ESTRATTI

La conservazione dei monumenti nel bacino del Mediterraneo

Influenza dell'ambiente costiero e dello spray marino sulla pietra calcarea e sul marmo

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Weathering effects on the mechanical behavior of granite; example from the Kavala granodiorite (Northern Greece)

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Introduction

It is already well known that building-stones require a rational research before being used especially for the construction of statues and other buildings of special importance, in order to resist in time. Furthermore, high protection activities must be carried for the conservation of the existing monuments. Rock weathering and microfissuring are two main factors which not rarely contribute to the gradual destruction of hard laboured monuments of historical significance.

Different kinds of rocks have been used as building-stones with marbles predominating. However, not few masterpieces all over the world are constructed of granite e.g. Concorde Square in Paris and the famous Egyptian obelisks.

The commercial term of granite, as a building material, includes not only the strictly scientifically determined granite but also gneiss, syenite, monzonite, granodiorite, as well as some other feldspathic crystalline rocks of similar textures, known scientifically as anorthosites and larvikites; diabases, diorites, gabbros and intermediate varieties sometimes quarried as building-stones for ornamental use, are sold also as "black granite".

Many investigators have worked on the influence of weathering, connected with the mineralogy and texture of the rocks, in relation to their mechanical properties (e.g. Castaing and Rabu 1980, Onodera and Asoka Kumara 1980, Aubertin and Larochelle 1984).

Particularly applied to Kavala (N. Greece) granodiorite, this study attempts to correlate different stages of weathering with the mechanical resistance of the rock. Some of the data used in this study were taken from Christaras et al. (1988) previous work.

Weathering of granites

Granite has been considered from antiquity as a symbol of strength. Unfortunately, areas of such occurens, free of all kinds of fracturing are not easy to be found, so that the utilization of granite as a building material is more restrained than than that of marble. Weathering which is a natural alteration by either chemical or mechanical processes, may have destructive effects on the rock. The weathering factors are mainly the constituents of the atmosphere, surface waters, soil and ground waters and temperature changes. Fissures and microfissures, when present, accelerate the weathering influence.

Mineral weathering in granite begins from feldspars (potassium feldspars and plagioclases) one of its main constituents, with micas and other easily altered minerals following. The alteration and decomposition of felds-pars has proved an important indicator of the different weathering stages in granites and other feldsphatic rocks (Tuxton and Berry 1957, Little 1969, Newbery 1970, Dearman 1974, 76, Malomo 1980, Baudracco et al. 1982).

As previously mentioned, besides chemical weathering, temperature fluctuation contributes also to the loosening of the rock. Because of a different thermal expansion coefficient, every mineral shows a particular mechanical behavior, depended on the temperature changes of the environment; the repetition of this phenomenon provokes the decomposition of the material, with porosity increasing and resistance decreasing. Pore water activity accelerates the decomposition process by shrinking-expansion and free-zing-fusion phenomena. Percolating water strengthens the weathering processes on feldspars and other easily effected minerals, by passing through the fractures.

Sampling and methods of study

Ten samples, representative of the range of weathered rock material, were collected from the same bulk of the Kavala granodiorite, Northern Greece, Southern part of the Rhodopian massif (fig. 2i). The granodiorite showing a texture of dynamic metamorphism, is composed of quartz, feldspars, biotite (often altered to chlorite) and muscovite as main minerals, as well as sphene, allanite, apatite, garnet and opaques as minor ones. The samples, as mentioned, were collected from locations showing a gradual weathering degree. Sample collection had to fulfill the following:

i) No sample must show visible cracks or other surfaces of discontinuity.

ii) Each sample had to be homogeneous and uniformly weathered, so as the specimens used for the different tests be equal.

Polarized microscope was used to examine more than one thin sections from each sample. So the texture, mineralogy, and alterations were determined in detail.

XRD patterns, with the use of a Philips diffractometer CuKa radiation (I.G.M.E. Athens), were obtained for each sample (fig. 1).

The quantitative expression of the weathering degree was one problem that we faced. Several methods have been proposed involving e.g. the measure of the ultra-sonic velocity (Irfan and Dearman, 1978a) and the measure of the abrassive pH of the feldspars (Malomo, 1980). The method that we used is direct microscopic observation of thin sections and measurment of the precentage of the unaltered and alteredd parts of each specimen. Microfissures were added to the altered parts. The relation

$$\frac{\%\ \text{altered minerals} + \text{microfissures}}{\%\ \text{unaltered minerals}} \quad \text{expressed as } 1/Ip$$

$$(I_P = \frac{\%\ \text{unaltered minerals}}{\%\ \text{alterede minerals} + \text{microfractures}} \quad \text{according}$$

to Irfan and Dearman 1978b), which we called "weathering index" can be considered as a direct expression of the weathering degree of the material, based on clearly petrographic criteria.

Test pieces for the physical and mechanical properties were cut cylindric with a diameter of 2.4 cm and a height of 4.8 cm, using the core drills of the Geophysical and Engineering laboratories of Thessaloniki University. Test results are presented in table 1.

The mean value of three tests was used for each sample and for each property. The rock was studied concerning

i) the bulk specific gravity ($d_{110}o$, ASTM C 97-47), which is obtained by dividing the dry weight (after drying for 24 h at 110° C) of the specimens by the total volume (solids and voids).

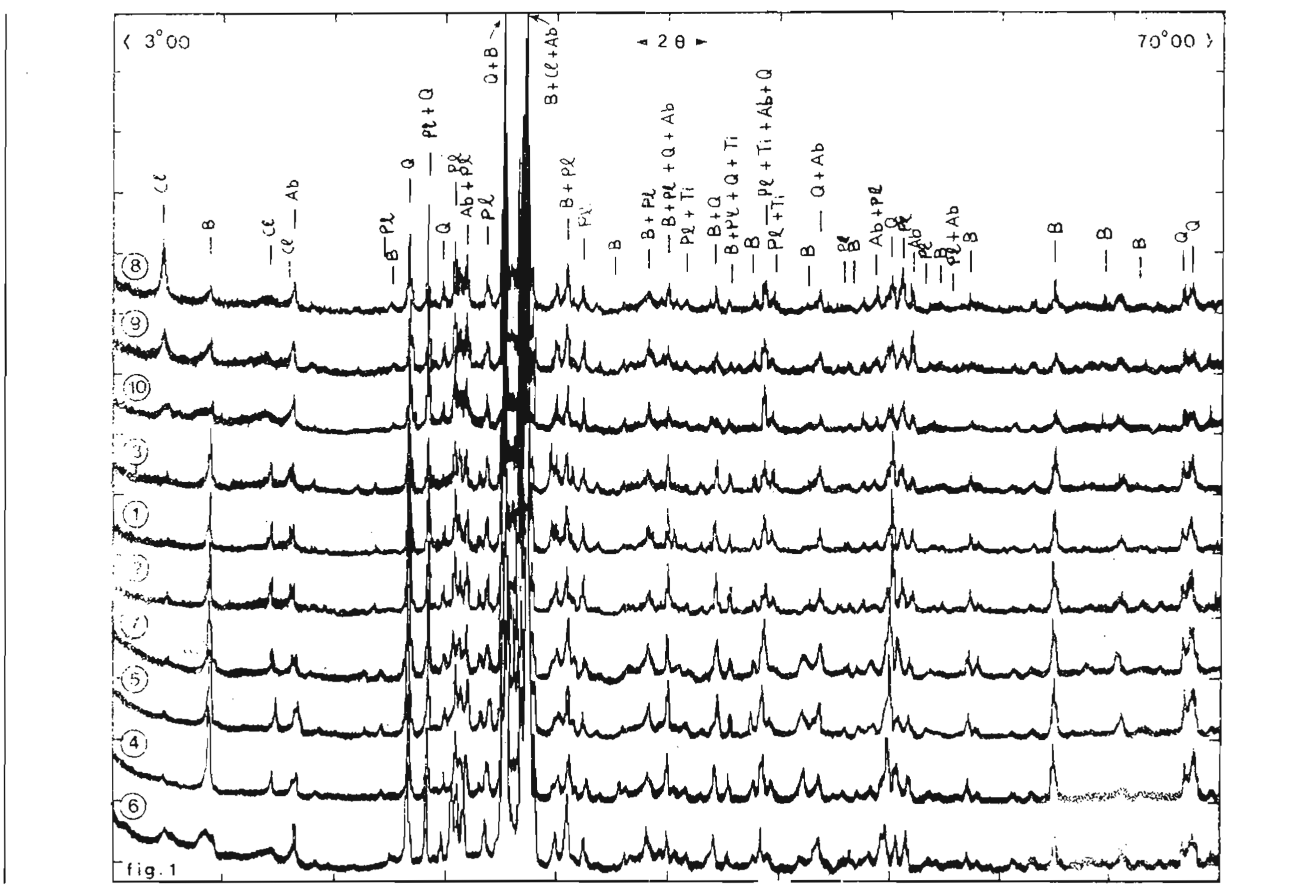

fig. 1 - *XRD patterns of the ten Kavala granodioritic samples. N^os 1, 2, 3, 8, 9, 10 from Christaras et al. (1988). Cl = Clinochlore, B = Biotite, Q = Quartz, Al = Albite, Pl = Plagioclase, Ti = Sphene*

ii) the water absorption, in vacuum (Ab, ASTM C 97-47), expressed as the ratio of the absorbed water weight (after a period of 24 h) to the dry weight of the specimens.

iii) the weathering resistance (W, ASTM C 88 soundness test) using sodium sulfate, in five cycles.

iv) the compressive strength (o_c, ASTM C 170-50) by dividing the compressive effort by the surface of the base of the cylinder. For this purpose the 10 tn compressive machine of the Thessaloniki Polytechnic School was used.

v) the Young's modulus (E, ASTM D 3148-72) which represents the ratio of stress to strain under given loading conditions.

vi) the tensile strength (o_t), applying the Brasilian method (Duriez and Arrambide, 1962), that is, breaking the dry granitic cylinders placed horizontally between the plates of the press. The tensile strength is obtained by dividing the compressive effort (P) by the lateral surface of the half cylinder ($1/2\ \pi dh$). Besides, a compressive strain equal to $3/o_t/$ is obtained in the same time. For each sample, two Mohr circles are traced, one with $o_c>0$ and $o_t=0$ and the second with $o_t<0$ and $o_c=3/o_t/$; the angle of internal friction (?) and the cohesion (c) are also given.

Statistic interpretation

The study showed a distinct influence of the weathering phenomena on the mechanical resistance and the physical

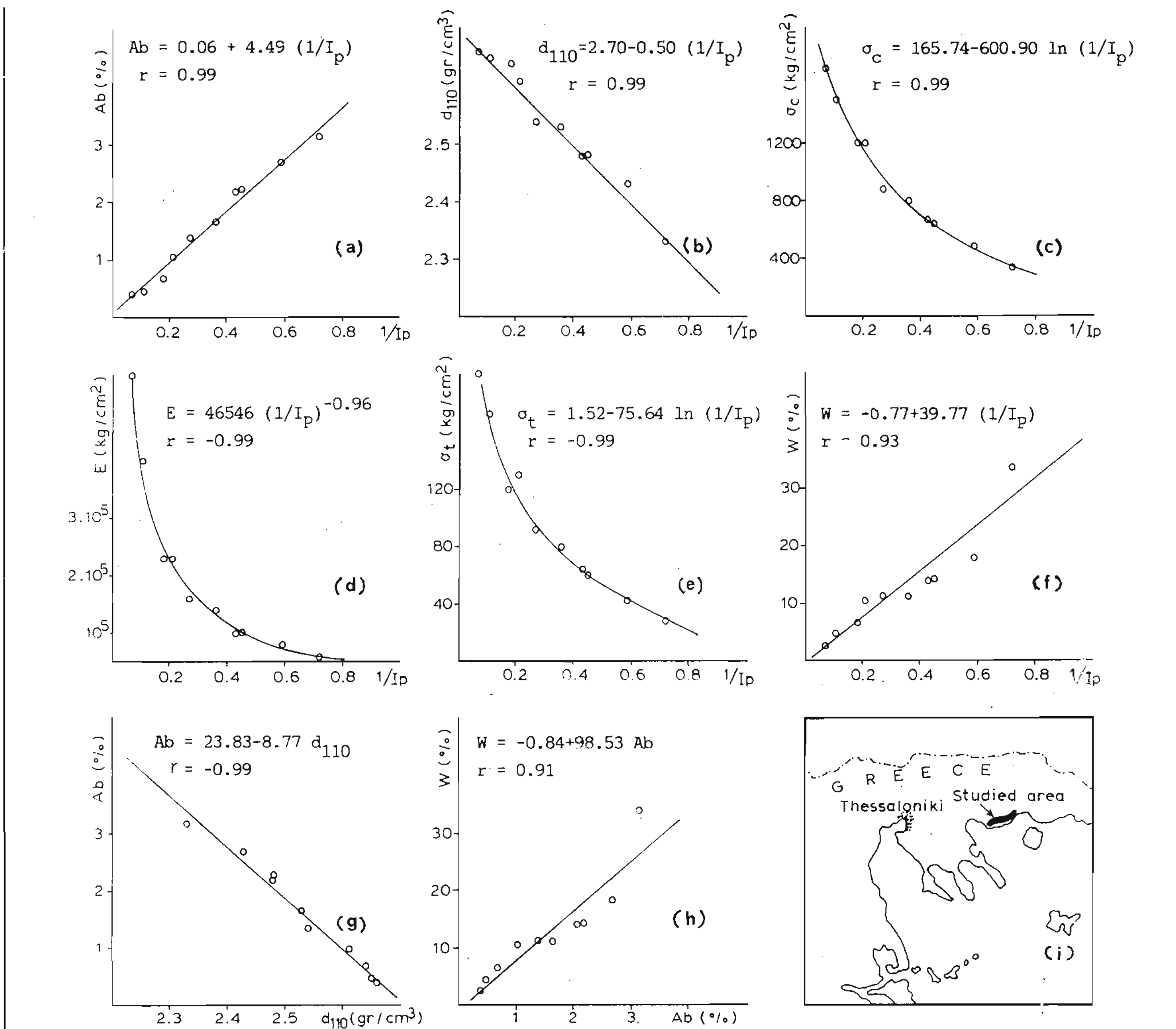

fig. 2 a, b, c, d, e, f, g, h - *Correlation diagrams between selected index tests and the weathering index.*
i - *sample location area*

properties of the studied granodiorite samples (Fig. 2a to h). This influence is expressed by linear and exponential regressions with a significant correlation coefficient, as follows;

$Ab = 0.06 + 4.49\ (1/I_p)$	$r = 0.99$	$r^2 = 0.98$
$d_{110}o = 2.70\text{-}0.50\ (1/I_p)$	$r = -0.99$	$r^2 = 0.98$
$o_c = 165.74\text{-}600.90\ \ln\ (1/I_p)$	$r = -0.99$	$r^2 = 0.99$
$E = 46546\ (1/I_p)\ \text{-}0.96$	$r = 0.99$	$r^2 = 0.99$
$o_t = 1.52\text{-}75.64\ \ln\ (1/I_p)$	$r = -0.99$	$r^2 = 0.99$
$W = -0.77+39.77\ (1/I_p)$	$r = 0.93$	$r^2 = 0.87$
$Ab = 23.83\text{-}8.77\ d_{110}{}^o)$	$r = -0.99$	$r^2 = 0.98$
$W = -0.84+8.53\ Ab$	$r = 0.91$	$r^2 = 0.83$

In order verify the significance of the studied correlations, with a probability of 99%, the coefficient $t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$ was calculated with the aid of the Student Tables according to which the correlation coefficients must be higher than 0.7646. The critical coefficient (r^2) in also hig, indicating the percentage of dependence on the regression, which confirms the influence and the role of the weathering on the mechanical behavior of the rock.

table 1 - *Experimental data of physical and mechanical features of the Kavala granodiorite*

Sample	$1/I_p$	$d_{110}{}^o$ gr/cm^3	Ab %	σ_c Kg/cm^2	σ_t Kg/cm^2	E Kg/cm^3	W %	φ^o	c Kg/cm^2
1	0.07	2.66	0.41	1725	202.8	$5.50*10^5$	2.42	43.83	367.6
2	0.11	2.65	0.48	1504	171.8	$4.00*10^5$	4.61	44.74	359.5
3	0.18	2.64	0.68	1194	122.6	$2.30*10^5$	6.42	47.86	229.9
4	0.21	2.61	1.04	1210	129.8	$2.30*10^5$	10.42	46.62	240.6
5	0.27	2.54	1.37	880	92.8	$1.60*10^5$	10.98	47.11	172.8
6	0.36	2.53	1.63	799	80.6	$1.40*10^5$	11.12	48.35	151.9
7	0.43	2.48	2.21	672	64.6	$1.10*10^5$	14.00	49.64	123.5
8	0.45	2.48	2.22	639	60.7	$1.00*10^5$	14.59	49.95	116.5
9	0.59	2.43	2.68	487	42.3	$0.78*10^5$	18.24	52.16	83.5
10	0.72	2.33	3.16	342	28.4	$0.55*10^5$	34.28	53.21	56.8

Conclusions

In the present study of samples, representative of a range of weathering of rock material in a single acid igneous rock, the Kavala granodiorite, has been examined in terms of physico-mechanical behavior to wards the weathering degree. The results are summarized as follows:

a) The method of the "point-counter" (modal analysis), used to determine the weathering extent of the rock, proved quite reliable revealing the real petrographic situation.

b) The influence of weathering of the mechanical behavior and the physical properties of the material is expressed by linear or exponential regressions. So, the weathering index (1/Ip), shows a positive linear correlation with the water absorption (Ab), and the weathering resistance (W), (fig. 2a, f), and a negative linear correlation with the bulk specific gravity ($d_{100}o$) (fig. 2b). Furthermore, the weathering index shows a negative exponential correlation versus the compressive strength (o_c), the Young's modulus (E) and the tensile strength (o_t), (fig. 2c, d, e). Water absorption (Ab) presents a negative linear relationship with the bulk specific gravity ($d_{110}o$), and positive one with the weathering resistance (W) (fig. 2g, h).

c) The exponential regressions $1/I_p$ vs o_c, o_t, E indicate that a slinght increase of weathering causes a great decrease of the mechanical resistance of the rock, a fact that emphasizes the significance of the mineralogical situation of the rock used as a building material. Hence, a careful examination of the constructing rock material of the monuments may contribute to the recognition of the real factors which have caused damage, so as the most proper chemical or natural conservation and protection measures be taken.

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