ELSEVIER

0267-7261(94)00025-5

Soil Dynamics and Earthquake Engineering 14 (1995) 307–312

0267–7261/95/$09.50

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

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(Received 5 July 1994; accepted 6 July 1994)

The Monastery of Symonos Petra, located in Athos mountain (Greece) was studied for geotechnical site investigation and building material weathering conditions. The site investigation comprised rockmass description and rock slope stability analysis. The interpretation 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 (13th and 16th century). These samples were examined regarding their origin so as the most suitable measures for preservation may be taken.

INTRODUCTION

Construction material 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 the 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 historical buildings were built without the geomechanical particularities of the construction area having been taken into consideration, in advance. Furthermore, the active neotectonic and seismotectonic conditions in the Mediterranean Basin change the stability conditions of the area where the monument was 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, probably 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 an example of great scientific interest (Fig. 1). It was built 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 base are still of that age. The western part of the present building was built in 1590 AD while the eastern part was built in 1890 AD. The tower at the shipyard of the monastery was built in 1563 and no restoration activities have been done until today.[1,2]

The monastery was investigated with regard to the slope stability of the construction area as well as the weathering conditions of the older mortars, that constitute the cementing material of the building stones and the critical factor of masonry strength. A part of the data used in the interpretation was presented in STREMA-93.[3]

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

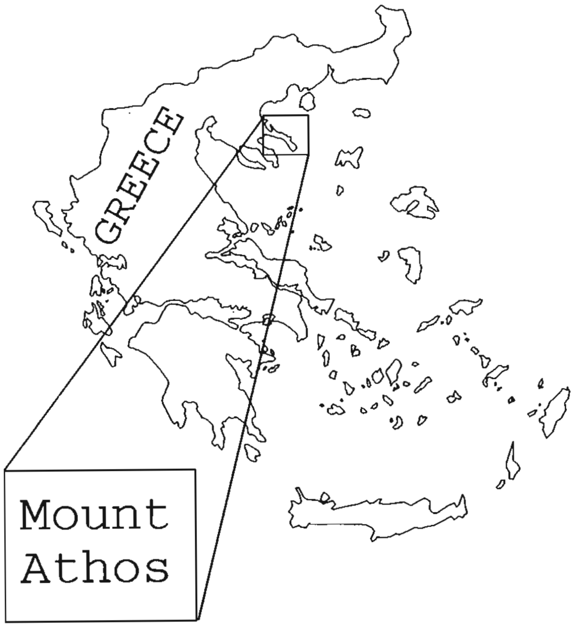


Fig. 1.

in-situ measurements, using specific instruments, such as strainmeters and extensionmeters, so as to determine their probable relationship with the existing 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 (13th and 16th century, Table 1). 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 may be taken.

SITE INVESTIGATION

The area where the monastery is built, is made up of a typical, coarse grain, dark colour granite, that belongs to the Serbomacedonian mass.[4] 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 in altitude between the lower and higher points is more than 90 m.

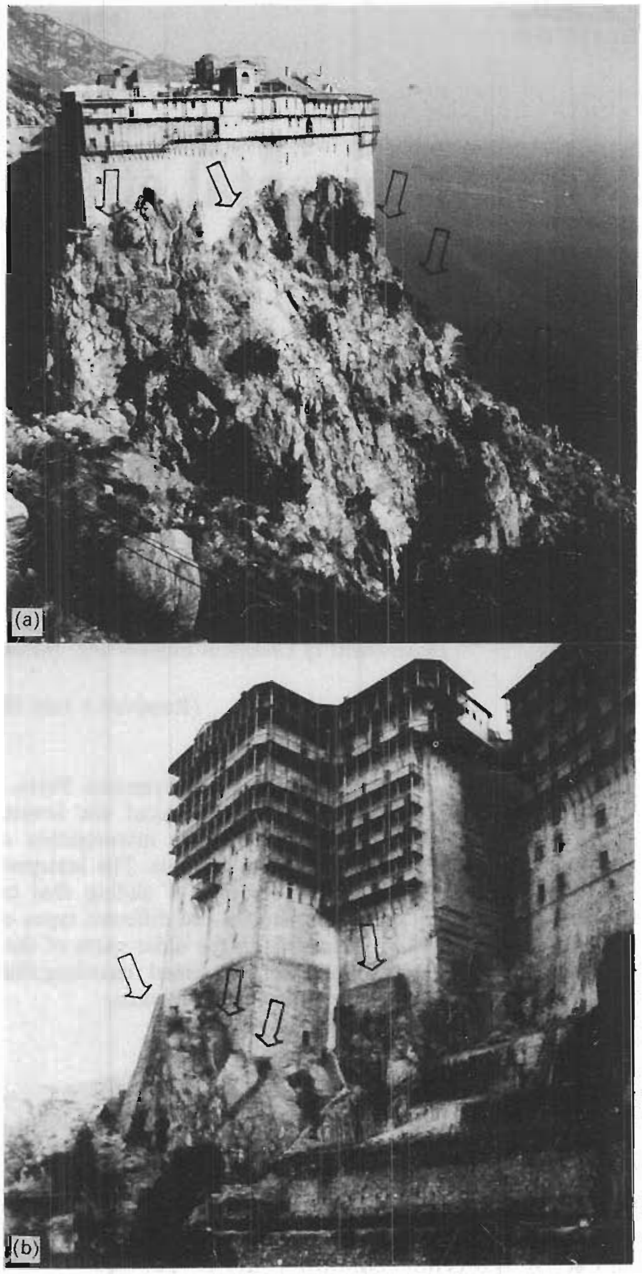


Fig. 2.

The area is totally fractured and traversed by joints of various directions. Many important faults of E–W and N–S general directions occur. From a first point of view,

Table 1. X-Ray diffraction data

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

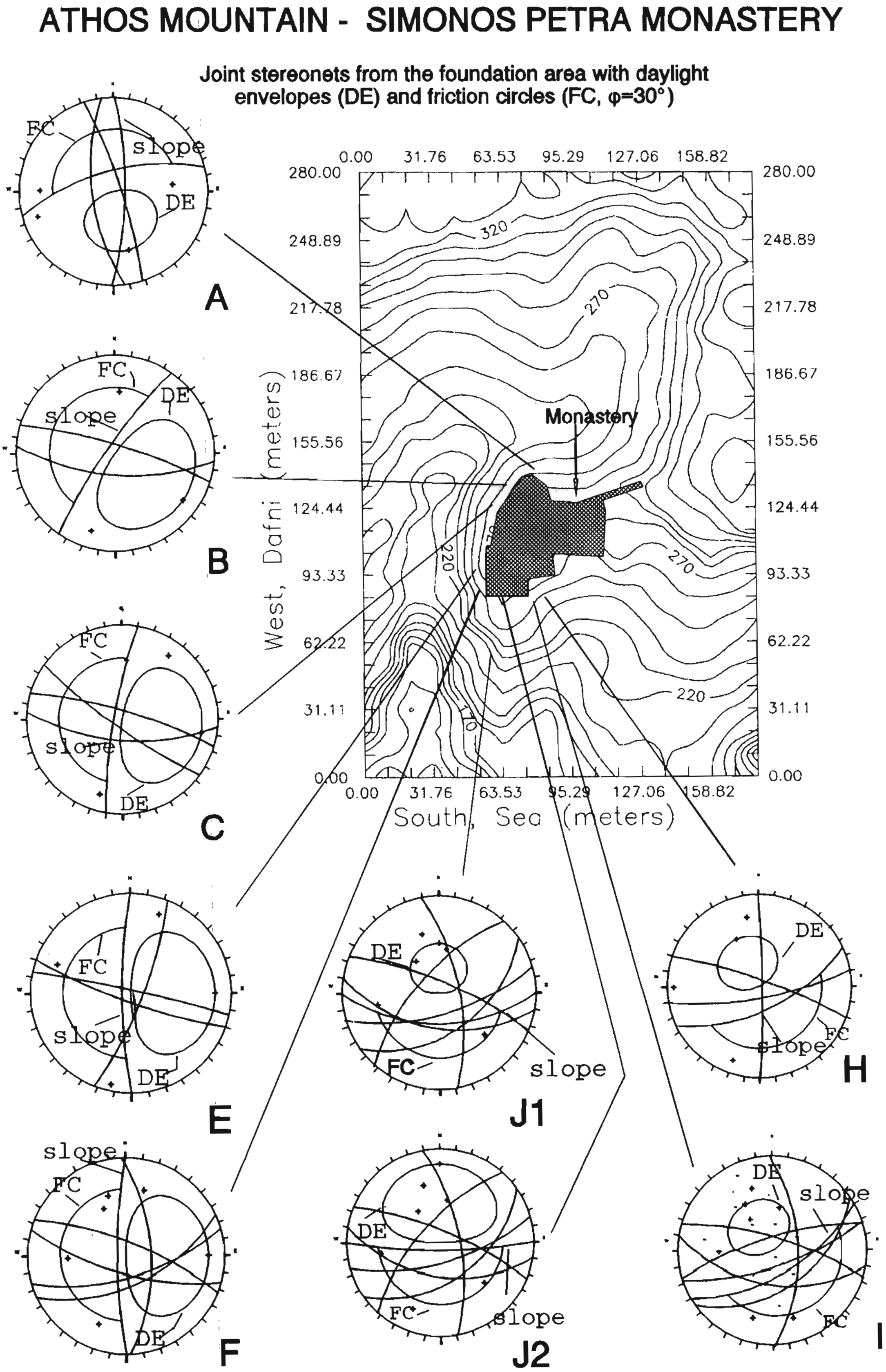

ATHOS MOUNTAIN - SIMONOS PETRA MONASTERY
Joint stereonets from the foundation area with daylight envelopes (DE) and friction circles (FC, φ=30°)
Monastery
West, Dafni (meters)
South, Sea (meters)
0.00
31.76
63.53
95.29
127.06
158.82
280.00
248.89
217.78
186.67
155.56
124.44
93.33
62.22
31.11
320
270
220
A
B
C
E
F
J1
J2
H
I
FC
DE
slope

Fig. 3.

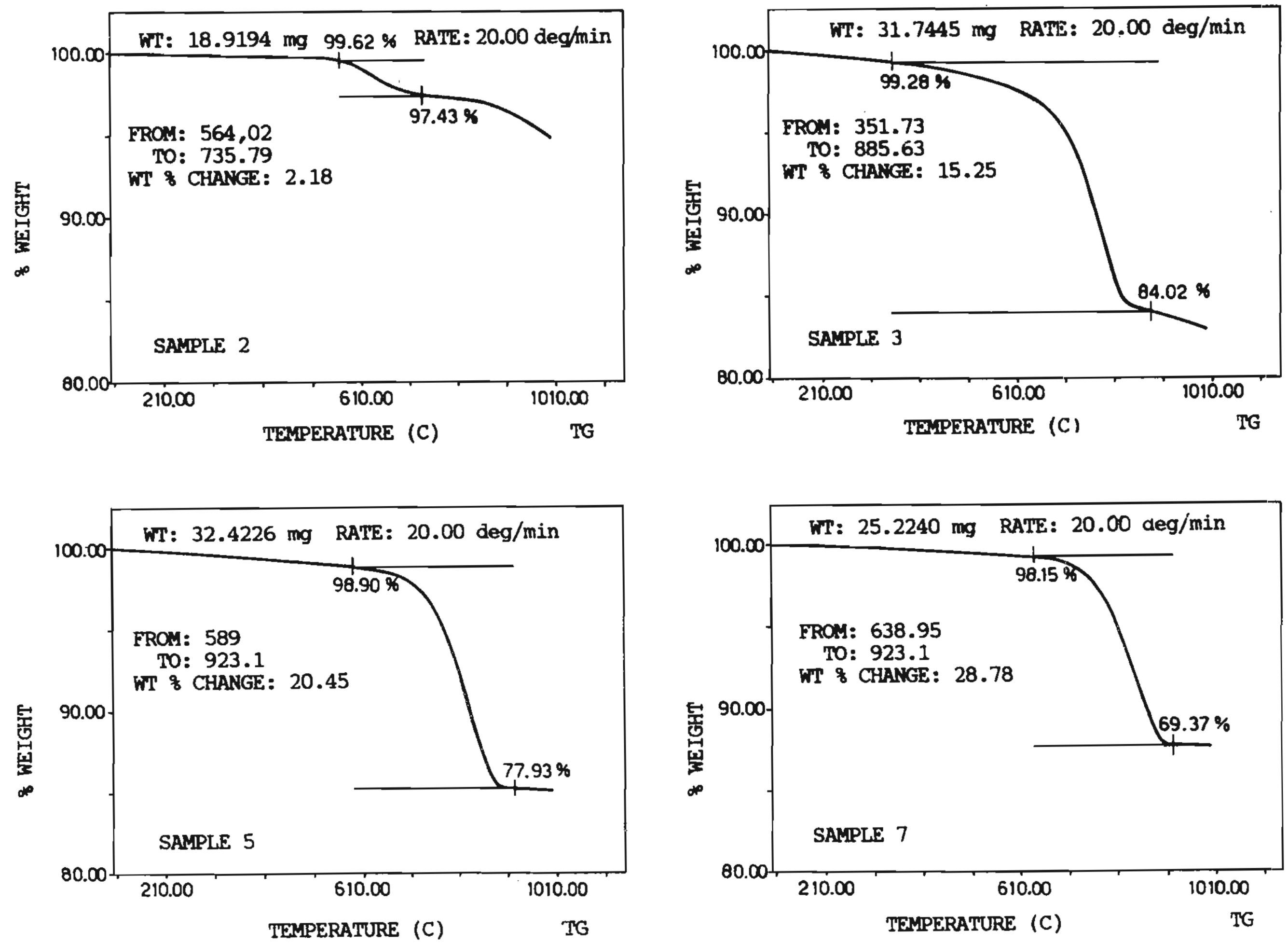


Fig. 4.

these discontinuities can cause unstable geotechnical conditions, especially at the slopes of the construction area (Fig. 2).

Schmidt diagrams from sites A to J2 refer to the rockmass where the monastery is built (Fig. 3). Slope direction as well as daylight envelope (DE) of joints that rise on the corresponding slope face are also given. The intersections of joint sets that determine probable wedge failure conditions, are also given using the tests proposed by Markland[5] and Hocking.[6] The friction circle was estimated equal to $\phi = 30°$.

Joints are generally medium to closely spaced. Widely spaced joints, of eastern dipdirection also occur; their aperture is usually narrow. Joints are usually unfilled, although some individual fractures are filled with breccia of granite.

The surface of the joints is rough; according to the chart of Barton and Choubey,[7] their roughness coefficient (I_f) is estimated at approximately 16–18.

A probable fault of SSW dipdirection, traverses the rockmass at site E, causing damage to the foundation of the monastery.

The statistical interpretation of the collected tectonic data show that the southern part of the studied rock-hill, is probably the more unstable one. At the other sites, the poles of the calculated joint sets do not fall in the daylight envelope. Furthermore, the intersections of the joint sets do not correspond to unstable wedge failure conditions.

At the southern part of the monastery, joints of SSW or SE dip direction cause probable wedge or planar failures.

CONSTRUCTION MATERIALS — CHARACTERIZATION AND WEATHERING

Three different types of building stones are observed as follows:

Monastery buildings

(a) Granite

Petrographically characterized as biotite granite to granodiorite also containing hornblend.[4] It is superficially weathered, but has a compact and durable inner.

(b) Talc schist

Composed of talc, chlorite, calcite and spinel, according to X-ray diffraction analysis (Table 1), poor in calcite

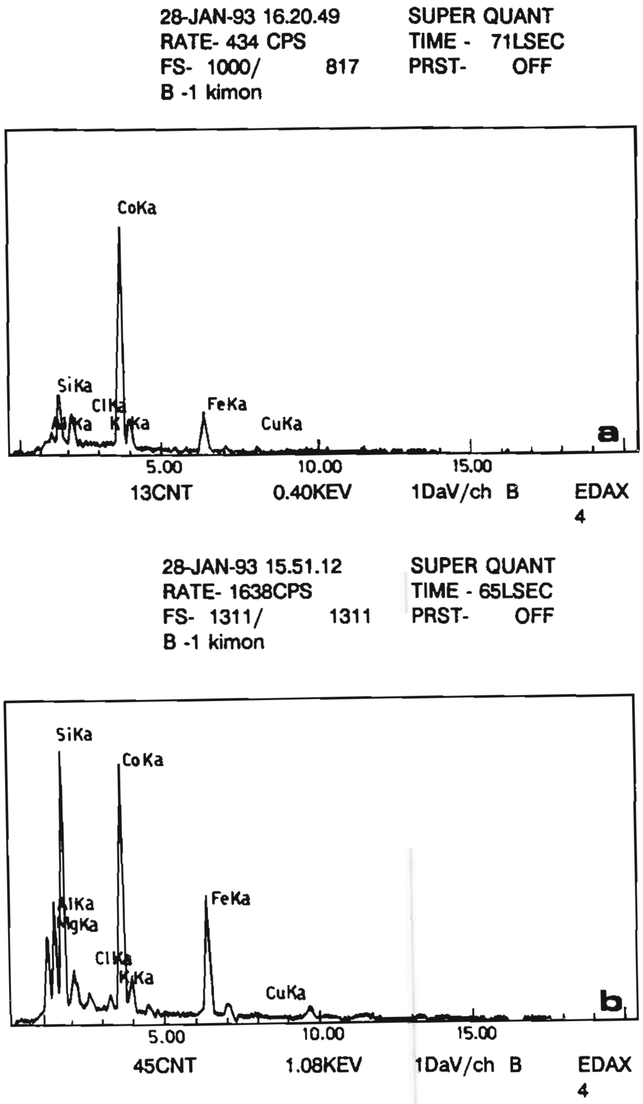


Fig. 5.

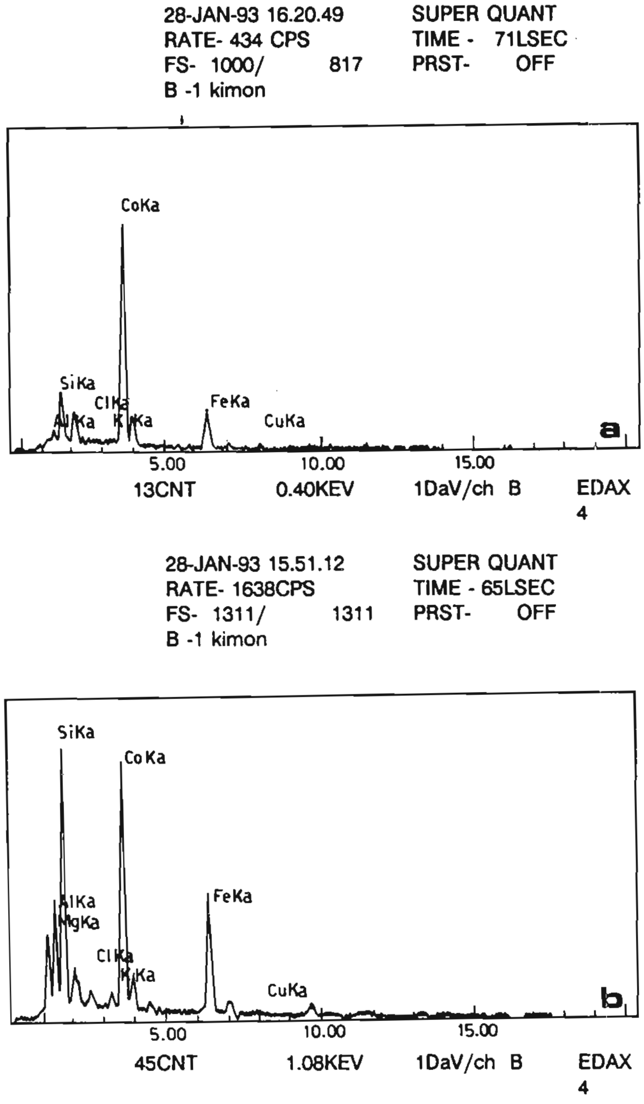


Fig. 6.

(content up to 2·18%, according to TG analysis). Optical microscopic observations show a finely grained mass with orientated fine grains of muskovite and chlorite. Iron oxide veins are transpassing the mass. A substrate susceptible to serious soluble salt decay problems is indicated. However, electron microprobe analysis does not reveal any CI 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 is any crystallized salt formation observed by SEM.

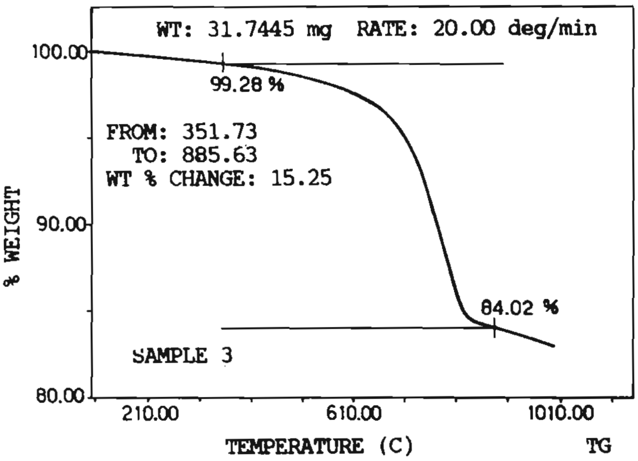
(*c*) *Amphibol, mica schist*
By polarized microscopy examination, a finely grained and well oriented mass is observed: hornblend, quartz, biotite, feldspars and epidote can be distinguished (substrate). The EDX-microprobe analysis shows (NaO: 1·64%, MgO, 2·58%, Al_2O_3: 12·42%, SiO_2: 63·59%, K_2O: 2·47%, CaO: 13·05%, FeO: 4·26%).

Even though feldspars could be susceptible to attack by sodium or chlorite or other ions, due to an ion exchange mechanism, their fine dispersion in the mass does not facilitate such a preferential decay.

Mortars

Concerning the mortars examined, all the samples from the monastery (2, 3 and 5) were decayed, whereas the samples from the arsenal (7, 8 and 9) demonstrated a cementitious texture not at all influenced by weathering. Optical microscopic observations demonstrated a good adhesion of the cementitious mortars to the substrate, whereas their scanning electron micrograph seemed to be similar to those of high pozolanic content, implying hydraulic character.[8] The rounded shape of the aggregates in comparison with the angular ones of the decayed mortars of the monastery supports the above conclusion.

Even though calcite crystals are elongated within the pores of the cementitious matrix and calcite is identified in all the arsenal mortars (Table 1: X-ray diffraction



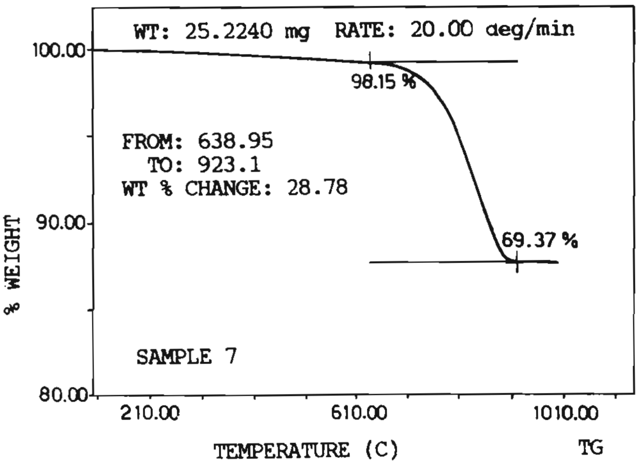


Fig. 7.

results), the energy dispersive (EDX) analysis shows a low calcitic content in contrast to the high Mg–Al–Si content (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 those of the monastery mortars, a considerably lower Sika–Alka and higher Caka peak is noticed (Fig. 5). TG analysis however indicates considerable weight loss at 910°C, implying an aluminium–magnesium transformation which for the arsenal mortars is almost double (Fig. 4). Hence, cement mortars with hydraulic character and excellent adhesion to the building stones are not altered by weathering, even in more intense saline atmospheres, as in the case of the arsenal, in comparison with the monastery, whereas the more calcitic mortars of the later are totally decayed.[9,10]

CONCLUSIONS

Different lithotypes like granite, talc schist and amphibol mica schist, although having clear mineral phase orientation and a texture susceptible to decay, do not show considerable degradation, apart from rather superficial alterations.

The main problem is the old calcitic mortar of the monastery structures, which are considerably decayed.

On the contrary, the old arsenal mortars, although in a more intense saline environment, show an excellent cement behaviour and adhesion to the substrate. Further research on their hydraulic components would be of interest for restoration of mortars, necessary for 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.
— There is an important discontinuity cut in the western side of the rockmass causing damage to the foundation of the monastery.
— According to our preliminnary data, the southern slope of the rock-hill shows relatively unstable conditions; further research on slope stability will lead to better preservation measures.

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