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La conservazione dei monumenti nel bacino del Mediterraneo

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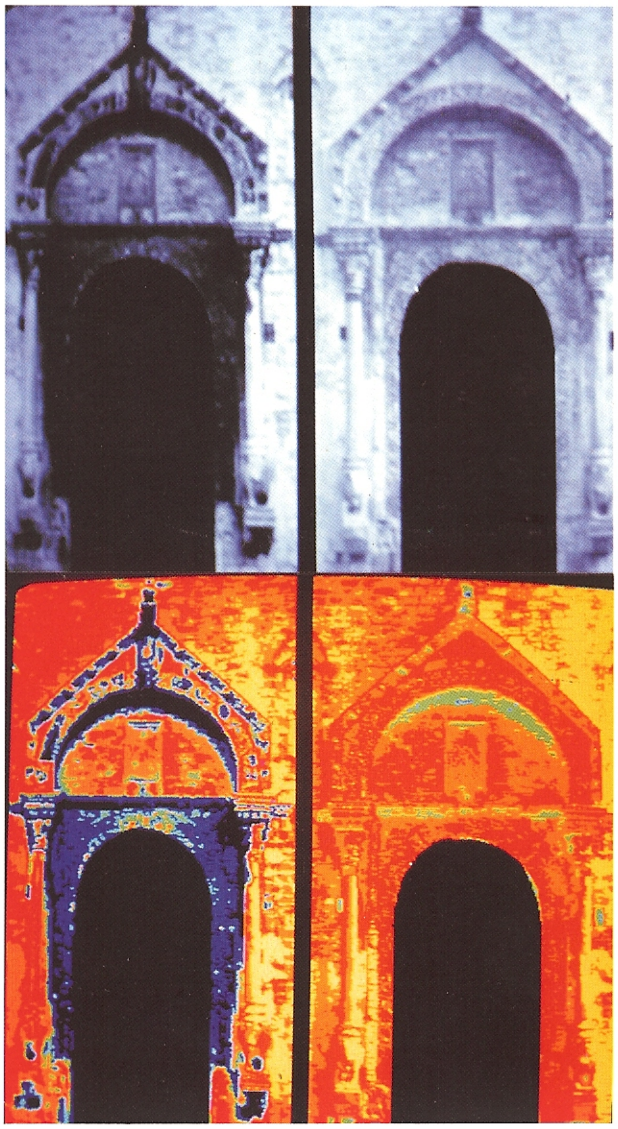

Weathering of granites and mechanical behaviour changing, in northern Greece

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Introduction

Granite is from the ancienity a symbol of strength and steadfastness. In nature the material is found weathered and broken, so that areas of rock free from all kinds of fracturing are not easily found. However, there are examples of monuments or new buildings costructed with blocks of some size, entirely free of fracture.

The weathering influence to the mechanical behaviour of rocks is nearly evident. The first easily weathered minerals, such as feldspars, can be used as an interesting index for the classification of the weathered granites. After Moye (1955) the decomposition of feldspars is an important factor for the classification of the weathered granites in "Snowy Mountains", in Australia. Tuxton and Berry (1957) and Little (1969) in their effort consideration to classify the granites of Hong-Kong characterise the decomposition of feldspars as a useful index for the classification of the weathered rocks. The same consideration has been expressed by Newbery (1970), Dearman (1974, 1978), Dearman et al. (1978), Baudracco et al. (1982) etc.

This study concerns the influence of the weathering degree on the mechanical resistance and physical properties of granites from Northern Greece, determined by statistic interpretation.

The occurences

The studied granitic occurences, are situated in Eastern - Central Macedonia and Thrace (fig. 1).

a) *The granite of Sithonia.* It is a batholite of eocenic age, intrusive into the series of Melissochori-Cholomon, presenting a contact metamorphism and a clear schistocity due to tectonic a contact metamorphism and a clear schistocity due to tectonic phenomena (Vergely, 1984).

From petrographic point of view, it can be characterised as a granodiorite than as a typical granite (Chatzidimitriadis et al. 1983). The material is presented coarse grained of grayish black colour (because of biotite). Under the microscpe microfissures are more or less abundant, with length of <0.5 mm, depending on the sample; plagioclases and potassic feldspars present and alteration to kaolinite and sericite while biotite is sometimes altered to chlorite.

The deformated parts show a quartz zone, parallele to the elongation of biotites, while plagioclases show pressure twinning phenomena.

b) *The granite of Arnea.* It is of messozoic age and is situated to the east of Thessaloniki, between the metamorphic rocks of the serbomacedonian massif. It is white in colour and is entirely weathered superficially, continuing inwards, with a progressive diminuition. In the interior it is presented more homogeneous, depending on the weathering degree. The material is characterised as medium grained with euhedral form grains which belong to the quartz and feldspars. Feldspars are entirely weathered but microfissures are not abundant in relation to the weathering.

c) *The granite of Fanos.* It is situated between the ophiolites of Guevgueli, to the NNW of Thessaloniki. It is of jurassic age and was studied in detail by Mercier (1965). From mineralogical point of vue, the material is coarse grained, rose in colour, with equidimensional angular grains which belong to feldspars and to quartz. Biotite is not abundant, and feldspars such as orthose and microcline which are almost entirely kaolinitisated and sericitisated,

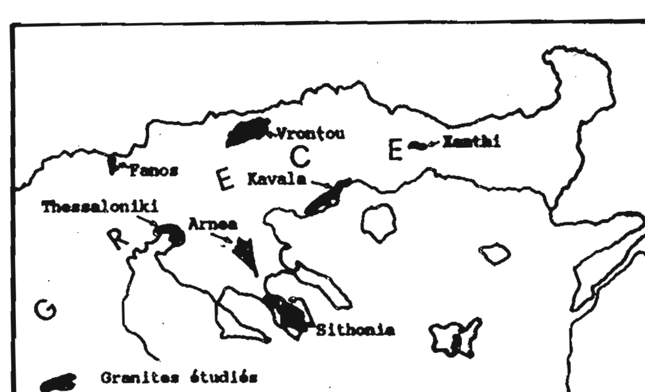

fig. 1 - *Location of the studied granites*

often show microperthitic phenomena. The material is entirely broken and weathered.

d) *The granite of Vrontou.* It is situated between the marbles and the other metamorphic rocks of the Rhodopian massif; it was studied in detail by Papadakis (1965) and Theodorikas (1983). From petrographic point of view, it can be characterised as granitic-granodioritic type, of medium grain size. Under the microscope the minerals are presented deformated and sometimes recrystallised. Potassic feldspars and plagioclases are kaolinisated and sericitisated, while biotite is partly chloritisated. The length of microfissures is <0.5 mm.

e) *The granite of Kavala.* It belongs to southern part of the Rhodopian massif. It is a granodiorite which is studied, petrographically and geomorphologically by Kromberg (1966), Kokkinakis (1977) etc. The texture of the material is that of dynamic metamorphosed granodiorite with coarse grains of the original igneous rock and foliation due to limited deromation. The coarse grains anhedral in shape (rounded or elongated) belong to feldspars (potassic and plagioclases) and quartz. The minerals show strain effects (bending, twinning, fracturing, alteration). Feldspars are altered to kaolinite and sericite while biotite is often altered to chlorite.

f) *The granite of Xanthi.* It is granodiorite of oligocenic age, which belongs to the Rhodopian massif (Christofidis, 1977). From mineralogical point of view, it is a medium grained hornblende - biotite rock, gray to grayish white in colour. Orthose and plagioclases are kaolinisated and sericitisated.

Weathering of granites

The first easily weathered minerals in granites are the potassic feldspars and the plagioclases (with micas and other less abundant easily altered minerals). In rocks where, chemical alteration had not yet started, the decomposition is succeded by temperature fluctuation. Every mineral shows a particular behaviour, depended on the environmental temperature changes, because of the different thermal dilation coefficient. The repetition of the phenomenon causes the decomposition and the loosening of the tight fabric of the material thus causing an increase of porosity and a decrease of strenght. Pore water activity accelerates the decomposition process by shrinking - expansion and freesing - fusion phenomena. Percolating water strengthens the weathering of feldspars resulting the loosening of granite, by passing through the fractures.

Methodes of research

For each one of the six occurences, samples from ten different positions have been used, under the following criteria.

a) Every position shoud present a visible different weathering degree.

b) At every position, samples should be homogeneous and uniformly weathered, so that one can use more test specimens of the same sample, for more tests.

c) No specimen should present visible fractures or other surfaces of discontinuity.

Concerning the quantitative determination of the weathering degree, several methods have been proposed, consisted in ultra sonic velocity measurements in the material (Irfan and Dearman, 1978) or the calculation of the abrasive pH of the feldspars (Malomo, 1980), etc.

The present method which was also used in our previous studies of Kavala granodiorite (Christaras et al. 1988, 1989), is a direct microscopic method, based on the determination of the weathered parts of the minerals (potassic feldspars, plagioclases, micas etc) and the microfissures, with the aid of the "point counter" machine.

The calculated "weathering index"

$$WI = \frac{\%\ (\text{min.alt.} + \text{fiss})}{\%\ (\text{min. unalt.})}$$

exprimes quantitatively very well the weathering result of the material, based on clearly petrographic criteria.

Physical and mechanical properties

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

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

b) 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.

c) The ultra sonic velocity (V, ASTM 597) in the material, as a good index characteristic of the physico-mechanical behaviour of the rocks. For this purpose the PUNDIT portable ultrasonic non distructive digital tester of Thessaloniki Faculty of Technology was used.

d) 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 the 10 tn loading system of the Thessaloniki faculty of Technology was used.

e) Their tensile strength (σ_t) according to ther "Brasilian method" (Duriez et Arrambide, 1962, Koumandakis, 1978) consisted in breaking the dry granitic cylinders placed horizontally between the plates of a press. The tensile strength is obtained by dividing the compressive force (P) by the half lateral surface of the cylinder. Besides a compressive stress, equal to 3 (o_t) is obtained in the same time. For each sample, two Mohr circles are traced, one with $\sigma_c > 0$ and $\sigma_t = 0$ and the second with $\sigma_t < 0$ and $\sigma_c = 3/\sigma_t/$; the angle of internal friction and the cohesion are also given according to the relationships tna $(45° - Ø/2) = \sigma_t / (\sigma_c - 3\sigma_t)$ and $c = (\sigma_c/2)$ tan $(45° - Ø/2)$.

table 1 - *Experimental data from the studied granites*

	WI	Ab %	d_{110} gr/cm^3	σ_c Kg/cm^2	σ_t Kg/cm^2	σ_c/σ_t	Φ^o	c Kg/cm^2	v mm/μsec	
SITHONIA										
S1	0.19	0.42	2.65	1438	151.9	9.47	47.06	282.5	4.44	1) $Ab = -0.35 + 3.98\,WI$ $r = 0.97$
S2	0.20	0.48	2.63	1360	138.1	9.85	48.17	259.8	4.29	
S3	0.27	0.76	2.60	898	82.0	10.95	50.95	159.4	4.10	2) $d_{110} = 2.70 - 0.38\,WI$ $r = -0.95$
S4	0.32	0.94	2.58	761	79.0	9.63	47.58	147.6	3.92	
S5	0.38	1,24	2.54	663	67.9	9.76	47.94	127.3	3.62	3) $\sigma_c = 2022.14 \cdot e^{-2.60WI}$ $r = -0.97$
S6	0.45	1.42	2.50	575	55.2	10.42	49.67	105.5	3.35	
S7	0.53	1.58	2.46	540	53.0	10.19	49.09	100.7	3.12	4) $\sigma_t = -3.49 + 0.10\,\sigma_c$ $r = 0.99$
S8	0.64	1.84	2.47	423	41.3	10.24	49.23	78.7	2.63	
S9	0.65	2.20	2.49	411	42.0	9.78	48.00	78.9	2.60	5) $v = 5.13 - 3.87\,WI$ $r = -0.99$
S10	0.72	2.95	2.42	288	27.3	10.55	50.00	52.4	2.35	
XANTHI										
X1	0.25	0.52	2.63	1013	115.5	8.77	44.80	207.6	4.26	1) $Ab = -0.75 + 4.88\,WI$ $r = 0.95$
X2	0.27	0.75	2.61	876	94.5	9.27	46.46	174.8	4.18	
X3	0.32	0.80	2.60	796	77.9	10.22	49.39	147.2	4.08	2) $d_{110} = 2.71 - 0.34\,WI$ $r = -0.95$
X4	0.35	0.76	2.61	741	67.9	10.91	50.86	131.5	3.78	
X5	0.38	0.85	2.60	697	69.0	10.10	48.86	130.7	3.84	3) $\sigma_c = 45.24 - 663.28 \ln WI$ $r = -0.98$
X6	0.42	1.29	2.56	566	48.6	11.64	52.43	96.2	3.55	
X7	0.46	1.42	2.56	580	54.4	10.66	50.27	104.7	3.35	4) $\sigma_t = -21.74 + 0.13\sigma_c$ $r = 0.97$
X8	0.48	1.85	2.55	513	55.0	9.32	46.64	101.8	3.10	
X9	0.50	1.78	2.55	520	38.7	13.44	55.60	80.3	3.26	5) $v = 5.35 - 4.26\,WI$ $r = -0.97$
X10	0.54	1.82	2.52	478	45.8	10.44	49.73	87.6	3.15	
VRONTOU										
V1	0.19	0.50	2.64	1323	148.0	8.94	45.38	271.2	4.68	1) $Ab = -0.43 + 4.50\,WI$ $r = 0.99$
V2	0.26	0.87	2.61	916	98.9	9.26	46.43	182.7	4.40	
V3	0.29	0.66	2.59	876	91.7	9.55	47.32	170.8	4.10	2) $d_{110} = 2.70 - 0.35\,WI$ $r = -0.97$
V4	0.32	1.00	2.57	750	69.0	10.87	50.76	133.5	3.94	
V5	0.37	1.28	2.56	683	75.1	9.09	45.90	138.3	3.73	3) $\sigma_c = 2425.23\, e^{-3.53WI}$ $r = -0.99$
V6	0:40	1.33	2.54	586	63.0	9.30	46.56	116.6	3.59	
V7	0.41	1.39	2.57	571	54.7	10.44	49.73	104.5	3.50	4) $\sigma_t = -12.46 + 0.12\,WI$ $r = 0.99$
V8	0.46	1.62	2.54	491	48.0	10.23	49.20	91.3	3.32	
V9	0.52	1.94	2.52	350	24.9	14.05	56.52	52.7	3.07	5) $v = 5.56 - 4.87\,WI$ $r = -0.99$
V10	0.62	2.40	2.48	290	25.4	11.42	51.96	50.0	2.58	
ARNEA										
A1	0.18	0.48	2.65	1350	158.0	8.54	43.98	286.9	4.42	1) $Ab = -0.58 + 4.83\,WI$ $r = 0.98$
A2	0.30	0.81	2.58	850	89.0	9.55	47.32	166.2	4.09	
A3	0.34	1.00	2.56	750	79.0	9.49	47.15	147.0	3.96	2) $d_{110} = 2.70 - 0.40\,WI$ $r = -0.95$
A4	0.35	1.00	2.55	759	82.0	9.25	46.42	151.8	4.00	
A5	0.38	1.11	2.55	717	62.1	11.55	52.23	122.6	3.83	3) $\sigma_c = 2437.82\, e^{-3.32WI}$ $r = -0.99$
A6	0.38	1.33	2.52	721	69.0	10.45	49.75	131.9	3.71	
A7	0.48	1.78	2.54	540	49.2	10.97	51.00	95.6	3.29	4) $\sigma_t = -21.49 + 0.13\sigma_c$ $r = 0.99$
A8	0.51	1.82	2.50	449	34.2	13.13	55.11	70.5	3.11	
A9	0.55	2.18	2.49	381	29.3	13.00	54.91	60.2	3.01	5) $v = 5.42 - 4.47\,WI$ $r = -0.98$
A10	0.62	2.48	2.45	299	23.2	12.89	54.72	47.5	2.49	
FANOS										
F1	0.20	0.51	2.64	1298	139.8	9.28	46.50	258.9	4.37	1) $Ab = -0.30 + 3.42\,WI$ $r = 0.98$
F2	0.30	0.60	2.62	1007	122.1	8.25	42.83	219.5	4.14	
F3	0.48	1.40	2.57	520	58.0	8.96	45.47	106.3	3.45	2) $d_{110} = 2.73 - 0.38\,WI$ $r = -0.94$
F4	0.48	1.32	2.57	500	42.0	11.90	52.95	83.7	3.32	
F5	0.49	1,35	2,52	473	46.1	10.26	49.28	87.7	3.35	3) $\sigma_c = 2244.33\, e^{-2.94WI}$ $r = -0.99$
F6	0.52	1.42	2.53	482	39.0	12.36	53.80	78.8	3.08	
F7	0.56	1.48	2.55	429	44.2	9.70	47.77	82.8	2.99	4) $\sigma_t = -11.10 + 0.12\sigma_c$ $r = 0.99$
F8	0.59	1.72	2.50	411	38.1	10.79	50.56	73.6	2.84	
F9	0.60	1.80	2.49	389	40.9	9.51	47.20	76.2	2.89	5) $v = 5.22 - 3.90\,WI$ $r = -0.99$
F10	0.68	2.12	2.45	341	29.0	11.76	52.66	57.6	2.62	
KAVALA (WI, Ab, d_{110}, σ_c, σ_t, according to Christaras et al. 1988,1989)										
K1	0.07	0.41	2.66	1725	202.8	8.50	43.83	367.6	4.85	1) $Ab = 0.06 + 4.49\,WI$ $r = 0.99$
K2	0.11	0.48	2.65	1504	171.8	8.75	44.74	359.5	4.69	
K3	0.18	0.68	2.64	1194	122.6	9.74	47.86	229.9	4.43	2) $d_{110} = 2.70 - 0.50\,WI$ $r = -0.99$
K4	0.21	1.04	2.61	1210	129.8	9.32	46.62	240.6	4.35	
K5	0.27	1.37	2.54	880	92.8	9.48	47.11	172.8	3.94	3) $\sigma_c = 165.74 - 600.90 \ln WI$ $r = -0.99$
K6	0.36	1.63	2.53	799	80.6	9.91	48.35	151.9	3.82	
K7	0.43	2.21	2.48	672	64.6	10.40	49.64	123.5	3.51	4) $\sigma_t = -18.98 + 0.12\sigma_c$ $r = 0.99$
K8	0.45	2.22	2.48	639	60.7	10.53	49.95	116.5	3.43	
K9	0.59	2.68	2.43	487	42.3	11.51	52.16	83.5	2.67	5) $v = 5.15 - 3.98\,WI$ $r = -0.99$
K10	0.72	3.16	2.33	342	28.4	12.04	53.21	56.8	2.28	

The results of the above tests for the studied granites are given in table 1.

Statistics

The statistic interpretation, of the experimental data, showed a direct influence of the weathering phenomena to the changing of the mechanical resistance and the physical properties of granites (fig. 2).

This influence is expressed by linear and exponential regressions, with a significant correlation, according the following data.

$Ab = -0.19 + 3.82\ WI$	$r = 0.90$	$r^2 = 0.80$
$d_{110}o = 2.79 - 0.30\ WI$	$r = -0.89$	$r^2 = 0.80$
$\sigma_c = 20009.8\ e^{-2.76WI}$	$r = -0.97$	$r^2 = 0.94$
$V = 5.28 - 4.22\ WI$	$r = -0.97$	$r^2 = 0.95$
$\sigma_t = -13.04 + 0.12\ \sigma_c$	$r = 0.99$	$r^2 = 0.99$
$Ab = 4.77 - 0.95\ v$	$r = -0.91$	$r^2 = 0.84$
$\sigma_c = 59.79\ e^{0.66\ v}$	$r = 0.90$	$r^2 = 0.81$
$d_{110}o = 2.21 + 0.09\ v$	$r = 0.90$	$r^2 = 0.81$
$Ab = 25.21 - 9.35\ d_{110}o$	$r = -0.94$	$r^2 = 0.88$

The measured correlations were verified as regards to their significance by calculation of the coefficient $t = r\sqrt{n-2}/\sqrt{1-r^2}$ with the use of the Student tables, according to which the correlation coefficient should to be higher than 0.33 (n-2 = 58).

The critical coefficient r^2 (*100) which shows the percentage of the dependence, due to the regression, is very high, confirming the influence of weathering to the definition of the mechanical behaviour of the weathered granites.

According the correlation diagrams, weathering index is

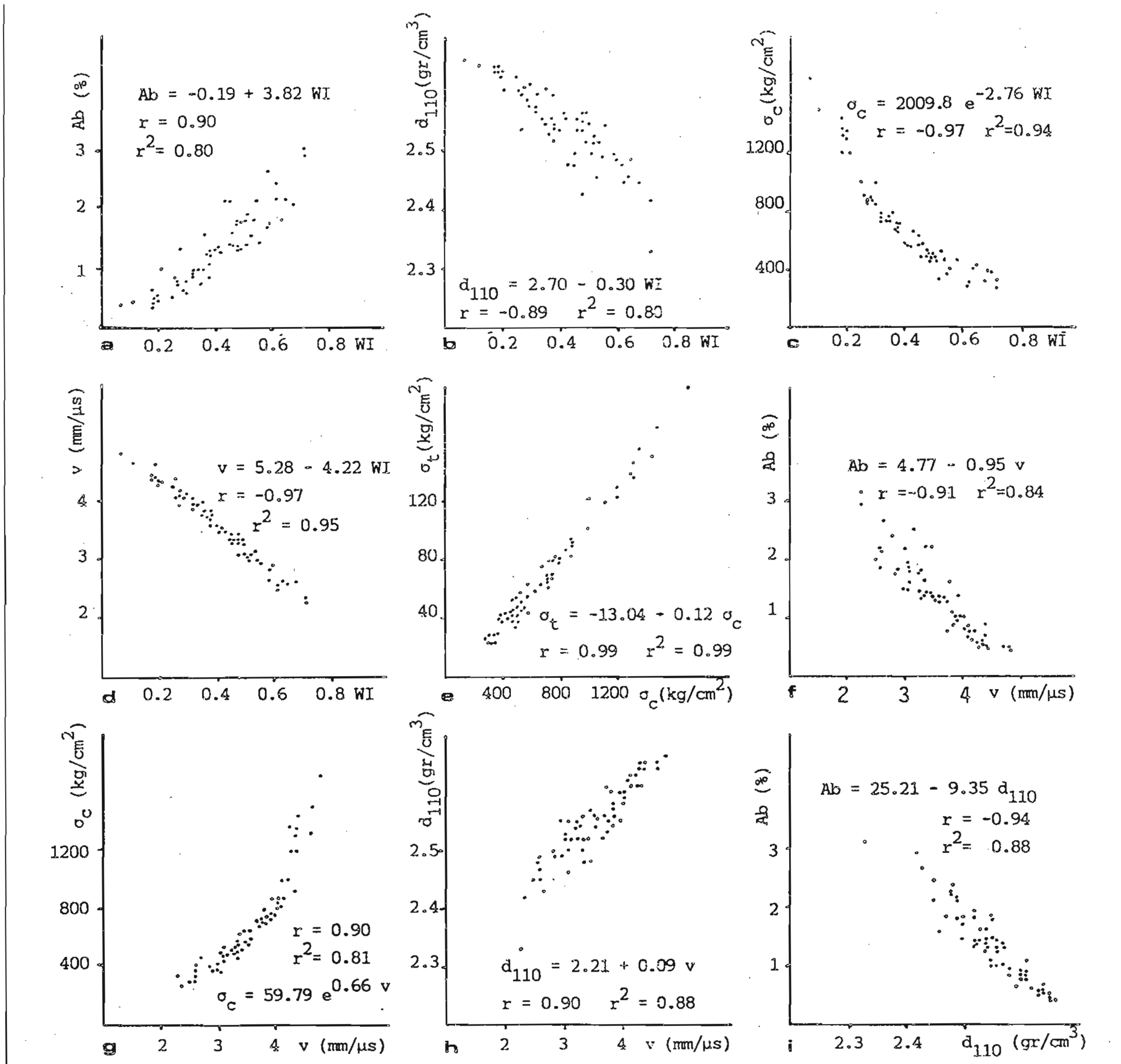

fig. 2 - *Regression diagrams of the studied properties*

correlated negatively to the ultra sonic velocity, confirming the consideration that WI can be used as a classification index. Compressive strength, which is correlated linearly with tensile strenght, shows a significant exponential correlation with ultra-sonic velocity and weathering index, confirming that a slight increase of weathering, (mainly of feldspars) causes a great decrease of the mechanical resistance, of the granites. Water absorption is correlated linearly, to the weathering index, in such condition that weathering index increasing causes the increase of the water absorption. This property is related to the existed negative correlation between the bulk specific gravity and weathering index, since the material becomes less dense by the weathering.

Conclusion

Six granitic occurences, in Northern Greece are studied, as regards to the influence of weathering to the physico-mechanical properties. This study showed that:

a) The used method of "point counter" for quantitative determination of the weathering result in granites, by measurment of the surface of microfractures and altered parts of minerals (mainly feldspars) can express with precision the weathering condition of the rock and can be related to other existed methods (e.g. ultra sonic velocity).

b) Test results from each studied granite are quite similar between the occurences, so that, they can be characterised as of more general consideration.

c) The influnece of weathering which was measured by the above method is related to the studied physicomechanical properties of granites as follows:

$Ab = -0.19 + 3.82\ WI$	$r = 0.90$	$r^2 = 0.80$
$d_{110}o = 2.79 - 0.30\ WI$	$r = -0.89$	$r^2 = 0.80$
$\sigma_c = 20009.8\ e^{-2.76WI}$	$r = -0.97$	$r^2 = 0.94$
$V = 5.28 - 4.22\ WI$	$r = -0.97$	$r^2 = 0.95$
$\sigma_t = -13.04 + 0.12\ \sigma_c$	$r = 0.99$	$r^2 = 0.99$
$Ab = 4.77 - 0.95\ v$	$r = -0.91$	$r^2 = 0.84$
$\sigma_c = 59.79\ e^{0.66\ v}$	$r = 0.90$	$r^2 = 0.81$
$d_{110}o = 2.21 + 0.09\ v$	$r = 0.90$	$r^2 = 0.81$
$Ab = 25.21 - 9.35\ d_{110}o$	$r = -0.94$	$r^2 = 0.88$

d) According to the calculated relationships, is shown that a slight increase of weathering can cause a significant decrease of the physico-mechanical resistance, a fact which proves the significance of the mineralogical situation of the constructing materials, especially when the material is consisted of different minerals with different physicomechanical characteristics.

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