THE

Mercian Geologist

Vol. 5, No. 4.

December 1975

THE MERCIAN GEOLOGIST

JOURNAL

OF THE

EAST MIDLANDS GEOLOGICAL SOCIETY

VOLUME 5 NUMBER 4

DECEMBER 1975

EDITOR: F.M.TAYLOR

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Mercian Geologist,
Vol. 5, No. 4, 1975.

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ISSN 0025 990X

Printed by the Nottingham University Press.

Front Cover: *Hippotamus amphibicus* Linnaeus. Occlusal view of Allenton mandible (F1030) showing canines and molar teeth. The alveoli (sockets) of the four incissors can be seen between the canines. Two large first incisor alveoli at centre with the smaller second incisor alveoli on either side. This is the typical tetraprodont condition as seen in the modern species. (See Jones and Stanley, pp. 259-271 of this issue).

DESCRIPTION OF HIPPOPOTAMUS AND OTHER MAMMALIAN REMAINS FROM THE ALLENTON TERRACE OF THE LOWER DERWENT VALLEY, SOUTH DERBYSHIRE

by

P.F. Jones and M.F. Stanley

Summary

The Allenton Terrace of the lower Derwent Valley has yielded a rich Pleistocene mammalian fauna from two closely spaced localities. Recent discoveries at Boulton Moor have considerably supplemented the original finds made at Allenton in 1895. Seven taxa are recorded, representing a typical Ipswichian assemblage dominated by *Hippopotamus*. A re-examination of the Allenton hippopotamus remains has been unaertaken and a description of the complete fauna from both localities is presented.

Introduction

The Allenton Terrace extends on the south side of the River Derwent from Derby (SK 355362) to Elvaston (SK 410325). It forms a prominent morphological feature which has an average altitude of about 42 m O.D., and lies approximately 5.4 m above the present river's flood plain.

Mammalian remains were first reported from the terrace by Bemrose and Deeley (1896). In an excavation at Allenton (SK 372325) these authors recorded an almost complete skeleton of *Hippopotamus* together with the breast bone of *Elephas* and femur of *Rhinoceros* (species not identified). Since that date, however, nothing further had been reported until the recent discoveries at Boulton Moor (SK 382317) only 1 km south-east of the Allenton site (Jones & Stanley, 1974). Here the three genera originally found at Allenton were represented again, together with four new species. The additional presence of brown bear (*Ursus* cf. *arctos* Linnaeus); hyaena [*Crocuta crocuta* (Erxleben)] red deer (*Cervus elaphus* Linnaeus); and ox or bison (*Bos* sp. or *Bison* sp.) gave an overall faunal assemblage which is regarded as being characteristic of the last (Ipswichian) interglacial (Sutcliffe, 1960. 1964, Stuart, 1974). The location of the sites and the distribution of superficial deposits is shown on text-fig. 1.

After their extraction, the Allenton bones were repaired and deposited in Derby Museum. Although a report on their discovery, and an account of the geology of the site, was made at the time (Bemrose & Deeley, 1896) no detailed description of the specimens collected has ever been attempted. The recent finds at Boulton Moor, and the subsequent need for comparative material, led to re-examination of the Allenton remains. An important supplement to this examination was a comparison of the material with corresponding specimens from other *Hippopotamus* localities in Britain.

A report on the significance of the Boulton Moor finds has been published elsewhere (Jones & Stanley, 1974). The purpose of this paper is to give a detailed descrition of all the mammalian remains that have been obtained from both of the bone-bearing localities in the Allenton Terrace.

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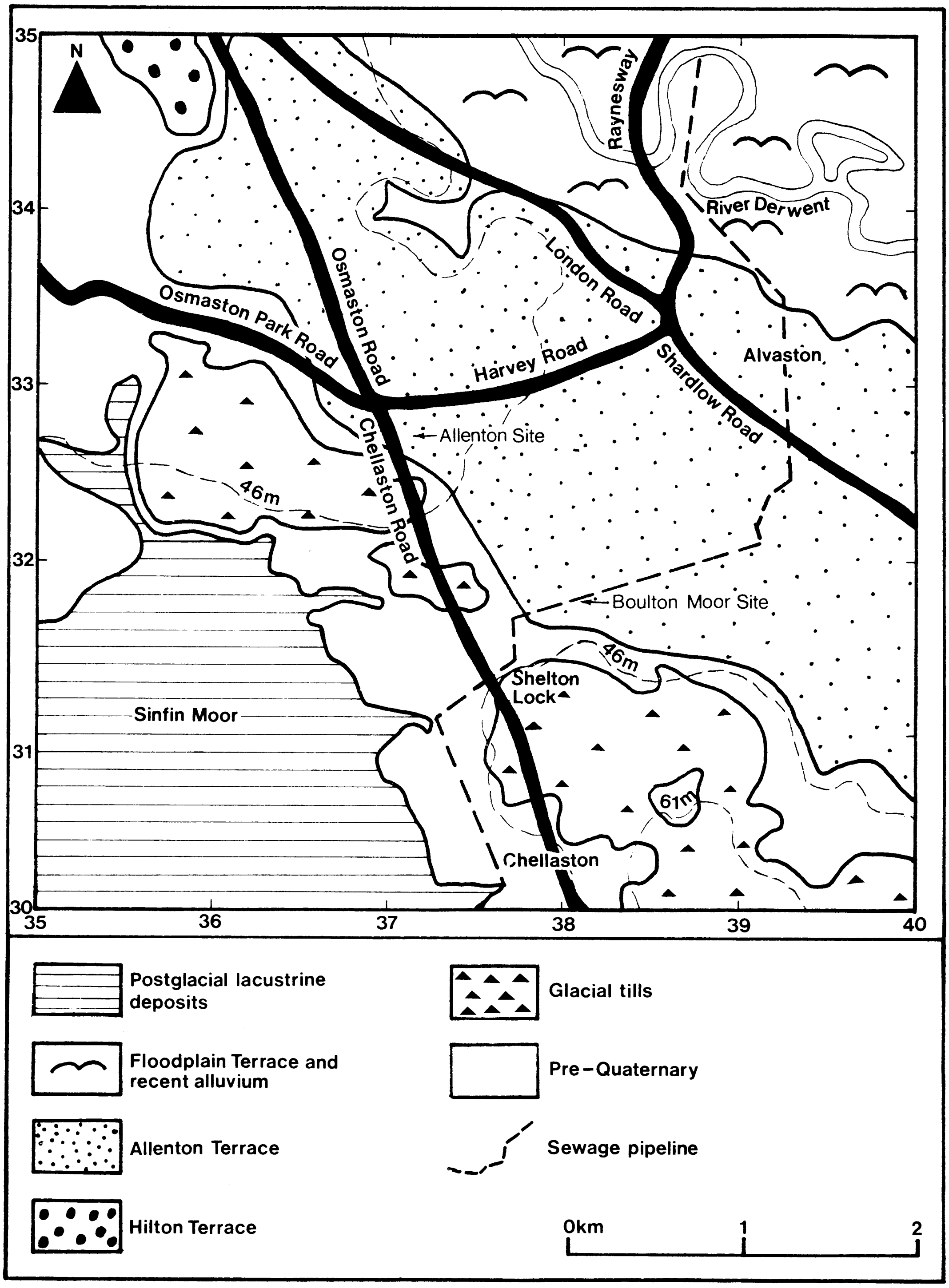
pp. 259-271, 1 text-fig. Cover of
this issue, Plates 11, 12 and 13.



Text-fig. 1. The superficial deposits in the south-east of Derby showing the location of the Allenton and Boulton Moor Sites.

The mammalian sites

The two mammalian sites occur towards the south-west margin of the terrace (text-fig. 1) where a narrow ridge of Keuper Marl capped by 'boulder clay' separates the intérglacial deposits from the low level post-glacial lacustrine deposits of Sinfin Moor. The latter have been recently described by Champion (1969).

At Allenton, the mammalian remains were found during excavations for a well in the yard of the Crown Inn (Bemrose and Deeley, 1896). The specimens were obtained from a depth of approximately 2.95 m in a layer of dark-coloured pebbly sand immediately overlying 'river gravel'. The bones were associated with plant remains that seemed indicative of 'a moist meadow or swampy ground and a temperate climate'. An elytron and thorax of a beetle were also found but their identification was not recorded. From an assortment of 127 bones and fragments obtained, it proved possible to reassemble a total of 51 complete, or almost complete, specimens. The large number of bones, their good state of preservation and their only slightly disturbed positions, led Bemrose and Deeley to the conclusion that the *Hippopotamus* skeleton was deposited almost entire at the spot where the bones were found, and made unlikely the possibility that they were derived from an older deposit. These authors envisaged the animal being stranded in an old channel of the River Derwent and quickly covered with sand and clay with only very slight disturbance.

The Boulton Moor mammalian remains were discovered in July 1973 during excavations for a major sewage pipeline which crossed the Allenton Terrace in a north-east to south-west direction. The requisite 6 m depth for the sewage pipes necessitated the trench being cut in two stages; after removal of the topsoil, a wide open-cut was first excavated to a depth of approximately 3 m by drag-line operations and then a narrower central trench was dug by a mechanical excavator. North-east of the mammalian locality this lower trench penetrated glacial till at a total depth of 3.5 m (Jones, 1974). However, as the excavations progressed towards the south-west, the till surface dropped down to below the floor of the trench to give a 6 m thickness of terrace sands and gravels. The majority of the mammalian remains were collected *in-situ* from coarse sandy gravels in the lower part of this exposed section. Although a few bones were picked up from tipped material on the trench sites, their provenance is not in doubt. A total of 56 bones, teeth and fragments was obtained. The material when repaired yielded 24 identifiable specimens and 20 unidentifiable fragments.

Description of the specimens

A complete list of the mammalian remains obtained from the Allenton Terrace is given in table 1. All the specimens are lodged in the Department of Natural History, Derby Museums and Art Gallery. The Museum accession numbers are 298/1895 and 947/1974 for the Allenton and Boulton Moor material respectively. Individual specimen numbers are quoted in the table and are referred to in the text.

The Allenton mammalian remains

The majority of the Allenton bones belong to *Hippopotamus* and are extremely well preserved. At an unknown date (? 1895) several of the bones were repaired with cement filler and wire, and an almost complete vertebral column placed on display in the Museum. In June 1972 the remains were cleaned, treated with a protective coating of polyvinyl butyral (P. V. B.) and then re-displayed.

Hippopotamus amphibius Linnaeus

Mandible (F1030; Cover; Plate 11, fig. 1). This is well preserved, but the right ascending ramus, except for the manibular condyle, is wanting. The left ascending ramus is broken and repaired; the coronoid process is missing. The exterior-anterior parts of

Table 1. List of specimens from the Allenton Terrace

ALLENTON SITE

Map Ref.	SK 371325
Reference	Bemrose & Deeley (1896)
Museum No.	298/1895

Hippopotamus amphibius Linnaeus

F1030	Mandible with two canines
F1031	Axis (2nd cervial vertebra)
F1032-1035	3rd-6th cervical vertebrae
F1036-1039	1st-4th thoracic vertebrae
F1040-1049	6th-15th thoracic vertebrae
(F1043	Neural spine of 9th thoracic vertebra)
F1050-1053	1st-4th lumbar vertebrae
F1054	Sacrum
F1055	Right innominate
F1056	Left innominate
F1057	Left femur
F1058	Left tibia
F1059	Left fibula
F1060	Left calcaneum
F1061	Left cuboid
F1062	Right fibula
F1063	Right calcaneum
F1064	Right cuboid
F1065	Right astragalus
F1066	Left lunare
F1067	Left scaphoid
F1068	3rd right rib
F1069	4th right rib
F1070	4th left rib
F1071	Shaft of rib, mid-distal half
F1072	Shaft of rib, mid-distal half
F1073	Shaft of rib, mid-distal half
F1074	Shaft of rib, mid-distal half

Elephas sp.

F1075	Breast bone fragment

Rhinoceros sp.

F1076	Right femur, midshaft

BOULTON MOOR SITE

Map Ref.	SK 382317
Reference	Jones & Stanley (1974)
Museum No.	947/1974

Hippopotamus amphibius Linnaeus

F831	Centrum of a thoracic vertebra
F832	Left tibia, mid shaft
F833	Radio-ulna, proximal articulation fragment.
F834	Left lower canine
F835	Left lower canine
F836	Left lower canine
F837	Left lower canine
F838	Lower jaw, ventral half
F839	Right lower first incisor
F840	Right scapula, distal fragment

? *Palaeoloxodon antiquus* (Falconer)

F841	Tusk fragments (4)
F842	Left scapula, distal fragment

? *Dicerorhinus hemitoechus* (Falconer)

F843	Left scapula, distal half
F844	Left innominate, mid portion

Ursus cf. arctos Linnaeus

F845	Left femur, distal half

Cervus elaphus Linnaeus

F846	Antler beam
F847-848	Antler tines

Crocuta crocuta (Erxleben)

F849	Left tibia, juvenile form

Bos sp. or *Bison* sp. (Bojanus)

F850	Right radius, proximal fragment
F851	Left radius, proximal fragment
F852	Left radius, proximal half
F853	Left metacarpal, proximal fragment
F854	Left scapula, distal fragment

both horizontal rami are missing exposing the small canine teeth to their roots. A worn but complete left third molar tooth (M_3) and half of a worn right third molar are preserved in the adult tooth row. The two first incisor teeth are missing but their alveoli are prominent in the broken anterior end of the symphysis.

1.	Maximum length (mandibular condyle - anterior curve of canines)	590 mm
2.	Length of horizontal ramus (behind M_3 - broken end of ramus)	370 mm
3.	Height of left ascending ramus (mandibular angle - condyle)	260 mm
4.	Length of symphysis (approx)	179 mm
5.	Height of jaw (in front of M_3)	140 mm
6.	Distance between horizontal rami at alveolus of M_3	88 mm
7.	Length of tooth row	270 mm
8.	Length of right canine; outside curvature:	390 mm
	inside curvature:	285 mm

Cervical vertebrae. The atlas (1st cervical) and the last (7th) cervical are missing and the remainder are highly abraded.

The axis (2nd cervical; F1031) is abraded at the articulating surfaces for the atlas; and the transverse processes are wanting. The area behind the odontoid process has been restored with cement filler. The neural spine has a rounded crest, cranially (transverse diameter 42 mm) and is broad and flat, caudally (transverse diameter 75 mm). The post-zygapophyses and centrum are intact but slightly abraded. The dimensions of the axis are given below.

1.	Length (odontoid process - dorso-caudal edge of centrum)	145 mm
2.	Max. transverse diameter across articulating surfaces for atlas	145 mm
3.	Max. transverse diameter across post-zygapophyses	121 mm
4.	Height from base of centrum (caudal end) to top of neural spine	178 mm

The 3rd - 6th cervicals (F1032-1035) are without their neural spines and transverse processes except for the presence of stumps of the right process (4th, 5th, 6th vertebrae) and the left process (5th vertebra). The pre-and post-zygapophyses are missing from the 4th and 5th cervicals. Maximum transverse diameter across post-zygapophyses: 3rd, 133 mm; 6th, 138 mm.

Thoracic vertebrae (F1036-1049). Of the full complement of 15 thoracic vertebrae only the 5th and 9th (except the neural spine) are missing. The neural spine of the 4th vertebra is missing, and all the spines except the 13th, 14th and 15th are abraded. The centrums are complete but those of the 4th, 6th and 8th vertebrae are abraded along their caudal edges. All the transverse processes are abraded; those of the 3rd, 4th (left), 12th (right) and 13th (left) are missing, and only stumps remain on the 6th and 14th vertebrae. The pre-zygapophyses of the 3rd - 10th and post-zygapophyses of the 3rd - 9th vertebrae are lost. In order to mount the skeleton for display the vertebrae were repaired and joined with cement filler.

	1st	11th	15th
Max. transverse diameter across transverse process	244 mm	166 mm	258 mm
Max. transverse diameter across pre-zygapophyses	154 mm	80 mm	97 mm

Lumbar vertebrae (F1050-F1053). All four vertebrae are present. Apart from slight abrasion of the transverse processes and edges of the centrums they are extremely well preserved.

		1st	2nd	3rd	4th
1.	Length of centrum (ventral surface)	78 mm	83 mm	85 mm	76 mm
2.	Max. trans. diameter across transverse process	369 mm	417 mm	492 mm	522 mm
3.	Base of centrum to tip of neural spine (cranial)	220 mm	226 mm	-	181 mm
4.	Height of centrum (mid-caudal end)	65 mm	62 mm	56 mm	54 mm

Sacrum (F1054). The Sacrum is complete and excellently preserved. The dimensions are given below.

1.	Max. length of sacrum	276 mm
2.	Height to top of neural spine (2nd sacral)	110 mm
3.	Max. transverse diameter across transverse process (2nd pseudo-sacral)	120 mm
4.	Max. transverse diameter across surface which unites with the ilium	309 mm

Pelvis. The right (F1055) and left (F1056; Plate 11, fig. 2) innominates were broken at the time of extraction and have been repaired. Both show signs of slight abrasion. The distal half of the right pubis and the distal extremity of the left pubis are missing. With these exceptions the pelvic girdle is complete and excellently preserved. The dimensions of the right innominate are given below:

1.	Max. length (iliac border to ischial border)	740 mm
2.	Length from acetabulum to mid supra-iliac border	385 mm
3.	Max. transverse diameter of ilium	455 mm
4.	Min. transverse diameter of ilium	111 mm
5.	Max. diameter of acetabulum (iliac to ischial border)	104 mm
6.	Min. diameter of mid-pubis (left innominate)	53 mm

Ribs. Only seven specimens of ribs were recovered. Of these, four (F1071-1074) are represented by mid-portions of shaft. The other three specimens comprise a proximal half with head and tubercle of a 4th right (F1069) and 4th left (F1070), and the proximal half with tubercle only of a 3rd right rib (F1068).

Limb bones. With the exception of the fibulae, all the limb bones which were recovered are complete and excellently preserved.

The left femur (F1057, Plate 12, fig. 1) is slightly abraded at the outer edges of the head, condyles and trochlear surface.

1.	Max. length (head to medial condyle)	529 mm
2.	Max. transverse diameter at condyles	179 mm
3.	Max. transverse diameter at head	101 mm
4.	Thickness (cranial-caudal) at mid shaft	76 mm
5.	Max. transverse diameter at mid shaft	86 mm
6.	Max. transverse diameter at proximal end	214 mm

The left tibia (F1058) is slightly abraded at the outer edges of the proximal condylar facets. The shaft is triangular in section with a very strong anterior crest.

1.	Max. length (intercondylar eminence to medial malleolus)	389 mm
2.	Max. transverse diameter across condylar facets	191 mm
3.	Max. thickness from notch to top of condylar crest	129 mm
4.	Max. transverse diameter at distal end	117 mm
5.	Max. thickness at distal end	83 mm
6.	Max. transverse diameter at mid shaft	74 mm
7.	Max. thickness at mid shaft	84 mm

The left (F1059) and right (F1062) fibulae both retain a short length of the shaft and the expanded distal end. The maximum diameter (cranial-caudal) at the expanded end is 81 mm.

The left (F1060) and right (F1063) calcaneum, left (F1061) and right (F1064) cuboid, and the right astragalus (F1065) remain of the pes. Bemrose & Deeley (1896) also listed a left and right metatarsal IV, but these bones are now missing.

Right Astragalus

Max. transverse diameter at tibial articulation 95 mm

	Calcaneum	L.	R.
1.	Max length (tuberosity to distal end)	222 mm	223 mm
2.	Max. transverse diameter	104 mm	105 mm
	Cuboid		
1.	Max. transverse diameter at distal end	84 mm	85 mm
2.	Max. height (proximal-distal)	78 mm	79 mm

The manus (fore extremity) is represented by a perfectly preserved left lunare (F1066) and a slightly abraded left scaphoid (F1067).

Elephant

The breast bone fragment (F1075) recorded by Bemrose & Deeley is still preserved, but the fragment is small and shows signs of strong abrasion. The derivation of this specimen is therefore a matter of uncertainty.

Rhinoceros

Only one specimen (F1076) attributable to *Rhinoceros* was discovered at Allenton. Re-examination has shown this to be the mid-shaft of a right femur with the 3rd trochanter missing. The bone is in a highly abraded condition.

1.	Length of specimen	211 mm
2.	Max. transverse diameter (mid-specimen)	73 mm
3.	Max. thickness at 2.	50 mm

The Boulton Moor mammalian remains

Although the bones and teeth found at Boulton Moor occurred as isolated individuals they were extremely well preserved. The majority were collected wet, placed in self-sealing polythene bags and removed to Derby Museum. Here they were slowly air dried, and then coated or vacuum impregnated with a solution of polyvinyl butyral in isopropyl alcohol (P. V. B.), modifying the technique of Rixon (1961). P. V. B. has proved stronger than an emulsion of polyvinyl acetate (P. V. A.). It produces a similar glossy finish, but cannot be used to treat wet specimens. The bones responded to the conservation treatment well, and with little change. The teeth showed slight crazing or cracking of the enamel and dentine due to the drying out process. However they are all now in a state of good repair.

The identification of the Boulton Moor mammalian remains was facilitated by a comparison of the specimens with material in the Department of Palaeontology, British Museum (Natural History). The willing assistance of the Museum staff is gratefully acknowledged.

Hippopotamus amphibius Linnaeus

Centrum of a thoracic vertebra (F831). The neural spine and transverse processes are wanting. Apart from part of the periosteum being missing on the ventral surface, the specimen shows good surface detail.

Left tibia, mid shaft (F832). The specimen is strongly abraded but retains a triangular cross-section and a strong anterior crest.

Right radio-ulna, proximal articulation fragment (F833). The medial half of the radius articulation and the prominent radio-ulna suture remain.

Left lower canines (F834-837). Four separate teeth were recorded all of which show signs of wear on their upper anterior surfaces. This is attributable to friction with the respective left upper canines and is quite normal in *Hippopotamus*. Specimens F834, and F836 are small but fairly complete teeth. Their dimensions are given below:

F834	Outside curvature	376 mm	Inside curvature	270 mm
F836	" "	340 mm	" "	261 mm

Specimen F835 (Plate 12, fig. 2) is very large, and almost certainly from an adult male. Unfortunately the anterior end was broken during extraction of the tooth from the gravels and is missing. The reconstructed outside curvature (750 mm) slightly exceeds that recorded for the largest isolated tooth found at the important *Hippopotamus* site of Barrington, Cambridgeshire (Reynolds, 1922 p.16). Specimen F837 is a small tooth, but only the interior half is preserved.

Lower jaw, ventral half (F838). This specimen was in a fragmentary condition and has been repaired. The size is compatible with the large canine (F835) and incisor (F839) teeth.

Right lower first incisor (F839). A very large tooth showing signs of normal wear on the upper surface as a result of friction with the corresponding upper first incisor.

Length: 423 mm Circumference at alveolar end: 206 mm.

Right scapula, distal fragment (F840). The acromion of the spine and the coracoid process are missing; the glenoid cavity is abraded.

1.	Length of specimen	157 mm
2.	Max. transverse diameter at neck	81 mm
3.	" " " of glenoid cavity	79 mm
4.	Max. thickness at 3.	61 mm

Elephant ? *Palaeoloxodon antiquus* (Falconer)

Elephant is represented by distal fragments of a left scapula (F842) and four fragments of tusk (F841). The glenoid cavity of the scapula is incomplete; the post-spinous fossa is wanting but part of the narrow pre-spinous fossa remains. It is not possible to determine the species from the remains found. However, the associated fauna suggests that *Palaeoloxodon antiquus* (straight-tusked elephant) is the most likely possibility (Sutcliffe, 1960).

Rhinoceros ? *Dicerorhinus hemitoechus* (Falconer)

Rhinoceros is represented by the distal half of a left scapula (F843; Plate 13, fig. 2) and the mid portion of a left innominate (F844; Plate 13, fig. 1).

The acromion of the scapula is indistinguishable and the mid-spinous process is broken above the post-scapular fossa. The coracoid process is wanting but the glenoid cavity is almost perfect. The specimen has excellent surface detail with only slight abrasion along the edges of the glenoid cavity.

1.	Length of specimen (mid-spine to glenoid cavity)	279 mm
2.	Max. transverse diameter at neck	96 mm
3.	Thickness at 2.	28 mm
4.	Max. transverse diameter at cavity	83 mm
5.	Thickness at right angle to 4.	69 mm

The left innominate shows good surface detail with only slight abrasion at the edges of the acetabulum. The ilium, ischium and pubis are incomplete.

1.	Max. transverse diameter of acetabulum	91 mm
2.	Width of acetabular notch	25 mm

It is difficult to determine the precise species of rhinoceros from these two bones. *Dicerorhinus hemitoechus* (narrow-nosed rhinoceros) is however the most likely possibility on account of the associated fauna (Sutcliffe, 1960).

Ursus cf. *arctos* Linnaeus

The distal half of a left femur (F845; (Plate 12, fig. 3) was found. Although broken and subsequently repaired, the specimen shows excellent surface detail with only slight abrasion at the edges of the articulation surface. The dimensions (given below) indicate a bear of large size.

1.	Length of specimen (half of whole femur)	247 mm
2.	Max. transverse diameter at proximal end (mid shaft)	46 mm

3.	Max. anterior-posterior diameter at 2.	40 mm
4.	Max. transverse diameter at tuberosity above condyles	115 mm
5.	Max. transverse diameter at condyles	103 mm

Cervus elaphus Linnaeus

Red deer is represented by an antler beam (F846) together with the separated bay (F847) and brow (F848) tines. The beam is rough with prominent gutters and no palmation.

Crocuta crocuta (Erxleben)

Hyaena is represented by a left tibia (F849) which lacks the distal and proximal epiphyses. The small size of the specimen, together with the absence of epiphyseal fusion, is indicative of a juvenile animal.

1.	Max. transverse diameter at mid shaft	17 mm
2.	Anterior - posterior diameter at 1.	20 mm

Bos. sp. or *Bison* sp. (*Bojanus*)

Specimens F850-854 are attributable to ox or bison. The determination of the exact species is difficult from the bones present. Specimen F852 (proximal half of a left radius) compares favourably with a left radius of *Bison priscus* Bojanus found at Windy Knoll, near Castleton, Derbyshire and now in the care of Sheffield Museum. However there is little difference between the radii of *Bos* and *Bison* and consequently a positive identification is not possible. Both bovids have been recorded as members of Ipswichian faunas. (Sutcliffe 1960).

Discussion

The mammalian remains recovered from the two sites in the Allenton Terrace amount to 71 identifiable specimens (table 1, p. 262). Of these, the majority (55 specimens) belong to *Hippopotamus*. The remainder are attributable to a minimum of six additional taxa, most of which were represented by only one or two isolated specimens. Many of the unidentifiable fragments recovered from Boulton Moor also probably belong to *Hippopotamus*. Several of these appear to be pieces of the mandible which was found broken and, although subsequently repaired, is still incomplete.

The *Hippopotamus* remains represent at least five separate animals. The four left lower canines found at Boulton Moor must have been derived from four different individuals which varied markedly in size. A fifth individual is clearly indicated by the almost complete mandible discovered at Allenton which retained both the left and the right lower canines (Plate 11, fig. 1; cover of this issue).

The large canine (F835) and incisor (F839) teeth from Boulton Moor indicate large animals, probably old males. Their size is compatible with the reconstructed ventral half of the mandible (F838) and it is possible that all three specimens are from the same animal. The other canines from Boulton Moor are smaller, and appear to be representative of juveniles or young adults.

The dimensions of the mandible and its associated teeth (F1030) from Allenton are certainly comparable with those of a young adult (cf. Reynolds, 1922, p. 9). The size of the axial skeleton supports this contention, although the limb bones are disproportionately larger than the equilvalent specimens listed by Reynolds (1922).

It is also notable that the Allenton limb bones were more heavily mineralised than both the mandible and the axial skeleton found at the same site. Furthermore all the bones were reported as being randomly distributed in the original excavation (Bemrose & Deeley, 1896).

On this basis, it might be tentatively suggested that the Allenton *Hippopotamus* remains are attributable to two separate animals and not one as was previously assumed (Bemrose & Deeley, 1896). However, there is an unfortunate lack of available information on size variation within the Pleistocene *Hippopotamus*. It is known that the modern African species is very variable (Hooijer, 1950) and Coryndon (1970) has recently expressed the opinion that any variation seen between one specimen and another may just be indicative of normal intraspecific variation. In the present state of knowledge, therefore, the evidence for two hippopotami at Allenton is inconclusive.

It is notable that the excavation which led to the discovery of the Allenton *Hippopotamus* remains was stopped prematurely by water seepage before an area of more than approximately 9 m^2 (11 feet by 9 feet) had been examined (Bemrose & Deeley, 1896). Several large bones were in fact recovered some 18 years previously during excavation of cellars at the same locality, but unfortunately the specimens were not preserved. The bones described in this paper, therefore, do not represent the full extent of the Allenton remains and it is extremely likely that further specimens still await discovery.

The apparent dominance of *Hippopotamus* in the overall faunal assemblage from the Allenton Terrace may be largely due to environmental factors. As stressed by Stuart (1974) the composition of an assemblage reflects not only the relative population density and life span of each taxon but also the distance of its habitat from the depositional site. Thus in many fluviatile deposits the over-representation of amphibious vertebrates, such as *Hippopotamus*, is only to be expected. Such animals which died in the water would also be more likely to have their skeletons preserved intact, except under swift-flowing and turbulent riverine conditions. In such circumstances the remains of terrestrial vertebrates would be rarer and complete skeletons unlikely as these would be washed in from the river's flood plain as the banks were eroded. The nature of the deposits seen at Boulton Moor (Jones & Stanley, 1974) and the faunal assemblage described in this paper, would appear to be in accordance with these views.

Mammalian remains are not normally the most useful for stratigraphical purposes. Bones and teeth are relatively resistant to abrasion and there must always be a danger that isolated specimens have been derived from an older deposit. Furthermore, the discovery of such remains tends to be a relatively rare occurrence and faunal assemblages are usually only built up over a long period of time. In addition, unless precise details of the provenance of the finds are recorded at the time, the age and ecological relationships of the specimens will always be in doubt. Many previous finds in river terraces are in fact difficult to relate to the stratigraphical sequence since the specimens were picked up from tipped material in gravel workings or from the conveyor belt and screens of the processing plants. The mammalian assemblage described in this paper is particularly notable for the following reasons:

1. the unusually large number of specimens that was obtained from a relatively small area in each of the two closely spaced localities,
2. the exceptional state of preservation and well defined surface detail of the majority of the specimens indicating that their transportation must have been minimal and burial relatively rapid,
3. the fact that almost all the specimens were collected *in situ* with the result that the precise details of the provenance of each are known.

In a recent study of the Pleistocene history of the British vertebrate fauna (Stuart, 1974) it has been suggested that certain faunal elements appear to be characteristic of each sub-division of the British Pleistocene time-scale. The stages of the Pleistocene are in fact defined on the basis of climatic change (Shotton, 1973), and the progressive fluctuation of climates through a succession of cold and temperate stages had a marked effect on the contemporary vertebrate faunas.

Stuart (1974) has shown that the intensified climatic fluctuations of the Middle and Upper Pleistocene accelerated the faunal changes so that temperate vertebrates were replaced relatively rapidly by 'steppe-tundra' faunas. It is also Stuart's contention that the subsequent return to temperate conditions did not result in an identical temperate fauna. This supports the earlier views of Sutcliffe (1960, 1964) who, with particular reference to *Hippopotamus* maintained that there were significant differences between the mammalian faunas of the penultimate (Hoxnian) and last (Ipswichian) interglacials. His suggestion that *Hippopotamus* was abundant in Britain during the Ipswichian interglacial (Sutcliffe, 1959) but absent during the earlier Hoxnian interglacial (Sutcliffe, 1960, 1964) as well as the post-glacial period has so far stood the test of time.

Nevertheless, it has been stressed by Sparks and West (1972) that lack of records does not necessarily imply complete absence and the possibility must always be borne in mind that the next Hoxnian site might well yield *Hippopotamus*.

The faunal assemblage from the Allenton Terrace is comparable with assemblages obtained from various Ipswichian localities in Britain (Sutcliffe 1960, 1964). It should be noted however, that the majority of the taxa, with the particular exception of *Hippopotamus* were represented only by isolated specimens and many are known to have quite long individual time ranges in the British Pleistocene (Stuart, 1974). If the currently accepted views on the Pleistocene history of *Hippopotamus* are correct (Sutcliffe 1959, 1964; Stuart 1974) then the presence, and the numerical abundance, of *Hippopotamus* in the Allenton Terrace fauna is of considerable stratigraphical significance.

Acknowledgements

The authors wish to thank Dr. A.J. Sutcliffe, Mr. A. Currant, Mr. P. Hooker (British Museum, Natural History), Mr. M.D. Jones (Leicester Museum) and Mr. T.H. Riley (Sheffield Museum) for assistance with the identification of specimens and for making their collections available for examination. We are also grateful to Mr. B.P. Blake (Director of Derby Museums) for the provision of facilities, Mr. D.J. Huntingdon for producing the text-figure and plates and Mrs. Lesley Bull for typing the draft. Mr. R.G. Fisher (Derby Borough Council) arranged access to the Boulton Moor site and Dr. P.G. Baker (Derby College of Art & Technology) kindly read and commented on the text.

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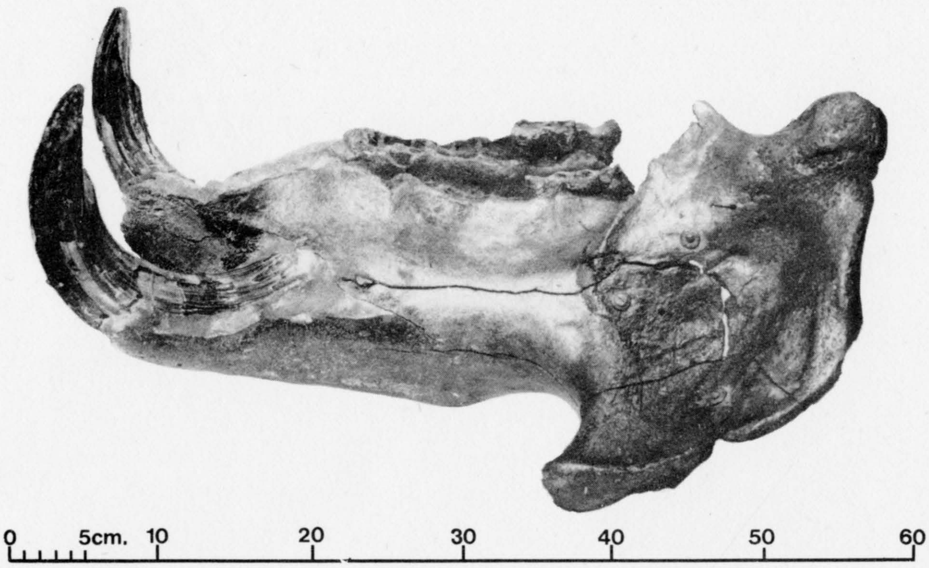

Fig. 1 *Hippopotamus amphibius* Linnaeus, Allenton
Left lateral view of repaired mandible (F1030)

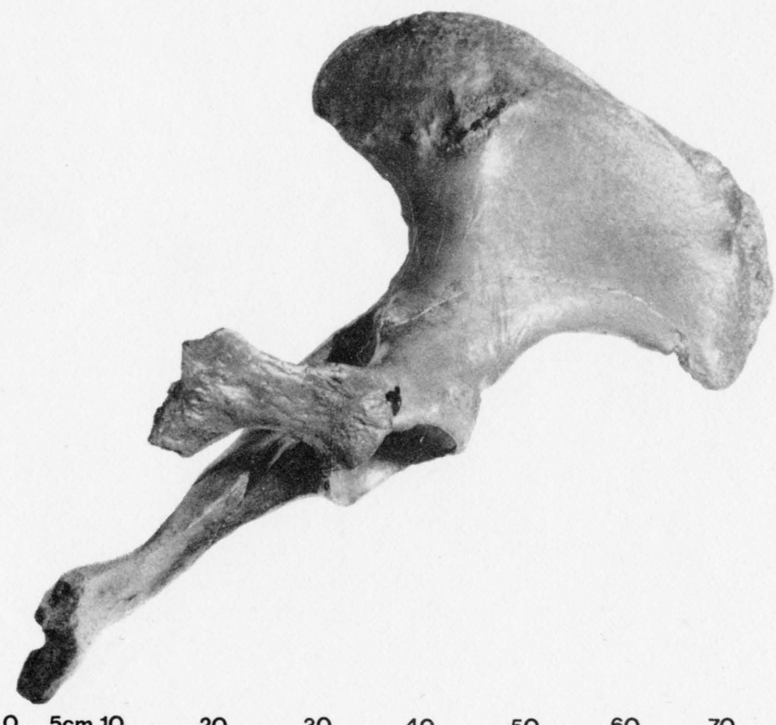

Fig. 2 *Hippopotamus amphibius* Linnaeus, Allenton
Ventral view of repaired left innominate (F1056)

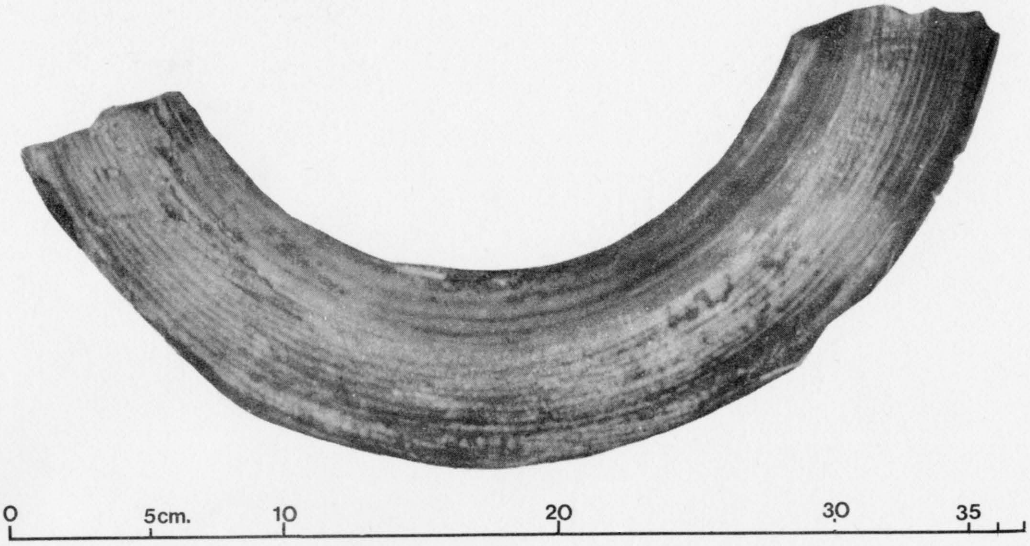

Fig. 1 *Hippopotamus amphibius* Linnaeus,
Left lateral view of left lower canine (F835) from Boulton Moor.

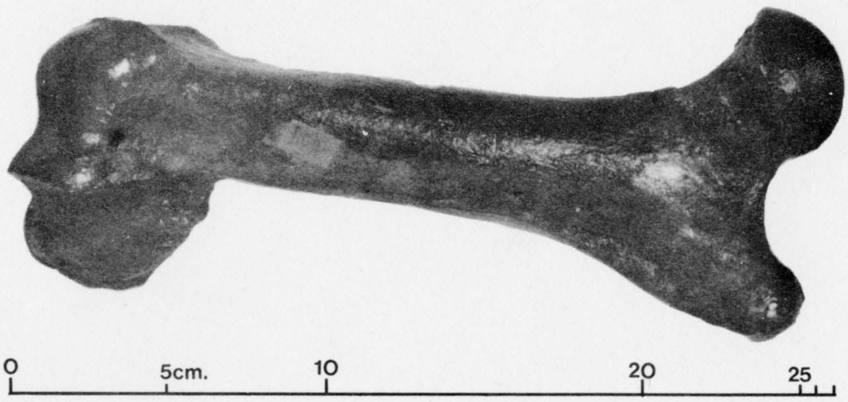

Fig. 2 *Hippopotamus amphibius* Linnaeus
Anterior view of left femur (F1057) from Allenton

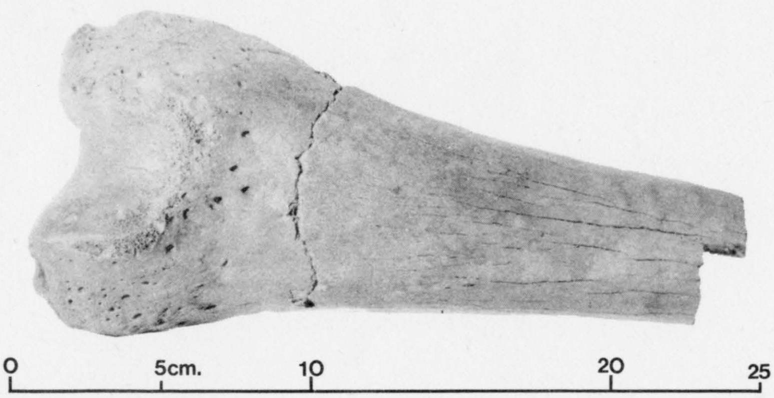

Fig. 3 *Ursus* cf. *arctos* Linnaeus, anterior view of disbal half of left femur (F845) from Boulton Moor

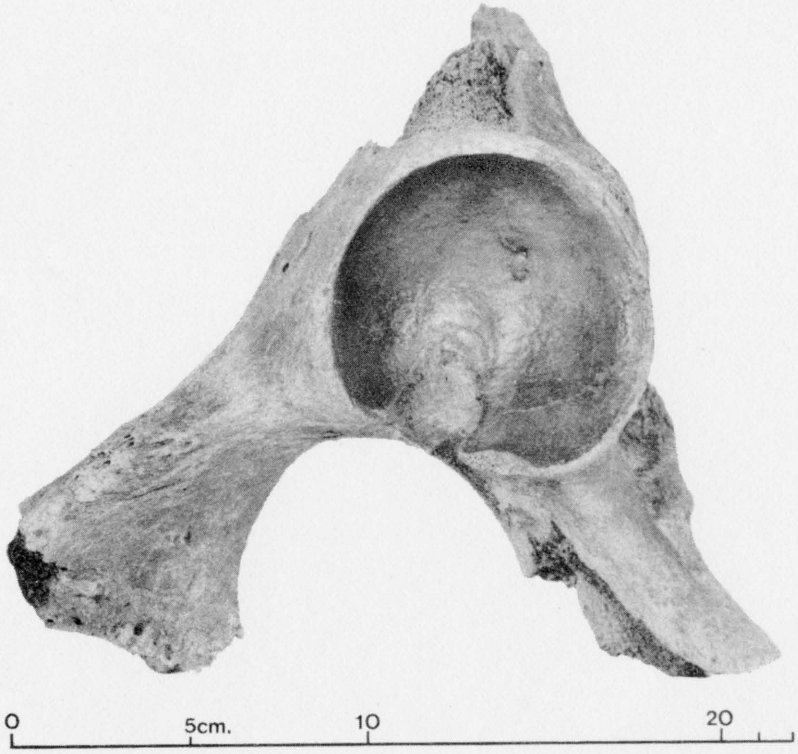

Fig. 1 ? *Dicerorhinus hemitoechus* (Falconer), Boulton Moor.
Left lateral view of left innominate, mid portion (F844)

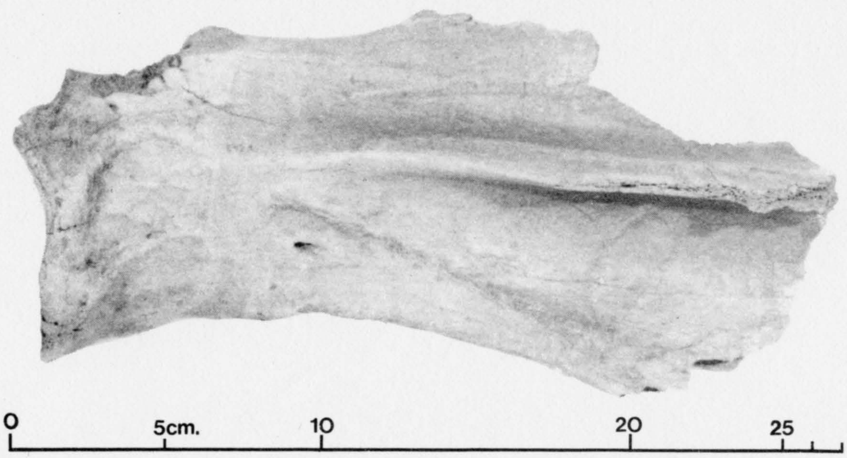

Fig. 2 ? *Dicerorhinus hemitoechus* (Falconer), Boulton Moor,
Lateral view of left scapula (F843)

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A VERTEBRATE FOOTPRINT FROM THE STONESFIELD SLATE (MIDDLE JURASSIC) OF OXFORDSHIRE

by

William A. S. Sarjeant

Summary

A vertebrate footprint *Pooleyichnus burfordensis* ichnogen. et sp. nov., discovered in the Stonesfield Slate (Jurassic; Bajocian) of the Burford district, Oxfordshire, in 1886 is described and illustrated for the first time. Reasons are advanced for considering this to be the footprint of a mammal or mammal-like reptile. The palaeogeographical implications of this find are discussed.

Introduction

In 1886, the natural cast of a footprint of a small vertebrate was collected by Mr. C. Pooley near Burford, Oxfordshire, from the Stonesfield Slate (Inferior Ooolite; Bajocian). The specimen was lodged in the British Museum, Natural History (R893BMNH). Though the discovery has been briefly mentioned (Sarjeant 1974) in an historical account of studies of vertebrate footprints in the British Isles, no illustration or description of the footprint has yet been published.

Although vertebrate footprints in profusion have been described from Permian and Triassic sediments, records of them from the Jurassic are relatively few. In Britain, they have been recorded in abundance only from Yorkshire (Sarjeant, 1974).

Moreover, if one examines footprint literature on a world scale, one finds that almost all vertebrate footprints recorded from the Jurassic are large, the footprints of dinosaurs are conspicuous and striking objects readily noticed by casual observers. Indeed Otto Kuhn, in his stratigraphical review (1958), recorded no small footprints whatsoever from the Jurassic. However, there is at least one other known occurrence of tracks of small Jurassic vertebrates, recorded from the Forest Marble north of Bath; the tracks were originally reported by George Poulett Scrope in 1831 and subsequently briefly mentioned by Thomas Barkas in 1873, but were not described or illustrated in either of these papers. Recently I was able to describe what I believe to be Scrope's specimens, two rather indistinct trackways with three digits on the pes (hindoot); surely the tracks of a small reptile. Apart from a single record of pterodactyl footprints (Stokes, 1957), these are the only small footprints yet described from world Jurassic rocks.

Pooley's discovery is thus of considerable interest still, not only because it is the only vertebrate footprint known from the Jurassic strata of the English Midlands, but also because it is one of the very few small footprints yet to be recorded from the Jurassic system of the world. A description and assessment of it is therefore presented here.

Systematic Description

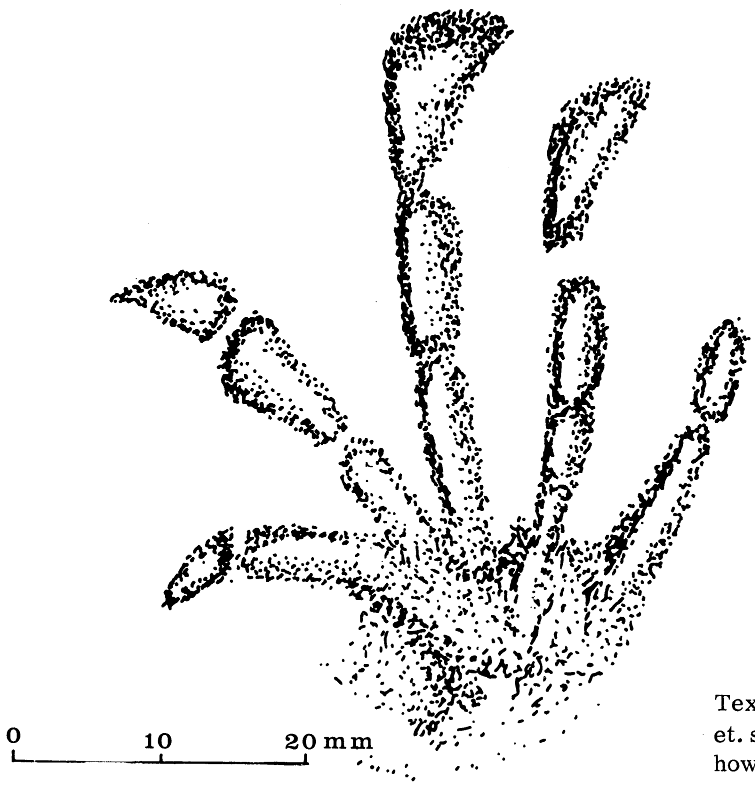
Kingdom Animalia

Class ? Mammalia

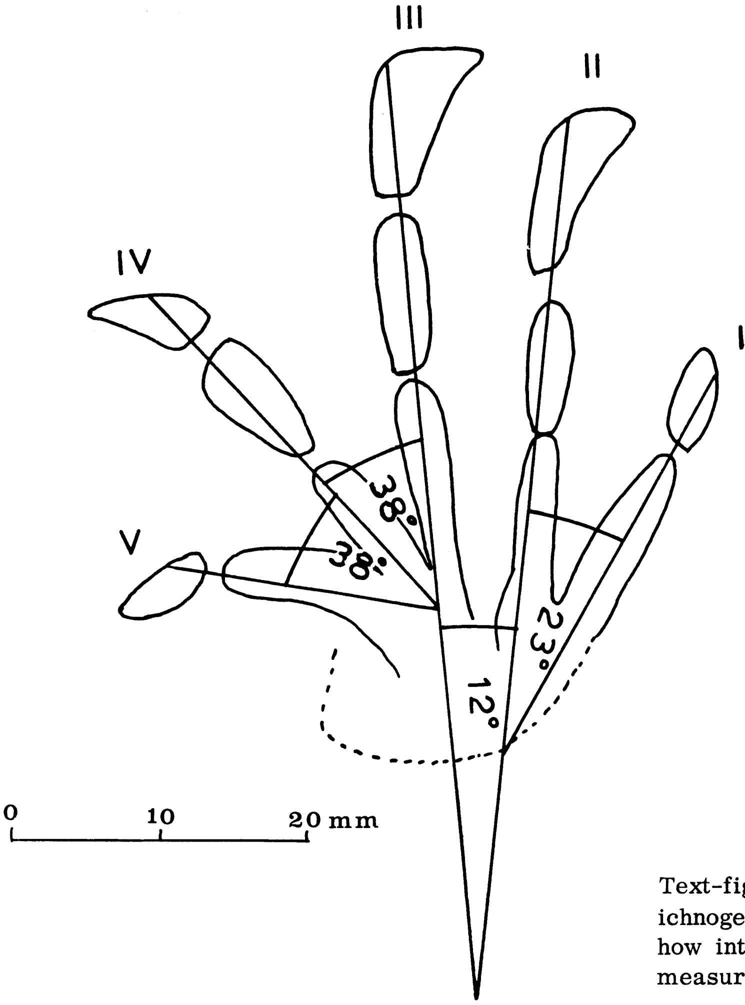
Pooleyichnus burfordensis ichnogen. et ichnosp. nov.

(Plate 14. : Text-figs. 1-2)

Mercian Geol. Vol. 5, No. 4, 1975.
pp. 273-277, 1 text-fig., Plate 14.



Text-fig. 1. *Pooleyichnus burfordensis* et. sp. nov. Sketch to illustrate how the morphology is interpreted; approximately the same scale as Plate 14.



Text-fig. 2. *Pooleyichnus burfordensis* ichnogen. et sp. nov., showing how interdigital angles were measured.

Pooleyichnus burfordensis ichnogen. et sp. nov. The holotype, specimen R893 BMNH. Photo. by Courtesy of the Trustees of the British Museum (Natural History).

Derivation of Name After the discoverer and the type locality.

Description Single cast of a right foot (manus or pes?). Pentadactyl, digitigrade; digits slim and radially arranged. Digit III is longest, digits I and V are relatively short. Digits II to IV show clear indications of short claws, those of digits II and III being directed inwards and those of digits IV and V outwards. The presence of claws on digit I is doubtful. Phalangeal formula is apparently 2, 3, 3, 3, 3,

Figured Specimen. Specimen R 853 BMNH, British Museum (Natural History), London.

Horizon and Locality. Stonesfield Slate (Inferior Oolite, Bajocian) near Burford, Oxfordshire, England.

Dimensions. Overall length 35 mm; overall breadth 33 mm. Length of digit I, 15 mm; digit II, 25 mm; digit III, 28 mm; digit IV, 22 mm; digit V, 13 mm. (Note: Because of the nature of preservation and the subjectivity of deciding where the cast ends, all measurements are necessarily imprecise).

Divarication of digits. (text-fig. 2). I-II, 23°; II-III, 12°; III-IV, 38°; IV-V, 38°. (For a discussion on divarication of digits consult Sarjeant, 1971, p.346).

Systematic Discussion

Footprints of small reptiles - rhynchocephalians, pseudosuchians, early lizards - are well known from the Permian and Triassic and have recently been comprehensively reviewed by Haubold (1971). Characteristic features of them are (a) the fact that digit IV is almost uniformly the longest digit; (b) where the digits are clawed, the claws of digits I-IV are all directed inwards, towards the centre of the trackway; (c) the fact that digit V is almost always reduced and may be opposed - it is, indeed, frequently not imprinted; and (d) the presence of four phalanges in two (III-IV) or more digits.

An apparent exception is furnished by *Gwyneddichnium* Bock 1952, from the Upper Triassic of the U. S. A., which is defined as having five radial digits with digit III longest. However, as Haubold has pointed out (1971, pp. 47-48), an examination of Bock's figures shows that the longest digit is not digit III, but digit IV. This is the only reptilian footprint yet described similar enough to merit comparison with the footprint here figured; the most similar species, *G. minor* Bock 1952, differs in that the digits are less radial, more forwardly directed, and do not exhibit comparable claws.

There are, indeed, no known footprints from the Jurassic that show any close comparability with the one here described. Whilst the basing of a new taxon on a single imprint is in general undesirable because of uncertainty concerning the form of the other foot and the pattern of the whole trackway, it is considered that the unique nature of this imprint fully justifies an exceptional procedure.

The remains of early mammals have long been known from the Stonesfield Slate (see Arkell, 1933. pp. 296-297); and fossil teeth and bones of mammals and mammal-like reptiles have, indeed, now been recorded as early as the late Triassic, in Britain and elsewhere. However, to my knowledge, there are as yet no records of mammal footprints from the Jurassic.

Can this footprint be that of a mammal? It resembles typical mammalian imprints in that digit III is longest, in the radial nature of the digits and the variable direction of the claws (compare, for example, the illustrations by Murie, 1954 Fig. 106, of meadow-vole sign [footprint track] and by Leutscher, 1960 p. 144, of shrew sign). The Stonesfield Slate mammals are mostly of small size, quite compatible with the size of these prints; knowledge of them is based primarily on fossil jaws and teeth, information on the character of the rest of the skeleton being meagre. In contrast, the only small reptiles known from these beds, according to Arkell (*op. cit.*), are pterodactyls, whose footprints, insofar as they are known, are entirely dissimilar from that here described (Stokes, 1957).

It thus appears highly probable that this footprint is that of an early mammal of small size; but it is recognised that the information available is insufficient to establish this beyond doubt and, indeed, that distinction between the tracks of mammals and those of mammal-like reptiles may well be impossible.

Palaeogeographical Discussion

The type area of the Stonesfield Slate is a small area of outcrop surrounding the village of Stonesfield, Oxfordshire, some 9 miles east-north-east of Burford. It is described by Rayner (1967, p.292) as "a fissile, sandy, oolitic limestone" - certainly not a slate in the normal geological sense. The name is derived from local usage since the limestone splits readily into thin flags, and was mined for a long time as a roofing material. By 1830, working had ceased (Arkell, 1933, p.296) and the Stonesfield Slate is no longer to be seen at outcrop in its type area.

Similar rocks crop out on the western side of the Cotswolds, where they have been worked until comparatively recently, for example in the area between Naunton and Condicote. It seems virtually certain that Pooley's specimen came from somewhere in this western outcrop rather than from Stonesfield itself, since a village 9 miles away would scarcely be referred to as "*near* Burford" in a countryside so crowded with villages as is Oxfordshire!

Both at its type locality and in its western outcrop, the Stonesfield Slate is rich in the remains of terrestrial organisms, notably plants (cycads, conifers and dicotyledonous plants), reptiles (pterodactyls and the carnivorous dinosaur *Megalosaurus*) and small mammals (multituberculates, triconodonts and pantotheres). In addition, marine reptiles (chelonians, marine crocodiles, and plesiosaurs) and a host of marine invertebrates are present. Arkell commented that the terrestrial remains were evidently "drifted into a shallow sea from neighbouring land" (1933, p. 297).

Such an explanation needs to be modified in this instance. The presence of a vertebrate footprint necessitates a phase during which the sediment surface was exposed, so that the footprint could be implanted, a phase of desiccation, so that it could be preserved, and a phase of rapid sedimentary accumulation, so that it could be infilled and cast before the underlying sediments were saturated and rendered potentially mobile. These processes could only have occurred on a shoreline.

Eastward from the western Cotswolds towards the Vale of Bourton, the Stonesfield Slate thins and is overlapped by the Taynton Stone, which comes ultimately to rest on the Fullers Earth beneath. An approach to a shoreline of some Jurassic island in the vicinity of Burford is perfectly possible; unfortunately, Pooley did not furnish sufficiently precise information to allow us to determine exactly where that shoreline was located. New information must be awaited before this can be established.

Acknowledgements

I am indebted to the Trustees of the British Museum (Natural History) for the opportunity to undertake this study, and in particular to Dr. Cyril A. Walker for furnishing the photograph of the specimen and information concerning it.

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

by

P. F. Jones and J. D. Weaver

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.

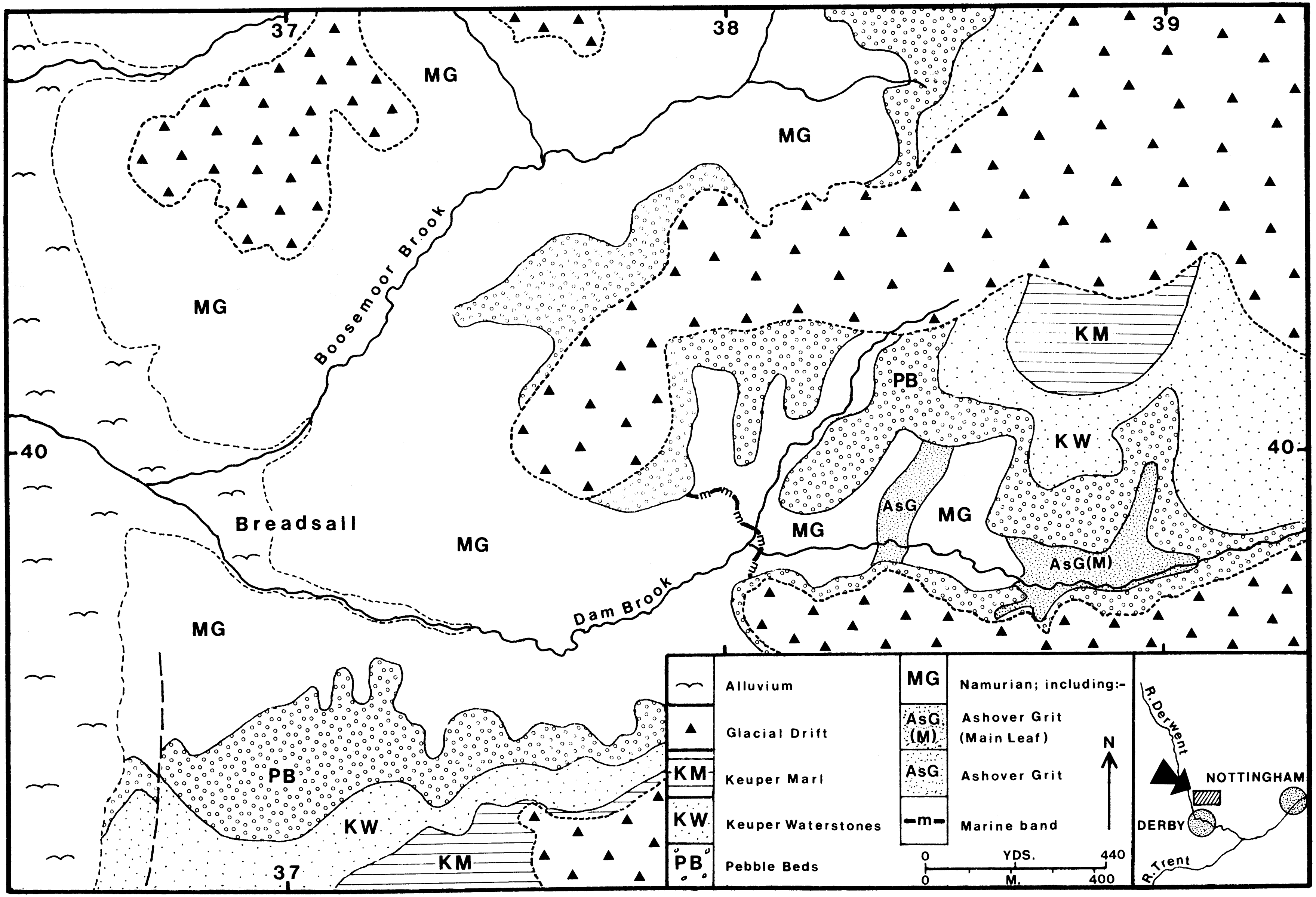
The folding is best seen along the most southerly stream, Dam Brook (SK 375396 to SK 388397) where there is an almost continuous exposure of the lower Namurian rocks, up to and including the Ashover Grit. The neighbouring Boosemoor Brook, 1 km to the north, flows across the same range of succession and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

Mercian Geol. Vol. 5, No. 4, 1975
pp. 279-290, 3 text-figs. Plate 15.

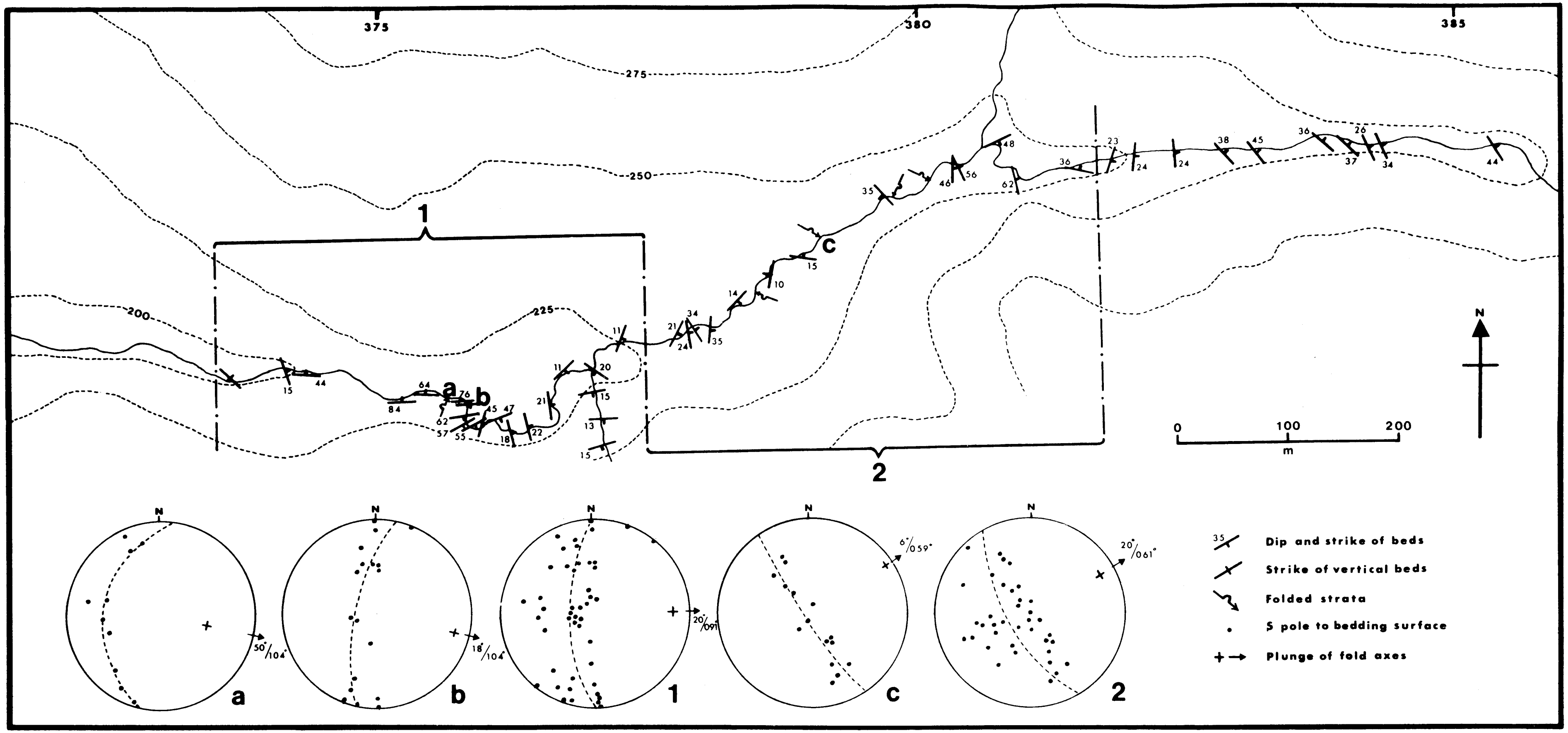


Text-fig. 1. General geology of the Breadsall area, Derbyshire.

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 SK 37753960

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).

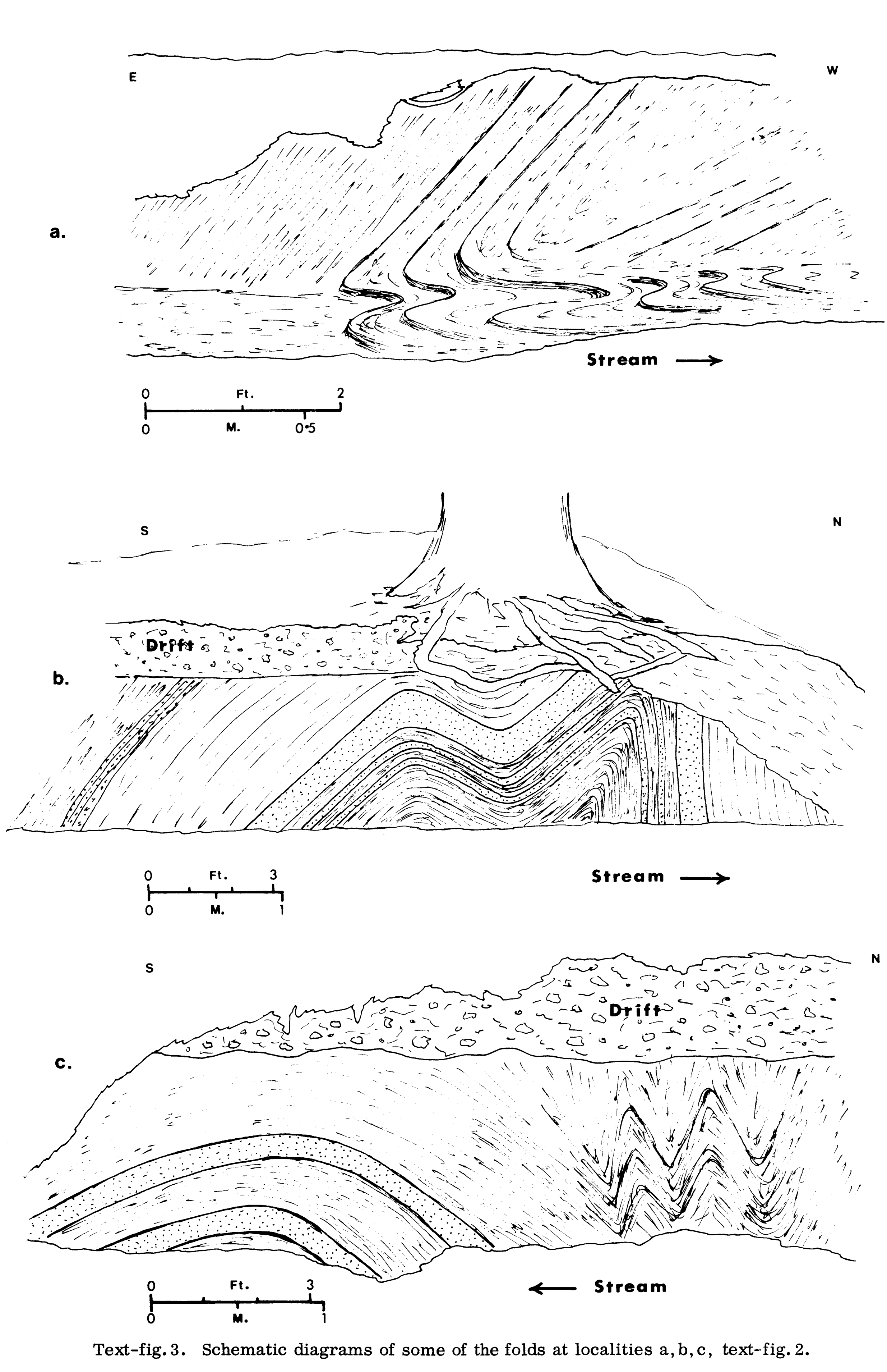
(2) The folding is most intense where the valley is deepest and the disturbance appears to decrease upstream as the valley becomes more open (compare text-fig. 2).

(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

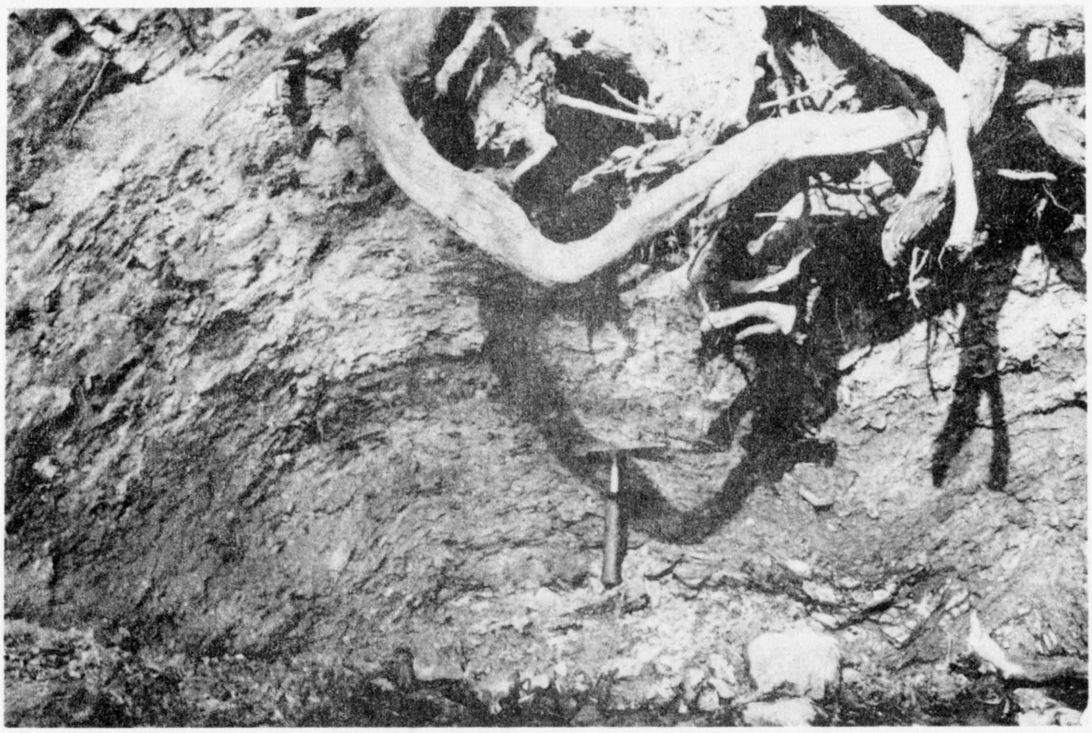


Fig. 1. Folding at locality b, text-figs. 2b, 3b.

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

The authors are most grateful to Mr. J. G. O. Smart and Dr. N. Aitkenhead of the Institute of Geological Sciences, Leeds, for useful discussion during the preparation of this paper. Thanks are also due to Drs. P. G. Baker, P. H. Bridges and E. Derbyshire for their careful reading and helpful criticism of the original manuscript.

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LEAD AND SULPHUR ISOTOPE RATIOS OF SOME GALENA SPECIMENS FROM THE SOUTH PENNINES AND NORTH MIDLANDS

by

P. G. Coomer and T. D. Ford

Summary

The isotope composition of lead, extracted from 17 samples of galena from the South Pennines, and 6 from small deposits in Triassic rocks to the south and east of the South Pennines, has been analysed. The analyses include recalculated figures from those analysed by Moorbath in 1962. The results show that the leads are extremely homogeneous and also anomalous (averages: $^{206}Pb/^{204}Pb = 18.45 \pm 0.02$; $^{207}Pb/^{204}Pb$ 15.62 ± 0.01; $^{208}Pb/^{204}Pb = 38.32 \pm 0.03$). Lead samples from Triassic rocks are isotopically similar to those of the South Pennines. Taken as a whole, lead analyses in the South and North Pennines define a significant isotopic trend similar to that defined by isotopically more heterogeneous Mississippi Valley lead samples.

The lead isotope homogeneity indicates an opportunity for the lead to mix prior to mineralisation and thus be derived from a distant source. Isotopic studies of trace quantities of lead extracted from potential host rocks are needed to understand further Pennine lead isotope abundances.

Analyses are available on the isotope composition of sulphur, extracted from 5 samples of South Pennine galena. The δ^{34} S-values range from +3.2 to -8.4 per mil. The very limited sulphur isotope evidence indicates that the sulphides formed at low temperatures, and that further study has great potential.

Introduction

In the years since Moorbath's (1962) survey of British isotope abundance studies, which included only 4 analyses from the South Pennine Orefield, considerable advances have been made both in the understanding and in the measurement precision of lead isotopes.

Only one isotope study of Pennine lead has been published since Moorbath's paper, that of Mitchell and Krouse (1971), who carried out a detailed study on galena from the relatively small Greenhow - Skyreholme area of the North Pennine Orefield. These authors concluded that the lead isotope compositions of the specimens are anomalous, when interpreted using simple models, in that the compositions yield meaningless negative model ages, suggesting that the ore deposit has not yet formed. Mitchell and Krouse (1971) compared their results with those of Moorbath, for other Pennine areas, and concluded that all such lead isotope compositions are anomalous and that those from the different areas of the Pennines may form part of a common isotopic trend. If this trend could be better established by using high precision analytical techniques not available to previous authors, for Pennine lead isotopes, it could yield useful geochronological information about the source rocks.

This contribution presents new lead isotope evidence obtained as a result of the new analytical techniques on galena samples from the South Pennines and North Midlands, and presents a theory to explain the significance of the results in the context of existing knowledge

Mercian Geol. Vol. 5, No. 4. 1975.
pp. 291-304, 2 text-figs.

of lead isotopes. The methods of analysis and the criteria for interpretation are discussed.

Sulphur isotopes have proved themselves to have great potential in constraining theoretical models of ore formation. Reconnaissance sulphur isotope measurements on several South Pennine galena samples are presented and the results discussed.

Geology

The South Pennine Orefield in common with the other Pennine Orefields, is characterized by galena-fluorite-barite veins in Lower Carboniferous limestones.

A series of approximately east-west striking mineral veins with closely associated pipes and flats occur within massive limestones interbedded with occasional basalts and tuffs (Ford, 1969). The chief vein minerals are galena, fluorite, barite and calcite. The history of mineralization is complex, with five or more distinct mineralization pulses having been recognized in some veins (Ineson and Al-Kufaishi, 1970; Firman and Bagshaw, 1974).

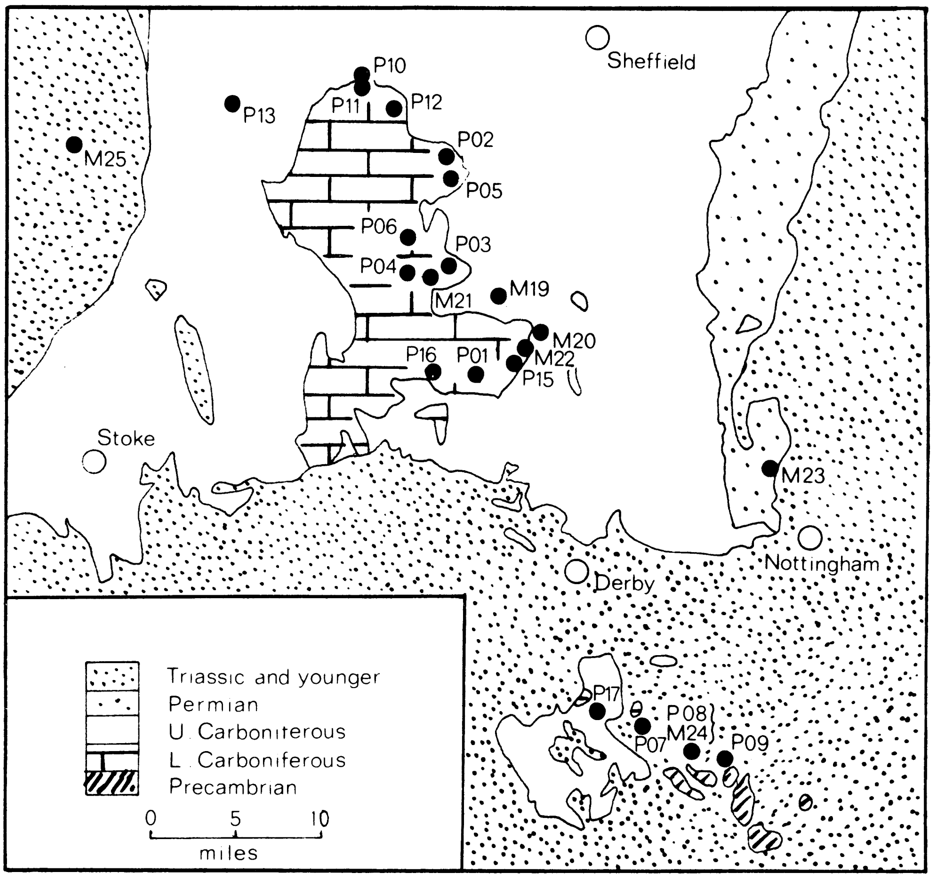
Moorbath (1962) analysed four South Pennine galenas and obtained lead model ages ranging from 150 ± 80 to 220 ± 70 m.y., but, as will be discussed in the next section, little value can be attached to these ages, because the model used has since been shown to be invalid.

Ineson and Mitchell (1973), have recently dated clay minerals separated from volcanic rocks adjacent to mineralized zones using the potassium/argon method. They interpret their results to indicate that repeated pulses of mineralization probably occurred within the South Pennine Orefield, with at least two main episodes at about 270 m.y. and about 235 m.y. respectively.

Mineralization is not confined entirely to the eastern margin of the South Pennines Lower Carboniferous outcrop. An important pipe deposit, containing copper and zinc, as well as lead, occurs further west in Lower Carboniferous limestones at Ecton. Smaller scale but widespread mineralization occurs at horizons within the Permian Magnesian Limestones (Deans 1961; Aldred 1969; Taylor and Elliott 1971) and at the Triassic/Lower Carboniferous unconformity to the south of the main orefield (Ford and King 1968). Ford (1969) suggested that the persistent mineralisation at this unconformity could be explained if the South Pennine mineralization, or a late pulse of it, occurred during Triassic times.

The ultimate source of the South Pennine lead ore has not yet been proven, but the lack of any known igneous body beneath the ore-field, combined with the recent discovery of evaporite beds at the base of the Lower Carboniferous in some parts of the area (Llewellyn and Stabbins, 1969; Dunham, 1973) points towards the metals probably having been leached by brines from buried Carboniferous rocks further to the east and migrating westwards. Preliminary fluid inclusion results by Smith (1973) are compatible with such a hypothesis.

For this study 17 galena samples were added to the analyses available from Moorbath's (1962) data (recalculated). 15 of these came from various types of mineralization widely scattered throughout the South Pennines Orefield. One sample came from the Ecton copper deposit and another from the unusual vein at Whaley Bridge; four further samples were from small deposits at or close to the Triassic/Lower Carboniferous unconformity situated in the North Midlands. Two further samples are from localities within the Permo-Triassic rocks of the same area. All the localities are shown on text-fig. 1.



Text-fig. 1. Sample Locations

Lead Isotopes

Lead isotopes vary in natural abundance because radioactive decay of uranium and thorium isotopes has progressively formed new "radiogenic" lead. Because lead in galena is effectively isolated from uranium and thorium at the time of formation, the present isotopic composition is controlled by what happened before precipitation.

The amount of radiogenic lead in the earth as a whole has progressively increased with time, so more recently mineralized galena deposits, by and large, have more radiogenic lead than older ones.

Lead has four stable isotopes: ^{204}Pb; ^{206}Pb; ^{207}Pb; and ^{208}Pb. Of these only ^{204}Pb is unaltered by uranium and thorium decay, that is, its abundance is constant so lead isotope variations are usually expressed relative to ^{204}Pb, as $^{206}Pb/^{204}Pb$ and so on.

The isotope ratios of a specific suite of galena samples can be interpreted only within the context of existing models, which have been evolved to explain lead isotope observations in general. Surveys of lead isotope models have been given by Russell and Farquhar (1960) and Doe (1970).

All lead isotope models make the basic assumption that at the time of formation of the earth all lead had the same "primeval" isotopic composition, and that natural abundance variations have been caused solely by the addition of radiogenic lead since that time.

The isotopic composition of primeval lead has been obtained by analysing lead extracted from the uranium-, and thorium-free troilite phase of meteorites.

The first model to be used widely was the so-called Holmes-Houtermans model. The assumption is made that the lead of any galena has spent the whole period between the formation of the earth and the precipitation of the galena in an environment whose U/Pb ratio was effectively constant in time. Lead in other galena samples evolved in source environments with a different U/Pb ratios. These assumptions allow a "model age" and a theoretical source U/Pb ratio to be calculated for lead in any single galena. The model was "calibrated" so that it gave reasonable ages on galena specimens of independently known age by adjusting the parameters, in particular the "age of the earth", within the then known uncertainties.

Despite the simplicity of its assumptions, the Holmes-Houtermans model allowed approximate, but useful ages to be assigned to a wide variety of galena specimens. Lead samples that yielded unreasonable or negative model ages were termed "anomalous". The model is no longer used, however, because its simple assumptions have been shown to be dubious. This is why Moorbath's (1962) model ages on British lead ores can no longer be accepted.

The next model to be used widely was the so-called Russell-Stanton-Farquhar model. These authors noted that many lead specimens, in particular those from conformable ore deposits closely associated with volcanic rocks, all fall on a single "ordinary growth curve" (text-fig. 2). The simplest explanation of this curve is that all these lead samples were tapped off at different times from an environment whose U/Pb (Th/Pb) ratio changed only as a result of the radioactive decay. The authors of this model further argued that this homogeneous source environment was the upper mantle. Lead samples that fall on this curve were termed "ordinary", whilst those that did not were termed "anomalous" and were assumed to have evolved for a considerable period within the earth's crust.

Kanasewich (1968) summarized models that could make sense of many suites of anomalous leads, which very often fall on lines that intersect the ordinary growth curve in text. fig. 2. These models assume that anomalous leads evolved in more than the two stages envisaged for "ordinary" leads, and hence were termed "multi-stage" models.

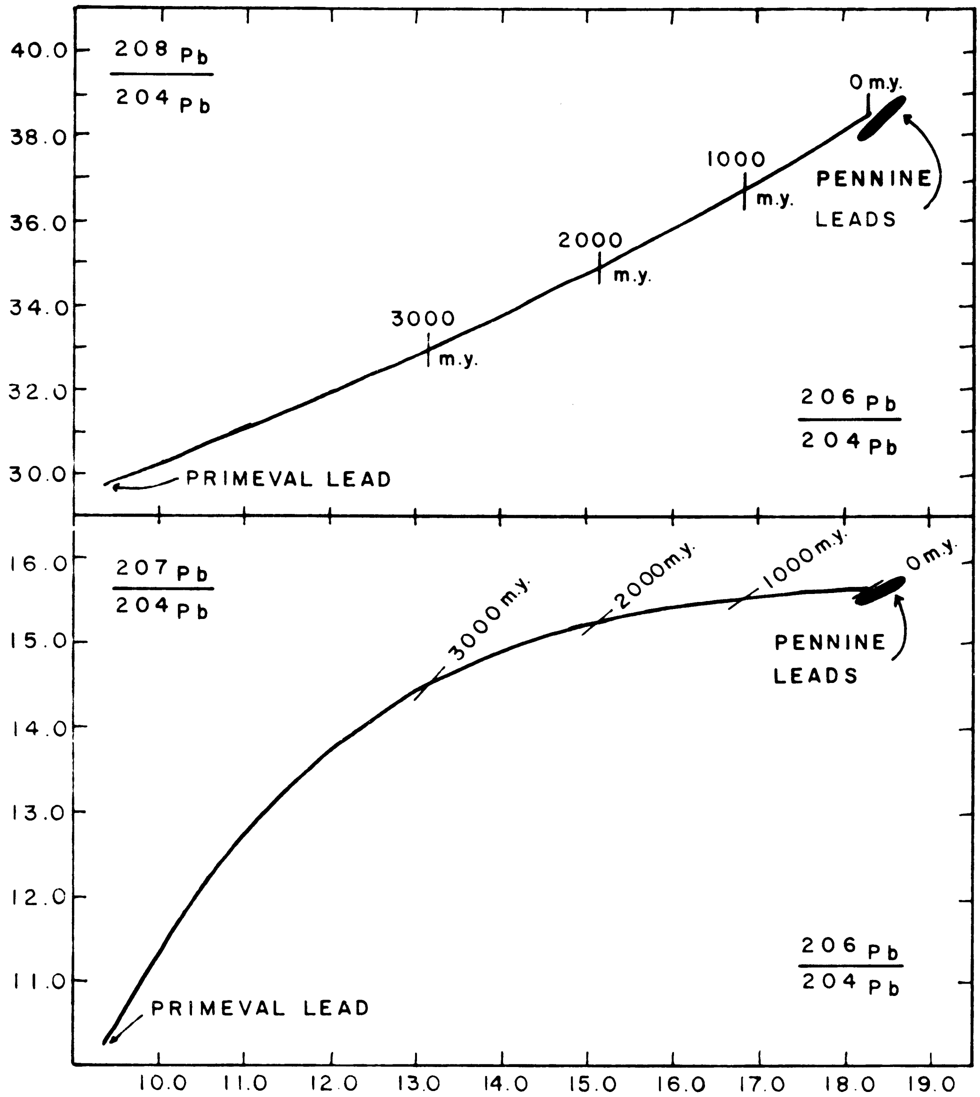
Richards (1971) recently summarized evidence which shows that, although the isotopic distribution represented by the curve in text-fig. 2, remains a fact, these ordinary leads cannot have originated in the upper mantle. This is because modern studies have shown that the mantle is not geochemically homogeneous and because leads extracted from modern mid-oceanic tholeiites, which almost certainly came from the mantle, are themselves anomalous.

As a consequence, emphasis has recently shifted away from using galena lead isotopes as a dating technique (except in cases where an uncertainty of up to ±200 m.y. is still tolerable, as in the Pre-Cambrian), and into using them more empirically as natural tracers, isotopically comparing lead from ore deposits with the lead extracted from various potential source rocks. An example of this type of application is that of Doe and Delevaux (1972).

Sulphur isotopes

In contrast to lead isotopes, sulphur isotopes vary in nature because small differences in the properties of the various isotopes result in their becoming fractionated during many geochemical reactions. Sulphur also has four stable isotopes but only ^{32}S and ^{34}S are present in sufficient abundance to be measured accurately.

Because sulphur from the sulphides in meteorites is very constant in isotopic composition, the Canon Diablo Troilite (CDT) has been accepted as the international standard, and all sulphur isotope measurements are quoted as δ values in per mil units (‰) relative to this standard:



Text-fig. 2. "Ordinary" lead isotope growth curve showing position of South Pennine leads

$$\delta^{34}S = \left(\frac{(^{34}S/^{32}S)\text{sample}}{(^{34}S/^{32}S)\text{CDT}} - 1 \right) \times 1000(‰)$$

A positive δ value indicates that the sample is enriched in ^{34}S relative to CDT; a zero δ value that it is isotopically identical to CDT, and so on.

Broadly, sulphur originating from deep in the earth's crust or upper mantle has δ values near to zero per mil, whereas sulphur that has been involved in low temperature reactions at the earth's surface usually exhibits a broad scatter of δ values (Jensen, 1967).

Analytical Methods

The lead was purified by lead iodide precipitation followed by two dithizone extractions (Tilton *et al.*, 1955). Isotopic analysis was performed using an A.E.I. MS5 mass spectrometer, an ion beam being obtained from lead sulphide on a rhenium filament (Doe *et al.*, 1967).

The mass spectrum was scanned in a series of continuous sweeps, the isotope ratios being obtained from the digitalised output using a polynomial curve-fitting program (Robertson, 1969) on a KDF9 computer. The Broken Hill standard lead (1003B) was analysed regularly, and correction factors, obtained by dividing the results for each ratio of the standard by the accepted value published by Cooper *et al.* (1969), were used to normalize our ratios. Replicate analyses of the standard, together with duplicate analyses on several samples, indicate our precision to be ±0.05 for $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ and ±0.15 for $^{208}Pb/^{204}Pb$. Uncertainty in measurement of the small ^{204}Pb peak was the most important source of error. This causes the preferred scatter indicated by the error bars shown in text-figs 3 and 4.

Sulphur was converted from galena to silver sulphide and then oxidized to sulphur dioxide in a stream of pure oxygen at 1200°C (Rafter, 1957). It was analysed on an AEI MS20 double-collecting mass spectrometer. The precision of the analyses, obtained by comparing replicate analyses of the standard and duplicate analyses of other samples, was about ±1‰. This is below that typically achieved by established laboratories (± 0.2‰)

Results and Discussion

All lead isotope results now available for the South Pennines and adjacent areas, including those of Moorbath (1962), are presented in text-fig. 3 and table 1 (p. 300). Sample locations are shown in text-fig. 1. Moorbath's results have been corrected so as to be directly comparable with the new ones, using a correction factor independently obtained by Mitchell and Krouse (1971).

Lead specimens from the South Pennines are isotopically extremely homogeneous, the total range in the ratio $^{206}Pb/^{204}Pb$ being barely larger than the analytical variation. Such isotopic homogeneity indicates that the lead in the various galena samples had every opportunity to mix before it was precipitated, and so was almost certainly derived from sources some distance from the present location.

The more extensive and precise results essentially confirm Moorbath's results (1962) for the isotopic compositions of galena deposits in the South Pennine Orefield.

Although no detailed study of a single vein has been undertaken, the homogeneity of the results over a wide range of ore types and deposits indicates that, at this level of precision, it will probably not be possible to distinguish different mineralization pulses using lead isotopes. Also, no district-wide isotopic zonations are observed.

Lead isotope compositions from the Ecton Copper Mine, the vein in Coal Measures at Whaley Bridge, and from the Permian Magnesian Limestone at Bulwell are indistinguishable from those in the main orefield. Lead samples from the Triassic deposits in Leicestershire are isotopically slightly more heterogeneous than those from the South Pennine Orefield, but have similar average composition.

On present evidence, therefore, lead isotopes indicate that the Permian and Triassic galena either had the same source as, or were eroded from, the South Pennine ores. There is no way of distinguishing between these possibilities using lead isotopes.

Text-fig. 2 shows that the lead isotope analyses fall mainly to the right of the ordinary growth curve of the Russell-Stanton-Farquhar model. They are therefore anomalous, and must have evolved in some crustal environment for a significant period before being mineralized.

Taken alone, the South Pennine results are too homogeneous to be interpretable using an anomalous lead model such as that proposed by Kanasewich (1968), but taken together with results from the North Pennines and adjacent areas (Mitchell and Krouse, 1971), there is evidence for a real isotopic trend (text-fig. 4) even though more data for the Alston Block are needed.

This trend is similar to that observed in the geologically similar Mississippi Valley deposits (Heyl, 1969), although the latter are isotopically much more heterogeneous, even on the scale of a single orefield. The isotopic heterogeneity in the Mississippi Valley has been ascribed to mixing of lead from different sources, and/or to derivation of lead from a geochemically variable source rock. However, until studies of the isotopic composition of trace leads in various potential source rocks for galena of the Pennine orefields are undertaken, as was done by Doe and Delevaux (1972) for southeast Missouri, further speculation on the significance of the observed isotopic trend is unwarranted.

Regional zonations have been observed across several Mississippi Valley Orefields (Heyl *et al.* (1971), where southerly ore deposits have slightly more radiogenic elements than the northerly ones. The effect is much smaller than observed in the Mississippi Valley districts, and is so near to the limit of significance at the level of precision achieved (similar to that achieved in this work) that it cannot yet be regarded as proven.

Although there is a hint of a similar zonation in galena in the Pennine orefields, the South Pennines having more radiogenic lead than the Alston Block, this cannot yet be proved on a wider basis, owing to insufficient analyses being available. There are only three analyses by Moorbath (1962) from veins in Lower Carboniferous limestones as far apart as the Mendip Hills, Halkyn Mountain and Hensingham in Cumberland which are isotopically indistinguishable from the South Pennine leads.

The five sulphur isotope analyses were made as a pilot study to test the potential of the method, and so firm conclusions cannot be drawn, especially as the precision obtained was not good.

The wide range (+3.2 to - 8.4‰) of δ values for sulphur isotopes from the five South Pennine galena samples strongly indicates that further study has great potential. Such a wide range is indicative of sulphur that has fractionated at low temperatures. The heterogeneity of the sulphur isotopes contrasts sharply with the homogeneity of the lead isotopes. The apparent decrease in $\delta^{34}S$ from north to south should be regarded as pure coincidence.

The spread of δ values lies within that observed by Solomon *et al* (1971) in the North Pennine (Alston Block) Orefield. It contrasts with, although includes, the narrow scatter observed by Mitchell and Krouse (1971) at Greenhow-Skyreholme.

Further studies, especially the analysis of barite δ ^{34}S-values would be of great interest.

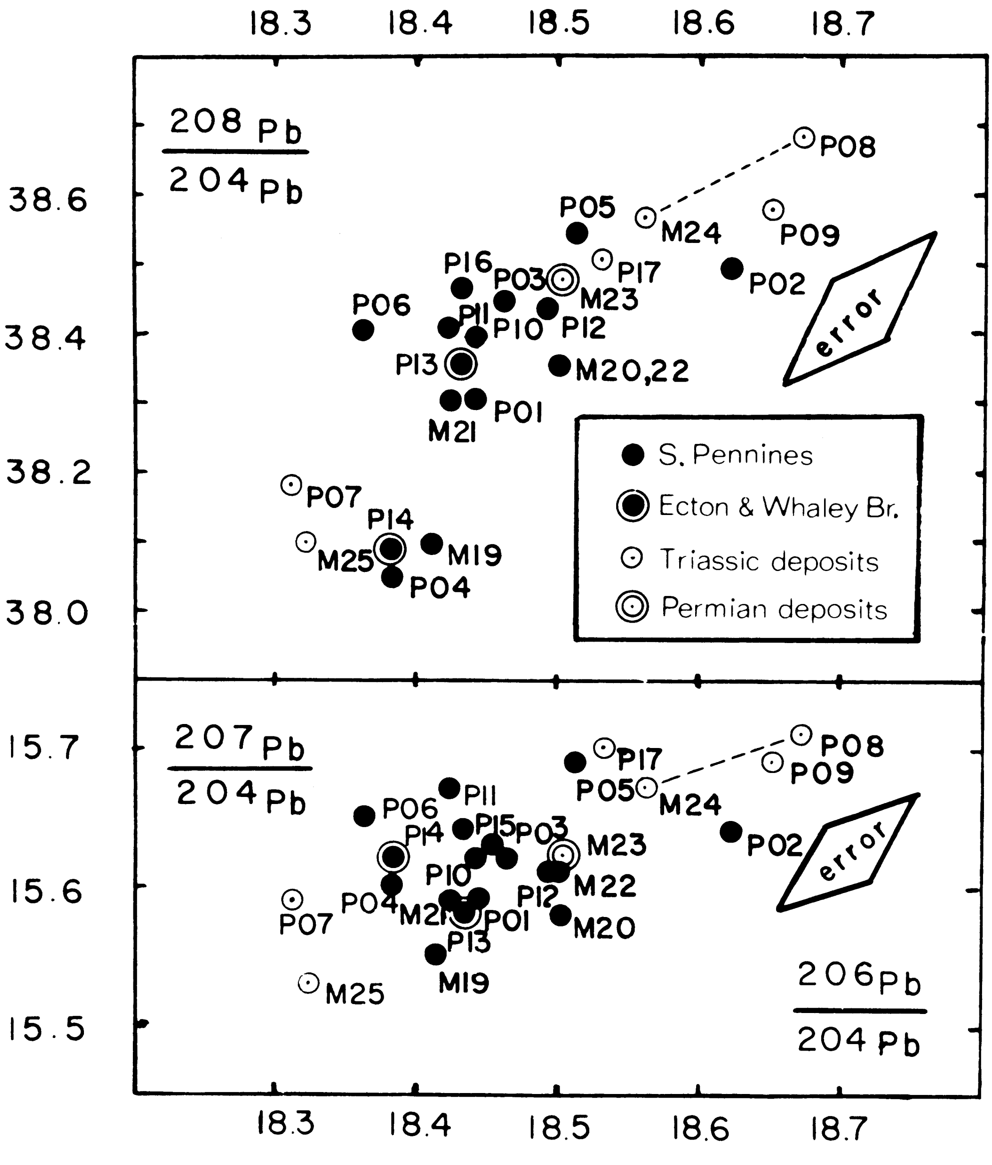
Conclusions

The homogeneity of lead isotopes in South Pennines galenas indicates that isotopic mixing must have occurred before deposition, and so the lead probably originated some distance away from its present location.

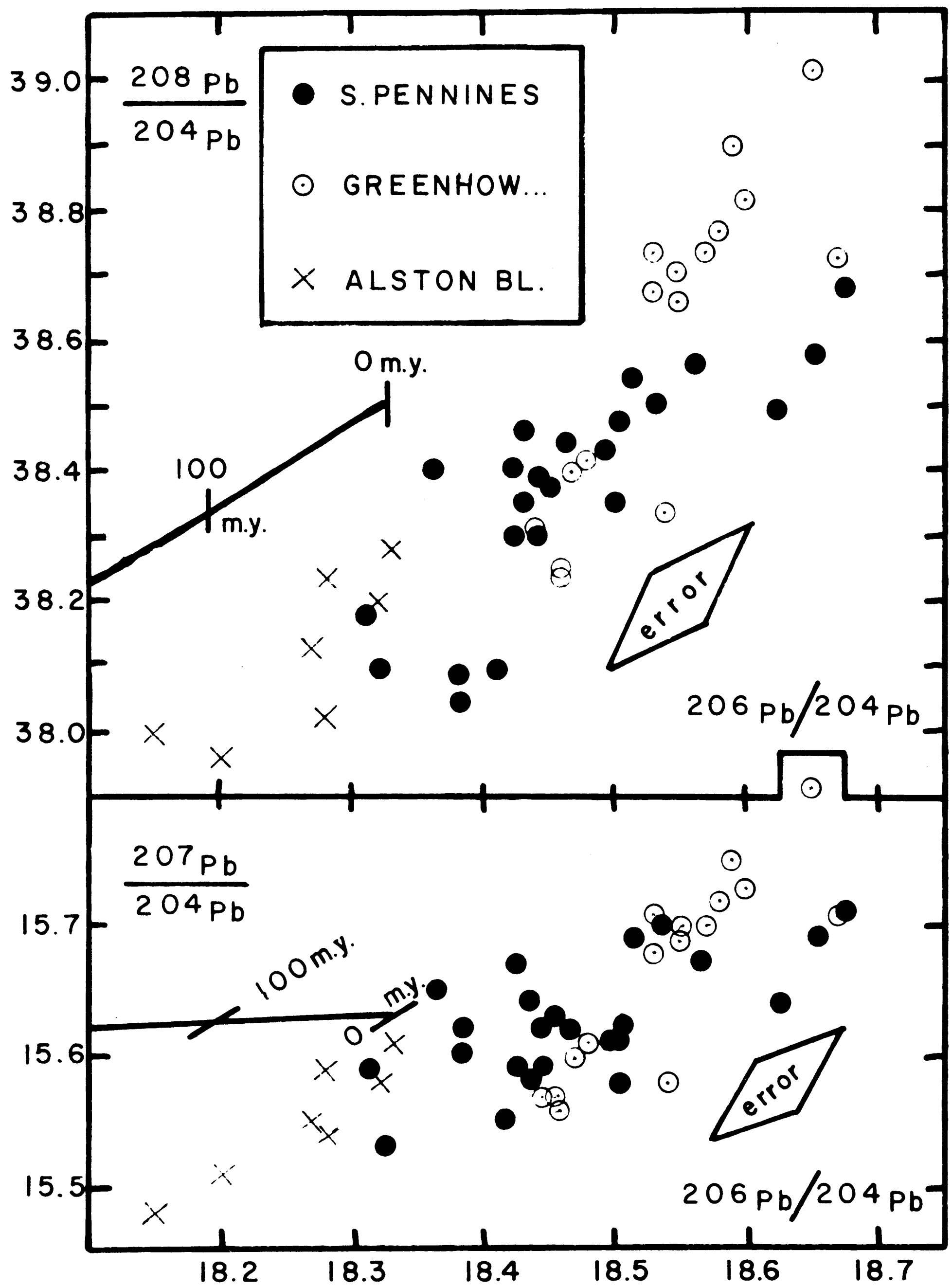
The lead isotopic compositions of galenas in small deposits in adjacent Permian and Triassic rocks are not significantly different from those of the South Pennines. Therefore, the former either had the same source as or were eroded from the latter.

A pilot sulphur isotope study points to wide δ S-values and indicates that further sulphur isotope study might have great potential. Precipitation of the ore minerals probably took place at low temperatures.

Taken together, the lead ores of the Pennines define a definite isotopic trend similar to that defined by the isotopically more heterogeneous Mississippi Valley deposits. Isotopic studies of trace leads extracted from various potential host rocks are required before the significance of this trend can be further elucidated.



Text-fig. 3. South Pennines and adjacent areas lead isotope data



Text-fig. 4. Combined Pennine lead isotope data

TABLE 1

LEAD AND SULPHUR ISOTOPE RESULTS

Sample	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	$\delta^{34}S$(‰)	Type [1]	Location, O.S. Grid Reference, Collected by
						SOUTH PENNINES OREFIELD[2]
P10	18.44	15.62	38.40	+3.2	V	Odin Mine near Castleton, SK133835, D.K. Robertson.
P11	18.42	15.67	38.41	+2.1	P	Treak Cliff Cavern near Castleton, SK136832, G. Lane.
P12	18.49	15.61	38.44	+0.2	P	Prospect at Smalldale Head near Bradwell, SK165813, G. Lane.
P02	18.62	15.64	38.50	-2.5	V	Ladywash Mine near Eyam, SK218775, T.D. Ford.
P05	18.51	15.69	38.55		V	Deep Rake on Longstone Edge, SK218736, T.D. Ford.
P06	18.36	15.65	38.41		V	Mogshaw Rake near Sheldon, SK183679, T.D. Ford.
P03	18.46	15.62	38.45		V	Raper Mine, Long Rake, near Youlgreave, SK216653, T.D. Ford.
P04	18.38	15.60	38.05		V	Spar Mine, Long Rake, near Youlgreave, SK186642, T.D. Ford.
[3]M21	18.42	15.59	38.31		V	Wheel's Rake, near Youlgreave Moorbath, (1962)
[3]M19	18.41	15.55	38.10		V	Millclose Mine, near Matlock Moorbath, (1962)
[3]M20	18.50	15.57	38.36		V	Riber Mine, near Matlock Moorbath, (1962)
[3]M22	18.50	15.61	38.36		V	Moletrap Mine, near Cromford Moorbath, (1962)
P15	18.45	15.63	37.88		F	Dene Quarry near Cromford, SK289563, G. Lane.
P01	18.44	15.59	38.31	-8.4	F	Golconda Mine near Brassington, SK249551, T.D. Ford
P16	18.43	15.64	38.47		P	Minninglow near Parwich, e.l.u. G. Lane.

DEPOSITS IN CARBONIFEROUS ROCKS OUTSIDE SOUTH PENNINES OREFIELD					
P14	18.38	15.62	38.09	P	Ecton Mine, Manifold Valley, SK099585, G. Lane.
P13	18.43	15.58	38.36	V	Rare vein in Coal Measures, Whaley Bridge, e.l.u. G. Lane.
DEPOSITS IN PERMIAN AND TRIASSIC ROCKS ADJACENT TO SOUTH PENNINES					
[3]M23	18.50	15.62	38.48		From top of Permian Lower Magnesian Limestone at Sankey's Potteries, Bulwell, Notts. Moorbath (1962)
P17	18.52	15.70	38.51		Deposit in basal Triassic conglomerate at Staunton Harold Leics., SK 376215, R.J. King.
P07	18.31	15.59	38.18		Mineralized neptunean dyke in basal Triassic conglomerate at Breedon Cloud Quarry, Leics., SK413218, R.J. King.
P08	18.67	15.71	38.69		Deposit in lower Triassic sandstone at Tickow Lane Mine, Garendon Park, Leics., SK 462186, R.J. King[4] (Equivalent to M24).
[3]M24	18.56	15.67	38.57		Sand as P08[4]
P09	18.65	15.69	38.48		Mineralized neptunean dyke in basal Triassic conglomerate near Shepshed, SK497180, R.J. King.
[3]M25	18.32	15.53	38.10		Deposit in Triassic conglomerates at Alderley Edge, Ches. Moorbath (1962)

[1] Type of deposit: V = vein (rake); P = pipe; F = flat.

[2] Deposits listed in order north to south.

[3] All Moorbath's (1962) analyses have been corrected so as to be directly comparable with our data using a correction factor INDEPENDENTLY obtained by Mitchell and Krouse (1971).

[4] See King and Ludlam (1969) for further details.

e.l.u. = exact location unknown.

Acknowledgements

This work was carried out as the thesis requirement for an M.Sc. degree by P. G. Coomer in the Leeds University, Department of Earth Sciences under the supervision of Dr. M. H. Dodson. The sulphur isotope analyses were made in the Manchester laboratories of A. E. I. Ltd. under the supervision of Mr. B. Hatcher. The authors thank Drs. R. J. King and G. Lane for providing several samples. P. G. Coomer was financially assisted by the National Environment Research Council.

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THE GRANTHAM FORMATION IN THE EAST MIDLANDS: REVISION OF THE MIDDLE JURASSIC, LOWER ESTUARINE BEDS

by

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Summary

The account of the Grantham Formation, including a marine unit, the Stainby Member, is based on sections of the Lower Estuarine Beds formerly exposed in open-cast Northampton Ironstone mines between Grantham, Oakham and Stamford, and on five core borings in the Fenland. The new formal formation name is proposed, in substitution for "Deltaic" or "Estuarine" Beds.

The Formation comprises an alternation of very fine-grained sands with marsh clays and a persistent median dark shale (Stainby Member) containing a varied fauna of marine bivalves. The overall thickness varies irregularly from 6 metres at the westerly outcrops to 1.5 metres at outcrop near Grantham, with an increase of the thickness to 5 metres or more at depth in the Fenland. Open marine conditions connecting with the Variable Beds of Northants possibly lay to the west or south-west.

Recent core borings have shown that the characteristic tripartite formation continues eastwards towards Boston, the median Stainby Shale Member retaining its distinct character and marine fossils. The name Grantham Formation is thus applicable across south Lincolnshire, but there is a change, offshore, north-eastwards into a development analogous to, and probably continuous with, the Yorkshire "Deltaic Series."

Introduction

The miles of faces of Inferior Oolite rocks in south-west Lincolnshire, Rutland and Northants, which were open twenty years ago, progressively shrank as the ironstone extraction operation was phased out in 1968-74 in favour of higher grade imported ore. The prospect of losing these highly informative sections led the writer to attempt to record them before they disappeared. The urgent problem was the stratigraphy of the Lower Estuarine Beds, since the Northampton Ironstone has been well documented and the Lincolnshire Limestone will, to some extent, remain available for study.

The interest of the Lower Estuarine Beds was increased by the discovery of a marine phase, originally found by the writer (in student days) around 1935 but subsequently unrecorded by others. This unit is not easy to detect, since fossil preservation is commonly poor and the marine shale disintegrates completely when weathered, or wetted in the unweathered state, but it has been found to be well developed in the area south-west of Grantham and has yielded quite a rich molluscan fauna. A brief listing of this was given in Kent (1971).

The investigation involved measuring nearly 40 outcrop sections, as opportunity permitted, over 5 years. 17 sections are listed in the following pasges, extending across south-west

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pp. 305-327, 2 text-figs.

Lincolnshire and north-east Leicestershire into Rutland. In addition, cores of five boreholes became available in the triangle between Lincoln, Grantham and Boston through the courtesy of Dr. J. A. D. Dickson. The abundant molluscan fauna requires detailed study.

Nomenclature

In Lincolnshire the term *Lower Estuarine* has generally been used for all the beds between the Lincolnshire Limestone and Northampton Ironstone, and the boundaries of these formations define the sedimentological unit described here. Further south, the much thicker basal part of the beds (locally white sands) has been included with the Variable Beds of Northamptonshire and with the ironstone itself as "Northampton Sands", a term which has been used quite differently by individual authors (Hollingworth and Taylor, 1951, p. 12). The alternative usage applies only to the basal part of the unit, consisting mainly of the ferruginous sands, which were, for example, excluded from the Lower Estuarine at Colsterworth (*op. cit.* p. 41). There is, however, no doubt that these beds belong to the same "Estuarine" (so-called) facies group, as is shown below, and the whole interval is here regarded as occupied by a single formation.

Although "Lower Estuarine" is a somewhat more appropriate descriptive name for the Lincolnshire development than "Deltaic", proposed by J. E. Hemingway for the approximate equivalent in Yorkshire, it is still an inadequate description; it is prejudiced by the former usage in different ways in both the Midlands and Yorkshire, and it is inadmissible as a formal name according to the rules of stratigraphical nomenclature devised by the Geological Society of London and International Committees.

The formal name *Grantham Formation* is now proposed for the beds previously known as the Lower Estuarine, specifically in the area between Lincoln, Sleaford and Kettering. It is named after a district particularly notable for workings of the Northampton Ironstone over the last 40 years. At the time of writing the formation is still fully exposed at Harlaxton, in No. 6 mine on the Grantham town boundary, and in the last active quarry, No. 4 mine, $1\frac{1}{2}$ miles further west. The type section may be taken as that measured in Colsterworth No. 2 mine, one mile west south-west of Colsterworth Church (SK 915232), Section No. 9 in the following account.

The formal name *Stainby Shale Member* is proposed for the dark shale unit with marine fossils in the upper-middle part of the Grantham Formation; the bed was particularly rich in fossils at Stainby Warren and at Stainby Glebe mine. The latter locality is designated as the type locality (Section No. 11).

In the Fenland, the cores of the beds below the Lincolnshire Limestone, the terminal parts of the borings, were only some 10 cm. in diameter, so that the material obtained represents an extremely small sample of this large area. Nevertheless it was sufficient to show that the Lower Estuarine Beds of the Fenland is similar in general facies and is probably continuous with that of the southern outcrops, so that it can be regarded properly as a continuation of the Grantham Formation, including the median dark shale, the Stainby Member equivalent.

It is known that off the north Lincolnshire coast a sharp expansion of the "Lower Estuarine" begins, with a great increase of sands, and, although data are inadequate for accurate definition of facies, the development compares broadly with that of Yorkshire and is better classified in line with the "Deltaic Series" of the north. The north-eastern limit of the named Grantham Formation thus approximates to the present coastline, but the boundary is, of course, transitional and arbitrary.

General Account of Lithology

The typical section can be summarised as follows:

The top member is usually a well-bedded ferruginous fine-grained sand, which may be interbedded with dark shale, as at Harlaxton. Vertical carbonised plant "rootlets" commonly occur except in the uppermost part. There may be no clear-cut boundary between this and the overlying basal Lincolnshire Limestone "Blue Beds" where these are de-calcified. Members of the Institute of Geological Sciences tend to take a boundary a little below the lowest limestone, but the present investigation has failed to find a break or any consistent marker around this part of the sequence. The relationships of the Lincolnshire Limestone and Grantham Formation in the area between Grantham and Stamford bear a marked contrast to those in north Northamptonshire described by Taylor (1946), in that the Lincolnshire Limestone here shows close parallelism with the bedding of the underlying formation with an absence of channelling at the contact. Thickness variation of the upper beds is gentle and relates in part to a general thinning towards the Witham Valley. (Sharp changes in total thickness of the Grantham Formation reflect variation in the development of the ferruginous sandy beds beneath the marine shale horizon).

The ferruginous sand usually passes down by gradation and/or interdigitation into the main median shale body. The transition is fairly rapid and may correspond with a break and re-working of the top part of the shale. Large channel features are extremely rare in the "Estuarine" of this area (a distinction from the Deltaic Facies of Yorkshire). The only case seen, in inspecting miles of quarry faces, is at Harlaxton, where the top sand group is channelled down into the shale member beneath in the easterly workings (SK 892314 to 896310). This channel cuts more deeply north-westwards, but as an isolated case has little significance.

The marine Stainby Member is essentially a lithological mixture. The greater part is dark grey, medium grey, brownish or dark blue-black fine muddy silt interlaminated with with streaks of coarser white silt or very fine-grained sand. Laminations are commonly a millimetre or less (with internal grading), in graded-bed units of 3-10 mm. Small scale flaser bedding predominates. Thicker sand streaks (5-10 mm) occur infrequently. The Member is characteristically fissile, separating into large sheets. Vertical carbonised "rootlets" penetrate the bed, particularly from the top, and there are common vertical holes (worm borings?) filled with fine white sand; these have been distorted during compaction of the shaly element in the sequence.

A distinctive dull grey thin sandy mudstone occurs in the lower part of the shale at Harlaxton, Warren Farm and at Stainby Glebe. At the former place this sandy mudstone passes laterally into fissile, slightly bituminous shale, or alternatively into ferruginous sandstone, which is rich enough in iron to develop box-stone structures on weathering. The sandy mudstone bed shows rather thicker sedimentary structures than the adjacent fine silts, being no doubt less compacted, and when fresh tends to be a little pyritic, presumably the original state of the iron. Fossils (particularly small *Aviculopecten*) occur in swarms, and there are several types of borings and "trails".

In addition to the borings, various other trace fossils occur, notably *Diplocraterion* at Colsterworth and Harlaxton and *Chondrites* at Harlaxton, Market Overton and Bicker.

Fossils are rare or absent in the upper part of the bed. The higher fossil streaks in the outcrop sections are made up of swarms of "*Corbula*" covering bedding planes. *Lingula kestevenensis* Muir-Wood occurs at what may be a consistent horizon a little above the base, mainly at or near Colsterworth and in the Fenland at Great Hale, Asgarby and Bicker, as well as at Market Overton near Oakham. At outcrop the main varied fauna is confined to the lowest 15-20 cms., sometimes the lowest 5 cms. Almost invariably shells are dis-articulated; they lie on bedding planes, rarely crossing the bedding even in the case of those which lived in a buried state (e.g. *Pholadomya*), and they consequently tend to be flattened.

The maximum variety of molluscan types was found at Market Overton. In all cases collecting was controlled by the physical conditions of the exposure, in particular by the difficulties provided by vertical unstable rock faces, and, with allowance for this, the next best faunas have been collected from Stainby Glebe, Sproxton and Hungerton. However Saltby, in the same westerly area, has been consistently disappointing, and the variation of preservation of the fauna seems partly fortuitous, as on a modern mud-flat.

Much of the fauna was probably pyritised; pyrite survives in the less weathered material at Harlaxton and at Market Overton. Nacreous preservation may persist in some cases. The predominantly poor preservation is presumably due largely to leaching through the porous matrix; for although the bed quickly breaks down to a sticky clay on open weathering, the predominant lithology is silt, and this material wets and dries easily.

At outcrop the base of the marine shale is almost always sharp, usually with a concentration of larger shells in the lowest 2-5 mm. The lowest 5-10 mm. is often quite sandy and in some places irregular pitted grey "mudstone" nodules occur at this level. A greenish lamina (0.5-1 mm.) may occur at the base. Most commonly the bed beneath approximates to fireclay - a structureless purplish-grey plastic clay with abundant vertical rootlets - presumably a marsh deposit. Elsewhere the marine bed rests directly on illsorted sand.

In the thicker development of the Grantham Formation, as at Saltby, the marsh-clay member is underlain by up to a metre of well sorted very fine-grained white sand, without significant structures other than vertical rootlets penetrating from the top.

The lowest beds of the Grantham Formation are commonly poorly exposed, being obscured by scree or quarry debris, and are much more variable in thickness and lithology than those above. Grey muddy sands seem to predominate; these commonly have a purplish tinge before weathering. At Harlaxton the sands are locally cemented into nodules of 0.3 - 0.7 metres diameter, with black pitted surfaces. The sands are variably ferruginous and pass into ironstone, which has occasionally been extracted with the main ironstone bed below. Carbonaceous shales may occur at the base, as at Harringworth in Northants and in some Fenland borings, but more commonly the interval lacks shales. At Colsterworth locally a 20 cm. cemented purple sandstone full of vertical plants is cemented on to the top of the Northampton Ironstone.

Upwards from the base of the Stainby Member, there is a progressive loss of the marine fauna and an increase in the "marsh" plant indices; the cycle was thus from marine to "estuarine".

Whether there is a second comparable cycle, lower in the Grantham Formation, is not clear. Although no lower true marine fauna has been found, *Chondrites* occurs in a separate lower shale at the Bicker boring, and the downward passage of the lowest sands at outcrop into a ferruginous facies suggests partial consanguinity with the (marine) Northampton Ironstone beneath; possibly these ferruginous sands were deposited in near-marine waters which became increasingly brackish as marsh conditions spread. The environmental implication of the very well graded white sands within this series is not entirely clear - possibly they are redeposited small sand dunes.

Palaeogeography

In the area south-west of Grantham, the Grantham Formation forms a half lens, with greatest thickness (7-8 mm) in the west and irregular attenuation, 1.7 to 2 m. close to the line of the valley of the River Witham, extending south to Exton and Ketton. The eastward thickness-change affects all the subdivisions of the Formation, the white sands thinning out first, the marsh clay next. The upper sands, the marine shale unit and the ferruginous sands beneath persist eastwards in attenuated form.

Southwards the formation continues across Rutland into north-eastern Northamptonshire, apparently losing the marine element north of the Welland Valley, although the median shale continues. No marine fossils have been found at either Exton in Rutland or Rushton near Kettering.

A correlation problem develops southwards, as the term "Lower Estuarine" has at times been limited to the upper part of the Lincolnshire Limestone and Northampton Ironstone sequence; the lower part, locally developed as the white sands, being classed with the "Northampton Sands", by Beeby Thompson (1921-28) and Arkell (1933). The sections recently available show that the Stainby Member continues southwards from Grantham to the Welland Valley, with local development of sandy partings, and that a second basal carbonaceous shale member is developed around Harringworth, directly above the ironstone. Thus a direct correlation can be made from Grantham into north Northamptonshire, and the lower sands of the former area are, at least in part, separated by an "Estuarine" (freshwater) plant bearing shale from the marine Northampton Ironstone.

Northwards from Grantham the Formation remains thin, 1.3 m at Belton and 1.5 m at Leadenham, with a major proportion of shale. North of Leadenham, not necessarily to be directly correlated, sands only are recorded at Coleby and Waddington. The Grantham Formation is absent at Lincoln, but at Fillingham (outcrop section) and Welton (borehole) it is again of mixed facies, although no marine fauna is known.

Beneath the Fenland, records of the equivalent "Estuarine" facies are scarce, since few boreholes have penetrated beneath the Lincolnshire Limestone, the main aquifer. They suffice to show, however, that beyond the attenuated Leadenham-Grantham-Colsterworth belt the Formation, still characteristically tripartite, expands again eastwards. The records show that, between Boston and Grantham, dark shale in the middle part is well developed and contains *Lingula*, in addition to marine lamellibranchs as at Colsterworth and Market Overton. Thus this marine belt has considerable east-west extension, perhaps between the edge of the Yorkshire delta and the facing margin of the contemporary shallows and shoreline of the London platform (text-fig. 1).

The molluscan fauna, with its abundance of "*Trigonia literata*" (*Myophorella*), suggests a relation to the Variable Beds (Upper Northampton Sands) of Northants., possibly via open marine waters lying west of the present Midlands' outcrops. The records in the Fenland, taken with the knowledge that off the Lincolnshire coast in the North Sea the Grantham Formation appears to be 30 metres thick or more, suggests that the main basin may nevertheless lie to the east. South Lincolnshire may occupy shallows between the main North Sea basin and the partly marine development of a northward Cotswold Basin extension.

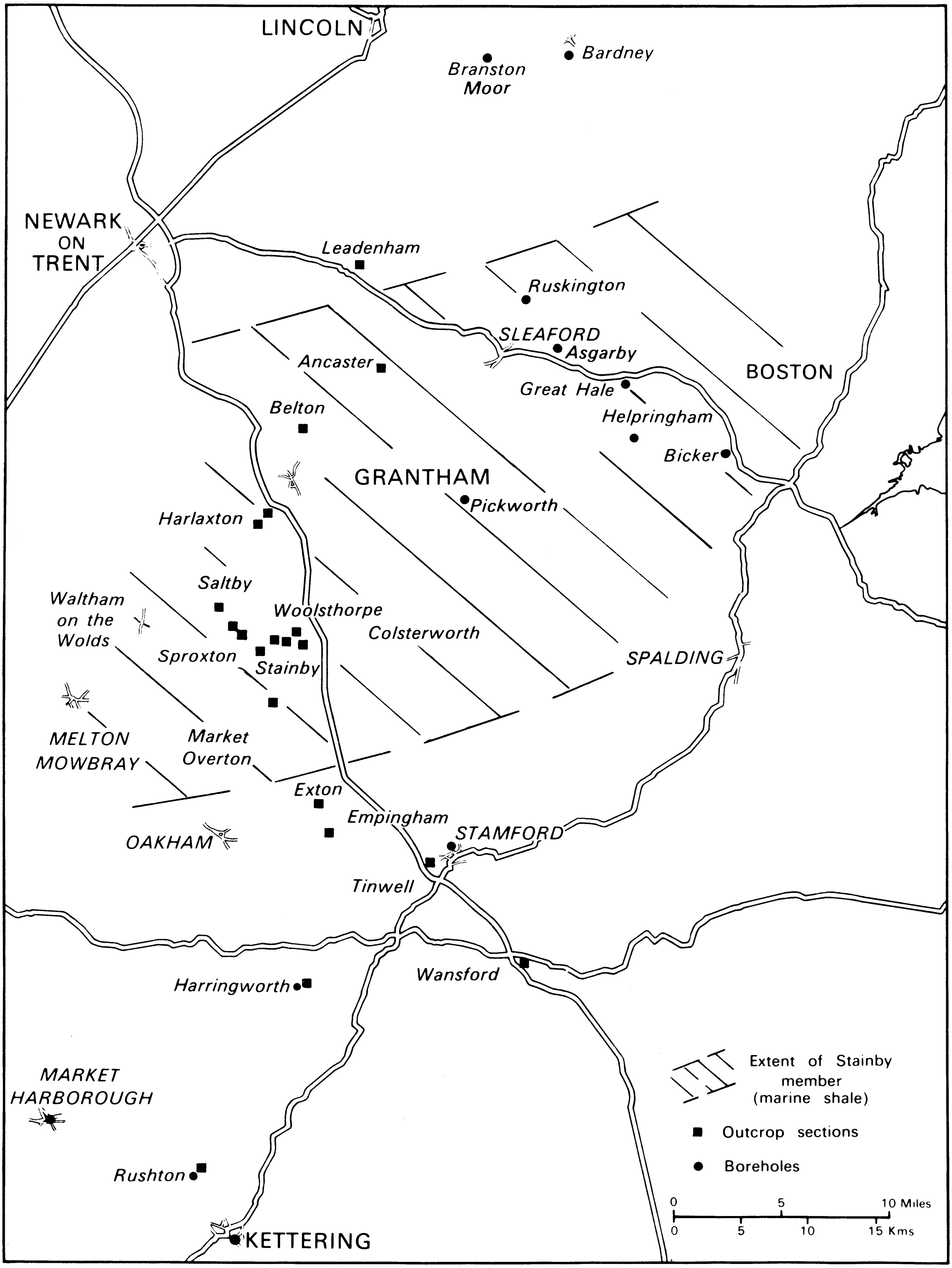
Measured Outcrop Sections

The sections which follow are arranged in geographical order from north-east to south-west and south (text-figs. 1 & 2). Records of a further 20 sections in the same area have been deposited with the Institute of Geological Sciences (Leeds Office). Reference to the author's specimen collections are given in the form PEK/505.

1. HARLAXTON - Warren Farm Face (No. 6 Mine)

The section is taken at the eastern end (410 m from the Grantham boundary) SK 904326 and is the north-easternmost modern working of the Northampton Ironstone. It was measured on the 14th April 1972.

		metres
Lincolnshire Limestone	2.76 m.	
Grantham Formation	2.80 m.	
Deeply weathered ferruginous shale with ferruginous sandstone streaks		0.48



Text-fig. 1. Locality map and distribution of the Stainby Member.

	metres
<u>Stainby Member</u>	
Finely flaser bedded blue-grey shale, brittle, disintegrating when wet, with pale silt and very fine-grained sandstone laminae; shale dark blue in the lower part.	0.23
Irregularly lensing fine sandy mudstone, occasionally with oblique bedding, ferruginous and oxidising to ironstone. Passes into papery sandy shale.	0.08
Dark shale with pale sandy streaks as above. Fallen blocks of dark shale with sandy streaks yielded occasional *Trigonia*, *Aviculopecten*, *Ostraea* etc. PEK/505.	0.15
Dull grey to purplish grey fine-grained sandy mudstone with abundant vertical carbonised rootlets, passing down into shaly mudstone.	0.43
Lighter grey silty mudstone	
- irregular junction -	
Light grey, faintly purplish, blotchily yellow-weathered fine sandy clay.	0.41
Rotten ferruginous sandstone, poorly - to un-bedded	0.76

<u>Northampton Ironstone</u> seen to 2.0 m.

The "sandy mudstone" is a distinctive rounded-weathering bed. Fossils are well preserved, tending to be nacreous in the unweathered state; traces of pyrite occur. Rare *Lingula* occurs in its upper part. In stratigraphical position, fossil preservation and lithology, it very closely resembles the "twin sandstone" of Stainby Glebe.

Eastwards (down dip) the sandy mudstone is much more oxidised and passes into brown ferruginous sandstone, with box-ironstone structure which obliterates most of the fossils, except for small *Aviculopecten*; small broad leaves (carbonised) and reed fragments occur.

The shales above have surfaces with swarms of "*Corbula*" at several levels; *Gervillia*, *Trigonia* and *Modiolus* (usually isolated valves) also occur. *Syncyclonema* occurs, showing the internal ribbing. Some (lower?) shale is full of "shell mash" made up of small round *Ostraea* juv. (cf. lower shale at Stainby Glebe). *Diplocraterion* is reported by J.A.D. Dickson.

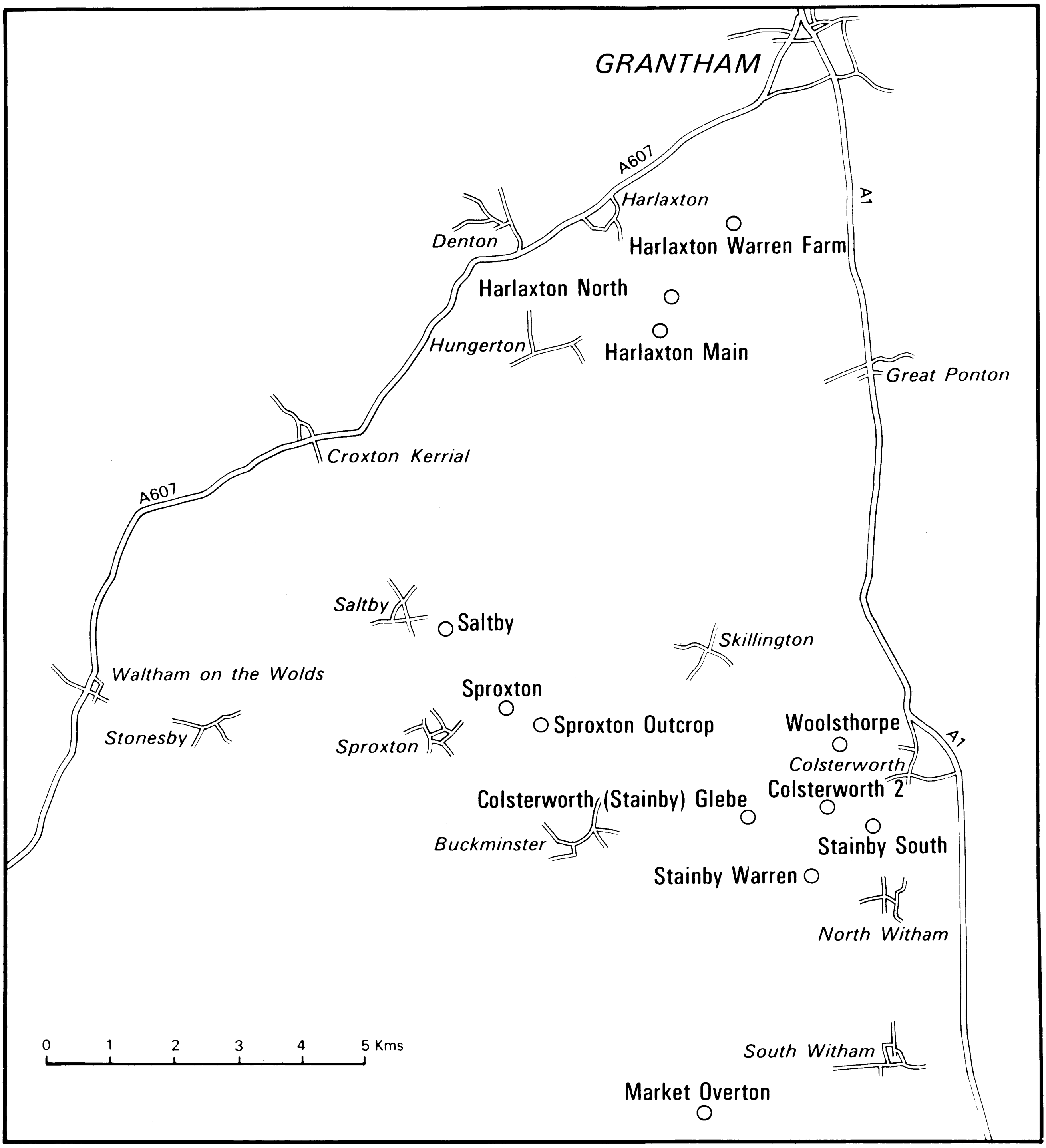
2. <u>HARLAXTON NORTH</u> (No.7 Face)

The section measured is in the middle of the face, SK 890311, recorded 26th May 1973.

<u>Lincolnshire Limestone</u> 1.5 m.

<u>Grantham Formation</u> 3.29 m.

Yellow-brown sandy marl (poorly exposed).	0.43
Richly ferruginous brown sandy and clayey silts with thin grey shaley partings.	0.41
<u>Stainby Member</u>	
Dull grey shales with soft ferruginous sandstone intercalations and ironstone crusts.	0.43



Text-fig. 2. Ironstone mine localities between Grantham and Oakham.

metres

Dark banded shale. Flaser bedded, fine, light and dark banding commonly showing tone gradation within laminae; sharp junctions at the base of pale silty units, which show micro-channelling into lamina below. Boundary most strongly marked from 75 mm - 175 mm above base. In lower part bedding planes are crowded with small shells. *Protocardium* (pyritised) and fragments of *Pholadomya* 0.66

- Film of sand on gently undulating contact -

Pinkish purple (fresh) to slightly purplish dull lead-grey blocky silty mudstone; abundant rootlets from the top downwards. about 0.61

Pale very fine sand or silt, poorly exposed.

Northampton Ironstone, seen to about 2.1 m.

3. HARLAXTON MAIN FACE (No. 4 Mine)

The main face at Harlaxton is the last operating mine in the Northampton Ironstone Formation, north of the Welland Valley. This face is 1.61 km long and the following column combines details from sections measured from 1969 to 1973 in the eastern part. (SK 895311 approx.).

Lincolnshire Limestone with basal ferruginous "Blue Beds".

Grantham Formation 3.21 m.

Ferruginous sandstone and shale. Regular alternation of fine-grained sandstone, weathering yellow and ferruginous in units of 50 - 120 mm, parted by three beds of blue grey soft shale, streaked with fine sandstone and with sandstone blebs, 30 - 70 mm thick. 0.43

(In the easterly part of the workings, the lower members of this sand group thicken and fill a channel, which cuts 610 mm deep into the underlying shale. This presumably continues a channel in the adjoining face of No. 7 mine. Elsewhere the junction is gradational).

Ferruginous sand, developing boxstone ironstone nodules. 0.05

Stainby Member

Dark grey shale, weathering light blue-grey and buff. Dark filled borings (?) in the upper part, vertical carbonised "rootlets" in the middle part. Minor proportions of light silt partings. Locally a grey cemented mudstone passes into ironstone at the base. 0.56

Closely banded blue-black shale and pale grey silt, with scattered shells, mostly small, except at the base, where the lowest 70 mm yielded *Pholadomya*, *Goniomya* ?, *Nuculana* ?, *Trapezium*, "*Trigonia literata*" (*Myophorella*), rare *Aviculopecten*, *Protocardium*, *Amusium*, rare small gastropods of *Cerithium* type (PEK/443) 0.34

- sharp junction -

metres

Light purple-grey tough clay, weathering to glutinous pug, varying to light chocolate brown. Densely bored in the upper part; locally with contemporary cracks filled with dark shale (overlying bed). Occasional chocolate-brown clay-ironstone nodules, septarian when large, with veins of "kaolinite". 0.5 m to 0.76

- strongly undulating contact -

Northampton Ironstone up to 1.07 m.

Yellow to grey siltstone and fine ferruginous sandstone with irregular nodular masses of chocolate brown ironstone with *Lioceras* cf. *opalinum* and abundant pelecypods in the upper part.

The two lowest members of the 'Lower Estuarine' (the marsh clay and basal sands) thin to about half the thickness given above towards the eastern end of the mine face and remain thin in the No. 6 mine 1.61 km further to the north-east. The main thickness change takes place within 200 metres.

4. SALTBY

Section 90 - 180 metres from the north end of the working face. SK 857262, measured 4th September 1971.

Lincolnshire Limestone 6.00 metres.

Grantham Formation 5.05 metres.

Brown ferruginous sand, locally about	0.23
Grey-brown flaser bedded shale and white silt, level bedded. (Somewhat disturbed, slickensided.)	0.18
Deep brown very ferruginous quartz sand, locally clean and pale.	0.15

- sharp junction -

Stainby Member

Brown and grey banded shale; silty intercalations are ferruginous and weather brown. Bands 3 - 10 mm, themselves finely banded. Vertical carbonised plants 5 - 25 mm long. (This is the weathered upper section of the main shale group continuing below) Thinning south from 0.6 to 0.33

- passage -

Light grey to dark grey shale "zebra-banded" with pale silt; individual units from a fraction of 1 mm to 3 - 4 mm. show graded tonal banding. Fallen blocks show some layers crowded with *Corbula*, common *Modiolus*, *Protocardium*, scattered *Trigonia* (*hemisphaericus* group). Thickens north to about 1.2 m with cut out of the white sand group below. At the section line - 0.63

	metres
Greenish grey shaly clay, very ferruginous, brown weathering.	0.13
Interbedded light grey clay and brown ferruginous silt.	0.13
- passing down -	
Medium purplish-grey clayey sand with abundant vertical carbonaceous roots, starting at the top of the bed or irregularly within it and into the bed below.	0 - 0.28
Olive brown clay, very silty, with carbonaceous vertical roots penetrating the bed below. The upper part is characteristically but discontinuously pale red-purple (pale magenta) with yellow joints; over 100 m or so of face.	0.12 - 0.25
- Undulating sharp erosional junction, ferruginised -	
White sand - very fine-grained, well graded, grains tending to roundness, white to yellowish mostly pure quartz sand, occasionally micaceous. Unbedded or with trace of level bedding. Cut out in the north as the shale group thickens.	0 - 0.94
Ochreous sand with ironstone layers.	0.13
Lead-grey very fine-grained clayey sand, with irregular brown ironstone crusts increasing to half bulk near the base.	1.60

Northampton Ironstone exposed to about 2.5 m.

5. SPROXTON

South Top Quarry, SK 867248, measured 30th August 1969.

Lincolnshire Limestone 12.8 m.

- gradational junction -

Grantham Formation 3.35 m.

Stainby Member

Finely laminated dark grey (damp) bluish grey clay, with flattened pale muscovitic silty blebs and streaks.	0.20
Alternations of dark shale and pale silts as above - with distinct bituminous smell when hammered - and yellowish grey finely banded mudstone. Vertical rootlets penetrating the whole thickness.	0.26
Finely laminated dark shaly clay and fissile silt as before, with abundant marine shells, including *Pteroperna*, *Trigonia*, *Pecten*, (*Amusium*), *Modiolus*, *Camptonectes*, *Pholadomya*, *Protocardium* ? ostracods, plant fragments (PEK/440)	0.42
More clayey shale with silt alternations, passing down into dark grey plastic clay.	0.32
Pale clayey sand, passing down into fine pale purplish sand, poorly exposed.	2.08

metres

Northampton Ironstone about 4.5 m.

6. SPROXTON "Outcrop Face". SK 873348.

On the upper slopes of Buckminster Bottoms valley; open in 1971-73. Measured 25th to 31st March 1972.

Lincolnshire Limestone 4.0 m.

Grantham Formation 2.97 m.

Soft brown clayey sand.	0.15
Flaser bedded brown and purplish ferruginous clayey sand.	0.08
Clear white fine-grained quartz sand, streaked with brown ferruginous sand and sandy shale, passing down into dull grey clayey sand.	0.20
Yellow brown laminated fine-grained sand with vertical dark rootlets, passing down by transition into laminated shale.	0.13
Stainby Member	
Blue grey rhythmic banded shale with thin white fine-grained sand streaks; main, fining-upwards, graded units 4 - 12 mm, with minor banding of about 0.5 mm. Shelly streaks with *Ostraea* etc. (small shells) 0.5 m down. White fine-grained sand streaks more numerous in the lower two-thirds; vertical holes filled with clear fine-grained quartz sand or lignite (borings ? or more probably some rootlets.). Abundant shells in iridescent preservation in the lowest 30 cm include *Ostraea*, rare *Lopha*, *Trigonia* (*costata* and *literata*" groups), *Oxytoma*, ribbed sp. (one only), *Aviculopecten* (common) *Amusium*, *Homomya* ?, *Pholadomya* (rare), *Pinna*, "*Corbula*", *Modiolus* sp., rare *Lingula*. (PEK/504).	1.17
Occasional deeply pitted pale mudstone nodules. (PEK/503)	0 - 0.05
Dark grey bedded or poorly laminated tough brown clay or clay-shale, becoming grey and slightly greenish downwards (unfossiliferous). Basally passing down into ochreous clayey ferruginous sand.	0.36
- sharp junction -	
Pale fine-grained clean quartz sand or soft sandstone with abundant vertical rootlets in the upper part. Bedding is indefinite, probably level.	0.61
Fine sand and ferruginous rubbly sandstone passing down into poorly exposed sandy ironstone (not used as ore; presumed part of the Estuarine Beds) about	1.22

Northampton Ironstone seen to about 2.5 m.

In the Stainby Member. there is an occasional surface covered with *Modiolus* and scattered specimens are fairly common. *Ostraea* (mainly small) are locally abundant, associated with small Pecten (*Amusium*); the commonest are "*liassica*" shape with an occasional form with broad-attachment ("*irregularis*"). One small oval form has a median radial sulcus extending half the shell length from the hinge. *Trigonia* specimens are fairly common. Some streaks are crowded with "*Corbula*" but this is subordinate. Small *Aviculopecten* are common but not dominant. *Lingula* valves occur separate in a sandy streak, associated with *Pecten* or *Aviculopecten*.

7. COLSTERWORTH: Woolsthorpe Face.

The northern part of the Colsterworth mining area has the Northampton Ironstone nearly flat lying, with the thin Grantham Formation showing remarkable evenness and continuity of individual beds. Bedding is simple and well developed throughout, with apparent perfect parallelism with the Ironstone and overlying Lincolnshire Limestone. The Stainby Member is probably represented by 25 - 50 mm of dark shale, but fossils were not found. Section at the north-east angle of the mine, SK 920242, measured 17th April 1971.

	metres
Lincolnshire Limestone 4.1 m.	
Grantham Formation. 1.83 m.	
Ochreous brown sand with grey layers.	0.10
Alternations of dark grey shale and fine white sand, with a median parting of ochreous sand.	0.15
Brown ferruginous ochreous fine/medium-grain sand.	0.05
Stainby Member	
Dull brownish-grey blotchy clayey sand with flattened clay inclusions and black shale streaks.	0.10
- passage -	
Deep blue-black shaly clay.	0.02
- sharp break -	
Medium grey banded clayey fine sand, layers (graded) 1 mm - 20 mm of light and dark banding. Common vertical rootlets truncated at the top of the bed, ferruginous basally	0.96
Drab grey very lignitic clayey sand.	0.13
Obscure interval.	0.31
Northampton Ironstone seen to 2.5 m.	

8. COLSTERWORTH - Glebe Farm Mine. SK 907245, (approximately) measured 9th January 1971.

Lincolnshire Limestone 8.5 m.	
Grantham Formation. 2.25 m.	
Ochreous soft sand.	0.31
Stainby Member	
Chocolate brown shale (very persistent bed) overlying thin white sand bed towards the south - prominent marker.	0.05 - 0.13
Greenish clayey sand, weathering ochreous. (passing down).	

north	metres	south	metres
Dark blue-grey carbonaceous shale	0.10	Dark blue shaly clay with fine pale silt bands; vertical plants. More thickly bedded and sandy at the base.	1.07
Dark blue, ferruginous weathering shale with vertical plants.	0.33		
Yellow brown irregular sand.	0.28		
Light grey shaley clay.	0.25		
Ochreous brown fairly hard ironstone, concretionary.	0.13		

Sand, light grey-green or soft, ferruginous and shaly. 0.51

Northampton Ironstone 2.90 m.

9. COLSTERWORTH No. 2 Mine.

Over the period 1968 - 1973 the most extensive faces were located 1-3 km south-west of Colsterworth village (No. 2 Mine), immediately north of the Buckminster road. Several sections were measured, the following near the western end of the face, SK 914233 (as at June 1970) was most informative.

Lincolnshire Limestone 5.8 m.

Grantham Formation 3.59 m.

	metres
Yellowish clayey sand, becoming streaky below.	0.51
- Gently undulating contact -	
Stainby Member	
Blue shale, dark, sandy.	0.15
Blue shale, dark, sandy, rootlet holes filled with white sand.	0.18
Flaser bedded grey finely pyritic shale: pale silty streaks in medium to light grey shale; dark carbonised rootlets. Scattered shells through the lower 60 cm., *Lingula* common about 20 cm above the base; at the base irregularly bedded dark carbonaceous silt with nacreous shells including *Trigonia*; in part very sandy with sandstone pebbles (PEK/452).	0.91
Faintly purplish silt or silty clay, with carbonised rootlets.	1.38
Purple ferruginous cemented sandstone with vertical rootlets (hard bed).	0.46

Northampton Ironstone 2.7 m.

The *Lingula* bed was particularly well developed at this locality; the species which occurs also in the Upper Estuarine Beds of the district, is identified as *L. kestevenensis* M. Wood. A little further west the shale becomes progressively sandier and, in 1969, the face cut a sand body, some 45 m. across, at the equivalent horizon; this sand yielded good specimens of the U-shaped burrows, *Diplocraterion*.

The ferruginous basal sandstone is notable; this is as hard as the underlying Ironstone but is densely penetrated by vertical rootlet holes which give the appearance of a columnar fracture.

Hollingworth and Taylor (1951, p.12) separated the basal sands in this section as "Northampton Sands", following practice in the Kettering district. The facies is however, clearly "Estuarine" and (as noted above) the whole of the interval between the Lincolnshire Limestone and the Northampton Ironstone is logically regarded as a single lithological unit.

10. COLSTERWORTH: Southern Face.

The mine is situated south of the Colsterworth - Stainby road and shows strong eastward attenuation of the Grantham Formation. The section is a little west of the middle of the face, (SK 920229) and was measured on the 23rd May 1970.

metres

Lincolnshire Limestone 6.00 metres. Normal development with basal ferruginous limestone.

Grantham Formation. 1.8 - 3.3 metres.

Medium or light brown streaky bedded ferruginous sand.	0.10
- sharp junction -	
Lead-grey fine-grained soft sand with sandstone, grading down to buff.	0.38
	0.33
Stainby Member	
Dull grey and brownish very sandy lignitic clay with vertical rootlets.	0.33
Pale and dark grey finely banded clay, streaked with pale silts, with thin brown fine sand partings. In the middle, a bed contains large shells including *Trigonia* (*Myophorella*); also *Corbula* (PEK/451).	0.66
Brownish sand at the top of obscure interval; thickness varies from 0.6 m to	1.82

Northampton Ironstone, 2.00 m. plus.

The upper beds of this section converge towards the Northampton Ironstone eastwards, as the basal beds thin. 400 m west of the "Old Post Lane" (the North Witham road) (SK 992229) the whole of the Grantham Formation is reduced to 1.35 m with only 5 cm of dark shale remaining in the middle part.

11. COLSTERWORTH: (Stainby) Glebe Mine.

Located 410 m. west of the western end of Colsterworth No. 2 mine on the plateau. The section is one fields-length north of Stainby Church, SK 904230 and was measured on the 22nd April 1972.

Lincolnshire Limestone 1.60 m.

Grantham Formation 2.40 m.

Soft ferruginous fine-grained sandstone.	0.05
Weathered blue shale streaked with brown ferruginous sand, developing limonite crusts on deep weathering.	0.23
Soft brown very fine-grained sandstone.	0.05

metres

Stainby Member

Weathered blue and brownish shale, with thin fine sandstone streaks and vertical carbonised plants. 0.41

Dark blue fairly pure shale, only minor streaking with fine-grained sand. sand and silt; some vertical plants. Scattered small shells in the lower part with occasional rich shelly streaks near the base. *Lingula* locally common near the base. (PEK/506). 0.71

- passage -

Twin sandy mudstones - two persistent beds of hard flaser-bedded sandy mudstone, tough, difficult to break or split. Carbonised vertical plants. Many shells, mostly in streaks, *Trigonia* common, large *Pholadomya*, pectinids. Streaks full of "*Corbula*" in the lower part (PEK/507). 0.20

- passage -

Dark grey shale with scattered nodules at the base. Scattered iridescent shells (PEK/508), particularly in sandy laminae close to the base. about 0.10

- irregular junction -

Pale faintly purplish fine-grained sandstone, abundant vertical plants and carbonaceous streaks, patchily stained chocolate-brown. Locally with numerous 15 cm septarian ironstone nodules, the veins being of white chalky material (kaolin ?). 0.61

Northampton Ironstone, up to 2.0 m.

12. STAINBY WARREN

The face is located north-east of Gunby village, and the section was measured at the north-west end of the workings. (SK 163221, 8th November 1969).

Lincolnshire Limestone. 3.5 m.

- irregular junction -

Grantham Formation. 4.14 m.

Dull grey silty shale, 10 cm, passing down into ferruginous shale with ironstone layers and nodules; grey shale bands occur near the base. 0.36

Rich brown ferruginous sand with some ironstone nodules. 0.38

Brownish-grey clayey sand, irregular base. 0.23

Yellow brown sand becoming clayey downwards, with abundant vertical rootlets which penetrate into the bed below. 0.25

Brown-grey clayey sand, greyer when fresh. 0.20

Stainby Member

Laminated brown and grey silty and sandy shale, fining downwards 0.84

- transition -

metres

Dark grey shale; blue grey with pale silty and sandy streaks, rich shelly layers. In the upper and middle parts, *Corbula* in great abundance; also *Protocardium*, *Aviculopecten*, *Modiolus*. Close to the base, there is a layer of large single shells, especially *Pholadomya* and Trigonids; lignitic lenticles occur in the middle part. There are white sand filled rootlet holes.	0.36

- sharp clean junction -

Grey sand (top only exposed) and obscure interval estimated at	1.52

Northampton Ironstone 3.0 m.

13. MARKET OVERTON Cottesmore No. 6 Mine, SK 896179.

The section recorded is east of the ramp down to the ironstone level and was measured on the 22nd May 1971.

Lincolnshire Limestone 3.3 m.

Grantham Formation. 5.40

Whitish and light brown streaky slightly ferruginous fine-grained sand.	0.18
Two thin beds of dark sandy shale, ferruginous.	0.02
Rich brown ferruginous fine-medium-grained sand with red-brown irony surfaces.	0.66
Gradation into very ferruginous sandy shale and grey shale.	0.08

Stainby Member

Dark, pale weathering, very sandy shale and lignitic sandstone alternation, with 100 mm white sand lens near the top, varying from predominantly finely current bedded fine-grain sand with shaly lenses above to dark grey shale banded with white silt below. Bivalves present in the lowest third, particularly abundant in shale/sand alternations of the basal 5 cm. *Lingula* occurs 10 - 20 cm above the base. Bivalves include *Trigonia* spp. (abundant), *Modiolus*, *Lopha*, (small spp.), *Inoceramus* (rare) *Ostraea*, *Pholadomya* (rare) Pectinids (*Chlamys* etc.) *Protocardium* (common). One small coral (*Anabacia* ?). Pyrite can be found throughout and some of the shells are pyritised. Large pieces of pyritised lignite (5x15 cm) are common near the base. (PEK/460).	0.86
Dull purplish grey silty clay which has acted as a slide plane with 'vertical' plant rootlets now disposed obliquely.	0.13
Dull purplish grey muddy sandstone, fine-grained, with abundant dark vertical rootlets.	0.61
Pale weathering grey sand with vertical rootlets.	0.91
Pale grey sandy mudstone (low weathering).	0.51
Yellow sand, medium-grained, kaolinitic, patchily ferruginous with a 200 mm yellow and reddish oolitic ironstone bed near the middle and irregular box-stone ironstone in the lower half.	1.45

Northampton Ironstone 2.5 m seen.

14. EXTON, Rutland.

Exton Park Mine, formerly United Steel Co. The section measured is at the western end of the main face, SK 930108 (approx.) recorded on the 24th June 1972. This locality is only 8 km south-south-east of the richly fossiliferous 'Lower Estuarine' of Market Overton, but none of the sections inspected yielded mollusca.

		metres
Lincolnshire Limestone, about 6 m.		
Grantham Formation. 4.28 m.		
Deep yellow-brown very ferruginous soft clayey sand (very fine-grained), with irregular lumpy development of yellow brown ironstone.		0.76
- sharp junction -		
Three persistent beds of dull grey shale with partings of light brown fine ferruginous soft sandstone (possible equivalent of the Stainby Shale Member)		0.33
Pale weathering buff fine-grained soft sandstone, penetrated by vertical rootlets from the upper surface.		0.18
Fine-grained soft sandstone, slightly ferruginous, weathering brown in 250 - 350 mm units separated by thin shaly partings. Sandstone units with cross-bedding which dips eastwards at 25-30°. Minor shale wisps on the lower cross-bed surfaces.		0.96
- transitional junction -		
Light brown shaley clay, with brown ferruginous sandstone intervals (irregularly lenticular).		0.51
Light grey harder sandy mudstone (mud-supported sand grains, very fine-grained) with wisps of darker shaly clay, lignitic, near the base.		0.53
"Gingerbread-brown" richly ferruginous sandstone, locally developing ironstone box structures, seen to		0.31
Obscure interval	about	0.60
Northampton Ironstone, about 2.4 m.		

15. HARRINGWORTH, Northants.

Section in the West Quarry, SP 920966, measured on the 19th May 1971.

Lincolnshire Limestone about 15 m.	
Grantham Formation. 3.66 m.	
Brown ferruginous shaly clay, with 1 cm. brown vertical plant casts which pass down (attenuated) into the bed below.	0.25
Medium blue finely banded silty clay. Laminae 0.5-2.0 mm of pale silt in dark blue clay, lignitic. There are dark vertical rootlets but no trace of marine fauna, either mollusca or problematica.	0.43
Pale grey silt, finely sandy, speckled with lignite; vertical rootlets.	0.23
- sharp line -	

	metres
Dark blue plastic clay, highly lignitic at the base.	0.38
Dull yellowish silty clay.	0.28
Silver-grey silt, blocky, slightly sandy.	0.10
Mottled yellow and grey pale clay with vertical plants.	0.46
Light-medium grey blocky silty clay, unbedded.	0.61
Medium grey tough silty clay, very poorly fissile, with fragments of lignite and very abundant plant fragments (nearly all "grass-shaped" leaves and stems), faint lavender purplish tinge. (PEK/461).	0.91
Very lignitic coaly shaly clay, ferruginous, apparently pocketed into the bed beneath.	0.08

Northampton Ironstone over 2 m.

16. RUSHTON, near Desborough.

Section at the western end of the face, SP 85.83, measured 1970.

Boulder Clay, chalky, 3.0 m.

Lincolnshire Limestone 6.0 m.

Grantham Formation. 8.30 m.

Soft brown ferruginous sand, partly with clayey matrix.	2.44
Pale khaki and ferruginous shale and sand.	0.05
Dark blue grey shale	0.61
- sharp flat junction -	
Dull grey unbedded sandstone, locally pyritic, with shaly intercalations near the top, wispy with white silt below. Black rootlets extending down from the overlying shale.	0.36
Medium dark/black shale and shaly sandstone, tough, hard, pyritic, very lignitic with large pieces of wood; variably sandy, white rootlets.	0.86
Grey well-bedded "zebra rock" - streaked dark shale and white sandstone. Vertical roots.	0.46
Pale lead-grey plastic clay with rootlets.	0.31
Dull purplish sands, ferruginous, clayey.	0.90
Main rootlet bed - white sand and sandstone, holes filled with purplish sands above.	0.46
White sands with horizontal streaks.	1.36
Fairly hard brown ferruginous sandstone.	0.43

Northampton Ironstone. 1.5 m seen.

17. TINWELL. Stamford.

The section, measured on the 24th November 1973, is in the lower part of a major water transfer pipe trench, TF 016061

		metres
Lincolnshire Limestone	1.7 m.	
(with the basal Collyweston Slate development)		
- sharply undulating contact developed by concretionary growth. Level stratification across the contact -		
Unclassified (probably basal Lincolnshire Limestone equivalent)		
Dull brown drab, very fine-grained uniform sand, (about 125 mm) slightly "mealy", with level faintly marked bedding, local sharp fine lamination indicated by carbonaceous films. Ferruginous ochreous layer at the base.		1.20
- Undulating contact, partly stratigraphical, partly due to cambering effect -		
Grantham Formation	0.73 m.	
Dark grey poorly-bedded carbonaceous clay.		0.05
Pale grey clay-bound fine sand (grade 150 - 200 microns) crowded with plant traces.		0.33
Deep yellow-brown ironstone and ferruginous fine-medium-grained sand. (mixed grade 100 - 250 microns.)		0.20
Pale grey clay, slightly mauve tinged, more usually light bluish, with vertical carbonised plant traces; weathering to a plastic clay.		0.10
White sand, ferruginous, above		0.05
Northampton Ironstone	4.50 m.	
Upper Lias	seen to 1.0 m.	

The Fenland Sections

The five detailed sections which follow are based on cores notified by Dr. J. A. D. Dickson and three of them use his lithological description. They are described in order from north-west to south-east from Branston Moor, near Lincoln, by way of Asgarby and Great Hale near Sleaford, and Pickworth, east of Grantham, to Bicker, south-west of Boston.

Very few other cored borehole sections are available in this area, since most water borings end in the Lincolnshire Limestone, and oil borings were not cored at this level. Three British Petroleum Company / British Gas borings in the Fenland are, however, relevant. In the Bardney No. 2, south-east of Lincoln (TF 1191, 6861) the Grantham Formation was 4.0 m thick, recorded as dark grey-green silty mudstone, grey to dark grey, pyritic fine to medium grained sandstone. Ruskington No. 1 near Sleaford (TF 0921, 4974) was logged as penetrating 7.0 m of dark grey sandy clay, blue grey sandy and white sandstone and medium grey clay. Helpringham No. 1 (TF 1753, 3884) was more like nearby Bicker (see below) with 7.5 m of grey sandy calcareous shale interbedded with white shaly sandstone. These records have the limitation of being compiled from cuttings only and the chances of any recognisable shells surviving were very small but they tend to show that the core hole sections are characteristic in thickness and lithology for the general area.

18. <u>BRANSTON MOOR</u> borehole.

About 8 km east-south-east of Lincoln. TF 0567,6767. Summary of the section by J. A. D. Dickson.

Lincolnshire Limestone base at 68.0 m. (depth from the surface)

Grantham Formation 2.8 m.

	metres
Very hard laminated sandstone (part of the core lost)	0.80
Sandy shales and sideritic mudstone, including dark laminated shale.	0.40
Mudstone with grit horizon; pebbles (including quartz) in the lower part.	0.40
Bioturbated micaceous clayey very fine-grained sandstone with pebbly base.	1.20

Upper Lias at 71.0 m. (top)

This section, in line with those of the northerly outcrops, lacks any distinctive median shale or recognisable marine unit. It is of interest in showing the incoming of the Grantham Formation eastwards from the Lincoln - Nocton area (a deeply buried Palaeozoic high) where the Lincolnshire Limestone rests directly on the Northampton Ironstone.

19. ASGARBY bore-hole.

4.8 km east-north-east of Sleaford, TF 146467. Lithology, summary by J. A. D. Dickson.

Lincolnshire Limestone base at 133.05 m. (depth from the surface.)

Grantham Formation 2.02 m. proved.

Bioturbated sandstone, core fragmented (? soft sand)	0.64
Stainby Member	
Dark grey to black fissile shale, slightly micaceous, with well preserved *Lingula* at 133.90 m.	0.24
Dark finely laminated shale and sand, with leaf fragments in the upper part, unidentifiable shell fragments and ostracods common below.	0.20
Soft sandstone with rootlets	0.32
Lensing sandy layers with black shale partings; rootlets.	0.62

\- lower core lost -

The section provides the northernmost record of the Stainby Member, with marine fossils, although the equivalent may well be represented by weathered shale at Leadenham and Ancaster in which fossils have not yet been found.

20. GREAT HALE bore hole.

9.6 km east-south-east of Sleaford, TF 168433. Lithology described by J. A. D. Dickson.

Lincolnshire Limestone, base 112.54 m. (depth from the surface)

Grantham Formation about 1.5 m proved.

Contorted sands.	0.07

	metres
Stainby Member	
Dark shale, with sand-filled desiccation cracks, above laminated, fissile shale and fine silty partings with *Lingula* sp.	0.23
Hard contorted sand, regularly laminated below.	0.23
Soft micaceous sand.	0.06
Sands and clays, burrowed.	0.13
Laminated siltstones with rootlets	1.65

- core lost, about 1 m. -

21. PICKWORTH bore-hole

12.8 km. east of Grantham, TF 0434,3375.

Lincolnshire Limestone, base 39.9 m, (depth from the surface)

Grantham Formation 0.38 m.

Dull grey sandy clay with clayey sand.	0.38

Northampton Ironstone ? about 2.0 m.

Sandstone and chamositic clay with red ironstone concretions.	0.17
Green slickensided clay, bright green above, duller below, with rootlets.	0.10
Greenish grey clay with pebbles and concretions of limestone etc.	0.07
Conglomerate of reddish ironstone pebbles (up to 6 cm. diam.) and grey limestone, in clayey matrix.	0.25

Upper Lias (top) 1.5 m. penetrated.

This section is in the area of attenuated Grantham Formation and is close to the easterly limit of the Northampton Ironstone as defined by ore borings. The conglomerate facies of much of it suggests a shoreline development of the Ironstone. Alternatively, the beds might be regarded as essentially a basal conglomerate of transgressive "Estuarine" facies but no conglomeratic base is known elsewhere. The section contrasts with that of the Colsterworth - Leadenham area in lacking the usually persistent Stainby Member.

22. BICKER bore-hole.

9.6 km south-west of Boston, TF 247383. Logged by P. E. K.

Lincolnshire Limestone base at 133.40 m. depth from the surface.

Grantham Formation. 4.40 m.

Fine white sandstone, bioturbated, with carbonaceous streaks, softer below.	0.20
Fine sandstone grading down into silty shale.	0.06
Stainby Member	
Fissile laminated interbeds of very fine-grained white sand and dark silty shale. Well preserved small mollusca, including cerithoid gastopods, *Pterinopecten* juv., *Protocardium.*	0.10

	metres
Markedly banded dark shale with thin pale silty bands. Small *Nuculana sp.* in floods covering bedding planes; rare *Lingula* sp.	0.10
Very fine-grained sandstone and siltstone, pale grey, and mudstone.	0.20
Moderately well bedded bioturbated dull grey fine sandstone.	0.12
Dark shale with white-sand-filled borings, irregularly slickensided. Passes down into sandy mudstone.	0.21
Highly pyritic irregular mixture of medium-grained white sandstone and grey mudstone. Pyritised *Chondrites*.	0.03
Dull grey mudstone and waxy clay, greenish, almost fire clay type. Slickensided. Borings as above.	1.20
- core disintegrated in the lower part -	
Harder grey sandstone and mudstone.	0.15
Soft dark mudstone.	0.09
Well banded pale grey siltstone with ironstone concretions.	0.41

Upper Lias (top) penetrated to 0.14 m.

This is the most easterly cored section of the Middle Jurassic in Lincolnshire; in fact, the most easterly cored section south of Spurn Head. It is of particular interest to see that the marine element in the Grantham Formation is maintained if not increased - the replacement of floods of "*Corbula*" by equally abundant *Nuculana* suggests more open sea conditions and the mollusca extend through a somewhat greater thickness than is usual at outcrop. On the other hand, the larger lamellibranchs (Trigoniacea), *Pinna*, *Pholadomya*, *Modiolus*, etc.) are missing. The latter include bottom living species and the difference could be symptomatic of deeper water in the east. The section is also notable for the development of a second marine or near-marine unit (indicated by *Chondrites*) near the base of the "Estuarine".

Acknowledgements

The writer is greatly indebted to Dr. J. A. D. Dickson, of Nottingham University, for arranging access to the Fenland water borings and his records on the 'Lower Estuarine Beds' there, and for critical reading of the typescript; also to the British Petroleum Co. Ltd., and British Gas for quotations of the sections in three other Fenland borings. Dr. L.R. M. Cocks of the British Museum assisted by identifying the lingulids from Colsterworth.

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EXCURSION TO THE MENDIPS AND QUANTOCK HILLS

Leader: P. J. Hill 10th - 12 May 1974

Friday evening The base for the excursion was at Weston-super-Mare, approximately 30 members arriving at the headquarters hotel at various times during the evening. After dinner, the leader gave an introductory talk on the geology of the area and outlined the itinerary for the weekend.

Saturday The sunny weather of the previous day had moved elsewhere and the party was greeted by heavy, overcast skies. The route lay southwards along the A38 over the Somerset Levels to Bridgewater, thence westwards along the A39 to Cannington. Here, an inlier of Carboniferous Limestone projects through the Trias cover (text-fig. 1). It is the most westerly of the inliers in the region and it has been suggested that the Carboniferous rocks were overthrust by Devonian strata and that the Cannington Inlier owes its presence to faulting which brought the underthrust mass to the surface. The party entered an actively worked quarry north of the village (ST 251403) and spent some time examining the limestone and associated features. Extensive mineralisation occurs at this locality, barite being particularly well represented. Excellent specimens of barite, together with associated malachite and azurite, were obtained from unwanted tip material. Fortunate members of the party were able to collect large specimens of the azurite in the newly developed north-east part of the quarry.

The party then rejoined the A39 and proceeded west approaching the Devonian inlier which forms the Quantock Hills. This structure is a pitching anticline, the axis of which runs northwest-southeast and plunges in a southerly direction. The next locality was at Quantockshead Quarry where the Lower Devonian, Hangman Grits were examined. These consist of fine-grained compact grits, purple, brown and red in colour, and pebbly in places interbedded with mudstone. Fossils are rare although plant fossils may be obtained along some of the flaggy bedding planes. Lunch was taken at the hostelry conveniently adjacent to the quarry.

The afternoon was spent in St. Audries Bay (ST 1043) examining the cliff section which exposes Keuper, Rhaetic and Lower Jurassic strata. The traverse started at the base of the steps leading down to the bay, where some 110 feet of westerly dipping Grey and Tea-Green Keuper Marls are exposed in the cliffs to the west of the steps. Numerous small faults displace the strata. The party proceeded in a westerly direction ascending the succession and examining the various horizons shown below.

Upper Triassic and Lower Jurassic

West Somerset Coast

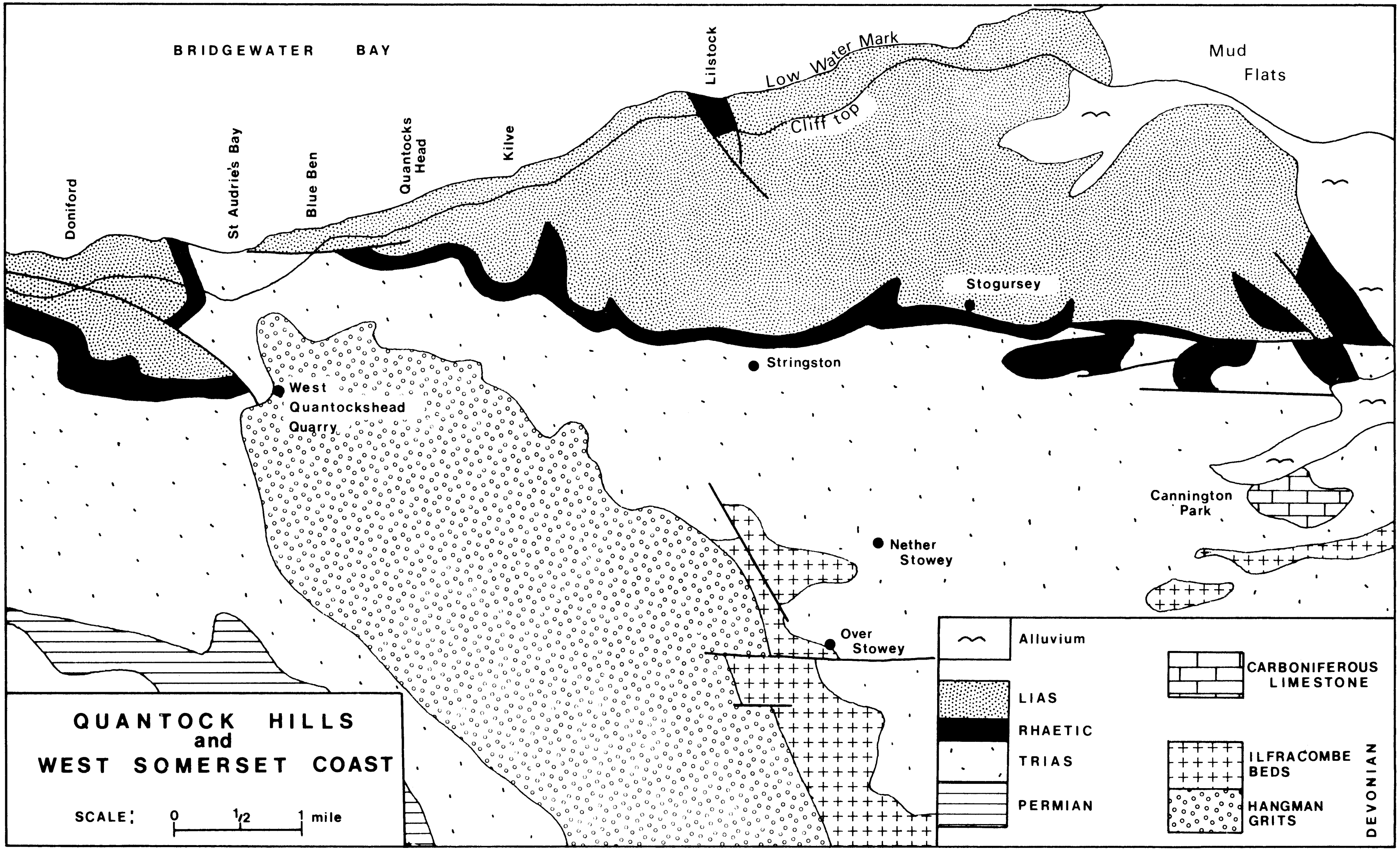
LOWER JURASSIC

Blue Lias

Arnioceras semicostatum zone

12. Dark grey shaly marls with thick bands of argillaceous limestone, and, near the base, a conspicuous band of paper-shales. Seen in the cliff above the cave east of Kilve Pill, by Kilve Farm and westwards to Quantockshead; also near Donniford Kiln. Large ammonites, *A. semicostatum Caenisites turneri*; *Cardinia*, *Pentacrinus*. (Not exposed in St. Audries Bay) 45 ft

Mercian Geol. Vol. 5, No. 4, 1975
pp. 329-334, 2 text-figs.



Text-fig. 1. Geology of the Quantock Hills and W. Somerset Coast.

Arietites bucklandi zone

11. Alternations of grey limestones, sometimes in thin bands, with shales and shaly marls, but merging into a more prominent mass of blue limestones with shaly marls. Seen west of Lilstock, by cave east of Kilve Pill, at base of cliffs by gangway near Kilve Farm, and thence to Quantockshead. (Not exposed in St. Audries Bay). 25 ft.

10. Alternate bands of thin blue and yellow (iron-stained) limestones, 25 or more in number, with blue and sometimes brown shaly marls. The limestones being jointed and standing out irregularly, present a zig-zag appearance amongst the clays. Seen in cliffs west of Lilstock, at base of Quantockshead, and in upper part of St. Audries. *A. bucklandi*, *Nautilus*, *Pleurotomaria*, *Gryphaea*, *Lima gigantea*, *Calcirhynchia calcaria*, *Pentacrinus*. 40 ft.

Schlotheimia angulata zone

9. Dark grey shale and grey marl with only occasional bands of limestone. Base of cliffs between Lilstock and Kilve Pill, and St. Audries Bay. *S. angulata*. 35 ft.

Psiloceras planorbis zone

8. Shaly marls, dark shales and bands of limestone. *P. planorbis*, *Caloceras johnstoni*, *Ostrea liassica*, *Modiolus minimus*. East of Lilstock, and St. Audries Bay. 20 ft.

UPPER TRIAS (RHAETIC)

Watchet Beds

7. Yellow-brown and grey shales with a rubbly limestone about the middle. *Ostrea Liassica*, *Modiolus langportensis*. 5 ft.

White Lias

6. Bluish-grey and cream calcite mudstone, with thin shale partings. *Modiolus*, *Lima valoniensis*, *Protocardia*. 4 ft.

Cotham Beds

5. Pale marls with thin limestones; ostracods, fish-remains. 7 ft.

Westbury Beds (Contorta Shales)

4. Dark fossiliferous shale with "beef" and thin, earthy limestones. *Pteria contorta*, *Protocardia rhaetica*, *Chlamys valoniensis*, *Dimyodon intus-striatus*. *Cardium cloacinum*. Bed 6 ft. from top, *Pleurophorus* Bed (*P. elongatus*) 14 ft. below that, Upper Bone Bed (fish, rolled bones, coprolites, quartz pebbles) 10 ft. above base, and Basal Bone Bed. (Bone beds not well represented) 33 ft.

Sully Beds

3. Grey silts ("marls") with impressions of *Pteria contorta* and other bivalves. 8 ft.

KEUPER

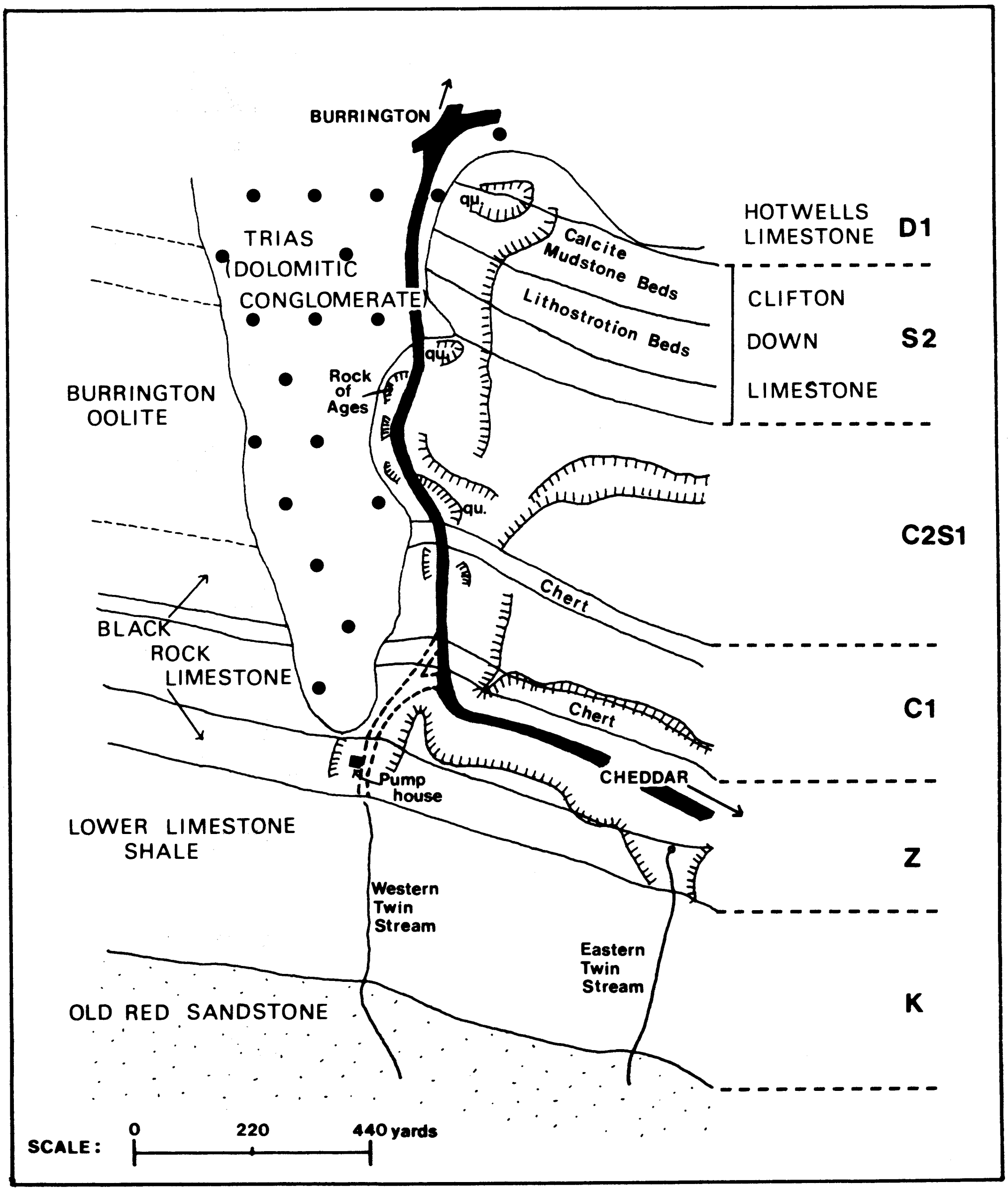
Grey and Tea-Green Marls

2. Grey silts with layers of gypsum, greenish towards base. 110 ft.

Red Marls

1. Red and variegated silts

Sunday The party set out on a reasonably bright morning and travelled east towards Burrington. Turning south near the village the deep, dry valley of Burrington Coombe



Text-fig. 2. Geological Map of Burrington Coombe

(ST 4758, text-fig. 2) was reached which cuts across the limestone ridge. The coombe is situated on the most northerly of the periclines (Black Down Pericline) which form the Western Mendips. The core of the anticline is formed of Old Red Sandstone, the limbs of Carboniferous Limestone. Members cars were parked near the base of the coombe in an unused quarry adjacent to the road, just below the 'Rock of Ages'. From this point, the party walked up the road, turning right, off the road, after about 500 yards, to reach the pump house and thence up the Western Twin Stream to the junction of the Old Red Sandstone and Lower Limestone Shale. The Devonian-Carboniferous junction here is transitional. Red, sandstones give way to alternating sandstone-shale horizons before the Limestone Shales are reached. The Carboniferous succession was examined in ascending order as shown below.

Section of Strata at Burrington Coombe

TRIAS	Dolomitic Conglomerate	
	Great Unconformity	
LOWER CARBONIFEROUS (DINANTIAN)		
VISEAN	Hotwells Limestone	
	D_1 zone:- 80 feet	fine-grained and crystalling grey limestone, *Dibunophyllum*, *Cyathophyllum*, *Productus hemisphericus*.
	Clifton Down Limestone	(d) thin bedded compact limestone 'china stone' and oolitic limestone.
	S_2 zone:- 540 feet	(c) fine-grained limestone, "*Seminula*" bands.
		(d) fine-grained limestone, *Lithostrotion* bands.
		(a) Oolitic grey limestone.
		Lithostrotion, *Carcinophyllum*, *Productus corrugato-hemisphericus*, *Chonetes*, "*Seminula*", *Cyrtina carbonaria*.
	Burrington Oolite	
	S_1 zone:- 130 feet	extends from quarry to Rock of Ages. Thin bedded oolitic limestones with shaly partings. Partly dolomitised. *Lithostrotion*, *Productus*, *Athyris*.
	C_2 zone:- 320 feet	Massive oolitic and foraminiferal limestones. *Michelinia*, *Productus corrugatus*, *Euomphalus*.
TOURNAISIAN	Black Rock Limestone	
	C_1 zone:- 740 feet	(b) dolomitised limestone 240 feet,
		(c) crinoidal limestone 350 feet cherty fossiliferous limestone 250 ft. *Caninia*, *Cyathophyllum*, *Productus pustulosus*, *Chonetes*, *Syringothyris cuspida*, *Spirifer*.
	Z_2 zone:- 140 feet	shelly limestones, shale partings. *Michelina*, *Zaphrentites*, *Caninia*, *Syringothyris*.
	Z_1 zone:- 140 feet	shelly limestones, shale partings. *Zaphrentites*, *Spirifer*, *Athyris*.
	Lower Limestone shales	
	K zone:- 500 feet	(2) narrow beds of crinoidal limestone, shale partings.
		(1) shales with thin limestones 'Bryozoa Bed' grit band at base.
		Spirifer, *Camarotoechia*, *Zaphrentites*.

With lunch-time rapidly approaching, the party then drove in an east-south-easterly direction to Radstock, stopping on the way for suitable refreshment. The first stop of the afternoon was at Kilmersdon, (ST 681537) just outside Radstock, where, on a coal tip from the nearby colliery, abundant plant fossils in Coal Measures rocks are to be found.

With time becoming limited, members next drove from Radstock along the A362 in the direction of Frome. About one mile past Buckland Dinham, a small road to the right brought the party to the entrance of the cement works at Vallis Vale. Walking through the works, the southern end of the vale was reached (ST 756492) where some 20 feet of Doulting Stone (Upper Inferior Oolite, Middle Jurassic) rests with strong angular unconformity on the underlying Carboniferous Limestone. The smooth, eroded junction between the two Formations is covered with flat oysters and bored by molluscs and annelid worms. The locality is designated as an SSSI and should be treated accordingly by all visitors. It was noted by the party however, that some infilling of the quarry with waste material had occurred though not at that time, to an extent which would mar its geological value. It is to be hoped that this situation subsequently has not been allowed to deteriorate.

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EXCURSION TO EARL STERNDALE AREA

Leader: N. Aitkenhead. 15th September 1974.

Because an account of a similar excursion has appeared recently elsewhere (Aitkenhead *et al.* 1974), this account is summarised. The following localities were visited and geological features seen by the party:

1. Jericho Quarry (0899 6748).

Pale thick-bedded calcarenites of the Bee Low Limestones, shelf limestones of the D_1 Zone (Lower Carboniferous) showing a band containing a few *Lithostrotion* colonies and brachiopods including *Davidsonina septosa*.

2. Dowel Dale (0759 6771)

B_2 Zone algal reef of Wolfenden (1958), forming crags on either side of the dale and passing southwards into fore-reef limestones with a rich and varied fauna of brachiopods.

3. Near Dowel Farm (0754 6751)

Fore-reef limestones as above in crags forming south-facing dip slope with overlapping Namurian shales seen in a small exposure under a tree near the foot of the crags.

4. South-west of Dowel Farm (0734 6747).

Pale limestones, possibly of fore-reef facies, rich in Canininoid corals.

5. At (0720 6741)

Conglomerate of well-worn shell debris in the back-reef.

6. Fault breccia at the foot of the north face of Chrome Hill (0712 6738) with galena-fluorite-calcite mineralization; and a fault plane covered with galena crystals nearby at (0725 6732).

7. South side of Chrome Hill at (0719 6706)

Limestone containing abundant gigantoproductoids resting on fore-reef micritic limestones which nearby show discordant bedding structures suggesting penecontemporaneous brecciation.

8. Summit of Chrome Hill (07086732) with fine views of the spectacular scenery formed by the limestone of the B_2 apron reef complex and the escarpments of the Longnor Sandstones (R_{1c} Zone of the Namurian) overlooking the upper Dove valley and also forming an outlying hill on the limestones north of Chrome Hill.

9. At (0705 6750).

Dark bituminous-smelling cherty limestones of D_2 age on the rim of a sink hole at the edge of the Namurian outlier of shale overlain by Longnor Sandstones to the north of Chrome Hill.

Conservation note: All readers who may use this itinerary to visit the area are asked to conserve the exposures listed above by refraining from hammering them and collecting only from loose pieces.

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PLEISTOCENE DEPOSITS IN LINCOLNSHIRE

Leader: D.N. Robinson 6th October 1974

The relatively soft deposits of the Pleistocene seldom command the attention of geologists in the same way as the hard stuff, of say, the Silurian. This excursion was an attempt to redress the balance and to demonstrate the form and content of boulder clay and outwash gravels. The excursion started at Tattershall and then moved to Low Toynton, lunched at Tetford and crossed the glaciated landscape of east Lincolnshire to Huttoft Bank. However, for Pleistocene chronological convenience, reference is first made to the Low Toynton exposure.

The Penultimate Glaciation (Saale) lasted about 60,000 years. At its maximum, all Lincolnshire, except the highest parts of the Wolds, was covered by ice, which streamed south over the Wolds and through the Bain gap in the chalk scarp incorporating much chalk and flint. The resulting deposition was the intensely chalky Calcethorpe Till which plastered the Lower Cretaceous platform to the south and south-west of the Wolds, and extends south beyond Horncastle. This is rarely seen at the surface, but the River Waring, a left bank tributary of the Bain, re-excavated its valley in this Till and near Low Toynton (TF 268710) has created a minor gorge feature exposing small cliffs of the Till. These were adequate to demonstrate the hard creamy-white nature of the deposit with numerous broken flints.

During the Last Glaciation (Weischel), from 75,000 to 25,000 BP, the ice covered eastern Lincolnshire up to the Wolds. The main advance of the ice reached its peak about 70,000 BP and plugged both the Humber and Wash gaps. This ice originated from Scotland, northern England and Scandinavia. The plugging of the gaps caused the impounding of a vast lake in the Fens, central Lincolnshire and lower Trent valley, its surface at about 100 feet O.D. The main drainage of the Wolds, a tundra island surrounded by ice and water, was by the Bain and Lymn systems. The Bain created a vast delta of flinty gravels, patches of fine gravel and sand and small patches of clays (accumulating in delta pools) which spread south from Horncastle across Kirkby Moor towards and beyond Tattershall and Coningsby into what is now Wildmore Fen. Remains of mammals such as mammoth, deer and woolly rhinoceros trapped on the island are found in considerable quantities in the delta gravels near Coningsby and Tattershall. One of the pits of the Castle Gravel Co., Tattershall (TF 208566) has organic lenses dated at c.45,000 BP, with an assemblage of insects and molluscs associated with an apparently treeless landscape. Excavations here are also down to the Kimmeridge Clay which provided an easy collecting ground including good ammonite fragments preserved in nodules. The attitude of the gravels was examined and a number of mammal bones and antlers were collected.

When the Weischel ice eventually melted, it left behind east of the Wolds a thick accumulation of reddish-brown and purplish-brown clay mixed with gravel and boulders - the Marsh Tills. It was spread in an uneven sheet some 80 feet thick over the underlying chalk platform up to the edge of the Wolds and is the foundation upon which the Marshland subsequently developed.

At the opening of the Post-Glacial period the level of east Lincolnshire stood much higher than it is now and the floor of the adjoining portion of the North Sea was dry land. The forest growing on the Boulder Clay was largely of pine and birch (with some oak later), a combination which reflects the cold conditions existing in Britain about 9500 BP. At the beginning of the Neolithic period the level of the land began to sink slowly. This resulted in a slowing down of rivers and streams and a consequent decline in the efficiency of the natural drainage. At the same time the climate became more warm and moist. These two influences together led to the growth of peat bogs which smothered the roots of the trees and caused the forests to perish. Analysis of the pollen content of the peat shows that the woodland then was made up largely of alder with some oak and lime and an occasional pine

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or birch. The peat dates from somewhere between 7000 and 4000 BP. This peat enclosing the stumps and trunks of trees which it filled forms the Submerged Forest. Subsequent deposits are 6 - 8 feet of buttery saltmarsh clay, freshwater clay and a thin layer of peat of Iron Age date, followed by layers of mud and silt which form the flat Outmarsh.

There was an offshore barrier of low morainic hills extending from Holderness to Norfolk which afforded some protection to the developing coast as the sea level rose in post-Roman times. The final breaching and destruction of the offshore barrier in the stormy 12th and 13th centuries resulted in the establishment of the dune system of the Lincolnshire coast. In the centuries since then, along the coast between Mablethorpe and Skegness, the waves have relentlessly worn away the fringe of the Outmarsh and cut back its margin to its present position. There are few historical records of damage at Huttoft which suggests that erosion has not been serious there. The survival of the Sea Bank (erroneously called 'Roman' - it is a piecemeal medieval construction) in that area and the substantial parish church (albeit with a brick 18th century chancel) support this conclusion. The coastline is still sinking relative to sea level, very slowly at about a foot a century.

The present beach form consists of a series of sand ridges at a slight angle to the coast with southward trending runnels between. It is in these runnels that the upper Marsh Till, Submerged Forest and Peat are from time to time exposed, as at Huttoft Bank (TF 542786). This exposure submits them to wave erosion. Within the last 30 or 40 years there have been an increasing number of artificial sea defences constructed along the coast and these have resulted in increased scour on the beach and thus the removal of the more spectacular remains of the Submerged Forest. Usually it can best be seen at low Spring Tides but even so the size of stumps seen in the 1920s and 1930s are seldom evident. On the occasion of the E.M.G.S. excursion sufficient of the deposits were exposed to allow examination.

Erosion of the Boulder Clay in particular has released the gravel, stones and boulders embedded in it. These are now spread over the foreshore as a beach deposit. A collection and study of the stones can be most rewarding as they show an almost infinite variety and give a clear indication of the origin and line of travel of the ice from Scotland, the northern Pennines, the north-east coast of England and from Scandinavia. Despite increasingly adverse weather conditions an interesting assemblage of erratic material was collected by members including Scottish granites and metamorphics, Carboniferous sandstones, Jurassic limestone, the Scandinavian rhomb porphory and occasional worked flints.

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REVIEW

FRED BROOK and MARTIN ALLBUTT 1973: *The Shropshire lead mines*. Hartington, Derbyshire: Moorland Publishing Co., 92+2 unnum.pp., 20 pls., 21 text-figs. £1.80.

The heyday of the Shropshire lead mines coincided with that of the Derbyshire mines - the late 19th Century - and their decline, like that of the Peak mines, was a consequence of increasing availability of cheaper foreign ores. In other respects, however, their history was quite different. Both areas were worked by the Romans, but after their departure the Shropshire ores were left unworked for almost fourteen centuries, whereas the Peak mines never really ceased to be worked. The history of Derbyshire lead mining thus spans 2,000 years, the Peak developing a unique community of free miners whose character is still evident in the whole landscape. That of the Shropshire mines spans only about 150 years; its influence on the landscape has been much less profound and the very fact that west Shropshire was once an important lead-producing area is already almost forgotten.

The mines of Shropshire were concentrated into the two NNE - SSW lines outcrops of the Mytton Beds (Ordovician flags and grits). These outcrops are brought to the surface by major faults and intersected by other faults; the veins generally have a southwest to northeast trend, but the geology varies greatly from mine to mine, occasioning many problems in prediction and exploitation to the mining companies. Mining recommenced in the mid-eighteenth century, on the Grit sett (local term for a mining property) in the western outcrops; development of the rich Snailbeach mines on the eastern outcrop and of many other mines, soon followed. Initially the mines were shallow, with water raised to the surface in barrels by horse-power. However, as drainage problems became more serious, it became necessary to construct drainage adits and eventually steam engines were used to pump the mines dry.

The area suffered a recession, brought about by falling prices, around 1835 and lead exploitation virtually ceased. It recovered in the early 1850's, however, and Cornish miners were brought in to develop the field; in consequence, the mine architecture became typically Cornish, with its high-chimneyed engine houses, and quite different in character from the mine buildings of the Peak. A second recession swiftly followed, brought to an end by the discovery of rich ore deposits at Tankerville and Roman Gravels. Production reached a peak in the 1870's. After that, declining lead prices made mining in Shropshire progressively less economic; by 1895, only the Snailbeach mine remained in operation and it too closed, its deposits virtually exhausted, in 1911. Thus, although a little "scratch" mining for lead by one or two men has occurred subsequently and although gangue minerals (especially barite) have been won from the tips, lead mining in Shropshire effectively ended over 60 years ago. The tips are growing over now, the mine buildings falling into ruin, and the last of the miners, some of them sufferers from the silicosis from which the Peak mines were free, fading away.

To rescue a part of the heritage so rapidly being lost, the Shropshire Mining Club was formed a decade ago; and now we have this book, the first full account of the Shropshire mines. This area was visited by the East Midlands Geological Society in 1969 (see *Mercian Geologist* vol.3, p.291); and many members will recall the immediacy of some of the mining remains, like the kibble at Snailbeach still full of crushed lead ore and the tipper trucks left by the tracks to rust into oblivion.

Accounts are presented of the history of each mine; and the overall history and productivity of the ores are briefly surveyed, plans and illustrations supplementing the text. The geology of the area is only discussed cursorily, however, and nothing is said about the mineralogy of the mines, interesting though this is. It serves as a good handbook to the area, therefore, but the geological visitor will require other texts to understand fully what he is seeing.

William A. S. Sarjeant.

REVIEW

Dictionary of Geology

Challinor J., 1967, 3rd edition, 298 pages, boards, University of Wales Press, Cardiff. Price (September 1975) £2.50.

Whitten D. G. A. and Brooks J. R. V. 1972 (Reprinted 1974) 500 pages approx., appendix bibliography, illustrated, paperback, Penguin Books, Harmondsworth, Middlesex, Price (1975) £0.75p.

For many years, Challinor's *Dictionary of Geology* has been a standard reference work for the meaning and spelling of geological terms. It has now been joined by a Penguin *Dictionary of Geology*, very attractive for students of geology if only that the price is about $\frac{1}{3}$rd that of the former. The Penguin dictionary is a paper-back, size 180×110 mm, is printed on thin paper, using small print but contains a number of illustrations. Challinor's dictionary is larger (220×145 mm), is printed on better quality paper, and is not illustrated. The print size is about the same as the Penguin dictionary and it is bound in boards.

As to the contents, at first glance the larger number of pages in the Penguin dictionary may give the impression that there are more words listed in this book than in Challinor's. However, the appearance may be deceptive for a straw poll through the "F" section reveals a count of 100 words in Challinor and 102 in the Penguin. From this one might draw the conclusion that the subject coverage of the two books would be the same and indeed there is a considerable amount of overlap but with some interesting differences.

The compilers of the Penguin have "concentrated on terms which seem to them to be in the widest use; special and local terms have been excluded"; such as East Midlands stratigraphical terms *e.g.* Matlock Limestone Group, Tupton Coal. Challinor makes the same point rather differently. In the preface to the first (1960) edition, he states: "There appears to be room among works on geology for one that will probe the subject by examining the meaning and usage of names and terms that stand for the more significant things, facts and concepts of the science". Still no obvious reason for differences in content that are readily discernible.

Delving a little more deeply into the "F" section there are about 40% of the entries common to the two books. Throughout, it would seem that the Penguin gives more mineralogical and palaeontological terms. Many terms are explained by the use of line diagrams and there is a handy (though not complete) cross-reference system. In Challinor's dictionary, the unique terms seem to concentrate on geomorphology and the more important British stratigraphical terms, *e.g.* Forest Marble. Another reason for the differences of content is the date of compilation. Although revised in 1963 and 1966, Challinor's book still reflects the terminology of the 1950's (fractional crystallisation), whilst the Penguin includes newer terminology up to the 1970's. It is no good looking for 'plate tectonics' in Challinor and curiously enough, whilst 'polar wandering' might be an expected absentee from this book, it is also absent from the Penguin.

It is interesting to compare entries common to both books. Whilst many have identical definitions, others show curious differences no doubt reflecting the 20 year gap in the original dates of publication of the books, and the authors' opinions.

Felsite (Challinor) "A very fine-grained igneous rock composed predominately of quartz and felspar or if porphoritic with a ground mass so composed..."

(Penguin) "A fine, evenly-grained acid or intermediate igneous rock forming dykes and veins both in the country rocks and in the parent plutonic mass...."

Is a felsite fine-grained or very fine-grained, porphoritic or non-porphoritic. ? There is no mention of colour or the fact that some people would not use the term anyway!

For odd words consult the Penguin dictionary for the meaning of 'frilling' 'flos feri' 'oedion' 'pedion' 'yardang' and Challinor for 'paulopost' 'floetz' 'formenreiche' - there is scope here for the Scrabble enthusiast.

It follows that although there are similarities in many entries, the two dictionaries are often complementary and together will form a coverage of geological terms in use during the greater part of this century.

Mention should be made of Challinor's inclusion of the source of the terms and the first time of use. On the other hand, one wonders who is likely to use the 'classified list' to be found at the end of this book. There is a useful appendix of mineral names and properties in the Penguin, but why no reference to Challinor in the bibliography. ?

All readers of the Mercian Geologist are encouraged to purchase one or both of these books so that the editor need no longer ask his contributors to explain terms included therein.

F.M. Taylor

REVIEW

WOODWARD, G.H. and WOODWARD, G.S., 1973 : *The Secret of Sherwood Forest. Oil Production in England during World War II.* Norman, Oklahoma; University of Oklahoma Press, xviii, 266pp., 33 illus. £4.00 (approx.)

The quietly pumping "nodding jennies" over the oil wells of Nottinghamshire, and Lincolnshire once a familiar though somewhat unexpected feature of the East Midlands landscape, are now restricted to the north of the region, particularly around Gainsborough. Many, may now know much about their history, for the drilling of the wells commenced covertly during the years of the Second World War at a time when questions were not welcomed. A popular account of the East Midlands Oilfields was published by BP (1962), but no reference was made to the American contribution to the early exploitation of the Eakring and Dukes Wood field, which is the subject of the new book.

For indeed it was to the southwestern United States that the British Government had to turn when exploitation of the Nottinghamshire Oilfields became urgently necessary at the height of the war with Germany. At that time, Britain had neither the equipment nor the experienced man-power for such a project and as this book relates, it was difficult enough to persuade any U.S. oil firms to commit men and resources to Britain at a time when their own men and resources were in urgent demand to develop U.S. resources for the war against Japan.

The possibility of oil occuring in Nottinghamshire was the accumulation of a number of observations gained over the years including hydrocarbons at the top of the Carboniferous Limestone at Windy Knoll, Castleton; seepages of oil in Coal Mines near Alfreton; and one successful boring for oil, among a number of unsuccessful ones, at Hardstoft, also in Derbyshire. A major anticlinal structure around Eakring had been suspected by local collieries working eastwards towards it; and a coal borehole at Kelham had proved traces of oil. The structure had been pinpointed by a seismic exploration survey by the D'Arcy Exploration Company (later BP Exploration) and the petroleum prospects appeared excellent.

There is little of this part of the story in the book, for it effectively commences with the flight of Sir Philip Southwell to Washington and hence to Oklahoma to obtain U.S. governmental support and to persuade two Oklahoma drilling companies to provide men and equipment. The story of the unravelling of wartime 'red-tape' will evoke wry memories for many readers; and the mutual amused incredulity of the Americans and the villagers and monks (for the drillers were lodged at Kelham!) is readily perceived from these pages. The core of the book, though, is the account of the day-to-day experience of drilling the wells for Britain's first oilfield, initially at Eakring and Duke's Wood and later at nearby Nocton. One hundred and six wells were drilled by the American crews within one year, 94 producing oil; although the quantities were relatively small, this made a very worthwhile contribution to Britain's war effort.

This is primarily a historical account and attempts no description of the bedrock geology. It would seem also that the authors know little British geology or geography, for the title of the book is misleading; the true "Secret of Sherwood Forest", from the geological point of view, is water. The oilfields were drilled under the cover of Waterstones and Keuper Marl, which have never had a respectable cover of oak trees and are east of the main area of Sherwood Forest. The book highlights the American achievement and attempts to maintain a sense of continuous excitement which, to the reviewers, becomes a little wearing at times; a more relaxed style would have ultimately been more effective. The book should be read in conjunction with the BP (1962) publication to get a full picture of the history of this first British oilfield.

Reference

BP 1962. *The Oilfields of Britain* London; British Petroleum Co.Ltd., 32 pp. illustrated.

William A. S. Sarjeant.

REVIEWS

SARJEANT, W.A.S., 1974 *Fossil and Living Dinoflagellates*. Academic Press Inc., (London) Ltd., viii + 182 pp., Frontispiece + 15 pls., 45 figs. Price £5.00.

Dinoflagellates are microscopic unicellular plants that form an important constituent of the marine plankton. At times of adverse environmental conditions these organisms retreat into an organic-walled cyst, from which they re-emerge when the environment improves. Fossil dinoflagellates comparable with the encystment stage of extant forms are known from strata of late Triassic age and younger, but the true stratigraphical range of the group almost certainly extends into much older systems. The small size, abundance, rapid evolution and wide geographical distribution of fossil dinoflagellates render them of immense value in the correlation of the strata in which they are preserved and the group is widely used in applied biostratigraphy. The rate at which research is currently progressing makes it difficult for the non-specialist to keep abreast of developments, and the publication of a book summarising the information accumulated in recent years is to be welcomed.

Dr. Sarjeant, as well as being a former editor of the *Mercian Geologist*, is an international authority on fossil dinoflagellates and his book will be most consistently used by other specialists or aspiring specialists. There is much included that will be of value to the general micropalaeontologist, but the book probably lies well outside the interests of most EMGS members. Nevertheless, it is fitting to provide this review of a book written by a member of the Society. (See also Sarjeant 1967).

The main text comprises nine chapters covering the following topics: ecology, morphology, reproduction and encystment of living dinoflagellates; the cyst morphology and classification of fossil and living forms; a history of study of fossil dinoflagellates, their stratigraphical history and an evaluation of their use. The general reader will probably find the first and last chapters of most interest. The first outlines the wide range of ecological niches occupied by dinoflagellates and discusses the spectacular population explosions (blooms) that occasionally occur in some species. Pigmentation imparted to the water during blooms causes 'red tides', an effect that gave the Red Sea its name and accounts for the biblical legend in which Moses and Aaron turned the waters of the Nile into blood (Exodus, 7, 17-21). The final chapter provides an interesting evaluation of the use of dinoflagellates in stratigraphy and palaeoecology.

The remaining chapters include a great deal of factual material, and the uninitiated reader will encounter much new terminology. Understanding of these terms would have been substantially aided by the inclusion of explanatory figures directly related to the text, an unfortunate omission in a book that is otherwise so profusely illustrated. The outline of stratigraphical history is very difficult to follow without the provision of range charts, but the palaeontologically important sections on encystment and cyst morphology are well-presented and very useful. The main text is supplemented by five appendices covering preparation techniques, classification and references.

The volumes of the Treatise on Invertebrate Palaeontology have for several years provided an invaluable reference for workers using invertebrate fossils. Dr. Sarjeant's book goes some way towards filling the need for a similar reference for dinoflagellates and is an essential purchase for any micropalaeontological library.

R.J. Aldridge

Reference

SARJEANT, W.A.S. 1967. *The Xanthidia*. *Mercian Geologist*, vol.2, No.3, pp. 245-266.

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THE MERCIAN GEOLOGIST

Journal of the East Midlands Geological Society

The journal first appeared in December 1964 and since that time, 18 parts, comprising 4 volumes have been issued; the last, vol. 5, no.3 in Sept., 1975. The Mercian Geologist publishes articles especially on the geology of the Midlands of England, but other articles have been published which relate to Midlands geology or are of current interest to geology generally. Contents include original papers, review articles, biography, bibliographies, excursion reports, book reviews and the Secretary's report on Society activities.

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