SUPERFICIAL VALLEY FOLDS OF LATE PLEISTOCENE AGE IN THE BREADSALL AREA OF SOUTH DERBYSHIRE

by

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Summary

Detailed mapping of stream sections in the Breadsall area of south Derbyshire has revealed a considerable amount of regionally abnormal folding affecting rocks of lower Namurian age. The folds appear to post-date a Wolstonian glacial till, but are themselves abruptly truncated by more recent solifluction deposits. It is suggested that they are of non-tectonic origin and probably developed as a result of periglacial activity during the Devensian.

Introduction

In the area around Breadsall (SK 370398) 4 km NNE of Derby a number of minor streams drain from the higher ground in the north and east towards the valley of the River Derwent (text-fig. 1). These streams deeply dissect a plateau feature comprised mainly of Triassic rocks with a superficial cover of glacial deposits, and have exposed lower Namurian rocks along their valley floors. The stream sections are of note since they show the exposed Namurian rocks to be affected by a high degree of regionally abnormal folding.

The folding is best seen along the most southerly stream, Dam Brook (SK 375396 to SK 388397) where there is an almost continuous exposure of the lower Namurian rocks, up to and including the Ashover Grit. The neighbouring Boosemoor Brook, 1 km to the north, flows across the same range of succession and contains similar structures, but outcrops are less frequent and the rocks only poorly exposed.

No mention of these structures was made in the original Geological Survey Memoir for this region (Gibson *et al.*, 1908). The area was recently re-surveyed by the Institute of Geological Sciences. (Sheet SK 33 NE; I. G. S. 1969). Although this survey noted the presence of "intensely disturbed" strata at SK 379397, the detailed nature and significance of the folding has not been described (J. G. O. Smart, personal communication). This paper gives a record of the structures seen along the entire Dam Brook section together with an interpretation of their probable mode of origin.

Succession

The Namurian rocks exposed along Dam Brook, Breadsall comprise a sequence of dark grey mudstones with intercalated grey and light-brown siltstones and sandstones. The sandstones become thicker and more numerous towards the top of the exposed sequence and culminate in the main bed of the Ashover Grit at SK 388396. Well developed sole structures, including flutes and grooves, were noted on the bases of some of the sandstone beds. The mudstones were frequently well laminated and contained numerous carbonaceous and thin ferruginous horizons. Bullions up to 0.6 m in size were particularly common between SK 375396 and SK 383398. The Institute of Geological Sciences (1969) recorded the presence of goniatites in Mill Plantation (SK 376396) indicating that the E. and H. zones are exposed

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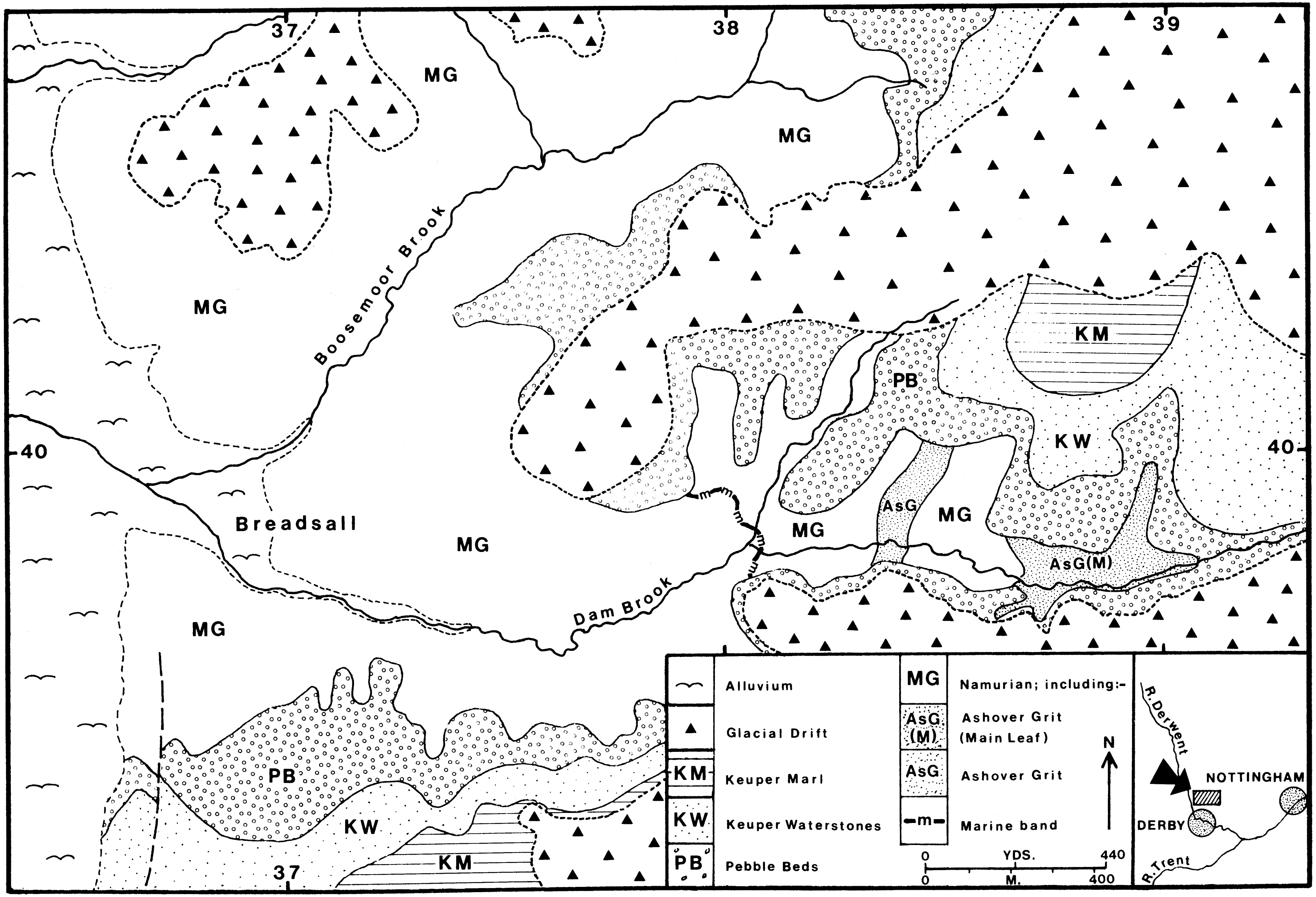
pp. 279-290, 3 text-figs. Plate 15.

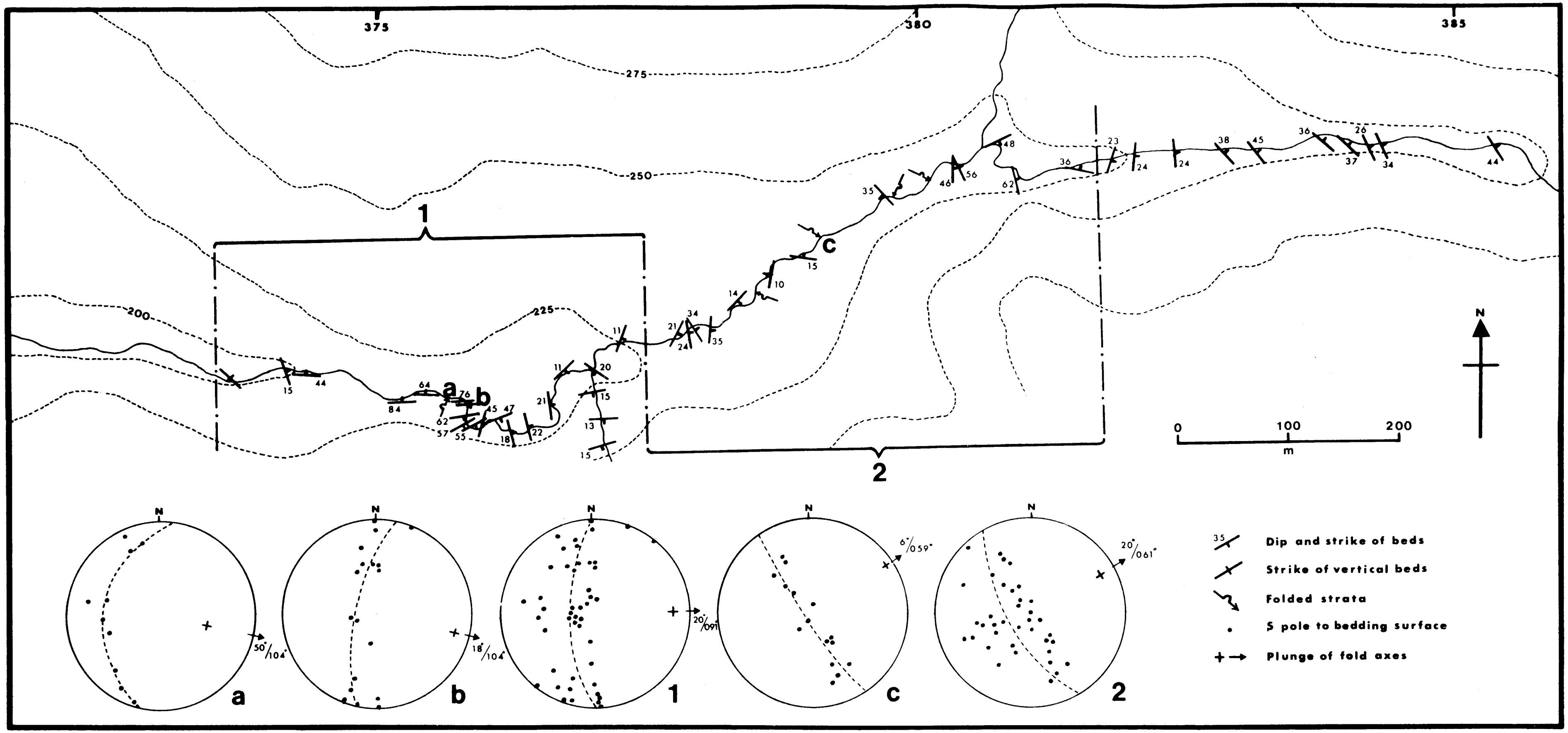


Text-fig. 1. General geology of the Breadsall area, Derbyshire.

in the lower part of the stream course. The position of the *Reticuloceras bilingue* marine band was placed higher up the valley at SK 381397 (text-fig. 1).

A measured succession for the lower part of the stream is given here to show the typical sediments developed and their thicknesses.

	Thickness (m)
Brown-grey silty clay with plant remains and carbonaceous horizons.	1.24
Fawn-grey quartzose sandstone.	0.39
Brown-grey silty clay with plant remains.	1.11
Fawn-grey quartzose sandstone.	0.65
Blue-grey quartzose sandstone.	0.25
Fawn-grey siltstone.	0.36
Purplish-grey micaceous siltstones with a thin sandstone at base.	3.15
Gap.	28
Grey siltstones and shales.	0.60+
Dark-grey quartzose sandstone.	0.29
Grey silty clay.	2.00
Grey clay with iron-staining.	0.51
Black muddy shales.	0.70
Grey quartzose sandstone.	0.32
Grey shales.	0.70
Grey siltstones and shales with iron-staining.	1.20
Grey nodular quartzose sandstone.	0.32
Grey siltstones and shales.	2.25
Grey muddy clays and shales.	1.60
Grey flaggy sandstone.	0.09
Grey muddy shales.	0.33+
Gap.	approx. 4 m
Grey muddy shales.	1.20
Grey clays and mudstones with ferruginous bands.	0.14
Grey silty shale.	0.18
Carbonaceous horizon.	0.005
Grey shales, silty mudstones with nodular horizons.	1.26
Fawn-grey flaggy sandstone.	0.25
Interbedded grey shales and grey flaggy siltstones.	0.41
Grey shales and thin sandstones bands.	0.79+



Text-fig. 2. Main structures developed along Dam Brook, Breadsall.

a, b, c, : Pi-diagrams of folding at the localities indicated -
a SK 37563956 b SK 37583955 c SK 37913970

1 : Pi-diagram of folding between SK 37353960 and SK37753960

2 : Pi-diagrams of folding between SK 37753960 and SK 38203975

Structure

Regionally the Carboniferous rocks of the area show a relatively simple structure. The beds strike north-south from Belper (SK 345475) to Little Eaton (SK 360418) before swinging into an east-west strike north of Derby. They are well exposed in several disused quarries where gentle dips of between 10° and 15° eastwards and northwards have been recorded. The overlying Permo-Triassic rocks dip gently eastwards and southwards at angles of up to 5°. A 12 m deep temporary section between Dam Brook and Boosemoor Brook (SK 372397) formerly showed Namurian mudstones with interbedded sandstones dipping north-eastwards at 10° (personal communication J. G. O. Smart).

The Namurian shales and sandstones along the length of Dam Brook are highly disturbed and show abnormally high dips, between 10° and vertical, and generally over 35° (text-fig. 2). Evidence of folding is present at a number of localities along the stream. However the nature of the folding is best seen at the following three localities: (a) SK 37563956, (b) SK 37583955 and (c) SK 37913970 (text-figs. 2 and 3). Structural details of these folds are given in table 1.

TABLE 1. Details of the main folds seen along Dam Brook

Locality	Fold	Plunge of Fold Axis Dip/Direction	Strike of Axial Surface	Inclination of Axial Surface	Inter-limb Angle
SK 37563956 (Fig 3a)	Syncline	48°/103°	094° - 274°	81° S	26°
" (Fig 3a)	Anticline	46°/104°	104° - 284°	vertical	47°
SK 37583955	Syncline	20°/104°	099° - 279°	78° S	67°
" (Fig 3b)	Anticline (S.)	10°/096°	098° - 278°	80° N	112°
" (Fig 3b)	Syncline	3°/098°	099° - 279°	82° N	115°
" (Fig 3b)	Anticline (N.)	3°/270°	092° - 272°	65° S	50°
SK 37703958	Anticline	horizontal	137° - 317°	vertical	140°
SK 37853966	Syncline	24°/030°	030° - 210°	vertical	110°
SK 37913970 (Fig 3c)	Anticline (S.)	2°/053°	052° - 232°	77° SE	94°
" (Fig 3c)	Syncline	horizontal	064° - 244°	vertical	64°
" (Fig 3c)	Anticline	horizontal	063° - 243°	vertical	65°
" (Fig 3c)	Syncline (N.)	horizontal	065° - 245°	vertical	62°

From table 1 it is seen that the majority of the folds plunge eastwards or north-eastwards, that is, upstream and in general the strike of their axial surfaces lies parallel with the trend of the valley. This is emphasised in text-fig. 2 where it is seen that from Grid Ref. SK 37353960 to SK 37753960 the valley trends 090° to 270° and the average trend of the folding is 091° to 271° with the average axial plunge of the folds 20°/091° (text-fig. 2i), while from Grid Ref. SK37753960 to SK 38203975 the valley trends 069° to 249° and the folds generally trend 061° to 241° and plunge 20°/061° (text-fig. 2).

A number of minor fault planes having the same general trends as the strike of the fold axial surfaces were noted.

Beyond SK 382398, in the Ashover Grit part of the sequence, the dips, although steeper than the regional dip, become regular averaging 34°/069°.

Origin

At first sight the fold structures seen along the stream section might appear to be of tectonic origin. However, their localised intensity would be difficult to explain unless it is suggested that they are associated with a major ENE-WSW wrench fault. Folds of similar type have been reported in association with major wrench faults in the South Wales Coalfield (Owen 1954, Weaver 1975). Such an explanation is at variance with the results of the field survey. No evidence of a major fault was found, while detailed mapping of the folds on a scale of 1 : 2,500 revealed the following significant features:

(1) The trends of the fold axial surfaces are parallel with the valley and generally the dips on the fold limbs are at right angles to the valley sides (text-fig. 2).

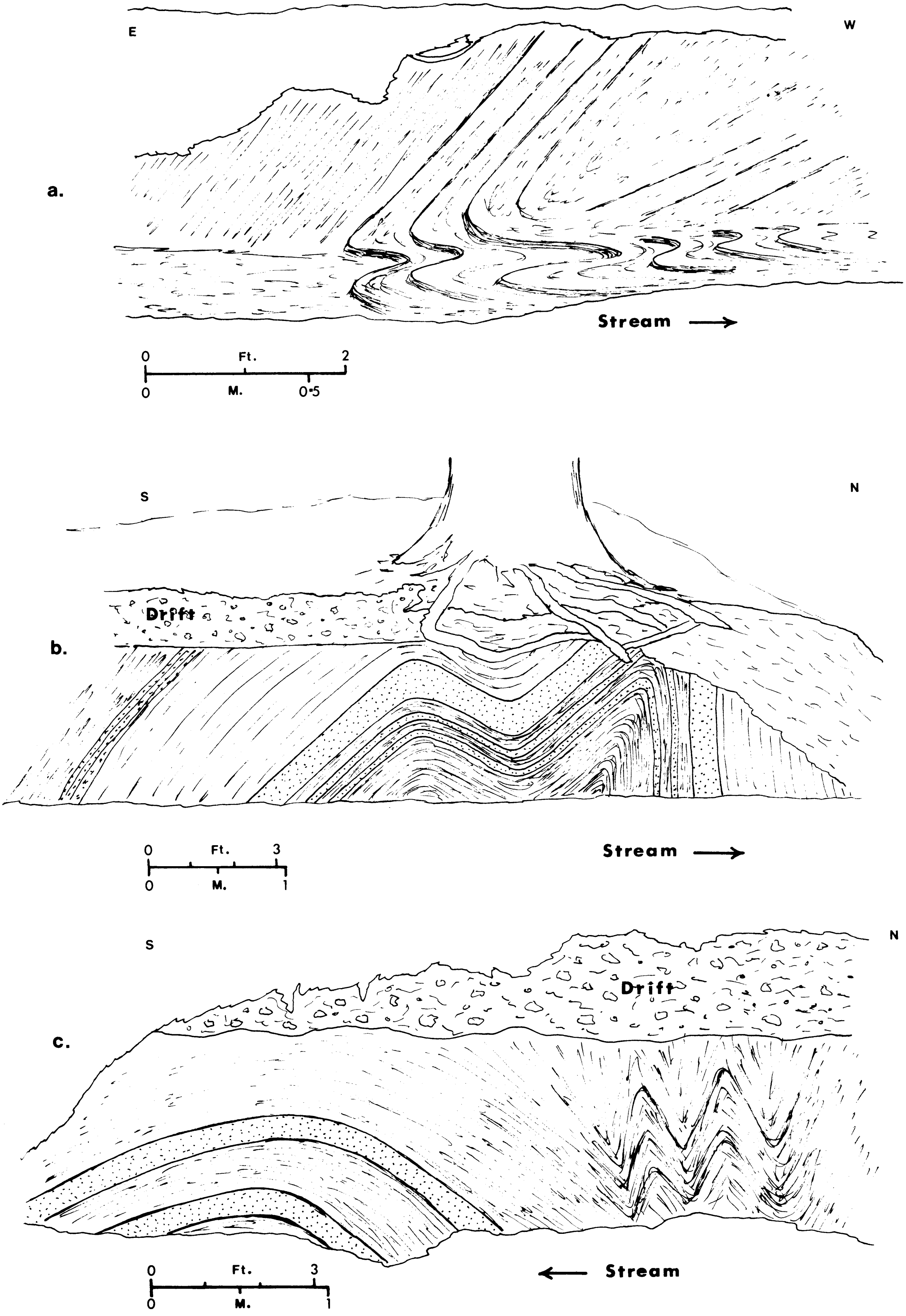
(2) The folding is most intense where the valley is deepest and the disturbance appears to decrease upstream as the valley becomes more open (compare text-fig. 2).

(3) The folds in general plunge upstream.

These factors indicate that topographic control was significant during the formation of the fold structures and suggest that a non-diastrophic origin is a more reasonable interpretation.

Folds produced by essentially superficial disturbances rather than deep-seated tectonic causes were first described in detail from the Northamptonshire Ironstone area (Hollingworth, Taylor & Kellaway, 1944) and analogous structures have since been reported elsewhere (e.g. Shotton & Wilcockson, 1951; Cook 1959; Smith, Rhys & Eden, 1967; Stevenson & Gaunt, 1971). They were originally attributed to a phenomenon called 'valley bulging', in which differential unloading, resulting from the valley-erosion of competent beds, induced plastic deformation of underlying incompetent clays. However, Kellaway & Taylor (1953) later demonstrated the inadequacy of this hypothesis by stressing the lack of any systematic relationship between the intensity of deformation and the nature of the rocks or the depth and shape of the valleys. Furthermore, the absence of distortion in any of the associated post-glacial sediments indicated that all movements had for some time ceased, despite the fact that the existing relief was greater than at any time in the present cycle of erosion. This suggested that particular environmental conditions were essential to the development of the Northamptonshire structures, and Kellaway & Taylor concluded that such conditions would only be attained in areas of perennially frozen ground during the Pleistocene.

Some support for these views was derived from the findings of Shotton & Wilcockson (1951) in a study of comparable structures at an opencast coal-site near Barnsley, Yorkshire. The concomitant folding of an 'older' gravel deposit and the abrupt truncation of both this and the folds by undeformed 'newer' gravels clearly demonstrated to these authors that the date of the disturbances was restricted to within the period of drift deposition. A probable



Text-fig. 3. Schematic diagrams of some of the folds at localities a, b, c, text-fig. 2.

Pleistocene age was also deduced by Cook (1959) for superficial structures at Upper Batley near Leeds, where strongly contorted 'Middle Coal Measure' rocks were sharply truncated by undisturbed drift deposits of 'boulder clay' type. Analogous structures in the Edale and Ashop valley areas of North Derbyshire are truncated by 'head' deposits (Stevenson & Gaunt, 1971, pp.338-39).

The Breadsall structures are very similar to those outlined above and it is particularly notable that they also are abruptly truncated by drift deposits (text-figs 3b, and c; Plate 15, fig. b). These are well exposed where the stream has excavated cliffs in the steep valley sides and comprise coarse sandy gravels resting on an eroded surface of Namurian shales and overlain by a gleyed brown clay containing sporadic pebbles of predominantly local origin. Apart from slight variations in thickness, the drift deposits show remarkable uniformity along the length of the stream section. A temporary exposure on the valley floor west of Mill Plantation, but 10 m north of the present stream position (37353963), recently showed a fresh section through 1.00 m light brown stoney clay and 0.75 m ferruginous sandy gravels resting on an eroded surface of steeply dipping black shales. The gravel is possibly of fluvial origin, but may represent downwash from the Bunter Pebble Beds exposed on the upper valley sides; the pebbly clay is almost certainly a colluvial deposit. Nowhere along the Dam Brook section do the drift deposits show any sign of deformation, except for the localised effects of soil creep and slumping on the unvegetated stream banks.

It is recognised that certain valley bulging effects can, under favourable circumstances, take place at the present day and indeed may be artificially induced by differential loading (Kent and also Watson in discussion of Hollingworth *et al*, 1944 p.35, 36; Gill and also Kent in discussion of Kellaway and Taylor, 1953 p. 372). However, given the similarities between the present instances and those described from elsewhere, the fact that movements are no longer continuing would strongly suggest that a Pleistocene non-diastrophic origin is the most likely explanation for the Breadsall structures.

Mechanism of formation

Although authors have generally agreed on a non-diastrophic origin for the majority of valley bulge structures, opinions have differed considerably over the precise mechanism of formation.

Kellaway and Taylor (1953) favoured the heaving action produced by the growth of ground ice beneath the lower valley sides and bottom. Shotton and Wilcockson (1957) placed greater emphasis on the downhill sliding of unstable surface layers during periods of thaw and stressed that at such times the clays would be much more susceptible to deformation because of their water-saturated and semi-plastic condition. However, Cook (1957) found that neither hypothesis gave a completely satisfactory explanation for all the structures observed at Upper Batley. Although downhill slippage was a possible cause for some of the folds, others showed diapiric tendencies and could not have formed in that manner. Even the suggestion that such structures were of composite origin, involving phases of frost heave subsequent to soil creep did not explain why all the folds were not similarly affected. It seems likely, therefore, that valley bulging phenomena may originate in a number of different ways.

Kellaway (1972) has reintroduced the idea of ice-loading to account for certain large scale valley bulge structures in parts of lowland Britain where uplift to the extent of 100 ft (30 m) has been reported (Hollingworth *et al.*, 1944). Mass movement of this magnitude, frequently displacing hard sandstones and limestones in association with over-consolidated clays, would require tremendous stresses over quite wide areas. The scale and intensity of structural deformation, its restriction to relatively narrow zones and the existing low relief suggested to Kellaway that in such instances glacial loading was the most likely explanation.

The Breadsall structures appear to reflect the relief of pressure upwards and outwards. Only the overturned fold (text-fig. 3, a) and chevron folding (text-fig. 3, c) are anomalous in this

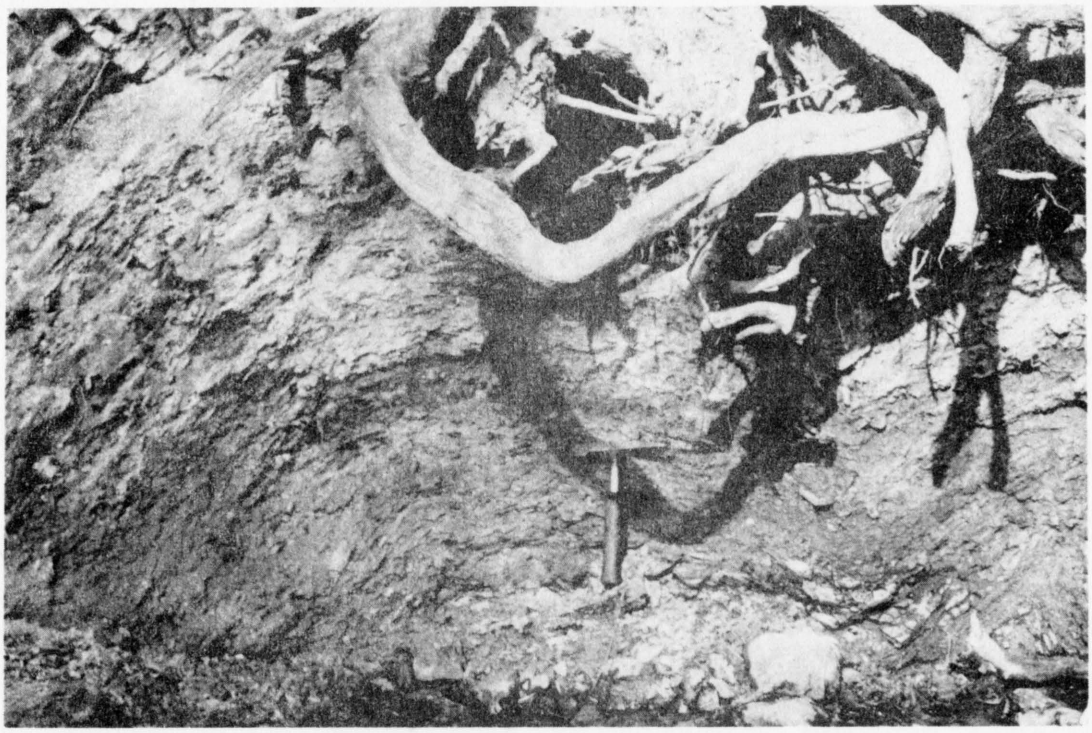


Fig. 1. Folding at locality b, text-figs. 2b, 3b.

Fig. 2. Folding at locality c, text-figs. 2c, 3c.

respect, but both situations may be attributed to partial collapse or sliding of the shales subsequent to uplift. The relationship between intensity of deformation and valley depth indicates that topography had a controlling influence on the development of the structures. The consistent up-valley (E and NE) plunge of the folds supports this view as it shows that the greatest uplift has occurred where the valley is deepest, i.e. towards the western end.

Glacial loading is certainly a possible cause of the uplift. However, in contrast to the examples described by Kellaway (1972), the disturbances at Breadsall are relatively small-scale. Taking into account the deep valley situation and the easily deformed bedrock, the apparent absence of large scale structures possibly implies that ice loading may be a less likely explanation in this instance.

A study of the causes of mass displacement in present day periglacial environments (Washburn, 1973 p. 86 - 90) suggests that a periglacial origin may be more applicable to the Breadsall structures. Both cryostatic pressure and artesian pressure are known to be capable of producing heaving, or even upward injection, of material trapped beneath a downward-freezing active layer and the subjacent permafrost table. Perhaps of greater significance, however, is the often considerable heaving or doming of the ground surface that results from the development of pingos. These ice-cored mounds are thought to form either by the progressive all-sided freezing of a water body or water-saturated sediment, or by the upward movement of artesian water into permafrost, where it freezes as injection ice (Washburn, 1973, p. 154). It is likely that water-saturated shales in valley floors would be extremely susceptible to deformation of this type. Although little information is available on the movement of artesian water in semi-permeable rocks, such as shales, under permafrost conditions, the necessary differences in hydrostatic head would certainly be augmented in a valley situation.

Pingos are widely distributed in present day permafrost regions of Northern Europe. The recent recognition of fossil forms in Britain (e.g. Mitchell, 1971; Watson, 1971, 1972; Watson & Watson, 1972) testifies to the existence of suitable conditions for their formation during the Pleistocene. Many occur in wide, open-valley situations (Watson & Watson, 1972). The mechanisms suggested for their formation seem equally applicable to the development of bulging in relatively deep, narrow valleys as at Breadsall.

Growth of ground-ice under the restrictive effects of the valley sides would probably give rise to elongated structures sympathetically related to the valley morphology. The eventual decay of the ice masses and subsequent irregular collapse of the bulged strata may well explain the presence of overturned folds. Associated cambering, noted by the Institute of Geological Sciences in more competent strata on the upper valley sides (J.G.O. Smart, personal communication), would help maintain the presence of folds in the valley bottoms. Subsequent solifluction of the thawed surface layers, coupled with renewed stream activity, would cause the truncation of the folds and the deposition of the colluvial deposits which now overlie them.

Age of the Superficial Structures

An approximate stratigraphical age for the structures occurring along Dam Brook, Breadsall may be inferred from their relationship to the Quaternary deposits in the area. The brook is one of several streams dissecting a fairly extensive till sheet stretching from Morley (SK 395410) to Spondon (SK 400360). Recent temporary exposures in this till sheet have shown the erratic content of the till to be essentially of 'northern' derivation. Posnansky (1960), basing his view partly upon the evidence of Jowett & Charlesworth (1929) in North Derbyshire, deduced that such 'Pennine drift' belonged to the same glacial episode as the Chalky boulder clay. This is now regarded as being of Wolstonian age (Shotton, 1973)

As the till in the Breadsall area occurs only on the interfluves, and is apparently absent from the valley floors and sides, it seems probable that the valleys post-date the period of till deposition. It is possible, however, that they were initiated in late Wolstonian times as a result of meltwater outflow towards the lower ground to the west. Downcutting would have continued during the succeeding Ipswichian interglacial but may have eventually lessened, as the terrace deposits found in the adjacent river valleys indicate that this was, in part, a period of extensive aggradation (Posnansky, 1960; Rice, 1968a; Jones and Stanley, 1974).

The fold structures themselves were probably developed during the colder phases of the Devensian. Although south Derbyshire is considered to have remained ice-free during this period by Posnansky (1960), glacial deposits have been reported in adjacent parts of south Staffordshire (Stevenson & Mitchell, 1955; Morgan, 1973) and the south Derbyshire area must have been subjected to quite intense periglacial conditions at this time. Devensian cryoturbation structures and related phenomena are widely developed throughout the East Midlands (Rice, 1968b). Frost wedges have been reported at Mugginton (SK 285439) in central Derbyshire (Bridges, 1964), and involutions of presumed Devensian age have been noted recently in the Beeston Terrace of the Trent Basin at Boulton Moor (SK 384317), only 8 km south of the area under discussion (Jones, 1974).

The gravels and solifluction deposits which now truncate and clearly post-date the superficial structures at Breadsall may be attributed to late Devensian or early Flandrian times. Since the time of truncation the stream bed has been downcut by a further 0.5 to 1.0 m.

Significance

When the geological significance of superficial structures was first recognised in Northamptonshire (Hollingworth *et al*, 1944) it was emphasised that such features were probably more common than had been previously realised. Although several examples have since been forthcoming, the structures have not been as widely reported as was perhaps anticipated. Similar features ought to occur wherever geological conditions analogous to those of Northamptonshire or south Derbyshire exist. It is interesting in this connection that the Institute of Geological Sciences have indicated the presence of 'contorted strata' in several valleys in the Turnditch and Wirksworth areas of Central Derbyshire, 10 km further north. This supplements the examples of bulging already noted in the Chesterfield area of North Derbyshire (Smith *et al.*, 1967) and suggests that, in Derbyshire at least, valley bulging may well be a common feature in valleys where competent beds overlie incompetent Carboniferous shales. As stream sections are the classic localities for exposures in geological mapping, the recognition of these structures is of obvious importance.

Conclusions

Stream sections in South Derbyshire display a considerable amount of regionally abnormal folding affecting rocks of lower Namurian age. The close relationship with the present-day local topography suggests that the structures have a non-tectonic origin. However, the abrupt truncation of the folded rocks by undeformed solifluction deposits indicates that all movements have now ceased. It is suggested that the folds developed under the influence of late Pleistocene (Devensian) periglacial conditions. Such features may be much more common in the Derbyshire area than the literature suggests.

Acknowledgements

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