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Karst Geomorphology

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GYPSUM DEGRADATION IN ITALY WITH RESPECT TO CLIMATIC, TEXTURAL AND EROSIONAL CONDITIONS

ABSTRACT: CUCCHI F., FORTI P. & FINOCCHIARO F., *Gypsum degradation in Italy with respect to climatic, textural and erosional conditions.* (IT ISSN 0391-9838, 1998).

Many experimental studies have been carried out on the meteorological degradation of carbonate outcrops, but to date only a few, without statistical relevance, on the same phenomenon on gypsum.

To measure the lowering of gypsum surfaces and to understand the controlling factors, a high numbers of measurements that can be compared to other results are needed. The Micro Erosion Meter (Mem) method was used because the tablet method, used in the past few years, has been found not suitable for gypsum. Furthermore, use of the Mem limits the systematic error to less than 0.05 mm.

This paper presents statistical results for gypsum dissolution using the Mem. In the last 9 years in Italy, over 4,000 degradation data have been collected, covering 15 gypsum lithotypes differing in petrography, texture and chronostratigraphy. The measurements were made at 26 different test locations and more than 220 measurement points, covering the whole of Italy. The test locations were chosen on the basis of their different climatic and morphologic conditions: the rainfalls ranging from 1,300 mm/yr. to less than 250 mm/yr.

The mean degradation for the whole area, after excluding values linked to climatic or limiting lithologic or climatic situations, is 0.91 +/- 0.36 mm/1,000 mm rain, which corresponds to an average degradation rate for the Mediterranean area of 0.70 +/- 0.17 mm/yr. The observed gypsum degradation ranged between 0.21 and 2.66 mm/1,000 mm rain.

The wide range in the degradation values experienced in this research, directly reflects the dramatically different environmental conditions in each of the experimental locations. It was concluded that the fundamental parameter in gypsum degradation is gypsum dissolution. This parameter reaches 85% of the theoretical solubility of gypsum in the Mediterranean basin. The second most important parameter for gypsum degrada-

tion is mechanical erosion, which in turn depends upon the lithological and textural composition of the sample and upon local climate. The water flow conditions may also be important, because gypsum solubility becomes significant only when a turbulent flow is present.

Finally, the relatively high value of annual degradation is the first experimental evidence that the karst cycle in gypsum is fast, no outcrop of this rock surviving more than a few hundred thousands years if exposed to meteorological agents.

KEY WORDS: Gypsum karst, Degradation, Climate, Italy.

INTRODUCTION

Dissolution rates of gypsum can be directly compared only when they are obtained using the same methods and under the same environmental conditions. In the past, several studies of denudation rates on carbonates (Trudgill, 1977; Cucchi & alii, 1996) and a few on gypsum have been carried out (Klimchouk & alii, 1997). Practically all these studies were based on loss of weight, or volume, of samples (Gams tablet method, 1981), during exposure to rainfall (Klimchouk, 1996).

The tablet method is suitable in carbonate environment, but in gypsum its usefulness is limited mainly because this rock has a higher degradation rate which depends upon several different parameters (Calaforra & alii, 1993).

For instance, while erosion is generally negligible in the studied carbonate environments, it may be relevant in gypsum, where mechanical degradation may even become the prevailing mechanism if the climatic conditions (strong winds, relevant night condensation etc.) are favorable (Calaforra, 1996).

Examples of regional and field measurements are relatively scarce on gypsum rocks, although there is a long history of studies on carbonate dissolution. Specific studies performed in the last few years have underlined the

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good results obtained estimating denudation rates by means of solute load (Gorbunova & alii, 1993; Klimchouk & alii, 1988).

The Micro-Erosion-Meter (Mem) method was used to perform this research because it is easy to use even in difficult environmental conditions, it provides good reproducibility of experimental data, and it limits experimental error to less than 0.05 mm.

This method was originally proposed by Dahl (1967) to measure the degradation of carbonate rocks, and further developed by numerous researchers (High and Hanna, 1970; Trudgill, 1970; Ford, 1971; Forti, 1981; Trudgill & alii, 1981). This method consists of measuring surface lowering by means of a Mem, placed on rivets fixed to the rock surface. A stiff 3-legged frame and the particular shape of the rivets allows measurements to be taken repeatedly, always in exactly the same location. A micrometer connected to the frame delicately lowers a metallic smoothed point to the surface, measuring the distance between it and the zero point on the instrument. In this manner surface lowering (due to solution and erosion) in a given span of time is equal to the difference between the value recorded by the Mem at the beginning and end of that interval.

The research involved the whole of Italy for a period of two years (9 years in the Borgo Grotta Gigante laboratory, Trieste). The results gave degradation values representative of gypsum outcrops in the whole Mediterranean basin. Moreover it has been possible to identify the main factors affecting degradation rates.

GENERAL DESCRIPTION OF THE TEST LOCATIONS

Many small and some larger gypsum outcrops are scattered throughout Italy, from the Alps in the north to Sicily in the south.

Sicily with a total outcrop area of more than 1,000 km² has the largest gypsum outcrop in Italy, followed by Emilia Romagna with more than 100 km².

The largest gypsum deposits are related to the «Gesso Solfifera» Fm. (Messinian in age). This formation has two main lithostratigraphical units with a maximum thickness of 1,500 m. From the bottom to the top, the lower evaporitic unit consists of diatomite and diatomite marls, evaporitic limestones, gypsum with intercalations of gypsiferous marl, and salts. The upper evaporitic unit consists of cycles of gypsum and gypsiferous limestones with sandy and clayed layers, bioclastic limestones changing laterally and upwards into gypsum, and clayed sands.

A few wide and thick gypsum outcrops belong to the Triassic «Burano» Fm. which is mainly located in the northern part of central Italy.

Finally there are also Palaeozoic and Mesozoic evaporites comprising typical trasgressive sequences, which gave rise to small outcrops in the Alps. Generally these gypsum units have a thickness of several metres and are often interrupted by faults or overthrusts.

Gypsum outcrops differ from each other not only in age but also in chemical composition, crystal size (from less than 0.1 mm up to 5 cm or more), texture and structure. All these parameters influence the effect of meteorological agents on rock degradation.

The 26 test locations were chosen to be representative of all the Italian gypsum formations and are located on gypsum exposed surfaces in 17 localities, which represent the most important gypsum outcrops in Italy (fig. 1). These stations also represent the main different morphological, compositional and textural conditions that Italian gypsum may undergo.

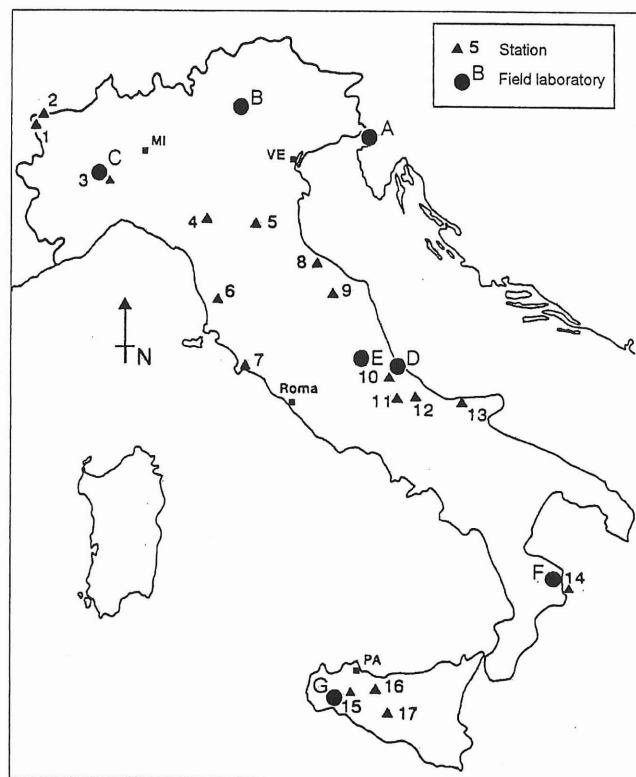


FIG. 1 - Map of Italy with location of the 17 test areas on natural outcrops (triangles) and of the 7 field laboratories (circles). See also table 1 and table 2.

Moreover, starting from the hypothesis that climate should be one of the prevailing factors on gypsum degradation, the test locations were also chosen to be representative of all the different climates existing in Italy: their location ranging from 36° to 47° latitude. Some test locations are located along the seashore (fig. 1, stations 7 and 13), while other stations are at different elevations and at variable distances from the sea; finally one location in western Alps (fig. 1, station 2) has an elevation of more than 2,000 metres a.s.l. (table 1).

For the whole area studied, annual average rainfalls range from 220 mm/yr. to 1,350 mm/yr.

TABLE 1 - Data from test locations on exposed bedrock

Locality	Sample	Elevation (m)	Exposure (months)	Total rain (mm)	Annual rain (mm/yr.)	Lithology	Measure points (n)	Total degradation (mm)	Annual degradation (mm/yr.)	Degradation /rain * 10 ³ (n)
La Thuile	1	1540	22	1311	715	Microcrystalline gypsum with anidrite and dolomite (Liassic)	8	1.14	0.62	0.87
Courmayeur*	2	2300	22	1311	715	Crystalline gypsum (Liassic)	8	2.62	1.43	2.00
Asti	3	320	24	1527	764	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	8	1.42	0.71	0.93
Val di Secchia	4.1	500	24	1585	793	Microcrystalline gypsum (Triassic)	5	1.26	0.63	0.79
	4.2		24	1585	793	Microcrystalline gypsum (Triassic)	6	1.80	0.90	1.14
	4.3		24	1585	793	Crystalline anidrite (Triassic)	2	1.55	0.78	0.98
Croara	5.1	330	24	1512	756	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	10	1.57	0.79	1.04
	5.2		24	1512	756	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	3	1.38	0.69	0.91
	5.3		24	1512	756	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	11	1.82	0.91	1.20
Casaglia	6	230	22	783	427	Crystalline gypsum (Miocene)	6	0.98	0.53	1.25
Orbetello	7	80	19	713	450	Macrocrystalline gypsum (Calcare cavernoso Fm, Triassic)	6	0.68	0.43	0.95
Onferno	8	400	24	1547	774	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	7	0.71	0.36	0.46
Arcevia	9	300	22	1481	808	Microcrystalline gypsum with sandy silt (gessoarenite of Gessoso solfifera Fm)	11	1.34	0.73	0.90
S.Valentino	10	330	24	1589	795	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	10	0.99	0.50	0.62
Palena	11.1	800	24	1429	715	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	3	0.77	0.39	0.54
	11.2		24	1429	715	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	4	1.03	0.52	0.72
	11.3		24	1429	715	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	4	1.07	0.54	0.75
Gissi	12.1	499	24	930	465	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	5	0.86	0.43	0.92
	12.2		24	930	465	Macrocrystalline gypsum (Gessoso solfifera Fm, Messinian)	3	0.73	0.37	0.78
P.ta Pietre nere	13.1	25	22	576	314	Microcrystalline gray gypsum with marly limestone (Carnian)	3	1.53	0.83	2.66
	13.2		22	576	314	Microcrystalline gray gypsum with marly limestone (Carnian)	7	0.85	0.46	1.48
Verzino	14	600	15	284	227	Microcrystalline gypsum with sandy silt (gessoarenite of Gessoso solfifera Fm)	10	0.68	0.54	2.39
S.Ninfa	15.1	617	19	530	335	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	2	0.49	0.31	0.92
	15.2	555	19	530	335	Microcrystalline gypsum with sandy silt (gesso arenite of Gessoso solfifera Fm)	5	0.69	0.44	1.30
Ciminna	16	696	19	813	513	Selenitic macrocrystalline gypsum	3	0.85	0.54	1.05
Campofranco	17	280	19	632	399	Selenitic macrocrystalline gypsum	2	0.63	0.40	1.00

* this value is affected by heavy snowfalls (up to 2 metres/year) which have not been taken into consideration due to lack of data.

In order to further improve the climatic significance of the experiment, seven field laboratories were set up in places where there was no gypsum outcrop (fig. 1, circles). Twenty-five gypsum samples (different in age and texture) were exposed in these laboratories. For example, in the Trieste field laboratory (fig. 1, field lab. A) two samples from Sicily (micro and macro crystalline gypsum from «Gessoso Solfifera» Fm.) and two samples from northern Apennines (Triassic crystalline gypsum) were exposed. In the Trento field laboratory (fig. 1, field lab. B) 13 different types of gypsum samples were exposed for two years.

In the field test locations as many rivets as possible were fixed, in order to obtain several measurements from each location. The final degradation value is the average of the different measurements (from 3 to 10) in the same pla-

ce and on the same lithology. In the present paper all available data have been utilized. However it is clear that 3-5 measurements for each location are enough to achieve reasonable accuracy (figures 2 and 3), where the degradation has essentially the same value from using 10 measures as from using only 2 or 3.

This fact allow us to assume that even in the laboratories, where the size of the gypsum blocks made a high number of measurements on the same sample impossible, the results may be considered reliable.

By means of over 4,000 experimental data from approximately 220 measuring points, the degradation of 15 different lithologies in 26 different measurement stations and of 25 different samples in 7 different field laboratories have been measured (table 1 and table 2).

Location: Croara
Station: 5.1

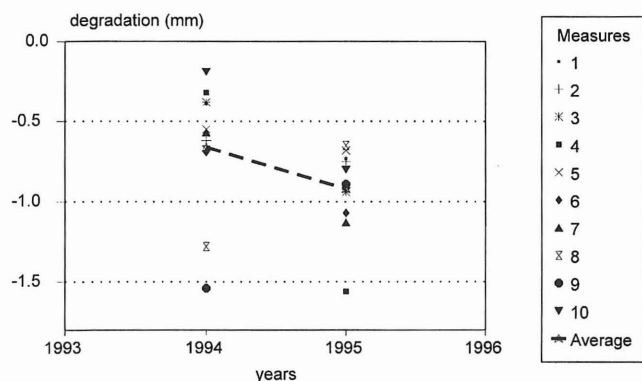


FIG. 2 - Experimental and average values for the 10 measurement points in the Croara 5.1 test location.

Location: Palena
Station: 11.1

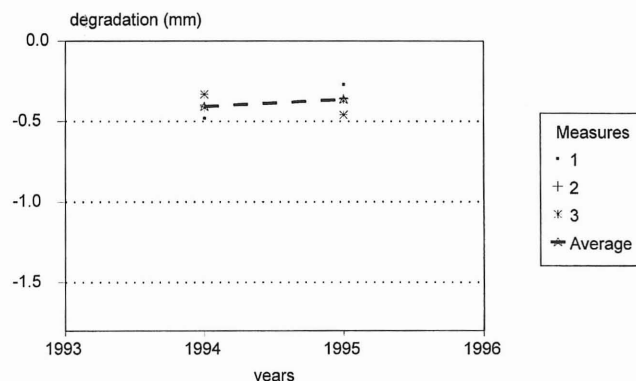


FIG. 3 - Experimental and average values for the 3 measurement points in the Palena 11.1 test location.

TABLE 2 - Data from field laboratories

Locality	Sample	Elevation (m)	Exposure (months)	Total rain (mm)	Annual rain (mm/yr.)	Lithology	Measure points (n)	Total degradation (mm)	Annual degradation (mm/yr.)	Degradation /rain * 10 ⁴ (n)
Trieste	A1	275	110	12100	1320	Crystalline gypsum (Gessoso solfifera Fm, Messinian)	1	8.92	0.97	0.74
	A2		110	12100	1320	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	1	8.03	0.88	0.66
	A3		80	8900	1320	Crystalline gypsum (Triassic)	1	4.74	0.71	0.53
	A4		78	8800	1320	Crystalline gypsum (Triassic)	1	10.78	1.66	1.23
Trento	B1	465	22	1903	1038	Microcrystalline gypsum with anidrite and dolomite (Liassic)	2	1.33	0.73	0.70
	B2		22	1903	1038	Crystalline gypsum (Gessoso solfifera Fm, Messinian)	4	1.57	0.86	0.83
	B3		22	1903	1038	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	3	1.54	0.84	0.81
	B4		22	1903	1038	Microcrystalline gypsum (Triassic)	1	2.11	1.15	1.11
	B5		22	1903	1038	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	2	1.54	0.84	0.81
	B6		22	1903	1038	Crystalline gypsum (Gessoso solfifera Fm, Messinian)	2	1.56	0.85	0.82
	B7		25	2317	1112	Microcrystalline gypsum (Permian)	2	0.49	0.24	0.21
	B8		25	2317	1112	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	4	2.05	0.98	0.88
	B9		25	2317	1112	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	4	1.45	0.70	0.63
	B10		25	2371	1112	Crystalline anidrite (Permian)	2	2.78	1.33	1.20
M.te Bondone*	B11	1540	25	2370	1112	Crystalline gypsum (Triassic)	1	2.37	1.14	1.02
	B12		25	2416	1160	Microcrystalline nodular gypsum (Permian)	1	0.66	0.32	0.27
M.te Bondone*	B13	1540	25	2416	1160	Saccharoid gypsum (Permian)	4	1.57	0.75	0.65
B14	25		2643	1269	Crystalline gypsum (Gessoso solfifera Fm, Messinian)	9	1.71	0.82	0.65	
Asti	C	300	24	1527	764	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	2	0.80	0.40	0.52
Chieti	D	300	24	1087	544	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	6	0.74	0.37	0.68
C. Imperatore*	E	2900	24	1166	583	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	4	0.78	0.39	0.67
Verzino	F1	600	13	284	262	Microcrystalline gypsum (Gessoso solfifera Fm, Messinian)	3	0.36	0.33	1.27
	F2		13	284	262	Microcrystalline gyp. with sandy silt (gessoarenite of Gessoso solfifera Fm, Messinian)	4	0.39	0.36	1.37
	F3		13	284	262	Gypsy sandstone (Gessoso solfifera Fm, Messinian)	2	0.56	0.52	1.97
S. Ninfa	G	560	19	641	405	Crystalline gypsum (Gessoso solfifera Fm, Messinian)	4	0.32	0.20	0.50

* these samples are affected by heavy snowfalls, which have been combined with the rainfall.

Data were collected every six months for two years. In the Trieste Borgo Grotta Gigante field laboratory data have been collected yearly since 1988 (Cucchi & *alii*, 1996). In this experimental field laboratory 25 carbonate rock samples and 2 gypsum samples have been exposed to atmospheric elements since January 1988, while 2 other gypsum were added in August 1990. They were exposed to a Mediterranean climate tending towards the continental, characterized by long, cold winters, variable springs and hot summers that prolong into autumn, with an average rainfall of 1,320 mm/yr.

RESULTS

The overall average value for gypsum degradation in Italy was 0.67 ± 0.31 (mean \pm SD) mm/yr.; the average value for natural outcrops being 0.61 ± 0.24 mm/yr., while that for samples in field laboratories being slightly higher: 0.73 ± 0.36 mm/yr. (table 3).

Excluding values linked to peculiar climatic, environmental or lithologic situations, the average degradation was 0.67 ± 0.31 mm/yr.; the average value for natural outcrops being 0.63 ± 0.16 mm/yr., while that for samples in field laboratories 0.80 ± 0.12 mm/yr. (table 3).

TABLE 3 - Average values of annual degradation and degradation per 1,000 mm rain

	Annual degradation (mm/yr.)	Annual degradation* (mm/yr.)	Degradation /rain * 10 ³ (n)	Degradation** /rain * 10 ³ (n)
Stations on exposed bedrock	0.61 ± 0.24	0.63 ± 0.16	1.10 ± 0.52	0.99 ± 0.42
Field laboratories	0.73 ± 0.36	0.80 ± 0.12	0.83 ± 0.38	0.83 ± 0.26
TOTAL	0.67 ± 0.31	0.70 ± 0.17	0.96 ± 0.47	0.91 ± 0.36

* Total values between 0.4 and 1.0 mm/yr. of annual degradation.

** Total values between 0.3 and 1.9 of ratio degradation each 1000 mm rain.

This slight difference was due to the difference in total amount rainfall over the field test locations and over the laboratories: comparing the average values of degradation for the same amount rain (1,000 mm), we obtain respectively 1.10 ± 0.52 for the natural outcrops and 0.83 ± 0.38 for the laboratories with an overall average of 0.96 ± 0.47 (figures 4 and 5).

The degradation value for natural outcrops is higher than that for field laboratories: this is acceptable because the natural outcrops may have peculiar lithologies, textures with high erosional degree and limiting climatic conditions (table 1, samples 2, 13.1, and 14) which have been taken

FIG. 4 - Variability of degradation in the field test locations. The average value for gypsum degradation is 0.99 ± 0.42 mm/1,000 mm rain, maximum deviations are referred to stations with peculiar climate or peculiar lithology and texture (see text).

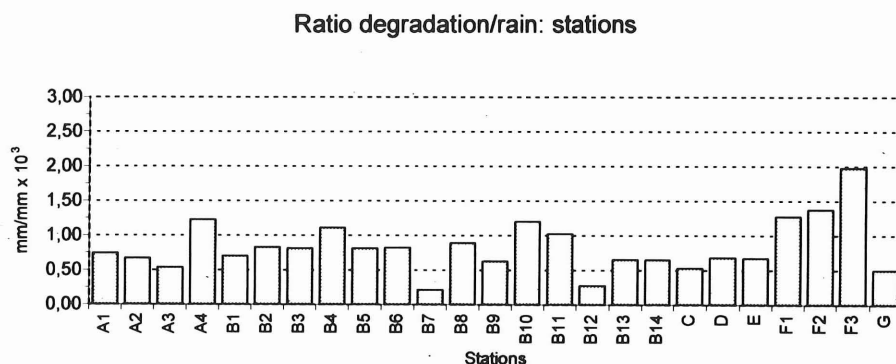
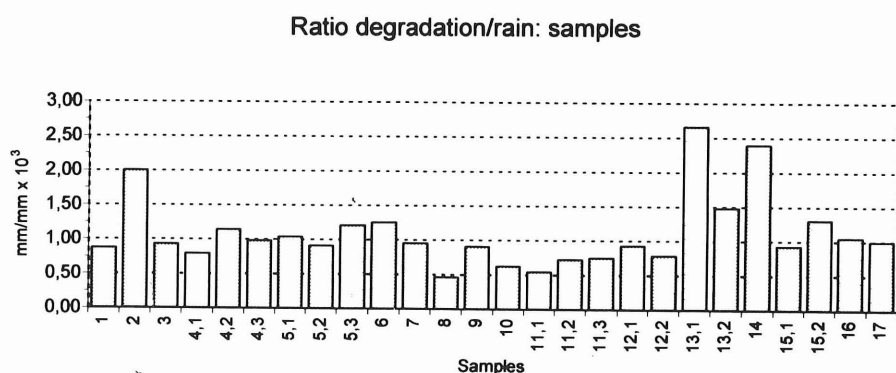


FIG. 5 - Variability of the degradation in the laboratory test locations. The average value for gypsum degradation is 0.83 ± 0.26 mm/1,000 mm rain, maximum deviations are referred to samples with unusual climate or unusual lithology and texture (see text).



into account, while in the laboratories only one sample showed a high degree of erosion (table 2, sample F3), but the solubility of other two (table 2, samples B7 and B12) was extremely low. By excluding all anomalous data the average values become 0.99 ± 0.42 for natural outcrops and 0.83 ± 0.26 for the laboratories, with an overall value of 0.91 ± 0.36 (table 3), which corresponds to 85-90% of the theoretical gypsum solubility, demonstrating the high solubility of gypsum rock and the rapidity of this process under normal rain conditions.

The slightly higher value obtained for the natural outcrops is acceptable due to the higher variability in climate and in lithology-texture, a context which may result in additional mechanical erosion.

The minimum degradation (0.21 and 0.27 mm/1,000 mm rain) was measured in two Permian samples of microcrystalline gypsum (table 2, samples B7 and B12) in the Trento laboratory, where they have been exposed to 1,112 mm/yr. rainfall.

These anomalous low values may be explained by the unusual texture of these partially dolomitic samples, which consisted of extremely small crystals strongly cemented to each other, thus giving rise to a structure allowing the development of flat polished surfaces which totally avoid or, at least, greatly limit water adsorption. Therefore rain flows over their surfaces without interference. This limits the standing water and hence the amount of gypsum dissolved is greatly decreased.

This fact was recently experimentally demonstrated by comparing the lowering of macrocrystalline and microcrystalline gypsum exposed to direct water dripping and to a laminar flow under a sandy-clay deposit (Cucchi & Forti, 1991). The samples directly exposed to dripping experienced a degradation (60% of the theoretical solubility for the macrocrystalline sample and 20% for the microcrystalline one) far higher than that measured over the buried ones (only 1.5% for both). The very low value measured for the buried samples clearly indicates that dissolution is hindered if only laminar flow is possible over the gypsum surface. Moreover the crystal size has practically no influence over the degradation, mechanical erosion being impossible in such conditions.

The highest degradation values (>2 mm/1,000 mm rain) corresponding to up to 250% of the theoretical solubility for gypsum were measured in samples of gypsum with significant levels of impurities, normally dolomite or silicates (table 1, samples 13.1, 14 and table 2, sample F3). These are responsible for the anomalous degradation rate, which is greatly enhanced by mechanical erosion.

This was confirmed by the anomalous behaviour of sample A4, which recently experienced a degradation higher than 2 mm over only 6 months. This sample is a Triassic crystalline gypsum containing dolomitic clasts.

For these samples, mechanical erosion is therefore the principal degradation mechanism, while dissolution has only a limited importance.

Another apparently high degradation rate is that experienced by a Liassic crystalline gypsum (table 1, station 2), but in this case erosion was not the responsible for the enhanced degradation. This sample is located in the Alps at 2,300 m. a.s.l. and it experiences snowfalls and 850 mm/yr. rainfall. It was not possible to evaluate the contribution of the snowfalls due to lack of data, but they normally range from 2 to 3 metres/yr. and therefore the total amount of water which came in contact with the sample was far higher than that from rainfall, which is the only variable reported in the table.

Messinian gypsum (18 outcrops and 16 samples) shows a general mean degradation value of 0.59 ± 0.22 mm/yr. with location values ranging between 0.98 mm/yr. and 0.20 mm/yr. (tables 1 and 2). The average overall value of the degradation toward 1000 mm rain is 0.93 ± 0.40 with location values ranging from 2.4 to 0.4. Excluding the values between 0.3 and 1.5 (samples 14 and F3 which suffered heavy erosion due their lithology and texture), the overall average value decreases 0.82 with an average value of 0.85 for natural outcrop and one of 0.79 for laboratory samples.

Triassic gypsum (6 outcrops and 4 samples) has higher average values (0.87 ± 0.37 mm/yr., range between 1.66 mm/yr. and 0.43 mm/yr.) than Messinian samples, both in the natural and laboratory tests (tables 1 and 2).

The average overall value of the degradation per 1000 mm rain is 1.19 ± 0.57 (ranging from 2.66 to 0.53). The higher average value for the Messinian outcrops and samples may be explained by the fact that Triassic gypsum normally has a smaller crystal size thus allowing slightly faster dissolution and also they often are less «pure» containing dolomite or other impurities, which enhance their mechanical erosion.

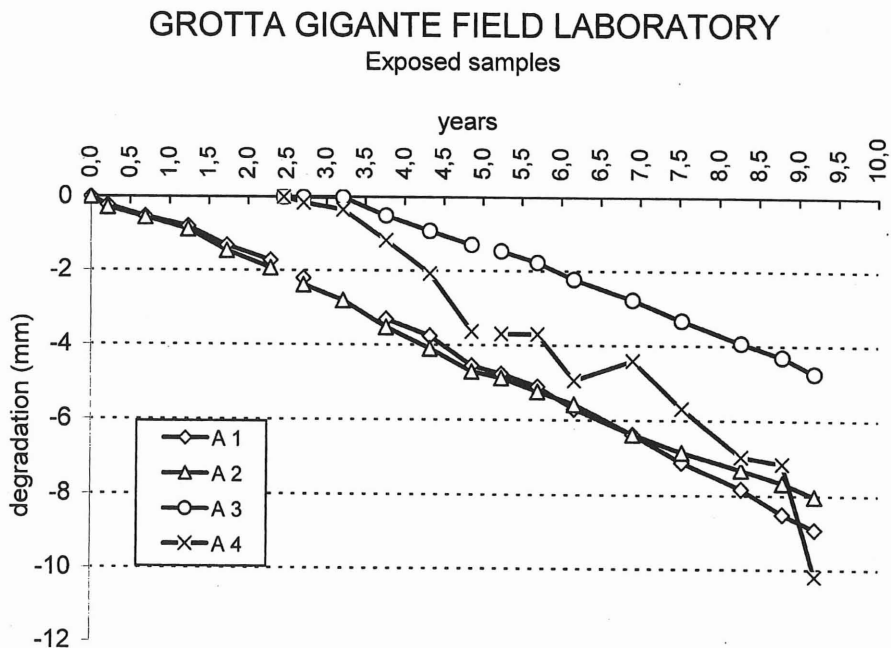
The data collected in the Trieste field laboratory over a longer span of time confirm the reliability of the data collected during our biannual research. While carbonates have annual degradation values between 0.010 mm/yr. and 0.035 mm/yr., gypsum surfaces lower between 0.71 mm/yr. and 1.66 mm/yr. (fig. 6), corresponding to 0.53 and 1.23 mm/1,000 mm rain respectively.

The relative high variability shown in Figure 6 is not unusual: three samples (A1, A2, A3) have a similar degradation ratio, and only sample A4 shows a more intense degradation ratio. This difference is due to its particular textural characteristics: it is a Triassic crystalline gypsum with dolomite clasts, and the enhanced observed degradation results from the random loosening (erosion) of these clasts.

General average value of degradation in macrocrystalline and microcrystalline texture are generally very similar: 0.71 ± 0.34 mm/yr. and 0.58 ± 0.22 mm/yr., respectively, the average overall value of the degradation per 1,000 mm rain being 0.91 ± 0.36 and 1.07 ± 0.63 respectively.

For Messinian macrocrystalline gypsum alone, the average value of annual degradation was 0.59 ± 0.23 mm/yr.

FIG. 6 - In the Trieste (Borgo Grotta Gigante on the Classical Karst) field laboratory the gypsum degradation values range between 0.71 mm/yr. and 1.66 mm/yr.



and the degradation per 1000 mm rain is 0.77 ± 0.20 (fig. 7). The degradation of microcrystalline gypsum is slightly higher than that of macrocrystalline ones, as expected.

Degradation per 1,000 mm rain varies between 1.20 (Croara outcrops) and 0.46 (Onferno outcrops). This wide range is caused by the strong rainstorms which characterize the Croara location (thus allowing higher values than expected due to mechanical erosion) and by the environmental conditions of the Onferno location, where the amount rain which really reaches the sample is less than this value, because its location is sheltered by a tall vertical wall.

OTHER DATA

Apart from the data presented here, the only Mem data available on gypsum degradation in the Mediterranean Basin are those from the Messinian gypsum outcrop of Sorbas, in the southern-western part of Spain (Calaforra & alii, 1993; Calaforra, 1996).

In this area the average degradation value was 1.32 mm/1,000 mm (ranging from 0.6 to 2.0), 33% higher than the average obtained for all Italian outcrops and 38% higher than the average for the Messinian outcrops, where the gypsum has the same lithological and textural composition.

Ratio degradation/rain:
Macrocrystalline Messinian samples

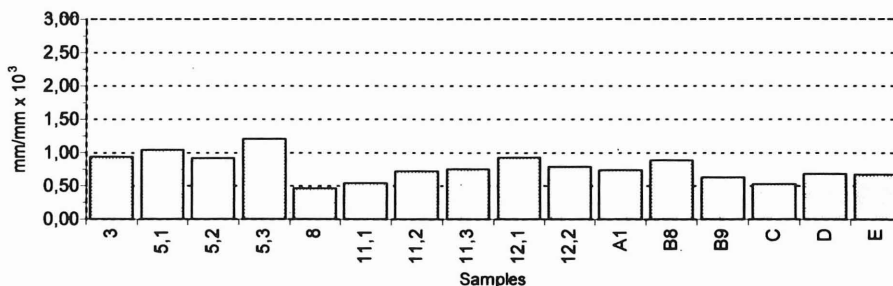


FIG. 7 - Average values for total degradation for total rainfall in macrocrystalline Messinian gypsum. The average value is 0.77 ± 0.20 mm/1,000 mm rain (see text).

The explanation of these higher values is given by the unusually hot and dry climate of the Sorbas Area, characterized by year round strong winds and a few (1-3) rainstorms which supply over the 80% of the total amount rain (less than 250 mm/yr.).

Both strong winds and rainstorms may induce mechanical erosion, but it is another mechanism that is primarily responsible for the erosion: the strong condensation that takes place every night. This phenomenon does not contribute to the direct dissolution of gypsum, but alters the gypsum surface by causing the deposition of weakly cemented gypsum powder, which is easily washed away during the rainstorms or blown away by winds.

At the time of the experiments in the Sorbas area, it was not possible to obtain a quantitative estimation of the contribution of mechanical erosion to the total degradation. Now the availability of the average degradation data for the Messinian outcrops of the Mediterranean Basin (82 mm/1,000 mm rain) allows the estimation of the erosional component in the Sorbas degradation. Assuming that all the average degradation may be attributed to simple dissolution, the excess value for Sorbas (50 mm/1,000 mm rain) must be due to mechanical erosion, which therefore account for 40% of the total phenomenon.

Degradation values a little bit higher but compatible with the present ones were recently reported by Klimchouk & alii, (1997). They were obtained by measuring loss of weight of gypsum tablets (Gams, 1981).

The obtained values are 0.25 mm/yr. for Ukraina and 0.28 mm/yr. for Spain, which correspond to a degradation between 0.9 and 1.5 mm/1,000 mm rain.

CONCLUDING REMARKS

This research reports on the variability of the mean degradation values for Italian gypsum. For the first time, the values have been shown to depend both to the sample age, texture and crystal size, as well as the different climate to which the sample has been exposed.

By using all the available data, the gypsum degradation value in the Mediterranean area has been set between 0.4 mm/yr. and 1.0 mm/yr. (0.70 ± 0.17). Data exceeding these boundaries are clearly related to local peculiarities of climate or to textural or compositional characteristics of the location.

The main factor controlling gypsum degradation has been shown to be the amount of rainfall, thus dissolution is by far the most important degradation factor and corresponds for the whole of Italy to 85% of theoretical gypsum solubility.

The second major factor seems to be the textural-petrographical setting of the sample, which may contribute to the effects of mechanical erosion. Our research has shown

that mechanical erosion (table 1 samples 13.1, 14 and table 2 A4, F2) under particular climatic situations may exceed dissolution. The textural-petrographical setting has more significance to rate of dissolution than does the age of the gypsum.

Crystal size in the samples plays a subordinate role with the respect to the previously considered parameters. The general trend is that smaller crystals are easily dissolved and therefore have a slightly higher degradation rate. The same higher solubility induced by smaller crystal size was observed while studying micritic and sparitic limestones (Cucchi & alii, 1996). In addition, in the case of gypsum, when the environmental conditions allow mechanical erosion, the breaking down of larger crystals and their subsequent removal due to erosion may cause a strictly local rapid degradation.

The important achievements of this experimental are twofold: firstly the high values found in the degradation justify experimentally the hypothesis that the gypsum karst cycle is fast. On the basis of the estimated mean annual degradation a gypsum formation, exposed to meteorological agents, cannot survive more than a few hundred thousands years.

Finally this study underlines that, avoiding dramatic climatic and/or lithological conditions, gypsum has similar degradation values throughout the Mediterranean basin. Therefore this value, (which corresponds to 85% of the theoretical solubility of gypsum) may also be useful for other gypsum areas with similar climates but where there are no experimental data available.

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