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THE MECHANISMS OF THE DIFFERENTIAL EROSION OF LIMESTONES

by
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ABSTRACT

The Passage Beds, which are commonly exposed in Mendip caves, comprise mechanically weak calcareous shale beds and tough coarse grained limestones (biosparrudites), it is the biosparrudites which have shown preferential erosion. The biosparrudites have an uneven surface with the fossils standing proud of the matrix. There are thus two scales of differential erosion, firstly between the shale and the coarse grained limestone beds, and secondly within the coarse limestone bed, between fossils and matrix. Chemical and microscopic work show that the former is attributed to differences in composition and the latter is primarily controlled by the texture of the limestone. For biosparrudites it is invalid to relate the dissolution rate of the components to the rate of erosion of the whole rock.

INTRODUCTION

A large proportion of Mendip caves are developed either partially or wholly in the Passage Beds, which lie between the Lower Limestone Shales below, and the Black Rock Limestone above. The Passage Beds comprise an alternating sequence of fine grained calcareous shales, and coarse grained fossiliferous limestones (biosparrudites). The beds are generally 5-10 cm. thick, lateral thinning and bifurcating of the beds is common. Differential erosion of the Passage Beds is widely observed in many Mendip caves, notable examples include the Streamway in Swildons Hole and the Mud Passage in G.B. cave. The coarse grained limestone beds though mechanically tougher than the shaly beds have been weathered back by up to 25 cm., though 10 cm. is more usual. This apparent contradiction initiated this study, which was carried out as a final year project whilst in the Geology department at the University of Bristol.

Chapman (1912) analysed the Passage Beds (presumably only the coarse beds) and he showed them to have approximately 5% MgO. Rauch and White (1977) studied the effect of lithology on the dissolution rate of limestones. They showed that the fastest dissolution rate for a silt free limestone occurs when the limestone contains 1-2.5% MgO, a higher proportion of MgO reduces the dissolution rate. Sweeting (1965) has shown that maximum cave development occurs in coarsely crystaline limestones, with fresh plates of calcite in a calcite matrix. This description is in accordance with that for the coarse beds and it is these which show the greatest weathering. Newson (1970) shows photographs of 'protruding siliceous fossils from East Twin Stream, Burrington'

(Plates 44 and 45); these are discussed in pages 97-98 of his Ph.D. thesis. Bull and Carpenter (1979) discussed the sediments which are produced by weathering of the limestones and shale beds. The work of Newson and of Bull and Carpenter implies that the fossils protrude from the matrix because they are silicified.

The study followed two themes, a) the differences in erosion between the coarse grained limestones and the shaly beds, and b) the differences in erosion within the coarse limestone beds. The aim of the study is to draw some tentative conclusions into the nature of the micro-weathering process occuring at the rock-water interface.

METHODS

A sample was removed for examination from the side of the Gorge in G.B. Cave, Charterhouse-on-Mendip, Somerset. The sample was removed from a position approximately 1.5 m. above the present stream level, and would now only be reached by flowing water in extreme floods such as that which occured in the Mendips in 1968 (Newson, 1970). The surface still gets wet due to condensation, and due to water flowing along joints and over the surface. The former is more important in summer but even then neither method is likely to have significant effect upon the weathering. The sample removed from the cave (Fig. 37) comprised three shaly beds separated by two coarse limestone beds. Closer examination showed that the shaly beds contained lenses of coarse material. The sample showed a maximum variation in relief between the coarse limestone and the shaly beds of 3 cm.

Three lines of investigation were pursued; a) detailed observation under a binocular microscope, b) X-ray diffraction, c) dissolution in acetic acid.

The weathered surface of the coarse limestone bed was examined under a binocular microscope, under a range of magnifications to investigate the fine details of the weathered surface. The shaly bed was disaggregated by immersion in an ultrasonic bath for 90 minutes, after which time 50% of the rock was in suspension in the water. This suspension was filtered and dried, enabling the individual grains to be observed under high magnification.

For X-ray diffraction and for the dissolution in acetic acid, clean unweathered samples of both the shaly bed and the coarse limestone bed were required. The whole rock was soaked in detergent solution for 24 hours to remove the excess mud. After rinsing and drying the shaly and coarse limestone layers were separated by chiselling. Samples of the coarse layer were freed of any remaining mud by immersion in the ultrasonic bath for 20 minutes. Samples from the two coarse beds were indistinguishable.

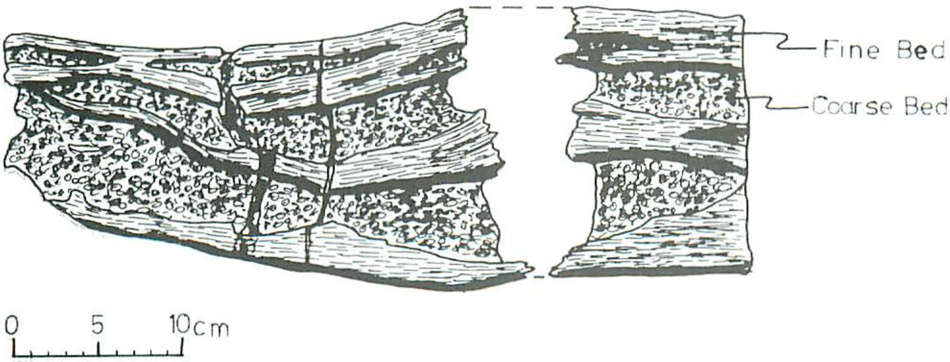

Fig. 37 Front and side views of the sample from G. B. cave

Samples of a) the shaly bed, b) the whole coarse limestone bed, c) the fossils of the coarse bed and d) the matrix of the coarse bed, were prepared for X-ray diffraction. Small amounts of each sample were ground in a ball mill for 15 minutes. The fine powders were placed on glass slides by precipitation from suspension in water by slow drying. The samples were analysed on the X-ray diffractometer in the University of Bristol Geology Department.

The quantity of insoluble material in the shaly and coarse limestone layers was established by dissolving accurately weighed samples of approximately 100 g. each in 10% acetic acid. 800 ml. of acetic acid were used for each sample, each week for five weeks the samples were filtered and fresh acid added. At the end of this time it could be safely assumed that all the carbonate had dissolved. After washing in distilled water and drying the residues were weighed.

RESULTS

A comparison of the shaly and coarse limestone beds.

SHALY BED	COARSE LIMESTONE BED
Hand specimen	
Mechanically weak, Fine irregular lamination, A few bryozoa imprints but otherwise unfossiliferous.	Mechanically tough, No layering within each bed, Highly fossiliferous with crinoid ossicles 1-2 mm. in diameter and a few brachiopod shells up to 1 cm. across. Nearly all the fossils are disarticulated.

Microscope studies	
Individual grains have a fairly constant size of 5 microns.	Interstices between fossils filled with 'mixed matrix' (Rauch and White, 1977) comprising subangular equant grains of calcite approximately 0.1 mm. in diameter surrounded by very fine grained iron stained micrite.
X-ray diffraction	
Mainly illite with lesser amounts of silica and calcium carbonate.	The major component was calcium carbonate in the form of calcite. The fossils were of high magnesium calcite with small amounts of silica. The matrix was mainly calcite with a small amount of illite.
Dissolution in acetic acid	
64% insoluble residue comprising fine grained clay minerals and silica.	7% insoluble residue comprising clay minerals and silica including three crinoid ossicles, which were presumed to be silicified. These represent only a minority of the fossils most of which dissolved, albeit slowly.

The two rock types may be formally described as a calcareous shale and a biosparrudite.

A number of 1 mm. wide calcite veins vertically transect both types of bed. The veins show about the same relief in the coarser limestone bed as the fossils but they are more weathered than the shaly bed. The coarse limestone bed contains areas of pure matrix devoid of fossils, these have a maximum size of 1 cm., they probably represent infilled voids.

The naturally weathered surface of the coarse limestone beds has a marked relief. The fossils stand proud of the matrix generally by approximately 1 mm. although the brachiopod shells have a relief of up to 5 mm. The sparrite crystals stand proud of their micritic coatings by approximately 0.1 mm.

Two interesting features arose during the dissolution of the rocks. Fragments of the coarse limestone layer, which initially had cleanly broken surfaces, developed a surface which closely resembled that of the naturally weathered coarse bed, after one week in the acid. After two weeks a residue had accumulated in the bottom of the beaker, this comprised fine calcite sand and fossil fragments, mainly crinoid ossicles, both of which dissolved over the following three weeks. The dissolution of the shaly layer was slow; after stirring, the fragments of soluble but as yet undissolved material sank to the bottom of the beaker and were soon covered with a layer of clay particles. This effectively isolated the soluble material from the main body of the acid, the clay layer was sufficiently substantial to hold bubbles of carbon dioxide which were only released on stirring.

DISCUSSION

This study can be divided into two sections, a comparison between the coarse limestone and the shaly beds, and between the fossils and the matrix of the coarse bed. The shaly beds are chemically resistant but mechanically weak, the reverse is true for the coarse limestone beds. One of the obvious factors which reduces the dissolution rate of the shaly beds is the high proportion of insoluble material. The experimental dissolution of the shaly beds showed that the carbonate could be effectively isolated from the acid by a layer of clay. A similar situation is presumed to occur in the natural system where the carbonate is isolated from the cave waters by the clay particles. These factors account for the protrusion of the shaly beds. Mechanical durability is not required for protrusion as the main erosional process in cave systems is dissolution. The coarse limestone beds contain over 90% soluble material with insufficient clay minerals to form an isolating layer.

There are two fundamental differences between the fossils and their matrix, chemical and textural. Chemically the fossils contain more magnesium and more silica than the matrix. The quantities of these two phases are small and although they do undoubtedly reduce the dissolution rate it is postulated that the effect of this is small in comparison with the effect of the textural differences. Texturally the fossils are well crystalised high magnesium calcite with single crystals up to 1 mm. across. The matrix comprises micrite covered calcite crystals up to 0.1 mm. across.

The dissolution of the coarse bed would appear to occur in four stages, 1) dissolution of the micrite, sparrite and fossils, not all at the same rate. The micrite having a small grain size has a large surface area and it dissolves relatively quickly. This is shown by the microscopic observation where the sparrite can be seen standing proud of its micritic coating. 2) Elimination of the micritic coating removes support for the sparrite crystals and they easily detach from the surface. 3) Likewise removal of the sparrite leaves the fossils unsupported and they too drop from the surface. 4) Dissolution of the components continues after the removal from the rock surface. The evidence for stage four comes from the dissolution experiments in acetic acid. This process is supported by Newson's (1970) observation of fresh calcite rhombs and crystals in resurgence sediments absent in swallet sediments. The dissolution of a fossil or a crystal of sparrite, once it is removed from the rock surface, has no effect on the erosion of the bed. Consequently the conclusions about the rate of limestone erosion, drawn from dissolution rates only, may be invalid where two or more types of carbonate exist within one bed.

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REFERENCES

BULL, P. A. and CARPENTER, I. A. 1979 Sedimentological investigations of Goatchurch Cavern and Sidcot Swallet, Burrington Combe, Somerset. *Proc. Univ. Bristol Spelaeol. Soc.*, **15** (1), 53-74.

CHAPMAN, M. B. 1912 The chemical examination of the Carboniferous limestones of the Avon Gorge. *Geol. Mag.*, **9**, 498-503.

NEWSON, M. D. 1970 *Studies of chemical and mechanical erosion by streams in limestone terrains.* Unpub. Ph.D. thesis, Univ. Bristol.

RAUCH, H. W. and WHITE, W. B. 1977 Dissolution kinetics of carbonate rocks. 1. Effects of lithology on dissolution rate. *Water Resour. Res.* **13** (2), 381-394.

SWEETING, M. M. 1965 Types of limestone and their relationship to cave formation. *Proc. IV Cong. Int. Spel. Ljubljana.*