THE SOLUTION OF GYPSUM AND LIMESTONE BY UPWARD FLOWING WATER

by

R. J. Firman and J. A. D. Dickson

Summary

Examples are described of gypsum and limestone which have been dissolved by upward flowing water. It is suggested that such artesian and subartesian waters are more often agents of corrosion than is generally recognised.

Introduction

That water will not flow uphill is a commonly accepted fallacy, yet every geologist familiar with artesian water realises that, when pressures due to a hydraulic head are released by drilling, water flows up a borehole. Such artesian water would equally readily flow upwards if released by fracturing due to tectonic movements or weathering, and on many occasions during geological history this must have happened. This paper describes examples of structures in the Newark Gypsum (R. J. F.) and Carboniferous Limestone (J. A. D.) which illustrates the potency of such upward flowing waters as agents of erosion.

(A) Newark Gypsum (Nottinghamshire)

The Keuper Marl normally contains disseminated gypsum. In layers near the surface this gypsum has usually been removed by percolating ground waters. Elliott (1961) records that this "solution zone" thickens westward from the Rhaetic escarpment and may be one hundred feet deep near faults. In boreholes sunk through the Newark Gypsum Series, the bottom of this solution zone can usually be detected by an increase in core recovery, by the more brittle and drier condition of the marl, by the absence of ochreous and blackened surfaces on the marl, and by the presence of finely disseminated gypsum. Most of the commercially workable gypsum lies below this solution zone but quite large partially dissolved masses of gypsum may remain in it. Some gypsum below this zone shows evidence of having been corroded. It is the study of structures in gypsum nodules, both within and below the solution zone, which provide evidence of the mechanics of this corrosion.

Description of the Structures

The Newark Gypsum Series consists of fifty to sixty feet of strata containing up to twelve beds of massive gypsum interbedded with marl. These gypsum beds consist of discontinuous nodules and lenses of

PLATE 21

Fig. A. Side view of specimen shown in Plate 22. Illustrates the smooth top and irregular bottom characteristics of many water worn gypsum nodules. Note the selenite on the side of this specimen.
Photographer: J. Eyett

Fig. B. Gypsum nodules from the Bellrock quarry at Staunton-in-the-Vale illustrating the general shape with flat or slightly convex tops. Three of the four nodules are upside down in the dumper. The one with a flat-top has been cracked in half and the undulating base can be clearly seen.
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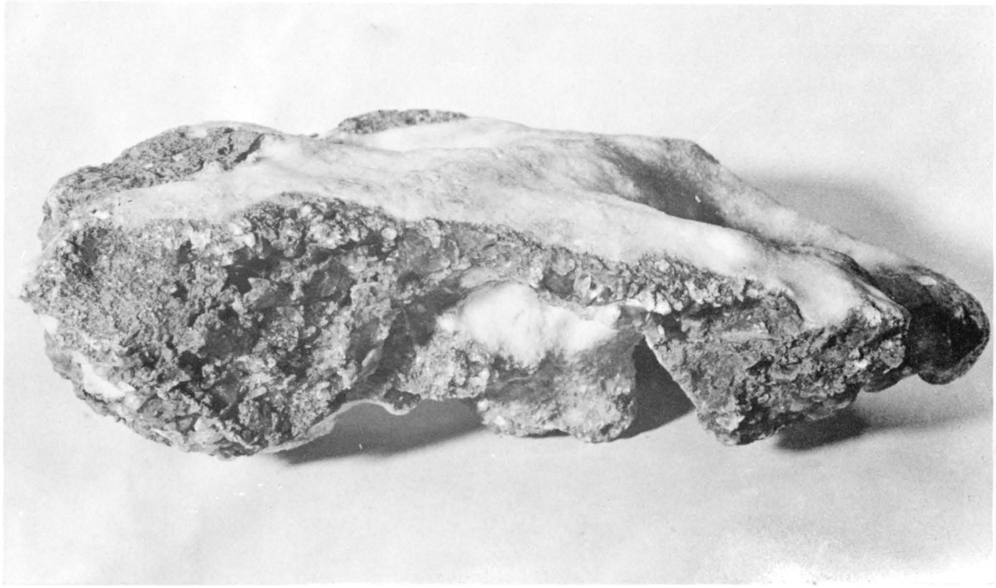


A

B

variable thickness (Firman, 1964). Within the solution zone as defined by Elliott (1961), often only the larger nodules of the thicker beds persist. In excavations for gypsum in the area west of Staunton-in-the-Vale (SK 816437), the bulk of the gypsum masses show evidence of solution from the base upwards. These "cakes" or "balls" of gypsum (Firman, 1964) usually consist of massive gypsum fringed with fibrous gypsum. When waterworn this fringe has usually been removed, but frequently fibrous gypsum has been dissolved only from the undersides of the nodules. Typically these nodules are flat or slightly convex on top and irregular underneath (Plate 21). Although the top surface is often waterworn, it is the base which provides the most striking evidence of corrosion. This unequal corrosion accounts for the shape of the nodules.

On the undersides, clusters of holes up to nine inches deep and two inches wide commonly occur. Where not lined with secondary selenite crystals they look, at first sight as if they had been drilled artificially. Comparable holes have not been seen on the upper surface of any of the nodules.

When followed up the dip the gypsum nodules are more extensively corroded. Several of the holes may coalesce and in extreme cases the holes may completely penetrate small nodules (Plate 22).

Origin and Age

Most of the structures described suggest corrosion by water from the base upwards. The smooth surfaces imply freely flowing water whilst the deep, perfectly cylindrical holes can best be explained by vortices of water rising under hydraulic head under the gypsum. Selenite ($CaSO_4 . 2H_2O$) and melanterite ($FeSO_4 \cdot 7H_2O$) in peat overlying the Newark gypsum series suggests that present day ground waters are precipitating sulphates in favourable circumstances. In contrast the absence of reprecipitated sulphates on many of the waterworn gypsum surfaces indicates that in places ground waters are circulating sufficiently freely to prevent precipitation. Some of these corroded surfaces look so fresh that it is possible the solution is still active: others however, are covered with so much unaltered selenite that they cannot now be undergoing attack by ground waters. There is no evidence to suggest that the present flow pattern of groundwater has changed appreciably since the ice-age although the quantity must be considerably smaller. Moreover, this flow pattern is entirely consistent with the gypsum solution structures. The present day circulation of the ground water may thus be a qualitative guide to the origin of these structures.

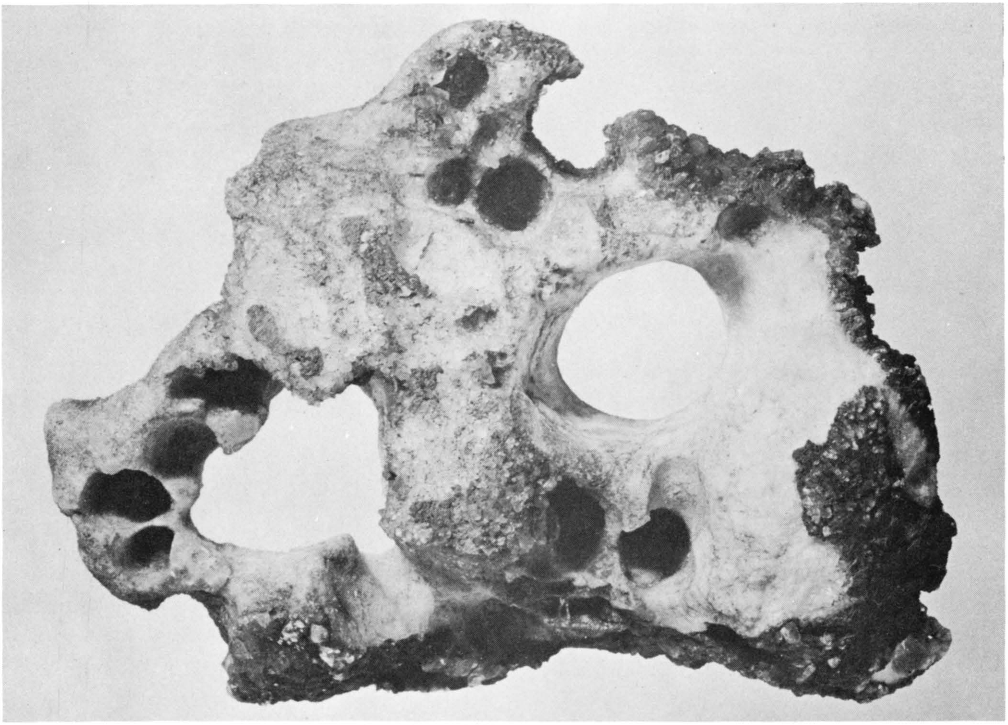
Excavations at Staunton-in-the-Vale in recent years have shown two sorts of ground water flow (Text-fig. 1). Firstly the upper part of the marl between the top-soil and base of the solution zone (as defined by Elliott) is saturated and drains very slowly. Detailed studies of the flow patterns in this zone have not been attempted but it seems likely that the direction of flow is largely controlled by the topography and the gradient of the water table. Secondly there is a well marked flow pattern down dip along favourable horizons and up joints and cracks under subartesian conditions. This flow pattern occurs to some extent within the solution zone and occasionally the solution zone itself extends down dip, but it is best developed in the competent marls below the solution zones. Here the water flows most freely down dip, at the gypsum-marl junction and through the more sandy layers. The sub-artesian nature of the circulation is shown by the way in which water bubbles out through the floor of the quarry.

The flow-rate would have been considerably greater when ice was melting in the Vale of Belvoir and must have fluctuated with changing rainfall. Substantially more cracks may have opened to allow upward flow of water as a result of freeze-thaw action during glaciation than at other times. Furthermore the soft melt waters would be more powerful agents of corrosion than the present hard ground waters. It is suggested, therefore, that the bulk of the corrosion of gypsum was accomplished during and shortly after the ice-age by ground waters with a similar flow pattern to present day ground waters. Some structures suggest more than one cycle of solution of gypsum and its redeposition as selenite and that the process is still continuing.

PLATE 22

Fig. A. Under surface of a water worn gypsum nodule showing several holes due to solution by upward percolating waters. A large cylindrical hole 6 cm. diameter and 9 cm. deep and an irregular shaped hole formed by the coalescing of several small holes penetrate the specimen. Other smaller cylindrical holes penetrate 1 to 7 cm. Over much of the surface selenite has crystallised indicating that in these areas solution was no longer active. Photographer: J. Eyett

Fig. B. Upper surface of the same specimen. Note the smooth water-worn surface where upward moving water flowing through the holes has spilt out on the surface. In contrast to the under surface (Fig. A) less selenite has been deposited. This specimen represents an extreme example of solution and probably represents a small undissolved remnant of a much larger nodule. The outer margin is largely covered with selenite but its shape indicates that it had previously been sculptured by upward percolating water. Photographer: J. Eyett



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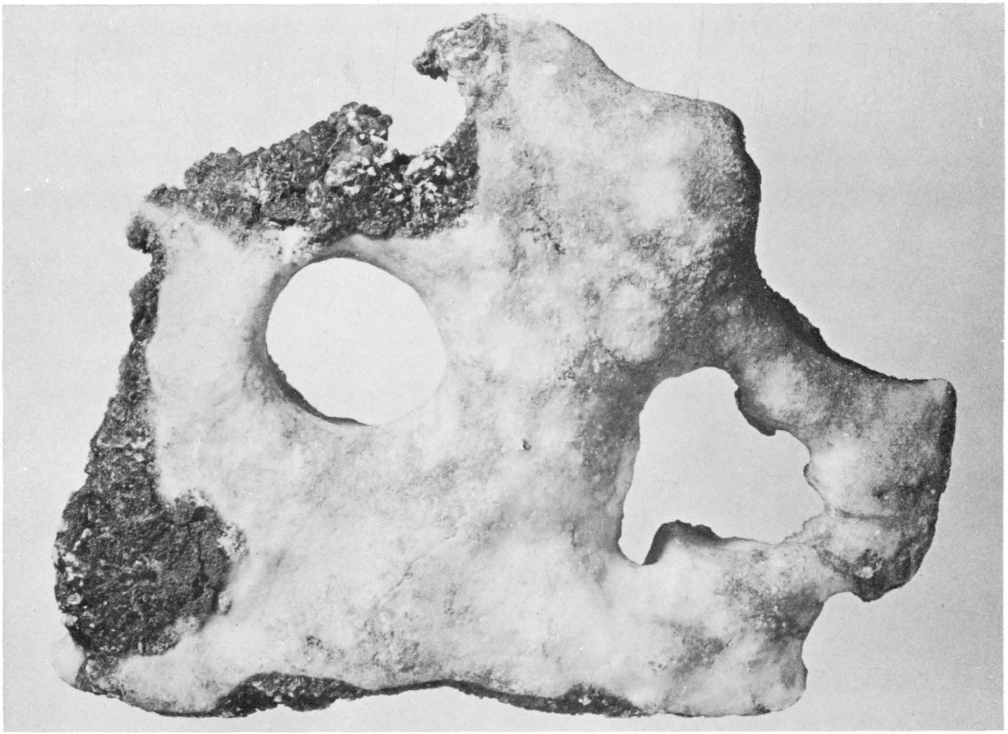
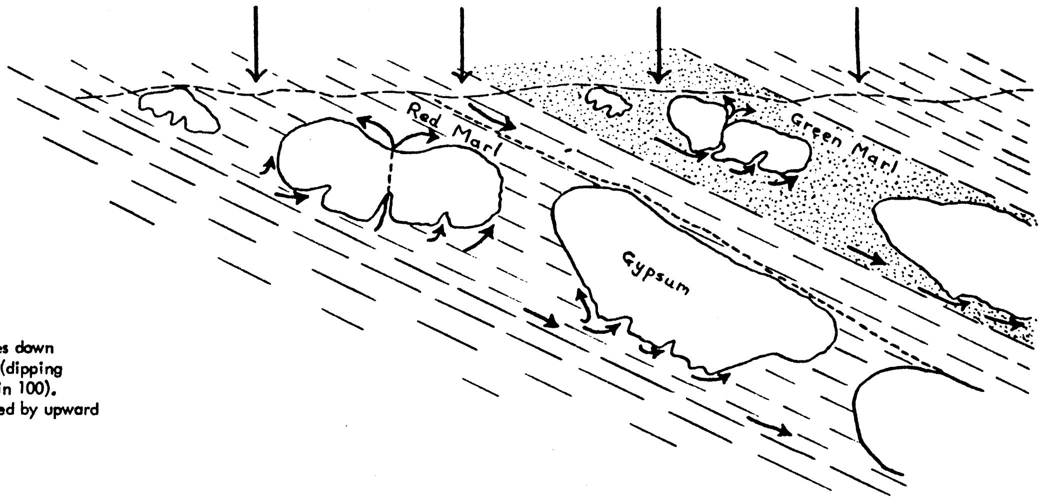


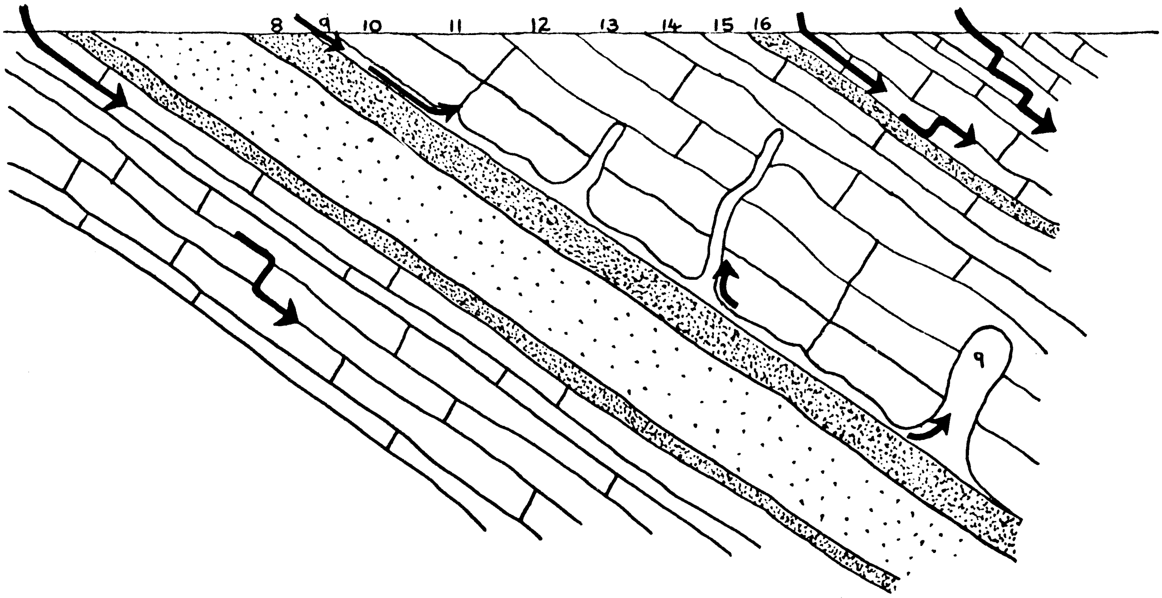
B

SOLUTION ZONE (5–15 feet) (All gypsum dissolved water gravitates downwards)



Water percolates down bedding planes (dipping at 1 in 50 to 1 in 100). Gypsum dissolved by upward flowing water

Text-fig. 1. Diagrammatic representation of the solution of gypsum. Not to scale. (Note the gross exaggeration of the dip)



Text-fig. 2. Diagram to show water circulation and development of solution structures in limestone. Dip exaggerated. Details of lithology given in Text-Figure 3

(B) Carboniferous Limestone (Cumberland)

Solution structures occur in the Carboniferous Limestone in a disused part of Clintz Quarry (NY 158364), northeast of Cockermouth, Cumberland. In this quarry a total of 60 feet of rock is exposed (Text-fig. 3), dipping at about 8° to the west. This part of the local succession contains coal seams with associated sandstones and shales, and it is between two such layers that the structures are developed (Text-fig. 3 and Plate 23).

Description

The structures consist of vertical sheets of clay which are continuous with a clay layer immediately above the second coal seam (bed 8 of Text-fig. 3). This clay layer varies in thickness from nothing to six inches. The vertical sheets are also very variable in size: some are up to three feet wide and reach the overlying shale layer (bed 16), nine feet above the second coal seam (bed 8). A small example is shown in Plate 23. This penetrates two inches along a joint plane into the overlying limestone (bed 10). The undersurface of bed 10 and the limestone walls of the structures have surfaces closely resembling the walls of subterranean caves. Many of these structures are virtually parallel sided, especially those which affect beds 10 to 13, for these beds are composed of a similar type of massive limestone. Most structures pinch-out in bed 14, which contains many shaley seams along stylolitic planes.

The clay which fills these structures has colour banding which shows a contorted and intricate pattern. In some of the wider structures the underlying coal seam (bed 8) is folded up into the structure and occasionally small fragments of coal are found embedded in the brown clay towards the top of the structure.

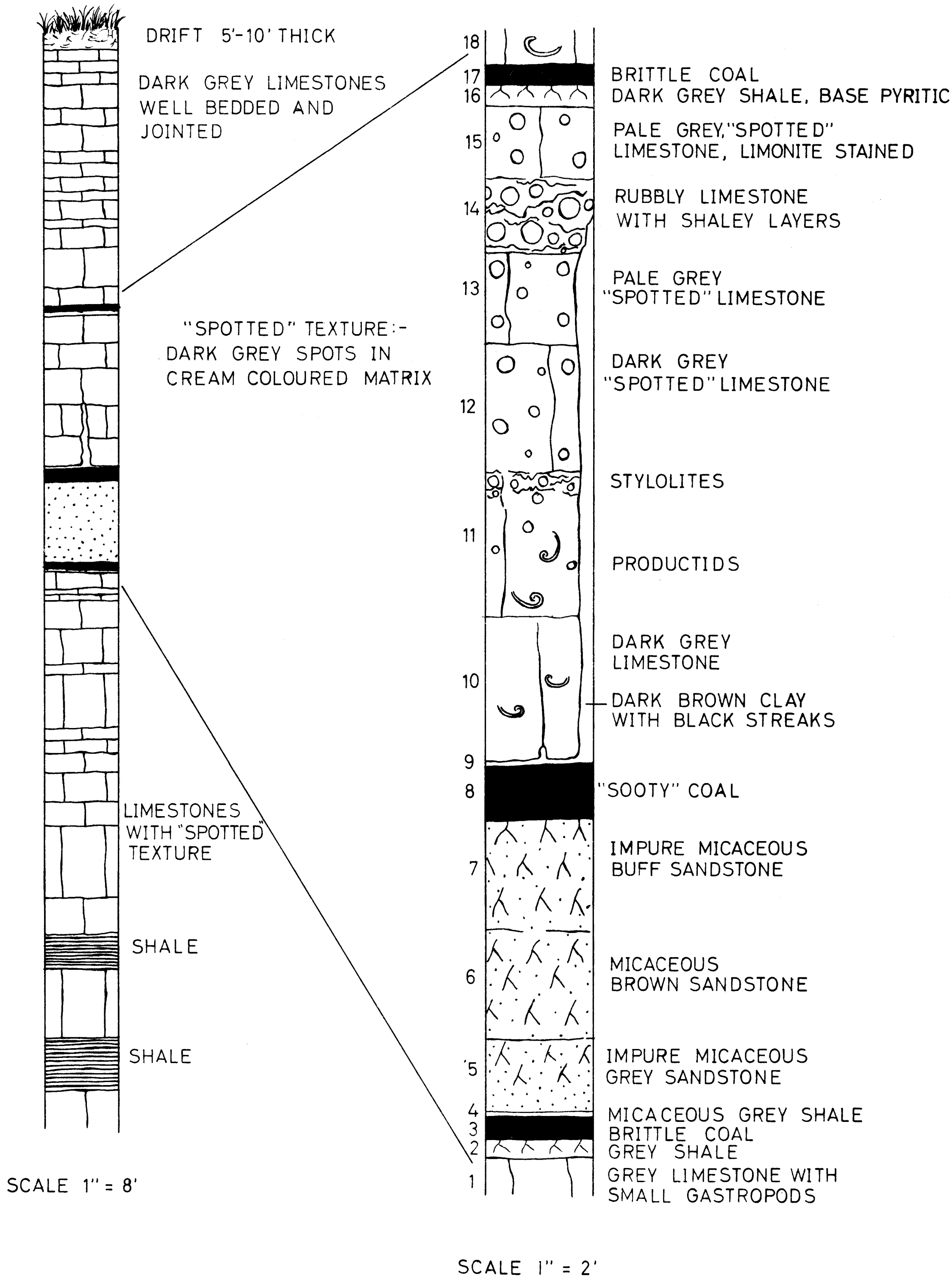
The distribution of these structures within the quarry is of some interest. The largest structures occur in the deepest part of the quarry, which is also the lowest level at which these beds can be examined. There is also a greater frequency of these structures in that part of the quarry.

Origin

The structures occur along joints in the limestone beds 10 to 15 overlying clay layer 9. Hence, the distribution must, in part, be controlled by the pattern of jointing. The limestone walls of the structures and the undersurface of bed 10 have an appearance similar to that of subterranean caves found in limestone. As the limestone on either side of these structures is undisturbed, it seems most probable that these structures are joints enlarged by solution.

The restricted occurrence of these structures may be explained by the distribution of impervious strata in this gently dipping sequence. If all beds at surface outcrop are supplied with water, the limestones will allow fairly unrestricted passage because, although non-porous, the abundance of joints renders them pervious. Thus water percolating through the limestones will collect above any impermeable layer and run down dip. During times of increased rainfall, drainage capacity in a down dip direction is insufficient to carry the extra water, and pressure builds up between the impermeable layer and the overlying limestone. The release of this pressure is accomplished by upward circulation of water along joints, which then gradually become widened by solution. The probable pattern of water circulation during the development of these structures is shown diagrammatically in Text-fig.2.

The brown clay fill of these solution structures is unlikely to have been washed in from the overlying boulder clay, which is grey and contains abundant pebbles. The arching of the coal seam (bed 8) into the base of some of the structures, and the small fragments of coal found high in others, suggest that the clay fill was squeezed up into its present position from a once continuous underlying clay layer (bed 9).



Text-fig. 3. **Carboniferous Limestone Succession from Clintz Quarry, North-east of Cockermouth, Cumberland**

Conclusions

In both examples the geological structure is simple consisting of gently dipping strata in which impermeable and partly soluble beds alternate. Such structures must abound in many areas where limestones or evaporites occur. There is nothing unusual about the circulation of ground water in the areas described. Artesian and sub-artesian ground waters are so common that it is remarkable that structures due to solution by upward flowing meteoric waters have not been more widely reported.

Acknowledgements

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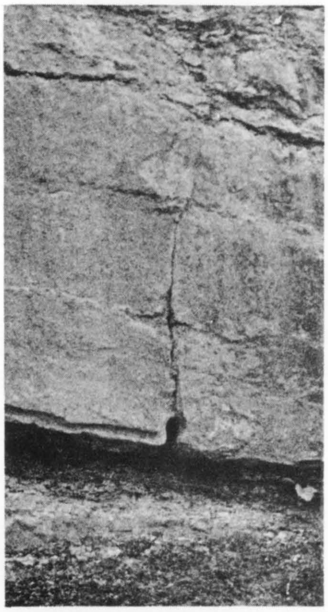
Plate 23.

A



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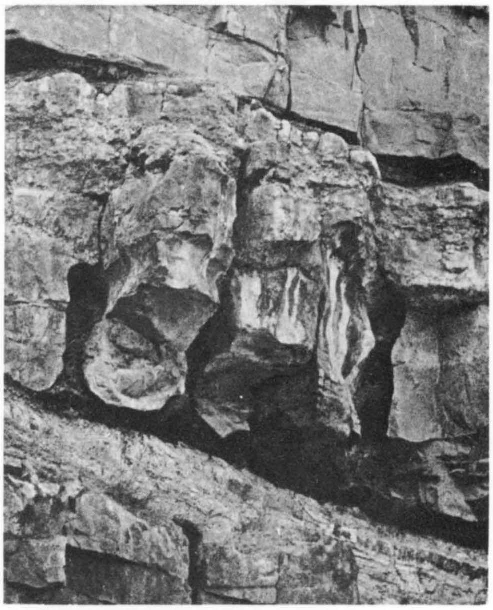

C

A. View of quarry face showing succession with solution structures in limestone (R. J. F. standing on scree slope).

B. Close up of area outlined in A. Small solution structure developed in bed 10 (Text-fig. 3) along a joint plane.

C. Large well developed solution structures filled with clay from Bed 9 (Text-fig. 3) and underlain by coal seam (bed 8, Text-fig. 3).