INTERNATIONAL EARTH SCIENCES
CONGRESS ON AEGEAN REGIONS
1 - 6 OCTOBER 1990
İZMİR - TURKEY

IESCA 1990

PROCEEDINGS

VOL.I

ECONOMIC GEOLOGY
ENGINEERING GEOLOGY
METAMORPHISM/MAGMATISM
MINERALOGY/GEOCHEMISTRY/PETROLOGY
PALEONTOLOGY
SEDIMENTOLOGY/STRATIGRAPHY

EDITED BY
M.Y.SAVASCIN   A.H.ERONAT

Σελ: 123 -134

Weathering of two archaeological sites in Creta/Greece; effects on the physico-mechanical properties of their building stones.

B.CHRISTARAS
Department of Geology, Aristotle University, 54006 Thessaloniki, Greece

Abstract

The building stones from the archaeological sites of Knossos,and Festos in Creta are studied, concerning their weathering condition and some of their physical and mechanical properties. The investigation includes: a)the mineralogy of the examined stones using microscopic and X ray diffraction methods, as well as in situ observations; b) the weathering condition either under the microscope examination or with ultra-sonic velocity measurements; c) the weathering resistance by salt crystallisation methods; d)the dry density and the water absorption; and e)the unaxial compressive strength. All test results were interpreted statistically and the derived relationships were expressed mathematically; correlation diagrams were also given.

Introduction

The archaeological sites of Knossos and Festos in Creta island, suffer the effects of the warm climatic conditions in the Mediterranean basin. Historical building stones exposed to atmospheric factors are captured to the action of various agents causing their destruction. Water/Salt combination, activated by the fluid circulation and evapo-transpiration, is one of the main factors which provoke the weathering and decomposition of a stone, by the creation of shrinking - expansion and freezing - fusion phenomena of pore water. The marine salts, are a permanent cause of natural pollution, not only on the coast but even more further inland, especially in islands. Components of smoke which react in the pores of the stones are also one of the atmospheric pollutants; non-metallic oxides, in particular sulphur oxides, dissolved in the water, reduce the water pH and form sulphuric acid which reacts with the mineral components of the stones, resulting in the formation of sulphuric salts, such as gypsum, in the case of limestones and sandstones.

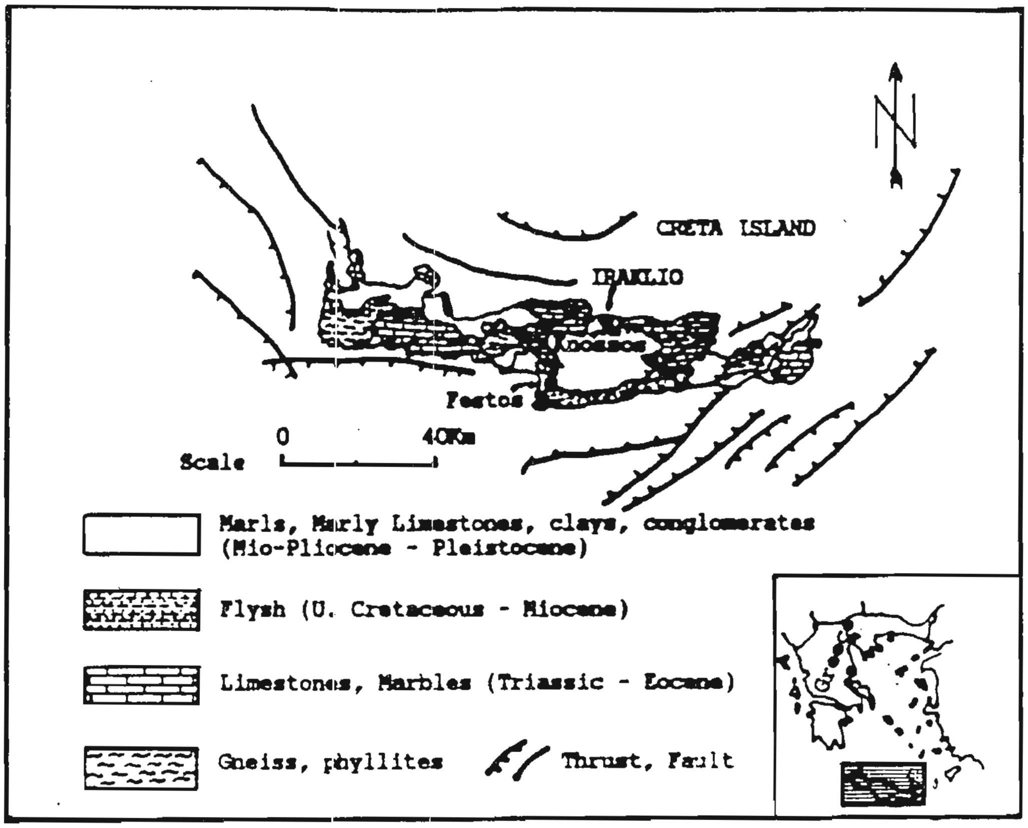

Fig. 1. Location of the studied area , with some geological data (Seismotectonic map of Greece, 1:500000 IGME, 1989)

In the studied archaeological sites of Knossos and Festos the building stones were mainly of marly limestones which are abundant in the surrounding area. A careful examination of the constructing material of the above ruins may contribute to the recognition of the real factors which have caused damage, so as the most proper chemical and natural conservation and protection measures be taken.

The archaeological sites

The area where the studied historical monuments occur, is located in the central part of Creta island in the southern part of Greece (Fig. 1).Excavations brought to the light remains of ancient towns as the result of a famous ancient civilisation dated since the neolithic times (Savignoni & de Sanctis, 1901, GNTO,1986).

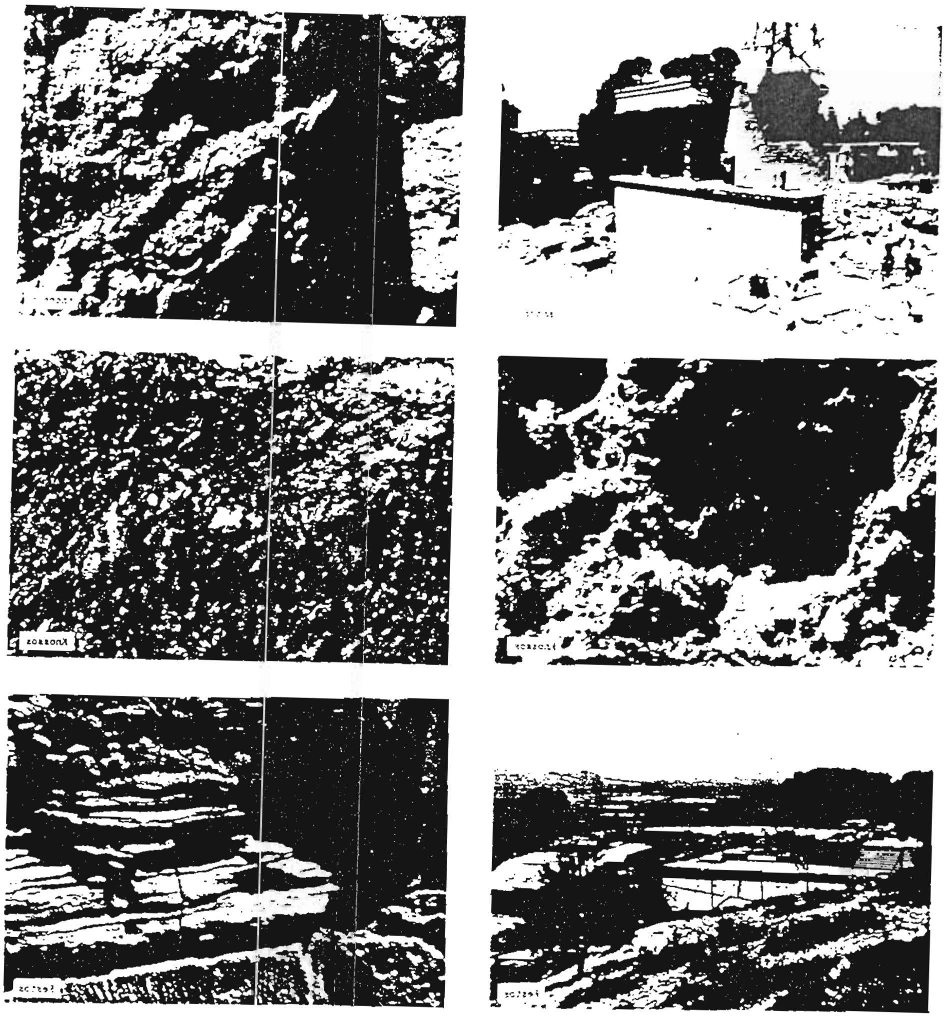

Fig. 2. Pictures from the studied archaeological sites. Weathering activity on the surface of the walls is obvious.

Knossos is situated in a distance of 5Km, to the south of Iraklio. It was inhabited since neolithic period and developed into the capital of the Minoan Kingdom, having its religious and administrative centre, the Palace, placed on the top of the hill. An earthquake and probable eruptions of Thyra volcano destroyed the town before 1890 BC. The new Palace, built in 1700 BC, presents a splendid architecture and is decorated inside with famous frescos. It was built on the rubble of an older Palace comprising an area of $21000m^2$. An earthquake and a fire destroyed it in 1570 BC (Galanopoulos, 1955). It was rebuilt in 1450, to be destroyed in 1375 BC.

A new town, which was built, was destroyed definitively in 823 AC (Fig. 2a).

Festos is the second most important centre of Minoan civilisation, situated 63Km to the South-West of Iraklio. The Palace which was built and destroyed the same period with the Palace of Knossos, is located on a hill, with a nice view to Messara plane, comprising an area of $1800m^2$ (altitude 100m, between Asteroussia and Psiloritis mountains). The town was destroyed definitively in 150 BC (Fig. 2e).

Geological data

Iraklio broader area is composed of Mio-Pliocenic sediments, mainly of fossiliferous marly limestones marls, sands, clays and conglomerates (Christodoulou, 1963, Symeonidis & Konstantinidis 1968, Fig.1). The ancient buildings in the area were constructed of marly limestones.

In Knossos the area is composed of marine sediments, with fossils of middle Miocenic age. These sediments are consisted, from the bottom to the top, of yellowish white marls, greyish green marls, yellow marls, brownish yellow marls and marly limestones.

In Festos, the hill where the Palace is built, is composed of interlayering fossiliferous (Tortonian) marls and marly limestones.

Durability of stones and weathering

The durability of a stone is a measure of its ability to resist weathering and so retain its original size, shape and physico-mechanical behaviour over an extensive period of time. Chemical weathering ,temperature fluctuation, moisture content and absorption ability contribute to the rock decomposition by loosening the rock fabric and by emphasizing any structural weakness.

The type of weathering varies from one climatic regime to another. In humid regions chemical weathering is more significant than that of mechanical disintegration. At temperature as in Creta, weathering is extremely active; pore water transporting salts, accelerates the decomposi-

tion of the material by shrinking - expansion and freezing - fusion phenomena. According to Bell and Dearman (1988), when the temperature of the water increases from $0^{0}C$ to $60^{0}C$ it expends some 1.5% exerting a pressure of up to $52MN/m^2$ within the pores of a rock. Percolating water strengthens the weathering processes on calcite, feldspars, micas and the other easily dissolved and altered minerals which are identified in the studied marly limestones, by passing through the fractures.
The presence of harmful soluble salts, such as sulphates and chlorides of Ca, Mg,and Na in pore water, as a result of reactions of atmospheric gases with rock minerals, is also a significant factor of stone decomposition; the crystallisation of these salts needs more water, a fact which provoke their expansion causing the loosening of the tie fabric of the stone.

Building material was studied both in situ and in the laboratory. The mineralogical composition of the collected samples derived either from the walls of the ruins of the archaeological sites or from the surrounding area was studied as follows;

i) By thin section examination under polarising microscope

ii) By XRD investigation(qualitative and semi-quantitative composition), with the use of a Philips diffractometer, CuKa radiation. Diagrams of representative samples are given in Fig. 3.

In Knossos the constructive material is of marly limestones, derived probably from the upper layers of the middle-Miocenic sediments.As accessories, some stones of pure marl are also found, in very small quantity; they are of brownish yellow marls, similar to those of the upper layer of the marly sedimentation phase, bedded under the marly limestone layer.

The constructive material, characterised as marly limestone, is composed of calcite 82%, kaoline, chlorite and micas 12% and some minor amounts of 4% and 2% of quartz and gypsum. The rock is white, medium grained with uniform relative grain size, angular to subangular grain shape with equidimensional form and rough surface texture. Unweathered stones are

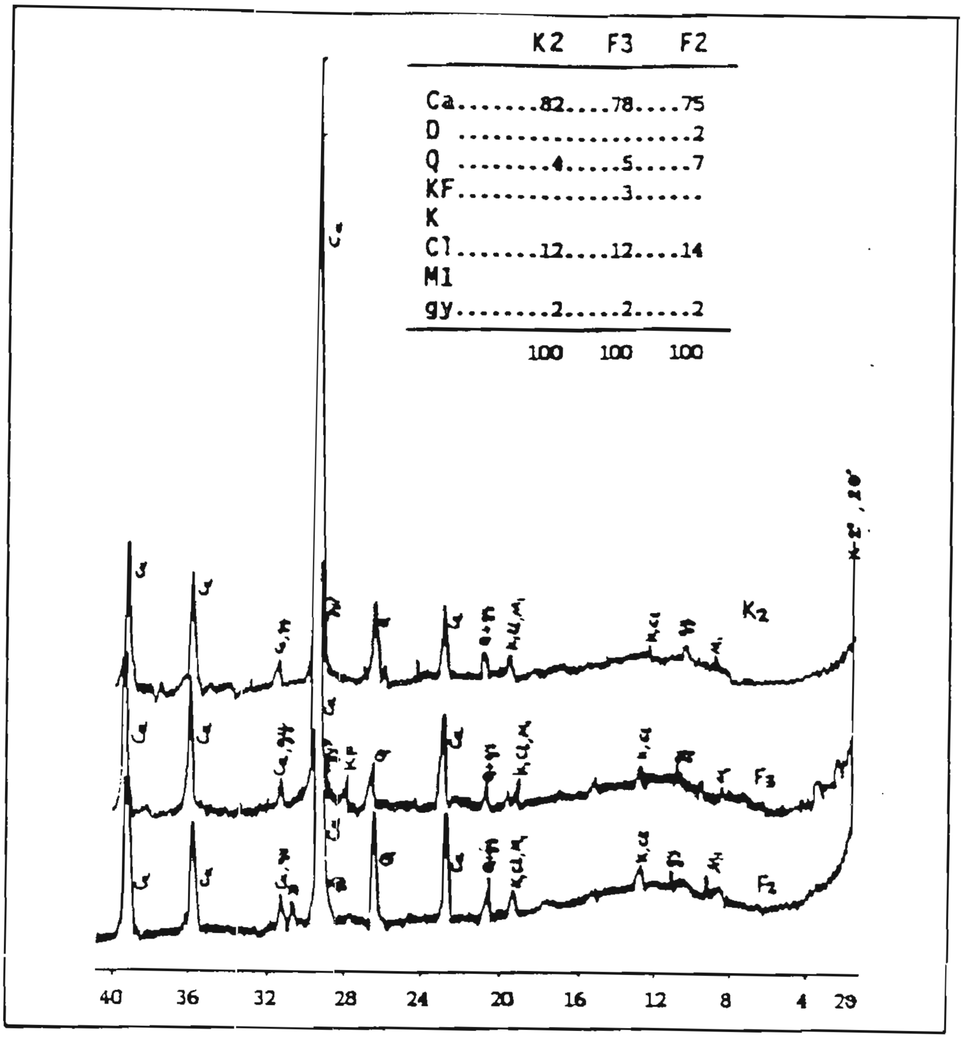

Fig. 3. XRD diagrams of representative samples. K2: Knossos (wall), F2,F3: Festos (wall), Ca: calcite, D: dolomite, Q: quartz, KF:K- feldspars, K:kaoline, Cl: chlorite, Ml: micas (muscovite), gy: gypsum.

Material description - Petrography

highly compact and durable. As it derives, weathering attacked strongly the building stones, starting from the surface and continuing inside thus loosening the tie stone fabric (Fig. 2b,c); many of the walls are covered by a layer of gypsum with crystals of 0.5 - 1.0cm length, in exceptional cases (Fig. 2d). The presence of sulphuric anions (due probably to the big eruption of Thyra volcano in 1890 BC or 1500 BC and to a great fire in historical time) in pore water cause the creation of sulphuric salts, such as gypsum, in reaction with calcite.

In Festos, the building stones of the Palace are also of fossiliferous marly limestone, derived probably from the upper part of the Tortonian layers.

The material is composed of calcite >75%, kaoline, chlorite and micas 12%, quartz 5% altered K-feldspars 3%, and traces of dolomite and secondary gypsum. The rock has a white colour and can be characterized as medium grained with uniform relatively grain size, angular to subangular grain shape with equidimensional form and rough surface texture. Unweathered pieces of stone are durables.Generally the material is strongly weathered, displaying a sandy shape at the surface, due probably to the different resistance of the grains to weathering (Fig. 2f); in many cases it displays also a high porosity. Gypsum grains like those of Knossos are absent.

Physical and mechanical properties

Tests were applied on cylindric specimens with a diameter of 24mm and height of 48mm, prepared by the use of a core drilling machine; the specimens were examined concerning:

i) Their dry density (d, ASTM C 97-47), obtained by dividing the dry weight (after drying for 24h at 110^{0}C) of the specimens by the total volume (solids and voids)

ii) Their water absorption (Ab, ASTM C 97-47), by dividing the absorbed water weight (after a bath of 24h, in vacuum) by the dry weight of specimens.

iii)The ultrasonic velocity through the material (v, ASTM 597, ASTM D 2845-83), as a good index characteristic of the physico-mechanical behaviour of

Table 1. Physicomechanical properties of building stones from the archaeological site of Knossos

Properties Samples	Dry density d (g/cc)	Absorption Ab (%)	Ultrasonic velocity v (Km/sec)	Compres. Stength σc (Kg/cs)	Weatherability W (%)
K1	1.82	3.30	3.78	378	32.05
K2	1.75	3.80	3.48	328	41.28
K3	1.72	4.50	3.33	300	40.12
K4	1.78	3.90	3.63	306	37.73
K5	1.45	6.75	2.54	210	43.53
K6	1.43	7.83	2.48	208	43.28
K7	1.40	8.66	2.50	200	45.38
K8	2.00	2.48	4.37	517	19.78
K9	1.96	2.70	4.20	504	12.47
K10	2.01	1.71	4.56	560	11.77

k1-k10 : Marly limestones

Table 2. Physicomechanical properties of building stones from the archaeological site of Festos

Properties Samples	Dry density d (g/cc)	Absorption A (%)	Ultrasonic velocity v (Km/sec)	Compres. Strength σc (Kg/cs)	Weatherability W (%)
F1	1.89	2.40	4.20	458	15.08
F2	1.75	7.82	3.38	326	40.22
F3	1.70	9.89	3.09	295	41.00
F4	1.86	4.25	3.44	360	37.37
F5	1.65	11.09	2.61	220	42.06
F6	1.57	10.38	2.59	220	42.77
F7	1.71	9.73	2.99	310	40.53
F8	1.74	7.67	3.43	330	39.72
F9	1.79	5.34	3.72	350	35.80
F10	1.83	4.89	3.82	393	28.18

F1-F10 : Marly limestones

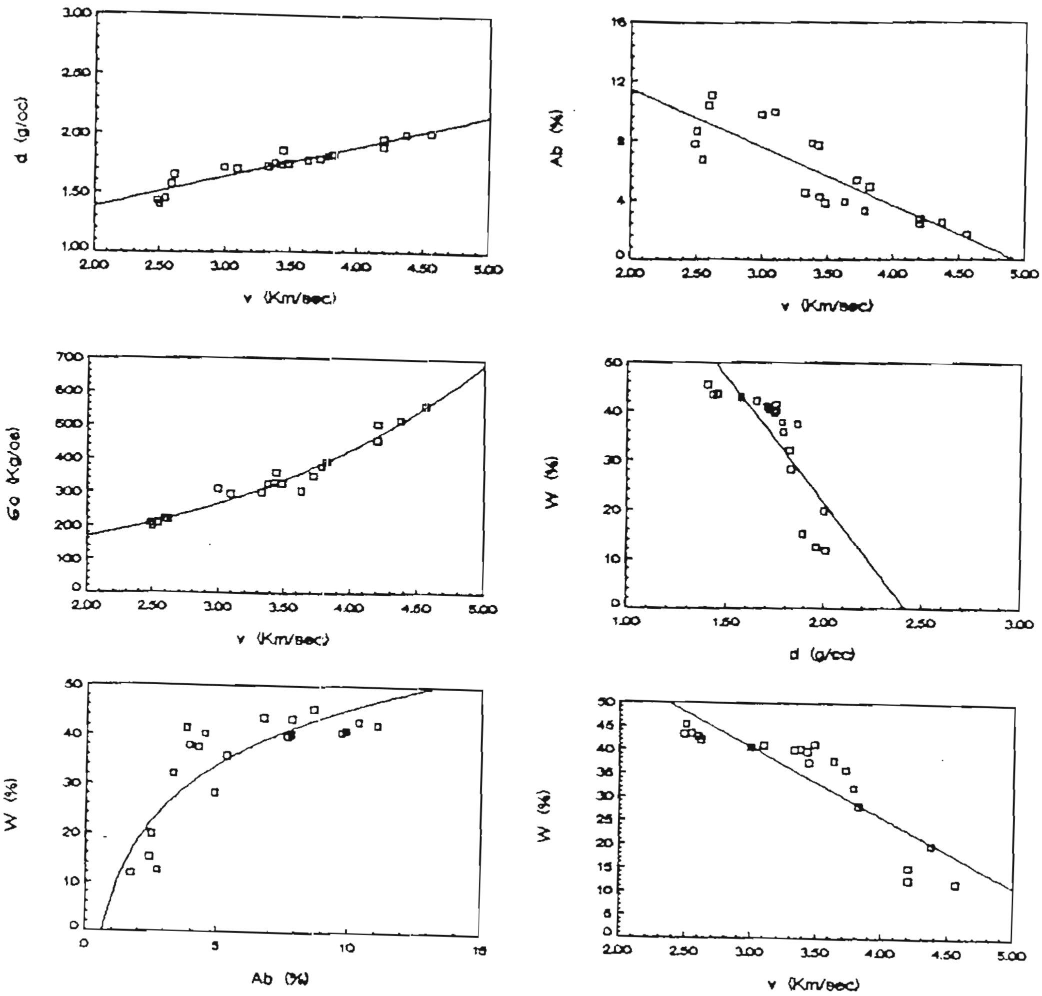

Fig. 4. Correlation diagrams of the studied properties.

ability of a material to weathering, can be expressed by the term "weatherability", as a % of loss of weight in soundness test.

According to the correlation diagrams, ultrasonic velocity is related linearly to the "weatherability", displaying a negative correlation, and confirming the consideration that it can characterize quite well the weathering condition and the further weathering resistance of the material. Ultrasonic velocity is related linearly also to the dry density and to the water absorption of the material confirming the consideration that ultrasonic velocity is higher in more dense and less porous materials, which normally show lower water absorption. The compressive strength is related positively, by exponential regression, with the ultrasonic velocity, providing that a slight decrease of ultrasonic velocity (related the rocks. For this purpose a PUNDIT portable ultrasonic non destructive digital tester was used.

iv)Their compressive strength (σ_c, ASTM C 170-50) by dividing the compressive load by the surface of the base of the cylinder.For this purpose a 10tn loading system was used.

v) Their weatherability (W), as an index characteristic of soundness and furthermore weathering resistance of the material. For this purpose soundness test (ASTM C 88) by attack with sodium sulphate solution, in five cycles, was used.

Test results for each archaeological site are given in Tables 1,2.

Interpretation of test results

Test results were interpreted statistically concerning the relationship (and influence) between the studied properties (Fig. 4). These relationships were expressed mathematically as follows:

i) $d = 0.87 + 0.25\ v \qquad r = 0.945$

ii) $Ab = 19.27 - 3.91\ v \qquad r = -0.849$

iii) $\sigma_c = 65.10\ e^{0.47v} \qquad r = 0.979$

iv) $W = 123 - 50.84\ d \qquad r = -0.811$

v) $W = 7.31 + 16.50\ \ln Ab \qquad r = 0.842$

vi) $W = 85.09 - 14.85\ v \qquad r = -0.879$

The correlations were verified concerning their significance by calculation of $t = r(n-2)^{1/2}/(1-r^2)^{1/2}$ using the Student Tables, according to which the correlation coefficient should to be higher than 0.52 (level 0.1, n-2=18).

Weathering condition is expressed directly by the ultrasonic velocity through the measured material, presenting generally a negative linear relationship; the ultrasonic velocity in an unweathered stone is usually bigger than 5Km/sec. Furthermore the weathering resistance, or better the to increase of weathering) causes a significant decrease of the mechanical resistance and specially of the compressive strength of the material. The logarithmic relation between the weatherability and the water absorption confirms also that at the first stages of weathering an inconsiderable increase of the water absorption, related to the porosity and weathering increasing, provokes a considerable decrease of the furthermore weathering resistance.

Conclusions

Building stones from the archaeological sites of Knossos, and Festos in Creta, were studied concerning their mineralogical and physico-mechanical data in relation to their weathering condition. The investigation aimed to the consideration of the weathering condition, resistance and behaviour of these stones so that the most proper measures of conservation be taken. The results of the study showed that:

i) The building stones which were used in these monuments are of fossiliferous marly limestone from the surrounding area, showing a significant weathering effects.

ii) Test results on samples from each area are quite similar because of the similar mineralogy of the materials as well as of the probably unique weathering conditions.

iii) The weathering condition and its influence to the studied physico-mechanical properties would be expressed mathematically (Fig. 4).

iv) According to the correlation diagrams and the calculated relationships, it is concluded that weathering activity is accelerated during the time causing more considerable phenomena, expressed mainly by exponential relationships.

References

Bell, F.G. & Dearman, W.R. (1988). Assesment of the durability of sandstones with illustration from some buildings in the North of England. Proceed. Symp. IAEG Eng. Geol. Anc> Works Monum. Histor. Sites, Athens, Balkema Editors, pp.707-716.

Christodoulou, G. (1963). Geological and micropaleontological investigation of the Neogene in Creta. Univ. athens, 154p. (in greek).

Galanopoulos, G. (1955). Erdbebengeographie von Griechenland (Taf. XVI - XIX), Ann. Geol. Pays Hell., athens, 6, pp. 83-121.

Greek National Turist Organisation -GNTO (1986). greece/Crete, 16p.

IGME (1989). Seismotectonic map of Greece, 1:500000.

Savignoni, L. & De Santis, G.(1901). Esplotatione Archeologica delle provincie occidentali di Creta. Monum. Antichi, Roma, XI, pp. 72-110.

Symeonidis, N. & Konstantinidis, D. (1968). Beobachtungen zu den Neogen - Ablagerungen des Zentral gebietes des Insel Kreta (Taf. LXXIV - LXXXIII, 5 Textabb.). Ann. Geol. Pays Hell., Athens, 19, pp. 657-688.