AN OCCURRENCE OF AUTHIGENIC GYPSUM IN PLEISTOCENE TILL AT BOULTON MOOR NEAR DERBY

by

Peter F. Jones

Summary

Authigenic gypsum occurring in Pleistocene till underlying the terrace sands and gravels of Boulton Moor, near Derby, is described and its mode of origin discussed. The gypsum is of fairly localised distribution and is believed to have formed as a result of ground water activity in post-glacial times. Solution of the bedded gypsum in the nearby Keuper Marl probably gave rise to the calcium sulphate content of the waters, and evaporation within the vadose zone caused a concentration sufficient for gypsum precipitation.

Introduction

During a study of the Pleistocene deposits in the Middle Trent Basin, temporary exposures, made available by excavations for a new sewage pipeline, were examined in detail. This pipeline provided an 8 km continuous section from Spondon to Chellaston, giving an almost complete NE-SW transect across the Lower Derwent Valley in an area of extensive superficial cover.

The sewer extended from Spondon sewage works (SK 390350) across the Derwent flood plain to Alvaston (SK 394334) and then via the terrace deposits of Boulton Moor to the Keuper Marl ridge at Shelton Lock (SK 375313). From here it skirted the lacustrine deposits of Sinfin Moor, before terminating at Chellaston (SK 374400). The route is shown in text-fig. 1.

On Boulton Moor (SK 384318), a 6 metre deep trench cut through the sands and gravels assigned to the Beeston Terrace (Clayton, 1953) and passed into glacial till below. The presence of this till beneath the terrace deposits on Boulton Moor was previously unrecorded. However, it is the unusual occurrence of authigenic gypsum in the till that is the subject of the present paper.

Location

Boulton Moor comprises approximately two square kilometres of flat pasture land situated 5 km south east of Derby and just north of Chellaston. Formerly more extensive, it has been gradually encroached upon in recent years by new housing developments, mainly from the Alvaston side.

The area forms part of a much broader terrace feature extending on the south side of the Lower Derwent Valley from Derby, through Alvaston and Elvaston, to the confluence with the River Trent near Aston. With an average height of about 42 m (140 ft) it lies approximately 5·4 m (18 ft) above the present Derwent flood plain from which it is separated by a marked break in slope, (text-fig. 3).

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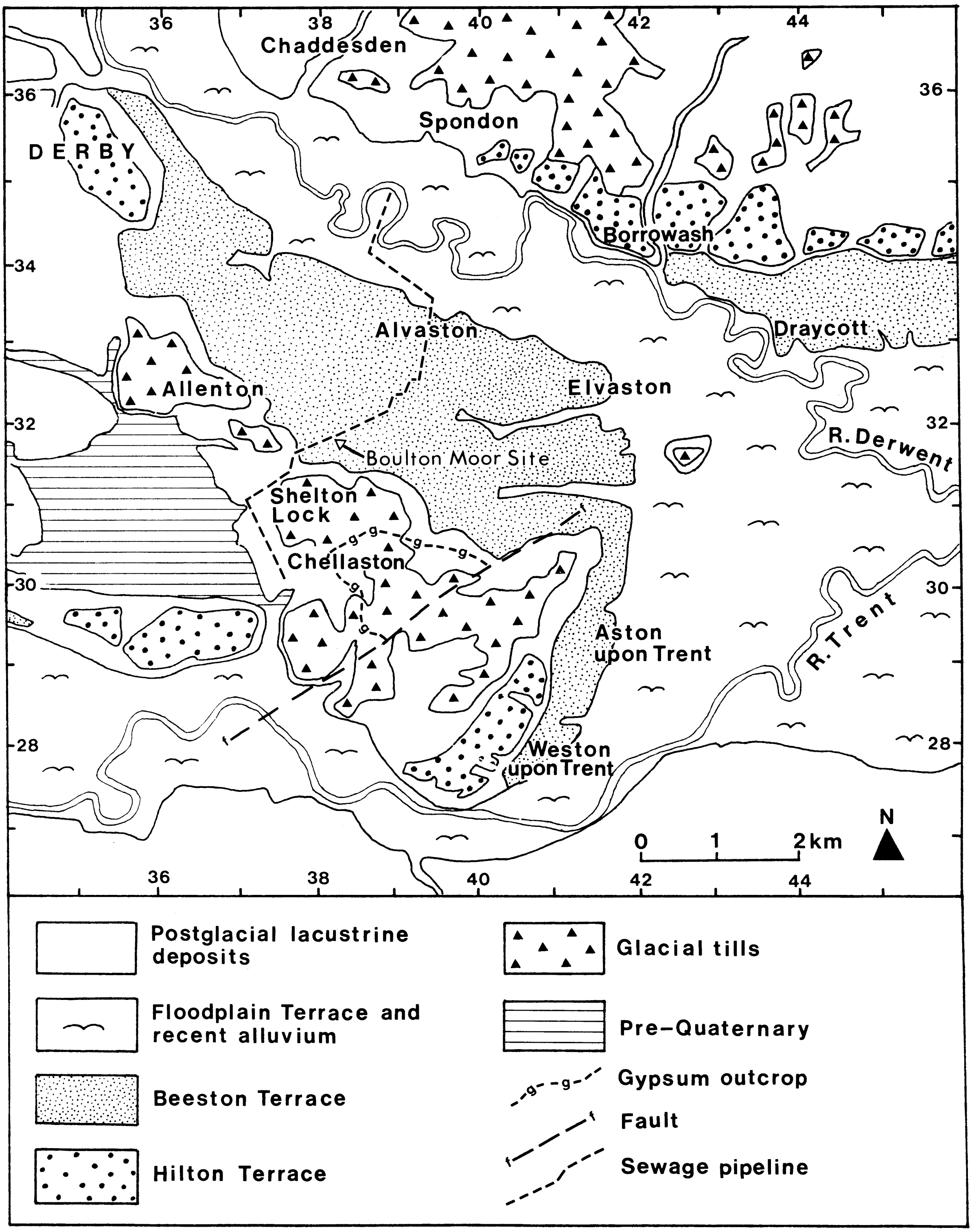


Text-fig. 1. Distribution of the superficial deposits in the area south-east of Derby, and the location of the Boulton Moor site.

The terrace is shown on the One-inch Geological Survey Map (Sheet 141) as terminating to the south west against higher ground composed of Keuper Marl with a capping of 'boulder clay'. It was described in some detail by Bemrose and Deeley (1896), following the finding by them of mammalian remains at a depth of 2·7 m in the gravels at Allenton, only 1 km west of Boulton Moor. Here they recorded *Elephas*, *Hippopotamus* and *Rhinoceros*, which prompted Posnansky (1960) to suggest a dating to the last (Ipswichian) interglacial. This view was supported by Shotton (1973)

Nature of the till

The locality at which the gypsiferous till was found is situated towards the centre of Boulton Moor, almost midway between Alvaston and Shelton Lock (text-fig.1). The till was encountered at a depth of 4 metres, beneath a variable sequence of sands and gravels (text-fig.2). It consisted of a stiff, compact, silty clay with an extremely varied suite of erratics. These could be divided into two general groups on the basis of their provenance: Carboniferous Limestone, Coal Measure, Millstone Grit and Triassic sandstones, black shale, chert, coal, and rounded quartzite pebbles (? Bunter) were indicative of northern derivation, while chalk, flint, oolitic limestone, pyritised ammonite fragments and *Gryphaea* indicated an eastern derivation. A number of erratics were completely exotic and these included pyroclastic and other igneous rocks similar to those found within the Borrowdale Volcanic sequence of the Lake District. Many of the Carboniferous Limestone, chalk and coal erratics were well striated.

It was not possible to establish the exact thickness of the till. The deposit was not bottomed here, although at least 2 metres were exposed in the trench. Unfortunately borehole records held by the Institute of Geological Sciences are for the area north of Boulton Moor and do not show the presence of glacial till. However, the reddish brown colour of the till matrix, together with included fragments of Keuper Marl, suggested that the Keuper surface may not have been far below.

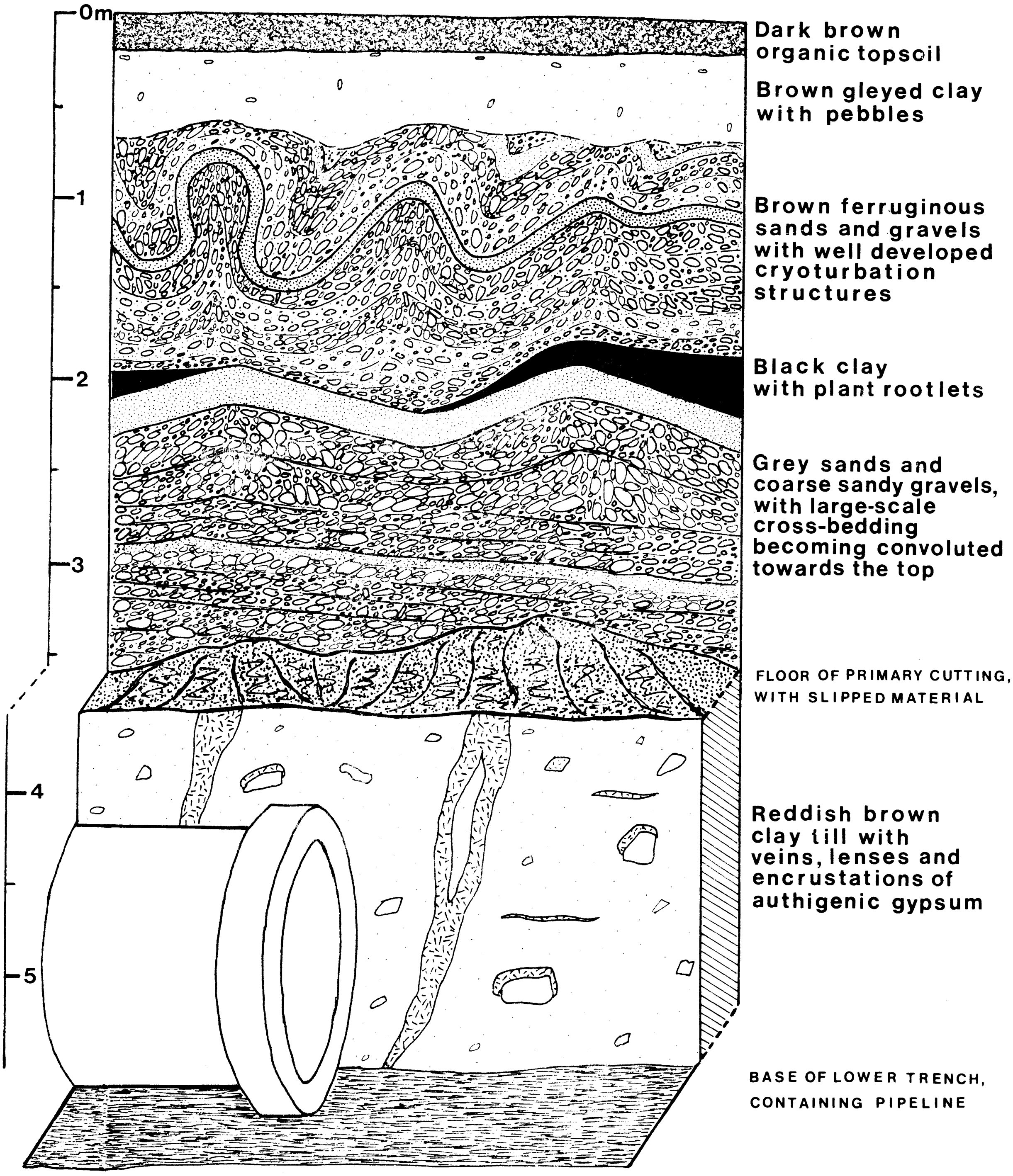
Lithologically, the deposit resembled the till overlying the Keuper Marl at Chellaston quarry, which was attributed to the Eastern (Chalky Boulder Clay) Glaciation by Posnansky (1960). This glaciation is now regarded as being of Wolstonian age (Shotton, 1973).

Nature and distribution of the gypsum

The gypsum was found to have three distinct modes of occurrence (text-fig.2), as follows:

1. as thin (< 5 mm), discontinuous, sub-horizontal veins and lenses;
2. as thicker (up to 150 mm), steeply inclined veins, commonly bifurcating; and
3. as encrustations around chalk and other erratics.

The gypsum comprising the thin sub-horizontal veins and encrusting some of the smaller erratics was finely crystalline (< 2 mm), anhedral, and of a crumbly nature. The thicker encrustations and vertical veins, however, comprised medium to coarsely crystalline gypsum with some large (20 mm) subhedral to euhedral crystals (Plate 7, fig. 4; Plate 8; cover of this issue). In general, these crystals had a lamellar habit and were frequently aggregated into an efflorescent arrangement, closely resembling the 'desert rose' structure sometimes displayed by barite. Many of the crystals were permeated by sand grains, a feature also characteristic of barite rosettes (Deer, Howie & Zussman, 1958, p. 190). In addition, the large vertical veins frequently enclosed striated erratics. This not only clearly demonstrates the authigenic nature of the gypsum but also indicates that it must have formed either as a result of replacement, or by forceful displacement, of the till matrix.



Text-fig. 2. Vertical section through the Pleistocene deposits at the Boulton Moor site. The depth requirement for the sewage pipeline necessitated the trench being excavated in two stages with the lower 'pipe-trench' being cut in the floor of a wide primary cutting. The contact between the till and overlying gravels was masked by slipped material from above.

The areal distribution of the gypsum in the till sheet as a whole was difficult to assess owing to a lack of suitable exposures elsewhere. However, there is some evidence to suggest that it is not ubiquitous and probably has a fairly localised distribution. No similar occurrences have been reported previously in any of the tills of the immediate area, nor has any been found by the author. Gypsum was not noted in till underlying the terrace gravels at London Road, Alvaston, (SK 394325) during an earlier excavation in Autumn 1971, nor was it encountered during the earlier stages of the Boulton Moor contract work. This, together with the fact that gypsum was found to be absent further west as the trench progressed towards the Keuper Marl ridge at Shelton Lock, suggests an overall NE-SW linear development of approximately 150 metres. It would, of course, be extremely useful to know the extent of the gypsum to the north, and especially towards Chellaston in the south, but this may only be revealed by future excavations.

Methods of gypsum formation

($CaSO_4.2H_2O$) gypsum, is a relatively common mineral. It is the most abundant sulphate and is known to occur in nature in a wide variety of ways. In the case of certain evaporite sequences it frequently forms extensive masses of considerable thickness but, at the other extreme, it may exist as single isolated crystals, or clusters of crystals, enclosed in a host sedimentary rock. A useful description of the various occurrences of gypsum is given by Groves (1958).

As early as 1885, Sir Archibald Geikie recognised at least five different ways in which gypsum may be formed:

1. as a chemical precipitate from solution in water, as when sea water is evaporated;
2. through the decomposition of sulphides and the action of the resultant sulphuric acid upon limestone;
3. through the mutual decomposition of calcium carbonate and sulphates of iron, copper, magnesium etc;
4. through the hydration of anhydrite; and
5. through the action of sulphurous vapours and solutions from volcanic orifices upon limestone and calcareous rocks.

Much has been written since on the subject and the tremendous diversity of gypsum, both in form and origin, has been firmly established. Many rare, and sometimes unusual, examples have been reported in the literature. However, the author has been unable to trace any reported occurrences of gypsum in British tills that would be analagous to the example described in this paper.

Origin of the Boulton Moor gypsum

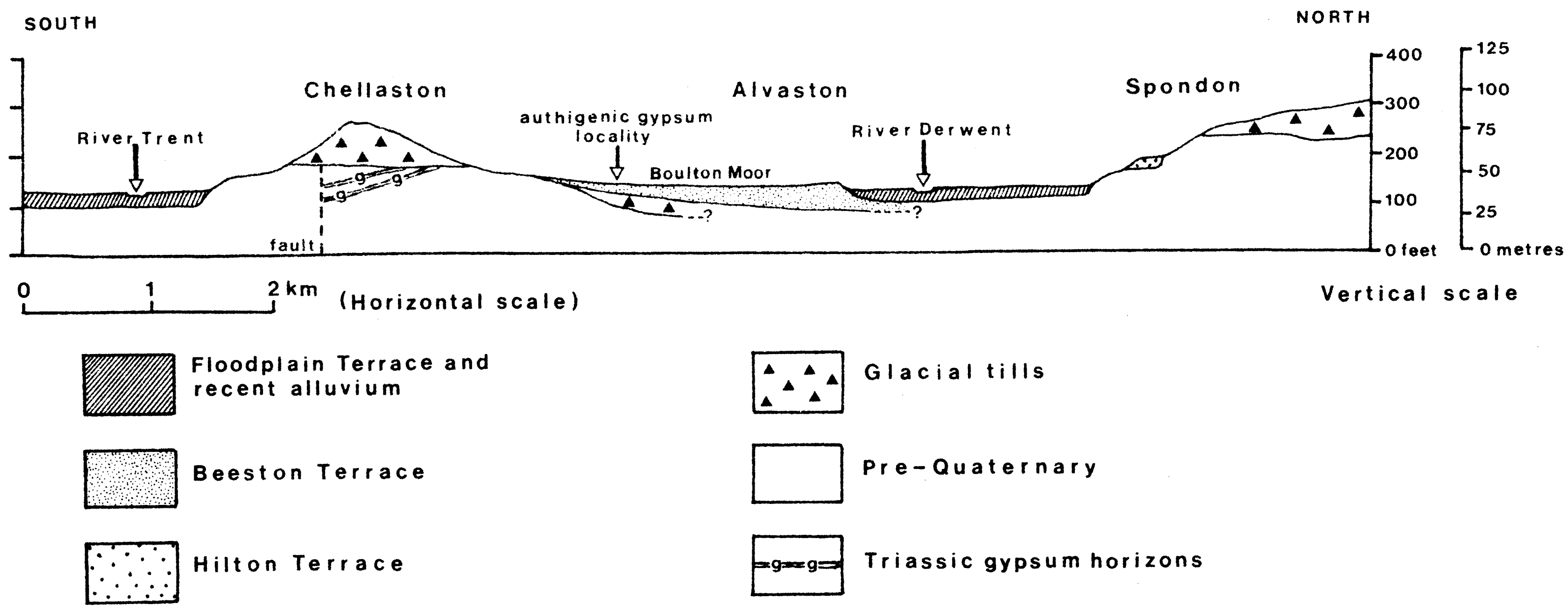
The Boulton Moor gypsum is clearly authigenic, as indicated by

1. the poikilitic crystals, with included sand grains;
2. the presence of veins with enclosed erratic clasts; and
3. the occurrence of gypsum as shells around certain clasts, including some with well developed glacial striations (Plate 7, fig. 1).

Two distinct modes of origin seem possible:

(A) precipitation by the chemical action of sulphuric acid on lime-bearing minerals or rocks; and

(B) precipitation from concentrated brine solutions.



Text-fig. 3. North-South section across the Lower Derwent Valley from Spondon to Chellaston. Length of section = 11 km. Vertical scale applies to the topographical profile only; thicknesses of the superficial deposits have been exaggerated for clarity.

(A) Reaction between sulphuric acid and calcium carbonate

Although the first process has been known for at least a century (e.g. Geikie 1885), and Smith (1919) regarded the "isolated occurrences" of gypsum so formed to be "a minor point well understood", there have been relatively few documented examples in this country. The euhedral, and often large, crystals found scattered throughout many of the English clays, such as the Oxford and Kimmeridge Clays of the Jurassic and the Tertiary London Clay, are usually attributed to this process. They are believed to be produced by the oxidation of sulphides, such as iron pyrites, resulting in the formation of sulphuric acid which attacks the calcareous shells and nodules to form gypsum. Sherlock *et al* (1960, p. 33), explained the absence of London Clay fossils (formerely calcareous) in many localities as being a direct result of this process, while Sarjeant (1962) reported that once-pyritous ammonites and other fossils of the Oxford Clay are frequently covered in an "armour" of gypsum crystals. Sarjeant also drew attention to flattened rosettes of selenite occurring between partings in the Edale Shales above Odin Mine, Castleton, as having formed in this manner, and speculated that similar developments of gypsum are to be expected in other shale horizons in Derbyshire. He regarded the process as one which may occur at any stage during diagenesis, but is probably most frequent when the sediment enters the zone of weathering and circulation of ground water.

There is some evidence to suggest that the process outlined above could be responsible for the Boulton Moor gypsum:

(a) iron pyrites does occur in the till as small nodules, crystalline aggregates and as the replacement material in derived fossils, e.g. ammonites (Plate 7, fig. 2);

(b) there is an abundance of calcium carbonate in the till, with chalk and limestone erratics being particularly numerous; and

(c) some of the gypsum is found encrusting chalk erratic nuclei (Plate 7, figs 1 & 3).

However, the total pyrite content is extremely small, and that which does occur is remarkably fresh. In addition, the chalk erratics that possess a gypsum "skin" show well developed original surface textures, such as striations, when the skin has been removed. This suggests that very little, if any, of their calcium carbonate has been utilised in the formation of the gypsum. It seems unlikely, therefore, that a reaction between sulphuric acid and calcium carbonate is responsible for the Boulton Moor gypsum.

(B) Precipitation from saline solutions

A more likely possibility involves precipitation of calcium sulphate from saline solutions. These might be of two types:

(i) connate: sulphate-rich waters included within the till at the time of deposition with the gypsum forming during the process of compaction.

(ii) meteoric: percolating ground waters enriched in calcium sulphate, moving upwards or downwards through the till.

The first hypothesis is unlikely since gypsum formed by this process would be much more widespread, and probably disseminated as isolated crystals throughout the till, instead of being concentrated into localised veins and lenses. The nature of the occurrence of the gypsum in the till suggests that percolating solutions played a dominant role in its formation. The vertical fissure deposits and gypsum encrusted clasts are consistent with a mechanism of precipitation in passageways by moving ground water. Although clay tills are largely impermeable, a limited movement of water is possible, particularly in near surface horizons, by way of soil structures and clast-matrix boundaries. The well developed "clay skins" present on structure faces and around clast surfaces testify to this process.

The concentration necessary for precipitation could be attained by evaporation. This takes place at the air-water interface which, in the case of most evaporite gypsum deposits, is generally the surface of a standing body of water such as a lake. However, as Blatt, Middleton and Murray (1972) point out, the air-water interface may also occur within the vadose zone (between the water-table and ground surface), where the pore space in the rock is partially saturated with brine and partially saturated with air. The fundamental requirement is that the evaporation rate should be sufficient to counteract the inflow of fresh water, or loss of brine from the system before it has had the opportunity to be concentrated to the point of calcium sulphate precipitation. Although a hot climate would normally be desirable for this process, it is by no means essential, and suitable conditions may equally well occur in arctic and antarctic regions at the present day. Reports of gypsum forming surface crusts on soil (Høeg, 1939) and snow (Corbel *et al.*, 1970) in Spitsbergen, and also occurring within morainic deposits in Antarctica (Gibson, 1962; Stephenson, 1966; Skidmore and Clarkson, 1972) are notable in this connection.

In extreme cases, rapid evaporation might give rise to a highly concentrated, supersaturated brine. Although some gypsum would be precipitated in the vadose zone, the brine, being denser than the ground water below, would tend to sink through the underlying sediment beneath the ground water-table. In such a situation gypsum would continue to precipitate as long as the brine remained supersaturated with respect to calcium sulphate. It is thus possible for some crystals to grow well below a saline ground water-table.

Source of the calcium sulphate solutions

The calcium sulphate solutions probably result from the action of ground water on soluble calcium and sulphate ions, the source of which could be either "primary" gypsum in the Keuper Marl or gypsum erratics in the till itself.

Gypsum is well known to be somewhat soluble in water (1 part dissolving in 415 parts of water at 0°C; Stone, 1920. p.17), with its solubility being increased considerably by the presence of sodium or magnesium chlorides (Groves, 1958, p.3). Greensmith *et al* (1971, p.47) estimated that as much as 20 tons of calcium sulphate are removed in solution from one square mile of the earth's surface every year. Visible evidence of the solubility of gypsum may be found in the various solution caves in certain areas of the world. D.R.McGregor *et al* (1961), for example, described 13 such caves in north-central Texas.

Several authors have shown that the solubility of calcium sulphate varies with temperature (Posnjak, 1940; MacDonald, 1953; Degens, 1965), and some have suggested that even small temperature changes may have an important effect on the equilibrium of saturated solutions (Hullet & Allen, 1902; Prider, 1940). These factors could be significant; as it is likely that temperature will have fluctuated considerably since the deposition of the till, favourable conditions for gypsum solution and precipitation may have been attained on a number of occasions. The solubility of gypsum is known also to vary with pressure, but as there is no reason to assume that pressure has varied sufficiently to be significant in the case of the Boulton Moor gypsum, this need not be considered further.

A problem arises with the direction and mechanism of groundwater movement. In a normal situation, solution by downward percolating waters might be expected. However, Firman (1968) drew attention to occurrences of gypsum in the Newark area that had been dissolved by upward flowing water and suggested that such artesian and subartesian waters are agents of corrosion more often than is generally recognised. The occurrence of selenite and melanterite ($FeSO_4.7H_2O$) in peat overlying the Newark gypsum series also indicated to Firman that such waters may at times precipitate sulphates in favourable circumstances.

There is no direct evidence to suggest which pattern of ground water flow has been dominant since the deposition of the Boulton Moor till, and it is possible, in fact, that both types may have been active at different times, depending upon the prevailing climatic conditions.

Taking this into consideration, and discounting connate sulphate solutions, three possible original sources for the calcium sulphate may be suggested. These are:

1. gypsum erratics in the till;
2. disseminated or bedded gypsum in the Keuper Marl underlying Boulton Moor; and
3. disseminated or bedded gypsum in the Keuper Marl forming the higher ground to the south.

Erratics of gypsum were not noted in the Boulton Moor till and although this may be indicative of their complete solution it is doubtful whether many would be present in the first place. The currently accepted ice movements into the Middle Trent Basin were from the north and east north-east (Posnansky, 1960) and there is little gypsum outcropping at the surface in these directions.

It seems unlikely that the Keuper Marl underlying the Pleistocene deposits on Boulton Moor contributed much to the sulphate content of the waters. Any disseminated gypsum which, according to Firman (1968), is a normal occurrence in the Keuper Marl at depth, would presumably have been removed by percolating solutions before the deposition of the till. This follows the findings of Elliott (1961), who recorded a "solution zone" of this sort in south Nottinghamshire extending westward from the Rhaetic escarpment. The presence of bedded gypsum is also doubtful; the main gypsum horizons occur at higher levels in the Keuper sequence (Haines & Horton, 1969. p.71) and, even though Champion (1969) required at least one bed of gypsum to explain the nearby Sinfin Moor depression as a solution hollow, none are shown in borehole records for the area held by the Institute of Geological Sciences (personal communication, 1973).

The most likely source of the calcium sulphate is the bedded gypsum of the Keuper Marl which forms the higher ground to the south. At Chellaston (SK 386302) quarrying has revealed at least ten bands of gypsum which dip very gently to the south south-east. These are shown on the One-inch Geological Survey Map (Sheet 141) to reach the surface, under a superficial cover, in Chellaston village, only 1 km south of the Boulton Moor Site (text-fig.1). A comprehensive account of the Chellaston gypsum was given by Smith (1919), who also drew attention to solution phenomena such as "swallow holes that have been leached out along lines of weakness.... and carry down surface waters to a level of some 20 feet below the floor of the quarry".

The south south-east dip of the Keuper Marl would probably induce the percolating ground waters to move in that direction and thus away from Boulton Moor. This suggests that surface waters were largely responsible for the transportation of the soluble calcium sulphate to the north. It is notable that the part of the ridge where the Chellaston gypsum outcrops is some 24 metres higher than the present till surface on Boulton Moor, and is dissected by minor valleys. Although these do not now carry surface streams they must have been active at various times in the recent past. It is therefore tentatively suggested that during a period of abundant surface run-off, perhaps resulting from conditions of permafrost or heavier rainfall, streams drained northwards to feed the groundwater system on Boulton Moor. These streams would be enriched in calcium sulphate from corrosion of bedded gypsum occurring in near-surface horizons of the Keuper Marl at Chellaston, or derived gypsum in the immediately overlying superficial cover.

Conclusions

The gypsum which occurs as veins and encrustations in an unrecorded till underlying the terrace deposits of Boulton Moor is clearly authigenic. The evidence available suggests that it is of fairly localised distribution and probably resulted from ground water activity within the vadose zone during post-glacial times.

During a period of increased surface run-off, streams drained northwards from the higher ground of Chellaston and Shelton Lock. These streams were enriched in calcium sulphate as a result of the solution of bedded gypsum occurring within the Keuper Marl and derived gypsum in the immediately overlying superficial cover.

On reaching Boulton Moor the surface waters percolated underground where evaporation within the vadose zone increased the sulphate content to the point of gypsum precipitation.

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Explanation for Plate 7

Fig. 1 Chalk erratic partially enveloped by a 10 mm thick crust of finely crystalline gypsum. Note the well developed glacial striations on the erratic surface where the gypsum has been removed (middle right).

Fig. 2 Pyritised ammonite from the glacial till exposed at Chellaston Quarry. Pyritised fragments of similar ammonites were found in the Boulton Moor till. This specimen was discovered by Mr. Robin Jeffcoat to whom the author is indebted for making it available to be photographed.

Fig. 3 Two chalk erratics with well developed skins of coarsely crystalline gypsum (c.f. fig. 1). The skins are 20 mm thick and contain euhedral selenite crystals up to 10 mm in length. The skin has been pulled away from the erratic on the right to show the nature of the erratic surface.

Fig. 4 Minor vein of coarse crystalline gypsum. Note the lamellar nature of the crystals.

Explanation for Plate 8

Fig. 1 Lateral surface view of part of one of the steeply inclined gypsum veins.

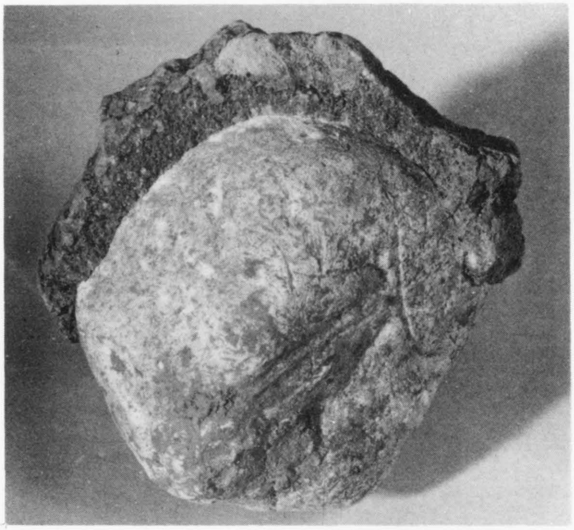
Fig. 2 Enlargement of part of the vein illustrated in Fig. 1. to show the crystal structure of the gypsum and the enclosed glacial erratics.

A : Erratic of Carboniferous sandstone

B : Erratic of Carboniferous shale with striations

C : Euhedral selenite crystal

D : Till matrix occupying voids between the gypsum crystals



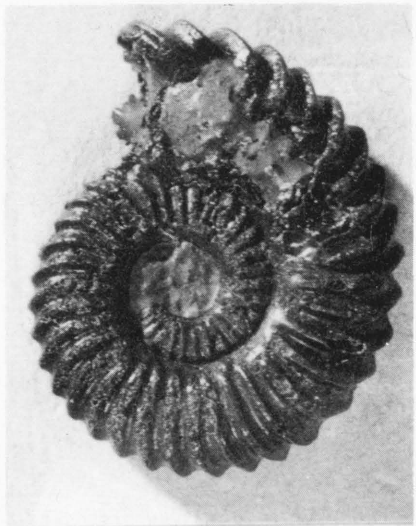
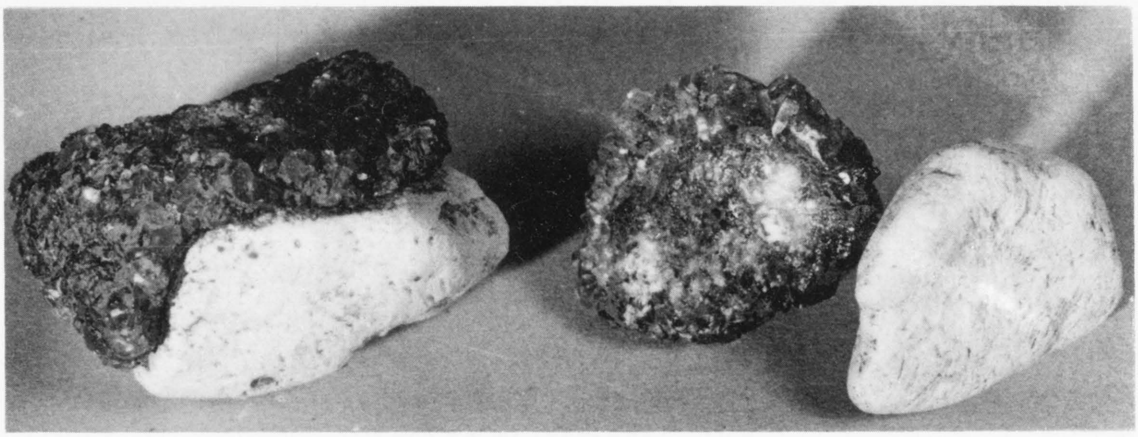


Fig 1 0 30mm

Fig 2 0 10mm



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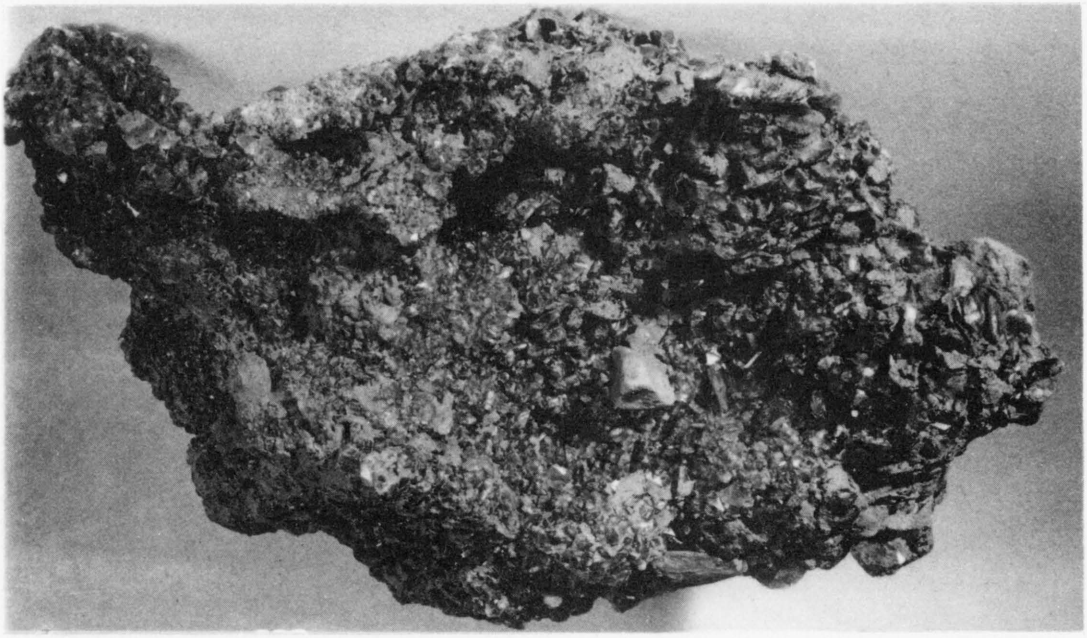

Fig 1

0 50 mm

Fig 2

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