The micro-petrography of the rock-gypsum of Nottinghamshire.

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ROCK-GYPSUM occurs as extensive deposits of considerable economic importance in the neighbourhood of Nottingham. The mode of occurrence and origin have been studied by several geologists, to whose work references were given in a recent communication to this Society.[1] Investigations have proceeded chiefly on field lines and microscopic examination has been somewhat neglected, except with respect to the contact relations of gypsum and anhydrite. Nevertheless, examination of thin slices from specimens collected in different parts of the district yields information of considerable interest and, it may be, of importance.

The genesis of these deposits is a problem much debated. The interest really centres around two modes of origin, namely, are the deposits segregations from calcium sulphate once widely distributed through the marls; or are they original saline residues? Recent field-work seems to indicate that both these modes of origin are represented in the deposits of the district. And, whilst the question of genesis is not the chief object of this paper, the bearing of the results of microscopic examination on the problem will be considered.

I. *Classification of the Deposits.*

The gypsum deposits of the district have been divided into two stratigraphical groups by the Officers of the Geological Survey.[2] These are as follows:—

'A' occurring in a belt of marl situated 60 feet downwards from the base of the Tea Green Marl.

'B' occurring in a belt of marl at a mean depth of 120 feet below the base of the Tea Green Marl.

[1] W. A. Richardson, The fibrous gypsum of Nottinghamshire. Min. Mag., 1920, vol. 19, p. 77.

[2] Mem. Geol. Surv., Min. Resources Great Britain, 1915, vol. 3, p. 9.

There appears to be no evidence that these two groups occur together in the same locality. The 'A' belt is found between Newark and Cropwell Bishop, and forms the north-eastern section of the deposits: the belt 'B', forming the south-western portion, extends from Gotham over the county boundary to Chellaston in Derbyshire.

This grouping is not merely satisfactory on stratigraphical grounds, but, broadly speaking, it also separates deposits with different field characters and, as will appear in the sequel, with distinct types of micro-structure.

The gypsum masses of belt 'A' possess many features common to concretionary deposits. The gypsum occurs in nodules flattened vertically, locally called 'balls' if large, and 'cakes' if small. The thickness of the 'balls' averages about one foot, but exceptionally it may amount to as much as four feet. Nodules of this size generally contain a core of anhydrite. Continuous beds are also present, but they seem to be an aggregation of closely-spaced 'balls'. The surface of such a bed, cleared of the overburden, has a humpy or coarsely mamillated appearance. These continuous beds are very apt to pass laterally into rows of 'balls' and vice versa.

Some 'balls' and 'cakes', similar to those of the 'A' belt, are usually present among the deposits of belt 'B'. This belt is, however, characterized by the presence of a main seam, which is rarely less than eight feet thick and is peculiarly constituted. It is not quite continuous, but consists of large masses, called 'pillars', which may be up to forty feet in diameter, and are generally some ten feet in thickness. These 'pillars' are separated by thin or thick vertical columns of marl riddled with veins of fibrous gypsum. The purest gypsum is always situated at the top of a 'pillar' and it becomes more and more contaminated with marl downwards, thus passing gradually into pure marl.

II. *The Micro-petrography.*

(a) *Deposits of Belt 'A'.*

Hand-specimens of the rock-gypsum from this belt present a uniform appearance. The rock has a saccharoidal structure; and its crystallization is of medium grain and is evident even to the naked eye. The gypsum is very pure, and usually white in colour, although it may have a delicate rose or blue tint, due in all cases to minute particles of either red or blue marl scattered uniformly throughout the mass. Apart from fibrous veins there are no gypsum crystals distributed in the adjacent marls and the junction between the nodules and the marl is sharp. No transition is to be observed, and no beds of marly gypsum or gypseous marl exist. The purity and isolation of the gypsum masses lend support to the concretionary hypothesis.

The prevailing type of micro-structure may be called *porphyritic*, and its general appearance may be gathered from the example drawn in fig. 1. The larger individuals are on the whole well formed and set in an interstitial matrix containing many euhedral crystals, although the majority are shapeless. The amount of groundmass bears no definite proportion to that of the large crystals, and there is every gradation in size from the largest crystal to the smallest individual of the matrix.

The porphyritic elements generally have lath-shaped sections, which vary in length from a fraction of a millimetre to some three millimetres. Doubtless these are chiefly sections of tabular crystals, though examination of hand-specimens shows that a needle-like habit is also developed. A regular direction of orientation cannot be detected either in hand-specimens or thin sections. The longer crystals, in fact, follow no law of direction, and a similar arrangement is found whether the section is cut from a horizontal or vertical plane in the nodule.

While this porphyritic structure is by far the more general, other types are found towards the centres of large nodules. Instead of the fine-grained groundmass large euhedral crystals may be enclosed by ragged gypsum plates, giving the rock an *ophitic* character. This type nearer the centre may merge into a sort of *granitic* structure. The crystallization is then coarser, and the individuals mutually interfere with each other's growth. These large elements may have a few small well-shaped crystals as inclusions. Finally, exceptionally large nodules —four feet or more in thickness—not infrequently have cores of blue anhydrite. The grain and structure of the rock, therefore, seem to exhibit some dependence on the thickness of the nodule.

No definite order of crystallization seems determinable. Both large and small crystals may be perfectly formed. Moreover, whilst the larger may mould the smaller, the reverse relation also occurs. It is probable that crystallization went on simultaneously, and remained active over a period during which the larger crystals grew at the expense of the smaller.

The only important inclusions in the rock are the particles of marl already mentioned. These are distributed chiefly between the crystals, and are not generally included in them. Only very exceptionally does marl vein the gypsum, and when it does so it appears to occupy a fracture formed later than the nodule.

(*b*) *The Anhydrite.*

The structure of anhydrite in the cores contrasts with that of the gypsum in two respects. Its crystallization is always very coarse, and the crystals are orientated with their long directions parallel. This can be seen in the lower half of fig. 2. The crystals have a stout prismatic habit, but owing to mutual interference during growth give crude rectangular sections. This character combined with the parallelism results in a structure coarsely schistose rather than granitic in

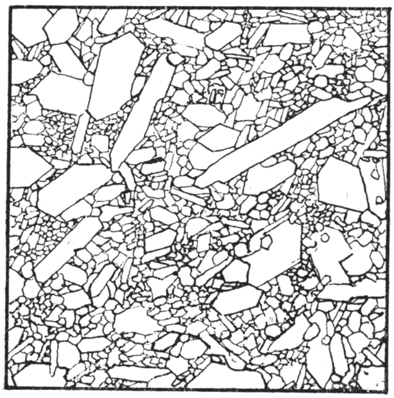

FIG. 1.

FIG. 2.

FIG. 1.—Micro-section from centre of gypsum nodule. Cropwell Bishop, Nottinghamshire. ×36.

FIG. 2.—Anhydrite forming the core of a gypsum 'ball'. Cropwell Bishop. ×17.

type. The orientation also imparts a good cleavage in hand-specimens—a feature never present in gypsum itself.

Upon the original structure of the anhydrite core a variety of secondary structures have been impressed as the result of strain. In the upper half of fig. 2 the crystal layers have been bent. This contortion is accompanied by the development of undulatory extinction, pseudo-twinning, gliding, fracture, and granulation of the crystals, especially at their edges. The granulation does not result in the production of a mosaic of new gypsum or anhydrite, but of an agglomerate of angular fragments of anhydrite, and is the result rather of the detrition of anhydrite than of its re-crystallization. These features are present in all anhydrite cores examined, and seem clearly the result of strains set up by hydration that has taken place at the contact.

The relation of the anhydrite to the gypsum has already been previously described by B. Smith.[1] There are, however, certain new features to which it seems desirable to call attention.

At the edge of the cores of the nodules anhydrite is penetrated by veins of gypsum, somewhat after the manner of altered olivine. In this case, however, the cracks have a crude rectangular arrangement apparently due partly to the rough parallelism of the anhydrite crystals, and partly to their rectangular cleavage. These cracks are generally filled with a fine-grained mosaic of gypsum, which in the neighbourhood of the core may have the characters of the granulite described below. The anhydrite itself is strained, and its contact with the gypsum-mosaic shows an exceedingly fine-grained marginal granulation with strong analogies to 'mortar-structure'. Passing outwards from the contact the normal structure of the gypsum-rock is soon reached and the hydration is evidently very local, as B. Smith concluded.

Anhydrite as it occurs in the main seam of belt 'B' presents differences in structure and distribution. It is by no means centrally placed and may occur at the edges or in fact at any point in a 'pillar'. The hand-specimens are almost white in colour and have a greasy lustre. Closer examination reveals a kind of laminated character, but the laminae are highly contorted. A polished surface shows complex folding and some miniature faulting comparable, for example, to that of the mica-schists and granulites of the Old Lizard Head in Cornwall.

Under the microscope these laminae are seen to consist alternately of anhydrite and gypsum. The anhydrite is in the form of long needles, sometimes with a parallel arrangement and sometimes in sheaves. A few of these needles are converted into gypsum. The folding is on a scale sufficiently small to be visible in the slices, and one arch is seen in fig. 3. In some places, as at *A* (fig. 3), the ordinary prismatic crystals of anhydrite are present, and here and there, especially in the heart of the folds, small patches showing coarse crystallization occur. The needles themselves are not bent even at sharp folds. Owing to their perfect cleavage they break rather than bend, and the curves are formed of a succession of short needles. There are transitions to the ordinary crystal type, and the question arises as to whether this needle-like habit is the original form or due to mechanical disruption of the normal

[1] B. Smith, Quart. Journ. Geol. Soc., 1919, vol. 74, pp. 195–199.

crystals under strain. It is difficult to decide definitely, but I am inclined to think that some process of disruption has taken place here and there.

The gypsum layers have a granulitic structure with uniform grain, but coarser than that found at the contact of the cores described above.

Besides the conversion of certain of these needles into gypsum, there is very little other indication of hydration. Yet hydration seems to be the only competent cause of the intense folding so often present. The volume increase on hydration is rather more than 40 per cent., and it would not require extensive hydration to give expansion sufficient to set up the strain required to produce the effects described.

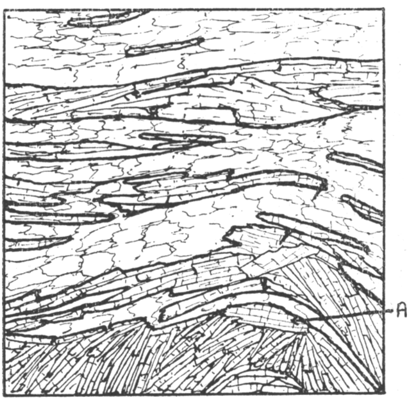

FIG. 3.

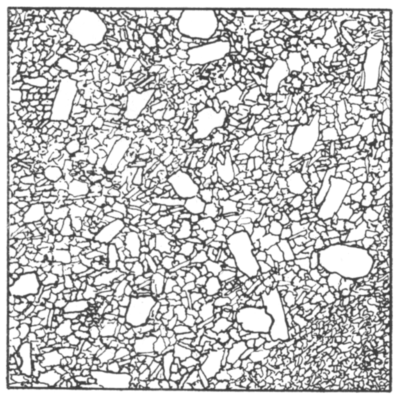

FIG. 4.

FIG. 3.—Laminar anhydrite and gypsum from the main seam. Kingston-on-Soar, Derbyshire. ×86.

FIG. 4.—Alabaster from the main seam. Aston Glebe mine, Chellaston, Derbyshire. ×86.

(c) *Deposits of Belt 'B'.*

The 'balls' and 'cakes' often associated with the main seam have similar micro-structure to those of belt 'A', and need not, therefore, be considered further.

In hand-specimens the gypsum of the main seam is much more compact and evidently closer grained than that of the nodules. The fractured surface may have a waxy or vitreous lustre, or it may be dull and opaque.

In this group also there is porphyritic structure, but it differs in many important respects from that of the 'A' group. The porphyritic elements are smaller, and form equidimensional grains without crystal outlines (fig. 4). The groundmass is an exceedingly fine-grained mosaic of gypsum, and in it the larger crystals are set without any regular mode of arrangement. This type appears to be characteristic of the thinner deposit of the Gotham-Kingston district, and I have found it also towards the outside of the large pillars at Chellaston.

A curious type is drawn in fig. 5. It is not very common. Patches of the slide have suffered severe compression, which is shown by an extreme state of undulatory extinction that can only be described as 'feathery'. Each of these patches seems to have consisted originally of several crystals variously orientated. Occasionally the patches are long,

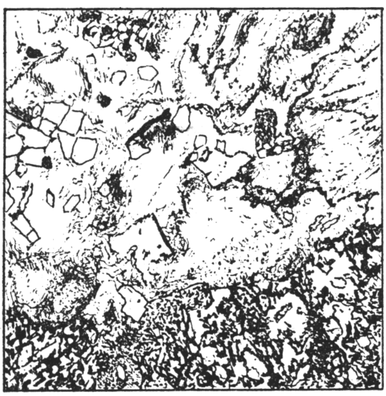

FIG. 5.

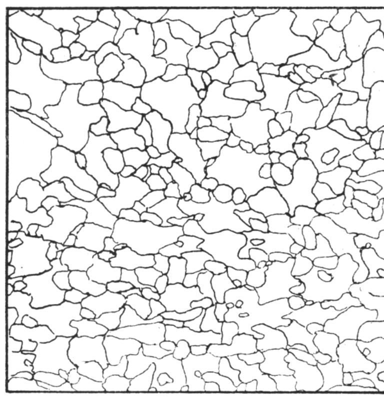

FIG. 6.

FIG. 5.—Alabaster from the main seam. Forman's quarry, Chellaston, Derbyshire. Between crossed nicols. ×17.

FIG. 6.—Alabaster from the main seam. Aston Glebe mine, Chellaston. ×36.

narrow, and roughly parallel to one another, when the structure closely resembles that of a true mylonite. This type may be some intermediate stage between the porphyritic and that described below.

The dominating structure of the Chellaston deposit can only be called *granulitic*. It is by no means confined to the Chellaston gypsum, but it is to be found in all pillars of the main seam. It is even found in some of the larger 'balls' in the neighbourhood of an anhydrite core. The grains vary somewhat in size. The margins are crenulated and interlock in complex fashion (fig. 6). Slight strain shadows are shown between crossed nicols, but no cleavage or twinning.

Inclusions in the main seam gypsum are more varied than in the nodular type. Marl particles are as usual distributed through the mass of the rock, often in sufficient quantity to give it a distinct tint. The marl is also commonly found in both thin and thick veins. These veins of marl have no parallel arrangement, nor are they horizontal in the field, but surround oval-shaped patches of gypsum, thus originating a reticulate pattern on the face of a large block, similar to the veins in brecciated marble. These veins increase in number and thickness downwards, and the base of the seam can often be described as a gypseous marl.

Minute rhombs of dolomite are to be found distributed through the seam, though I have not detected them in the gypsum of the 'cakes' and 'balls'. At Chellaston there are found ellipsoidal masses so crowded with rhombs that the slides consist almost entirely of them. The dolomite rhombs of these segregations are set in a matrix of gypsum similar to that of the neighbouring rock. These patches of dolomite occur either in the gypsum or isolated in the marl. They appear to be clearly concretionary, and are evidence that local segregation has gone on even in this bed. A qualitative analysis of this dolomitic rock showed the presence of much lime, carbonate, and sulphate, a fair quantity of magnesia, and some silica and alumina.

A mineral with high refractive index and low double refraction occurs rarely in some slides either in the form of small rounded grains or as very minute prisms. The larger of these grains resemble celestine, but there is no previous record of its occurrence.

III. *Conclusions.*

It now remains to inquire what support microscopic study lends to the current theories relating to the origin of these deposits. All workers either agree that the nodular forms are concretionary, or at least admit that segregation has played an important part in their formation. The main seam of belt 'B' has recently been studied by B. Smith (loc. cit., p. 201), who concludes that it was deposited in stratiform manner, and, beyond a little local brecciation, has undergone no change since its deposition.

Before passing to apply the evidence here obtained, it may be pointed out that something can be gathered as to the probable structure of an original precipitate of gypsum. Two specimens of such material were examined—one from Moravia and the other from California. These deposits, judging from the description, appear to possess all the characters of sedimentary rocks, and the hand-specimens have well-marked bedding lines. Microscopically both rocks are porphyritic, of medium grain, and the larger crystals tend to lie on their flat sides. Sections cut parallel to the lamination, therefore, present a rather different appearance from those cut at right angles to it. In the former equidimensional sections predominate, and in the latter lath-shaped sections. Well-formed crystals are rare, and the majority have irregular or ragged outlines. Somewhat similar features appear to characterize the rock-gypsum of the Paris basin, as for example in the thin section figured by Lacroix,[1] although the porphyritic elements are larger.

Turning now to the nodular types it is evident that the above-mentioned characters are not present. Their chief feature is the number of euhedral crystals. Moreover, attention has already been drawn to the curious dependence of the structure on the size of the nodule. This change in grain and structure undoubtedly belongs to the period of formation. A certain amount of re-crystallization in fibrous veins under the influence of pressure has been previously noted, but this also must have taken place before the withdrawal of solutions. Pressure alone acting on a *dry* rock would produce not re-crystallization, but brecciation and comminution. The hypothesis of a concretionary process acting over a sufficient period offers a fair explanation of structural changes and also of the occurrence of anhydrite. If contact with the solution were sufficiently prolonged, larger crystal grains would, according to the general rule, grow at the expense of the smaller, and a porphyritic structure with well-formed elements would result. The process would remain active longer at the centres of the larger nodules than elsewhere, allowing the development of a coarser crystallization and even of a granitic structure. These transformations would doubtless be facilitated by the action of a moderate pressure, which would always act in the direction of reducing the volume of the deposit and increasing its compactness. Moreover, it is reasonable to assume that some pressure would be called into play during concretionary growth, and that it would be greatest at the centres of the largest nodules. Where growth then has been carried to a certain stage against resistance, the tendency to reduce the volume of the deposit will become greater, and a conversion of gypsum into anhydrite may well take place. The coarse schistose structure of the anhydrite cores affords further evidence favourable to

[1] A. Lacroix, Nouv. Archiv. Mus. d'Hist. Nat. Paris, 1897, ser. 3, vol. 9, p. 227. Plate X, fig. 1 (cf. also fig. 5).

a process of this sort. Although little is known as to the influence of pressure on the formation of anhydrite, the conditions of its stability under the state of pressure, temperature, and concentration, pertaining at a certain stage of concretionary growth in a buried deposit, must be different to what they are in open water.

The characters of the main seam of belt 'B' are quite different and point to a different genesis. The comparative impurity of the rock, its downward transition into marl, and, as B. Smith noted, the presence of dolomite all favour original precipitation. The original structure was probably porphyritic, with anhedral elements and a lack of parallelism of its constituents. No stress need, I think, be laid on this last characteristic, and in other respects the structure strongly suggests original precipitation. The anhydrite, too, possesses a different habit to the nodular occurrence, and is distributed in a manner not antagonistic to original precipitation.

The structure that has been called 'granulitic' must certainly be attributed to the effects of pressure acting, doubtless, in the presence of water. The pressure might be due to external causes, i.e. to earth-movements or the dead weight of overlying deposits. There is, however, little indication that the Midland Trias has been appreciably subjected to movement stresses. On the other hand, vertical loading would affect all deposits equally, or, indeed, the small masses might be expected to suffer most and the larger to be more resistant.

Possible internal sources of pressure are also two in number, namely concretionary growth and hydration of anhydrite. Now, whilst the pillar-like form of the deposit and the dolomite segregations doubtless indicate local rearrangement at some stage, B. Smith has shown conclusively that extensive segregation of material brought from a distance has not taken place. Yet it is only to the latter process accompanied by *intrusive* growth that one may look for a competent cause of pressure.

The only probable source of pressure that remains is hydration of the anhydrite, and there are many facts that favour this view. The granulitic structure is present at all anhydrite contacts; the anhydrite layers of the Gotham-Kingston deposits are highly contorted; and at Chellaston, where the granulitic structure is dominant, there is no anhydrite present. The last suggests that complete hydration has taken place and left marked effects on the rock-structure. In most cases, it is true, the evidence does not point to extensive hydration. Still the resulting expansion is sufficiently great to give rise to considerable strain, even though only a small body of anhydrite be involved.

Conformable disturbance of the bedding over gypsum masses is occasionally observed. It is often seen over the large pillars of the main seam at Woodlands quarry, Chellaston (fig. 8), but I have found little trace of it in the main seam to the east where the bedding above the pillars seems generally horizontal. In the Kingston district, however, the deposits are not so favourable for observation of this character. Lines of nodules are involved and the date of disturbance is accordingly later than their formation. On reference to fig. 8 it will be seen that horizontally the disturbance corresponds to the flat top of the pillar, and vertically it is only shallow and by no mean comparable to the great thickness of the pillar.

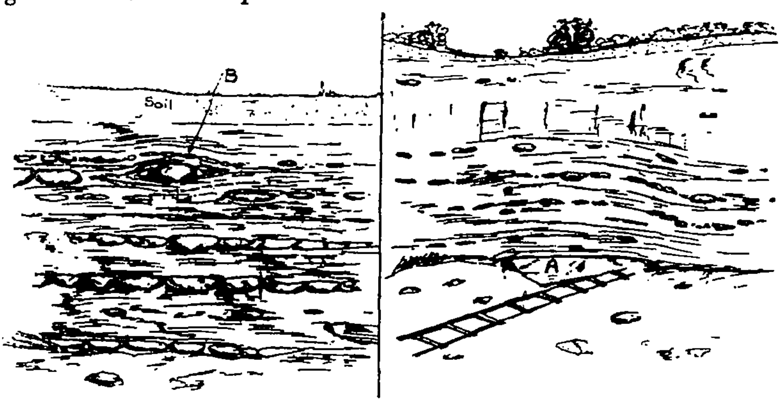

FIG. 7. FIG. 8.

FIG. 7.—Conformable displacement of bedding over a large nodule of rock-gypsum (B). Hawton, near Newark.

FIG. 8.—Conformable displacement of bedding and nodular lines over large alabaster pillar (A : 15 feet diameter). Woodlands quarry, Chellaston, Derbyshire.

Similar conformable disturbance is to be seen over some very large nodules in the beds of belt 'A' (fig. 7). The significant points of occurrence are: (1) the phenomenon is comparatively rare and is not found over every large mass. (2) Adjacent beds of gypsum and nodular lines are involved. (3) The balls are of the size that often include anhydrite cores.

This phenomenon cannot be regarded as evidence of concretionary displacement either at Chellaston, for, as B. Smith insisted, the disturbance is too insignificant; or in belt 'A', for it is not only rare but involves adjacent masses presumably of the same date of formation. Differential compression might conceivably have operated at

Chellaston, but its rarity in belt 'A' does not favour external pressure as a cause. On the other hand, the vertical movement seen is of an order consistent with uplift due to hydration of a moderate mass of anhydrite; and the phenomenon is distributed favourably to the view that hydration is its cause. Thus it is present in the main seam where anhydrite is absent and the granulite structure dominant; whilst in group 'A' it occurs only in the neighbourhood of those nodules that may have contained anhydrite—the cases are, however, too few to establish an inverse relation.

Summary.

1. Microscopic examination of rock-gypsum reveals a wide range of structure, and many metamorphic types are represented. In the nodular masses there seems to be a dependence of grain and structure on the size of the mass.

2. Anhydrite appears as cores only in very large nodules, and would appear to originate under physical conditions established when concretionary growth reached a certain stage. In the main seam anhydrite is distributed without regard to the size and form of the bed, and in lamellae alternating with gypsum.

3. Microscopic evidence supports the view that the main seam chiefly originated by sedimentary deposition, possibly modified by some segregation during deposition; and that the nodular types are concretionary in origin.

4. The metamorphic characters are secondary effects of pressure originating in the partial or complete hydration of the anhydrite.