized microscopy examination a finely grained and well oriented mass is observed:hornblende, quartz, biotite, feldspars and epidote are distinguished (substrate). The EDX-microbrobe analysis shows (NaO: 1,64%, MgO: 2,58%, $Al_2O_3$:12,42%, $SiO_2$: 63,59%, $K_2O$ : 2,47%, CaO: 13,05%, FeO: 4,26%). Eventhough feldspars could be susceptible to sodium or chlorite and other ions attack, due to an ion exchange mechanism, their fine dispersion into the mass, does not facilitate such a type of prefferencial decay.

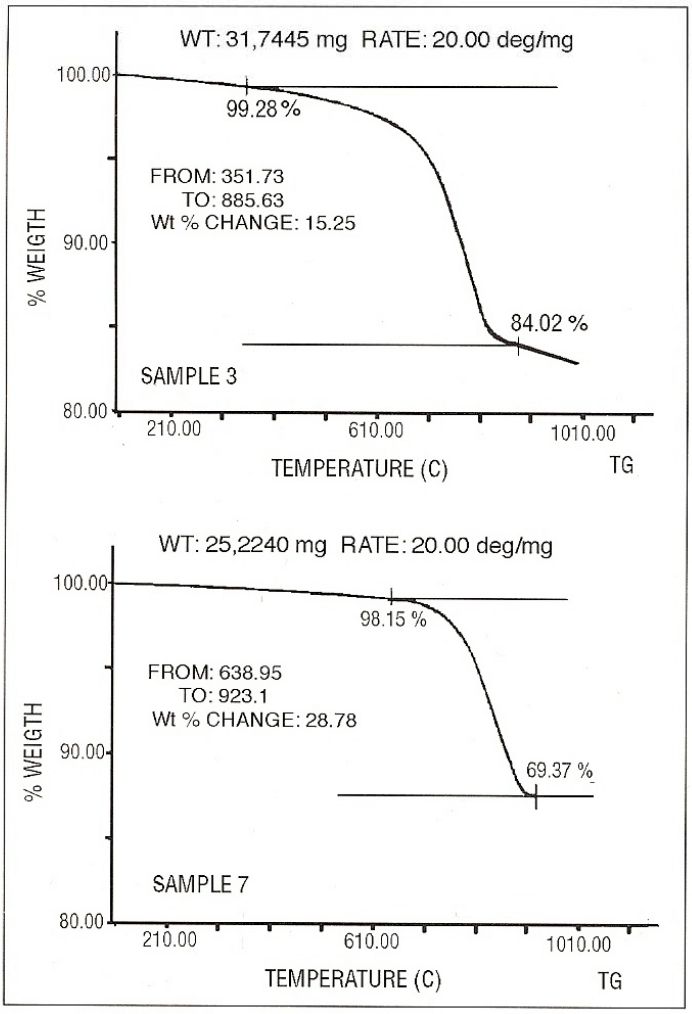



*Fig. 4 - EDX - overall result (cementing mateials - aggregates). a) Monastery (sample 5); b) Arsenal (sample 8).*

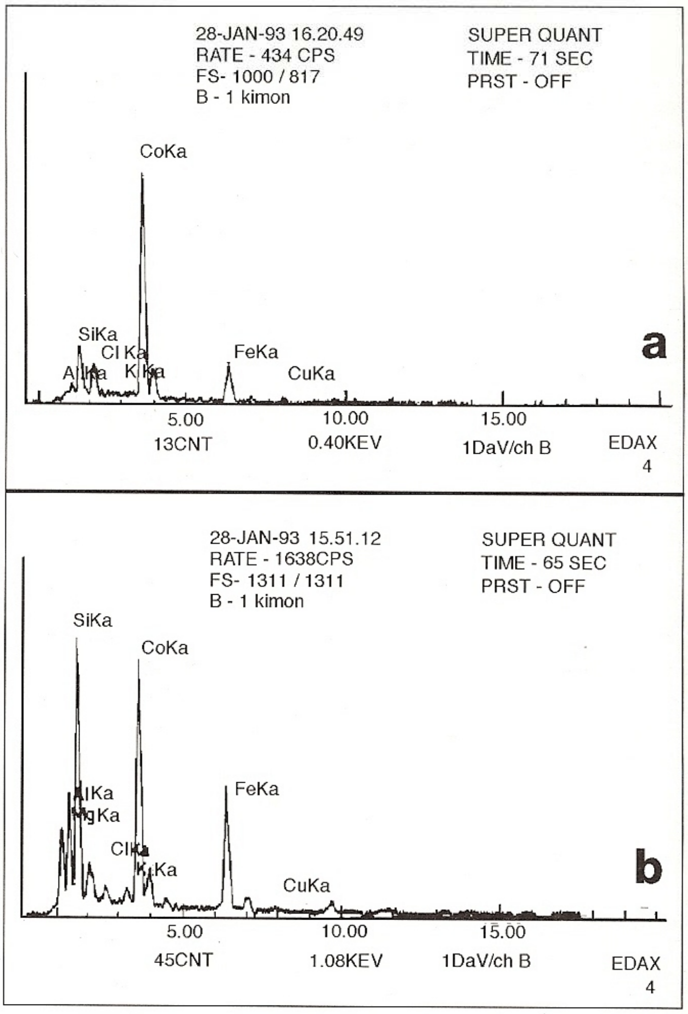



*Fig. 5 - Thermogravimetrical (GT) result of mortars collection from the Monastery (3) and the Arsenal (5).*

## Mortars

Concerning the mortars examined, all the samples from the Monastery (2,3,5) were decayed, whereas the samples from the Arsenal (7,8,9) demonstrated a cementicious texture not at all influenced by weathering. Optical microscopy observations demonstrate a good adhesion of the cementicious mortars to the substrate, whereas their scanning electron micrograph seems to be similar to these of high pozolanic content, implying hydraulic character (Lewin,1981). The rounded shape of the aggregates in comparison with the angular ones of the Monastery decayed mortars is supporting the above conclusion.

Eventhough calcite crystalls elongate within the pores of the cementious matrix and calcite is identified in all the Arsenal mortars (Table I - XRD results),the energy dispersive (EDX) analysis show a low calcitic in contrast to the high Mg-Al-Si contents (MgO : 29,91% , $Al_2O_3$ : 7,99% , $Si_2O$ : 56,12% , CaO : 0,13% , $Cr_2O_3$ : 0,30% , $Fe_2O_3$ : 6,25% ), as far as cementing material is concerned. Comparing these data to the Monastery mortars, a considerably lower Sika - Alka and higher Caka peak is noticed. TG analysis however indicates considerable weight loss at the 910° C, implying an aluminum-magnesium transformation which for the Arsenal mortars is almost double. Hence, cement mortars with hydraulic character and excellent adhesion to the building stones are not altered by weathering, even in more intense saline atmospheres, like in the case of the Arsenal, in comparison with the Monastery, whereas the more calcitic mortars of the later are totally decayed.

## Conclusions

Different lithotypes like granite, talc schist and amphibol mica schist, eventhough with clear mineral phases orientation and texture susceptible to decay, do not present considerable degratation, appart from rather superficial alterations. Main problems present the old calcitic mortars in the case of the Monastery structures, which are even absolutely decayed.

On the contrary, old Arsenal mortars, even in more intense saline environment, present an excellent cement behaviour and adhesion to the substrate . Further research on their hydraulic components would be of interest for restoration mortars, which are of need to the Monastery work.

The geotechnical site investigation at Symonos Petra Monastery showed the following:

- The rock-hill, where the Monastery is built, is totally fractured.
- Important discontinuities of general E-W and N-S directions cause damage both to the building andthe foundation rock-mass. The instability phenomena are probably more impresive at the southern and western slopes of the rock-hill, by means of planar and wedge failures.

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