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Reform of Carbonate Rock Subsurface by Crustose Lichens and Its Environmental Significance

CAO Jianhua and WANG Fuxing
Institute of Karst Geology, Chinese Academy of Geological Sciences, Guilin, Guanxi 541004

Abstract Crustose lichens are distributed extensively in karst areas in Southern China. They can be found on the surface of carbonate rocks. Through biophysical and biochemical processes, crustose lichens reform the subsurface of carbonate rocks and in the meanwhile change their physical and chemical properties: (1) the mechanical strength decreases by 17.04° on average (up to 33.2°); (2) the chemical solution surface area increases from 28.26% to 75.36% (lichen microholes considered only); and (3) the water–holding capacity is greatly improved. Comparative field experiments between biokarst samples underneath crustose lichens and fresh rock samples with the same composition and texture show that the corrosional rate of carbonate rocks of the former is 1.264–1.643 times higher than that of the latter. Crustose lichens are considered as an activator of the surface corrosion of carbonate rocks.

Key words: crustose lichen, carbonate rock, biokarst, corrosion, environmental significance

1 Introduction

Lichen is a compound plant of algae and fungi. It possesses strong adaptability and can live on the surface of dry rocks. Lichens can be even found in places where other higher plants cannot live. Therefore, the lichen (especially crustose lichen) has become the main object of biokarst research since the 1960s and its important role in controlling the corrosion of underlying carbonate rock and the development of microforms of rock surface had been recognized long before (Sollas, 1880; Fry 1922). Previous researchers have focused their attention on the microforms of carbonate rock surface produced by crustose lichen (Danin and Garty, 1982; Danin et al., 1983) and the study on the biochemical mechanism of the corrosion of boreholes by lichens through analyzing the organism secretion at the interface between lichens and carbonate rocks (Jone et al., 1981; Ascaso et al., 1982). Therefore, whether lichens colonizing on rock surface accelerate (Danin et al., 1983) or hinder (Sweeting, 1972) the corrosion of underlying carbonate rocks has always been under discussion. The key to the problem is to search for a method which is capable of measuring the crrosion rate of carbonte rocks underneath the crustose lichens (Viles, 1987).

Based on the observation and collection of lichen biokarst samples from the karst areas in southern China and identification and related experiments in the field and labs, this study involves the following subjects: reform of the subsurface of carbonate rocks and changes of physical and chemical properties of the underlying rocks, such as increase of water–holding capacity, weakening of the physical strength of rock surface, enlargement of the chemical solution area, and acceleration of the corrosional rate of underlying carbonate rocks due to crustose lichens.

2 Reform of the Subsurface of Carbonate Rocks by Crustose Lichens

Crustose lichens colonize on the surface of carbonate rocks and thus reform the structure of their subsurface. Meanwhile, a number of biokarst microforms are produced. The method to study their characteristics, types and distribution inside the rocks is to observe thin sections of biokast or rock samples with powerful biological microscopes or S.E.M. (scaning electron microscope). Since relatively deep–going and detailed researches have already been done in this aspect (Viles, 1984; Zhang, 1993), we are merely to give two more points in this paper. (1) Lichen corrosional microholes are produced by lichen fruiting and their shapes depend on different species of lichen genera. For example, the microholes produced by the perithecia of *Rhizocarpon* sp. are pot–like or ellipsoid in shape and those formed by the apothecia of *Graphid* sp. are in the shape of twisting groove. (2) The distribution, developing direction and density of crustose lichen microholes are influenced by the texture and composition of carbonate rock substrate and the microenvironment. Conseqently, there exists a corresponding relationship between lichen microforms and the environment.

3 Physical and Chemical Properties of Carbonate Rock Subsurface Changed by Crustose Lichens

3.1 Crustose lichen and water–holding capacity of carbonate rocks

We chose three lichen biokarst samples, $40 \times 10 \times 10$ mm^3 in dimension, each of which is divided into two with the cut parallel to the surface. The upper part is a biokarst sample and the lower is a fresh rock sample with the same texture and composition. Then, all samples are subjected to a moisture–losing test by evapouration and an active mositure–sucking test. The moisture–losing test is performed like this: fully saturated samples are weighed

Table 1 Results of the comparative experiments of the water–holding capacity between biokarst and fresh rock samples

Serial number	Moisture–losing by evapouration				Active moisture–sucking			
	MLA (mg)	Ⓒ/Ⓡ	DOE (h)	Ⓒ/Ⓡ	MLA (mg)	Ⓒ/Ⓡ	TDE (h)	Ⓒ/Ⓡ
93LGR098–1Ⓒ 93LGR098–2Ⓡ	33.0 9.9	3.3	1.42 1.42	1.0	8.1 0.5	16.2	0.75 0.50	1.5
93LGR095–1Ⓒ 93LGR095–2Ⓡ	16.0 2.4	6.6	1.00 0.42	2.3	1.9 0.5	3.8	0.50 0.50	1.0
93LGR143–1Ⓒ 93LGR143–2Ⓡ	11.6 2.8	4.1	1.33 0.50	3.1	4.1 0.2	20.5	0.66 0.16	0.41
Average	60.6 15.1	4.0	3.75 2.26	1.66	14.1 1.2	11.8	1.91 1.16	1.67

Note: MLA: moisture–losing amount; MSA: moisture–sucking amount; TDE: time duration of experiment; Ⓒ–biokarst sample; Ⓡ–rock sample.

once every five minutes by a 1 / 10,000 electronic balance until the weights remain constant. The procedure of the active moisture–sucking test is as follows. The same samples are kept in an incubator with a temprature of 48 ± 2℃ and a relative humidity of 27 ± 2% for 1.5 hours and then taken out of the incubator and cooled in a desiccator. While being cold, the dry samples begin to actively absorb mositure in a natural indoor condition at a temperature of 24℃ and a relative humidity of 85%; then the weight changes of these samples are measured once every five minutes by a 1:10,000 electronic balance until the weights remain constant. The test results are shown in Table 1, which shows that (1) the moisture–losing amount of the biokarst samples, on an average, is 4 times as much as that of the relevant rock samples and the time duration for biokarst samples, on an verage, is 66% longer than that for the relevant rock samples; (2) the active moisture–sucking amount of biokarst samples, on an average, is 11.8 times as much as that of the relevant rock samples and the time duration for biokarst samples, on an average, is 67% longer than that for the relevant rock samples. It can be seen consequently that the water–holding capacity of rocks will be greatly improved when lichens colonize on the rock subsurface and that the photosynthesis–respiration rate of the lichens will be increased, thus hastening the secretion of lichen acid and the exchange of lichens with CO_2 (Link et al., 1985). This will influence the corrosion of the underlying carbonate rocks.

3.2 Mechanical strength of carbonate rock subsurface

The case–hardness of carbonate rock is the problem which has attracted a great interest of some petrologists and geomorphologists (Day and Goudie, 1977; Ireland, 1979; Fang et al., 1985).

Table 2 Case–hardness of carbonate rock outcrops at different positions in the Yaji Experimental Site, Guilin

Serial No.	Lichen colonizing position (a)	Rainwater dissolving position (b)	Fresh rock surface (c)	(c)–(a)	(c)–(b)
1	15.8	24.0	49.0	33.2	25.0
2	33.0	40.0	51.0	18.0	11.0
3	31.0	35.0	42.0	11.0	7.0
4	30.0	40.0	44.0	14.0	4.0
5	32.5	39.0	45.5	13.0	6.5
6	28.0	32.0	41.0	13.0	9.0
Average	28.38	35.00	45.42	17.04	10.42

We employed the semiquantitative Schmidt hammer to measure the physical strength of carbonate rocks in the Guilin Experimental Site of Karst. The same rock outcrop should be measured several times. Case–hardnesses at three positions (lichen colonizing position, rainwater dissolving position and fresh rock surface) are exactly obtained (see Table 2). The preliminary results are as follows. (1) The case–hardness of fresh rock varys greatly (from 41.0° to 51.0°), indicating that the texture and composition of rocks are the key factors for the case–hardness. (2) Compared with fresh rocks, the case–hardness of the rock at the lichen–colonizing position decreases by 17.04° (up to 33.20°) and that at the rainwater dissolving position decreases by 10.42° on an average (up to 25.00°). This means that physical and chemical weathering is more apt to take place on rock surface.

3.3 Effective chemical solution area of carbonate rock surface

Dogue and Yuan (1987) deemed that 4–5 (m wide structural cracks tend to possess water permeability, in other words, enlarge effective chemical solution areas. The observation of lichen / rock sections shows that lichen boreholes resulting from phycobionts (with algae as part of the lichen) and corrosional microholes produced by lichen fruitings are all larger than this scale. Here, we take only the lichen microholes into account to roughly estimate the enlargement of effective chemical solution areas of rock surface. All the microholes are approximately regarded as spheres and their diameters are assumed to be 150–200% of their apparent diameters. Two different types of microholes are chosen depending on apparent features of the lichen corrosion. One is sparse microholes with an apparent diameter of 0.2 mm and a density of $1.0 / mm^2$ and the other is crowded microholes with an apparent diameter of 0.1 mm and a density of $6.0 / mm^2$. On account of the existence of lichen microholes, the enlargement of effective chemical solution areas of rock surface may be calculated according to the following formula:

$$\frac{[4\pi(nR)^2 - \pi R^2] \times N}{S}$$

where n is a constant (1.5–2), R is the apparent diameter of microhole, N is the number of microholes in unit area, and S is the nuit area.

According to the formula, the areas of chemical solution are increased by 28.26–50.24% and 42.39– 75.36% for sparse and crowded microholes, respectively.

4 Carbonate Rock Corrosional Rate Increased by Crustose Lichens

How to exactly and effectively measure the biokarst corrosional rate is an interesting problem to biokarst researchers. We tried to make use of a comparative method to solve this problem. Four representative biokarst samples were selected. The lichen genera covering the carbonate rock surface are found to be greyish yellow *Rhizocarpon* sp., brownish red *Rhizocarpon* sp., greyish green *Graphid* sp., and dark green *Lecanora* sp. Besides, a sample of rainwater solution was chosen for the comparison. The four samples and the comparative one were made to be $15 \times 15 \times 10$ mm^3 in dimension, each of which was divided into two parts with the cut parallel to the surface. The upper part is biokarst samples and the lower is relevent fresh rock samples with the same texture and composition. After weighed, all the samples were laid on the roof of a building in the Chinese Museum of Karst Geology in Guilin. The samples are dissolved continuously by rainwater in the same conditions. The test was performed from 14 July to 23 August, 1995. At the end, their weights were measured again. The resultant corrosional rates are listed in Table 3, which indicates that (1) the corrosion amounts of biokarst samples increase by 26.1-64.6% (averaging 46.43%) compared with that of the corresponding rock samples; (2) the corrosion amount of the rainwater sample is slightly higher than that of the corresponding rock samples.

5 Discussion

Comprehensive investigation of the biological evolution during the geological history shows that organisms, particularly plants, consume CO_2 in the atmosphere to produce useful organic carbon and carbonate rocks, which provide a material basis for karst development (Fairbridge, 1978). In the global carbon cycle, organisms are an important coordinator and

Table 3 Results of the comparative corrosional experiment between biokarst and fresh rock samples (from 14 July to 23 Auguest, 1995)

Serial No.	Biokarst © rock ®	Lichen genera	Weight before experiment (g)	Weight after experiment (g)	Losing weight (mg)	(©–®) / ®
93LGR003–1©		Greyish yellow	2.6968	2.6877	9.1	
93LGR003–2®		*Rhizocarpon* sp.	3.0732	3.0672	6.0	0.5
93LGR013–1©		Brownish red	2.9159	2.9072	8.7	
93LGR013–2®		*Rhizocarpon* sp.	3.4003	3.3934	6.9	0.261
93LGR015–1©		Greyish green	3.4311	3.4224	8.7	
93LGR015–2®		*Graphid* sp.	3.3848	3.3789	6.0	0.45
94MLR026–1©		Dark green	3.4935	3.4856	7.9	
94MLR026–2®		*Lecanora* sp.	3.4174	3.4126	4.8	0.646
94MLR020–1©		Rainwater	3.4967	3.4916	5.1	
94MLR020–2®		solution	3.2280	3.2230	5.0	0.02

guardian of the surface system of the earth (Zhang Yun, 1992). In recent years, studies have revealed that the karst system is of importance to the global carbon cycle in regulating and controlling atmospheric CO_2 (Yuan, 1993, 1995, 1997). In karst areas, therefore, not only the biological community exercises significant influence on the CO_2 dynamic state in the atmosphere, but also organisms can increase the corrosional rate of carbonate rocks to remove CO_2 from the atmosphere. As a result, a new direction has been pointed out for biokarst study. As we mentioned above, crustose lichens are widely distributed on carbonate rock surface in southern China. They cover 5–30% of the rock outcrops in bare karst areas and 30–70% in forest karst areas. Microstructure of crustose lichen / rock samples shows that the boring–corrosion of lichens reforms the rock subsurface structure as deep as 0–2 mm and changes some of their physical and chemical properties, thus increasing the corrosional rates of the carbonate rocks underneath crustose lichens by 26.1–64.6%. The crustose lichens significantly accelerate the CO_2 flux at the interface between the lithosphere and atmosphere, so they may be called an activator of the corrosion of carbonate rock surface.

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About the first author

Chao Jianhua Born in Jiangsu Province in 1963; graduated from the Department of Earth Sciences, Nanjing University in 1987. Since 1990 he has been engaged in research work on biokarst and global carbon circulation and published his monograph Biokarst and more than ten related papers.