PALAEOCURRENT DIRECTIONS AND THEIR BEARING ON THE ORIGIN OF THE BRASSINGTON FORMATION (MIOCENE-PLIOCENE) OF THE SOUTHERN PENNINES, DERBYSHIRE, ENGLAND

by

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Summary

The mid-Neogene Brassington Formation consists of sediment preserved in solution hollows in the Carboniferous Limestone of the Southern Pennines. Measurements of cross-bedding in the arenaceous sediments and pebble orientations in the rudaceous sediments confirm that an important source area, probably a former extension of the Bunter Pebble Bed escarpment, lay due south of Brassington. The identification of a source area south of Brassington implies that the Southern Pennines have been uplifted by over 300 m since the Lower Pliocene, resulting in a reversal in the slope direction.

Introduction

Recent publications have discussed the stratigraphy and palaeobotany of the Brassington Formation and the karstic subsidence mechanisms which have preserved the bodies of sand, clay and gravel in the Carboniferous Limestone at contemporary levels of erosion (Ford & King, 1968 and 1969; Boulter & Chaloner, 1970; Boulter, 1971; Boulter *et al.*, 1971; Walsh *et al.* 1972, and Ford 1972a and 1972b. There is now general agreement that the subsidence outliers are small relics of what was once a widespread, if not continuous, sheet of mid-Neogene sediment which covered the Southern Pennines at an altitude not lower than the present-day summit levels in that area. The presence of this datable sedimentary layer, which was at least 70 m thick in some places, indicates that the Pennine uplift, at least the latest phase of it, was a comparatively late-stage addition to the British landscape, being at earliest Lower Pliocene (Walsh *et al.*, 1972). The sedimentology of the Brassington Formation has hitherto been neglected but a considerable amount of unpublished analytical work by M. Ijtaba and D.B. Thompson has elucidated much about the nature of the source rocks and conditions of deposition. Little previous work has been carried out on the palaeocurrent indicators, and conjecture about the palaeoslope down which Brassington sediments were transported to the Southern Pennines has been based on indirect evidence only. A derivation generally from the south was favoured by Ford & King (1968 and 1969) and Ijtaba (1973), whereas Hughes (1952) suggested that cross-bedding in Brassington sands exposed around Brassington indicated a derivation from the north and east, though he presented no statistical data.

The palaeocurrent studies described here relate only to cross-bedding structures and pebble orientation. Comprehensive measurements were made at all sites available during

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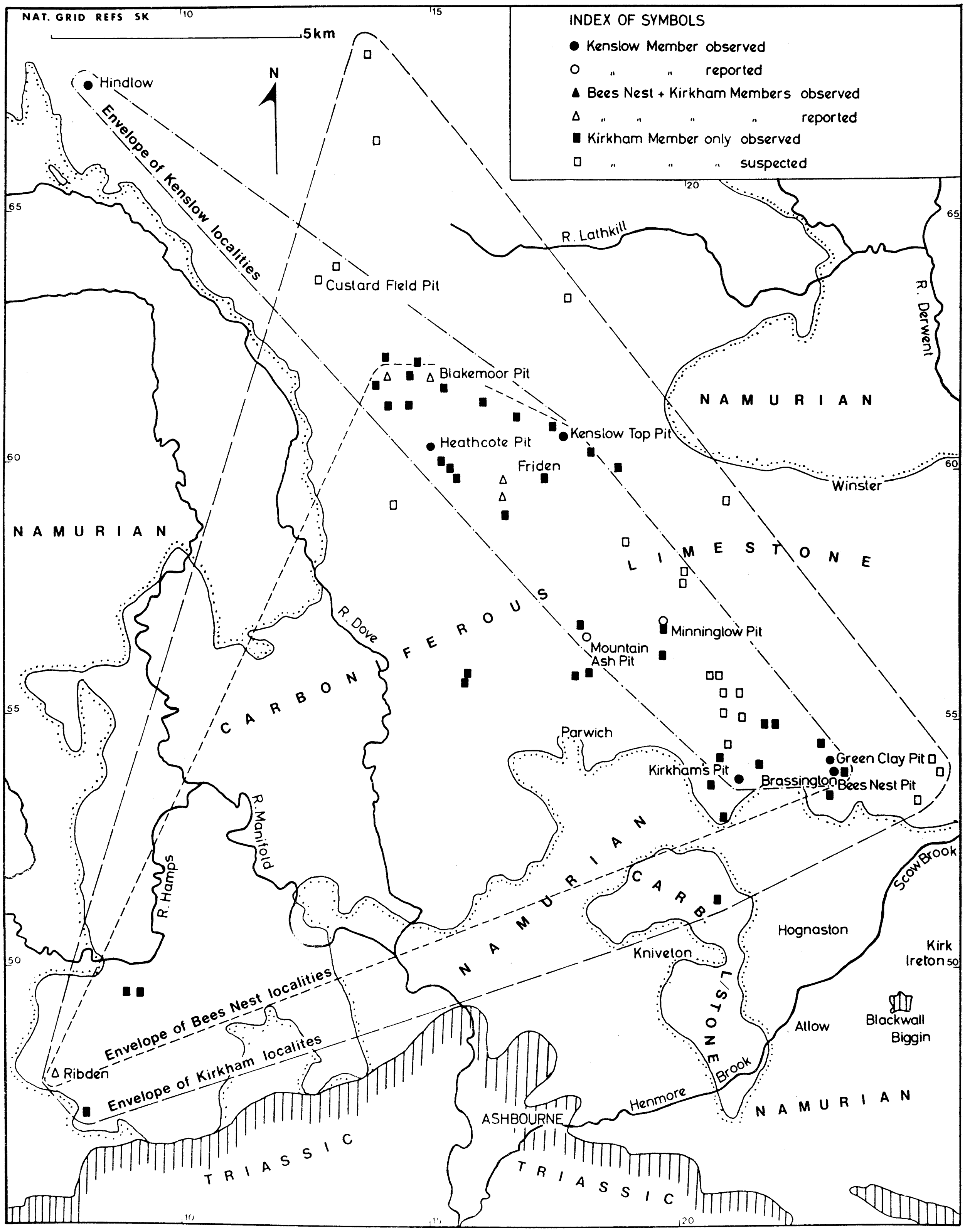
1980, pp.47-62, 16 text-figs.



Text-fig. 1: Map to show -
(1) the localities mentioned in the text, and
(2) the distribution of the Brassington Formation solution subsidence masses.

1975 and 1976. Regrettably only a handful of the sixty or so exposures available during the heyday of sand extraction during the 1940s and 50s (Yorke, 1961) now remain. This may be the first occasion when a palaeocurrent study has been based on evidence fortuitously preserved by solution subsidence mechanisms.

Later sections of this paper are digests of the final year undergraduate Project reports of Collins, Newton, Scott and Turner, to which reference may be made by special request (T.C.U. Department of Civil Engineering, Numbers 859, 792, 797, and 903, respectively).

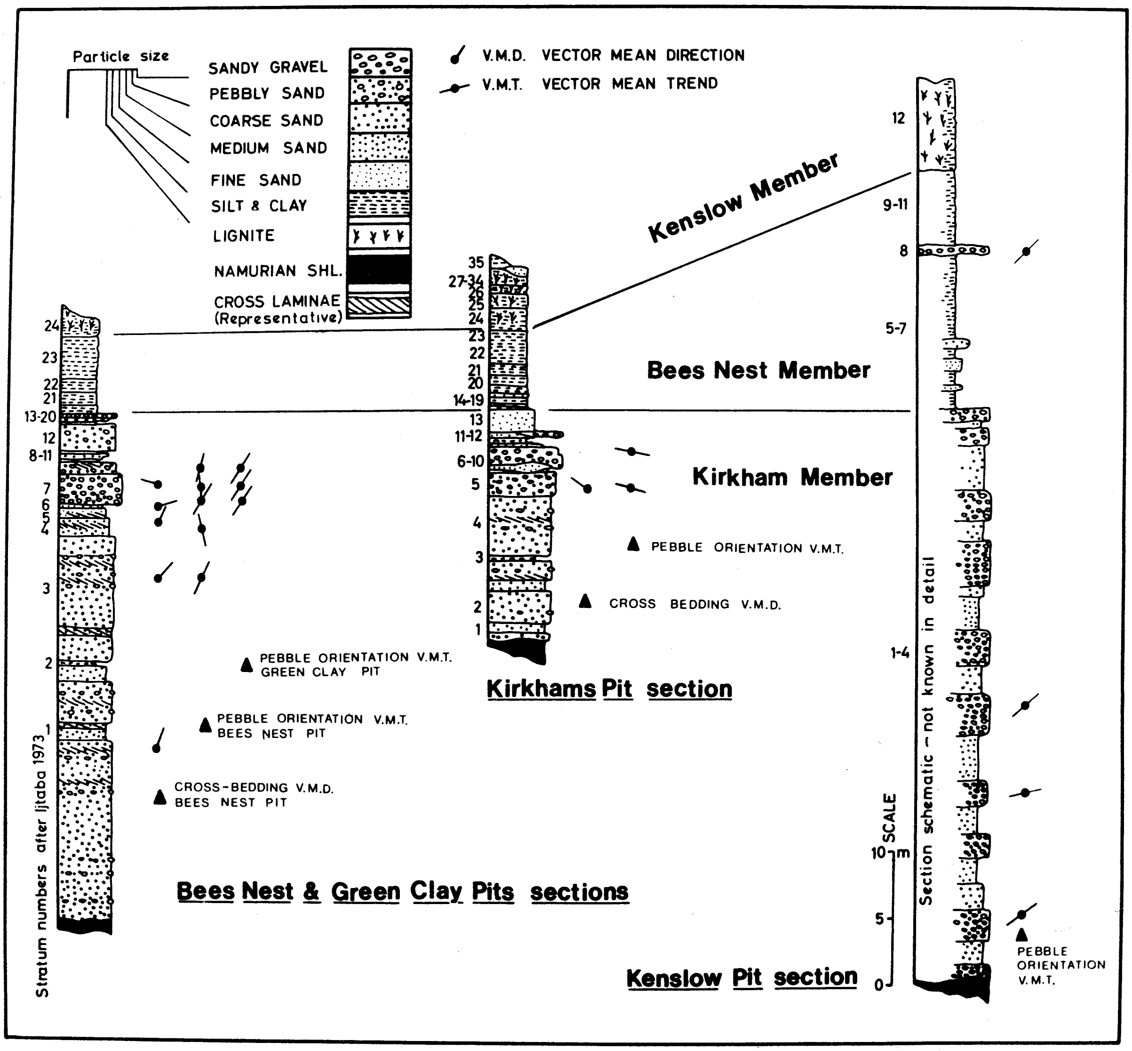
Stratigraphical control

The eight localities where palaeocurrent analyses have been made (text-fig. 1) are not evenly distributed across the area within which Brassington Formation outliers have been reported. None of the subsided sediment masses in Staffordshire is now exposed, while a recent deterioration of sections in the country between Winster and Parwich effectively means that the sites now available fall into two separate groups, a southern group centred around Brassington village (the Bees Nest, Green Clay and Kirkham's Pits) and a northern group around Friden (the Kenslow Top, Kenslow Lesser, Heathcote, Blakemoor and Custard Field Pits). Relative to the envelope which surrounds the outermost known subsidence masses (text-fig. 1), the southern group lies more or less at the south-east corner, whereas the northern group lies midway along the north-eastern side. There is no evidence, however, that the envelopes figured in any way approximate to the margins of the basin of deposition. There is no positive evidence of the former boundary to the area of deposition.

The broad details of the stratigraphy were proposed by Boulter *et al.* (1971) and elaborated by Walsh *et al.* (1972), Ford (1973) and Ijtaba (1973). The tripartite lithostratigraphic division of the formation into Kirkham, Bees Nest and Kenslow Members (text-fig. 2) appears to hold good for all of the sections excavated since 1971 and only two minor revisions need to be mentioned here. In the sections at Heathcote Pit (late 1975) a flora of Kenslow type has been identified by Boulter and Wilkinson (personal communication) from a pale grey clay which is in unfaulted contact with thick gravel beds. Overall stratigraphical relationships in this section were still obscure when it was last examined (March 1976) but it is likely that the underlying Kirkham Member also contains a Kenslow flora. The whole sequence may therefore be approximately of Miocene-Pliocene boundary age (see the discussion of the age of the older Brassington sediments in Walsh *et al.* (1972) and Ford (1972b).

Secondly, it is reported that in late 1975 richly-carbonaceous pale-grey clays were exposed in the trough of a particularly deep subsidence mass at the western end of the Green Clay Pit. Samples proved not to be pollen-bearing, but the carbonaceous layers are undoubtedly in a stratigraphical position analogous to that of the Kenslow Clays exposed about 300 m away in the Bees Nest Pit. This discovery reinforces the view that the Kenslow Clays were as widespread in their development as the earlier Brassington sediments. In recent years the Kenslow flora has been exposed at five localities (Hindlow, Kenslow Top, Heathcote, Kirkham's and Bees Nest Pits). It has also been reported from Minninglow Pit (Howe, 1897) and Mountain Ash Pit (A. Kirkham, personal communication) and is represented by the carbonaceous clays at the Green Clay Pit.

Despite thickness variations, individual beds can quite confidently be traced through the various sections around Brassington (Ijtaba, 1973). Details of the bed-by-bed stratigraphy and sedimentology have not yet been determined for the northern group of sections, though the sudden change from dominantly arenaceous to dominantly argillaceous sedimentation in the Kenslow Top succession could be a very close time-equivalent of the change from Kirkham to Bees Nest Member in the type section at the Bees Nest Pit. A similar sharp sedimentary change is noted at the boundary between Bees Nest and Kenslow Members.



Text-fig. 2: Diagrams to show -
(1) the correlation of the Brassington Formation sediments at the Bees Nest, Green Clay, Kirkham's and Kenslow Top sections, and
(2) a summary of the palaeo-current indicator data.

Lithofacies

The following lithofacies have been recognised in the Brassington Formations:

(i) Sands

The bulk of the Kirkham Member in the southern pits consists of poorly-sorted medium- or fine-grained sand or silty sand, all of an orthoquartzitic composition. General lack of sorting suggests that the sediments were deposited rapidly (Ijtaba, 1973). The grain surface texture studies of Wilson (1979) indicate that the quartz grains from the Kirkham Member are angular to subangular, and that rounded grains are frequent only at certain levels in the Kenslow Top and Kirkham's Pits sections. The angularity appears to be related to the development and retention of euhedral quartz overgrowths on Bunter grains, which presumably predate the deposition of the Kirkham sediments. The bulk of the Kirkham sand is remarkably structureless. Irregular developments of planar, alpha-type cross-bedding form the only common variant.

A comparison of the plots of mean size against standard variation for the Brassington sands with the plots of Friedman (1961) for dune and river sands confirms the alluvial nature of the sediments. On the basis of the above data, one of the authors (Ijtaba, 1973) has considered them to have formed as piedmont fans or sheets, an interpretation which may well explain the lithologically similar succession but fluctuating thickness present in the various southern pits. In many respects, the sands seem to correspond broadly to the channel bar or sand-flat deposits described by Cant and Walker (1978) from the sandy braided South Saskatchewan River.

(ii) Pebbly sands

The pebbly strata of the Brassington Formation are seldom true gravels. Whereas there is a considerable amount of gravel throughout the Kirkham Member in the northern Pits and in the upper part of the Kirkham Member in the southern Pits, it is nearly always a minor fraction of the bulk of the sediment, and the term 'pebbly sand' is the most appropriate in classifications such as those of Folk (1954).

Over 90% of the pebbles in the Brassington Formation are quartzites and most of the remainder are of durable lithologies. Cobbles of maximum $a:b$ cross section 180 x 120 mm are preserved at the Bees Nest Pit. 150 x 100 Kirkham's Pit and 130 x 70 at Kenslow Top. These sizes clearly reflect the considerable competence of the stream flow at certain times in the history of the area of deposition.

Almost invariably, cobbles and pebbles have smooth surfaces and are ovoid in shape; imbrication is rare, reflecting the general absence of discoidal clasts. Thompson (personal communication) considers the coarse fraction to comprise short-travelled and little-modified Bunter Pebble Bed clasts. He also reports that rolled ventifacts are present in small quantities and are locally common and believes them to have formed in the alluvial environment of the Mio-Pliocene when pebbles derived from the Bunter Pebble Beds were first sand-blasted, then eroded, transported and redeposited.

There is a general lack of internal structure in the pebbly sand strata suggesting that immediately prior to deposition, the gravelly sediment moved as mass-flow "diffuse gravel sheets" on channel floors; the gravelly braided stream course deposits described by Hein and Walker (1977) from the Kicking Horse River of British Columbia may offer a broadly comparable modern analogue. Movement of the gravel fraction presumably took place only at peak flood stages in the distributary system and the gravelly bodies then remained as lag concentrates.

(iii) Pebbly clays

This lithofacies, which so far is recognised only from the Kenslow Top succession, is a pebble grade gravel supported by a dominantly clay matrix. Internal stratification is restricted to a feeble parallel alignment of the clasts, which are hardly ever in contact. Since the clay could not have settled from suspension except in near-stagnant conditions, it is considered that this stratum may represent a thin mud-flow deposit (Bull, 1964), although it is hard to fit this into an environmental reconstruction.

(iv) Silts and clays

The bulk of the Bees Nest and Kenslow Members are technically clays, sandy clays and laminated sandy silts. Ijtaba (1973) determined that the clays are dominantly illitic, for which the widespread outcrops of Namurian shales and mudstones at the southern end of the Pennines offer themselves as a fairly obvious source; indeed, derived Namurian miospores have been recognised in the Kenslow clays (Boulter, 1971). The fact that they have not yet been found in the Bees Nest sediments causes no concern for the redness of those clays indicates a strong oxidising environment in the source (and possibly depositional) areas.

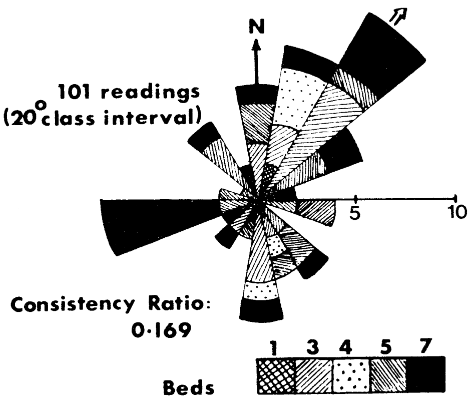
Whereas the cessation of sandy/gravelly sedimentation after Kirkham Member times may simply indicate that the source areas had been stripped of their Triassic cover, it is also possible that a general flattening of the fluvial gradients both in the provenance areas and the basin caused much more vertically--accreting overbank flood-plain material to accumulate (material of silt/clay grade which previously was taken across the basin and out to sea). Many of the fossil plant genera described by Boulter (1971) indicate that some of the Kenslow clays were deposited in swampy conditions.

Cross Bedding Analysis

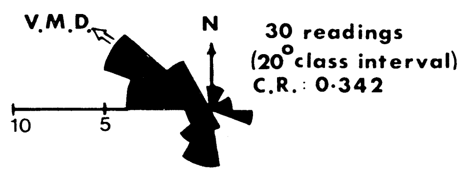
Cross-bedding has been found throughout the entire sequence of the Kirkham Member at the Bees Nest Pit. Altogether 101 sets have been measured, classified (Allen, 1963) and related to the stratigraphy established by Ijtaba (1973); the measurements were made in October 1975. At Kirkham's Pit measurements were more difficult to make, owing to the more rainwashed and structurally distorted sections there; nevertheless, 30 sets of cross-bedded strata were recorded. A careful search was made for cross-bedding structures at Kenslow Top Pit, but despite the extensive exposure there, only four poorly preserved examples were found. The writers conclude that sedimentary processes at Kenslow Top simply failed to create cross-bedding structures to the same extent as in the south. No traces of cross-bedding have been observed in any section of the Bees Nest or Kenslow Members, both of which are dominantly argillaceous. Directional corrections necessary owing to the severe collapse rotation of the Brassington sediments into solution cavities, were accomplished using stereographic nets.

Bees Nest and Kirkham's Pits (text-figs. 3 & 4)

Two vector diagrams have been prepared. The first diagram (text-fig. 3) shows a bed-by-bed plot of the orientation of vectors measured at Bees Nest Pit. The vector mean indicates palaeoflow towards the north-east, but there are subsidiary modes indicating palaeoflow towards the SSE and west. The second (text-fig. 4) shows a plot of all the vectorial data from Kirkham's Pit. There the vector mean is directed towards the north-west, with subsidiary modes to the south and ESE. The stratigraphical framework (text-fig. 2) suggests that the two sequences were broadly contemporaneous.



Text-fig. 3: Bed-by-bed plot of all cross-bedding measurements at Bees Nest Pit.



Text-fig. 4: Plot of all cross-bedding measurements at Kirkham's Pit.

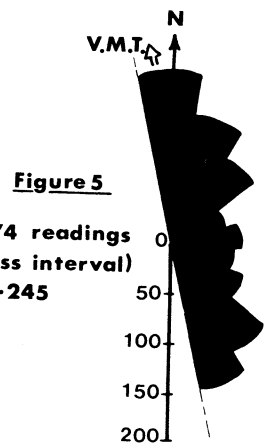
Pebble orientation analysis

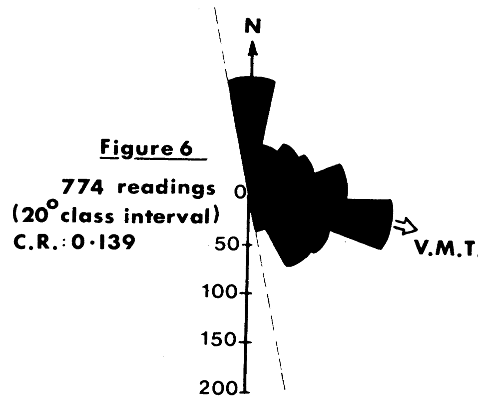
Pebble orientation studies were made in March 1976. A total of 3,611 measurements was made at 20 individual sample locations in eight pits. Except in the one case discussed below, gravelly strata amenable to such study were restricted to the Kirkham Member. Azimuths of pebble long axes of planar beds were measured, and in each case the lengths of the *a* and *b* axes were recorded. In the belief that the larger the pebble, the more likely would its alignment indicate the palaeocurrent, only pebbles which had an *a*-axis longer than 20 mm were recorded. Unrug (1957) considered that in many rudaceous sediments, relatively small pebbles simply take up the spaces determined by the voids between earlier deposited larger pebbles. Furthermore, in the belief that, the more elongate the particle, the more likely would its alignment indicate either the palaeocurrent direction or the normal to this (Kalterherberg, 1956), only pebbles where the ratio of *a* to *b* axes was greater than 4:3 were used. Dip and strike values for the host bed structure were recorded by reference to major bedding traces such as continuous clay bands. With a view to trying to determine whether plastic deformation of the host-bed fabrics had taken place during the rotation associated with subsidence, the degree to which the host bed was cemented was noted.

A sample location constituted a pit face having a more or less continuous exposure over an area of not more than 3 square metres. A minimum of 60 measurements were taken at each; in some locations more than 200 were taken. Potter & Pettijohn (1963) stated that, normally, 100 measurements are adequate for statistical purposes. Only a few of the sample locations were bedding surfaces, nevertheless, care was taken to ensure that the number of sections parallel with dip was equal to the number of sections parallel with strike. At some locations the records required no rotational correction as dips were less than 25° (Ten Haaf, 1959); but a correction for rotation was necessary for most locations and this was achieved by stereographic projection and trigonometry.

(i) Bees Nest and Kirkham's Pits (text-figs. 5 & 6)

Two vector diagrams have been prepared. The first, (text-fig. 5), shows a plot of all vectorial data from Bees Nest Pit. There the vector mean trend is clearly established in a N-S direction. The diagram is broadly conplementary to that of text-fig. 3. The second diagram, (text-fig. 6), shows a plot of vectorial data from Kirkham's Pit. The plot is clearly bimodal, with a N-S trend nearly as strongly developed as the vector mean trend of ESE - WNW. This plot is broadly complementary to that of text-fig. 4.



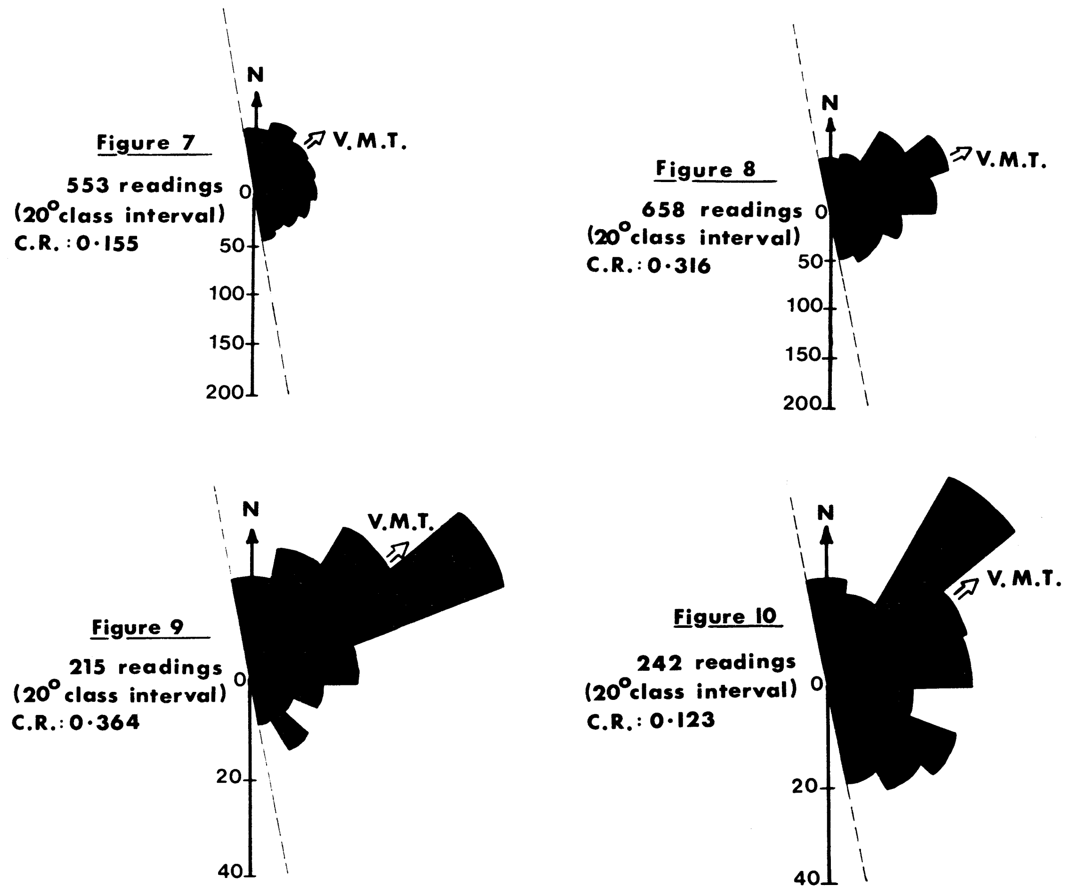


Text-figs. 5 & 6: Rose diagrams showing plots of pebble orientation at the Bees Nest and Kirkham's Pits, respectively.

(ii) Green Clay, Kenslow Top and Kenslow Lesser Pits (text-figs. 7,8,9 & 10)

The results of measurements taken in the Green Clay Pit are of particular interest as all sample locations were in horizontal beds in the troughs of sag-synclines. A total of 553 measurements was taken from gravel strata equivalent to Bed 7 of the nearby Bees Nest Pit section (text-fig. 2). A composite plot of three sample locations (text-fig. 7) represents the data from three gravel layers, each about 0.5 m thick. Unfortunately, the result shows no consistent alignment of pebbles. A composite plot of three sample locations representing the Kirkham Member at Kenslow Top Pit (text-fig. 8) shows a fairly well defined vector mean trend in an ENE-WSW direction.

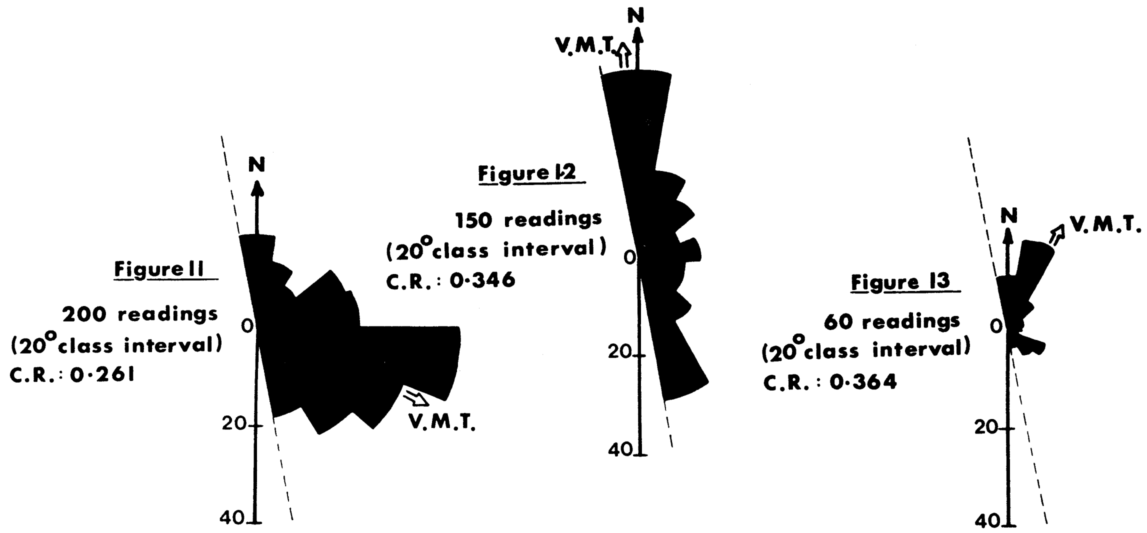
Of special interest at Kenslow Top Pit is the presence of the stratum of gravelly-clay facies, which lies stratigraphically at about the middle of the Bees Nest Member. This stratum appears to be the youngest pebbly development yet detected anywhere in the Brassington Formation and the only one of post-Kirkham age (text-fig. 2). The plot for the 215 pebbles measured at this sample location is shown as text-fig. 9. The plot is again nearly unimodal, the vector mean trend being well-defined at ENE-WSW; there is a weak subsidiary mode at SE-NW. Two sample locations, both from unknown stratigraphical horizons in the Kirkham Member in the Kenslow Lesser Pit have been combined to represent a composite for the Kirkham Member as a whole (text-fig. 10). The result is comparable to that from the nearby Kenslow Top Pit; there is a strong vector, mean trend at ENE-WSW with a subsidiary mode at SE-NW.



Text-figs. 7, 8, 9 & 10. Rose diagrams showing plots of pebble orientations at Green Clay (7), Kenslow Top (8 & 9), and Kenslow Lesser Pits (10). See text.

(iii) Heathcote, Blakemoor and Custard Field Pits (text-figs. 11,12 & 13)

In each of these localities only one sample location from an unknown stratigraphical horizon in the Kirkham Member was established. At Heathcote Pit (text-fig. 11) the vector mean trend is directed strongly at ESE-WNW, with a subsidiary mode at N-S. At Blakemoor Pit the plot is nearly unimodal (text-fig. 12) with the vector mean trend directed N-S. A feeble mode at E-W is also observed. The plot of the horizon in the Kirkham Member at Custard Field Pit (text-fig. 13) is bimodal. The vector mean trend being directed at NNE-SSW; a subsidiary mode is noted at ESE-WNW.

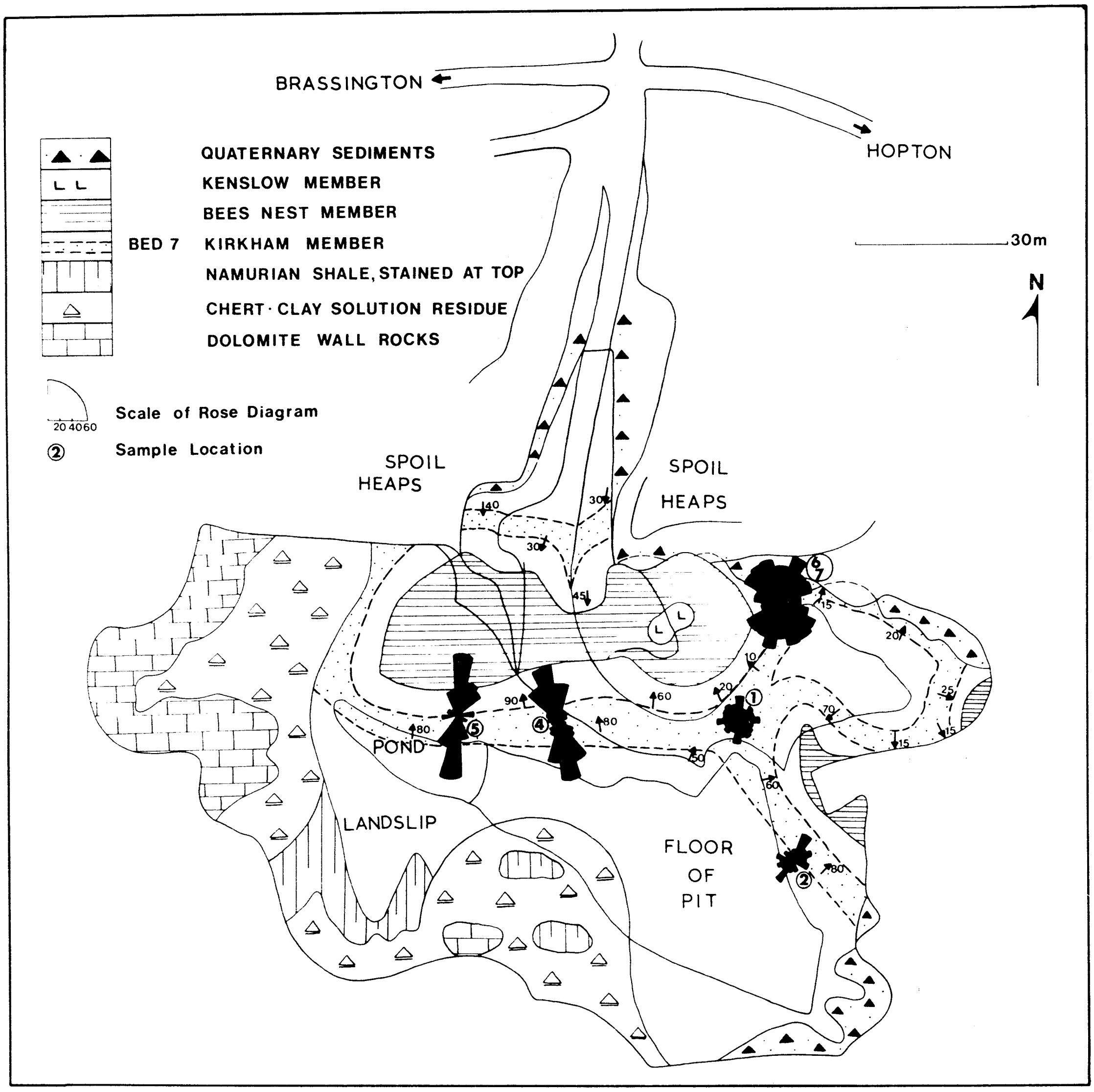


Text-figs. 11, 12 & 13: Rose diagrams showing plots of the pebble orientations at Heathcote, Blakemoor and Custard Field Pits, respectively.

The Validity and Interpretation of the Results

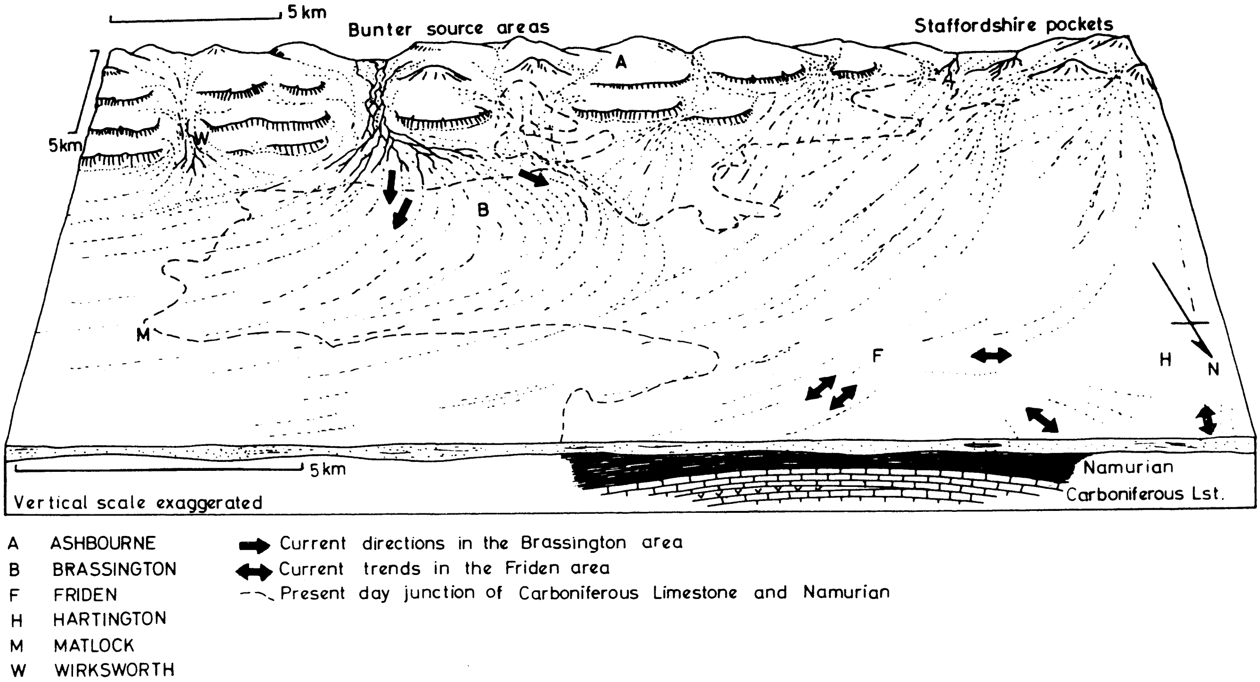
An attempt has been made to establish whether the rotation during subsidence which has affected most of the sections, has caused the palaeocurrent structures to be distorted. Some beds are locally inverted in a bulb-shaped structure at Kirkham's Pit. If it had been found that pebble long-axes were consistently parallel with the dip of rotated beds, this would have rendered the results suspect. It was found, however, that at practically all locations there was a sufficiently-wide range of long axis alignment to deny the possibility that any superimposed tectonic stretching had affected the pebble fabrics. At the Bees Nest Pit, for example (text-fig. 14) there is a remarkably consistent correlation between the vector mean trend from sample location to sample location regardless of whether the beds are steeply dipping or near-horizontal, cemented or uncemented. (In parts of this pit, cemented beds have become dislocated by faulting, presumably a result of subsidence; the cementation may therefore be assumed to be pre-subsidence. Thus it is concluded that subsidence rotation has had no significant effect on the directional orientation of pebble fabrics and the sets of cross-strata in any section studied.

The writers are well aware that there is no universal agreement that the preferred orientations of pebble long axes, even when clearly defined in statistical terms, necessarily gives proof of the direction of current flow in the immediate predepositional environment. However, there seems to be general agreement that in a high energy piedmont or flood-plain environment (*vide* p.51 above) pebbles are likely to have come to rest with their long axes either parallel with (mass moving) or at right angles to (rolling) the direction of flow (e.g. Krumbein, 1940; Ruchin, 1958; Sengupta, 1966; Rust, 1972; Hein and Walker, 1977). In any case it must be remembered that in the Kirkham Member at the Bees Nest and Kirkham's Pits there is a regular interdigitation of beds which yield statistically useful cross-bedding data and beds yielding useful pebble fabric data. Providing that the results from both are closely parallel, the cross-bedding data can clearly help to interpret the flow directions which have produced the pebble fabrics. The composite mean trend (V.M.T.) for the pebble long axes for all the beds at Bees Nest Pit (974 measurements) is 173/353° (text-fig. 5). The vector mean direction (V.M.D.) for 101 cross-bedding measurements is 036°. At Kirkham's Pit, the V.M.T. for 774 pebble measurements is 105/285° (text-fig. 6), whereas the V.M.D.



Text-fig. 14: Map of the Bees Nest Pit to show -
(1) the stratigraphy
(2) the sample locations for pebble orientation studies, and
(3) rose diagram compilations for measurements on Bed 7.

for cross-bedding measurements is 305° (text-fig. 4). The composite V.M.T. for all measurements from all levels in the southern group of pits (2,301 measurements) is 000/180°, whereas the composite V.M.D. for all the cross-bedding directions in the southern sections (131 measurements) is 010°. The writers conclude therefore that comparisons are close enough to deduce that a majority of the pebbles in the Kirkham Member gravels were generally deposited with their long axes selectively disposed parallel with current flows. A fairly consistent northwards directed flow, both in time and space is indicated for the southern group of sections (text-fig. 2).



Text-fig. 15: Hypothetical reconstruction of the palaeography of the Brassington Formation basin of deposition in mid-Kirkham Member times (partly after T.D. Ford)

Palaeogeographical and geomorphological implications

The present results only provide a very localised picture of the palaeogeography of the Brassington Formation in mid-Neogene times. Even if every subsided mass of the original formation sequence so far located had been exposed at the present time, it is doubtful if anything more than a very generalised picture of the distribution pattern of stream flows would have been forthcoming. But, of course, this is only a part of the picture and much can be deduced from complementary sedimentological studies. Several useful conclusions can be made at this stage.

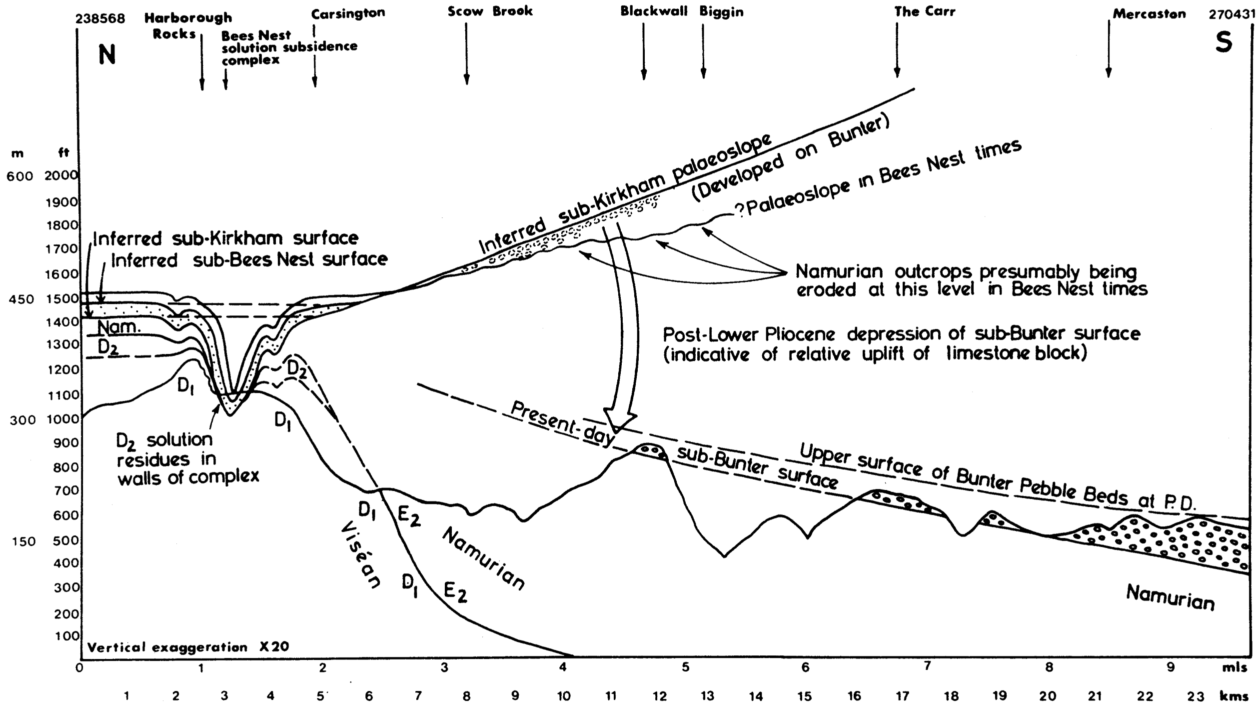
The present results support the hypothesis that an important provenance lay generally to the south of Brassington. Indeed, in view of the great lithological similarities of the sections around Brassington, there may have been a large river which drained an outcrop of rapidly eroding Bunter Pebble Beds in the block of country now cornered by the villages of Hognaston, Atlow, Kirk Ireton and Biggin (text-figs. 1 & 15). However, gravel pockets of supposed Brassington type have been worked near Kniveton (SK212509), so the edge of the depositional area must have lain further south for at least part of Kirkham Member times. Divergence of palaeocurrent directions in the three pits of the southern group suggests the construction of an alluvial fan with distributaries delivering large amounts of coarse sediment near to the edge of a subsiding basin.

There is no justification for conjecturally extending this fluvial pattern to the north because there is no control from cross-bedding structures in this northern group of exposures, and trends established from pebble fabric analysis are very variable. The thick gravel beds as exposed in the Kenslow Top section show that persistent flows of considerable competency took place here throughout Kirkham Member times. The Firms which extract sand and gravel locally for use as refractories believe that the Kirkham Member in the northern group of sections is composed of relatively finer grades of both sand and gravel than the deposits in the south, but the facies is otherwise comparable and it is puzzling that cross-bedding structures are so rare there. It is possible that the northern sediments were formed as another fan, built up, say, from the east or north, which coalesced with that built up from the south.

It is simply not possible to determine whether the general attitude of the palaeoslope which formed the southern margin of the basin altered significantly after Kirkham Member times. Certainly, the supply of gravel into the basin was abruptly terminated and overbank silty-clay deposition rapidly took its place. The gradients on the palaeoslope may have become gentler through the general southerly recession of the Bunter Pebble Bed source. Eventually, there must have been a more or less complete removal of gravel sources from a wide strip marginal to the basin. There seems to be no need to invoke any change in the trend of the palaeoslope. Removal of the Bunter cover (to produce the bulk of the Kirkham Member) could have exposed the underlying shaley Namurian outcrops which are still present in the Hognaston-Atlow-Kirk Ireton-Biggin block. Erosion of the Namurian foundation, and also, possibly, the Carboniferous Limestone of the Kniveton Inlier, would adequately account for the source of the dominantly illitic clays of the Bees Nest Member.

One of the more fascinating, if seemingly intractable problems about the Brassington Formation, is the destination of the drainage beyond the > 220 km^2 wide area within which Brassington sediments have been preserved. Supposed freshwater Neogene sediments have been described from solution subsidence hollows in the Carboniferous Limestone outcrops of north-east Wales, (Walsh & Brown, 1971), and it is tempting to regard these and the Derbyshire Neogene as coeval coastal plain alluvial deposits peripheral to a marine basin centred on Liverpool Bay and/or the Cheshire Basin. Unfortunately, no evidence whatever has yet come to light that these parts were open seaways in the mid-Neogene; nor is there any evidence that such Tertiary Basins as have been discovered on the floor of the Irish Sea have been the sites of internal drainage systems. Perhaps the simplest explanation to fit existing data is that the Brassington mainstream (and others contributing sediment to the Derbyshire Neogene area) were deflected into a more easterly course out of the basin and flowed into the North Sea as a very early analogue of the modern Trent (text-fig. 15). If the thickness of the Brassington Formation preserved in the Derbyshire solution hollows is truly representative of the mean local thicknesses of the prism (i.e. if it is not exaggerated as a result of solution subsidence effects which were concomitant with sedimentation), the total original volume of the Formation must have been in excess of 10 km^3. There can be little doubt that at least some of this now forms Plio-Pleistocene sediment in the North Sea Basins. It is suggested, therefore, that those same streams which deposited the Formation came later, through crustal movements, to remove their earlier-formed deposits eastwards. Hey (1976) has reported the occurrence of Bunter Pebble Bed-type clasts in the pre-Anglian succession of the East Anglian Pleistocene; conceivably at least some of these are Brassington Formation clasts, which have been re-cycled for a second time.

Finally, some comment must be made on the remarkable uplift which must have taken place along the southern end of the Pennines since Lower Pliocene times. Walsh *et al.* (1972) have proposed that the surface on which Brassington Formation sediment was deposited cannot have been much less than 420-450 m A.O.D. (1,400 - 1,500 ft.) in the Brassington area (text-fig. 16). By extension, the Kirkham Member here being some 30 m thick, the surface on which Bees Nest Clays were deposited must have been at about 450-480 m A.O.D. Clearly, at a time when the Bees Nest Clays were being deposited, the Namurian outcrops to the south of Brassington must have been higher still, say a minimum of 60 m. The general level of the provenance area must thus have been at about 510-540 m A.O.D. However, the hill summits on the supposed source area at the present time generally lie at about 240-270 m A.O.D. and at least one of these, that at Blackwall (SK 257497) still possesses what has been interpreted as a capping of Bunter Pebble Beds (Ford, 1972b). D.B. Thompson (personal communication) informs the writers that pebble lithology studies at Blackwall indicate that the percentage of Triassic-type pebbles and ventifacts is about half way between those of the Bunter Pebble Beds proper and the Brassington Formation. By implication, the former sub-Bunter surface cannot have been much lower than the general level of the modern hill summits in this source block.



Text-fig. 16: Diagram to show -
(1) the present-day physiography of the southern end of the Pennines, and
(2) an hypothetical reconstruction of the physiography in Lower Pliocene (Brassington Formation) times.

Thus, in a horizontal distance of no more than 3 km at most, the Lower Pliocene palaeoslope has been reversed in see-saw fashion, the relative swing being of the order of 1 in 10 when expressed as a gradient, and with a relative vertical displacement of 300 m as a minimal effect. Presumably, this was a fairly simple upwarp of the southern end of the Pennines, as nothing suggestive of a southwards-facing fault-scarp has been reported in the upper reaches of the Henmore Brook Valley (hereabouts termed the Scow Brook), where the main effects of the warp must have been felt. Hinges ("Charnières") of similar proportions and age have recently been postulated to explain certain major geomorphological features of the Welsh landscape, e.g. the north-western front of the Snowdonian Block (Battiau-Queney, 1980).

The cause of this remarkable uplift is not known, but it has an interesting association with the Derby Earthquakes of 1903, 1904 and 1906. Davison (1924, p.263) attributed the 'quakes to movement on a fault which trends 026° through Ashbourne and Hognaston at a depth of "several miles". The effects of the Derby Earthquakes show that there are two epicentres, the one 2.5 km east of Ashbourne, the other 5 km west of Wirksworth (these are ca. 12 km apart). On the basis of other recent earthquake effects in the North Midlands, Davison concluded that there is a pattern of interfering active folds of Caledonoid and Charnoid trend in the area. One interpretation of the fault movements is that the Ashbourne and Wirksworth epicentres lie close to the intersection of a Caledonian syncline with a Charnian syncline (Davison, 1924, p.408) which thus coincides roughly with what is considered in this paper to have been an area much depressed since the Lower Pliocene.

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