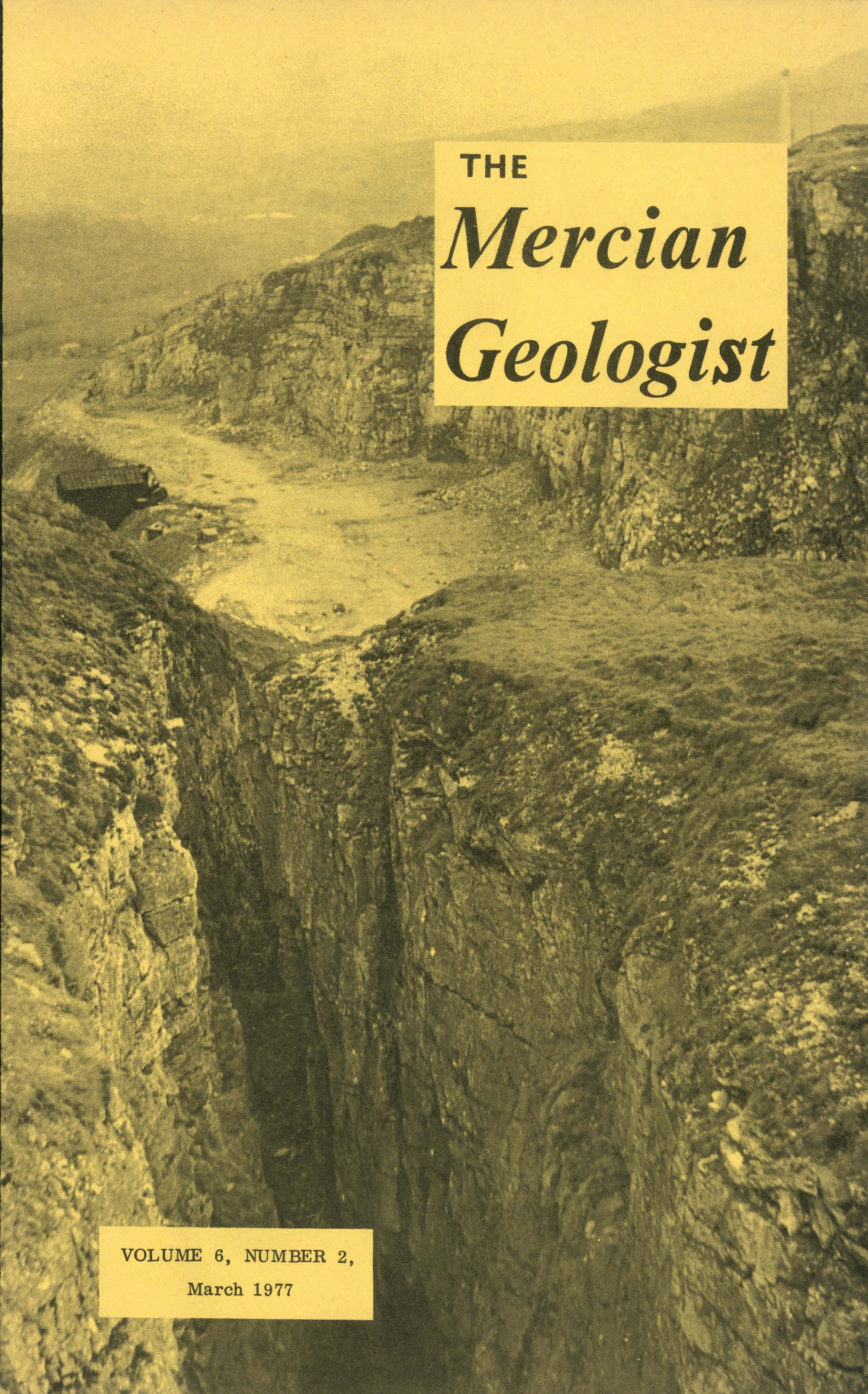
THE
Mercian Geologist



VOLUME 6, NUMBER 2,
March 1977

EAST MIDLANDS GEOLOGICAL SOCIETY

THE MERCIAN GEOLOGIST

Editor:

F. M. Taylor.

Volume 6

Number 2

March 1977

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Mercian Geologist, Vol. 6, No. 2, March 1977.
pp. 81-144. Plates 5-7.

THE EAST MIDLANDS GEOLOGICAL SOCIETY

Council 1976/7

Address for Correspondence:

General Information,
Membership.

The Secretary,
East Midlands Geological Society,
54 Cyprus Road,
Mapperley Park,
Nottingham, NG3 5EB.

Tel. No. (0602) 609430.

ISSN 0025 990X

Printed by the Nottingham University Press.

Front Cover: Old workings of Dirtlow Rake, Pin Dale, Derbyshire.
Towards the east - north - east.
Photograph, 1963, by J. Travis. See pp. 81 - 96.

DERBYSHIRE WRENCHES AND ORES - A STUDY OF THE RAKES' PROGRESS BY SECONDARY FAULTING

by

R. J. Firman

Summary

The morphology of most of the Derbyshire rakes suggest that they were initiated as short primary wrench faults which were subsequently extended by a series of curved secondary faults. Geometrically they resemble fault patterns predicted by Chinnery (1966a). Using his terminology, it is suggested that in Derbyshire there are examples of the lengthening of wrench faults in the A1 and A2 modes, *en echelon* variants of these modes; and complex combinations. Complementary B type faults are rare, and it is doubtful if Chinnery's C, D, E and F type faults are represented. Propagation and lengthening is frequently from west to east and movement along the faults is small in relation to their length. Mineralisation is considered to be unrelated to the initiation and propagation of primary and secondary faults. It is ascribed to late phases of dilational reopening of primary and secondary faults and of systematic joints, possibly during periods of uplift or dilation doming during earthquakes.

Unambiguous examples of second-order faults (Moody & Hill, 1956) have not been recognised in Derbyshire and it is considered that most patterns of mineral veins in Derbyshire can be satisfactorily explained in terms of combinations of Chinnery's (1966a) primary and secondary faults and systematic joint patterns.

Introduction

In Derbyshire the widest and most continuous mineral veins are called "rakes". These have long been regarded as the main channelways for mineralising fluids (Farey, 1811). Geometrical considerations led Shirley and Horsfield (1940) to claim that Moss Rake occupies a wrench fault. More recently Ford (1969) drew attention to the prevalence of horizontal slickenside striations on walls and mineral fillings and implied that most of the Derbyshire rakes occupy wrenches. Subsequently an attempt has been made to indicate the net displacement of these supposed wrench faults (Ford and Ineson, 1971). Unfortunately the evidence is often ambiguous; horizontal slickenside striations may indicate only one component of a series of complex displacements and in the absence of near vertical 'markers' such as dykes or axial planes it is often impossible to evaluate the relative importance of strike slip movement.

In spite of these difficulties it is reasonable to assume that long, straight, vertical rakes, like Moss Rake, fill wrench faults. Others (e.g. Odin Rake, Ford 1967 Fig. 9.2) are now known to be far from straight and consequently are difficult to explain by Anderson's model (1951). Furthermore, the overall pattern of the Derbyshire rakes is quite unlike those predicted and described by Anderson (1951) in his classic publication. Thus some other explanation is required.

One explanation, examined in detail in this paper, is that the Derbyshire rakes typically consist of short straight primary wrench faults which were later extended by a series of curved secondary faults (cf. Chinnery, 1966a). If this is correct then Anderson's (1951) criteria apply only to the straight parts of the rakes and the morphology of the rest is likely to be similar to that predicted by Chinnery's mathematical model.

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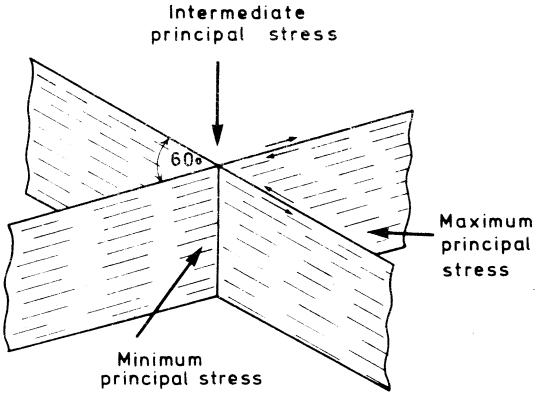
1977. pp. 81-96, 14 text-figs.

The term "secondary faults" is used in this paper exclusively to describe faults generated at the ends of wrench faults due to the build up of stress. They are confined to the *ends* of pre-existing faults and should not be confused with "second-order faults" which according to McKinstry (1953), Moody and Hill (1956) and Price (1968) may form anywhere along the length of pre-existing faults where stress concentrations developed due to friction.

In this paper the evidence for primary, secondary and second-order wrench faults is examined and the relative importance of these and systematic joints (Weaver, 1975) as channelways for mineralising fluids is evaluated.

Evidence for primary wrench faults

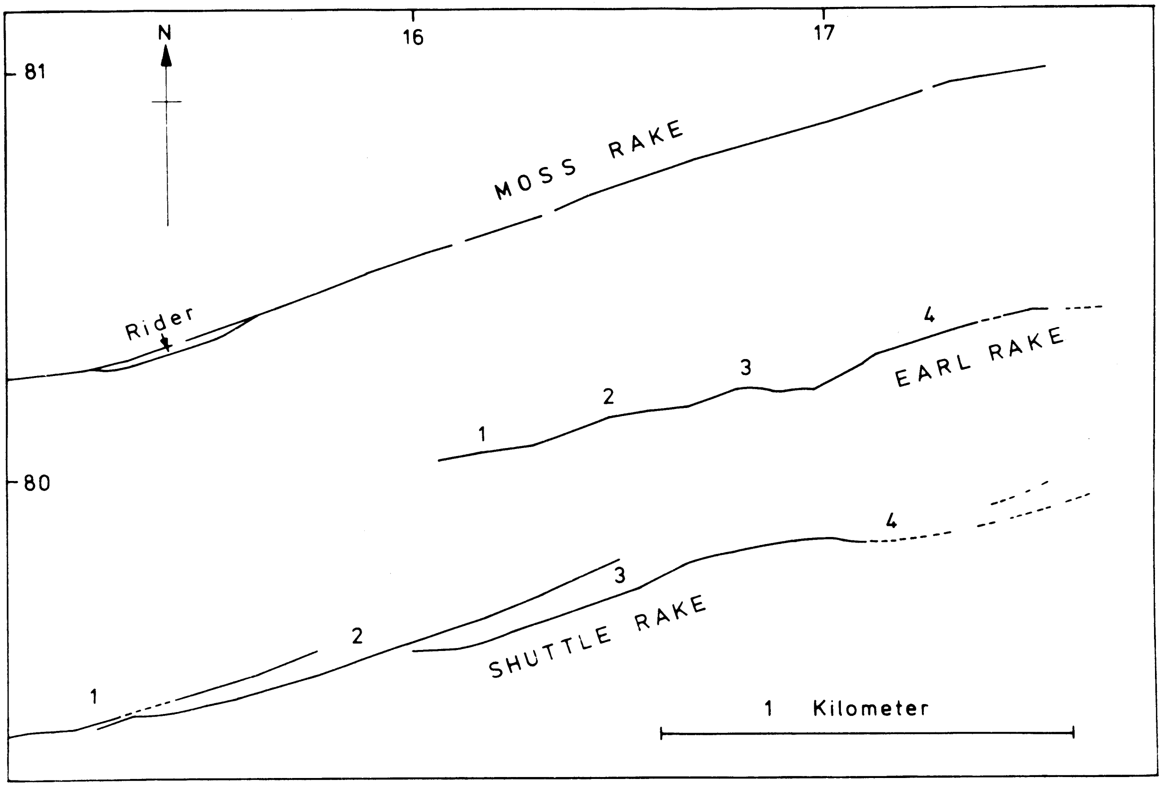
Anderson (1951) in his classic book applied the Navier-Coulomb theory of failure in brittle substances to the interpretation of faults formed in stress regimes in which the maximum and minimum principal stresses are horizontal and the intermediate principal stress is vertical (text-fig. 1).



Text-fig. 1. Orientation of the principal stresses and shear planes during wrench faulting. Note that the fault planes may be curved or corrugated in the vertical profile but take a straight course along the direction of movement. Slickenside striations are often developed as shown and the dihedral angle between the fault planes is often about 60° but depends on the internal coefficient of friction of the rocks traversed.

In such conditions the wrench fault surfaces would tend to be vertical and to develop horizontal slickenside striations. Along the direction of movement the fault is likely to follow a straight course and hence have a straight outcrop but it may have a more sinuous vertical profile (Anderson, 1951).

Straight outcrops, near-vertical fault surfaces and evidence of strike-slip movement are characteristic of some, but by no means all of the Derbyshire rakes. In some instances only parts of a rake are straight; others are gently curved; some seem to consist of a series of short curved faults, which may be inter-connected or *en echelon* (text-fig. 2), and others (discussed later) are considerably more complex. Some rakes may be depicted as straight lines on the geological map solely because of a lack of evidence of their true course. Nevertheless many rakes are straight and Farey's (1811) contention that "rake veins generally preserve a pretty straight course," is broadly true. Thus although many Derbyshire rakes and veins conform with Anderson's (1951) description of wrench fault morphology there are several whose horizontal profile is unlike the wrench faults described by him but which nevertheless exhibit evidence of strike slip movement.

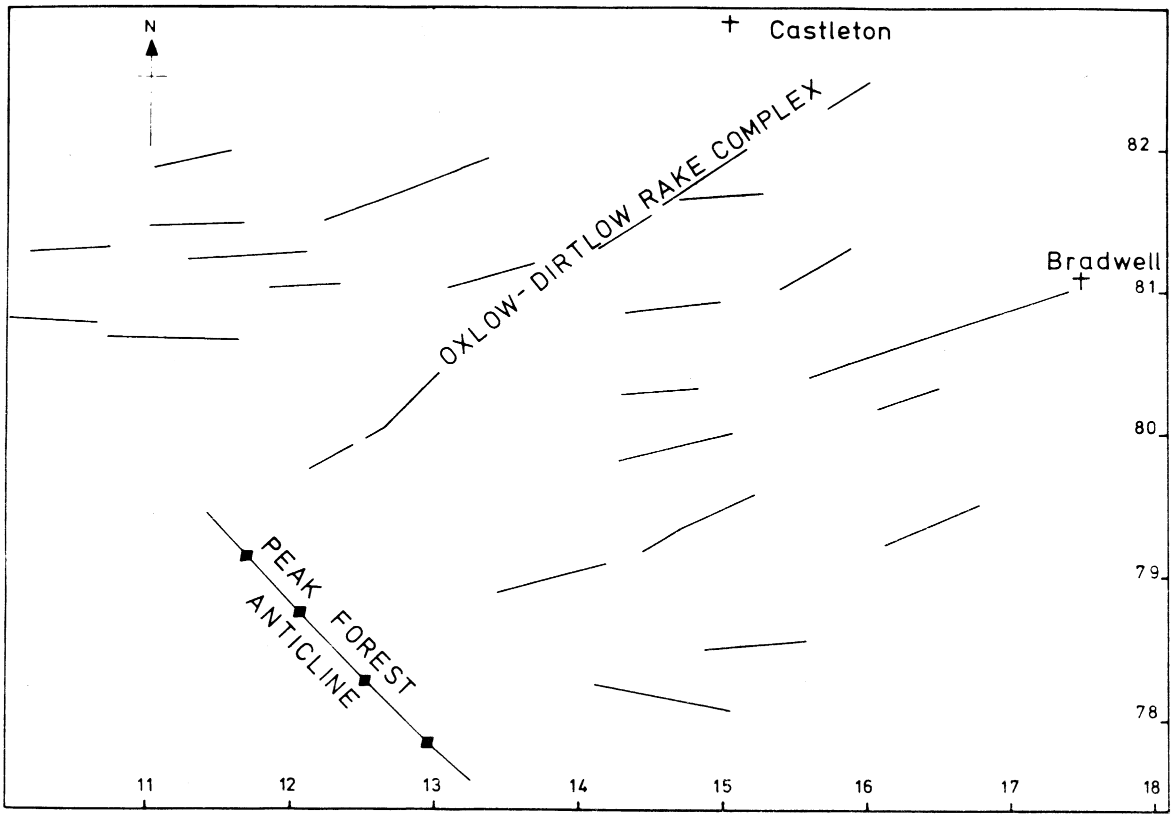


Text-fig. 2 Three parallel faults in the Bradwell area showing markedly different morphologies. Moss Rake is essentially straight, but encloses a limestone 'rider' or 'horse'; Earl Rake appears to have been propagated by a series of curved fractures apparently convex to the north, and Shuttle Rake consists of a series of *en echelon* curved shears convex to the south. Based on I. G. S. six maps SK18SE and SK17NE.

Other discrepancies are noted when the overall pattern of rakes is considered. It is not easy to identify complementary wrench fault patterns, nor is the probable direction of movement along the faults consistent with that predicted by Anderson.

Anderson's simple classical concept cannot therefore be applied to all the Derbyshire rakes. Admittedly Anderson's simple pattern applies only to isotropic conditions and stresses produced in a heterogeneous basement and during folding might be expected to modify profoundly this pattern. Nevertheless the variability of the pattern of rakes contrasts with the simple pattern revealed by the systematic joints (Weaver, 1975) and, in the writer's opinion, the hypothesis that the rakes are compounded of primary and secondary wrench faults has much to commend it.

Text-fig. 3 attempts to identify primary faults in the Bradwell area. With the exception of the Dirtlow and Oxlow Rake complex these have a fairly consistent east and west orientation which contrasts with the greater variability of the curved portions of the rakes. It is not the purpose of this paper to explain the generation of the primary shears but it is interesting to note that Stevenson and Gaunt (1971 p. 34) suggest that the Dirtlow Rake Fault may have been active during B_2 - P_1 times. Thus it appears possible that its anomalous trend may be due to reactivation of a basement fault.



Text-fig. 3 Possible primary wrench fractures in the Castleton-Bradwell area based on the relatively straight parts of rakes as shown on I. G. S. maps (2½ inch Special Sheet Castleton and Edale.) Note the anomalous direction of the Oxlow-Dirtlow Rake fractures which may be due to basement control. (see text pp. 87-88).

Evidence for Chinnery's Type A secondary faults

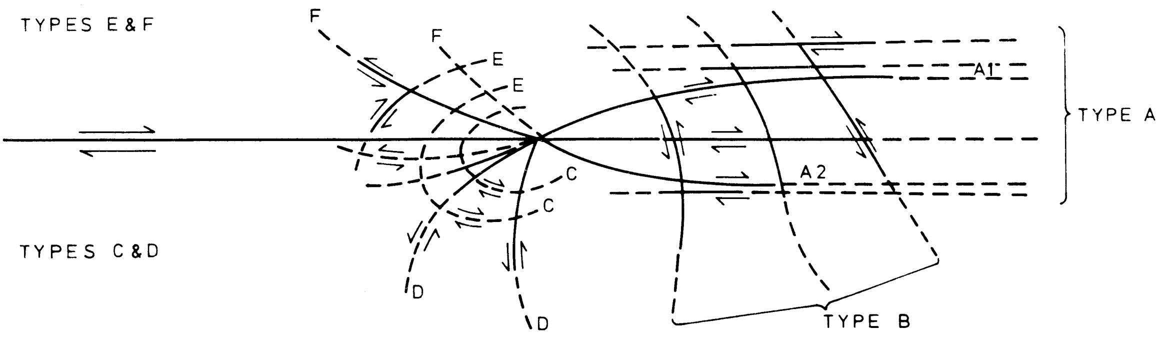
The assumption that only the straight portions of strike slip faults in the Carboniferous Limestone were primary implies that they were subsequently extended along a series of short, frequently curved, fracture surfaces often about 0.5 to 1 km long. Of all the mathematical studies of wrench faults which have been published only one (Chinnery, 1966a) predicts that wrench faults are likely to extend themselves along curved surfaces. This analysis, confirmed Anderson's contention (1951 p. 164) that only at the ends of wrench faults could sufficiently strong concentrations of shear stress be built up to produce secondary faults. Anderson (1951) realised that his model, based as it was on a fault of infinite depth, was not sufficiently refined to allow more than a qualitative explanation of "splays" commonly observed at the end of wrench faults but Chinnery's (1966a) more rigorous analysis permits a more precise definition of the localisation, size and shape of secondary faults.

Chinnery (1961, 1963) had previously used the "elasticity theory of dislocations" as developed by Steketee (1958) to calculate the stress changes which accompany strike-slip faulting. Subsequently (1966a) he argued that, since Steketee (1958) had shown that the displacements and stress changes are independent of the initial stress, the calculated changes in the stress components *during* faulting could be added to the initial stress components to obtain the stress distribution *after* movement had ceased. The pattern that Chinnery obtained showed "that although the initial stress is reduced over most of the length of the fault there are strong concentrations near the ends" which could cause secondary faults. Chinnery (1966a) suggested that secondary faulting was likely where the maximum shear stress after faulting was equal to, or in excess of, the maximum shearing stress which existed before faulting and was also very likely in regions of tension. In regions of compression the secondary faults were assumed to be aligned at about 30° to the principal axis of compression whilst in regions of tension the fractures were expected to develop approximately parallel to the planes of maximum shear stress. Using these assumptions Chinnery was able to predict the geometry of secondary faults (text. fig. 4) from the stress distribution after faulting.

Chinnery (1966a) showed that the pattern of stress distribution and of predicted secondary faults should be symmetrical only when the principal stress axes are inclined at 45° to the primary fault. According to him this corresponds to the classical case of "pure shear" and might be an appropriate model to describe the relative movement of continental blocks. However, all the examples given by him (Chinnery 1966b); by Moore and Shanti (1973) and the Derbyshire rakes described in this paper, are asymmetric and it appears that his "uniaxial compression" model which assumes that the maximum principal compressive stress was at 30° to the primary fault is the most appropriate model for general use (text-fig. 4). In theory the pattern of predicted secondary faults will be more symmetrical than shown in text-fig. 4 as the angle between the fault and the maximum principal stress approaches 45° and more asymmetric if less than 30°, but the changes are slight.

One possible objection to applying Chinnery's model to Derbyshire is that his calculations were based on a fault model 200 km long, 10 km deep with a net displacement of 5 m. Although, this is too large for Derbyshire it may be scaled down without altering the geometry of the predicted secondary faults. For example a fault 2 km long, 100 m deep with a net displacement of 50 mm should produce the same array of secondary faults as those predicted for the larger model. However, although the straight and presumably primary, portions of the Derbyshire rakes rarely exceed 2 km (text-fig. 3) lead mines often are more than 100 m deep and some were worked below 300 m. It seems probable that most faults are much deeper and therefore in Derbyshire the ratio of length to depth is much less than the 20 : 1 ratio of Chinnery's model. According to Chinnery (1966a) this should not alter the geometry but should cause the secondary faults to extend further from the ends of the primary wrench faults. Field evidence seems to support this assertion since in Chinnery's model, type A secondary faults lengthen the primary fault by about one eighth of its total length whereas in Derbyshire the lengthening appears to be approximately equal to the length of the primary fault. Apart from this difference Derbyshire wrench fault extensions fit exceedingly closely to those predicted by Chinnery (1966a) - indeed the fit is closer than many examples quoted by Chinnery (1966b) himself.

The complete range of secondary faults predicted by Chinnery (1966a) is very complex (text-fig. 4) but in practice it is most unlikely that they will all form at the end of any one fault. As indicated in the caption to text-fig. 4 different shears require different stress



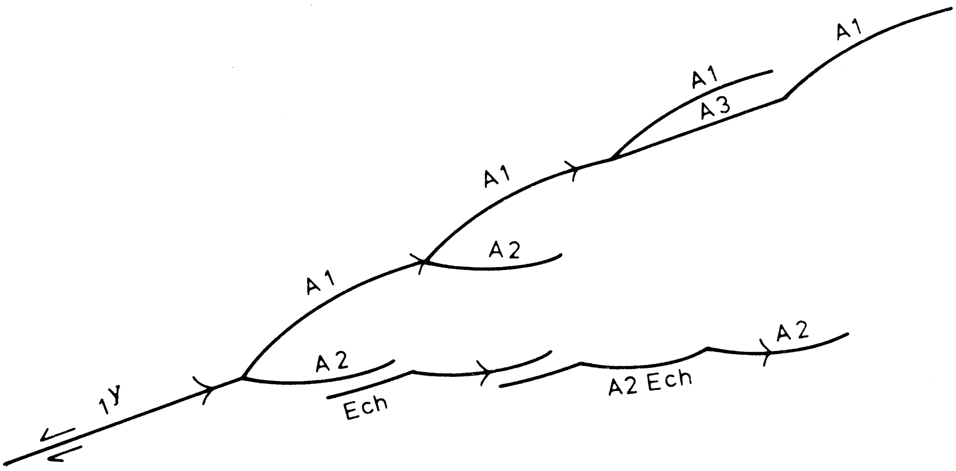
Text-fig. 4 Likely directions for secondary faulting under uniaxial compression (after Chinnery 1966a). According to Chinnery types A and B require high shear stress; types C and D form in regions of overall tension and types E and F need both high shear and high compressive stress conditions.

conditions for their formation and in addition the formation of one secondary shear may sufficiently reduce the accumulated stress to prevent the formation of complementary shears. Thus in Derbyshire, types A and B, which according to Chinnery (1966b) form in conditions of high shear stress, are far more common than all others and of these, type A, which has the effect of lengthening the fault, is far more common than the complementary type B set. This latter observation may be biased by the fact that most of the complementary fractures can only be recognised, in Derbyshire, when they have been mineralised. Because type A fractures are extensions of the main fault they are much the most likely of all Chinnery's predicted faults to be mineralised and hence the most likely to be shown on old mine plans or by surface evidence of old workings. Nevertheless Chinnery himself (1966b) commented that in New Zealand type A faults are common and type B apparently absent.

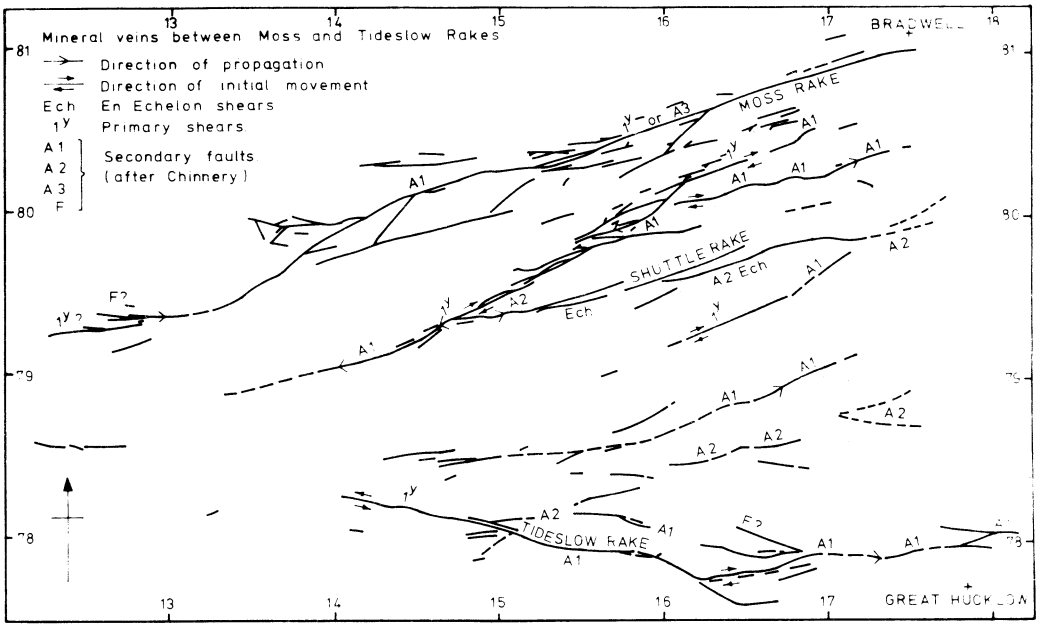
A geometric similarity between those faults predicted by Chinnery and those observed in Derbyshire is illustrated by several subsequent text figures. In the absence of any alternative explanation it is accepted in this paper that the curved portions of the rakes were generated as secondary faults and the reader is left to judge from the following examples how closely the geometry fits that described by Chinnery.

According to Chinnery (1966b p.183) in conditions of uniaxial compression the A1 mode of lengthening is more likely than the A2. Text-fig. 5 shows the theoretical orientation a dextral wrench fault, formed in response to an east-west regional stress, and extended in the A1 and A2 modes respectively.

The Bradwell area provides good examples of wrench faults which appear to have extended themselves along curved fractures analogous to Chinnery's type A faults. Here the relatively simple pattern exemplified by text-fig. 5 is analogous to many of the veins which radiate from the Peak Forest Anticline (text-fig. 6). Moss Rake (West), Earl Rake, Nether Water Vein and High Rake (I. G. S. six sheets SK18SW, SK18SE and SK17NE) exhibit a geometry consistent with an eastward propagation and extension of dextral wrench faults in the A1 mode; Shuttle Rake appears to represent an *en echelon* extension in the A2 mode as on text-fig. 6, and less convincingly the White Rake - Tideslow Rake system appears to be a sinistral fault with both A1 and A2 components.



Text-fig. 5 A possible example of the lengthening of a dextral primary wrench fault by the different types of secondary faulting suggested by Chinnery's model. Legend as in text-fig. 6.

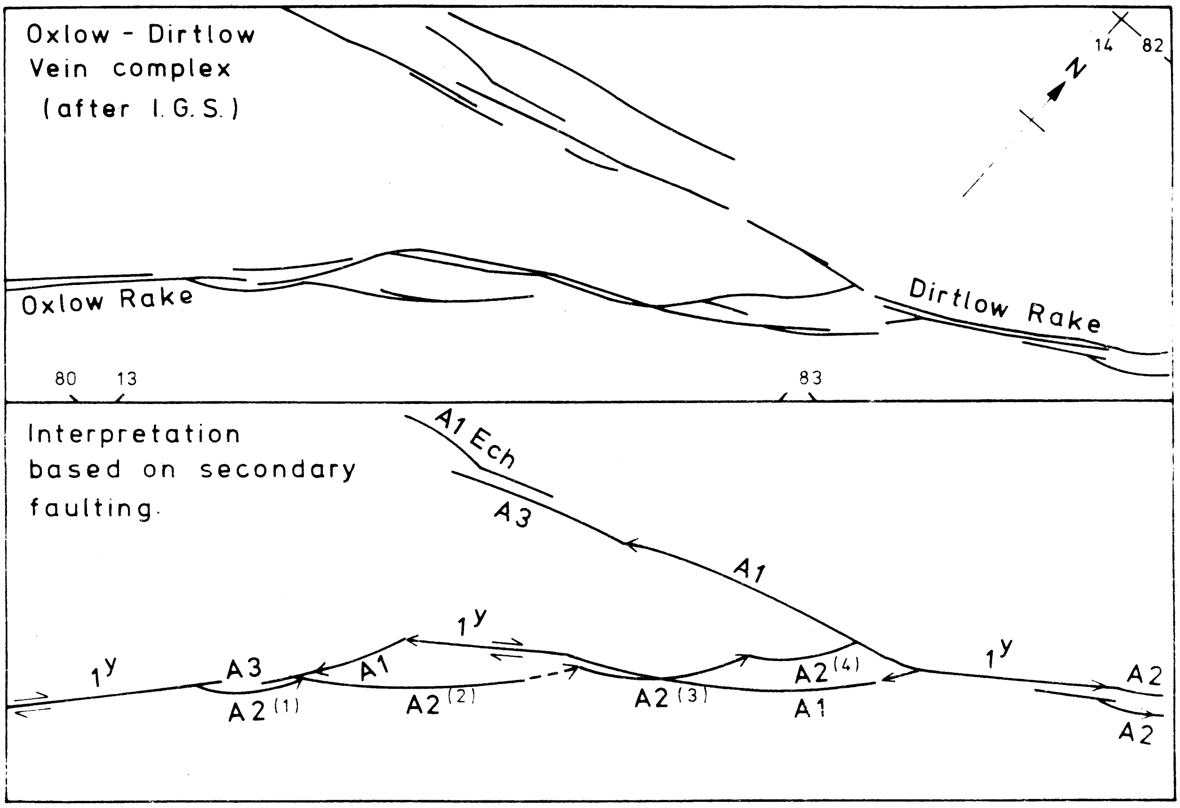


Text-fig. 6. A tentative structural interpretation of the mineral veins between Moss Rake and Tideslow Rake. Note that the arrows indicate the *initial* movement implied by the geometry and *not* the net displacement. Although generally similar to the pattern shown in text-fig. 5, the actual pattern above as mapped (I. G. S. $2\frac{1}{2}$ inch Special Sheet Castleton and Edale) is more complicated because of a greater number of primary fractures and because of westward as well as eastward propagation. Tideslow Rake appears to be part of a sinistral fault system. If this is correct the dihedral angle between complementary wrench faults is much less than 60° in the Bradwell area.

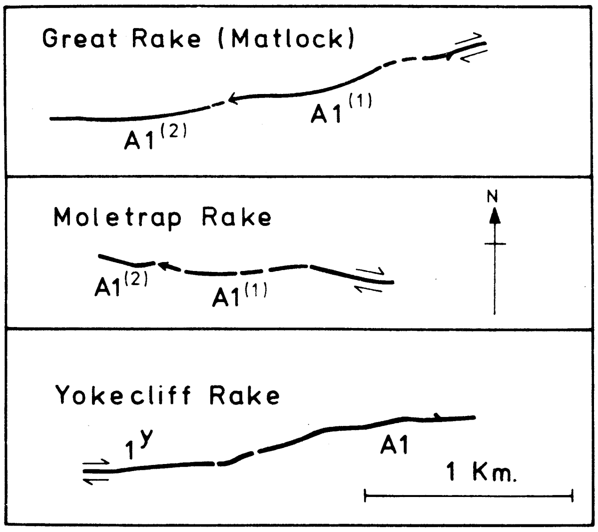
Considering this evidence only, a very good case could be made for faults being initiated and propagated from the crest of the Peak Forest Anticline in response to stresses associated with the formation of that anticline. However, applying Chinnery's secondary fault geometry to other mineral veins suggests that several fractures originated on the flanks of the anticline (text.fig. 3) and were then extended up the eastern limb from east to west. Amongst these are the western end of Shuttle Rake and parts of the Oxlow-Dirtlow fracture system. This latter vein complex is much more intricate than any other in the Bradwell area. By no means can all fractures in this belt be satisfactorily explained by Chinnery's hypothesis. Nevertheless if it is postulated that master faults with slightly different orientations were initiated in several places along the Dirtlow-Oxlow line and secondary A type faults spread out north-eastward and south-westward from these small primary faults much of the complex geometry can be satisfactorily explained (text-fig. 7). Other fractures may have formed during re-shearing.

Probable type A secondary faults occur elsewhere in Derbyshire but less prolifically than in the Bradwell area. Good examples, traced on the I. G. S. special $2\frac{1}{2}$" to 1 mile Matlock Sheet include Great Rake (Matlock), Moletrap Rake and Yokecliff Rake in the southern part of Derbyshire, (text-fig. 8).

Detailed underground surveys frequently demonstrate that where surface mapping has indicated a straight vein it actually consists of a series of curved fractures (e.g. Mandale Rake, Tune, 1969; and Odin Rake, Ford, 1967 and Ford & Rieuwerts, 1976). The geometry of Odin Rake is particularly interesting since it is possible that the rake changes direction with each change of limestone lithology. Theoretically a fault will extend, "until the fault reaches a region where the initiating conditions are modified" (Anderson, 1951 p. 66).

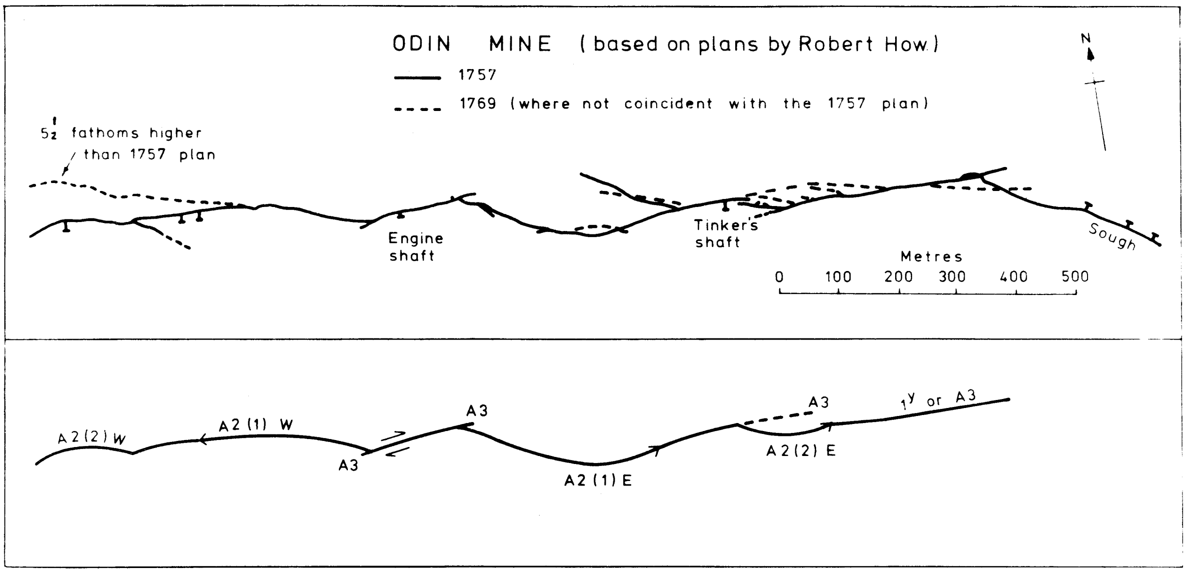


Text-fig. 7 A portion of the Dirtlow-Oxlow Rake complex as shown on the I. G. S. six-inch map (SK18 SW) together with a tentative interpretation based on the assumption that the complex developed from a few short primary wrench faults which were extended both north-eastward and south-westward by secondary faults.



Text-fig. 8 Examples from the south-eastern part of the limestone outcrop, of rakes probably propogated eastward and westward in the A1 mode by secondary faults. (I. G. S. $2\frac{1}{2}$ inch Special Sheet. Matlock).

At Odin, the modified condition may well correspond with varying lithology since changes in fault orientation seem on the 1757 plan by Robert How to correspond to reefs rising from the general level of the limestone. Unfortunately most of the Odin Mine is inaccessible and differences between 1757 and 1769 editions of mine plans by Robert How are sufficient to throw doubt on their accuracy. Nevertheless these plans (xerox copies of which were kindly lent by Dr. Trevor Ford) can plausibly be interpreted in line with Chinnery's hypothesis (text-fig. 9).



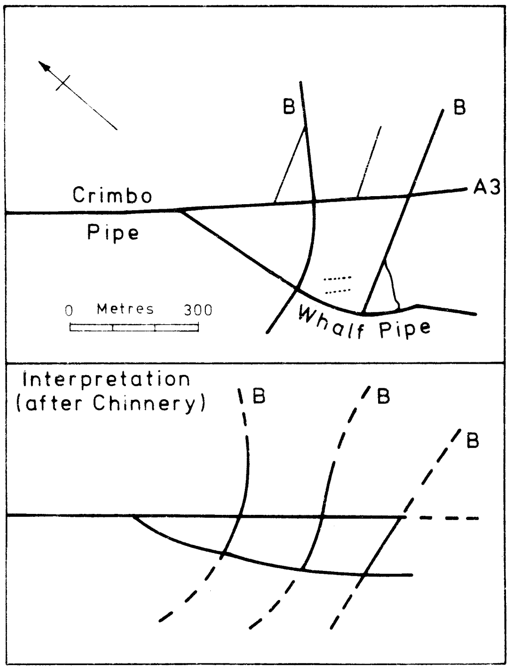
Text-fig. 9 A plan of the Odin Rake (based on surveys by Robert How) with a possible structural interpretation involving both eastward and westward propogation in the A2 mode from a short primary fault. Like the west end of Moss Rake and Whalf Pipe (text-fig. 10) the curvature on the early A type fractures is greater than that predicted by Chinnery for secondary faulting under conditions of uniaxial compression and approaches the curvature postulated by him for pure shear.

Thus fractures analagous to Chinnery's type A faults appear to be very common in Derbyshire. They are particularly abundant in the northern part of the limestone outcrop and are rare in the south where the majority of veins appear to fill the systematic joints (Weaver 1974) which are much more numerous than mineralised wrenches and associated secondary faults. The curvature along most of the supposed type A faults is comparable to that predicted by Chinnery (1966a) for shearing under uniaxial compressive stress when the maximum principal stress was at 30° to the resulting shear. The greater curvature, exhibited, for example, by the western end of Moss Rake and Long Rake, near Yougreave, could, if Chinnery is correct, be due to a more deep-seated origin in conditions approaching pure shear. However, the majority of the Derbyshire "rakes" appear to have been initiated as shallow wrench faults which were subsequently extended by a series of type A secondary faults. The total strike slip movement was insignificant and often so masked by later strike-slip and dip-slip displacements that the original direction of movement cannot be determined.

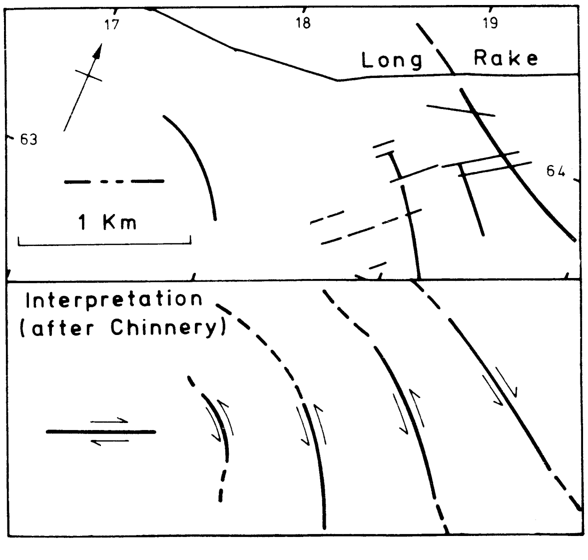
Examples of complementary secondary faults

(Chinnery's type B)

Secondary faults complementary to type A faults are rare, possibly because they have not been subsequently mineralised and hence remain undetected, but more probably because the formation of type A faults sufficiently relieved the stress to inhibit their formation. The examples illustrated in text-figs 10 and 11 are similar, but not identical to those forecast by Chinnery (1966a) and moreover include a number of other mineral veins (possibly joint fillings) which obscure the pattern.



Text-fig. 10 Crimbo and Whalf pipes and associated veins based on surface and underground information (after Robey, 1969).

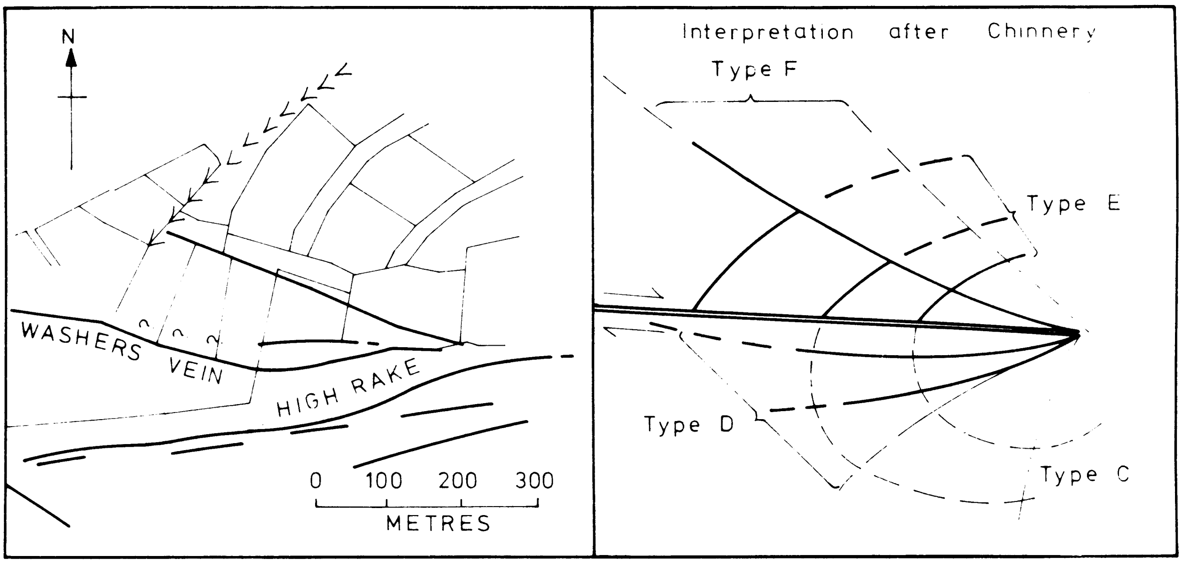


Text-fig. 11 Possible type B faults in the Long Rake area (Author's mapping).

Possible examples of other types of secondary faults

Faults shown on text-fig.12 are the most convincing examples, known to the writer, of mineral veins which could possibly represent some of Chinnery's other types of secondary faults. None will convince the sceptic and indeed it appears more probable that either Chinnery's types C, D, E and F did not form in Derbyshire or if they did they were not mineralised and hence cannot be seen where the limestone is not exposed. Curved geomorphological features emphasised by the curved walls in the Tideslow Rake area may be a fortuitous coincidence and not as tentatively implied in text-fig.12, type E secondary faults.

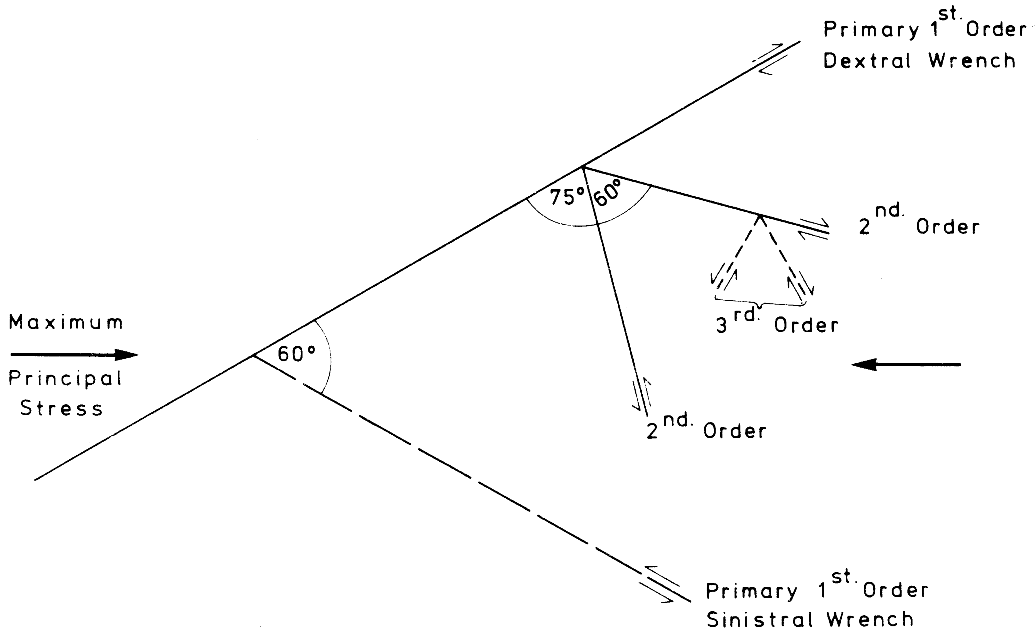
Whatever the true status of types C, D, E and F secondary faults the writer is of the opinion that there are sufficient examples of types A and B to strongly suggest that they are prevalent in Derbyshire.



Text-fig.12 A possible example of types D and F faults near Washers Vein, Tideswell. Geomorphological features exemplified by the valley and emphasised by curved walls could conceivably be controlled by type E secondary faults. (Based on I.G.S. map SK17NE).

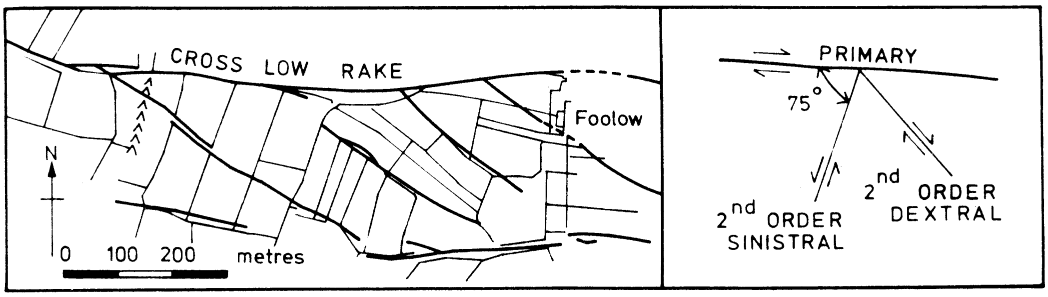
Second-order faulting

Second-order faulting caused by the frictional forces generated by wrench faults was first proposed by McKinstry (1953) and elaborated by Moody and Hill (1956). The latter authors suggested that further movement along second-order faults would generate third-order faults orientated as shown on text-fig.13. Both McKinstry, and Moody and Hill have been severely criticised by Chinnery (1966b) who maintains that their arguments are mechanically unsound and that in any case stress concentrations sufficient to cause faulting can only build up at the ends of major faults. However fault patterns similar to those predicted by Moody and Hill (1956) have been recorded from many parts of the world and have been attributed by many authors to second and third-order wrench faulting. A radically different explanation for second-order faults was proposed by Price (1968). He suggested that earthquake shock waves generated by the incremental movements of wrench faults may cause momentary and transient modifications of the static stress field sufficient to cause fractures to form adjacent to the major faults with orientations similar to those forecast by Moody and Hill (1956). These fractures might later be extended during renewed movements of the primary fault.



Text-fig. 13 Primary, second- and third-order fault systems expected from an east-west maximum principal stress system as predicted by Moody and Hill, 1956 (cf. text-fig. 5, p. 86).

It is not the purpose of this paper to evaluate the relative merits of the static theories of McKinstry, and Moody and Hill, compared with Price's dynamic theory, but merely to ascertain whether there are any fault patterns in Derbyshire which geometrically resemble second-order faults. One feature of many second-order fault patterns described in the literature is that fractures tend to be developed on one side only of the primary wrench. Using this feature the obvious candidates are fractures adjoining Coast Rake, Long Rake and Crosslow Rake (text-fig. 15). If these fractures were initiated as second-order faults, then only one of the two complementary directions is present. Weaver (1975) has shown that the mineral veins trending south-south-east from the Coast Rake are parallel to the systematic joints. Observations by the writer demonstrated that the same relationship holds south of Long Rake where joints in Shining Bank Wood Quarry and adjacent to the Bowers Vein form a rectilinear pattern parallel to the principal veins other than Long Rake itself. It thus seems most likely that the mineral veins adjoining Coast Rake and Long Rake fill systematic joints and not second-order faults as previously suspected (Firman and Bagshaw, 1974). Owing to lack of rock exposures the Crosslow area is more difficult to evaluate. Curiously one set of stone-walls and a valley are parallel to the theoretical direction of the complementary second order fault. It is therefore possible that the veins south of Crosslow Rake do fill one set of second-order faults but in the absence of measurable joints this is difficult to prove (text-fig. 14).



Text-fig. 14 Veins adjacent to Crosslow Rake - a possible example of second-order faults. Based on I. G. S. six-inch map, (SK17 NE).

Thus, in Derbyshire, the evidence for "second-order faults" is weak whereas the case for "secondary faults" is strong.

Mineral veins, wrench faults and systematic joints

Weaver (1975) has demonstrated convincingly that in the south-eastern part of the Derbyshire Dome the majority of mineral veins shown on Geological Survey maps fill systematic joints. His illustrative rose diagrams show the close comparability between vein and joint patterns but this statistical approach obscures the fact that some of the widest and historically the most profitable veins (i.e. the "rakes") do not conform to the systematic joint pattern. Morphologically Great Rake (Matlock), Moletrap, Yokecliff and several other rakes appear to be primary wrench faults extended in the A mode (Chinnery 1966b) by secondary faulting. Their curved segments contrast markedly with the predominate rectilinear mineral vein patterns; therefore, the south-eastern part of the mineral field is compounded of veins filling primary and secondary wrenches *and* systematic joints. This contrasts with the Bradwell area (text-fig. 6) where mineral veins in wrench faults predominate and only very thin uneconomic veins (scrins) or joint coatings occur in the systematic joints.

The arguments for the rakes as primary and secondary wrench faults should not be allowed to detract from Weaver's clear evidence of mineral veins filling systematic joints. In some areas such as Crich, Ashover and Bonsall Moor the mineral veins in systematic joints were economically very important and at Millclose (Traill, 1939) the value of minerals filling joints, albeit widened by corrosive waters, was probably in excess of all the minerals won from the Derbyshire rakes.

To explain the complete pattern of Derbyshire mineral veins the mechanism of both faults and joints needs to be considered.

Mineralisation

Mineralisation in Derbyshire is not confined to faults and joints and is not restricted to one period of time (see Firman and Bagshaw, 1974, for a fuller discussion). Nevertheless fault and joint fillings account for a substantial part of the Derbyshire mineralisation and many of the major fluorspar replacement ore bodies are adjacent to major rakes. Intuitively it might be expected that much of the mineralisation of the rakes coincided with their initiation and extension, perhaps by hydraulic mineralisation (Phillips, 1972). Several lines of evidence suggest that this is incorrect.

(a) Many faults were propagated from west to east whereas evidence (reviewed by Firman and Bagshaw, 1974) suggests that the minerlising fluids tended to move up dip from east to west.

(b) Mineral zoning does not coincide with stages in the extension of wrench faults.

(c) Wrench faults and joints are not necessarily contemporaneous (Price, 1966) yet in many areas they contain the same mineral assemblages suggesting that both structures opened simultaneously during mineralisation.

(d) Euhedral minerals are often found growing on horizontal slickenside striations which developed in the wall rock prior to mineralisation.

Such arguments do not preclude some mineralisation coinciding with the initial propagation of primary and secondary wrench faults but they do strongly suggest that the bulk of the mineralisation was due to the reopening, probably by hydraulic fracturing, of pre-existing primary and secondary wrench faults at a late stage after both the faults and systematic joints had fully developed.

The timing and mechanism of this reopening and mineralisation is uncertain but the textures and structures in the veins indicate that it was episodic and that dilational periods were interspersed by periods of renewed strike-slip and oblique-slip movements often accompanied by brecciation (Firman and Bagshaw, 1974). Slickenside striations on the mineral fillings are often differently orientated from those on the wall rocks (e.g. Ford, 1976), indicating a reorientation of the stress system between phases of mineralisation. Ford's contention (1976, p.36) that slickenside striations on the wall rocks of the Odin vein are probably evidence of a late phase of movement of the opposing walls as they ground against the sides of the mineral fill is at variance with the evidence here and elsewhere in Derbyshire that the minerals nucleated on an already slickensided surface. Wall rock slickenside striations in the writer's opinion almost invariably formed before mineralisation began.

Dilational reopening of pre-existing fractures, both before and between periods of mineralisation, might result for instance from uplift, renewed folding in anticlinal areas or dilation doming during shallow earthquakes. Circulation of mineralising brines could result from processes analogous to the seismic pumping suggested by Sibson, Moore and Rankin (1975) but whatever the true explanation the mineralisation appears to be largely unrelated to the initiation and propagation of the primary and secondary wrench faults.

Conclusions

The geometry of most of the Derbyshire rakes strongly suggests, in the writer's opinion, that they were initiated as short primary wrench faults 0.5 to 1 km long which were subsequently extended along a series of curved secondary faults similar to those predicted by Chinnery (1966a). The commonest means of extension is, as forecast by Chinnery, in the A1 mode; but the A2 mode is frequent and extensions in both the A1 and A2 modes of *en echelon* shears has also been observed. This latter means of extension was not suggested in either of Chinnery's papers (1966a and 1966b) and has not been recorded in any subsequent papers by other authors but seems to be a legitimate addition to the modes of extension suggested by Chinnery. As in the examples quoted by Chinnery the complementary type B secondary faults are uncommon. No wholly convincing examples of Chinnery's types C, D, E and F secondary faults have been located and thus secondary faulting in Derbyshire is virtually limited to the types A and B. This, according to Chinnery (1966a), implies high shear stress conditions without the accompanying high compressive stress required for types E and F or the overall tension needed for types C and D.

The reasons for one mode of extension being adopted in preference to another is not understood and is apparently not predictable from surface lithologies or published gravity and magnetic data. If the mode of extension, curvature and length of secondary faults could be related to measurable parameters a useful means of predicting the course of the rakes eastward under the Namurian cover would be available to the prospector. Much more research is needed to solve this problem.

Second-order faults, as defined by Moody and Hill (1956), appear to be rare or absent and most vein patterns reminiscent of second-order faults are more plausibly attributed to mineralised systematic joints.

Mineralisation appears to be unrelated to the initiation and propagation of the primary and secondary wrench faults. It is attributed to periods of tensional reopening of these faults and systematic joints and not to hydraulic mineralisation accompanying the initial opening. The Derbyshire wrenches and ores are thus not contemporaneous and the wrenches have a long history of initiation, propagation and extension before the ores were formed. The wrenches' progress is thus not synonymous with the rakes progress, although it is a necessary prerequisite.

Acknowledgements

Text-figs. 2, 3, 6, 7, 8, 12 and 14 are based on information provided by Institute of Geological Sciences, U.K. maps - National Environmental Research Council copyright. The information used is gratefully acknowledged and reproduced here with the permission of the I. G. S. Director.

The author is grateful to Drs. Aldridge and Field for providing the essential ingredients from which the title of this paper was fashioned and to all his colleagues for many stimulating discussions. The writer takes sole responsibility for the views expressed, although he gratefully acknowledges his debt to a stimulating series of papers by Chinnery and to ideas and suggestions from many sources.

Grateful thanks are due to Miss Alyson Hargreaves for her patience in preparing the typescript and Mrs. Josie Wilkinson for the diagrams.

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R.J. Firman,
Dept. of Geology,
The University,
Nottingham, NG7 2RD.

BRACHIOPOD "NESTS" FROM THE MARLSTONE ROCK-BED (JURASSIC) OF WARWICKSHIRE

by

R.W. Blake

Summary

Clusters or 'nests' of brachiopods, now situated in the Marlstone Rock-Bed, Warwickshire, originated on stable areas of the sea floor. Mobile sediment was instrumental in preventing uniform spat cover. Terebratulids (*Lobothyris punctata*) and rhynchonellids (*Tetrarhynchia tetrahedra* and *Gibbirhynchia northamptonensis*) avoided direct competition by means of separate nests, which once established grew at each larval settlement period. Nest size was primarily determined by recruitment rate per breeding season. Due to the death of old, centrally situated individuals a nest could break up and be scattered by current action. Most of them were preserved by sudden sediment influx and rapid burial. Peripheral shells were choked and infilled by sediment, but centrally situated ones, having had time to effect valve closure, were infilled after burial by coarsely crystalline calcite.

Introduction

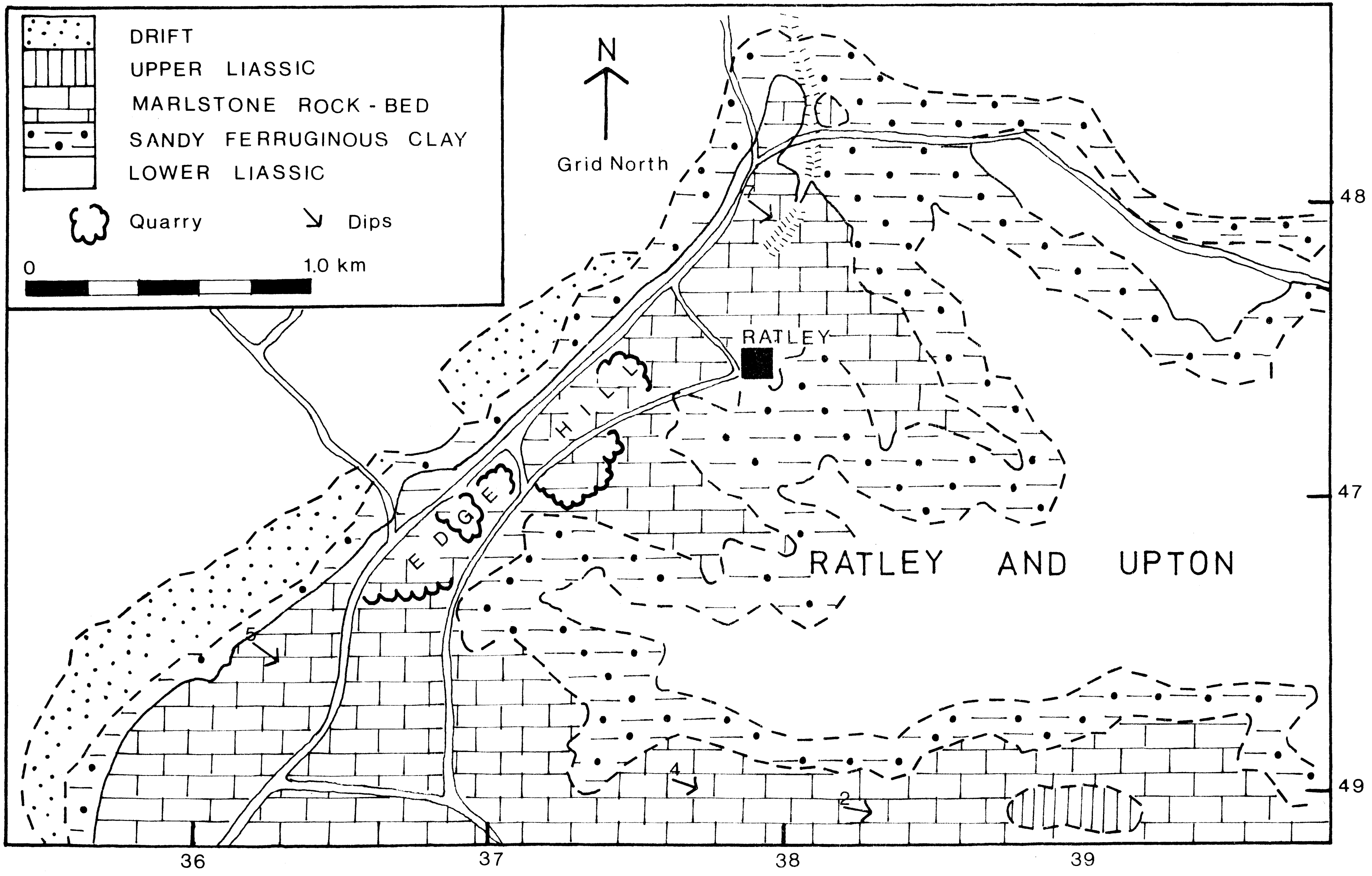
The Marlstone Rock-Bed of the Middle Lias (*Pleuroceras spinatum* zone) of Central England is characterised by the presence of discrete clusters of brachiopods which are often referred to as nests (Ager 1954, 1956). Hallam (1961) interpreted those of Leicestershire as life assemblages and attributed peaks in the size-frequency distributions of dissected nests to distinct brood categories.

Here answers to basic questions concerning the nature of the nests are suggested. The questions are:

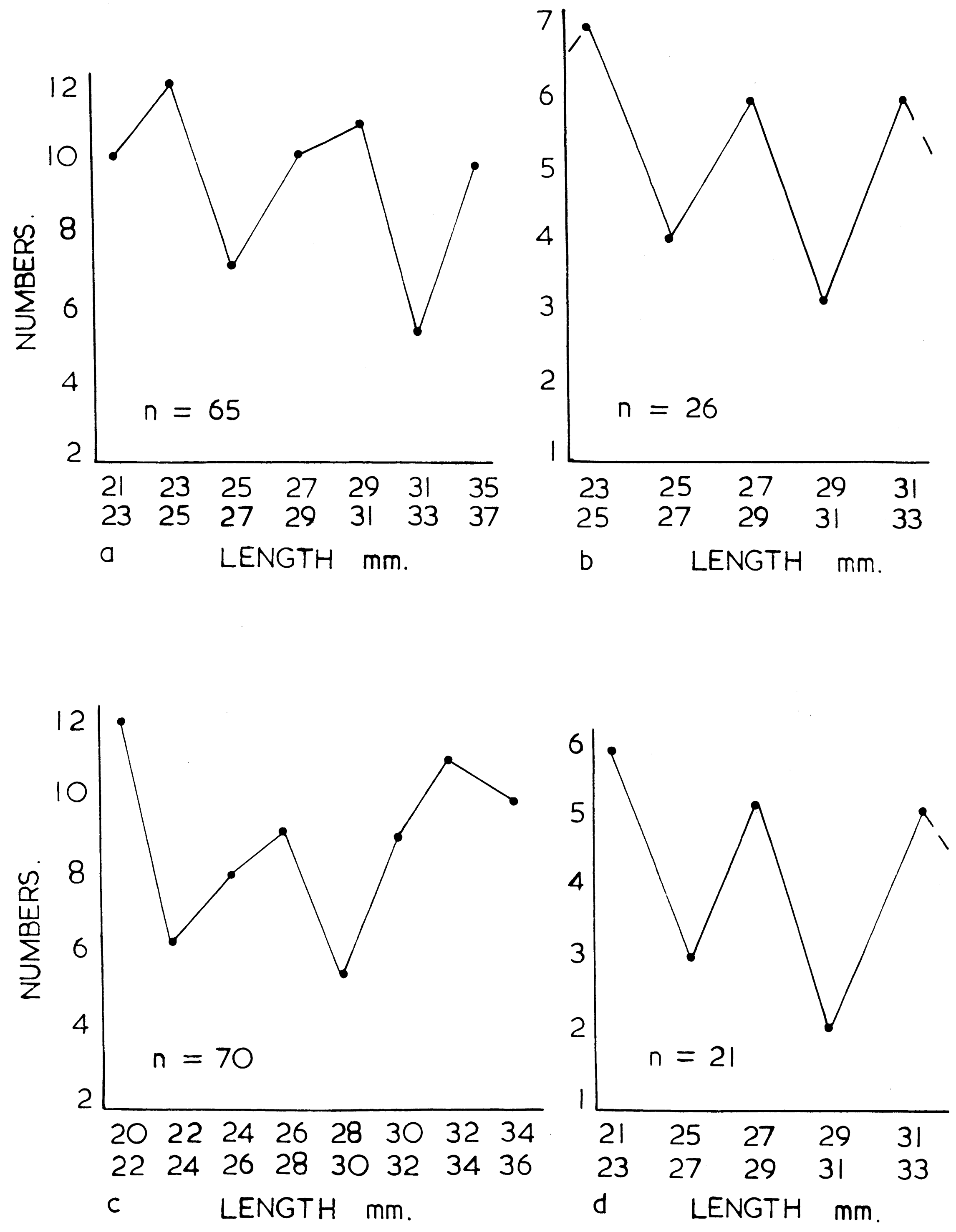
1. Why and how did a nest form?
2. What determined nest size?
3. What mechanisms were responsible for nest preservation?

The main rock type is a calcitic sideritic fragmental limestone with prominent ooliths of chamosite (Taylor 1949; Whitehead 1952). Hallam (1967) thought that the siderite was precipitated at an early stage of diagenesis, as a result of interaction of ferrous and carbonate ions in the interstitial solutions. Several explanations have been suggested for the origin of the chamosite ooliths. Chamosite, containing ferrous iron, is presumed to require reducing conditions for its formation. However an abundant benthonic fauna clearly signifies oxidizing conditions. Cayeaux (1922) suggested that the ooliths formed in agitated waters as aragonite ooliths do today. This is unlikely as modern carbonate banks are not reducing environments. It has been suggested (Pulfrey 1933: Caillere & Kraut 1954) that the chamosite formed in a gel by a concretionary action. Dunham (1960) has pointed out that the chamosite ooliths have little resemblance to the concretionary pisolitic chamosite of certain bauxites. Hallam (1967) has suggested that the reducing environment required for the formation of chamosite could have existed within the sediment. Burrowing organisms could have brought the newly formed chamosite to the surface where it must have been stable in an oxidizing environment. Porrenga (1965) has found chamosite in modern faecal pellets and it is possible that faecal pellets on the Marlstone sea floor were an important source of chamosite.

Mercian Geol. vol. 6, No. 2, 1977,
pp. 97-102, 2 text-figs.



Text-fig.1. Geological map of the Ratley district.



Text-fig. 2. Size-frequency distributions of four of the nests studied. The number of brood categories indicated is three, in both large (a and c) and small (b and d) nests. They are considered to be representative of the fourteen nests studied.

Fourteen nests were studied in detail, all consisting of the terebratulid *Lobothyris punctata*. They were all collected from a single horizon (approximately 50 cm from the base of the Marlstone Rock-Bed) from exposures in the quarries of Hornton Quarries Ltd at Ratley, near Edge Hill. The general geology of the Ratley district and the location of the quarries are shown on text-fig. 1. The nests studied were ovate in shape, ranging in size from 25 cm in length, 10 cm in height to 40 cm in length and 15 cm in height.

Nest formation and composition

Prominent ooliths of chamosite suggest that large areas of the Marlstone sea bed were mobile; these areas would not be suitable for larval settlement. Where stable areas occurred (e.g. around clumps of calcareous worm tubes and coarse shell material) larvae would settle. Intertwined worm tubes were found directly below three of the nests studied. Aggregation at the settlement site would form the basis of a nest. As the nest grew (by individuals settling on each other) it would offer increasing stability and physical protection to the individuals that composed it.

Rudwick (1970 p. 161) points out that modern brachiopods are often found attached to each other. He considers this to be the result of intense competition for settling space in environments where oxygen and food are abundant (Rudwick 1962). On the Marlstone sea bed settling space itself was limited due to movement of sediment and this explains why brachiopod larvae might settle on fixed, established, shells.

Mixed nests containing both terebratulids (*L. punctata*) and rhynchonellids (*T. tetrahedra* and *G. northamptonensis*) are rare, only two were found during a three week search. When found together they are often associated with isolated crinoid ossicles, shell debris, fragmented belemnite guards and disarticulated bivalve shells. Such associations indicate that these are not life assemblages in the sense of Hallam (1961). I suggest that terebratulids and rhynchonellids avoided direct competition by means of separate nests.

Few other fossils are associated with the nests. The bivalves *Pseudopecten equivalis* and *Entolium corneolum* are the forms most commonly found adjacent (within 50 cm) to the nests. The above forms were probably active swimmers (like modern pectinids) and would not have competed with the brachiopods for nest sites. Other bivalves such as *Oxytoma inequivalis*, *Oxytoma cynipes*, *Modiolus scalprum* and *Protocardia truncata* occur commonly in horizons above and below those of the brachiopod nests.

Nest Size

Size-frequency distributions (length: anterior - posterior axis against numbers) of both large (over sixty specimens) and small (less than thirty specimens) nests show an average of three peaks, text-fig. 2. Each peak is assumed to represent a single brood category (Hallam 1961). During each period of larval settlement nest size would increase as new individuals settled on established nests. The two main factors which determined nest size were the recruitment rate per breeding season and the number of breeding seasons for which the nest was thriving. As both large and small nests possess an average of three distinct size categories it is concluded that recruitment rate was the more important of the two. However due to retardation of growth with increasing age, coalescence of size categories could occur and may account for the low number of peaks on the size-frequency distributions of some of the larger nests.

After a period of time, due to the death and eventual detachment of old, centrally situated individuals a nest could become unstable and break up. It is not possible to say how long it would be before this occurred. Very little is known about the life span of modern brachiopods. The terebratulid *Pumilus antiquatus* has an estimated life span of three years (Rickwood 1968). Paine (1969) estimated a maximum life span of nine or ten years for *Terebratalia transversa*. It would seem that most of the larger living brachiopods have a life span of at least several years (Vogel 1959).

Mechanisms responsible for nest preservation

After the break up of a nest, shells would be transported by current action and little indication of the nest's existence would be preserved. This mode of destruction was probably not common, as isolated, disarticulated brachiopod valves, showing signs of transportation are rare. However they do occur, sometimes within 50 cm of well preserved nests.

Two types of shell infilling material are noted, coarsely crystalline calcite and sediment. Many of the larger nets show a differentiation of the infilling material, centrally situated specimens being infilled by coarsely crystalline calcite. Small nests were commonly infilled by sediment only. It is possible that such nests were overwhelmed by a sudden influx of sediment (Hallam 1961) which choked only peripherally situated specimens, the more centrally situated ones having had time to effect valve closure. Peripheral shells would offer a degree of physical protection to the central ones. Subsequent to burial calcite would be precipitated in the centrally situated shells.

The existence of two modes of destruction is consistent with the fact that transported shells and single valves would be buried simultaneously with thriving nests, during sudden sediment influx.

Acknowledgements

I am indebted to Mr. C. Stewart for introducing me to the location at which this work was carried out. I am grateful to Prof. J.W. Murray, Dr. A. Hallam and Miss A.P. Wilby for useful criticisms and to the management of Hornton Quarries Ltd for access and specimens collected.

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R.W. Blake,
Department of Zoology and
Dove Marine Laboratory,
University of Newcastle-upon-Tyne,
Newcastle-upon-Tyne,
NE1 7RU.

EXPOSURES OF THE WIDMERPOOL FORMATION (DINANTIAN) IN SOUTH DERBYSHIRE

by

J.D. Weaver and M.F. Stanley

Summary

Detailed investigation of the surface exposures of the Widmerpool Formation north-west of Derby has revealed that these upper Visean sediments are mainly composed of thin limestone, sandstones and shales. Detrital fragments in the sandstones indicate derivation from an area composed of igneous and metamorphic rocks. Sole structures on some of the sandstone units suggest a south-easterly source, possibly the Charnwood Forest area.

Introduction

The Widmerpool Formation is a local facies of the Upper Visean developed in the area between the southern margin of the Derbyshire Limestone massif and Charnwood Forest. The age of the Formation ranges from B_2 - P_2 (goniatite zones). The rocks have been described as a "basin" or "gulf" facies (Lees & Taitt 1945, Falcon & Kent 1960, George 1963) deposited in a deep trough, trending E - W, situated to the south of the Derbyshire massif, extending from Grantham in the east and opening westwards into the North Staffordshire Gulf (Falcon & Kent 1960, Sylvester-Bradley & Ford 1968). It has been stated by these authors that this trough was present throughout Dinantian and Namurian times. The Widmerpool Formation is characterised by substantial thicknesses of shales siltstones, and thin sandstones and limestones, being proved in boreholes to be 645 m thick at Duffield (SK 343422) and at least 799 m thick at Widmerpool (SK 632280) (I. G. S. 1967, 1968, Edwards 1951). At the surface, exposure is poor but seven small outcrops of the formation have been studied between Turnditch and Mackworth (text-fig. 1). This paper gives, for the first time, an account of these exposures.

Description of Exposures

(i) Cold Lane, Mackworth (SK 31363770) Here the Widmerpool Formation is seen faulted against the Keuper Waterstones, as shown in text-fig. 2. About 1.6 m of sandstones and siltstones with thin grey clays are exposed at the south-western end of Cold Lane (text-fig. 3). The sequence starts with 0.15 m of finely laminated siltstones and mudstones bearing plant remains; the main constituent of the siltstones is angular and sub-hedral quartz showing strained extinction. Above these siltstones a very fine, fawn sandstone 0.095 m thick, exhibits a scoured base. In this sandstone the grains (50 - 100μm) are angular to sub-hedral and are mainly composed of strained quartz associated with small amounts of microcline and haematite. The grains are cemented by calcite with some haematite. The base of the sandstone shows prod marks, groove marks, and incipient flute marks. The orientation of these indicates that the underlying silt was scoured by a northward flowing current. The mean direction of palaeoflow towards 329° , (Table 1, p. 108).

(ii) Kirk Langley, Old Quarry (SK 29163888) A(1) The sequence, 2.4 m thick, comprises fawn, pink, buff and grey sandstones interbedded with thin grey clays. The upper part is also exposed in the field on the west side of the quarry. Some 0.5 m below the top of the succession a buff and pinkish grey sandstone 0.61 m thick is developed. This fine to medium grained (100 - 300μm) sandstone is composed of strained quartz (70% - 80%), associated with grains of

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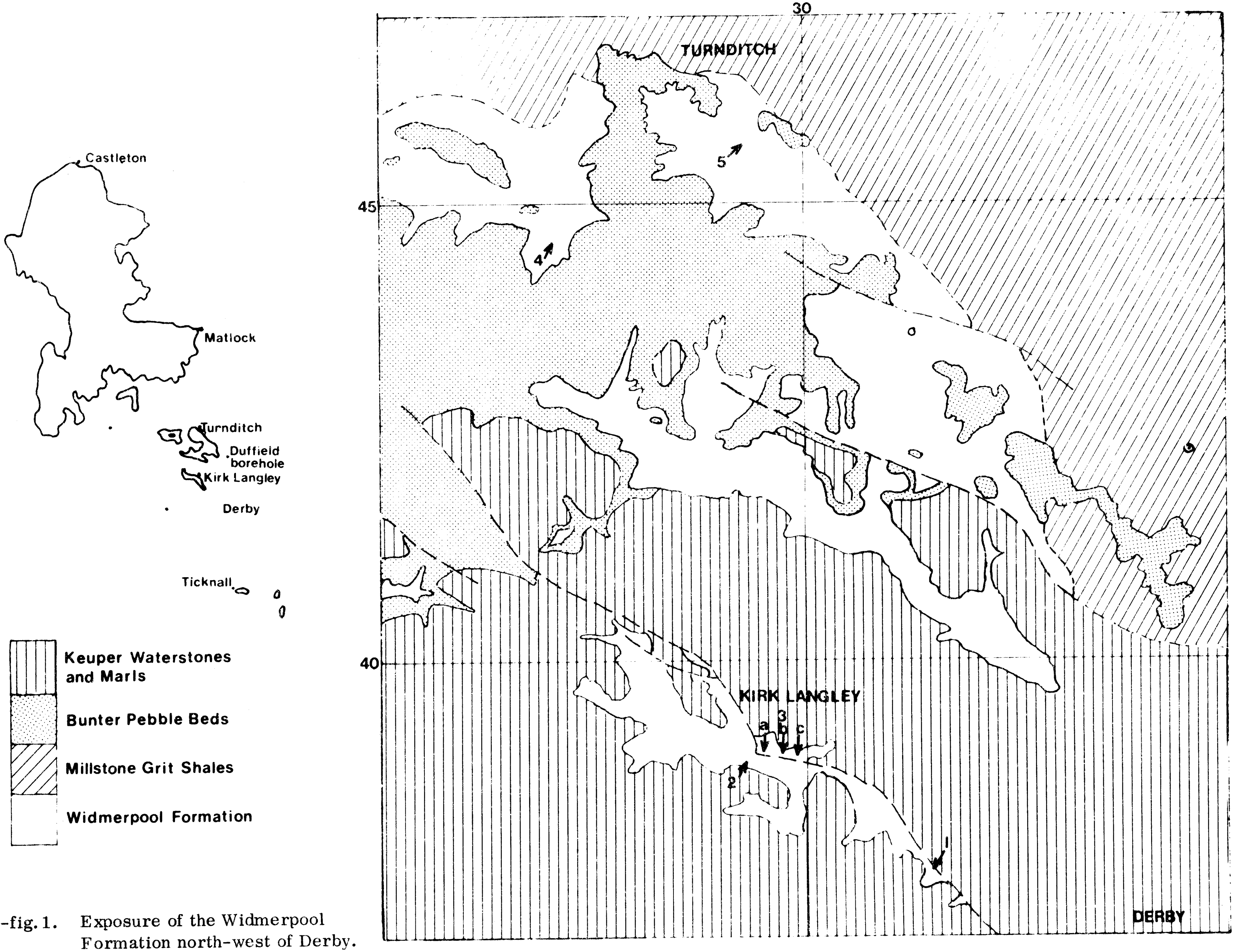
(1) A. For details of the measured sections, see appendix p. 114 et. seq.

Mercian Geol. vol. 6, No. 2, 1977,
pp. 103-117, 5 text-figs. Appendix.



Text-fig. 1. Exposure of the Widmerpool Formation north-west of Derby.

microcline, and fragments of quartzite and schist. Biogenic clasts, mainly crinoid columnals are also present. The sandstone has a calcite cement and is stained by haematite.

(iii) Flagshaw Brook, Kirk Langley A. Along the stream section three exposures of the Widmerpool Formation were noted.

(a) SK 29453900 Some 0.6 m of clays and sandstones are exposed in the bank of the stream. In the middle of the sequence there is a fine grained (100-200 μm) yellow-grey flaggy sandstone (0.14 m) thick with a scoured base, composed of angular, strained quartz (80% - 90%) and grains of labradorite, microcline and fragments of quartzite and volcanic rocks. The base of the sandstone shows prod and groove casts, which indicate a mean direction of palaeoflow (current) towards 342°.

(b) SK 29613896 A small exposure, (0.18 m) in the stream bed reveals 0.13 m of grey clay interbedded with a friable, fine-grained (100 - 150μm) yellow-brown sandstone 0.05 m thick. This sandstone is composed of angular strained quartz (90%) with fragments of quartzite and volcanic rocks and grains of labradorite. Its scoured base shows prod and groove marks, which indicate a mean direction of palaeoflow towards 315°.

(c) SK 29813892 In the bank at this locality some 1.2 m of sandstones, siltstones and mudstones are exposed. Generally at least 50 - 60% of the sandstones are composed of angular quartz grains showing strained extinction. Fragments of quartzite are common; grains of microcline and labradorite and volcanic rock fragments are also present. Some of the units, between 0.02 and 0.065 m thick, fine upwards with fine to medium grained sands (150 - 300 μm) near the base and silts (20 - 50 μm) at the top. These sandstones are stained with haematite and have a calcite cement. The lowermost sandstone shows calcisiltite laminae (grain size 20-50 μm and quartz content 40%), alternating with fine grained quartz sand laminae (grain size 100 - 150 μm and quartz content 80%). This lowermost sandstone has a scoured base with prod, groove, bounce and brush marks which indicate a mean direction of palaeoflow towards 327°.

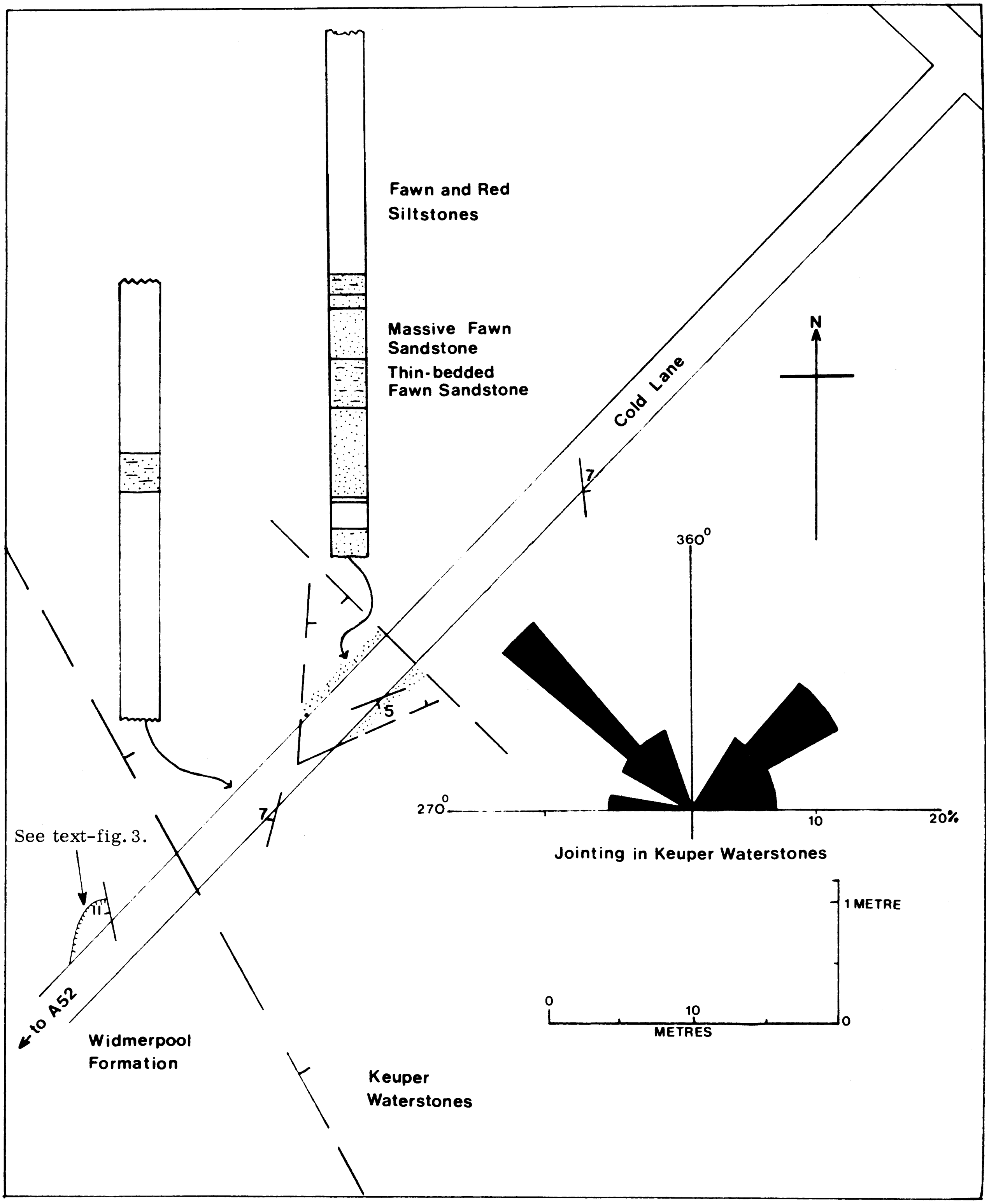
(iv) Black Brook, Hulland (SK 27304458) The stream exposure here shows about 1.9 m of black shales and mudstones. Some of the shales contain plant debris and calcareous concretions. Generally the mudstones contain thin layers (75 - 110 μm thick) of biogenic clasts, micrite and carbonaceous material. A small amount (up to 15%) of detrital quartz silt (10 - 25μm) is present. These are angular and show strained extinction.

(v) Cow Lane Quarry, Turnditch (SK 29314551) A. This is the most extensive sequence of the Widmerpool Formation exposed in the area totalling some 6.5 m. Unfortunately the quarry is considerably overgrown and at least a further 7 m of the succession is now covered over. The best exposure is the north face of the quarry and shows an alternating sequence of thin limestones, calcareous shales and clays.

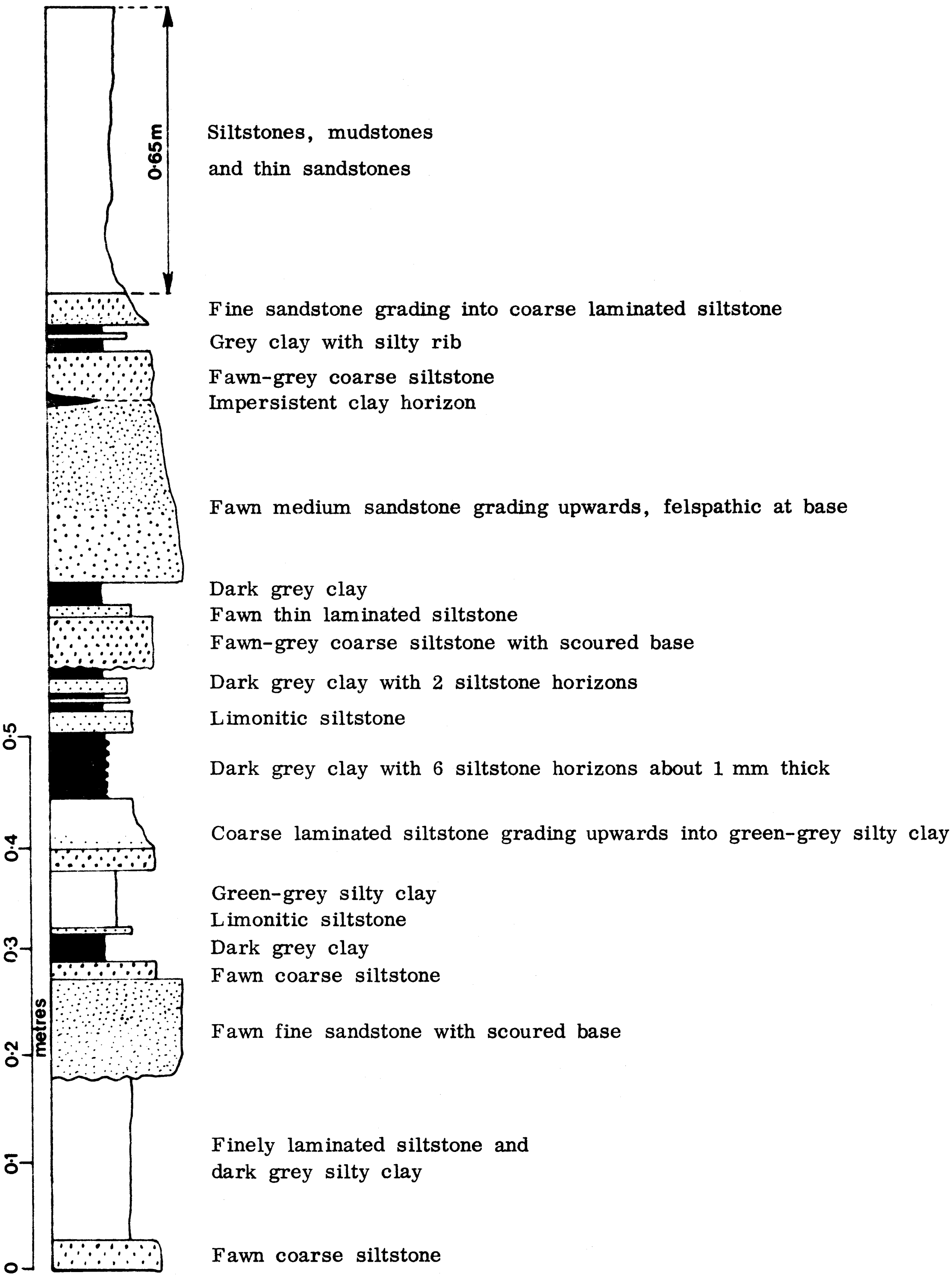
The sequence becomes more shaley towards the top. The limestones in the lower part of the succession are predominantly composed of crystalline calcite.

All the limestones have planar bases and tops and appear as distinct lithological units. Generally the limestones in the upper part of the succession contain a greater amount of detrital quartz. Some show a banding which gives the impression of grading (text-fig. 5b). Coarser layers containing large amounts of shell debris give way upwards to finer layers with detrital grains of quartz. Most of the limestones contain fragments of macro-fossils together with abundant microfossils. These include echinoderm plates and spines, shell fragments, platform conondonts, foraminifera and calcispheres. Detrital grains of quartz in these limestones rarely amount to more than 5% of the rock, they are angular, show strained extinction and are generally 50 - 150μm in size, although some attain 300μm.

On the east side of the quarry (SK 29484547) a small exposure some 0.72 m in thickness shows 0.5 m of mudstones underlain by over 0.22 m of a coarse sparite (300 - 500 μm). This limestone contains fragments of crinoids, brachiopods and echinoderm plates. Also present are angular grains of strained quartz, 50 - 100 μm is size together with quartzite fragments.



Text-fig. 2. Geological sketch map of Cold Lane, Mackworth, (SK 31363770)



Text-fig. 3. Detailed section of the Widmerpool Formation, Cold Lane, Mackworth

Sediment Transport

At all the localities the sandstones and detrital limestones contain grains of quartz showing strained extinction, microcline and labradorite and fragments of quartzite, schist and volcanic rocks. The grains and fragments would suggest that the sediments were derived from an igneous and metamorphic terrain exposed during Upper Visean times. The nearest area would have been the Charnwood Forest region to the south-east. The orientation of current markings support this suggestion. The vector mean for all the current marks observed (Table 1) is 331° with a range from 309° to 354° (text-fig. 4).

Table 1

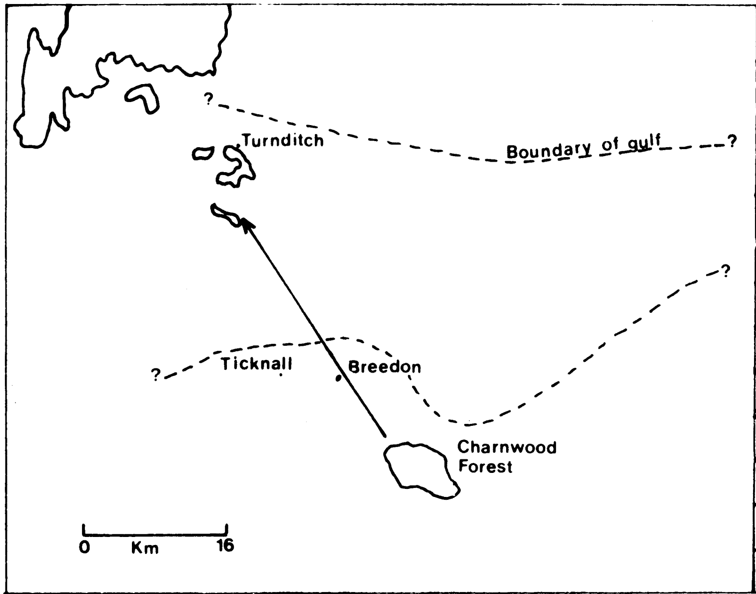
Locality	Grid. Ref.	Sediment transport directions (in degrees).
Mackworth	SK 31363770	332. 333. 325. 323. 328. 327. 338. 339. 340. 310. 328. 331. 338. 309. 338. 310. 328. 332. 329. 330.
Kirk Langley	SK 29453900	345. 354. 343. 338. 342. 351. 345. 340. 331. 325.
Kirk Langley	SK 29613896	320. 318. 311.
Kirk Langley	SK 29813892	338. 336. 322. 328. 330. 328. 318. 311. 329. 331.

Synthesis

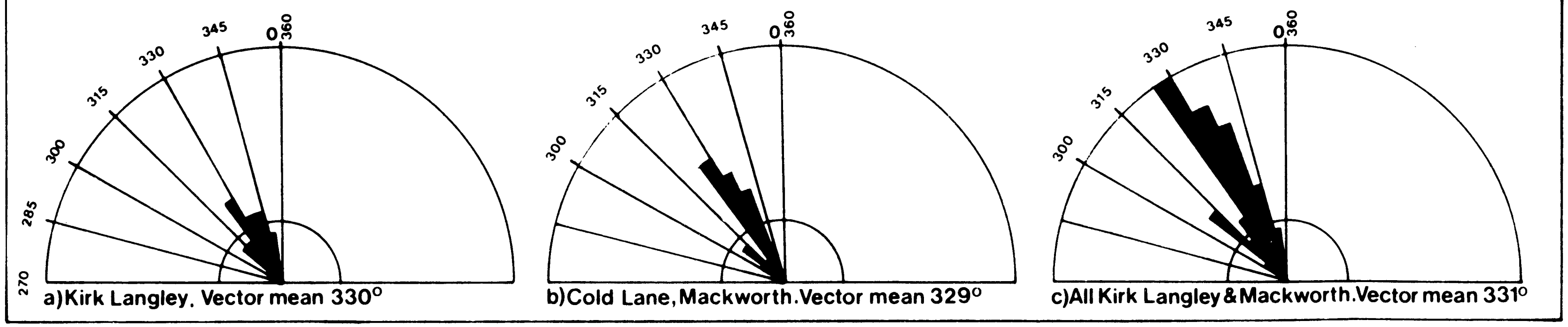
Although the Widmerpool Formation as recorded in the Duffield Borehole (I. G. S. 1967, 1968) ranges in age from the upper part of B_2 to the top of P_2, it is not possible to date the small surface exposures described or to correlate them with each other or with the borehole logs. However it seems reasonable to suggest that they may lie within the uppermost 120 m of the Duffield borehole sequence as no surface exposures of the Upper Dolerite Sill a prominent lithological unit found in the upper part of the Duffield bore-hole, have been observed. This would imply a P_2 age for all the surface exposures.

Other rock exposures of probable P_2 age are found on either side of the Widmerpool Formation outcrop, near Matlock (A) to the north and at Ticknall (A) to the south. Near Matlock the Cawdor limestones and shales are exposed at Cromford Station (SK 302574) and at the western end of Cawdor Quarry (SK 384606) (A).

At Cromford some 5 m of black calcareous shales are exposed and at Cawdor Quarry there is a sequence of cherty limestones and shales passing upwards into black calcareous shales totalling 16 m. Little or no detrital quartz was found in the limestones at Cawdor quarry but a fauna of crinoid columnals, brachiopod and bivalve shells, echinoderm plates and calcispheres was noted. At Ticknall (SK 362239) some 7 m of nodular grey limestones interbedded with shales are seen passing upwards into 4 m of buff sandy limestones. The latter consist of up to 50% angular quartz grains, (50 - 300μm) showing strained extinction. In addition to the grains of quartz, orthoclase and andesine, fragments of quartzite, schist and volcanic rocks are present. The beds of limestone comprise quartz rich and calcite rich layers. The composition of the detrital grains in these limestones is similar to that found in the Widmerpool Formation sequences, and may suggest a similar derivation, from the southern margin of the basin.



Class Interval	298 389		2961 3896		2945 3900		Kirk Langley All a		314377 b		ALL c	
	No	%	No	%	No	%	No	%	No	%	No	%
350·54	–	–	–	–	2	20	2	8·7	–	–	2	4·7
345-49	–	–	–	–	2	20	2	8·7	–	–	2	4·7
340-44	–	–	–	–	3	30	3	13·0	1	5	4	9·3
335-39	2	20	–	–	1	10	3	13·0	4	20	7	16·3
330-34	3	30	–	–	1	10	3	13·0	5	25	8	18·6
325-29	3	30	–	–	1	10	4	17·4	6	30	10	23·2
320-24	1	10	1	33	–	–	2	8·7	1	5	8	7·0
315-19	1	10	1	33	–	–	2	8·7	–	–	2	4·7
310-14	1	10	1	33	–	–	2	8·7	2	10	4	9·3
305-09	–	–	–	–	–	–	–	–	1	5	1	2·3
TOTALS	10	100	3	99	10	100	23	99·9	20	100	43	100·1



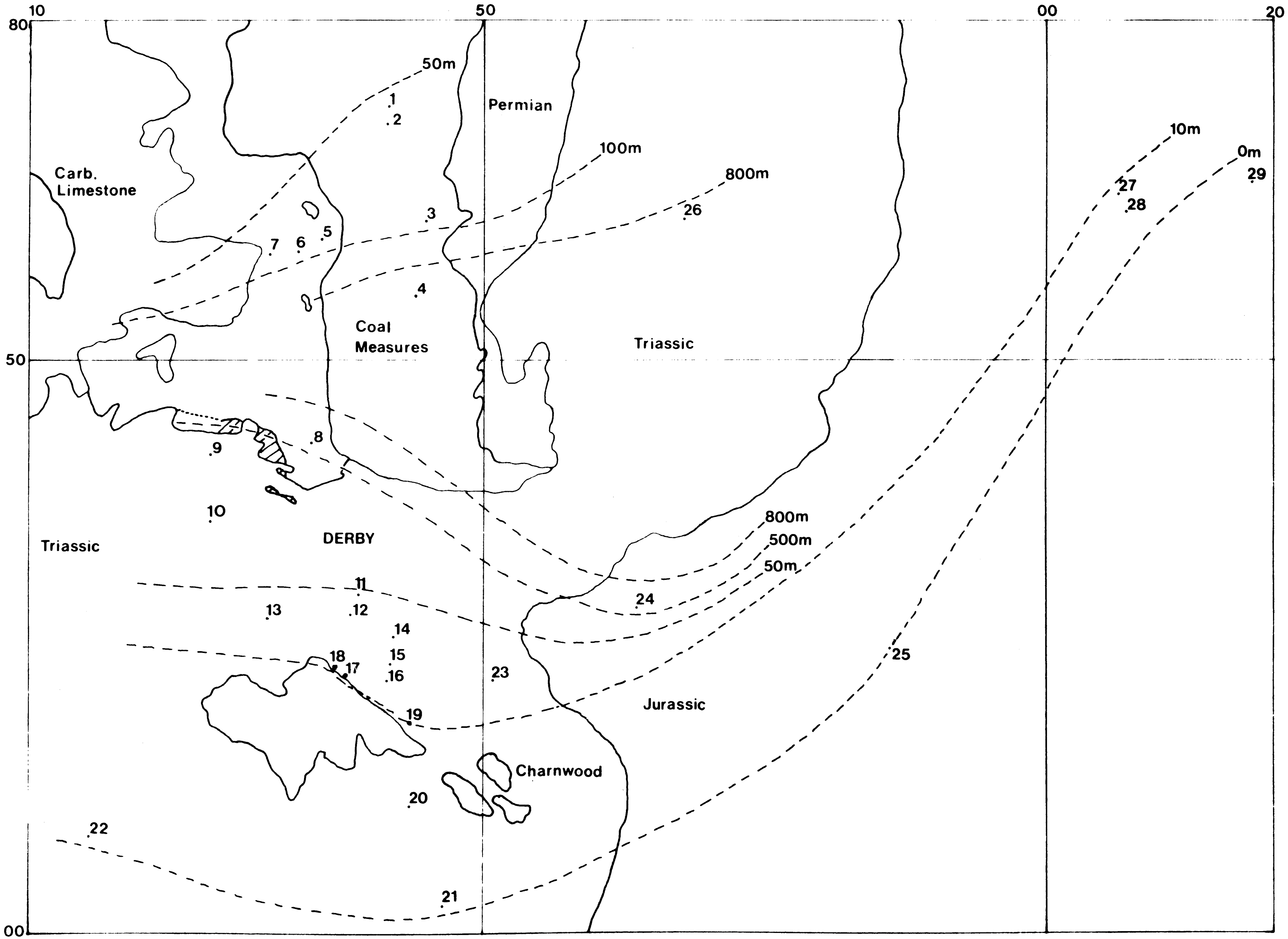
a)Kirk Langley. Vector mean 330°

b)Cold Lane, Mackworth. Vector mean 329°

c)All Kirk Langley & Mackworth. Vector mean 331°

Text-fig. 4. Palaeoflow directions for Kirk Langley and Mackworth

	Borehole	Thickness in metres of probable P_1 - P_2 age	Lithology
1.	Brimington	53	Limestone
2.	Calow No. 1	29	Limestone & mudstone
3.	Hardstoft No. 1.	37	Limestone
4.	Ironville No. 2.	11+	Limestone
5.	Highoredish	90	Shale on limestone
6.	Tansley	14+	Shale on limestone
7.	Johannesburg No. 9	18+	Shale on limestone
8.	Duffield	525	Mudstones, sandstones & thin limestones
9.	Brailsford	47+	Shale & thin limestones
10.	Trusley	54+	Shale & thin limestones
11.	Chellaston No. 6	34	Sandy limestone & shale
12.	Stanton	15+	Shale & thin limestones
13.	Repton Lawn Bridge	2+	Shale & thin limestones
14.	Castle Donington	10+	Shale & thin limestones
15.	Tonge	25	Shale & limestone
16.	Breedon Cloud	24	Dolomite
17.	Dimminsdale	12	Shale
18.	Calke	10	Shale
19.	Grace Dieu	10	Shale
20.	Ellistown Colliery	8	Dolomite, sandstone & shale
21.	Stockhouse Farm	8	Conglomerate & sandstone
22.	Whittington Heath	1	Limestone
23.	Hathern	30+	Shale & sandstones & thin limestones
24.	Widmerpool	799	Mudstones & thin limestones
25.	Sproxton	0	- - -
26.	Eakring No. 146	898	Limestone & shale
27.	Nocton No. 1.	0	- - -
28.	Dunston No. 1.	9+	Mudstones
29.	Stixwould	0	- - -



Text-fig. 5. Isopachytes for P_1 - P_2 zones within the East Midlands

Using borehole data compiled from Boulton (1934), Edwards (1951), Falcon & Kent (1960), Fox-Strangways (1905), I.G.S. (1967, 1968) Lees & Taitt (1945), Mitchell (1954), Mitchell & Stubblefield (1941), Parsons (1917) and Smith *et al* (1967) an attempt (text-fig. 5), has been made to draw isopachytes for the P_1 and P_2 zones and to consider the broad palaeogeography of the area. It appears that the Upper Visean shoreline in the south ran along the northern edge of Charnwood Forest, which George (1958) suggested was part of a more extensive land-mass running E - W across the Midlands and central Wales, referred to as the "Mercian Highlands". Adjacent to the land area there appears to be a narrow carbonate shelf border which passes northwards into the basin of the Widmerpool Gulf. To the north the Derbyshire Massif rises gently within the sea to form a broad carbonate platform. The borehole information points to uplift of the Mercian Highlands with detritus being carried northwards into a subsiding basin, which is bordered to the north by a more stable platform area.

It is expected that further studies of cores from the Duffield and Trusley boreholes together with examination of the surface exposures around Ashbourne and Kniveton will refine the palaeogeographic picture. Finally spores obtained from a number of localities will help in the dating and possible correlation of the surface exposures.

Acknowledgements

The authors wish to thank Dr. Paul Bridges for critically reading the manuscript and for his helpful comments and Mrs. Lesley Bull for typing the draft.

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Michael F. Stanley, A.M.A.,
Derby Museums & Art Gallery,
The Strand,
Derby, DE1 1BS.

John D. Weaver, B.Sc., Ph.D., F.G.S.,
Division of Geology,
Derby College of Art & Technology,
Kedleston Road,
Derby, DE3 1GB.

Appendix - Detailed Sections

(ii) KIRK LANGLEY (old Quarry SK 29163888)

	m
Drift	-
Yellow-fawn-grey sandstone, medium grained, planar base	0.42
Yellow-fawn clay	0.06
Brown sandstone	0.015
Sandy red-brown clay	0.035
Yellow and pink-grey sandstone, beds 0.05m. thick	0.61
Silty grey and pink clay with thin fine-grey sandstone layers	0.06
Massive buff-grey sandstone	0.36
Pink-grey clay with siltstone layers	0.07
Pink-grey sandstone	0.025
Pale-grey clay	0.035
Yellow-grey sandstone	0.115
Pale-grey clay	0.02
Grey and pink-grey sandstones, poorly developed scours at base	0.035
Pale-grey clay	0.015
Fawn-grey sandstone	0.08
Grey clay	0.02
Yellow-grey sandstone	0.085
Grey clay	0.01
Grey and fawn-grey flaggy sandstones	0.30+
Total:	2.37

(iiia) KIRK LANGLEY Flagshaw Brook (SK 29453900)

Drift	-
Grey clay	0.16
Yellow and grey silty clay	0.05
Yellow-brown silts	0.01
Yellow-grey sandstone with scoured base, flaggy & plant fragments	0.14
Grey plastic clay with silty bands	0.19
Grey fine grained sandstone	0.03+
Total:	0.58

(iiic) KIRK LANGLEY FLAGSHAW BROOK (SK 298389

Finely laminated brown-grey siltstone	0.10
Alternating laminae of grey and fawn sandstone with mica?	0.025
Green-grey sandstone, irregular base	0.12 - 0.17
More rubbly fawn sandstone	0.05
Grey silty clay with darker grey bands	0.02
Fawn-grey silty clay with small iron nodules	0.02
Grey silty clay with darker grey bands	0.03
Grey sandstone with planar base	0.06 - 0.065
Brown-grey silty mudstone	0.02
Dark grey-brown sandstone	0.015 - 0.025
Dark-grey shaly silty mudstone, calcareous	0.17
Grey sandstone with planar base	0.02 - 0.025
Dark-grey silty mudstone	0.07

	m
Fawn laminated siltstone	0.04
Fawn-grey silty mudstone	0.03
Dark-grey sandstone with planar base	0.05 - 0.055
Dark-grey and light-grey laminated silty mudstone	0.13
Sandstone with scoured base, calcareous	0.03 - 0.035
Grey silty mudstone	0.10 +
Total:	1.18

(v) COW LANE QUARRY TURNDITCH (SK 29314551)

Brownish-grey muddy shale - paper shale	0.05
Brown mudstone	0.02
Yellow-brown limestone, planar base	0.03
Brownish-grey muddy shale	0.165
Grey limestone, planar base	0.065
Brown-grey muddy shale	0.02
Siltstone band	0.002
Brown-grey muddy shale	0.04
Grey limestone, irregular base	0.01 - 0.025
Brown silty mudstone	0.015
Brownish-grey muddy shale	0.015
Brown mudstone	0.01
Brownish-grey laminated muddy shale	0.13
Grey-brown calcarous mudstone	0.025
Grey-brown, iron stained muddy shale	0.21
Grey limestone, planar base	0.08
Grey muddy calcareous shale	0.07
Grey limestone	0.01
Grey muddy shale	0.28
Grey mudstone	0.01
Brownish-grey limestone, planar base	0.165 - 0.18
Brownish-grey muddy calcareous shale	0.115
Greyish-fawn siltstone	0.01
Brownish-grey calcareous shale	0.42
Grey muddy limestone, planar base, laminated	0.04
Grey muddy shale	0.07
Beef calcite	0.01
Grey limestone, planar base	0.03
Calcareous mudstone	0.03
Grey muddy shale	0.11
Grey muddy limestone, planar base	0.07
Grey-brown muddy shale, laminated	0.205
Grey limestone, planar base	0.32
Grey brown limy muddy shale	0.125
Calcite band	0.004
Grey-brown calcareous shale	0.12
Grey-brown limestone (0.15 m thick) thickening locally	0.10 - 0.34
Grey-brown calcareous shale	0.22
Limonitic horizon	0.01
Grey-brown calcareous shale	0.04
Hard grey calcareous shale	0.13
Grey and grey-brown limestones, planar top and base	0.05

	m
Dark-grey muddy shale	0.20
Dark-grey muddy limestone, planar top and base	0.08
Dark-grey platy limestone	0.03
Dark-grey muddy shales	0.13
Hard dark-grey limestone	0.03
Dark-grey soft muddy shales	0.11
Grey limestone with planar base grading upwards into shales	0.205
Thin platy limestones with shale partings (5 mm thick)	0.04
Dark-grey calcareous shale-soft	0.14
Dark-grey harder calcareous shale	0.36
Iron-rich horizon	0.01
Dark-grey clay	0.10
Grey limestone	0.025
Grey clay	0.12
Grey limestone, planar base	0.135
Grey muddy shale	0.05
Hard grey calcareous shale	0.035
Grey shale	0.26
Light grey limestone, planar base	0.035
Grey shale	0.08
Light-grey limestone	0.21
Grey shale	0.03 +
Total:	6.426

Cawdor Quarry (W. end) (SK 284606)

Black calcareous shales, some paper shales, brachiopods and bi-valves	4.0
Massive black limestones	1.0
Black limestone	0.2
Black calcareous shales	2.5
Black limestone	0.4
Black shales	0.25
Dark-grey-black limestone	1.0
Black shales	0.25
Dark grey and black limestones, cherty with thin shaly partings	6.0 +
Total:	15.60

TICKNALL SUCCESSION (Combined localities SK 362239)

Thin bedded yellow-brown sandy limestone	1.75
Silty grey and pink-grey clay	0.04
Buff sandy limestone with grey clay partings	0.06
Silty grey and pink-grey clay	0.05
More massive buff sandy limestone	2.10
Light-grey limestone	0.18
Shell band	0.075
Grey and pink-grey limestones	0.46
Shell band-giganto productids	0.10 - 0.18
Fawn-grey and grey limestones	0.53

Buff and pink shale	0.04	
Medium grey limestone	0.70	
Dark-grey muddy shale	0.15	
Dirty grey limestone	0.15	- 0.20
Grey-brown shale	0.10	
Medium grey knobbly limestone	0.055	
Grey-brown shale	0.04	
Medium grey limestone	0.27	
Thin dark-grey clay and shaly limestone	0.03	
Medium-grey limestone	0.10	
Dark-grey shaly limestone and grey clay	0.09	
Medium-grey limestone crystalline	0.15	- 0.17
Grey clay with thin dark-grey shaly limestone	0.20	
Massive lighter-grey limestone, more regular base	0.64	
Grey shale	0.03	- 0.06
Nodular grey limestone	0.07	- 0.14
Grey brown shale	0.04	- 0.08
Nodular light-grey limestone	0.21	
Dark-grey-brown shale	0.08	- 0.10
Medium grey, more well bedded limestone impersistent shaly parting in middle	0.47	
Grey brown shale	0.11	
Nodular, light-grey limestone with thin shaly parting in middle	0.16	
Dark grey and grey-brown shale with thin impersistent limestone in middle	0.14	
Thin rubbly limestone and grey-brown shale horizons - units 0.10 - 0.15 m in thickness	1.25 m+	
Total	10.93	

PALAIOSPHAERIDIUM, A NEW ACRITARCH GENUS FROM THE TREMADOC OF ENGLAND

by

S. M. Rasul

Summary

A new acritarch genus, *Palaiosphaeridium* gen. nov. is recorded from the Shineton Shales of the Wrekin district, Shropshire, England, where it occurs throughout the Tremadoc succession. The genus is represented by the two new species, *P. kamax* sp. nov. (type species) and *P. mikram* sp. nov.

Introduction

The present investigation is based on fifty-two samples collected from Tremadoc rocks exposed in the Wrekin district of Shropshire, England, where the representative formation is the Shineton Shales. A detailed geological account of this area was given by Stubblefield and Bulman (1927). The type area of the Tremadoc Series exposed in North Wales is highly metamorphosed and consequently unsuitable for acritarch study. However, the stratal equivalents of the Tremadoc Slates of North Wales are well represented in the Wrekin district and are largely undeformed. The general succession of the Shineton Shales and the macrofossil contents of individual beds are as follows:

General succession	Macrofossils
Arenaceous Beds	*Lingulella nicholsoni* and *Acrotreta sabrinae*
Shumardia Pusilla Beds	*Shumardia pusilla*. *Agnostos calvas* var. *latemarginalis*,*A. callavei* and *A. dux*. *Euloma monile*, *Parabolina triarthra*, *Asaphellus homfrayi*, etc.
Brachiopod Beds	*Obolus quadratus*, *Lingulella nicholsoni*, etc.
Clonograptus Tenellus Beds	*Clonograptus tenellus*, *C. tenellus* var. *callavei*, *Leptoplastus salteri*, *Broggeria salteri*, etc.
Transition Beds	*Clonograptus tenellus* and *C. tenellus* var. *callavei* *Shumardia curta*, *Dictyonema flabelliforme*, etc.
Dictyonema Flabelliforme Beds	*Dictyonema flabelliforme*, *Acrotreta nicholsoni*, *Bellerophon*, etc.

In general, the highest beds of the Shineton Shales tend to be arenaceous with decline of acritarch species but with this exception, the thick mass of shales is homogeneous in character and rich in acritarchs. The rocks are usually bluish-grey in colour but occasionally weathered to olive-green. For an outline account of the acritarchs, *Mercian Geologist* readers are referred to Sarjeant (1967), and to Downie (1973).

In general, assemblages of acritarchs observed in the Shineton Shales are in excellent state of preservation (Rasul, 1974). Downie (1958) calculated that about 100,000 individuals are

Mercian Geol, vol. 6, No. 2, 1977,
pp. 119-121, Plate 5.

present in each gram of rock from the *Shumardia Pusilla* Beds. The present author has discovered some new forms of acritarchs which are assigned to two species of a new genus, *Palaiosphaeridium*. All type specimens described in this paper are in the collections of the micropalaeontology laboratory, Department of Geology, University of Sheffield.

Systematic description

Group ACRITARCHA Evitt, 1963
Subgroup ACANTHOMORPHITAE Downie, Evitt and Sarjeant 1963
Genus *Palaiosphaeridium* gen. nov.
Plate 5, figs. 1-3.

Derivation of name: Greek, *palaios*, ancient and Greek, *sphaira*, ball.

Diagnosis: Body spherical, single walled, thin, smooth; wall ornamented with distinct, hollow, cylindrical processes, variable in length and width and nature of the tips; the tips are usually round, sometimes flat, rarely pointed; tips of a few processes are occasionally forked. The inner space of the processes communicates with the body cavity.

Type species: *Palaiosphaeridium kamax* sp. nov., Brachiopod Beds, Tremadocian, Wrekin district, Shropshire, England, described below.

Remarks: The genus which most closely resembles *Palaiosphaeridium* is *Archaeohystrichosphaeridium* (Timofeyev 1959), but the new genus is distinguishable from the latter by its typical cylindrical processes. Timofeyev included many dissimilar forms in *Archaeohystrichosphaeridium* and no type species was designated for the genus. It is therefore invalid according to the International Code of Botanical Nomenclature. Leoblich and Tappan (1976) chose a type species making *Archaeohystrichosphaeridium* a junior synonym of *Cymatiogalea* Deunff 1961. *Baltisphaeridium* (Eisenack) Eisenack 1969 differs from *Palaiosphaeridium* gen. nov. in having processes not communicating with the body cavity and possessing a larger size range of central body.

Palaiosphaeridium kamax sp. nov.

Plate 5, figs. 1 and 2.

Derivation of name: Greek, *kamax*, pole, post, shaft.

Diagnosis: Body spherical, may appear ellipsoidal on being collapsed; wall is thin, smooth; processes are numerous, hollow, cylindrical, pillar like; tips are usually rounded, rarely angular or forked; sometimes they are flat; the processes are quite variable in width.

Holotype: Slide ref.: B12/1-267.1187, Brachiopod Beds, Tremadocian, Wrekin district, Shropshire, England. (Grid Ref.: SJ 589038).

Dimensions: Body diameter 21 (min). - 44 μm (max).; length of processes 11 - 45% of body diameter; width of processes 1.5 - 9.5 μm; number of processes in optical section 9 - 20.

Holotype: Body diameter 25.5 μm; length of processes 11 - 24% of body diameter; number of processes in optical section 11.

Remarks: Specimens of this species shows great variability in width of their processes.

Palaiosphaeridium mikrum sp. nov.

Plate 5, fig. 3

Derivation of name: Greek, *mikras*, small, little, referring to smaller size of the test.

Diagnosis: Body spherical, small, smooth and thin walled; processes are hollow, cylindrical; their tips are rounded or sometimes pointed.

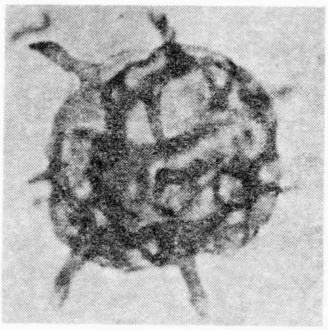

Fig. 1. *Palaiosphaeridium kamax* sp. nov (holotype) × 1250. Slide ref.: B12/-267.1187.

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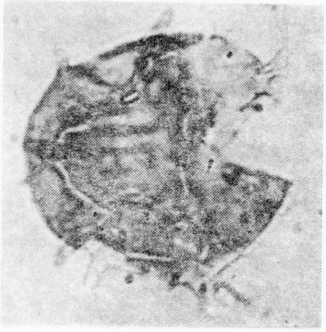

Fig. 2. Another specimen of *P. kamax* showing a partial equatorial split. × 1250. Slide ref. B 14/1 - 572.138.

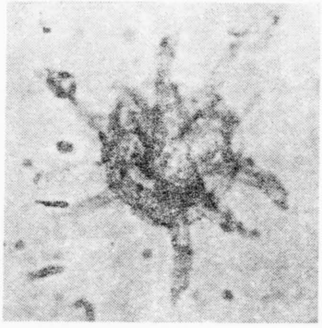

Fig. 3. *P. mikram* sp. nov. × 1250 (holotype). Slide ref.: B3/1 - 49.1279.

Holotype: Slide ref.: B3/1-49.1279, Brachiopod Beds, Tremadocian, Wrekin district, Shropshire, England.

Dimensions: Body diameter 11 (min) - 16 μm (max); length of processes about 25-60% of body diameter; number of processes in optical section 7-15.

Holotype: Body diameter 16 μm; length of processes about 50% of body diameter; number of processes in optical section 15.

Remarks: *Palaiosphaeridium mikram* sp. nov. can be distinguished from *P. kamax* by its smaller size. Although this species comes within the size range of genus *Micrhystridium* Deflandre, it is more closely related to the genus *Palaiosphaeridium* in respect of its cylindrical processes.

Acknowledgements

The present investigation, a part of doctoral thesis, was carried out at the University of Sheffield under the supervision of Processor C. Downie.

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S. M. Rasul,
Department of Geology,
King's College,
University of London,
London.

AN UNUSUAL OCCURRENCE OF SANDS AND GRAVELS IN DERBYSHIRE

by

Cynthia V. Burek

Summary

A block of sand and gravel, located within glacial till above the River Lathkill at Raper Pit, Derbyshire, is described in detail. The block provides evidence of pre-till transportation and deposition, probably as fluvioglacial outwash material, although other sources are considered. This occurrence is unique on the Derbyshire limestone and bears no relationship to the pocket sand deposits found elsewhere on the plateau, which are of a different lithological composition and age. Sedimentary structures are still preserved in the unconsolidated sand suggesting that transportation of the block occurred whilst it was in a frozen state. The deposit may shed light on climatic events immediately prior to the deposition of till in the northern Derbyshire area.

Introduction

A report on the preliminary investigation of a temporary exposure of sands and gravels, incorporated within glacial till, is presented in this paper. The exposure, unique on the Derbyshire limestone plateau, was first noticed in October 1974. This excavation is now partly filled in, and the deposit is no longer readily available for consultation. There are no published accounts of similar deposits in this area.

Glacial till is present to a limited extent on the limestone plateau, text-fig. 1; much less extensive than the deposits found around its margins on the outcrops of Millstone Grit and Edale Shales. This unusual exposure occurs above the River Lathkill and lies in a relatively flat interfluve area known as Haddon Fields, at an average elevation of 200 m. Traversing the area are several old lead veins of which Long Rake, near Youlgreave, has been recently quarried for fluorite. It is on the north face of East Raper Pit, a single excavation on this vein, that the unique sand and gravel deposit occurs (SK 217652).

Elsewhere on the Derbyshire limestone plateau, pocket sand deposits have been described (Yorke, 1961, Boulder, 1971) resting in hollows. Blue clay overlying the sand pockets has been dated Mio-Pliocene. Thus the sand and gravel deposits described below and the sand pockets are not contemporary in age. Further they bear no similarity in appearance either structurally or lithologically.

The Glacial Till

The glacial till in the vicinity of the Raper Pits, lies above both the Carboniferous Limestone and the Edale Shale, attains a maximum thickness of 15 m and feathers out east and west with a fall in altitude. Capping the till is 1 - 2 m of 'loess' which has been leached in the top 60 cm. The 'loess' appears to lie conformably over the till and the only evidence which might separate the two deposits in time, is frost-shattered boulders in the uppermost part of the till (Ford, personal communication). However, based on previously established river terrace sequences [1], clay translocated soil profiles [2], and glacial till distribution and sequences established elsewhere in the U.K. [3], it is thought that two different cold periods are represented by the till and 'loess' deposits. Therefore from evidence also

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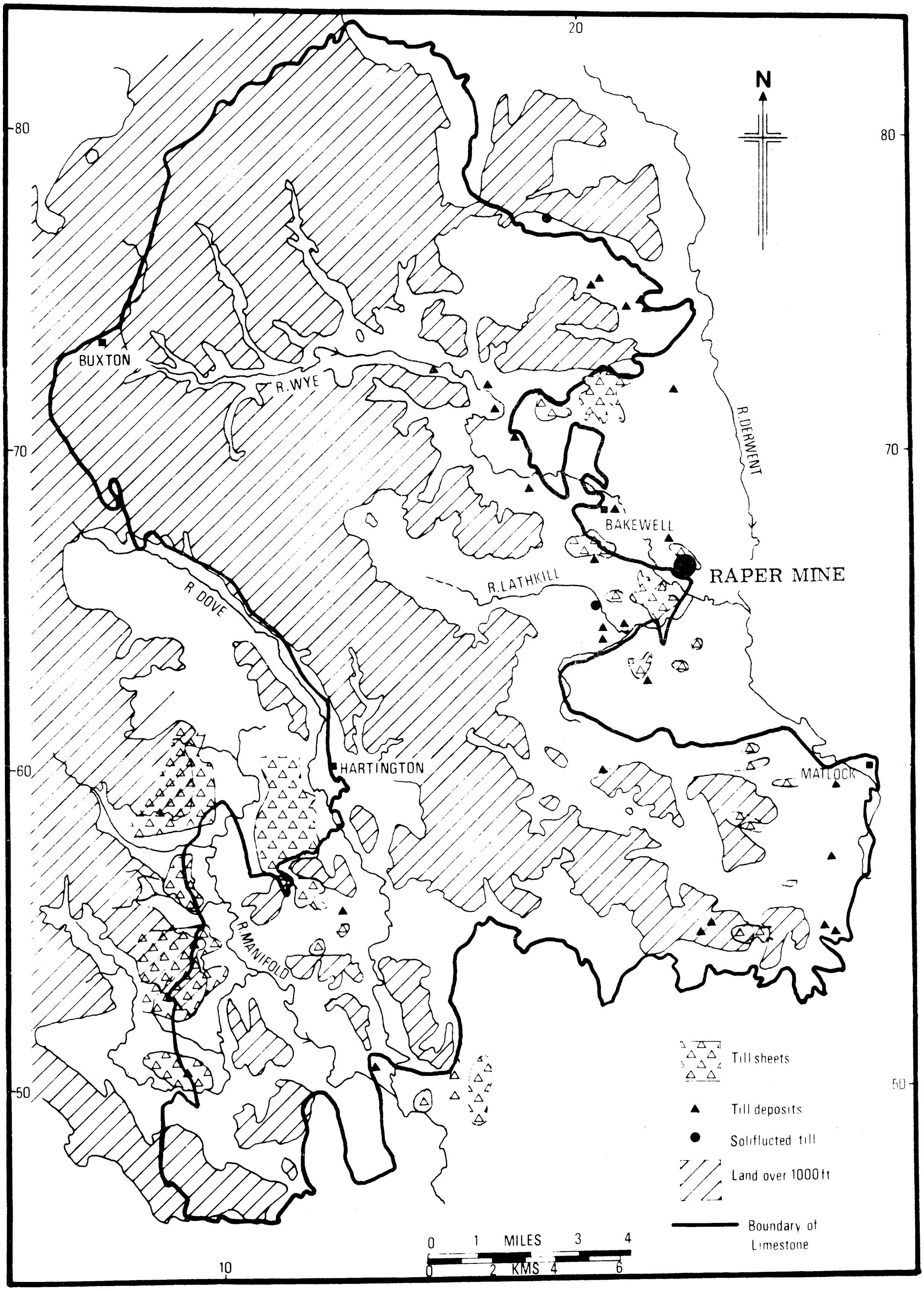
[1] Johnson, 1954; Waters and Johnson, 1958; Clayton, 1968.

[2] Cazalet, 1969.

[3] Mitchell, et. al., 1973.

Mercian Geologist, vol, 6, No. 2, 1977.
pp. 123-130, 3 text-figs., Plates 6 & 7.

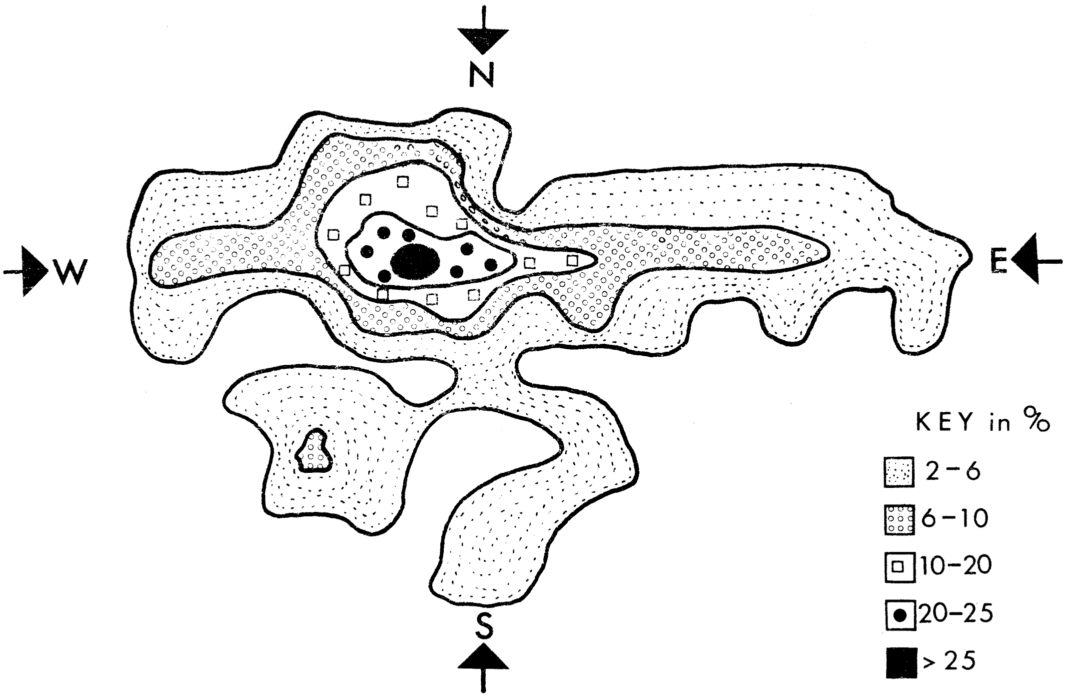


Text-fig. 1. Distribution of glacial till on the Derbyshire Limestone Plateau and the location of the Raper Pit.

based on altitude, location and weathering features, the till is generally thought to be Wolstonian in age and the 'loess', Devensian.

The boulder clay has a dark, yellowish-brown colour (Munsell Colour 10YR4/2 wet), and contains striated limestone erratics up to 1.5 m^3, shale fragments, weathered dolerite boulders and rounded Millstone Grit erratics set in a clay matrix. Only a few foreign or far-travelled erratics, eg., Shap Granite and Borrowdale Volcanic boulders have so far been found, despite systematic searching. It is concluded that this is primarily a locally derived till.

Pebble orientation of 50 erratics within the till on the north face (text-fig. 2), and the rare erratic rock types point to a north or northwest direction for the ice source, which agrees with the general idea of ice movement over the col at Dove Holes during the later part of the Pleistocene[4]. The sand and gravel block contained by the till would also be derived from a north or north-west direction.



Text-fig. 2. Pebble orientation diagram (based on 50 readings)

The Sand and Gravel Block

Within the confines of the exposure the block measured 1.3 × 2 m. Nothing is known of its extent at right angles to the face: it does not appear to be in the south wall of the excavation, 35 m away. It is a block of alternating sand and gravel layers which appears to have been tilted through 90° (text-fig. 3; Plate 6), and now lies approximately 5 m below the turf level, incorporated within the till. Current bedding, Plate 7, fig. 2) has been detected in one of the sand beds, determining the original orientation of the material and the sequence of deposition (Table 1).

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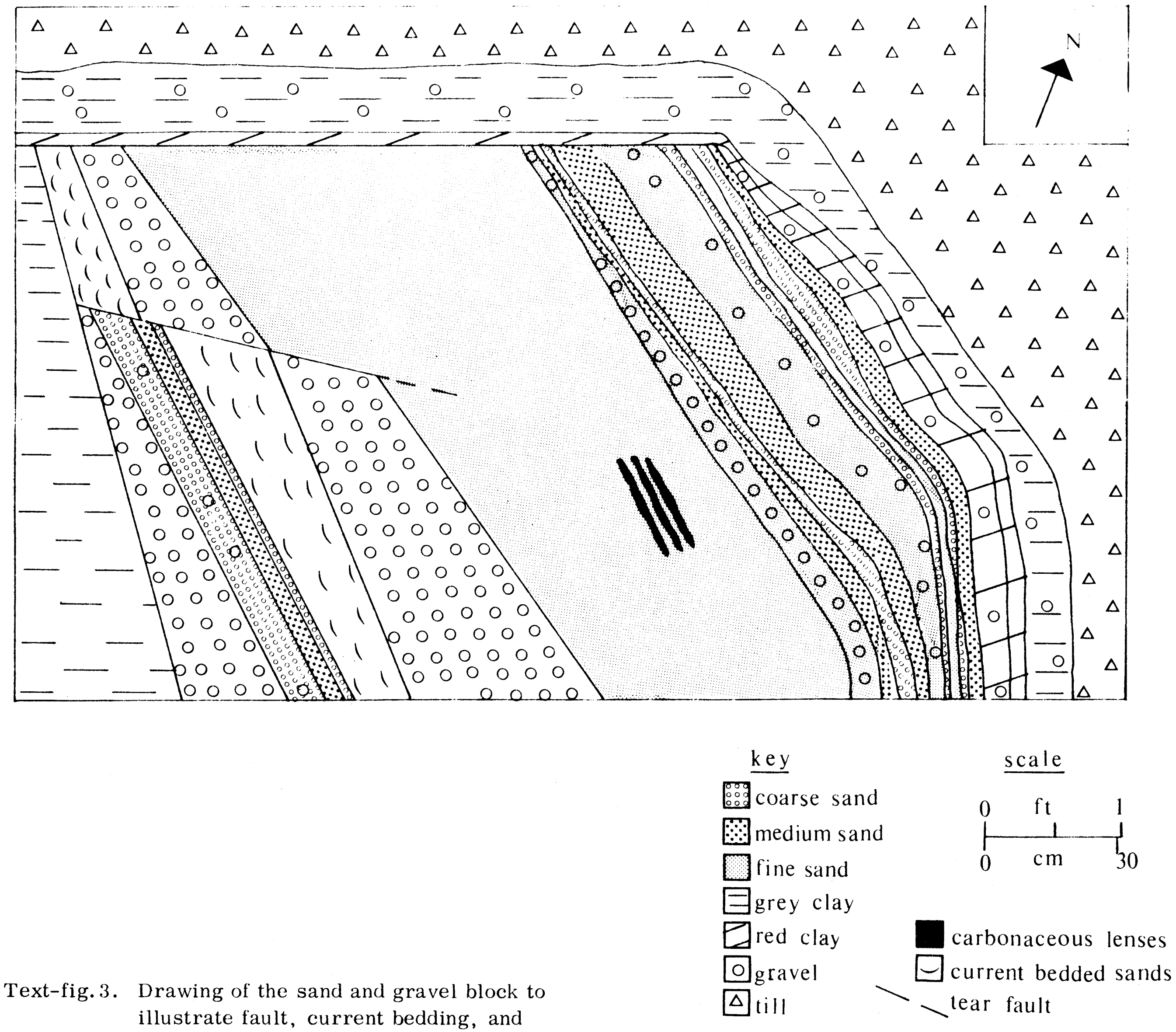
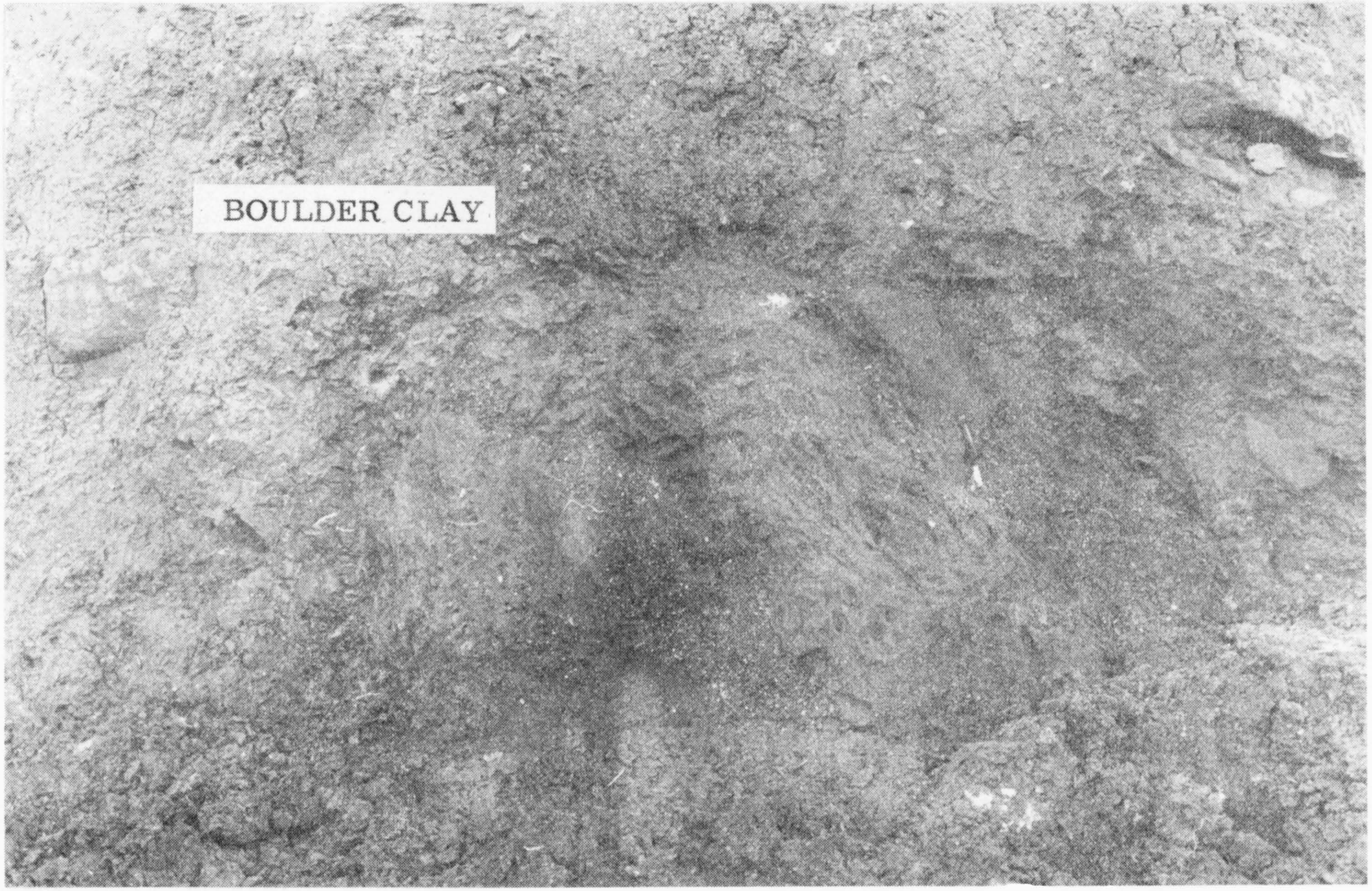
[4] Dalton, 1945, 1958; Waters and Johnson, 1958; Straw and Lewis, 1962; Burek, to be published.



Text-fig. 3. Drawing of the sand and gravel block to illustrate fault, current bedding, and carbonaceous lenses. Cf. Plate 6, opposite.

Plate 6



Block of sand and gravel within boulder clay cf. text-fig. 3.

Table 1 Sequence within the Block

		cms
22	Till	
21	Grey clay with pebbles	12.7
20	Red clay partially surrounding the block	2.5 - 5.4
19	Red clay with pebbles	7.6
18	Medium sand	5.1
17	Coarse sand	2.5
16	Fine sand	2.5
15	Coarse sand	2.5
14	Gravel in a sandy matrix	15.2
13	Medium sand	10.1
12	Coarse sand	2.5
11	Medium sand	2.5
10	Gravel in a sandy matrix	7.6
9	Fine sand with coal lenses occurring 12.7-22 cm from the top	27.2
8	Gravels	22.9
7	Current bedded sands	20.4
6	Coarse sand	2.5
5	Medium sand	5.1
4	Coarse sand	7.6
3	Gravel	7.6
2	Stoneless clay merging with	
1	Till	

A tear fault (Plate 7, fig.1) 36 cm from the top of the block shows a lateral displacement of about 26 cm. At the west end, above and below the fault, four sand and gravel layers are missing if the sequence here is compared with that of the east end. This indicates that erosion of the block probably took place before, or during, inclusion of the erratic within the till.

The above observations imply that in three dimensions, the deposit is an irregular block, included within the till. Transportation has resulted in some erosion, rotation, and dislocation. As the block has not been completely broken up and fragmented, it is assumed that it was frozen and has not moved far from its source.

The Origin of the Sand and Gravel

Theories on the origin of the sand and gravel deposit from which the block has been derived can only be considered as tentative because of the small exposure and unique occurrence. A number of possible source areas are considered.

The most likely origin would be fluvio-glacial, possibly as an outwash sand and gravel spread. The deposit could underlie the till in the vicinity of Raper Pit or be present at a similar or higher level away from the immediate area. The relationship between the block within the till and the underlying Edale Shales cannot readily be seen in the northern face. However, the southern face, 35 m away, exhibited bedrock lying 1 - 2 m below the northern lower limit of undisturbed till, indicating the absence of sand and gravel deposits between the till and bedrock. A similar relationship is visible in other faces of both the East and West Raper Pits; one would assume that this was the case on the north face where the contact is obliterated by quarry debris. If there were such deposits, they have long since been eroded away and were either incorporated within the till deposits further south or they were washed into the limestone joints and possibly into cave systems.

Similar sand and gravel deposits are known to occur above the Edale Shales to the north. Therefore the block could have been picked up from above the shale outcrop and transported south down the Wye valley.

A third explanation may be found in deposits associated with a pre-glacial course of the Lathkill River. The block could have been picked up from the former floodplain deposits, when it was flowing at a higher altitude. This would suggest a downcutting of 122 m to present river level, because of the present elevation of the block.

Whilst the alternation of fine, medium and coarse sands and gravels suggest fluvio-glacial deposition originally as outwash sands and gravels, the available evidence does not rule out en- or sub-glacial stream sedimentation. These deposits e.g. kames, are normally ill-sorted, current-bedded sands and gravels with ill-defined layering and are generally unlike the lithological characteristics of the block. As they are formed during the late stages of glaciation, they would normally be located, if found at all, in their original place of deposition. However, during another cold phase, the deposits could have been moved in the frozen state and retain their characteristics although rotated, eroded, and dislocated.

The Red Clay

Attention can now be focused on the red clay (20, Table 1, p. 126) which partially surrounds the block. The clay seems to be a transitional phase as it is neither part of the block, nor part of the till. Preliminary analytical work on this clay, which may eventually provide a clue to the depositional processes at work, has shown that it has a geochemical composition as indicated in Table 2. The table shows a significant difference between the composition of the red clay and both the block and till. The outwash material has high SiO_2 and Al_2O_3 values whereas the red clay has lower SiO_2 values but high Al_2O_3 and K_2O reflecting the higher clay mineral content.

Table 2 - Geochemical Data of Sand Inclusion Clay and Till Samples

in %	Block (average of 5 samples)	Clay	Till (6 samples average)
SiO_2	67.8	56.7	49.6
Al_2O_3	14.2	18.4	11.9
Total Fe Oxides	6.3	6.4	4.5
K_2O	1.7	3.3	1.5
MgO	1.1	2.6	1.3
CaO	9.2	2.1	20.5
in ppm			
MnO	731	443	1083
Cd	105	58	111
Ga	17	28	10
Li	70	119	76
Mo	34	9	35
Sr	210	102	282

The analyses were obtained using an ARL 2900B direct reading emission spectrometer located at Leicester University. (For instrumental conditions see Celenk, 1972, and Cubitt, 1975).

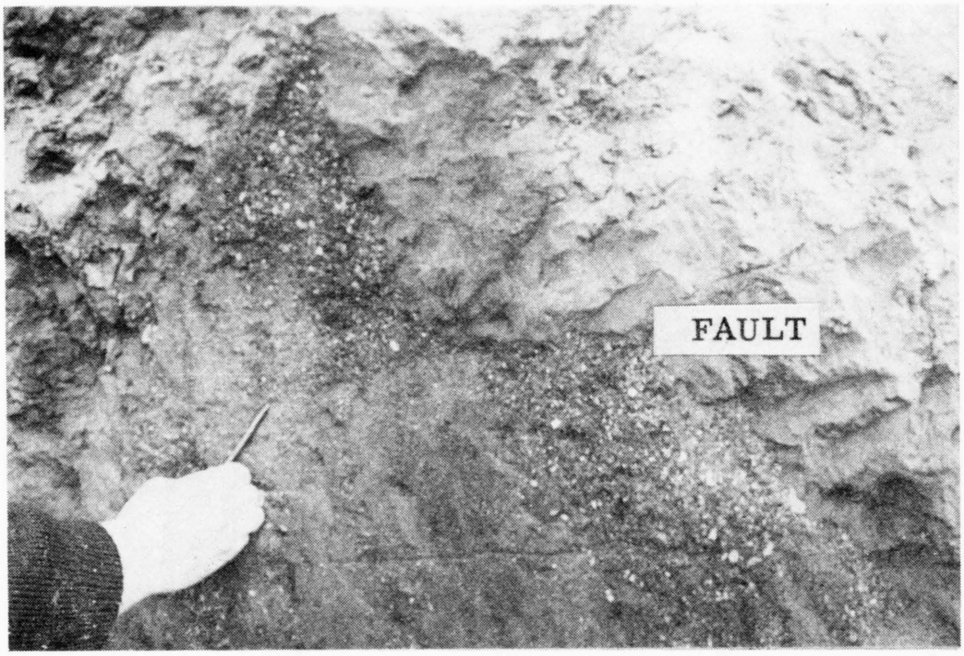


Fig. 1. Tear-fault at the edge of the block.

Fig. 2. Band of current bedding within the block.

The till is characteristically high in CaO and relatively low in SiO_2 and Al_2O_3. Trace element distribution supports the separation of the block, clay and till produced initially from the data on the major oxides. High Cd, MnO and Sr values in the till exemplify this separation and are thought to represent possible substitution of these elements for Ca^{++} in the calcite lattice. Similarly, lithium, which is concentrated in the red clay, is probably associated with high clay mineral content. The depositional nature of the red sediment remains unclear, and work continues on this aspect.

Discussion

Several inferences can now be drawn from this single occurrence. The block of sands and gravels is a remnant of former fluvial conditions as outwash, en-or sub-glacial streams or Lathkill flood-plain deposits. From consideration of the lithology and emplacement a sand and gravel outwash origin is favoured. If this assumption is accepted the history of the block allows a relative chronology to be established for Pleistocene events in North Derbyshire.

1. Fluvial or fluvio-glacial conditions, enabling deposition of the sands and gravels.
2. Periglacial conditions capable of freezing unconsolidated material.
3. Glacial Wolstonian conditions permitting the incorporation and transportation of the frozen block into the glacier. The Edale Shale cover would be removed in part during this phase.
4. Substantial downcutting by local rivers and removal of much glacial debris and underlying Edale Shales.
5. 'Loess' deposition in the Devensian.

If the block originated from high level River Lathkill floodplain deposits, ideas on the present drainage evolution of the limestone and the removal of the shale cover must be revised. When the material was incorporated within the till, the River Lathkill may have been flowing at least 122 m above its present level, and therefore, provide a relative date for the evolution of the area's drainage.

Conclusions

Despite the poor exposure of undisturbed boulder clay on the Derbyshire Limestone Plateau, which is partly responsible for the lack of knowledge concerning Pleistocene events in the area, the conclusions drawn from the study of the Raper Pit exposure are thought to be significant.

1. The sedimentary structures in the unconsolidated sediment of the block are undisturbed and indicate, therefore, that the block was transported in a frozen state.
2. During transport, the block must have been rotated, as the current bedding lies in a nearly vertical position.
3. Faulting occurred during transport and whilst the block was in a frozen state, because during movement, the block remained entire and did not disintegrate.
4. There is no evidence of sands and gravels at the till/limestone boundary in these excavations.
5. The deposit is thought to represent former outwash sands and gravels, rather than en- or sub-glacial stream deposits, or high level Lathkill floodplain deposits.
6. The block is of earlier origin than the till in which it is incorporated. Despite a lack of macrofossils and palynological dating evidence, a tentative Wolstonian date is assigned to the till and period of transport based on evidence reviewed by Burek (to be published), Shotton (1976, personal communication) and presented here.
7. An earlier date (Wolstonian) is allocated to the source outwash sands and gravels and a later date (Devensian) for subsequent downcutting of the local rivers and 'loess' deposition.

Acknowledgements

The author would like to thank Laporte Industries Ltd., for access to Raper Pit; J. Moseley, N. Worley, R. Burek and B. Basset for field assistance; Drs. T.D. Ford and B.M. Hand for useful discussion; and Drs. E.H. Muller and J. M. Cubitt for critically reading the manuscript. Miss V. Rutherford of Leicester University ran the emission spectrometer and is duly thanked.

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Cynthia V. Burek,
Department of Geology,
Syracuse University,
Syracuse,
New York, 13210.
U.S.A.

GEOLOGY IN THE GOYT VALLEY AND NEAR MACCLESFIELD

A FIELD MEETING REPORT

Leader: Fred M. Broadhurst — Sunday, 1st June 1975

The object of this excursion was to see the range of sediments and faunas preserved within the Upper Carboniferous rocks of the Southern Pennines. In particular the non-marine bivalve body fossils preserved within the shales and mudstones of the Coal Measures in the Goyt Valley were to be contrasted with the trace fossils left by non-marine shells in the sandstones of the quarries near Macclesfield.

Goyts Moss (SK 017716) There is a convenient car park (SK 018716) near the exposures but the nearest point for a coach is at a lay-by on the A537 road at SK 018709. In the bed and banks of the R. Goyt westwards of SK 017716 is a sandstone the top of which contains rootlets. This rootlet bed yields interesting specimens in that the black carbonaceous material of the rootlets is conspicuous in the light grey matrix of the sandstone. Above the sandstone there is much loose shale but a few metres downstream from the sandstone exposure the upper part of the Goyt's Coal (equivalent to the Belperlawn Coal of Nottinghamshire) was seen. At other exposures in the vicinity (notably below Derbyshire Bridge at SK 017719) this seam can be seen to rest directly upon the rootlet bed in the sandstone. The Goyt's Coal, well over one metre thick, was extensively wrought in the pre-railway era and the coal used principally for lime-burning in the Buxton area. Numerous mine tunnels can be seen and members (expecially young ones) were warned not to enter workings such as these because of the danger of meeting not only rock falls from the roof but also deoxygenated atmosphere. After examination of the coal the party turned its attention to the shales and mudstones forming the roof of the coal and extending upwards as a cliff in the north bank of the R. Goyt. These shales contain rich courses of non-marine bivalves dominated by the genus *Carbonicola*. The shells were collected and found to contain all growth stages. In many cases the two valves of a single shell were found still attached at the hinge although the valves were in the 'open' position. It was argued that the evidence pointed to death and fossilisation at the site where the shells had formerly lived. Other fossils including fish scales and plant remains were also found.

Finally the roadside exposures at SK 017717 were examined and revealed a local unconformity within the Coal Measures together with a number of small faults.

Kerridge (SJ 936771) After lunch and refreshment at Kerridge the party walked to Sycamore Quarry (SJ 937767) where, by the courtesy of Mr. A. M. Earl, the Milnrow Sandstone was examined. The escape shaft *Lockeia* caused by the upward escape of *Carbonicola* through rapidly deposited sand layers is abundant at certain levels of this quarry. The contrast between the modes of preservation of the bivalves between here (trace fossils only) and Goyts Moss (body fossils preserved in the sediment in which the shells once lived) was emphasised. In addition to *Lockeia* other trace fossils were found, notably the worm-like trace *Cochlichnus* and the xiphosure *Kouphichnium*. The party also noted the presence of various sedimentary structures in this quarry including parting lineation and cross-stratification.

Axe Edge (SK 032711) The party returned towards Buxton and the coach parked in a lay-by on the A54 opposite the pumping station at SK 033714. A small stream was followed upstream to an outcrop of the *Reticuloceras superbilingue* marine band at SK 032711. The characteristic features of *R. superbilingue* were noted and this goniatite together with its associated fauna were collected. Immediately above the marine band highly sheared shales were noted and explained as having been deformed during the folding of the Goyt Syncline.

Mercian Geol., vol. 6, No. 2, 1977,
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GIBRALTAR POINT, LINCOLNSHIRE AND THE NORTHERN FEN EDGE

Leader: D. N. Robinson 21 September 1975

The purpose of this excursion was to demonstrate the geology and scenery of the Fen edge between Tattershall and Skegness and the southern Wolds between Gunby and Winceby, together with the coastal processes which have generated the complex of shoreline features at Gibraltar Point.

From Tattershall to Mareham-le-Fen the route crossed the vast delta of flinty gravels, with patches of fine gravel and sand, created by the River Bain flowing south into Lake Fenland during the Last Glaciation (Weischel) 75,000 to 25,000 BP. To the north of the A155 the undulating country is the intensely chalky Calcethorpe Till of the Penultimate Glaciation (Saale) which plastered the Lower Cretaceous platform of the west and south-west Wolds.

The route diverted from the A155 to pass through Old Bolingbroke, situated in an embayment cut by spring-head sapping of Sow Dale and its tributary into the Spilsby Sandstone platform, and floored by Kimmeridge Clay. A good view was obtained of Bolingbroke Castle (1220-30; parts were derelict by 1600; was involved in Civil War 1643 after which it was largely pulled down) built of Spilsby Sandstone of both grey-green (glauconitic) and brown (iron-rich) types, said to have been quarried near Miningsby to the west but more likely from the steep edges of the dales focussing on Bolingbroke from north and east.

The route ascended onto the Spilsby Sandstone platform with its steep edges and abundant remains of early man on Old Hall Hill. By West Keal church the party stood on the degraded sea cliff of the Last Interglacial (Ipswichian). Along the foot of the slope is a narrow line of outwash sand and gravel from the edge of the ice sheet of the Last Glaciation. Extending to the south is the terminal moraine of that ice sheet, a low ridge which separates East and West Fens. Those Lindsey fens, together with Wildmore, were the last to be drained in the first decade of the 19th century.

Descending the degraded cliff to the A155 and A16, the route turned off again to pass through Toynton All Saints, a street village on the degraded cliff, where the slope is much shallower. At the foot of the slope were medieval pottery kilns (12th-13th and 16th centuries) using Kimmeridge Clay, and fen peat for fuel. The sites have been excavated but abundant potsherds can be found in a cultivated field.

A tortuous route was followed via Holton Holegate (hollow way - though the edge of the Spilsby Sandstone platform) crossing the River Lymn where its north-south meandering course was determined by a glacial spillway channel during Last Glaciation, and then across the undulating Middle Marsh (Marsh Till) and flat Outmarsh (largely marine silts). Eventually the route joined the A52, a medieval 'country bank' (erroneously called the Roman bank, a name still perpetuated in Skegness).

Until the 13th century Skegness was a 'ness' on the coastline at the corner of the Wash, the whole being in the shelter of the offshore barrier of low clay/sand islands from Holderness to Norfolk. The final breaching and destruction of that barrier resulted in the establishment of the beach and dune system on the Lincolnshire coast, the basis being re-sorted glacial sands and gravels thrown up on the shoreline. As the action of longshore drift is north to south, a sand and shingle spit with dunes gradually extended from what is now central Skegness to Gibraltar Point. This is the main line of dunes which form the Seacroft golf course and the west dunes of the Gibraltar Point Nature Reserve (Lincolnshire Trust for Nature Conservation). It had extended thus far by the second half of the 18th century and allowed gradual reclamation of Croft Marsh to the west.

The pattern of new beach ridges, many stabilised as dune systems, with intervening

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saltmarshes, which have developed in the last 150 years is graphically displayed in the new Visitor Centre where members spent some time after lunch. A matter for on-going study and investigation are the reasons for the great seaward growth of the coast in the area of the reserve over the last 50 years. The amount of material accumulated cannot be accounted for solely in terms of longshore drift. It appears that some is coming from offshore sources to the north-east.

Detailed investigations have also been made over the past 25 years into changes in beach profiles and in particular into the development of the spit. The changing fortunes of the beach and spit are in contrast to the extensive mud flats and saltmarshes where finer material from the Wash 'sedimentation tank' is deposited under sheltered conditions. By following the permanent nature trail members were able to observe the succession of saltmarsh and sand-dune features together with the pattern of ridges and runnels exposed on the foreshore at low tide and the offshore sand-banks. The party walked to the distal end of the spit to observe the contrasts in depositional features by the outfall of Wainfleet Haven. It also enabled an investigation of the amazingly varied assemblage of erratic material (originating from Scotland, northern Pennines, north-east England and Scandinavia), which occur on the spit.

The return route followed the A158 across the Outmarsh to Burgh-le-Marsh and the Middle Marsh to Gunby corner. To the north is the spur of the Wolds thinly capped with Chalk. At Candlesby the route crossed a spur caused by the harder Roach Stone in the Lower Cretaceous series. Further west the hamlets of Scremby and Grebby are sited on a similar narrow platform.

At Sausthorpe the route turned south off the Spilsby Sandstone platform which surrounds the Lymn valley floored by Kimmeridge Clay, crossing the river, back on to the platform near Raithby, there capped by Calcethorpe Till. On both sides of the valley road cuttings in the edge of the sandstone platform were noted. To the south of the A1115 is the cleft of Sow Dale and to the north the multiple valleys of Snipe Dales Nature Reserve (Lincolnshire Trust) - both the result of vigorous spring-head sapping. At Winceby top, excellent visibility allowed a view of Lincoln Cathedral - the Lincoln Gap, Tattershall Castle and Boston 'Stump'. The route turned south to cross the undulating country of Calcethorpe Till rejoining the A155 and so back to Tattershall.

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EXCURSION TO THE COTSWOLD HILLS

Leader: P.G. Baker 7th - 9th May 1976

Friday evening The base for the excursion was at Gloucester, approximately 30 members arriving at the headquarters hotel during the evening. After dinner, the leader gave a short illustrated introductory talk on the geology and tectonic history of the area and outlined the itinerary for the weekend.

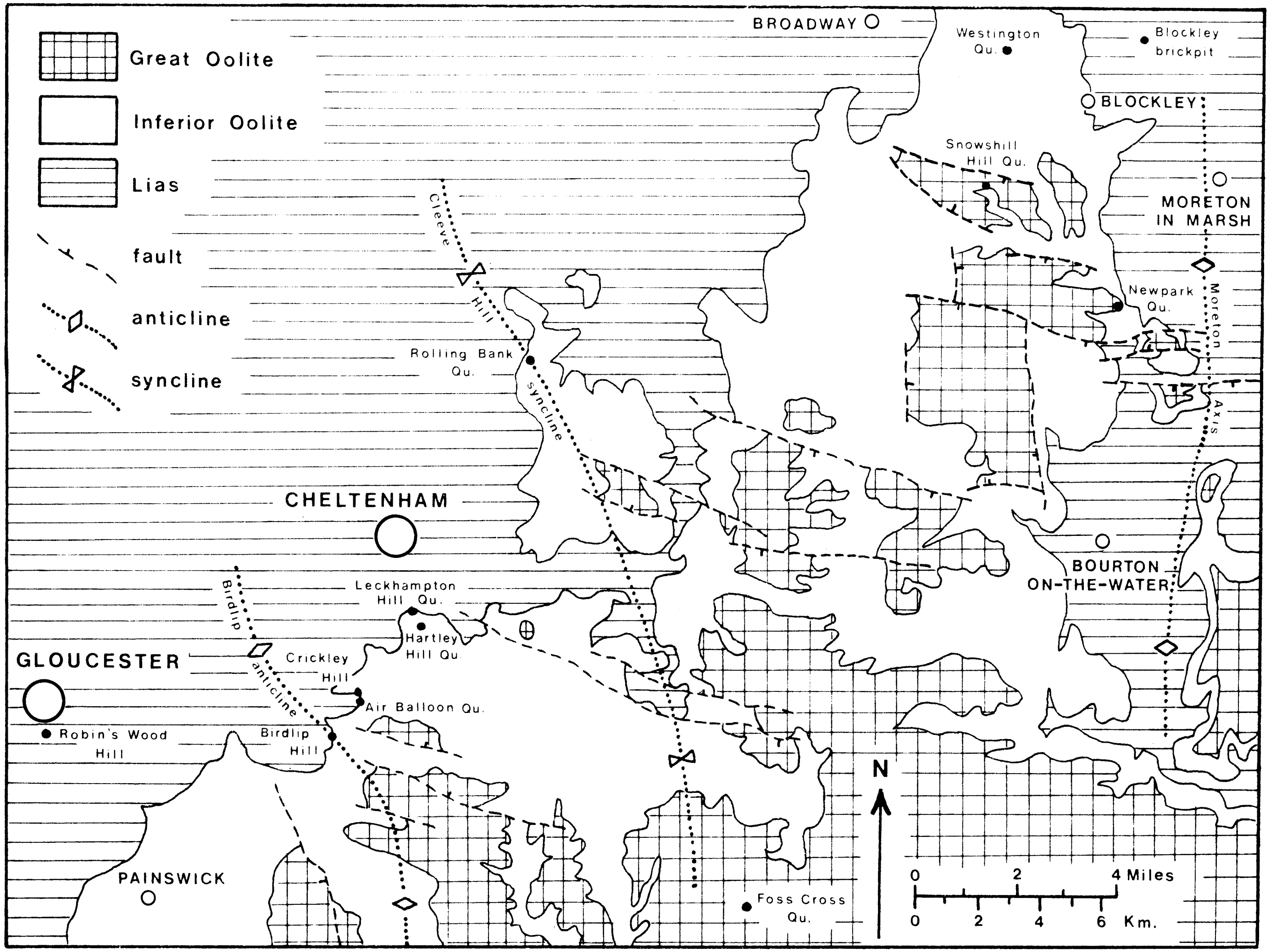
Saturday The day dawned sunny and the party, swelled by several members staying locally, assembled at the outlier (text-fig.1) of Robins Wood Hill (SO 834148) Tuffley, on the outskirts of Gloucester. This abandoned brickpit, now an S.S.S.I. and rapidly deteriorating, still affords a reasonable exposure of the top of the Lower Lias (Davoei Zone) and the Middle Lias. The succession, in two workings, shows mainly grey clays and shales with nodule and ferruginous bands, the most prominent of which, the Spinatum Sandstone, dominates the upper working. The lower face was formerly much less obscured and a detailed account of the full succession exposed there may be found in Ager (1956). Material from the ferruginous horizons, unwanted by the quarrymen, was dumped in a tip on the east side of the pit. This tip provided excellent collecting facilities, yielding bivalves, *Pentacrinites* columnals, belemnites and small *Androgynoceras*.

From Gloucester, the party proceeded along the A417 in a south-easterly direction and climbed the Cotswold scarp to Birdlip. Here, after negotiating the rather steep slope up to the exposure, members were able to examine a section in the old Knap House Quarry (SO 925147) showing Upper Trigonia Grit (marking the base of the Upper Bajocian Transgression) resting on eroded Upper Freestone (text-fig.3D) in the core of the intra-Bajocian, Birdlip anticline (text-fig.1).

Proceeding northwards along the top of the scarp at Barrow Wake the party was disappointed to find the fine view across the Vale of Gloucester somewhat obscured by heat haze. The next stop was at the small, very overgrown but equally important S.S.S.I. (SO 933158) near the "Air Balloon" inn. Here, Upper Trigonia Grit was again seen but now resting on Middle Bajocian (Middle Inferior Oolite) deposits, higher stratigraphically (text-fig.2, 3C) than those at Birdlip just under one mile to the south. Leaving this exposure, the party then proceeded on foot to a point 350 m. to the north-west where the base of the road section (SO 932160) up Crickley Hill was examined. At this point, just back from the road, 0.8 m of unfossiliferous black shales of Upper Lias age were seen, overlain by ferruginous calcisiltite and rubbly limestone of the basal Scissum Beds (text-fig.2). The route up the hill, towards the "Air Balloon" and very welcome lunchtime refreshment, lay through Lower Inferior Oolite strata and members of the party were able to collect fine specimens of algal pisolite from the Pea Grit. A comprehensive account of this section may be found in Ager (1969).

After lunch the party proceeded further northwards via the B4070 to the shallow working known as Hartley Hill Quarry (SO 951181). A small vertical face runs (on the east side of what is now arable land) northwards to Charlton Kings Common (SO 952185). This section shows Upper Trigonia Grit resting on a bored, oyster encrusted erosion surface in Notgrove Freestone (text-fig.3B). The party, on foot, embarked on a circular tour of the area. A vantage point above Charlton Kings enabled members to admire the view northwards across Cheltenham and beyond. The party then proceeded westwards, pausing to consider the significance of a small old working (SO 950185) exposing 1.2 m of Gryphite Grit with its characteristic *Gryphaea sublobata* Deshayes, overlying 2.4 m of Buckmani Grit. The floor of this old working marks the top of the underlying Lower Trigonia Grit from whence may be obtained the coral *Thecosmilia gregaria* (M'Coy). The presence of these deposits at a slightly lower level than the Notgrove Freestone shows that the Middle Bajocian succession is thickening again as one moves northwards, away from the Birdlip anticline towards the Cleeve Hill syncline. The route continued westwards towards the famous landmark of the Devil's Chimney (SO 946184)

Mercian Geol. vol.6, No.2, 1977.
pp.137-144, 5 text-figs.



Text-figure 1. Geological map of the area showing the generalised outcrop of the main lithostratigraphical divisions and position of tectonic axes. Only the faults which significantly affect outcrop are included.

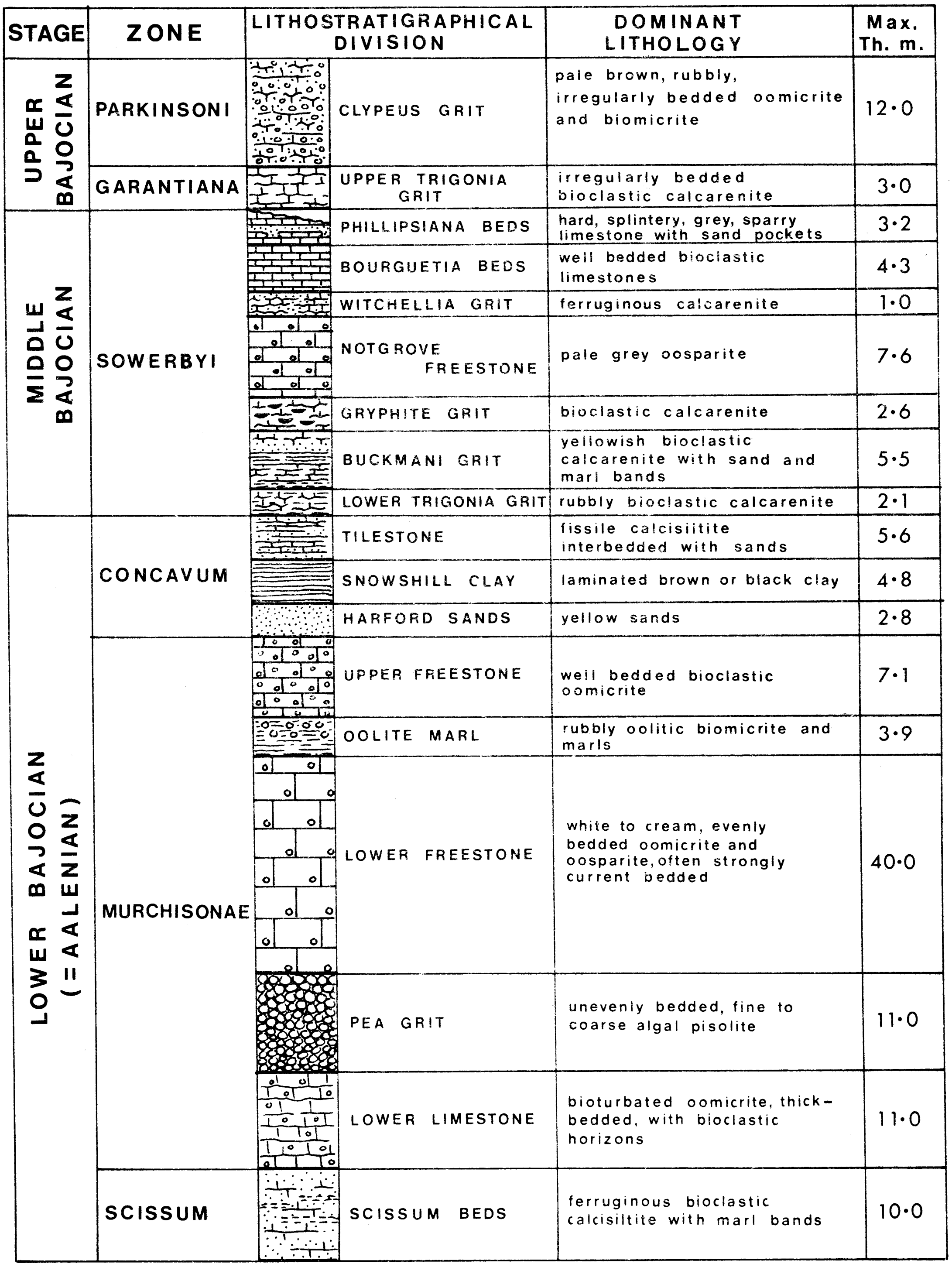
source of much local legend but in fact, nothing more exotic than a legacy of ancient quarrying activity. Adjacent to the Devil's Chimney members of the party were able to collect the characteristic fimbriate terebratulide *Plectothyris fimbria* (J. Sowerby) from an easily accessible exposure of Oolite Marl. The party then proceeded via the classic Leckampton Quarry (SO 949186) (Ager 1969) pausing to compare the Scissum Beds with those seen at Crickley Hill and then moving on to a small quarry (SO 953187) excavated entirely in a slumped mass of Upper and Lower Freestone at the western end of Charlton Kings Common. By now the circuit was almost closed and the party had only to climb diagonally, collecting fossils on the way, to reach the top of the Common and the route back to the transport. By now the heat was becoming oppressive but it did enable the leader to demonstrate that the "Beware of Adders" signs were no idle warning as several of these attractive little snakes, resplendent in their Spring russet-brown and black markings, were seen gliding out of the path of the heavy boots of the leading members of the party.

Time was now short and the well-known Rolling Bank Quarry (SO 987266) where the Upper Trigonia Grit can be seen resting on a bored erosion surface in the Phillipsiana Beds (text-fig. 2, 3A) in the trough of the Cleeve Hill syncline (Richardson 1929, p. 52) was not visited. Instead, Salterley Grange Quarry (SO 946177) in Lower Freestone, at the southern end of Leckhampton Hill was visited and members were able to speculate on the true nature of three small faults visible in the quarry face.

Sunday The party set off in a south-easterly direction following the Ermine Way (A417) towards Cirencester. Turning left at Daglingworth cross-roads, the party passed through North Cerney and eventually, three quarters of a mile east of Calmsden, arrived at Foss Cross Quarry (SP 055092) to compare the shallow water Bathonian sedimentation with the Bajocian deposits already seen. The quarry exposes about 8.5 m of marls and limestones belonging to the White Limestone Series. The quarry was a large one and interesting for the rapid lithological variation of the beds around the face. Prior to becoming an S. S. S. I. it was used as a refuse tip by Gloucestershire County Council. However, the north-west face is largely untouched and the general succession is shown in text-fig. 4. One of the most spectacular fossils when the quarry was in work, was a deep pink (hence "Beetroot Stone") alga *Solenopora jurassica* Nicholson. Unfortunately the source of the darkest specimens appears to be exhausted but representative specimens may still be obtained from fallen blocks on the quarry floor, approximately half way along the face. Other fossils still reasonably plentiful are the brachiopods *Epithyris oxonica* Arkell and *Digonella digonoides* (S. S. Buckman).

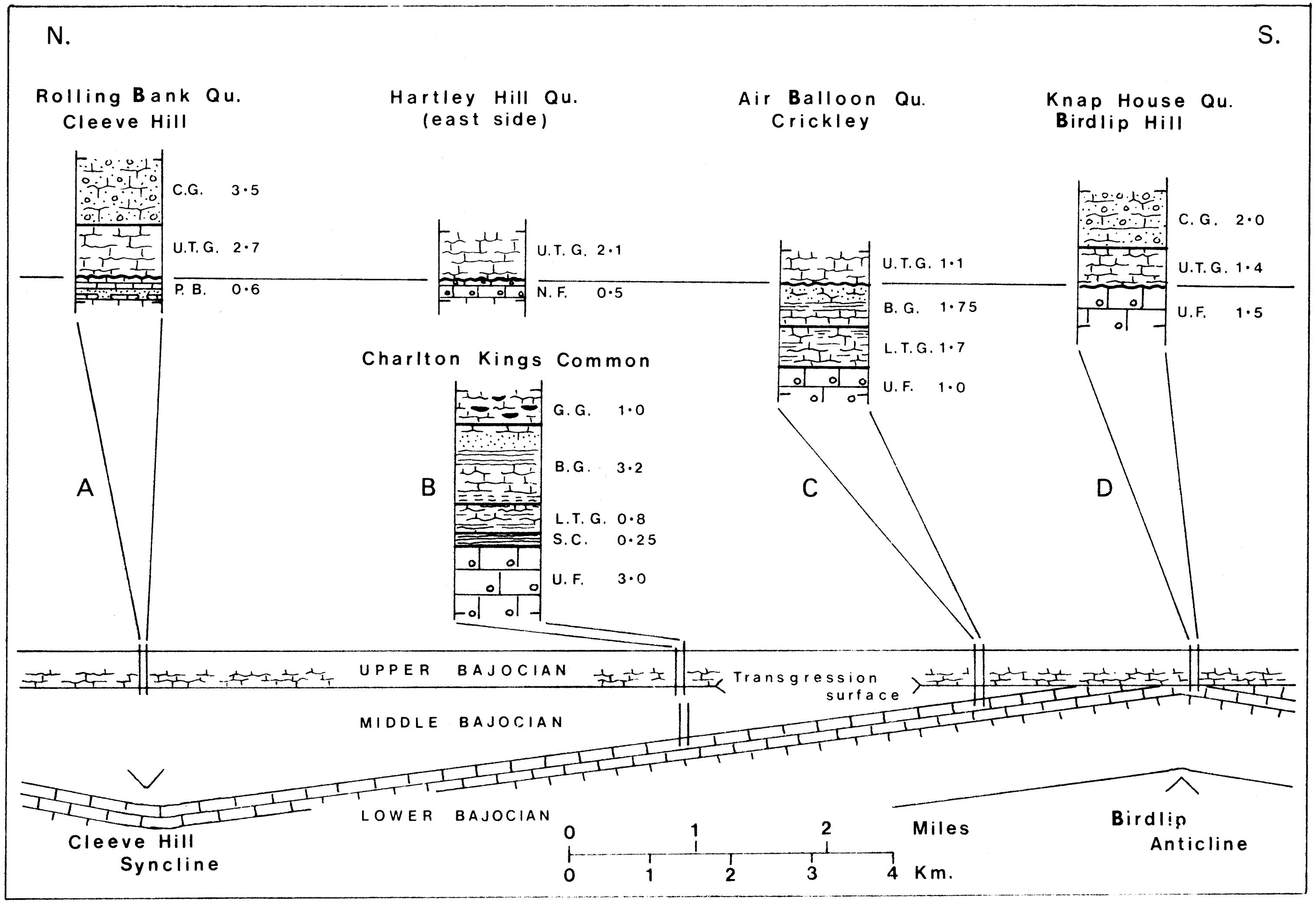
From Foss Cross the party travelled north-eastwards up the Fosse Way to Stow-on-the-Wold and then up the A424 to Newpark Quarry (SP 175284) near Longborough. The quarry shows about 5.0 m of Chipping Norton Limestone, thin-bedded in the upper half and more nodular in the lower half. Belemnite and *Ostrea* fragments were obtained from the nodular beds, which consist of nodules of very hard grey sparry biomicrite in a matrix of light brown-grey silty biomicrite. The leader had previously obtained part of a *Teleosaurus* scute from this horizon and while the majority of the party retired to the nearby "Coach and Horses" for lunch, the lure of vertebrate remains kept some members hammering and one of these was rewarded with a fragment some 10.0 cms. in length, possibly a fragment of a mandible of *Steneosaurus* sp.

After lunch the party resumed its northward course up the A424 and then via a minor road to Snowshill Hill Quarry (SP 131322) to compare the much thinner Chipping Norton Limestone with that of the previous locality, and to collect corals from the rich fauna of the "Coral Bed" of the Sharps Hill Beds. The strata exposed in the quarry are shown in text-fig. 5. The Coral Bed owes its name to the abundance of a reptoid coral *Microsolena excelsa* Edwards and Haime set in a blue-grey clay matrix. Also collected were *Cyathophora pratti* Edwards & Haime, *Isastraea limitata* (Lamouroux) and *Thamnasteria lyelli* (Edwards and Haime). Attention was drawn to the epifauna on these corals and to the very numerous *Lithophaga* borings in them, indicative of a distinct pause in sedimentation at this horizon. In addition to corals, brachiopods, *Kallirhynchia* sp. (crushed) and *Epithyris* sp., together with bivalves, *Modiolus* sp. and *Liostrea* sp. were obtained. Weathered out from the Nerinea

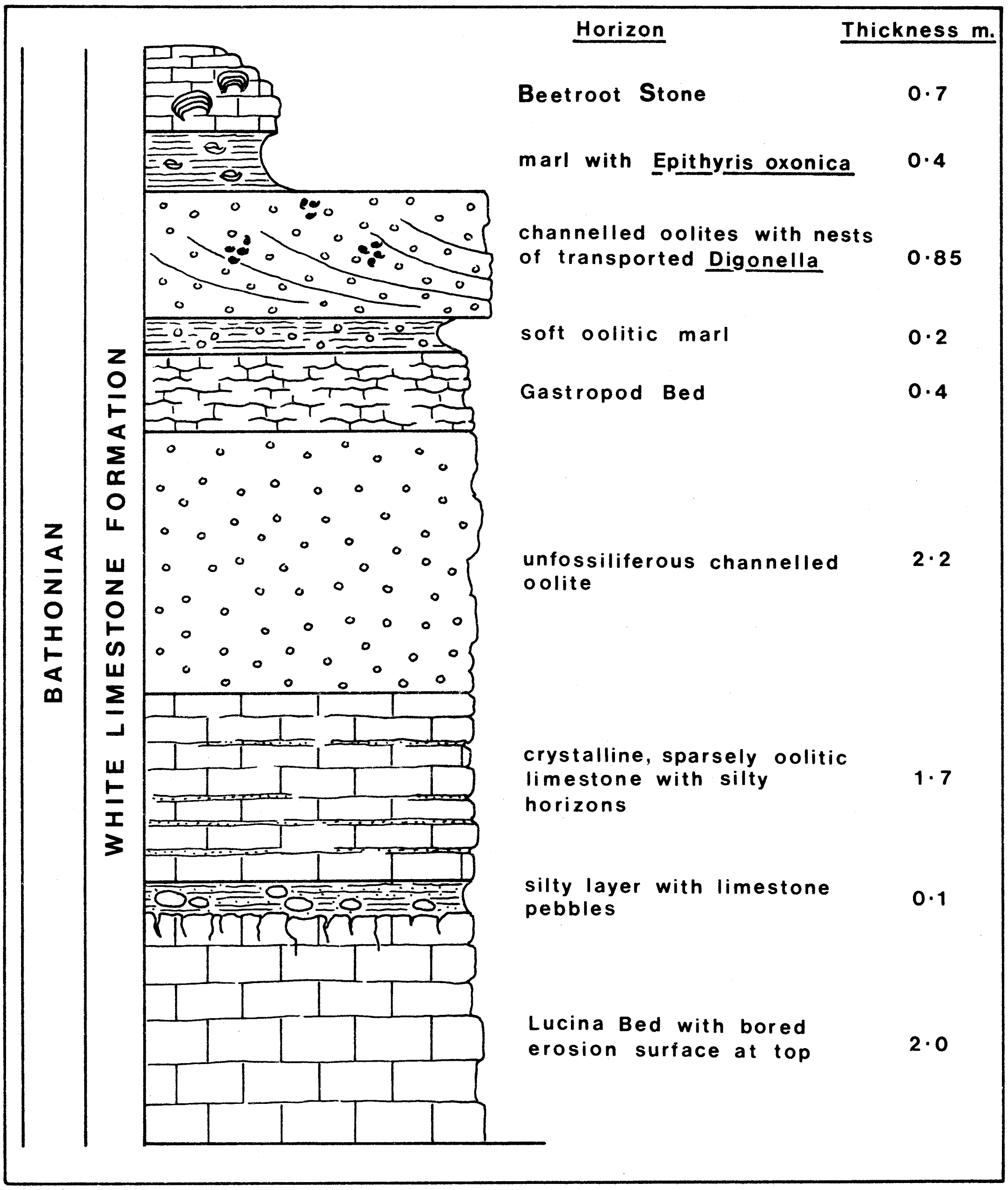


STAGE	ZONE	LITHOSTRATIGRAPHICAL DIVISION	DOMINANT LITHOLOGY	Max. Th. m.
UPPER BAJOCIAN	PARKINSONI	CLYPEUS GRIT	pale brown, rubbly, irregularly bedded oomicrite and biomicrite	12·0
	GARANTIANA	UPPER TRIGONIA GRIT	irregularly bedded bioclastic calcarenite	3·0
MIDDLE BAJOCIAN	SOWERBYI	PHILLIPSIANA BEDS	hard, splintery, grey, sparry limestone with sand pockets	3·2
		BOURGUETIA BEDS	well bedded bioclastic limestones	4·3
		WITCHELLIA GRIT	ferruginous calcarenite	1·0
		NOTGROVE FREESTONE	pale grey oosparite	7·6
		GRYPHITE GRIT	bioclastic calcarenite	2·6
		BUCKMANI GRIT	yellowish bioclastic calcarenite with sand and marl bands	5·5
		LOWER TRIGONIA GRIT	rubbly bioclastic calcarenite	2·1
LOWER BAJOCIAN (= AALENIAN)	CONCAVUM	TILESTONE	fissile calcisiltite interbedded with sands	5·6
		SNOWSHILL CLAY	laminated brown or black clay	4·8
		HARFORD SANDS	yellow sands	2·8
	MURCHISONAE	UPPER FREESTONE	well bedded bioclastic oomicrite	7·1
		OOLITE MARL	rubbly oolitic biomicrite and marls	3·9
		LOWER FREESTONE	white to cream, evenly bedded oomicrite and oosparite, often strongly current bedded	40·0
		PEA GRIT	unevenly bedded, fine to coarse algal pisolite	11·0
		LOWER LIMESTONE	bioturbated oomicrite, thick-bedded, with bioclastic horizons	11·0
	SCISSUM	SCISSUM BEDS	ferruginous bioclastic calcisiltite with marl bands	10·0

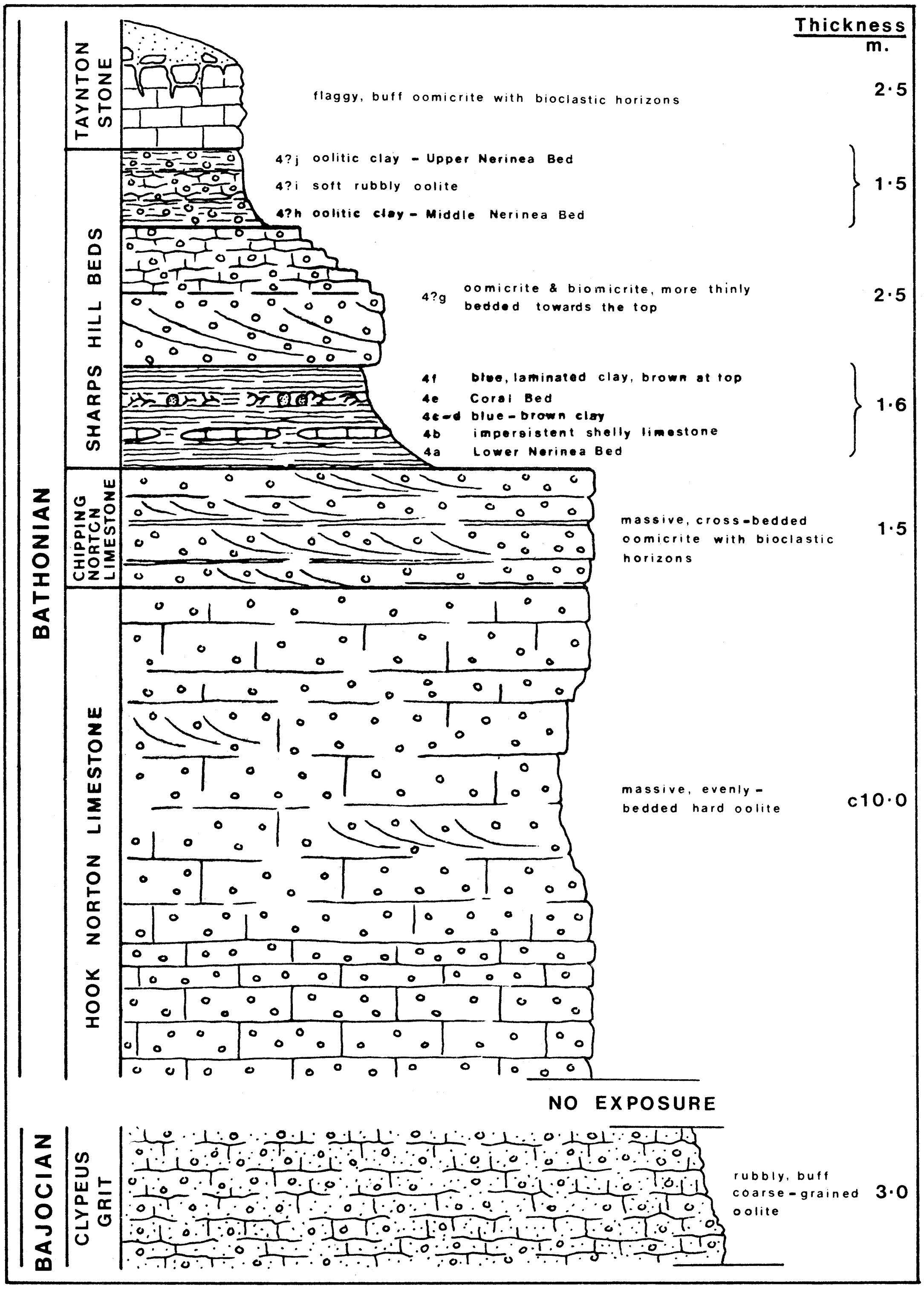
Text-figure 2. Diagram to show the lithostratigraphical divisions and dominant lithologies of the Inferior Oolite of the Cotswold area.



Text-fig.3. Diagram to show the transgressive nature of the Upper Trigonia Grit between Birdlip and Cleeve Hill. Horizon identification as in text-fig.2. Thickness of strata shown in metres.



Text-figure 4. Generalised section, showing the major lithological units exposed in Foss Cross Quarry (N.W. face).



Text-figure 5. Generalised section, showing the major lithological units exposed in Snowshill Hill Quarry.

Beds and accumulating on the floor of the upper working (surface of Chipping Norton Limestone) were numerous gastropods of *Aphanoptyxis* spp., *Neridomus* sp. and a few *Natica* sp. A detailed account of the fauna of the Sharps Hill Beds may be found in Barker (1969).

Rejoining the main road the northward trend continued up the A44 and B4081 to Westington Hill Quarry (SP 139367). The geology of this quarry is published in Baker (1974) and nothing further need be added except that re-working of the quarry has exposed new sections through the very fossiliferous Oolite Marl.

The excursion ended stratigraphically where it had begun - in the Lias. The final visit was to the Lower Lias locality in the Ibex Zone near Blockley Station (SP 182369). This section, famous for its fossils, particularly ammonites, is so well documented (Callomon 1968 p.202) that no further description is required here. The many ammonites except for fragments of *Liparoceras* sp. and *Lytoceras* sp. were not in evidence but members were able to collect abundant specimens of belemnites and bivalves *Pleuromya costata* (Young & Bird). *Mactromya cardioides* (Phillips), *Pholadomya* sp., *Gryphaea* sp. and *Chlamys* (*Aequipecten*)*prisca* (Schloetheim) from the Pecten Bed.

Conservation Note: S.S.S.I. indicates that the locality has been designated a "Site of Special Scientific Interest" and casual collecting, except from loose material is prohibited.

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P.G. Baker, B.Sc., Ph.D.,
Division of Geology,
Derby College of Art and Technology,
Kedleston Road,
Derby, DE3 1GB.

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