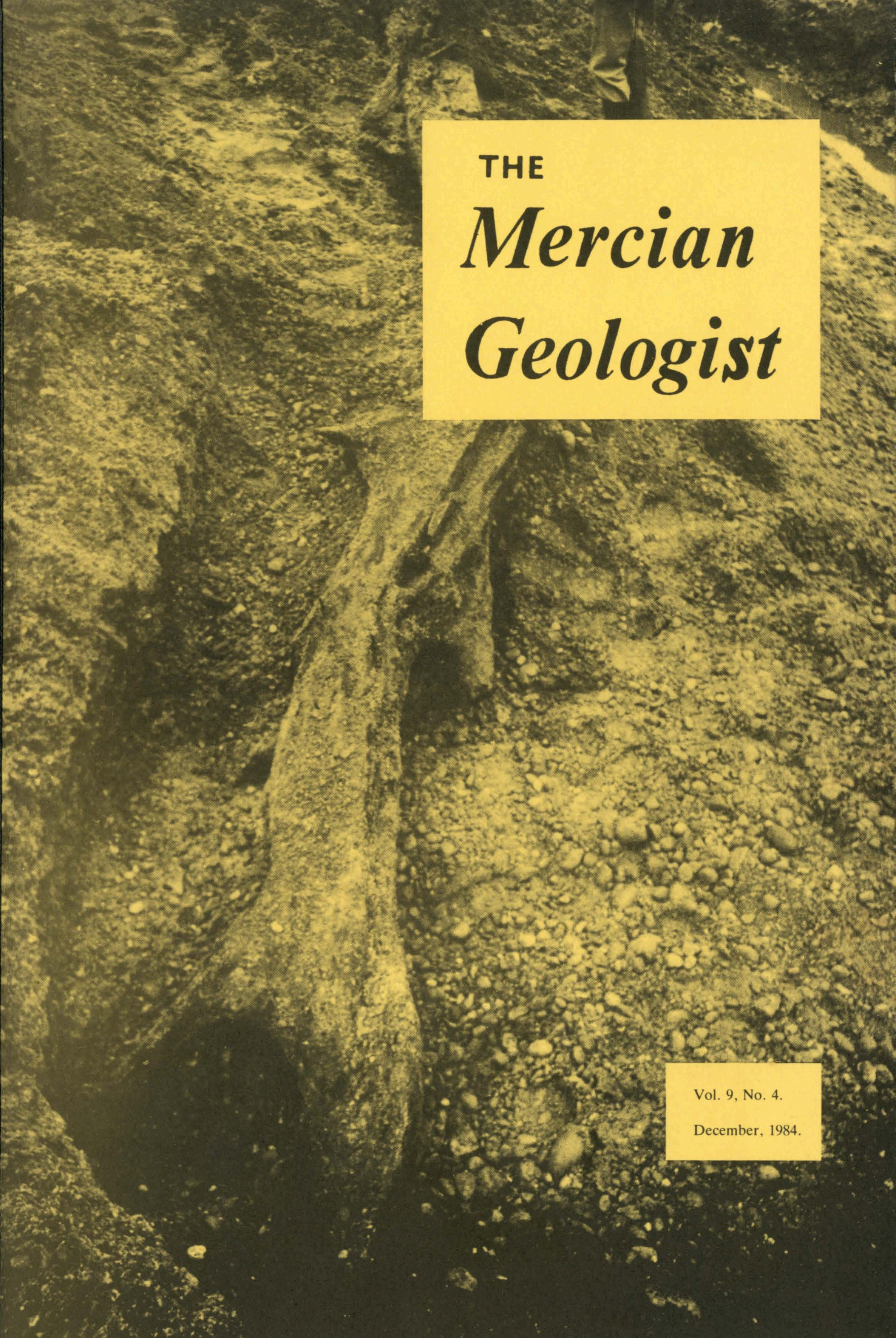

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Front Cover: The top of an oak trunk showing the abraded stumps of the branches. Found in the Colwick gravels.

FLANDRIAN COURSES OF THE RIVER TRENT AT COLWICK, NOTTINGHAM.

by

C.R. Salisbury, P.J. Whitley, C.D. Litton and J.L. Fox.

I'll have the current in this place damm'd up;
And here the smug and silver Trent shall run
In a new channel, fair and evenly:
It shall not wind with such a deep indent.

Henry IV Part 1, Act III, Scene 1.

Summary

Geological, archaeological, dendrochonological and radiocarbon dating techniques have been used to investigate five fluvial channels occupied by the River Trent over the last 6000 years. The earliest channel was identified by establishing the distribution, orientation and age of transported tree trunks deposited in the gravel. The trunks lie with their roots upstream showing both the direction of flow and the former line of the river. Radiocarbon evidence suggests that this channel dates from c. 5400 to 3300 yr. B.P.. A Roman channel was plotted using borehole data and the stratigraphical evidence associated with two Iron Age log boats. Later courses were traced from archival and archaeological evidence, especially that provided by Saxon, Norman and Tudor Weirs. Methods used to calculate the rate of river migration are discussed and a tentative figure of 0.3m per year is suggested as an average rate of lateral movement since medieval times.

Introduction

Gravel has been quarried by the Hoveringham Company in the Nottinghamshire parish of Colwick, since 1970, from an area of about 20 hectares between Colwick Hall and the Holme Sluices (text–fig.1). Although the area lies north-west of the modern course of the Trent, it includes several meanders of an old loop of the river. These meanders were abandoned after the flood prevention scheme in 1955 which resulted in the construction of Holme Sluice and the widening of the William Jessop canal cut of 1800.

Quarrying exposed sections in the floodplain deposits which consisted of 2–6 m of sand and gravel with a 1–2 m overburden of alluvial silts and clays. These deposits were underlain by the Mercia Mudstone Group, (formally Keuper Marl) which floor the "anomalous trench" described by Posnanski (1960). Straw (1963) suggests that this one to one and a half mile wide channel was cut through the Triassic rocks at the end of the penultimate glaciation when the Trent adopted a new course between what is now Long Eaton and Newark along the western margin of a mass of decaying ice which was blocking the Vale of Belvoir. It is also suggested that during the last cold stage of the Pleistocene (Devensian) this trench was filled by the Beeston gravels at a time when the area to the east was covered by a vast lake caused by blockage of the Humber and Wash by ice. When this proglacial lake drained away, in later Devensian times, the Trent cut down through the Beeston gravels to form a floodplain, leaving terraces along the edge of the valley at Newark, Bassingfield and Beeston text–fig.15 (Straw, 1963).

With the final disappearance of the melted ice, the river no longer migrated across the whole valley but incised a new floodplain, leaving the remains of the former floodplain isolated as terraces. As the river became increasingly underfit, it eventually settled into its present meander belt which wound between these floodplain terraces, sometimes eroding them but mostly meandering across the new (Flandrian) floodplain. Floods throughout Flandrian times provided a thick deposit of alluvium which covered the whole valley floor. By early Boreal times (Pollen Zone V: c. 8700 B.C. - 8000 B.C.) the alluvium probably supported a dense woodland of birch, aspen, pine, and hazel and by late Boreal times (Pollen Zone VI: c. 8000 B.C. - 6500 B.C.) elm and oak

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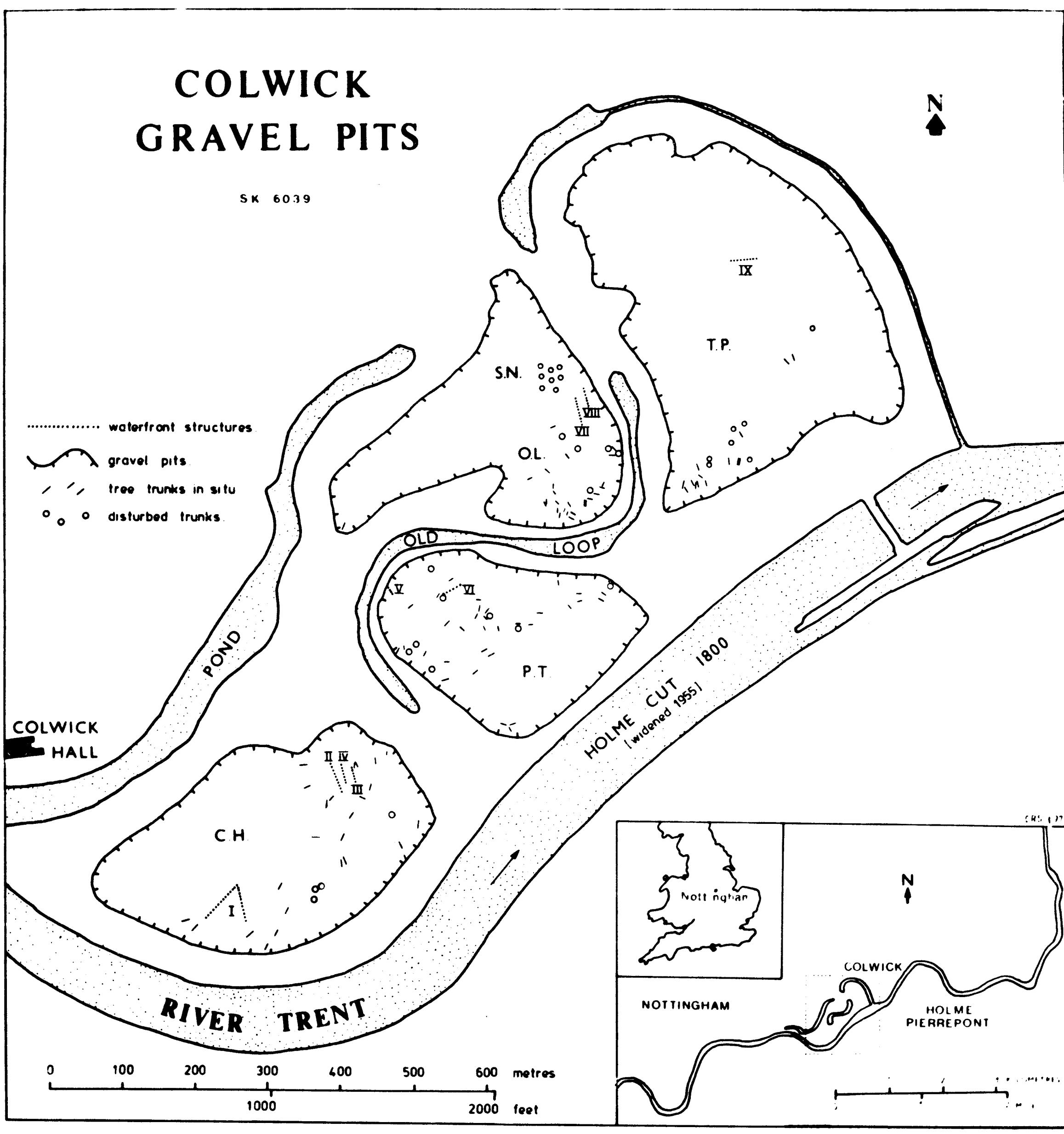
plates 23-25

had appeared. The densest forest cover, before Man had started to clear the forest, would have been in Atlantic times (Pollen Zone VIIa: commencing c. 6500 B.C.). The woodland was not a homogeneous mixed oak forest but a mosaic of regional and probably local plant communities, each with its dominant species (Rackham, 1980). It is at this period that the sequence of river movements described in this paper begins.

In 1973, a medieval fish weir was uncovered by quarrying. This was found *in situ*, in the lower 2 m of gravel between Colwick Hall and the present river course (SK 606389). The weir was excavated and has been described elsewhere (Losco-Bradley & Salisbury, 1980). Continued quarrying revealed the first of many ancient tree trunks lying horizontally in the lower levels of the gravel. It was recognised that tree-ring analysis of these trunks might contribute to a dendrochronological master curve for the East Midlands as well as to the history of river deposition and channel migration. A systematic study was thus initiated which continued until the Autumn of 1978 when quarrying operations ceased and the pits were landscaped to form the Colwick Country Park. During this period, 133 trees were studied, 120 archaeological artifacts collected and 9 waterfront structures recorded. The pit was visited two to three times a week for surveillance and more often when specific excavations and survey were needed. Because of the speed and nature of the quarrying, a few trunks were moved or reburied before sampling could take place, but most were examined *in situ*. This study was possible only because the pits were pumped dry to facilitate the quarrying. For convenience, the names given by the authors to each pit have been retained. These are Colwick Hall (C.H.); Para Trent (P.T.); Swans Nest (S.N.); Old Loop (O.L.) and Trout Pond (T.P.). Their positions are shown in text–figure 1.



Text–fig.1. Gravel pits at Colwick, Nottingham. I is the Norman Weir, VII and VIII are the Tudor Weirs and IX is the Saxon Weir

All radiocarbon dates in the paper are shown first as raw data accompanied by their reference number and then quoted to two standard deviations. A calibrated equivalent age using the tables of Clark (1975), is included in parentheses to facilitate comparison with archaeological data. The purpose of this paper is to show how archaeology, dendrochronology and cartographic techniques can be used to demonstrate the history of river movement over thousands of years. Although it covers only two miles of the floodplain of the Trent, the method is applicable to other parts of its course and, indeed, to any river that has sub-fossil tree deposits in its floodplain.

Survey Details

The Floodplain Gravels

The quarrying revealed stratified deposits of sand and gravel which lay largely beneath the water table. The post-Devensian reworking of these floodplain deposits through the whole depth of the gravel was confirmed by the presence of waterfront structures and many artifacts within half a metre of the floor of the pit.

Many measurements of the quarry faces were taken to establish the thickness of gravel and finer grained alluvial deposits and these were supplemented by borehole information to enable cross sections of the pits to be drawn. Construction of these sections drew heavily upon a comprehensive survey of borehole data and thickness contours of the Colwick and Holme Pierrepoint area carried out by Spenceley (1971). Large scale cross bedding of the gravel and sand was found everywhere. Over wide areas these cross strata dipped at an angle of between 3° and 8°, starting immediately beneath the alluvial overburden and dipping almost to the bottom of the gravel. These cross strata represent the successive surfaces of a point bar as it grew along the axis of a migrating meander. For this reason, the direction of the dip slope must be at right angles to the flow of the river (Cummins & Rundle, 1969). No old land surfaces were found and no evidence that the trees were in their original growth position. One old water course was found in the Trout Pond pit (T.P.). Text–fig.13.

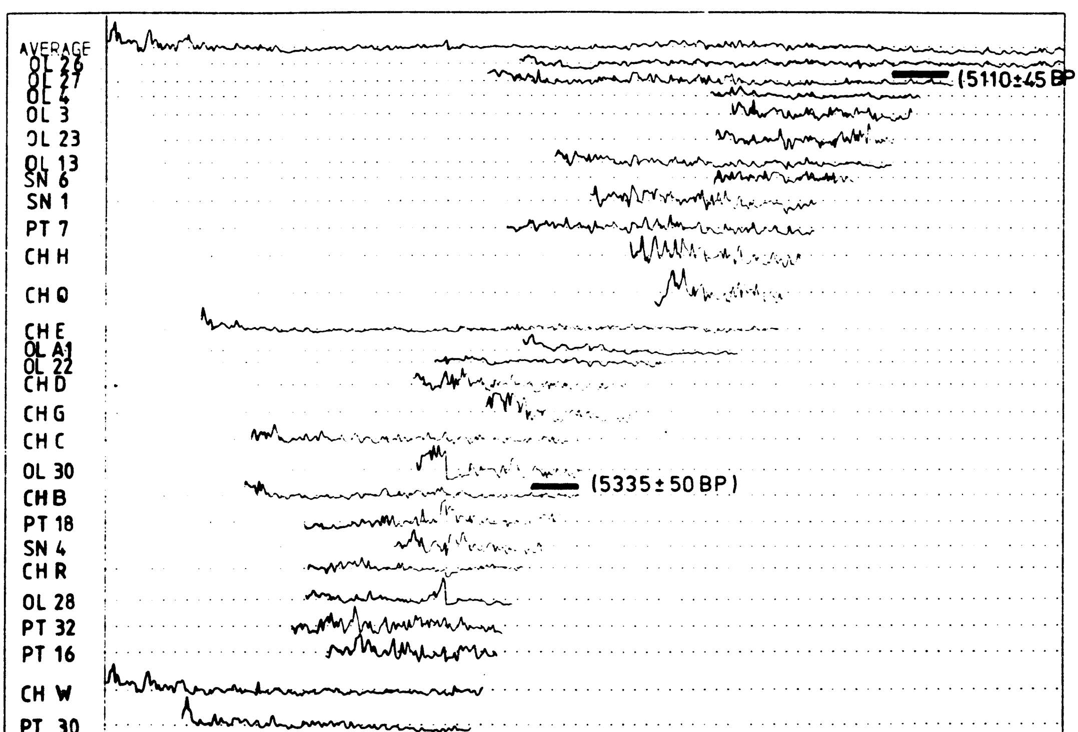
Lumps of sticky silt, containing reed peat, but no shells, were found in the lower deposits of all the pits, often in areas where there was a concentration of trunks. They were irregular in shape with a very clear line of demarcation between silt and gravel and their significance is considered to be the same as similar deposits found in the floodplain gravels at Holme Pierrepoint (Cummins & Rundle, 1969). They are interpreted as masses of silty overburden that had tumbled from the levee and been redeposited in the river bed during channel migration. Some trunks lay in this silt but most were covered by clean water-washed gravel with soft silty sand round their lower surfaces. Occasionally, the gravel yielded mammalian remains including horse, cow. deer and human bones. No man made ditches were found in the upper deposits.

Trunks

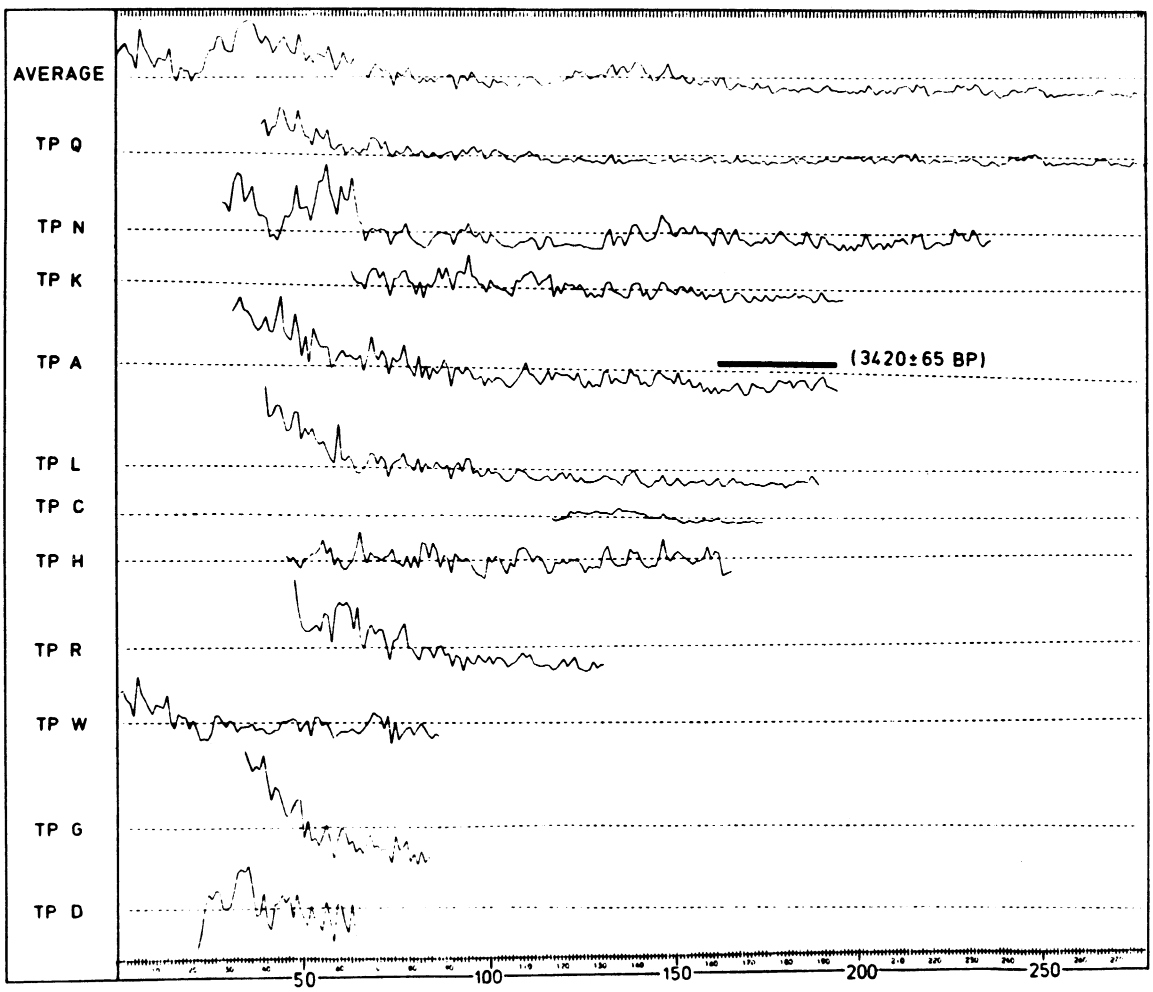
As each trunk was uncovered, its shape and the position of any roots and branches was recorded on a sketch. The height of each trunk above the floor of the pit was recorded and its orientation was measured at both ends of the trunk using a Silva compass. The position of each trunk was then fixed by means of triangulation from known reference points obtained from the O.S. National Grid. After code marking and photography, a complete disc 4–5 cm thick, was cut with a chain saw. Removal of adhering sand and gravel in order to avoid damage to the saw unfortunately entailed the removal of any remaining sap wood. Discs were taken only from the oak trunks. Oak was easily identified because of its intensely black colour, extreme hardness, and envelopment by reduced iron "pan", precipitated by the action of tannic acid on the gravel. The iron coating was sometimes so hard that it required a pick axe to remove. 124 trunks were of oak out of a total of 133 trees and of these, 42 had their roots pointing upstream and 14 downstream. The other tree and shrub species were ash (4), yew (1), hazel (1), elder (1) together with fragments of willow and elm. The oak was indistinguishable from bog oak but the other species of wood had lost most of their cellulose and lignin and although the histology was well preserved, the timber was very soft and fell to pieces when allowed to dry out. This fragility probably accounted for the small number of trees other than oak found as most of them would have disintegrated during episodes of movement and redeposition associated with channel changes.

Although roots and branches of the oak trunks were usually absent, no tool marks, or other evidence of human interference, were found. Branch stumps were characteristically worn to points and trunks were fluted by gravel abrasion (front cover). When sap wood was specifically looked for before log cleaning, only a few of the normal 20–25 rings were present and sometimes it could be found only in crannies. The sap wood and outer 10–20 mm of heart-wood were alway extremely soft having lost most of their cellulose through anaerobic bacterial action (cf. Carruthers, 1979) but retaining their cellular structure in perfect detail with no evidence of fungal action. In contrast, the centres of many trunks were in an advanced state of aerobic rot, typical of a modern hollow tree, with white mycelium still visible to the naked eye. The presence of sap-wood which, in aerobic conditions, might be expected to rot off in five years, suggests that the trees were deposited in the gravel soon after falling. The trees were tall, straight and narrow with few side branches and most of the trunks had the wide rings of a fast growing, well watered and nourished tree. This is in marked contrast to the squat, narrow ringed oaks that grow on the dry sandstone plateau of Sherwood Forest, and suggests that the trees came from a dense stand of floodplain forest. Similar deposition of trunks has been found at Barrow on Trent, Derby (SK 352279), Attenborough, Nottingham (SK 525345), The Meadows, Nottingham (SK 575394), and Holme Pierrepoint, Nottingham (SK 625398). Each of these sites is on the floodplain gravel. Extensive enquiries amongst gravel quarrymen in the Middle Trent region confirms that tree trunks have never been recorded from the Floodplain Terrace deposits. The terraces are the relics of the floodplain that was incised into the Beeston gravels at the end of the Devensian, and the tundra conditions at that time would have prevented the growth of oak trees. Ice wedge casts and cryoturbation features (involutions) are common in this Devensian terrace at Holme Pierrepoint.

Dendrochronological dating of oak timber is based on the assumption that oaks growing in the same area, at a given time, will present a similar pattern of wide and narrow growth rings in response to climatic and biological stresses. The construction of a chronology involves the collection of samples from progressively older timber whose patterns of ring widths overlap in time. A minimum of eighty rings should be present to provide a statistically valid overlap. As ring patterns of timbers from dated buildings are cross-matched, the resulting chronologies are linked to the present and precise felling dates can be attributed to timbers of previously undated buildings. Where timbers are too old to be linked to modern precise ring sequences, as at Colwick, correlations of groups of trees are expressed as "floating chronologies" and imprecisely dated by radiocarbon measurement (see Laxton *et al.* (1979) for details). Of the 124 oak trees at Colwick, 64 trunks had enough rings to be incorporated in the dendrochronological study and of these 38 correlated and could be combined into two floating chronologies, using the method described in Baillie and Pilcher (1978). The first chronology, based on the analysis of 27 trunks in Colwick Hall, Para Trent, Old Loop and Swans Nest pits, spans 576 years. Radiocarbon analysis of the outer 30 rings of two of the trunks suggests a Neolithic age (text–fig.2). Trunk OL 27 has a radiocarbon age of 5110 ± 45 yr B.P. (Q–2028) [c. 3855–4040 B.C.] and similarly trunk CH B has a radiocarbon age of 5335 ± 50 yr B.P. (Q–2029) [c. 4025 B.C.–4290 B.C.]. The second chronology based on 11 trunks in Trout Pond pit appears to span 280 years in the late second millennium B.C. (text–fig.3) on the basis of a date obtained from trunk TP A of 3420 ± 65 yr B.P. (Q–2044) [c. 1640 B.C.–1975 B.C.] which falls within the Bronze Age. Of the 64 trees that were measured, 26 failed to correlate with either sequence and in a small number it is likely that local environmental conditions such as frost pockets or caterpillar defoliation would distort the ring pattern. For the majority, it must be assumed that they lay outside the limits of the two relatively short tree ring sequences. This is born out by the radiocarbon dating of the randomly chosen trunk PT 26 which yielded an age of 3540 ± 40 yr B.P. [c. 1850–2050 B.C.].



Text–fig.2. Graphical plot of the ring widths for trunks in pits C.H., O.L., P.T., and S.N., shown in their correct chronological position and with the floating chronology or average on the top line.



Text–fig.3. Graphical plot of the ring widths for trunks in TROUT POND, shown in their correct chronological position and with the floating chronology or average on the top line.

Much longer floating chronologies, dating from 7000 B.C. have been measured in trunks from floodplain deposits in Central Europe (Schmidt, 1973) and these have recently been precisely dated back to 2800 B.C. (Becker & Schmidt, 1982; Baillie, 1983). This has been based partly on cross dating with the Belfast bog oak chronology which is now precise and dates back to 5300 B.C. (Baillie *et al.*, 1983; Baillie, 1983).

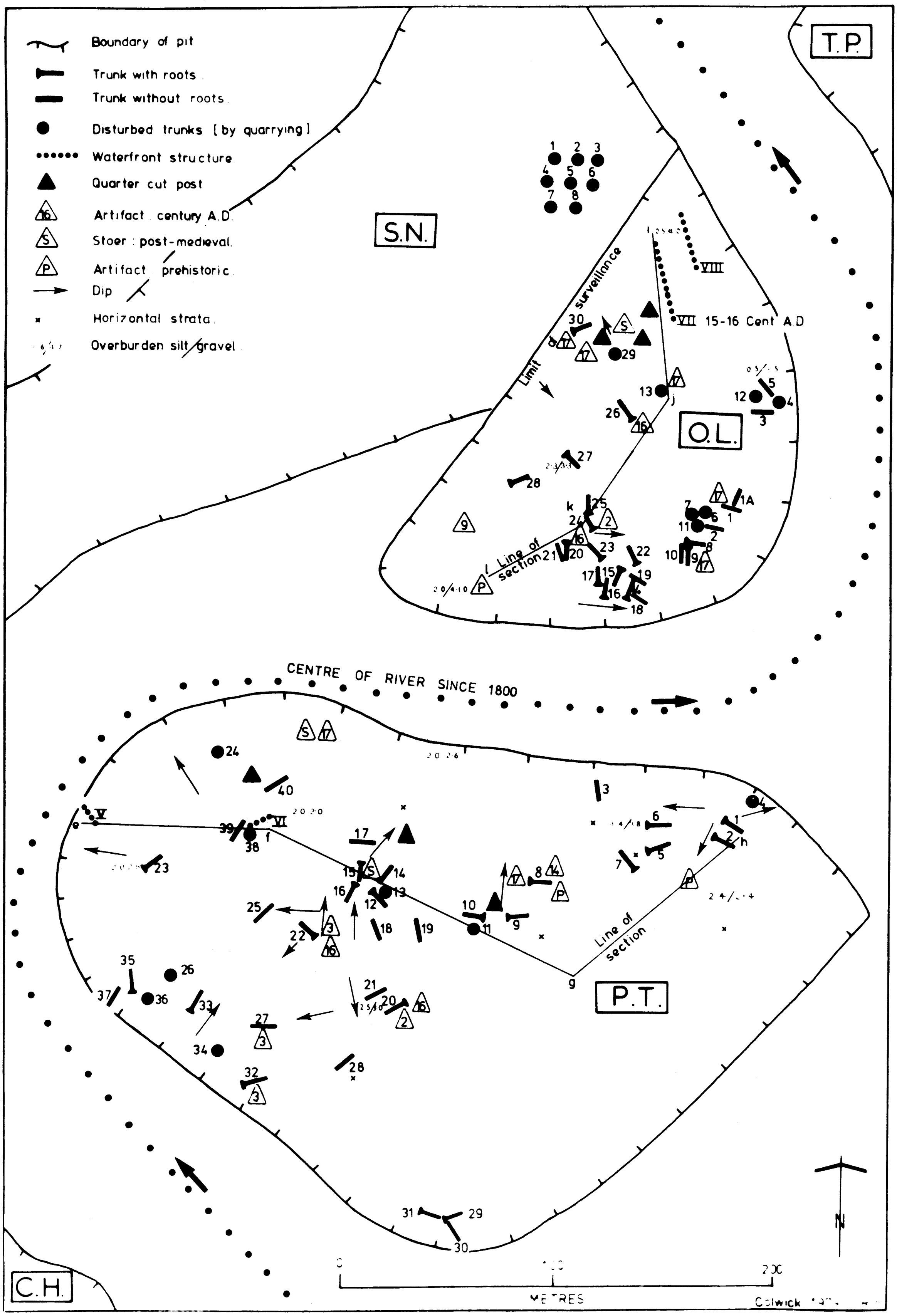
Unfortunately, the Colwick floating dendrochronology curves do not cross date with the Belfast chronology (unlike wood from Carlisle and Swan Carr, near Durham) but it is hoped that it may cross date with the German chronology. Lack of suitable timber makes it unlikely that the 2500 year gap will be bridged between the younger Colwick chronology and the beginning of the precise East Midlands medieval chronology with extents back to Circa A.D. 800 (Simpson G. pers.comm.).

Artifacts

The position of archaeological artifacts was recorded. Unfortunately, because of disturbance during gravel extraction, it was unusual for these to be found *in situ*. The majority of the artifacts were actually found on the conveyor belt but a general estimate of their initial location could be made to within an area of approximately 25 square metres. Since all objects, apart from waterfront structures, are redeposited this degree of uncertainty is not important as artifacts can give only a *terminus post quem* or minimum age for when the gravel was deposited and, for example, it was not uncommon to find prehistoric and post-medieval pot sherds close together.

Waterfront Structures

These were single or multiple lines of posts, reinforced by wattle or brushwood, and driven into the banks or bed of ancient river channels. They were dated by radiocarbon assay to the Saxon, Norman and Tudor periods. They were the only objects found that were definitely in their original positions. They had been buried



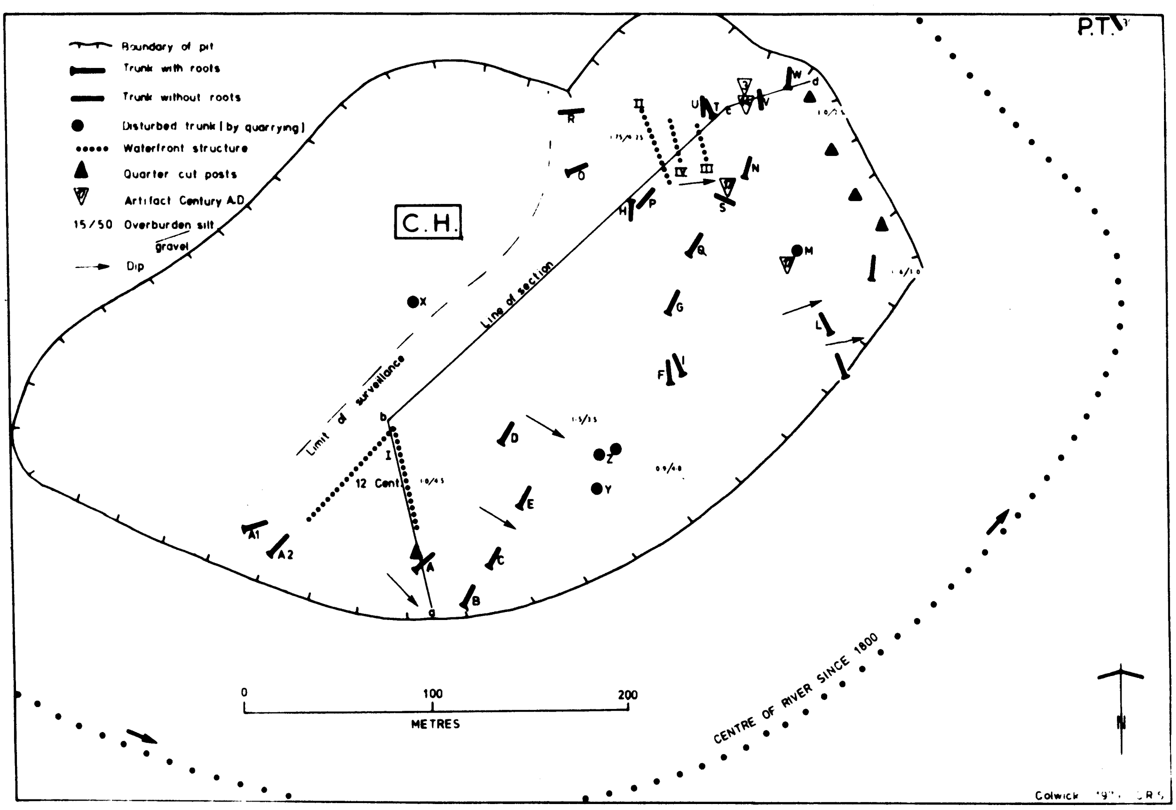
Text–fig.4. Para Trent (P.T.) Old Loop (O.L.) and Swans Nest (S.N.) gravel pits.

in the lower 2–3 m of gravel and left behind by the meandering river so that they were found up to 160 m away from the modern channel. The Saxon and Norman structures were almost certainly fish weirs. The late Tudor structures were more substantial, probably "training" or "flash weirs". They ran nearly parallel with the river banks and were placed in shoaling areas to narrow the river and so increase the depth of water to four feet [1.22 m] for barges. (Historical Manuscripts Commission, 1911; p. 172; p. 175). The removal of temporary dams would provide a sudden "flash" of water. The weirs were usually badly damaged by river action but the posts, although often pushed over to a near horizontal position or snapped off were still effectively *in situ* and often their pointed tips had penetrated the Triassic bedrock on the floor of the pit. They were the only structures that could give accurate evidence of the time scale of river meandering and, unfortunately, no sealed deposits of datable artifacts were found associated with them. Many of the posts were of ash and none of the oak posts had the eighty rings which is the minimum number required to make an overlap which is statistically acceptable in dendrochronology. Thus radiocarbon determination was the only available dating method and this was used in spite of its uncertainty which spans up to 200 years in materials of this age. Displaced posts, riven into quarters, similar to those found in the Tudor weirs of Old Loop pit, (VII and VIII text–fig.1 and 4), were always deposited in areas of gravel containing pottery sherds which gave a *terminus post quem* of 16th - 17th century A.D.. This type of post probably dates from the 16th century onwards.

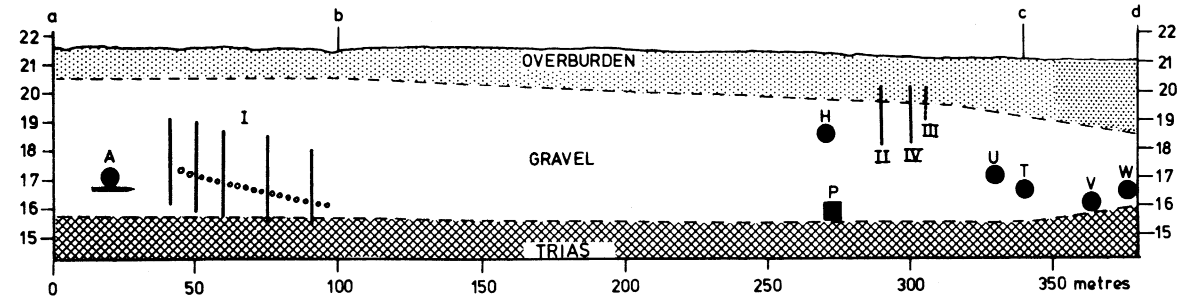
Details of the Pits

Colwick Hall (C.H.)

This pit (shown in text–fig.5 and fig.6) is located between Colwick Hall and the river Trent (text–fig.1). All the trunks, except those labelled H and W, lay within one metre of the pit floor. Eighteen of these trunks had roots pointing upstream whilst only one (trunk H) pointed downstream. In most cases, only the root buttresses remained, but trunk F retained an extensive root system (Plate 24). Samples of wood were weighed in air and in water and it was found that for medium sized trees such as trunk O, with a diameter of 55 cm, the estimated waterlogged weight in air would be 2800 kg, whilst the apparent weight in water was 500 kg. For a large trunk, like E, with a diameter of 110 cm, the waterlogged weight in air would be 16000 kg, apparent weight in water 2800 kg. The trunks were consistently aligned in a southwest to northeasterly direction and the dip of the gravel stratification at right angles to this trend confirmed that they were deposited along the direction of flow of the river (Cummins & Rundle, 1969). The tree ring widths of trunks B, C, D, E, G, H, Q, R and W were correlated to form part of the fourth/fifth millennium B.C. dendrochronological sequence (text–fig.2). Eight other measured trunks could not be correlated.



Text–fig.5. Colwick Hall (C.H.) gravel pit.

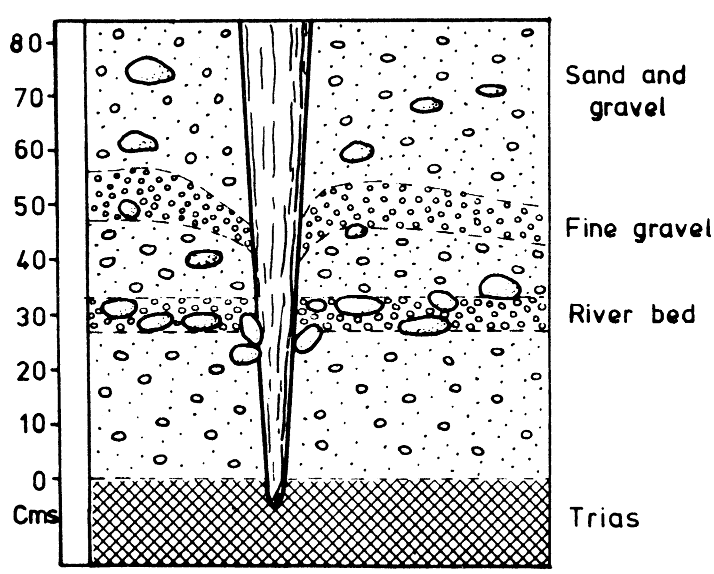


Text–fig.6. Section a - b - c - d through C.H. The ancient river bed at I is 30 cm above the pit floor. Height in metres above O.D.

Waterfront Structure I consisted of two fences of round sectioned posts and wattle, meeting at right angles to form a V-shaped plan. It has been interpreted as a Norman fishing weir (Losco-Bradley & Salisbury, 1980) and dated by two radiocarbon estimations to contain timber which grew between c. A.D. 1005 and A.D. 1330 [820 ± 70 yr B.P. (HAR–552) and 860 ± 60 yr B.P. (HAR–846)]. It had been well preserved by being rapidly covered with gravel during meander movement and kept in a waterlogged and anaerobic environment. The eastern half was partly excavated and found to preserve the former river bed which was represented by a layer of cobbles and sand free gravel (Plate 25). The bed was 1.5 m above the pit floor at the south-eastern end, dipping down to 0.3 m at the apex of the weir (text–fig.6), where the sharpened posts had all been driven through the gravel and into the Triassic bedrock (text–fig.7). The western arm had been almost totally destroyed by quarrying but enough evidence remained to suggest that it lay at about the same level as the apex. A post at the south-western end had been driven 50 cm into the Mercia Mudstone. Eye witnesses report that the western arm of the weir formerly extended almost twice as far as shown on the map, being seen to disappear into the face of the quarry. At the north end of the pit were found three alignments of quarter cut posts (II, III, IV) of a type similar to those used in the Tudor weir described below. Originally they would have been wattled or supported bundles of brushwood (kids) to form short fences (kidweirs). The dip of gravel stratification shows they were set parallel to the river flow and their position in the upper layers of gravel suggests that they were riverbank revetments. Their purpose would have been to prevent riverbank erosion and so facilitate the passage of boats by preventing the river becoming wide and shallow.

The 16th century artifacts found in the north-eastern part of the pit showed that this gravel cannot have been deposited earlier than that date. Many quarter cut posts, which also date from this period, were found in this area.

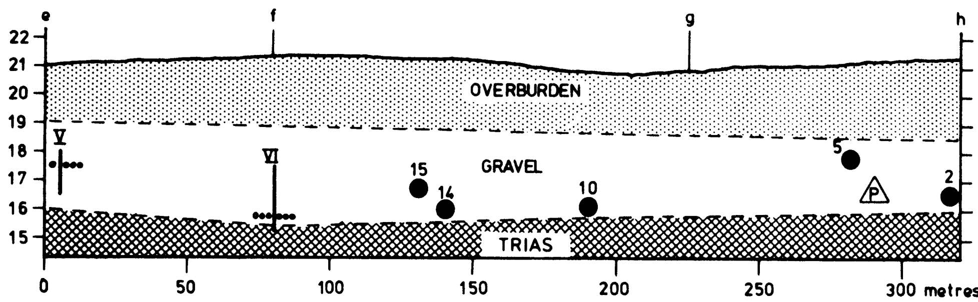
A sharpened, round section post, identical with those of the Norman weir, was found pinned beneath trunk A. Trunks B, C, D and E have all been dated to around 4000 B.C. (text–fig.2), and trunk A, which lay immediately adjacent, can be assumed to be of the same date. A 6000 year old trunk on top of a 1800 year old post must mean that the trunk had been moved, at least once, from the place of its original burial in the gravel.



Text–fig.7. Post of Norman Weir I driven through the ancient river bed and later buried by gravel.

Para Trent (P.T.)

This pit (shown in text–fig.4, 5 and 8) occupied the core of a meander south-east of the old river course. All the trunks lay within one metre of the floor of the pit except trunks 5, 6, 19, 20 and 21 which were all between one and two metres of it. Trunks 4, 7, 14, 16 and 32 belong to the 4000 B.C. tree ring sequence (text–fig.2) but 19 other measured trunks could not be correlated. Trunk PT 26 was randomly chosen for radiocarbon dating and found to be 2000 years younger at 3540 ± 40 yr B.P. (Q–2027) [c. 1850–2050 B.C.]. Only the tapered stumps of branches were left on trunk 2 (front cover). They were surrounded by clean gravel indicating that the branches had rotted or worn away before the trunks were moved and redeposited. Of the twenty trunks examined, only eight still retained any sap-wood and this was vestigial in most cases. Trunk 9 was yew, the only conifer found anywhere during the current investigation. The gravel bedding had no consistent trend to its dip and much of it was horizontal so that the orientation of the trunks gave the best indication of the alignment of the channel at the time of their deposition. The excavator estimated that the roots of the twelve trunks pointed upstream and six downstream.



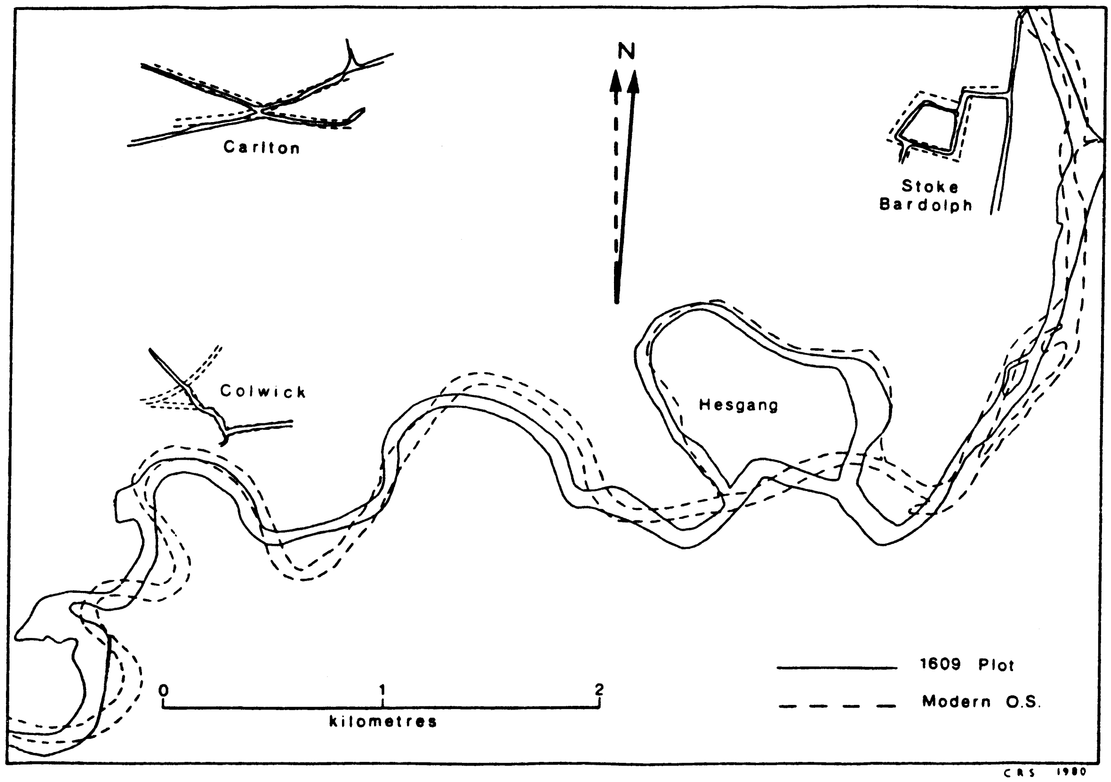
Text–fig.8. Section e - f - g - h through P.T. The ancient river bed at VI is 30 cm above the pit floor. Height is in metres above O.D.

The position of artifacts in the gravel showed that most of the core of the meander was deposited not earlier that the 16th - 17th century. This, together with the jumbled appearance of the trunks, suggested a very unstable river channel and probably braiding within the major meandering thalweg. The trunks, themselves, by causing obstructions, would have contributed to this movement (Collinson, 1978) and trees washed down from higher up the river would have been trapped, contributing to their wide age span.

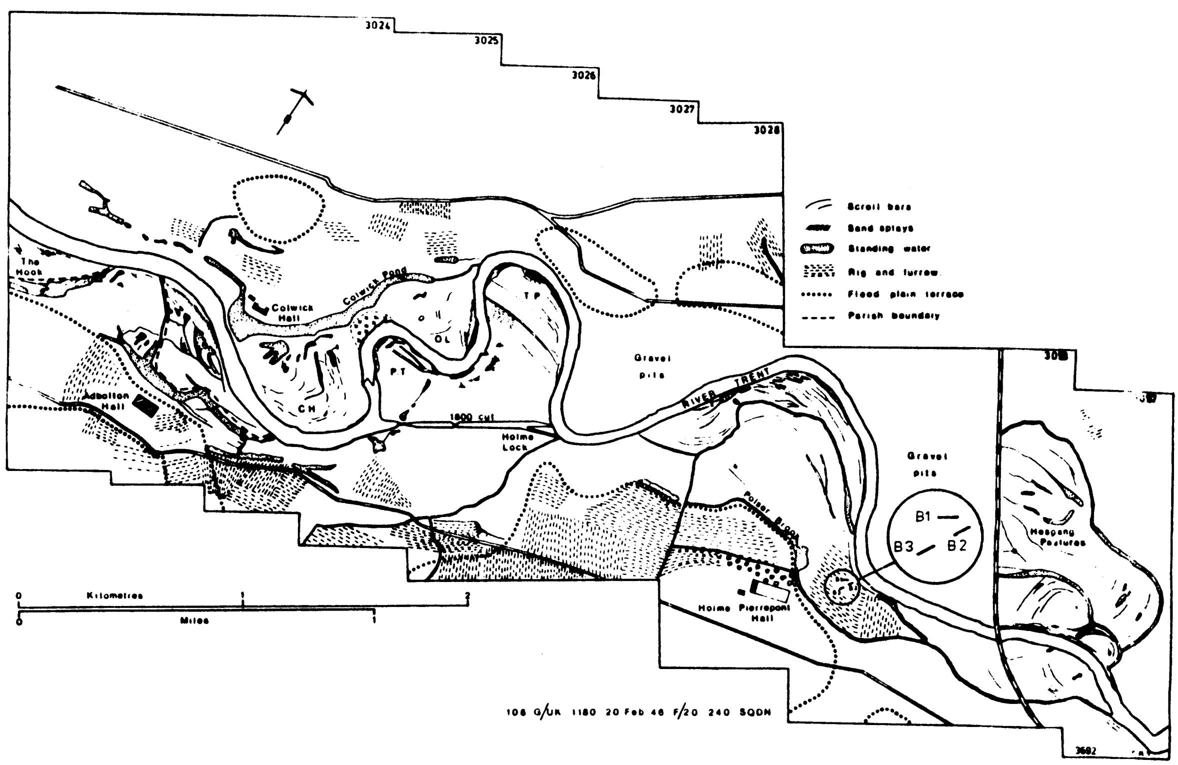
A stower S was found near trunk 5 and seven more, together with a 17th century sherd, lay in the gravel north of trunk 40. Stowers are two pronged, wrought iron implements attached, by socket and nails, to the end of barge poles. They were used to push or punt boats along the river, especially when a sail would be dangerous because of shoaling. Two of them had initials stamped on them in 16th or 17th century lettering. Many of those found had the end of the ash pole snapped off inside the socket, suggesting they had been lost whilst negotiating what may have been a particularly treacherous reach of the river. Text–figure 9, drawn from the 1609 Plot of Sherwood Forest (Public Records Office, 1609), shows this bend to be wide and irregular. This is confirmed by Sandersons Map of 1834 and an aerial survey in 1946 (text–fig.10) shows this tip of the meander to be a marshy area of reclaimed river bed.

Waterfront Structure VI in the west end of the pit, was an alignment of quartered ash posts identical in construction to the 16th century Structure VII (text–fig.4) and preserved an ancient river bed 0.3 m above the pit floor (text–fig.8). It lay parallel to the surrounding trunks and its posts had been pushed over in a north-east direction in the same axis as its alignment confirming that it had been constructed parallel to an earlier course of the river.

Waterfront Structure V was probably a revetment.



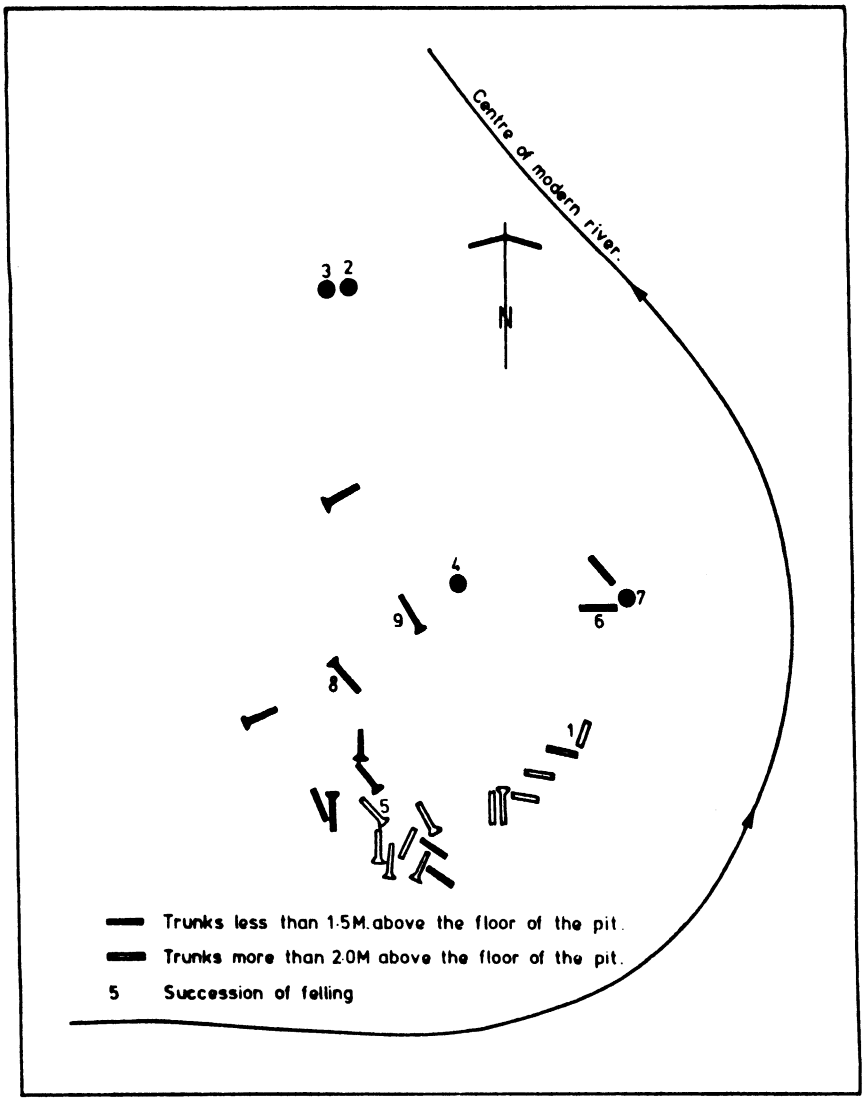
Text–fig.9. The Trent as recorded in 1609 and its modern course, showing the movement of the meanders. (Magnetic north is shown by a dashed line).



Text–fig.10. Map drawn from 8 vertical aerial photographs taken on 20th February, 1946, 10 days after maximum flooding. B_1, B_2, B_3, are the positions of the iron age canoes.

Old Loop (O.L.) and Swans Nest (S.N.)

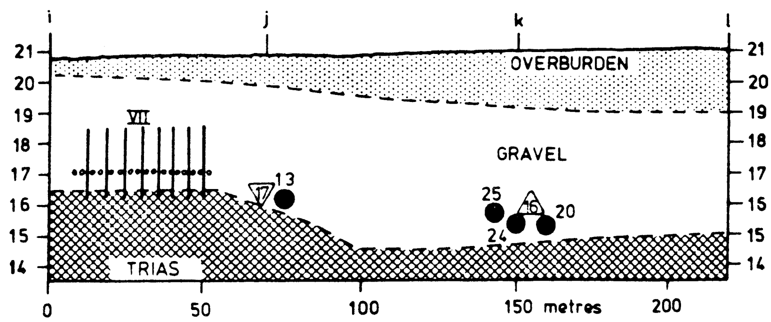
This pit (shown in text–figures 4 and 12) occupies the core of a meander north of the old river course (text–fig.1). The Swans Nest area had been quarried before this survey began. Eight fragments of disturbed trunks were found in the north-eastern corner but no trunks were found elsewhere in the pit and this was corroborated by the site workmen.



Text–fig.11. High and low level trunks in O.L. and S.N. Note the random sequence of felling.

In the Old Loop there was no consistent alignment of the trunks and the method of quarrying left few areas where the dip of the gravel beds could be observed. Seven trunks (9, 14, 15, 16, 17, 22 and 23) were lying 3 m or more above the floor of the pit, whilst nine trunks (3, 5, 18, 19, 20, 21, 24, 15 and 26) lay within 1 m of the floor (text–fig.11). The alignment of the higher trunks was approximately north-south whilst that of lower was northwest-southeast. This is the only pit where a substantial number of "high level" trunks was found. However, the difference in alignment between the high and the low level trunks was not significant and it seems certain that all were deposited in the same period of river channel movement. Ten trunks in Old Loop (A1, 3, 4, 13, 22, 23, 26, 27, 28 and 30) and three trunks in Swans Nest (1, 4 and 6) belong to the 4000 B.C. tree ring sequence but four of the measured trunks do not correlate. Nine of the dated trunks are shown in text–figure 11 which illustrates that their positions, relative to their order of felling, is quite random. From this, it can be inferred that the trunks have been redeposited and this is confirmed by the finding of five post-medieval artifacts, *in situ*, at the same level as the trunks (text–fig.12). A Derbyshire lead ingot weighing approximately 140 kg, of the 16th - 17th century, was found near trunk 13 on the floor of the pit to which it must have sunk in some boating disaster. A 16th century Cistercian Ware jug was 1 m above the floor near trunk 24 and a 17th century shoe lay touching the top of the 6000 year old trunk 30. Quartered oak and ash posts of a type used in the 16th century Waterfront Structure VII lay pinned beneath trunks 25, 26 and 30 of the 4000 B.C. sequence.

The other unstratified artifacts confirm that most of the gravel inside this meander could not have been deposited earlier than the 16th century. This general picture of braiding and shoaling within the meandering channel is reinforced by the finding of a third broken stower, with post medieval initials, near trunk 29.



Text–fig.12. Section i - j - k - l through O.L. The ancient river bed at VII is 60 cm above the pit floor.

A bronze spear head about 3500 years old was found in the south western corner of the pit.

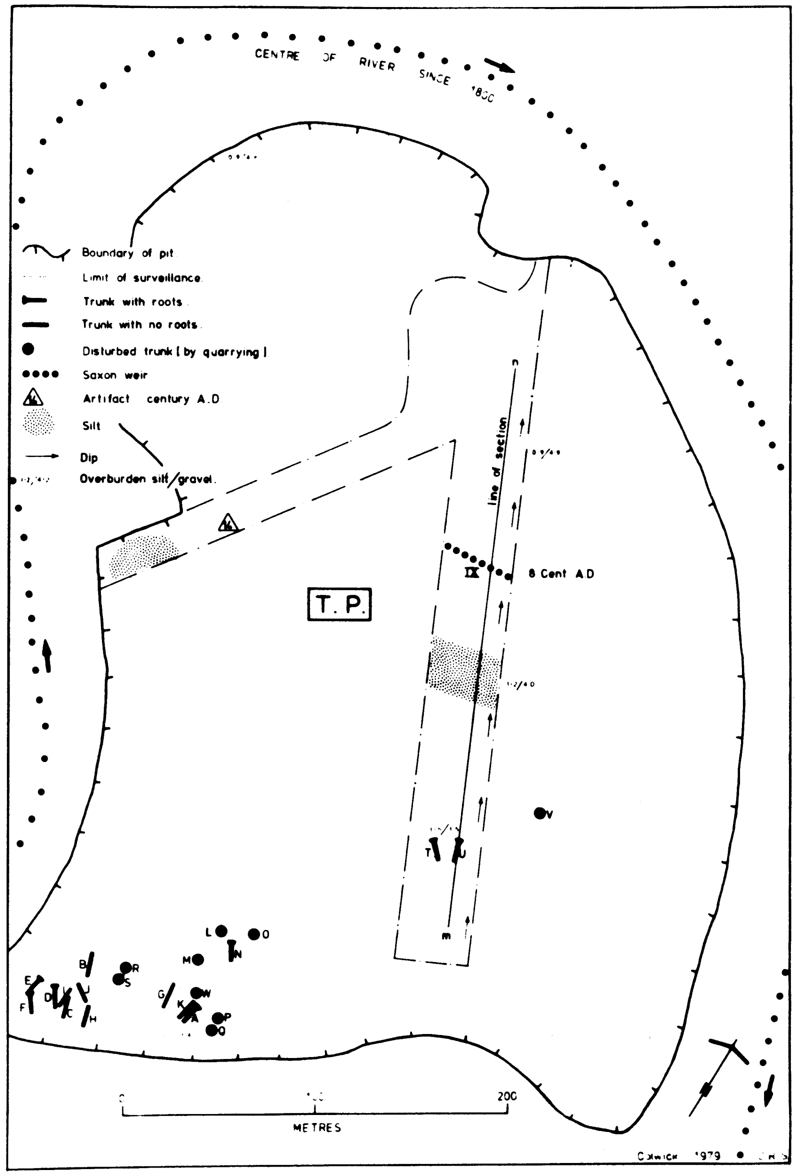
Two massive weirs made of ash posts and brushwood (VII and VIII) and over 38 m in length, lay parallel to each other and to the modern meander, preserving the Tudor river bed 0.6 m above the pit floor (text–fig.12). The structure labelled VII had been pushed over by the river in a north-westerly direction. It has been radiocarbon dated to 345 ± 60 yr B.P. (Q–2031) [c. A.D. 1435–1635] and was probably a training or kidweir constructed in the 16th century to aid the burgeoning coal trade (Historical Manuscript Commission, 1911; p. 530).

Trout Pond (T.P.)

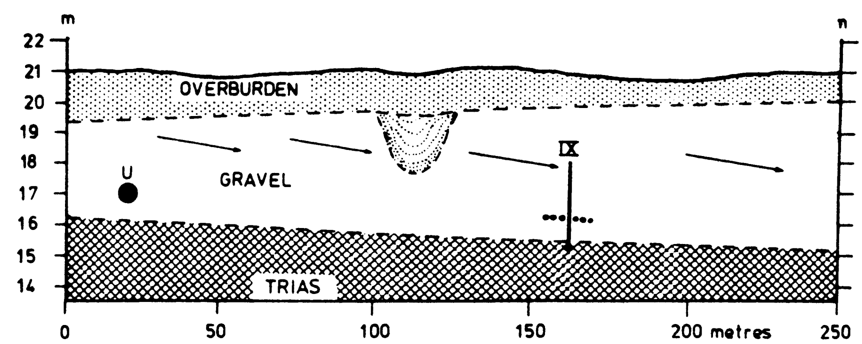
This pit (shown in text–figures 13 and 14) occupies the core of a very large meander south of the old river channel (text–fig.1). By the time the present survey began, most of the gravel within this meander had been extracted and the pit flooded. Two corridors of gravel remained under a road and conveyor belt. In 1978, the pit was drained to remove the remaining gravel and an undisturbed cluster of trunks was revealed in the south-western corner. These trunks were not more than 1.5 m above the Triassic bedrock floor with their roots pointing towards the north end. Trunk A has been radiocarbon dated to 3420 ± 65 yr B.P. (Q–2044) [c. 1640–1975 B.C.] and correlates with eleven other Trout Pond trunks (A, C, D, G, H, K, L, N, Q, R and W) to form a floating tree ring curve of 280 years (text–fig.3). Five other measured trunks did not correlate. No other trunks or posts were found in the rest of the meander core and this was confirmed by the site workmen.

The cross bedding of the north-south gravel corridor showed a cosistent dip of about 8° towards the apex of the meander suggestion that this meander had migrated steadily in a north-westerly direction. A small overflow channel, now silted, cut into the gravel strata (text–fig.14) and must post-date the gravel deposition. This channel ran obliquely across the north-south corridor and aligned with a mass of silt seen in the east-west corridor. It is in line with the swale seen in text–figure 10 which must have been deepened to form an overflow channel during floods. The 14th century sherd gives its earliest possible date.

In the centre of the pit was a post and wattle fence at least 35 m long and preserving an ancient river bed 0.7 m above the Triassic floor of the pit. This was interpreted as a Saxon fishing weir (Salisbury, 1981) and has been radiocarbon dated to between A.D. 600–A.D. 925 [1260 ± 65 yr B.P. (Q–2030); 1130 ± 30 yr B.P. (UB–2351)]. Pressure of river flow had made it collapse in a north-eastern direction. Such a weir would have been built obliquely across the Saxon course of the river and this is confirmed by finding the alignment to be at 40° to the direction of the dip in the gravel cross bedding.



Text–fig.13. Trout Pond (T.P.) gravel pit.



Text–fig.14. Section m - n through T.P. The ancient river bed at XI is 75 cm above the pit floor. Height is in metres above O.D.

Discussion

The presence of scroll bars and sloughs (text–fig.10) shows the river surrounding Colwick Hall pit (C.H.) to be a meander that has expanded steadily in a lateral direction but with little downstream movement. The 12th century weir is about half way along the radius of the meander and yet lies within 50 m of trunks dating to 4000 B.C.. Artifacts found in the immediate vicinity, and at the same depth, show that the gravel was deposited round these ancient trunks in historical times. Dendrochronology gives evidence of a cluster of trunks with ages spanning several hundred years but their location, relative to the river, is unrelated to their position on the floating tree ring curve (text–fig.11). The trunks could have originated upstream and been brought down by successive floods to be redeposited on point bars and shoals. If so, trunks would be expected to occur throughout the meander belt and in all areas of the floodplain. At Colwick much of this belt had no trunks and instead they were found in a sinuous band just north of the axis of the belt. At Holme Pierrepoint, gravel extraction revealed a similar band of trunks stretching west from the region of the log boats (text–fig.10) as far as the modern river and continuing the curve of the Colwick trunks. Extensive quarrying elsewhere north and south of the river, at Hesgang and between Holme Pierrepoint and Adbolton has revealed no more logs. (No wood is found in the Flood Plain Terrace deposits which were laid down under tundra conditions). The most likely explanation is that groups of trunks, already deposited in the gravel, were eroded by meander expansion. The trunks, weighing up to 16 tonnes, would slump into the thalweg and, because of their waterlogged state, would remain in the channel lag deposit or move no more than a few metres downstream. Since slumping tends to occur as the flood is subsiding (Gregory & Walling, 1973) they would be unlikely to move far.

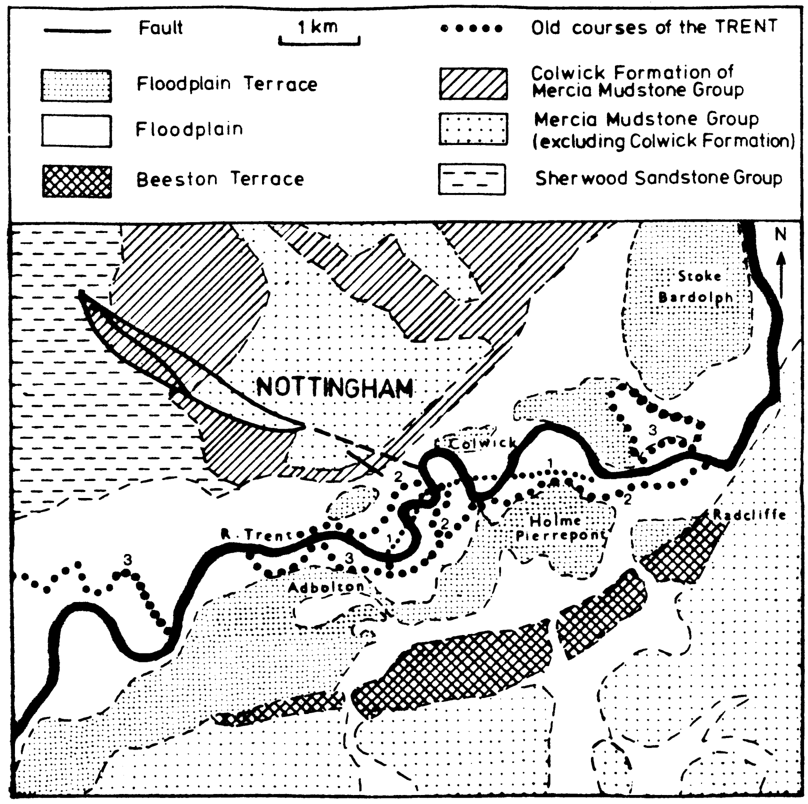
It is postulated that a flood could uproot a whole stand of trees. Not being waterlogged initially, they would move greater distances but in the process would be severely abraded and lose all of their smaller branches and roots (front cover). Where the river shoaled, the trunks would ground and be covered with gravel.

The position of the trunks in a broad sinuous band may well represent the trace of the river channel between 4000 and 1700 B.C. (see 1 in text–fig.15), through which the present and probably an earlier course of the Trent meandered. During the Bronze Age, the river valley became settled and probably cleared of trees so it is unlikely that many trunks will have been deposited in the river after the middle of the second millennium B.C.

Colwick Hall pit shows the classic meander deposit of stratified gravel dipping towards the apex of the point bar. The picture is highlighted by alignment of the trunks with thalweg flow. 75% of the trunks were deposited with their roots pointing upstream and it is probable that as the thicker butt of the trunk would trail behind the slimmer top when it was dragged along the bed of the river, so the orientation of the trunks would show not only the line of the channel but the direction of the current flow. It is suggested that where the channel braided, the alignment of the trunks gives a better indication of the river flow than the dip of the gravel cross bedding. In the Para Trent and Old Loop pits gravel dip is often random in direction and this maybe due to the formation of linear bars by accumulation of coarse sediments in the channel, dividing it and so causing the river to braid. It seems likely that tree trunks could have this effect. In addition, transverse bars and chutes (Collinson, 1978; p. 34) might appear, thus accounting for the high level trunks and the "chute cut off" of the tip of Para Trent meander (Collinson, 1978; p. 35), as is shown in both text figures 9 and 10.

In Trout Pond pit there is a return to the regular dipping stratification which, on the evidence of a single strip of gravel, appears to point straight up the axis of the meander. This does not match the angle of the scroll bars (text–fig.10) or the change in channel position since 1609 (text–fig.9) both of which suggest that the meander was moving downstream as well as migrating laterally.

Borehole evidence (Spenceley, 1971), summarised in text–figures 16 and 17, shows a curving deposit of thick silt and minimal gravel, south of Old Loop and still visible, in time of flood, as a string of pools (text–fig.10). This is an abandoned meander with its northern extension destroyed by the modern meander belt. The trunks in Trout Pond have all been turned at right angles to the flow of the 4000 B.C. - 1700 B.C. channel with their roots to the north, a clue to the northerly swing of the later meander as well as confirming its north to south flow. The meander may have continued as an abandoned river channel, known as Colwick Hall Pond, and carbon dating or pollen analysis of this peat filled channel might test this hypothesis. This ancient meander can also be followed downstream along a brook flowing to Holme Lock and then, via an area without gravel, (seen on text–fig.16), to a stretch of deep silt underlying the course of the Polser brook. This silt was observed by workers of the Hoveringham Gravel Company when the whole north west of Holme Pierrepoint Hall was quarried in 1967 prior to the construction of the Nottinghamshire National Watersports Centre and Country Park. At this time, three log boats were exposed (SK 629395) lying in the lowest strata of a point bar deposit which was surrounded by an abandoned meander (Cummins & Rundle, 1969; MacCormick, 1968). The log boats were radiocarbon dated to c. 390 B.C. - A.D. 140 [2060 ± 86 yr B.P. (B.P. – 132)]. When this meander was abandoned, it filled with silt leaving a small depression on the surface which is now occupied by the Polser brook. The whole of the area is covered by medieval ridge and furrow which is, itself, being eroded by the modern river (text–fig.10). This



Text–fig.15. Geological map of the Colwick area showing old courses of the Trent. (1) 4th/2nd millenium B.C. course (2) Roman course (3) Medieval course prior to 14th century.

channel is the same as that described by Posnanski (1960) although evidence shows it to have followed a slightly different course (2 on text–fig.15). To judge from the position of the Iron Age boats and the rate of meander migration (see below), this section of the river course was probably in use in Roman times. The abandoned meander at Colwick was cut off by a bridging channel which probably joined with the abandoned meanders at Adbolton Hall and "The Hook" (text–fig.10). These latter are parish boundaries and must date from Saxon or earlier times, indeed, if the line of the Adbolton meander is extended across the modern river, it passes through the Norman weir and its accompanying alignment of trunks. It has already been demonstrated that Colwick Hall and Trout Pond meanders had been established by Saxon times. By the time of Edward I (1272 - 1307) the river ran for half a mile in two channels adjacent to Adbolton and Colwick Hall (Stevenson, 1885; pp. 419 - 421) but Sir Richard Byron - the Lord of Colwick, trenched and deepened the latter so that by 1392 it was said in evidence that "the water of Trent from old times was wont to run through the aforesaid vill. of Adbolton .... but the course .... is now so much filled up by sand, earth, growing willows and piles .... that no course of water exists there now but is wholly turned into the aforesaid trench" (Stevenson, 1885; p. 419). The old channel by Colwick Hall pond may have been this "trench" which was itself abandoned by another river shift. Evidence of sudden movement of a channel is given by Wilkins (1974) who describes a major flood, sometime between A.D. 1301 - 1416, which left half of Wilford parish in what is now The Meadows, of south Nottingham (Channel 3, text–fig.15). The archaeological and geological evidence has shown a chaotic and possibly braided development of the Para Trent and Old Loop meanders. However, by the 16th century, they must have been well established as it is possible, by drawing a curved line between weirs II, III, IV, VI, VII and VIII to trace a course for the river parallel to the modern meander but slightly up valley. This course can be followed further downstream to a large swale, with standing water, north of the Polser brook (text–fig.10). In 1967, during gravel quarrying, another kidweir was revealed beside this swale (SK 628399) and excavation (MacCormick pers.comm., 1967) showed it to be the same both in construction and age as those at Colwick. Its radiocarbon date was 304 ± 70 yr B.P. (Q–870) [c. A.D. 1445–1675]. This swale is now being eroded by the modern river but it can be followed as far as Hesgang. It is known that in 1570, Lord Willoughby of Wollaton Hall Nottingham, was "improving" the Trent, at great expense, to facilitate the shipment of coal to London (Historical Manuscripts Commission, 1911; p. 530). Further proof of this Tudor course is demonstrated by the 1609 Plot of Sherwood Forest estate map (text–fig.9). By superimposing the position of the villages of Carlton, Colwick and Stoke Bardolph upon the Ordnance Survey Map, the earlier position of the meanders is shown to be the same as that followed by the weirs (text–fig.9). Two other features on this map are of special interest and support its accuracy. The grid drawn on the 1609 map is slightly easterly of modern magnetic north and this is the correct position for the 17th century. Secondly, the area called Hesgang Pastures appears on the 1609 map to be a meander in the process of becoming an Oxbow lake. This is confirmed by the identical outlines on both this map and the Ordnance Survey (text–fig.9). Hesgang Pastures remained part of Radcliffe parish until the boundaries were rationalized in the 19th century. This area is designated a floodplain terrace on the Geological Survey Map (No.126) although it is the core of a meander and Bronze and Iron Age artifacts were found when the gravel was quarried. An attempt has been made to estimate the rate of meander migration since early medieval time. Taking a line at right angles to the scroll bars, the distance was measured between the centres of the various weirs and the centre of the river in A.D. 1800, the date at which the banks of the Trent were established. Each distance was divided by the age of the weirs to one standard deviation of their radiocarbon dates. The following values were obtained for the rate of meander migration.:-

Weir IX	(Saxon)	0.17–0.21 m per year
Weir I	(Norman)	0.39–0.53 m per year
Weir VII	(Tudor)	0.21–0.35 m per year

Comparison of these rates shows a wide variation but the mean average of 0.3 m per year gives a "rough and ready" figure for use in the Middle Trent Valley. For instance, using the radiocarbon dates of the Holme Pierrepoint log boats, it can be estimated that the Trent would have flowed in the region of the Polser brook in A.D. 135 - 465.

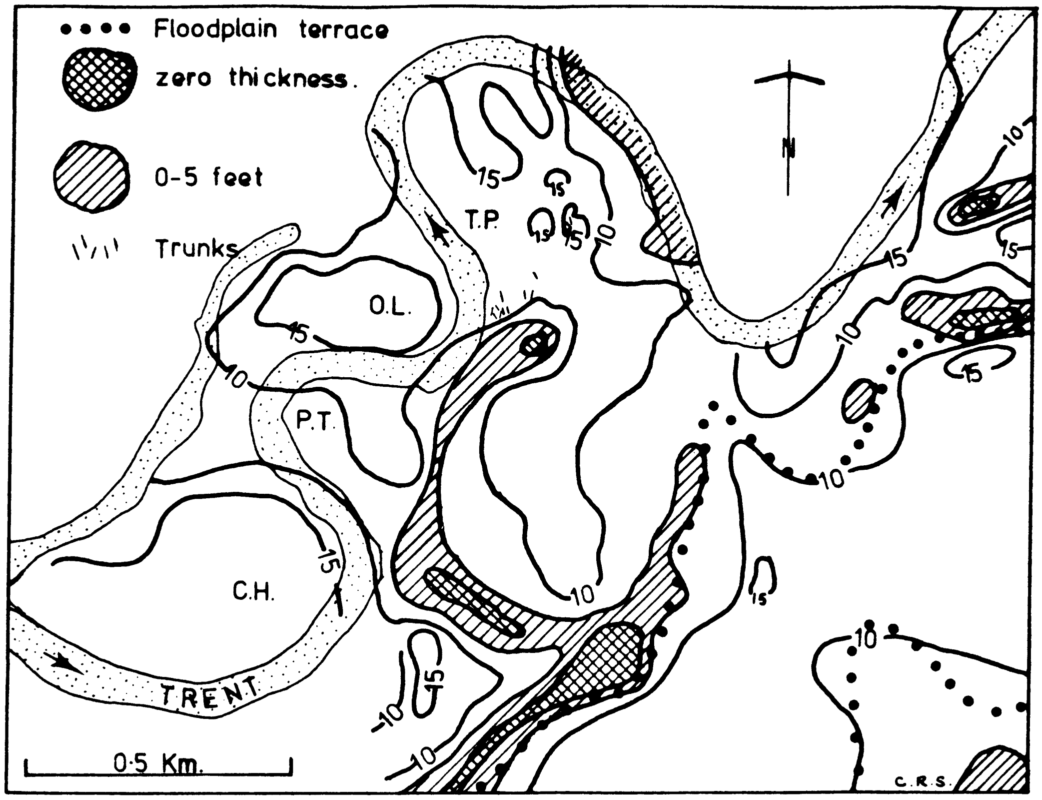
Summary and Conclusion

This paper describes the changes in channel position, over the past 6000 years, of a mature river in a wide floodplain. A two mile stretch of the Trent lying in the parish of Colwick and Holme Pierrepoint was studied but the methods used (summarised in Table 1) can be applied to any river with deposits of commercially useful gravel.

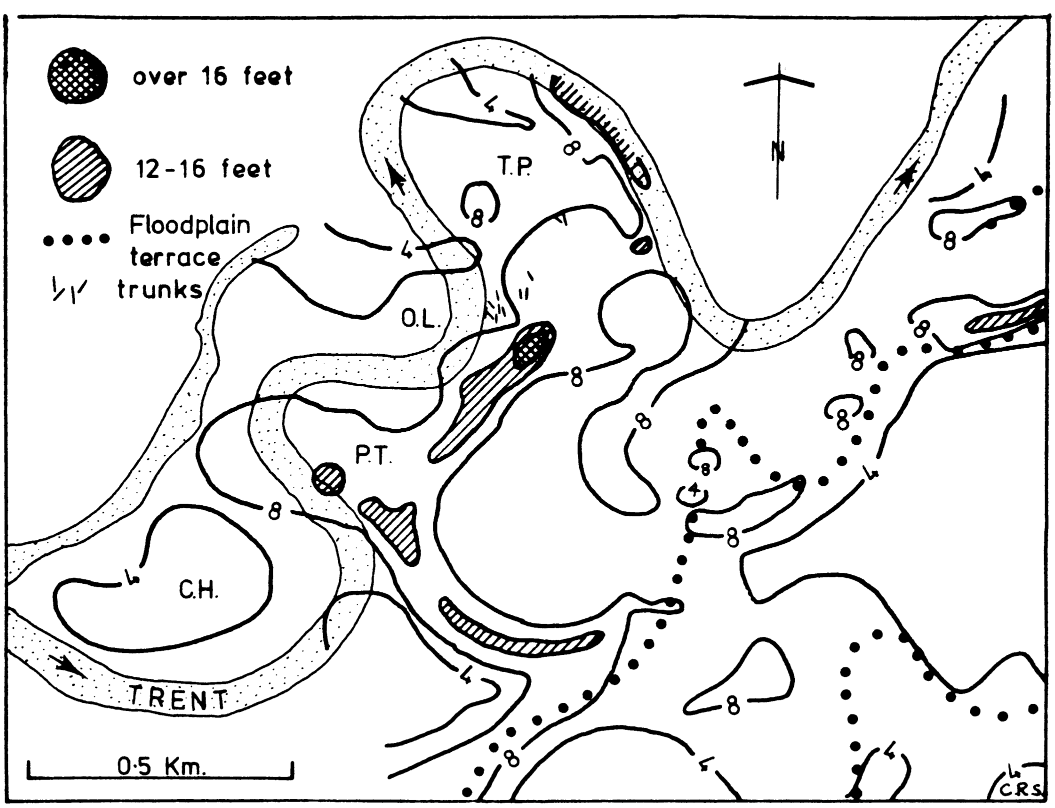
Table 1

Ancient Course	method of Dating	Evidence of the Course	Text–Figure
4000 - 1600 B.C. The Neolithic/ Bronze Age	Dendrochronology Radio-carbon	Alignment of sub fossil oak trunks	15 (1)
400 B.C. - A.D. 400 The Iron Age/Roman	Radiocarbon Archaeological (log boats)	Borehole data: Aerial photography: Trunk alignment: Cross bed stratification	15 (2)
A.D. 700 - A.D. 1200 Saxon/Norman Age	Radiocarbon Parish boundaries	Archaeological (Fish weirs): Cross bed stratification	
A.D. 1300 - A.D. 1500 Medieval Age	Archival	Parish boundaries: Aerial photography	15 (3)
A.D. 1500 - A.D. 1650 Tudor Age	Radiocarbon Maps Archival Archaeological (Sherds and metal objects)	Archaeological (bank revetments) Maps	9
A.D. 1800 and Stabilization Canal Age	Maps	Modern course	

This study has confirmed that archaeological artifacts in floodplain gravel are laid down in a lateral sequence, the layers accumulating as the meander expands. This is unlike the conventional picture of a vertical accreted sequence found in most archaeological sites such as those on the alluvial overburden. Borehole data gave remarkable evidence of early channels that were invisible even to aerial photography and the peat contents of the cores could be used for radiocarbon dating and vegetational analysis for pollen.



Text–fig.16. Thickness contours of gravel at Colwick obtained from borehole measurements. River course 2 on text–fig.15 appears infilled oxbow (after Spenceley, 1971).



Text–fig.17. Thickness contours of silt overburden at Colwick obtained from borehole measurements. River course 2 on text figure appears as an infilled oxbow (after Spenceley, 1971).

The most useful observation on the tree trunks was that they mostly lie with their roots upstream, showing both the direction of flow and the line of the river. It was hoped that a complete dendrochronological sequence could be established, dating back from the present, providing an Old World comparison with the Bristlecone Pine chronology in America, as has now been done using Oaks both in Ireland and Germany. This proved impossible because no trunks younger than 1600 B.C. were found, supporting the archaeological evidence of settlement and clearance of the valley in the Bronze Age. However, study of new trunks, as they appear, may alter this view.

The most striking archaeological observation was the preservation of ancient river beds under wooden weirs and revetments. If it is possible to date the posts by dendrochronology, as has since been done at Castle Donington and in the Idle at Eaton (personal observation), then river beds can be dated to within 20 years provided there is a master chronology with which to correlate the dates. In the East Midlands, this chronology goes back to A.D. 882. This is in stark contrast to radiocarbon dating of material of this age which gives a range of uncertainty of up to 500 years at the 98% confidence level.

The R.A.F. aerial survey of February 1946 was taken vertically and during flooding at a time when many features had not been obscured by modern farming, flood control and town expansion, it was particularly useful for detecting silted channels, scroll bars and ridge and furrow.

For the past 200 years, navigation downstream of Shardlow has required the construction of dams and locks and the channel has been stabilized by stone-walling and dredging. Upstream, where the Trent and Mersey Canal has usurped the navigation, the river is still uncontrolled and actively eroding its banks. Near Castle Donington, the remains of post and stone revetments, built in the 18th century before the canal was dug, now run down the middle of the stream or even cross to the opposite bank so that, by being archival evidence, it would be possible to estimate the rate of river erosion.

The Trent remains a large, powerful and unstable river as it always has been.

Acknowledgements

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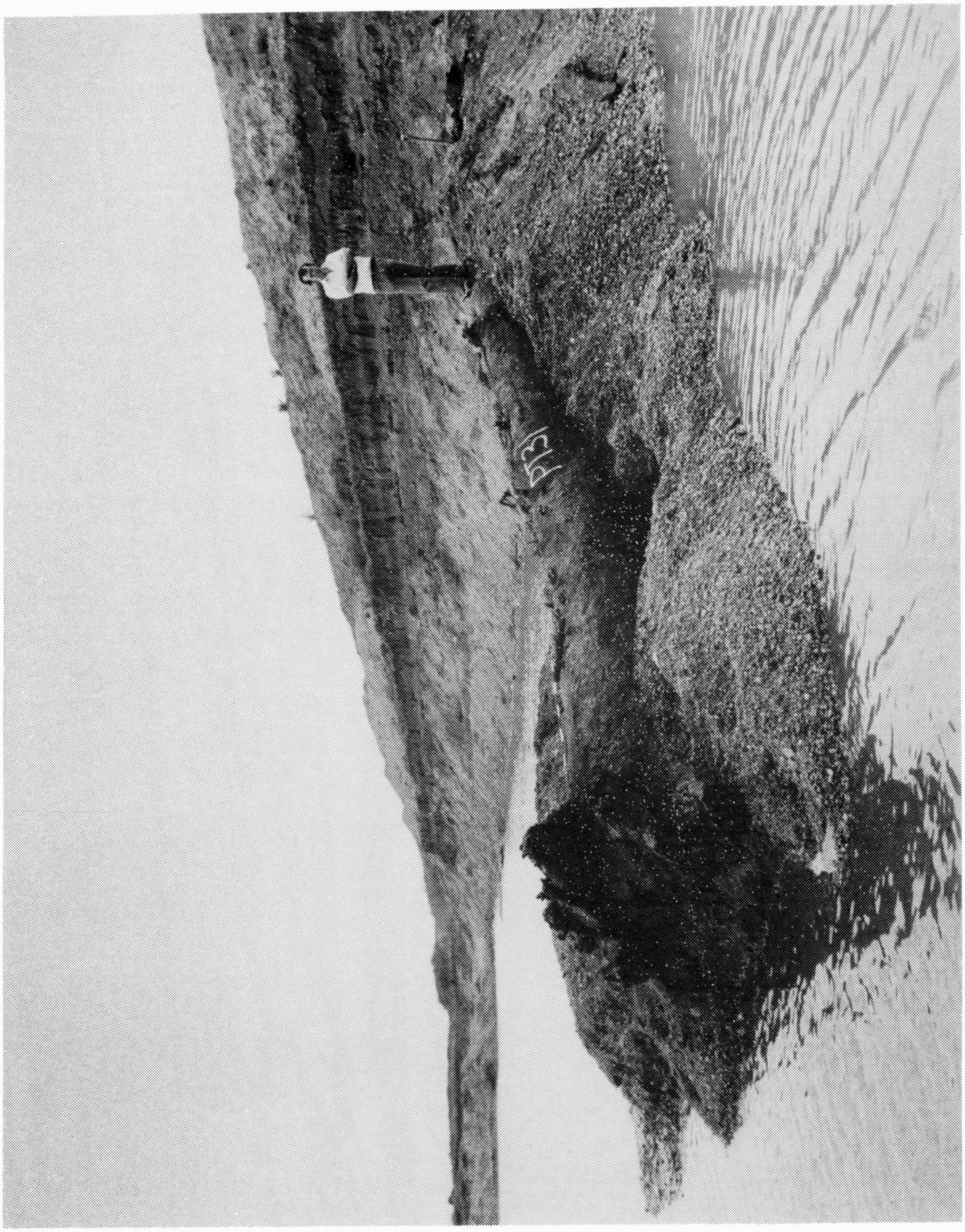
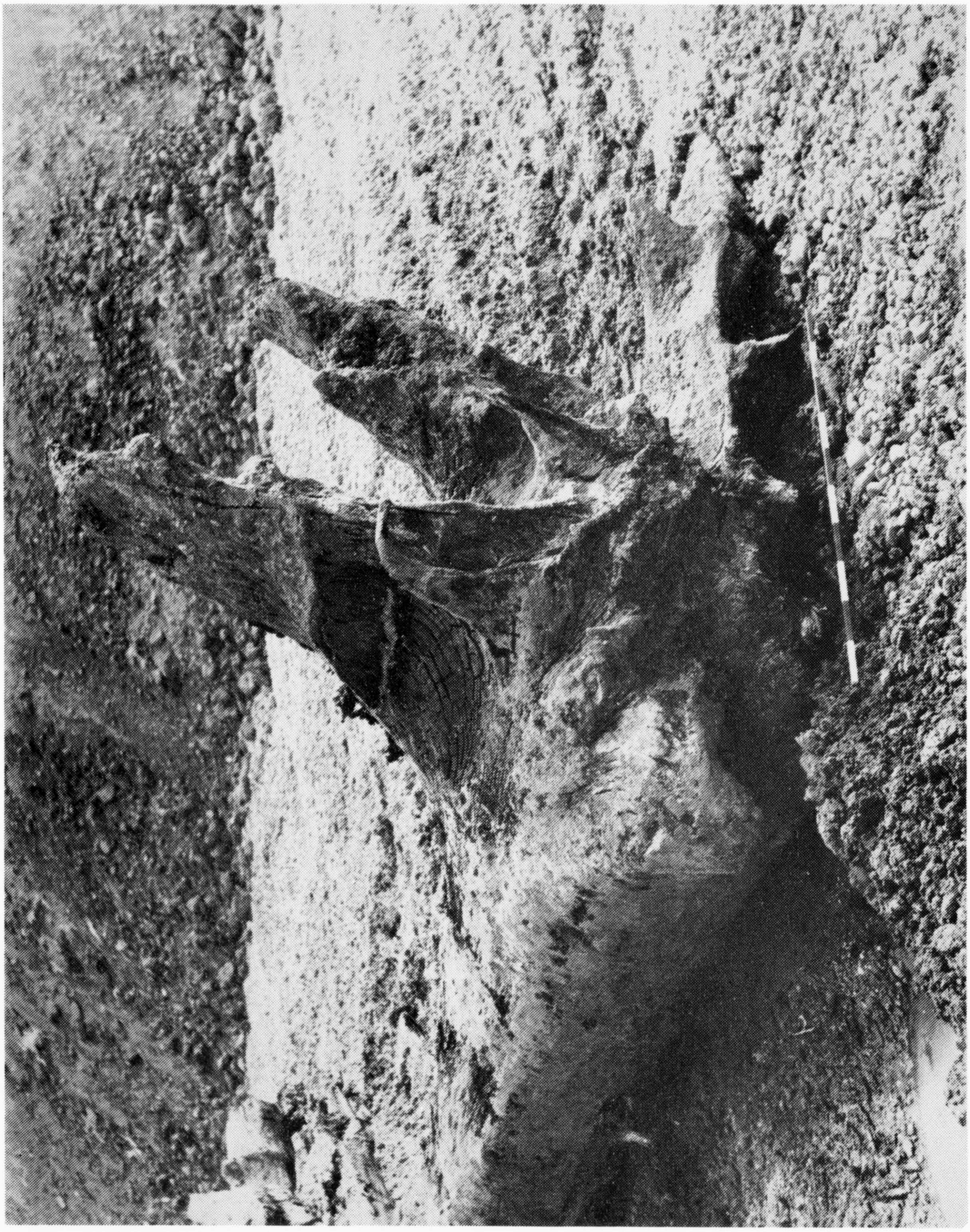


A tall, slim forest oak with no side branches, typical of many found in the Colwick gravels.



Roots of an oak tree from the Colwick gravels. Not in situ.

An old river bed, preserved as a stratum of cobble, beneath the Norman Fish Weir at Colwick.

THE OCCURRENCE OF A DINOSAURIAN PHALANX IN THE LOWER OXORD CLAY OF PETERBOROUGH, CAMBRIDGESHIRE

by

David Martill

Summary

A dinosaurian bone, probably a 1st or 2nd phalanx of the IV or II digit of an ornithopod dinosaur is described. The significance of dinosaurian remains in fully marine sediments is discussed with respect to the proximity of land and other palaeogeographic problems.

Introduction

Dinosaur remains account for approximately 1.0% of fossil reptile accessions from the Lower Oxford Clay of England in British museums. It is therefore important that all such finds from this formation are recorded. The purpose of this paper is to record an isolated bone discovered by a workman in one of the large brick pits in the vicinity of Peterborough, Cambridgeshire.

The discovery was brought to light when in the autumn of 1983 a collection of fossil reptile bones arrived in the City Museum, Peterborough. The collection includes the remains of ichthyosaurs, plesiosaurs, pliosaurs and crocodiles. Most of the material is of a fragmentary nature, although a portion of the axial skeleton of a ?*Cryptoclidus* is included. Amongst this material is an isolated dinosaurian bone, City Museum, Peterborough accession number - R50/1984.

The material was collected from the now disused brick pit known as Hicks and Gardner No. 3 (M.Howe, pers.comm.), which lies to the south of Peterborough, East of the main A15, National Grid Reference TL 1985.

The pit was dug for the Lower Oxford Clay (Callovian), a highly bituminous shale from which the Fletton brick is made. Usually the Lower Oxford Clay is dug in the jason to athleta zones, but in this vicinity only the jason to coronatum zones are present, the athleta zones having been removed by glacial erosion. It is therefore probable that the specimen came from one of these two zones, with the basal shell bed (Bed 11 of Calloman, 1968) being the most likely horizon (Duff, 1974).

Description

The dinosaurian bone is a well preserved isolated 1st or 2nd phalanx of the IV or II digit respectively, of the pes of an ornithopod dinosaur (text–fig.1). The bone is 40 mm long, 37 mm wide anteriorly, 41 mm wide posteriorly, 19 mm high centrally, 24 mm high anteriorly and 30 mm high posteriorly. The articulatory facet with the metatarsal or 1st phalanx is flat, with slight rugosity and a central depression, the trabecular nature of the bone is exposed indicating some wear to have taken place. The intraphalangeal articulatory facet, for 2nd and 3rd phalanx is smoothly convex, with a medium depression. There is a lateral and dorso-ventral constriction of the bone centrally, with a pronounced depression of the sides anteriorly. Nutritive foramina are conspicuous laterally, dorsally and ventrally. Some post-mortem cracking of the bone has taken place.

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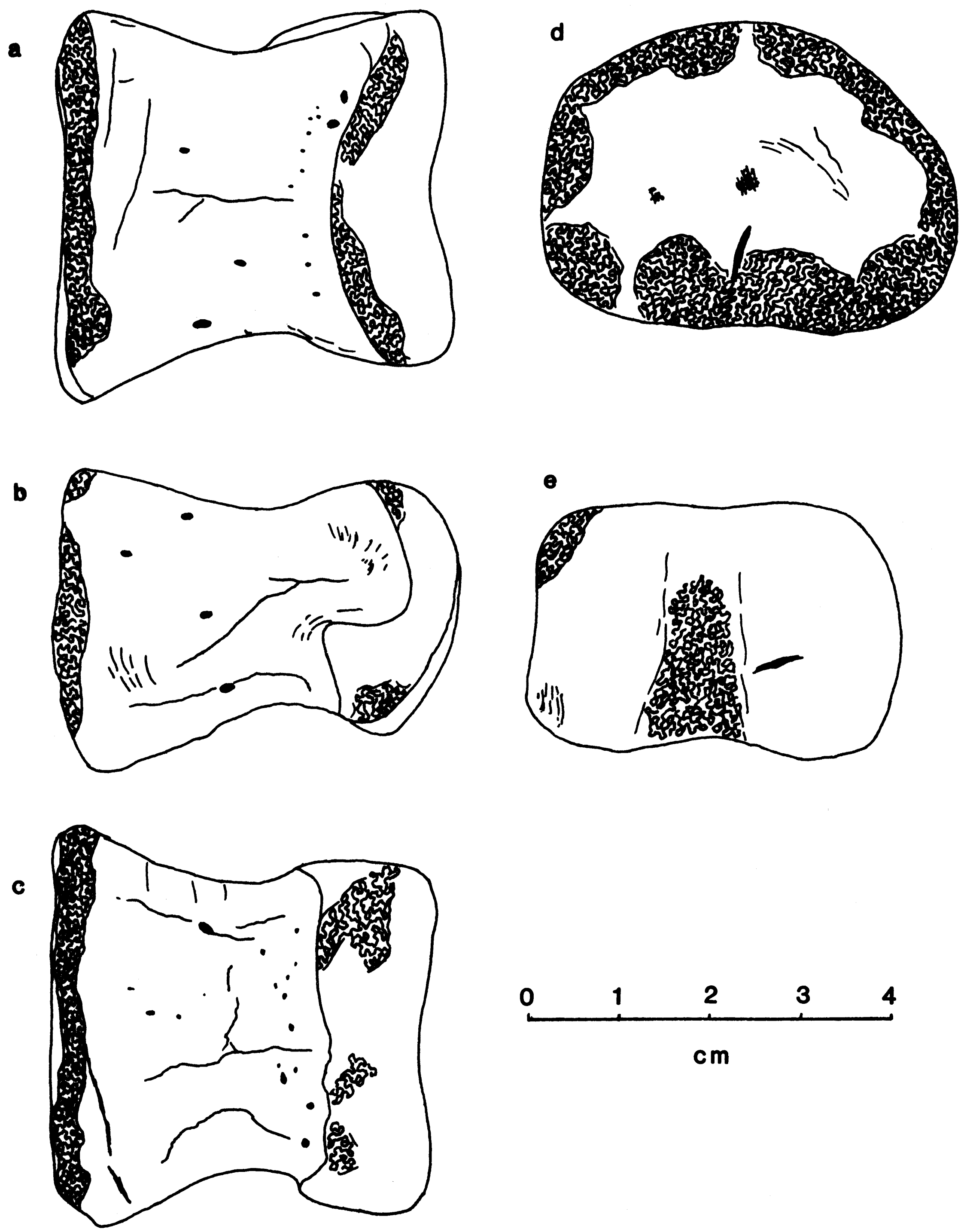
1984, pp. 209-211, 1 text-fig.



Text-fig. 1 Five views of specimen R50/1984 an ornithopod dinosaurian pes phalanx, a) dorsal view, b) right lateral view, slightly oblique from below, c) ventral view, d) posterior view showing facet for union with metatarsal, e) anterior view showing intraphalangial articulatory surface, all x 1.5.

Affinities

The above description proves that the bone is from an ornithopodous dinosaur, and has close affinities with phalanx elements from the pes of the igaunodontidae. It is not possible, or desirable, to attempt to identify the bone with any known genus, other than to suggest that strong similarities exist with *Camptosaurus* (Galton and Powell, 1980) and some hadrosaurs (Romer, 1956).

Recent work on dinosaurs from the Oxford Clay (Galton, 1973, 1974 a & b, 1975, 1977 a & b, 1980 a & b, 1981, Charig, 1980 and Walker, 1964) show that the Lower Oxford Clay contains a rare, but diverse fauna. Amongst this fauna are two ornithopod dinosaurs, the camptosaurid *Callovosaurus leedsi* (Lydekker) and a possible hypsilophodontid ?*Dryosaurus sp*. Each is known only from isolated bones and it is possible that this specimen may have come from one of these dinosaurs.

Discussion

The Lower Oxford Clay is a fully marine formation yielding abundant cephalopods, bivalves and gastropods; and comparatively abundant marine reptiles. The occasional discovery of dinosaur bones, and the superabundance of fossil wood indicate that land was in close proximity.

Apart from a few rare, complete or partially complete skeletons, dinosaur remains in the Oxford Clay consist of isolated bones only. The dinosaur remains so far discovered in the Oxford Clay are likely to be the prey of large crocodiles or carnivorous dinosaurs. Large crocodiles are known to drag their prey into water to drown. Such a process would enable at least a few mutilated carcasses to drift into the sea. Crocodiles are a common element of the Peterborough fauna, although the forms, *Steneosaurus* and *Metriorhynchus* were fully adapted to a marine environment, more terrestrially adapted crocodiles may have lived in local rivers and estuaries.

Acknowledgments

I should like to thank Dr. Peter Crowther of Leicester Museum for bringing the new Peterborough accesion to my attention.

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PRESIDENTIAL ADDRESS 1984
PARADOXES OF THE COLORADO PLATEAU

by

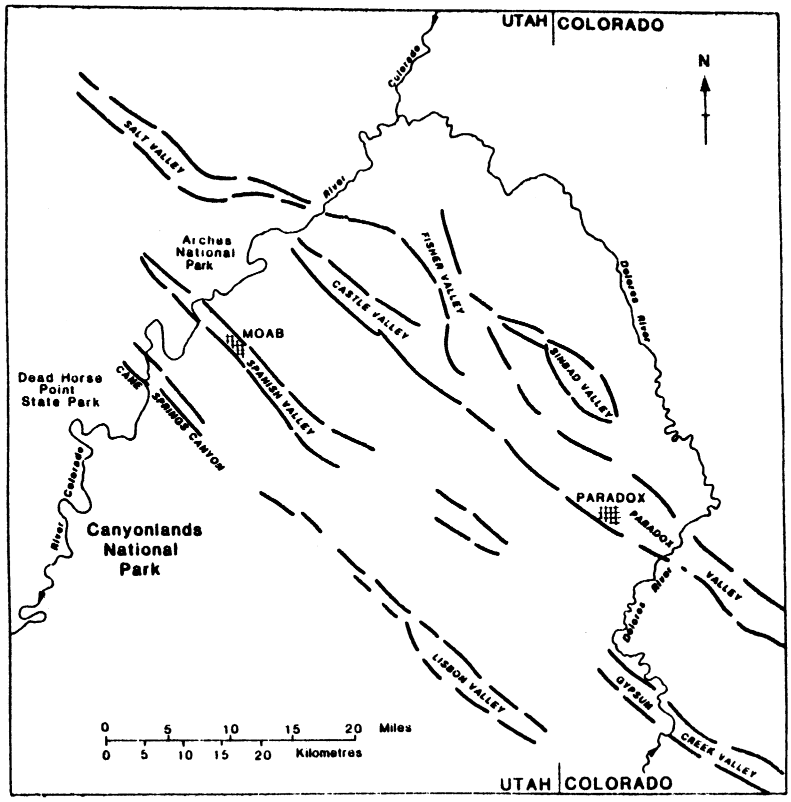
Trevor D. Ford

Summary

Study of the geological history of some 200,000 square miles of the southwestern United States reveals numerous paradoxes. The drainage crosses structures in unexpected fashion. Marine transgressions came from different directions; fluvial and aeolian sediments were supplies from contrasting directions. An enclosed salt basin contains large hydrocarbon reserves, with their distribution related to basement faults. Precambrian rocks tell a very incomplete story of a billion years of sedimentation and plate tectonics. Igneous activity and metalliferous mineralization are largely confined to Cenozoic rocks. Plate tectonic hypotheses can explain only some of the features, and many problems remain unsolved.

Introduction

The title of this Presidential Address is taken from the name the early settlers of last century gave to a feature they found in eastern Utah — the Colorado River flowed across and not along a flat-floored valley. It flowed out of one canyon, across the valley floor and back into another canyon (text-fig. 1)! To them this was an enigma, something unexpected — a paradox! As we now know this paradox is because the general southwesterly course of the river was superimposed from a higher stratigraphic level on to a transverse salt intrusion where subsurface solution had removed some salt and caused the partial collapse of the cover rocks. A return to this topic will be made later.



Text-fig. 1 Sketch map to show the relationship of the salt valleys to the meandering course of the River Colorado and its tributary Dolores River.

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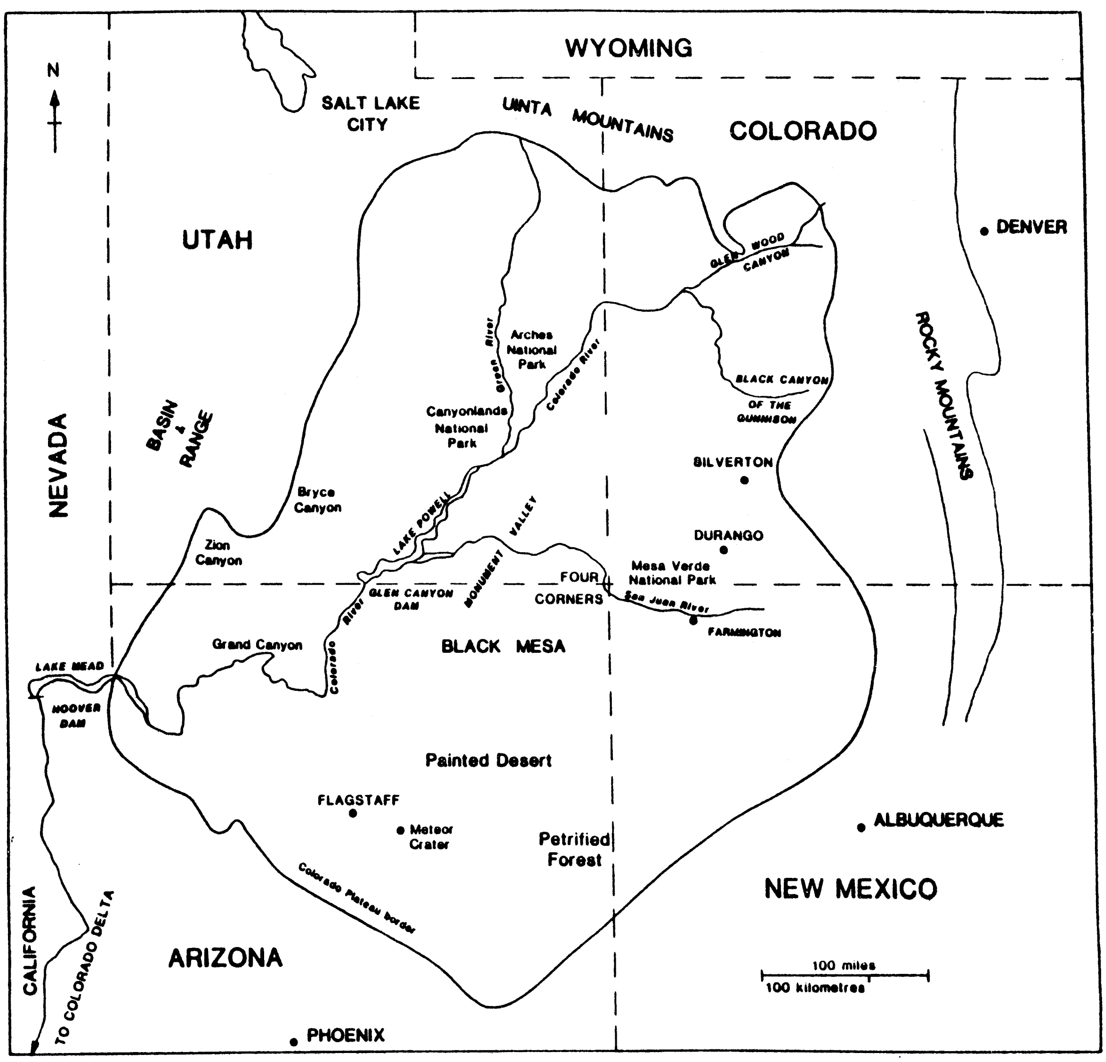
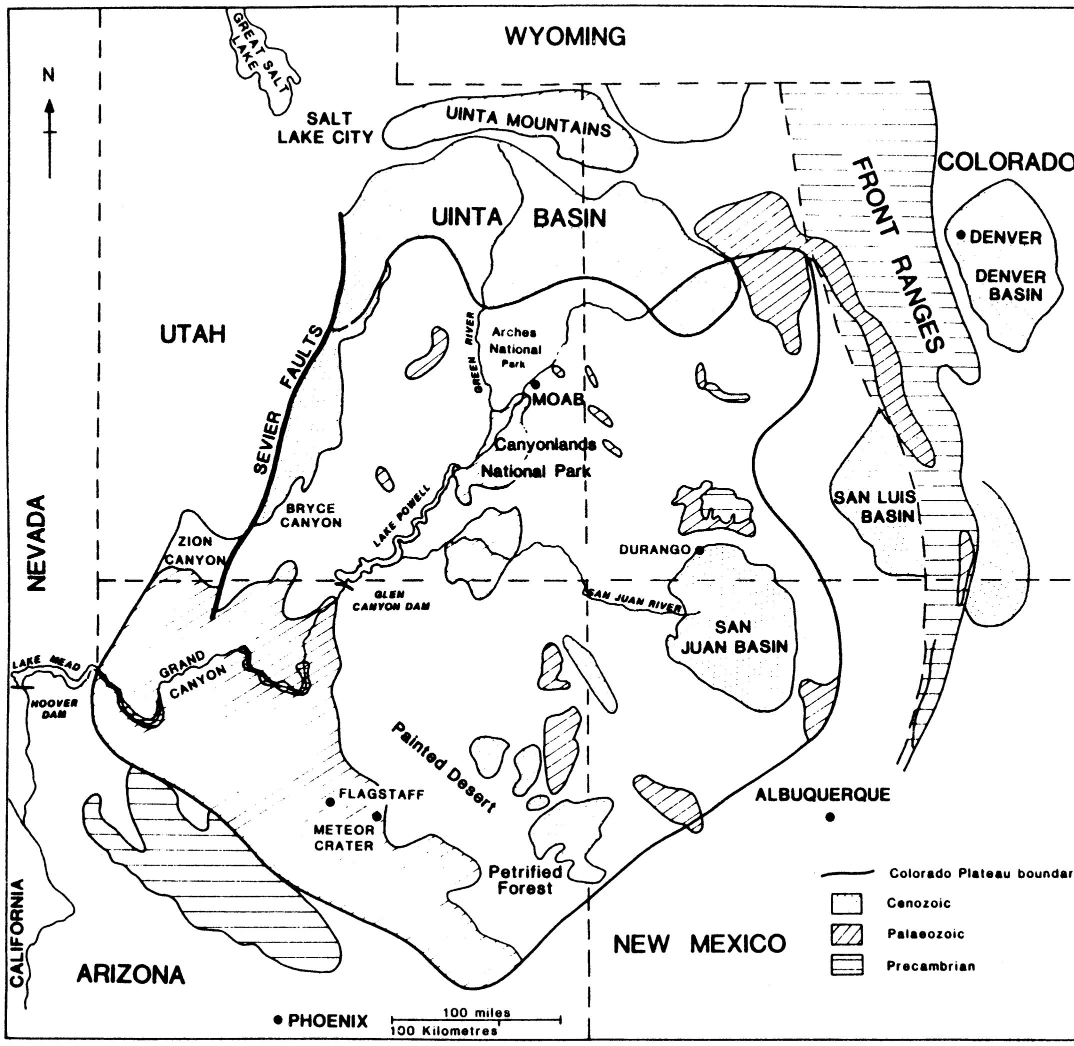
The Colorado Plateau is an area of the southwestern United States which includes many of the great scenic marvels, such as the Grand Canyon (text-fig. 2; Plates 26A & B). It may be defined as those parts of the States of Utah, Colorado, New Mexico and Arizona which lie between the Front Ranges of the Rocky Mountains on the east and the block-faulted ranges of the Basin and Range Province to the west. Within the Front Ranges there are a number of small sedimentary basins, partly masked by volcanic outpourings, so that the Plateau boundary is a matter of opinion, and is variously taken to include or exclude the San Juan volcanic and other mountains. To the south the Plateau is bordered by the great receding escarpment of the Mogollon Rim, (Plate 27A) which overlooks much lower ground with many Precambrian outcrops in central Arizona and New Mexico. To the north of the Plateau are the Uinta Mountains, a major east-west upwarp across northeastern Utah. Much of the Plateau is at altitudes of over 2,000 m and parts rise to nearly 3,500 m. In area it is about three times that of Britain, so we are dealing with the geological evolution of a vast area in the short space of one lecture. Whilst I obviously cannot go into every aspect of the Plateau's history I hope that my discussion of the following problems will focus your thoughts on the geological arguments and methods of analysis which can be applied in the Colorado Plateau, and, in so doing, I hope that you will think about some of the paradoxical problems of British stratigraphy which still await solution.

The climate of the Plateau is mostly semi-arid, though the higher mountains attract some precipitation and are covered in pine forests. The run-off and snow melt give rise to the limited river network, almost all flow being via the Colorado River and its tributaries. A few of the highest peaks show evidence of glaciation but otherwise the landscape is partly fluvial and partly desert. The latter characteristic meant that the region was one of the last on the North American Continent to be explored by Europeans; indeed John Wesley Powell's exploration of the Grand Canyon in 1869 is really the starting point of detailed penetration by white men. Indian tribes occupied much of the region then and still have vast reservations, such as the Navajo reservation which is virtually a nation within a nation.

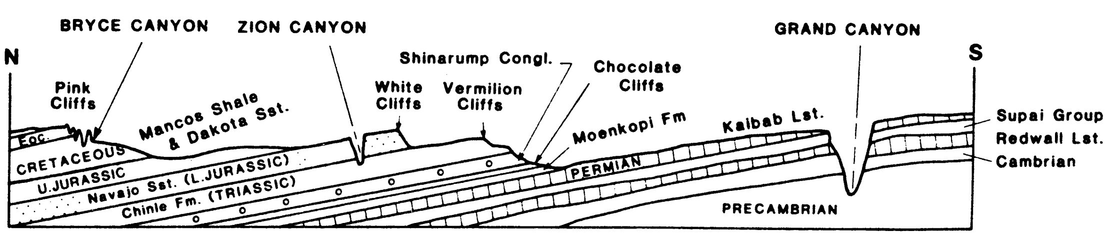


Text-fig. 2 Sketch map of important locations in the Colorado Plateau area.

The stratigraphy of the Colorado Plateau is relatively simple (text-fig. 3). A Precambrian basement, partly crystalline and partly sedimentary, is covered by sedimentary strata ranging from Cambrian to Tertiary in age. Over much of the Plateau the strata are flat-lying and individual beds of rock can be traced without a break for as much as 400 km in such places as the Grand Canyon. However, there is an overall regional northerly dip so that Mesozoic and Cenozoic rocks form much of the Plateau surface in the northern half. The alternation of hard and soft strata is reflected in the Grand Staircase of escarpments, particularly well developed in the Grand-Zion-Bryce Canyon area (text-fig. 4).



Text-fig. 3 Generalized stratigraphic map of the Colorado Plateau, with important sedimentary basins indicated.



Text-fig. 4 Diagram of the 'Grand Staircase' of northward inclined strata in the Grand Canyon, Zion Canyon, Bryce Canyon area of the southwest Colorado Plateau.

In spite of its apparent simplicity the Plateau has a number of strange features. Some are not quite what they appear to be at first sight; others are the result of unexpected or concealed processes; some defy explanation. These are the paradoxes forming the subject of this address.

The topic of this address is large and the literature extensive. I have consulted numerous publications and only the most pertinent have been cited as references. Particularly useful sources have been the books by Breed and Roat (1978), Hintze (1979) James (1973), Kent and Porter (1980), Nations and Stump (1981) Baars (1983) and the Geological Atlas of the Rocky Mountain Region (R.M. Atlas, 1972).

Drainage Paradoxes

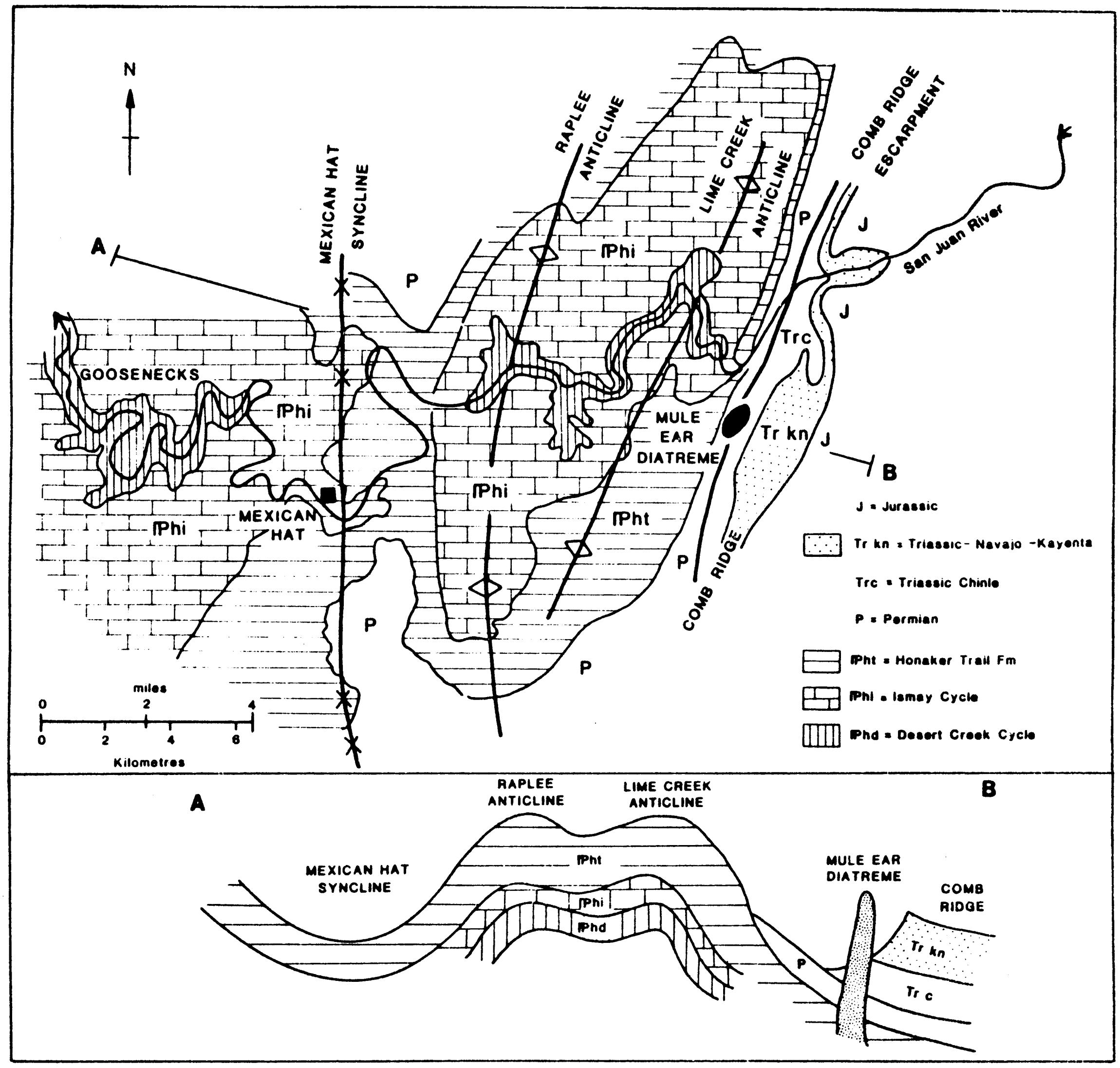
The Colorado Plateau is drained largely by one of the longest rivers in North America, the Colorado, and its tributaries. This is a paradox in itself. Its course is generally southwestwards, but the general level of the Plateau surface is higher in the southwest than the north east. True, the river has its sources in the Front Ranges, west of Denver, outside the Plateau proper, but it would be more logical for the drainage to turn south towards the Gulf of Mexico. Charles Hunt (1969), McKee et al. (1967) and Beal (1968) have discussed a general sequence of events of river-capture, tectonic diversions and abandoned routes to which I will return. However, I want only to concentrate on two aspects here—the San Juan Canyon through the Raplee anticline and the Grand Canyon itself.

The course of the San Juan river from Bluff to Mexican Hat, Utah, starts in a wide but shallow canyon mostly cut into horizontal Navajo Sandstones (lowest Jurassic) (Baars, 1973). As the river approaches the Raplee/Lime Creek anticline the strata tilt up to more than 45° and the canyon walls alternately recede through mudstones and converge through harder rock formations (text-fig. 5; Plate 27B). The anticline itself is made of Pennsylvanian cyclothems of limestone, shale and some sandstone, over 300 m thick, and the river plunges straight into a wall of these cylothems to enter a narrow winding canyon in places 300 m deep. It meanders about, passes by abandoned ox-bow canyons, and emerges some 15 km further on the other side of the anticline to meander gently through low-lying Triassic mudstones. With the almost bare rock landscape there is no doubt that this is a classic example of superimposition from a former cover of Permian to Cretaceous strata once overlying the Pennsylvanian. Other impressive incised meanders have been superimposed from the Mesozoic cover on to Pennsylvanian strata further downstream at the Goosenecks (Plate, 28A). Powell's early suggestions of antecedence where the fold rises as the river cuts down is difficult to support here though it may have been a factor. The paradox of a river cutting a gorge through an anticlinal ridge instead of going round it is thus explained. And what the San Juan does on moderate scale is just what the Colorado River has done on a large scale in the Grand Canyon.

The Grand Canyon is incised for some 500 km length and 1500 m depth into the Kaibab Plateau in northern Arizona. The paradox is again, why cut through the upwarp and avoid going round it? Again the disposition of the surrounding Mesozoic strata makes it quite clear that they once extended over the present Plateau surface of Permian dolomites, and that superimposition from a much higher stratigraphic level has occurred. But the Kaibab Plateau is now at 2500-3000 m above sea level and to add another few thousand metres of Mesozoic beds would give an unacceptable altitude, possibly higher than the present source regions! Here it seems that there is evidence of antecedence and that the Kaibab upwarp has been growing during incision of the canyon, as Powell suggested. There is still more to it, however, for McKee et al. (1967) and Beal (1968) have both suggested that the earliest course did not cross the upwarp but went southwards to join the Rio Grande drainage. Tectonic uplift in Southern Arizona blocked this outlet and a lake was formed. When early drainage cut its headwaters back across the Plateau from the west it captured the Ancestral Colorado and as the knick point went back up the Little Colorado it drained the lake into the Grand Canyon. This is a nice tidy hypothesis but Rice's work (1974, 1983) on the terraces of the Little Colorado has failed to reveal any evidence of early terraces grading southwards into the Bidahochi Lake, only of terraces grading in the same direction as the Little Colorado flows today. An unsolved paradox? The mechanism of incision of the headwater channel across the Upwarp is yet another puzzle: Hunt (1969) suggested that some part could be due to a large collapsed cave, whilst McKee et al. (1967) regarded the headward eroding gully as sufficient, fed as it would be by precipitation from prevailing westerly winds. The precocious cave theory versus the precocious gully theory (Breed, 1970)! As something of a speleologist, I can say that I have seen no evidence of any large former caves in the appropriate sections of the Grand Canyon.

The solutions to these paradoxical problems may well lie in the little studied western Grand Canyon area. Here Young 1979, 1981) has demonstrated the presence of former deep canyons cutting across the line of the Grand Canyon. These were filled with aggradation gravels and ash-flow tuffs by Miocene times, and are no longer easy to recognize. Sedimentary features indicate that the drainage was northwards and northeastwards, i.e. contrary to the present drainage direction, implying the presence of a high altitude source region at the southern end of the Sierras with drainage to the northeast. Later massive downfaulting and down-warping of the source region is amply demonstrated, e.g. by the westward downthrows on the Hurricane and Grand Wash fault systems. Comparable uplift of the southwest Colorado Plateau is shown by the displacement of gravels and lavas along the Mogollon Rim (Pierce et al., 1979). The Plateau uplift may be associated with the plate tectonic recoil of the Basin and Range province from early uplift to late downwarping and the ancient drainage system was dismembered by late Miocene times. Headwards erosion into the fault scarps then gave us the Hualapai drainage which cut back across the Kaibab upwarp as noted above. Young (1979, 1981) also noted that the Grand Canyon outlet cuts through lacustrine sediments of Miocene age, and the mouth of the Colorado in the Gulf of California cannot be older than the Gulf itself which is known to date from perhaps no earlier than earliest Pliocene. This implies that the present course of the Colorado River is no more than about 5 million years old, but there are lavas within the western Grand Canyon 1.2 to 3.8 million years old. This convergence of dates before and after the incision of at least the western Grand Canyon can lead into a chronological paradox, and obviously more study of the problem is urgently needed.

The argument for a former northeasterly course of the drainage across the southwestern corner of the Plateau leaves us with yet another riddle: where did the river flow to? Where was its mouth? Dating of lava flows and ash-fall tuffs places the main flow in the Eocene when much of the western Utah was occupied by a lake which in turn linked with lake Gosiute in Wyoming where the lacustrine Green River Formation was deposited. An Eocene ancestral River Colorado flowing northeast across the southwestern margin of the Plateau could well have emptied into such a lake system. But this then raises the question of where did the lake itself empty? And it leaves us with yet another paradox—the ancestral river flowed north to Green River, whereas the present day Green River itself is a tributary of the Colorado and flows south!



Text-fig. 5 (a) Sketch map of the canyon of the San Juan River through the Raplee/Lime Creek anticline, southeast Utah (after Baars, 1983a).

(b) Diagrammatic section through the Raplee/Lime Creek anticline.

Stratigraphic Paradoxes

Views of the Grand Canyon and of many of the other canyons give the impression of "layer-cake" stratigraphy, with beds going on for ever more or less horizontally. Traversing the Colorado Plateau one can pick out familiar strata like signposts and again the impression is of continuity of beds. But this is a false impression—a paradox! No single bed of sediment can be laid down over such a vast area without variation and simultaneously—most beds are diachronous. Obviously space does not permit consideration of all the stratigraphic variations on the Plateau so only a few can be considered and then only briefly. (Further details are summarized in the Rocky Mountain Geologic Atlas 1972).

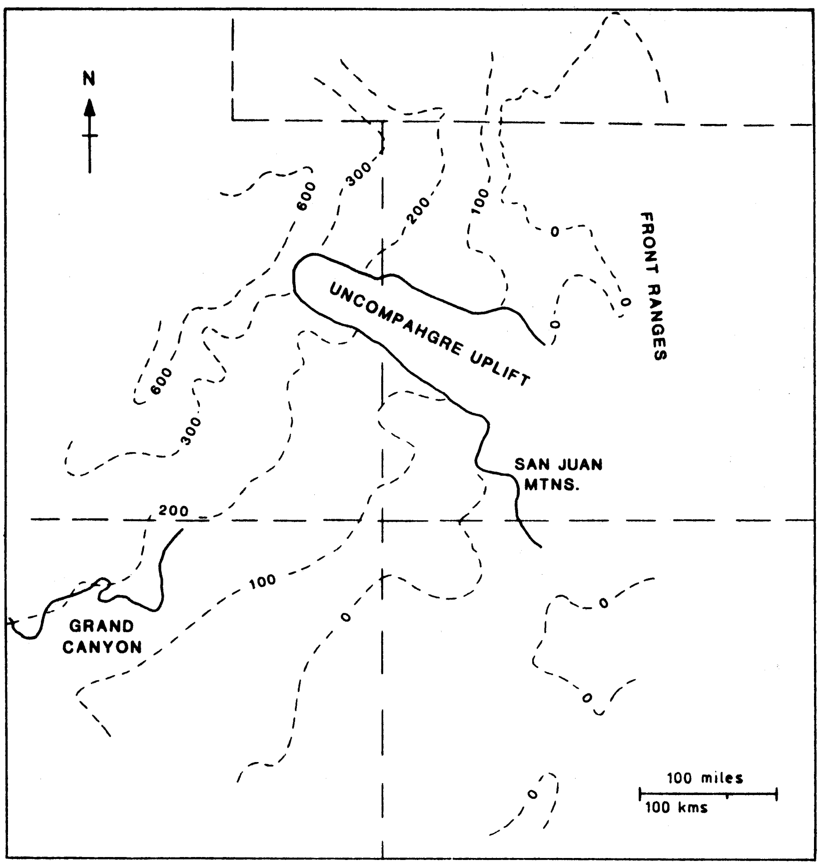
Immediately above the Great Unconformity in the walls of the Grand Canyon is the Cambrian Tapeats Sandstone, some 100 m thick (McKee and Resser, 1945). Coarse-grained at the base it becomes finer and marked with abundant trace-fossils towards the top. Occasional shale bands contain fossils, such as trilobites. These make it clear the Tapeats Sandstone is diachronous—in the western Grand Canyon it is of Lower Cambrian age whilst in the east it is Middle Cambrian. So collectively it is a shallow-water formation of clastic detritus deposited as the marginal sediments of a massive marine transgression. McKee and Resser (1945) have given details. The equivalent Ignacio Quartzite in the San Juan Mountains is much thinner and its exact age is not known. Though apparently a direct continuation of the Tapeats sandstone palaeontological evidence suggests that it is Upper Cambrian in age (R. M. Atlas, 1972). Thus it continues the diachronous transgression. Some areas of the Plateau have no Cambrian beds and remained exposed throughout Cambrian times. The zero isopach may be thought to indicate the position of the Cambrian shoreline but, just as the Tapeats Sandstone is diachronous, so also may such a shoreline be diachronous.

Ordovician strata are limited to a westward-closing gulf in central Colorado and there are no Silurian strata at all. These indicate widespread regression partly reversed by limited transgression in the Devonian. The massive Mississippian Redwall Limestone of the Grand Canyon seems to have equivalents over much of the Colorado Plateau, but again, if detailed subdivision is considered along with palaeontology, there were two major transgressions and two regressions, and much of the Plateau was never covered (McKee and Gutschick, 1969; De Veto, 1980a). Isopachs show that the Mississippian is missing over the Uncompahgre Uplift and much of the eastern Plateau (text-fig. 6). The Mississippian also thins over some of the uplift areas such as the Defiance uplift. Transgression of Mississippian seas clearly took place from an ocean in the west and only in parts of the period did the seas circumvent the uplifts into some of the more easterly basins (R. M. Atlas, 1972). The "ocean" to the west is an enigma as still further west there is evidence of an orogenic belt at this time—the Antler Orogeny, so perhaps our "ocean" is a back-arc trough.

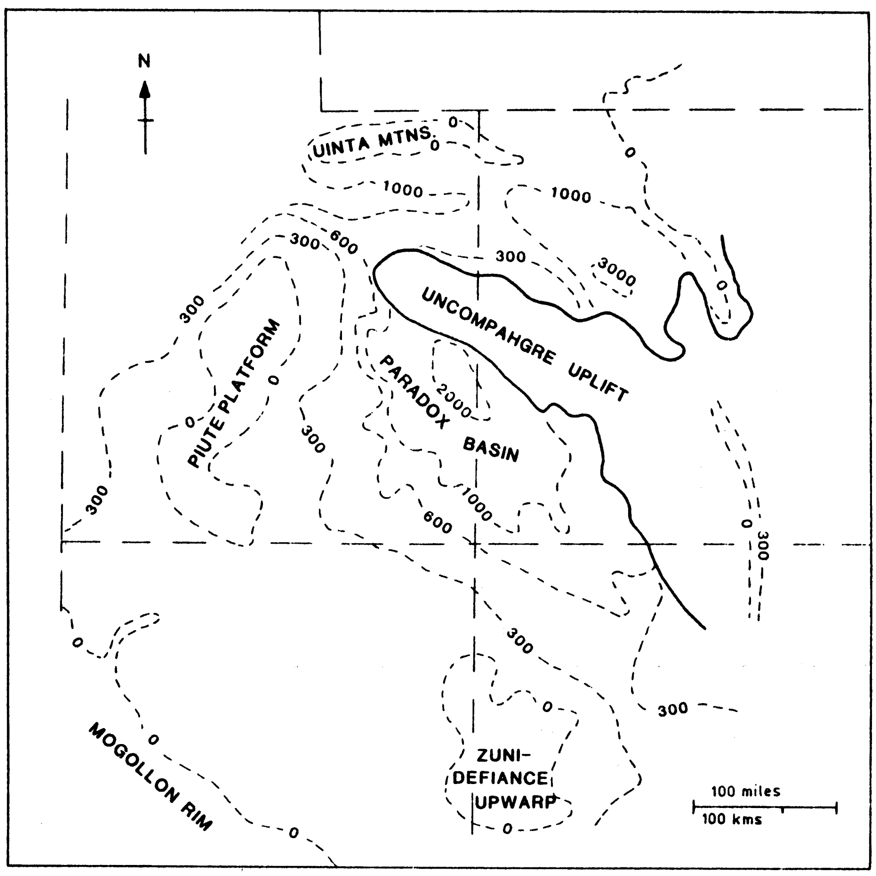
There seem to be no Namurian strata in most of the Plateau area; in fact Pennsylvanian beds rest with marked disconformity on an eroded and chanelled surface of the Mississippian in the Grand Canyon (McKee, 1982). Much further east, at Molas Pass in southwest Colorado, Pennsylvanian shales blanket a palaeokarstic surface cut into Mississippian limestones (Plate 28B). When Pennsylvanian sedimentation resumed it was in marked contrast to the earlier marine transgression, being formed of fluvial sandstones and minor shales in repeated cyclic build-outs of fluvial fans. The sediment source was from the north, at right angles to the direction of marine transgression. Even then, sedimentation was not continuous and occasional thin limestones and conglomerates mark periods of emergence, minor erosion and brief marine transgression before the fluvial regime was resumed. Isopachs show that the Pennsylvanian maintained a fairly even thickness over much of the Plateau, but there was a deep downwarp in the Paradox Basin (text-fig. 7).

In the east of the Plateau uplift of the Ancestral Rockies gave rise to spectacular fans of breccia and conglomerate in the Fountain and Maroon Formations, often seen resting unconformably on Precambrian gneisses. A marine gulf in central Colorado gave cyclothems with spectacular reef developments near Minturn (De Voto 1980a; Wray, 1983). Comparable algal reef mounds are common in parts of the Paradox Basin on the Utah/Colorado border, and are discussed later.

Permian sedimentation in the Grand Canyon region gives at first muddy fluvial sediments followed by the widespread aeolian Coconino Sandstone, with dune-bedding clearly indicating a northerly wind direction and source (McKee 1933; Poole 1962). A minor enigma here is the presence of occasional reptile footprint trails on the topset bedding which lead to the crest of an ancient dune and stop—where did the reptile go? Simply, when it went over the crest it encountered loose sand and slithered rapidly down the fore-slope leaving no footprints! The early Triassic Shinarump Conglomerate (remarkably like our own Bunter Pebble Beds) outcrops widely in the Painted Desert and north and north east of the Grand Canyon. Some of its pebbles were derived from parent rocks of Precambrian and Palaeozoic age now outcropping in central Arizona, 1000 m lower in altitude today (Dodge 1973). As there is insufficient evidence of massive faulting to account for this discrepancy, the paradox can only be solved by proposing that the parent rock masses were once very much higher!



Text-fig. 6 Isopachs in metres of Mississipian strata on the Colorado Plateau.

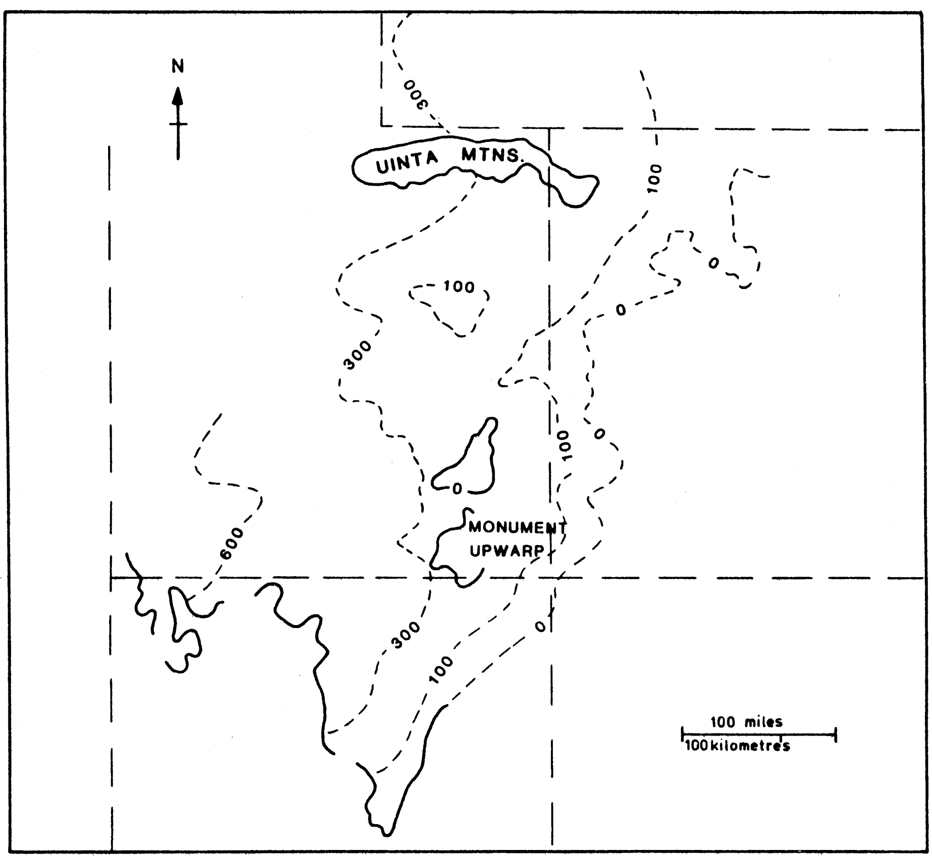


Text-fig. 7 Isopachs in metres of Pennsylvanian strata on the Colorado Plateau, showing the Paradox Basin downwarp.

Jumping ahead, late Triassic to early Jurassic sedimentation is marked by much more aeolian sandstone in the Glen Canyon Group, including the massive Navajo Sandstone, now so well seen in the walls of Zion canyon (Plate 29A). Here the paradox is that the ispachs and wind-directions indicate a source to the west, where in Carboniferous times there was marine trough (text-fig. 8). By Navajo Sandstone times orogenic activity west of the Plateau had provided a new mountain range along the western edge of the continent, the beginnings of the Sierra Nevada, with easterly subduction causing uplift, metamorphism and granitic intrusion. Even so, it is difficult to envisage this new mountain belt as being sufficient to supply the sheer quantity of sand in the Navajo Sandstone, up to 500 m thick, covering an area 500 by 400 km (Poole 1962; McKee 1979).

The Colorado Plateau remained a region of terrestrial sedimentation through most of Jurassic and Lower Cretaceous times with widespread sheets of fluvial sandstones and shales again derived from the Californian mountains to the west. There were some marine invasions: the middle Cretaceous marine Mancos Shale and its correlatives contain ammonites, though there was no seaway in the west from which the marine transgression took place. This time the sea came in from the south, the Gulf of Mexico region.

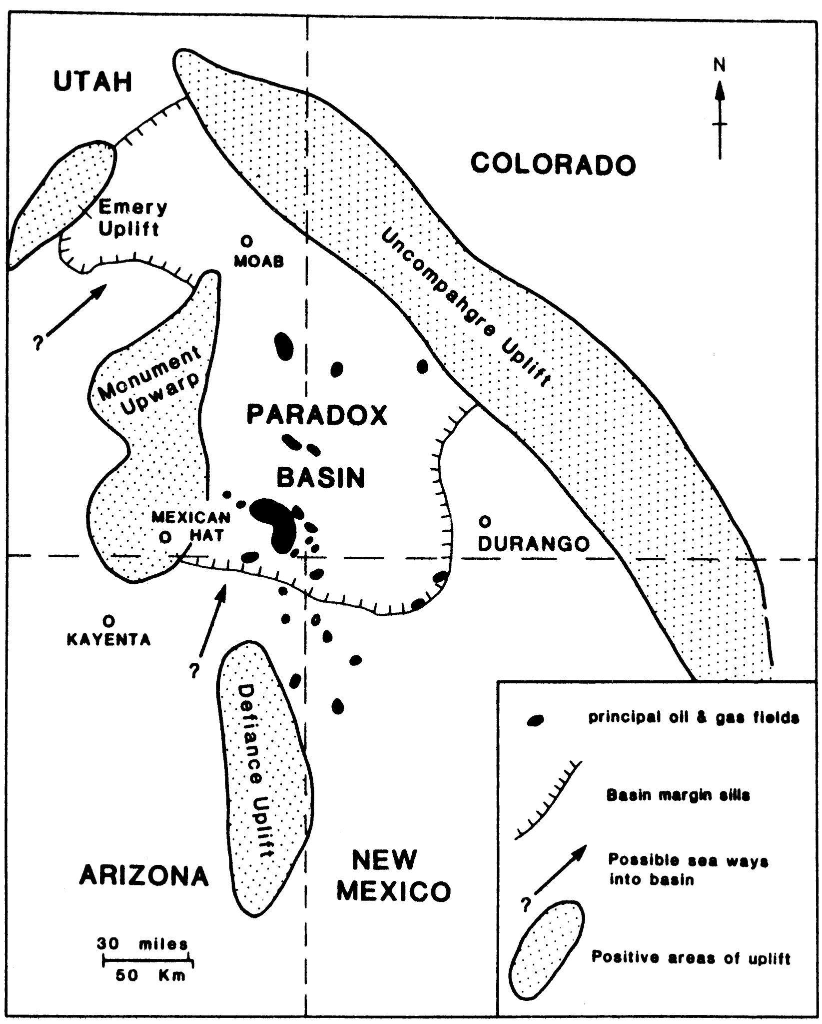
Our stratigraphic saga ends in the early Tertiary with a fluvial system across much of the Plateau draining into a group of lakes in which the Wasatch Formation was deposited (R. M. Atlas, 1972). Coarse conglomerates mark the northwestern margins in central Utah but to the southwest calcareous clays and silts now form the high plateaux into which Bryce and other spectacular canyons have been cut. At nearly 3000 m altitude they are amongst the highest parts of the present Plateau and so present the paradox of where were the lake shores and whence came the drainage into the lake? At least a partial answer is that the block faulting along the western margin of the Plateau has uplifted the lake sediments above their source area, which must have included some part of the former roof above the granite plutons of the Sierras.



Text-fig. 8 Isopachs in metres of upper Triassic to lower Jurassic aeolian sandstones on the Colorado Plateau (the zero line is partly an erosional truncation).

Before leaving the enigmas of the stratigraphic record, it is profitable to return to a limited area in Pennsylvanian times—The Paradox Basin. Trending roughly northwest to southeast across eastern Utah into western Colorado, the basin is some 300 km long and 150 km wide (text-fig. 9). It is characterised by some 2000 m of Pennsylvanian cyclothems containing thick evaporites and today yielding a considerable amount of oil and gas. Much of our knowledge comes from subsurface investigations by the oil industry (Wiegand, 1981) summarized by Baars (1983). The basin is bounded by the Uncompahgre Uplift on the northeast, upfaulted Precambrian with a thin Palaeozoic cover. To the nortwest, west and southwest the Basin is less will-defined by the Emery, Defiance and Zuni upwarps.

The problem is that the Basin has such a thick sequence of cyclothems and that so many of them contain evaporites. Each cyclothem is effectively: limestone—black shale—some sandstone—evaporite. The latter is mainly halite and the depositional salt thickness may have been over 2km in some fault-bounded half-grabens. Carbonate rocks are best developed round the margins as shelf sediments, bordered by reef mounds (Choquette, 1983) with pene-contemporaneous black shales in the centre; sandstones and conglomerates, if present, appear to be fans of fluvial input from the northeast, from the Uncompahgre Precambrian, which had rejuvenated uplift at the time of the raising of the Ancestral Rockies. The limestone and shale is followed by anhydrite and halite, with a little potash. These can only be deposited if one envisages a partially closed basin with a sill over which sea-water flows inwards to balance evaporation within, thereby providing a continuous supply of salts. Cyclic repetition of evaporites and clastic sediments suggest an intermittent breaking and re-establishment of the sill and gulf by tectonic movements.



Text-fig. 9 Sketch map of the Paradox Basin and its oilfields.

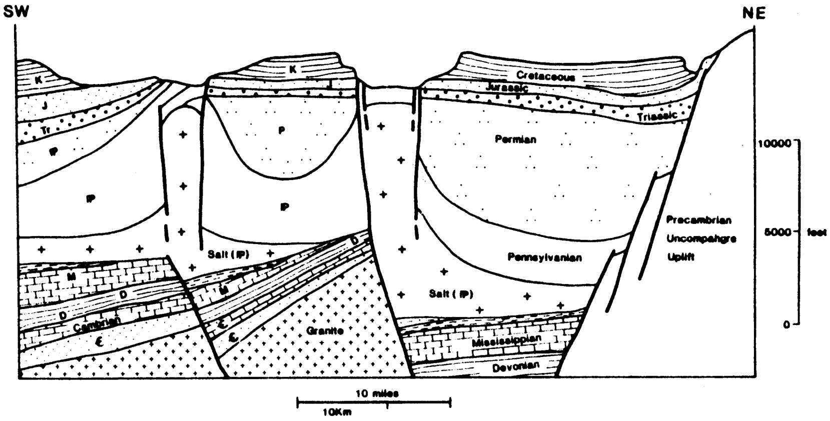
A possible alternative explanation for the Paradox salt basin is that proposed by Hsü (1972) for the western Mediterranean and other giant salt basins. This hypothesis involves the total evaporation of sea-water in a deep marine basin cut off by tectonics from the rest of the oceans. The possible application of this hypothesis to the Paradox Basin has not been examined, though the repeated cycles of evaporites and clastic sediments imply the unlikely event of frequent re-establishment of the deep basin and total evaporation. The shallow silled gulf seems the more likely explanation of this saline paradox! Perhaps instead we should look for eustatic, perhaps global, changes of sea-level? If the latter explanation is correct, can we correlate the changes with episodic glaciation in the Southern Hemisphere and in turn with British Coal Measures cyclothems? This may be asking too much of stratigraphic correlation but it is a hypothesis which cannot be disregarded.

The Paradox basin is a rich oil region, having yielded nearly 300 million barrels of oil and over 200 billion cubic feet of gas, with perhaps four times as much still in place (Baars and Stevenson, 1982). But whence came so much hydrocarbon accumulation? Put simply, from the black shales in Pennsylvanian cyclothems, rich in organic detritus and buried to a depth appropriate for hydrocarbon maturation; the oil then migrated into limestones and dolomites in the same cyclothems. Reefs in particular were good traps (Choquette, 1983). The cap rocks were either salt or shales in higher cyclothems.

The geological map of the Paradox Basin shows a series of parallel NW-SE salt anticlines (Carter & Craig, 1970) one of them being the Paradox anticline where we started this address. But why the linear salt structures? A combination of geophysics and deep drilling has shown that each anticline lies along a fault affecting the Precambrian crystalline basement. Variations in the thickness of Lower Palaeozoic strata over the fault blocks suggest that movement started in Cambrian times and has continued at intervals since then (Baars and See, 1968). Salt diapirs have risen above the upturned edges of fault blocks, demonstrating that basement tectonics can have effects on much younger structures and on modern geology, surely yet another paradox (text-fig. 10). To make things even more complicated than they seem at first, some of the salt anticlines are now topographic troughs, because the uplifted crests have been eroded off, the subsurface salt has been dissolved and the remaining cover strata have sagged into the space left by the missing salt (text-fig. 1). The topographic effects are well seen in Arches Nation Park (Hoffman 1981) and east of Moab, as at Onion Creek (Plate 29B) where exceptionally thick Plio-Pleistocene alluvial gravels have been deformed by the uprising salt (Colman, 1983).

The distribution of oilfields is closely related to the salt intrusions, which sometimes form up-dip flank traps. But more commonly it is the basement fault scarps which have influenced sedimentation in the Phanerozoic cover rocks; in particular reef development appears to lie along basement fault trends, and reefs are often rich in oil.

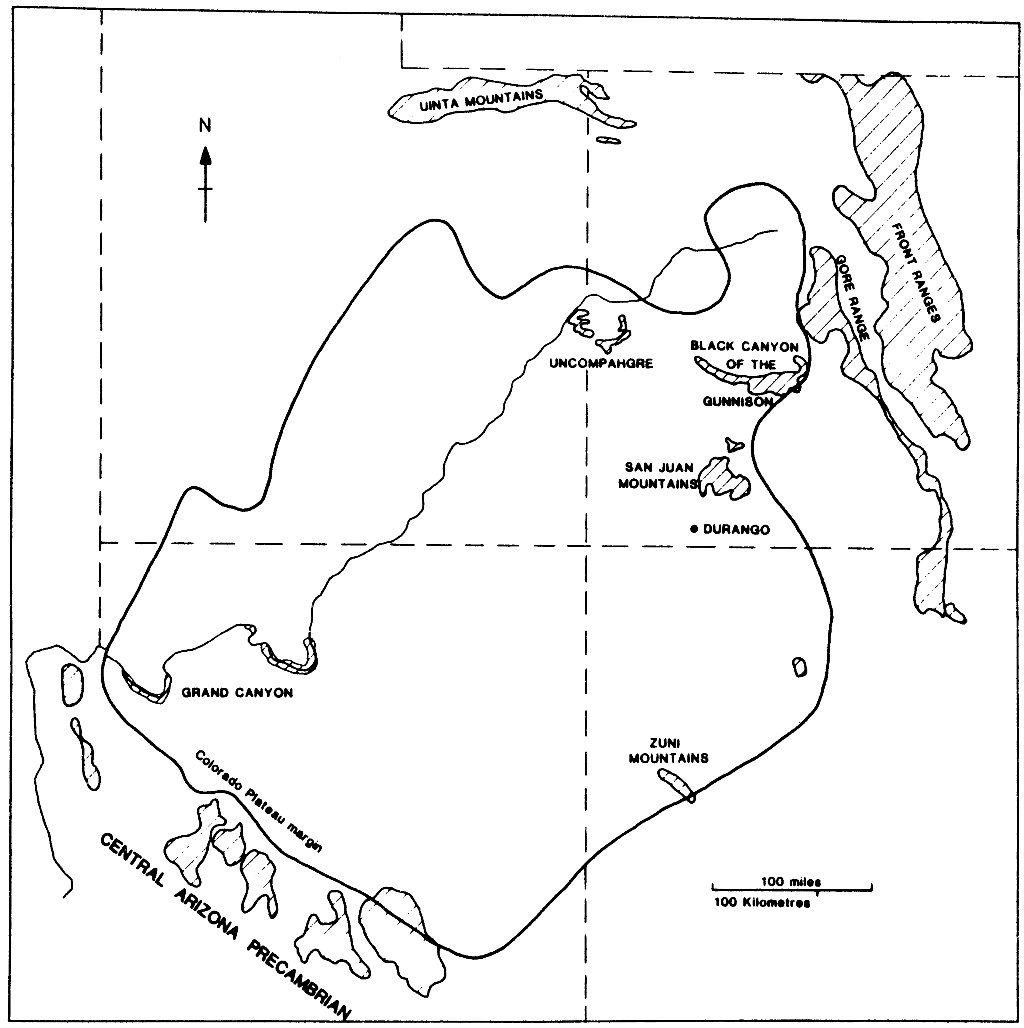
The Paradox Basin has only recently yielded the final paradox of its structure. Following deep seismic profiling across the margin of the Uncompahgre Uplift north of Arches National Park, deep drilling has proved that the margin is not a simple normal fault but is in fact a high-angle reversed fault so that the Precambrian is thrust over Mississippian and Pennsylvanian strata (Gries, 1983). Comparable structural situations are known in Wyoming to the north of the Plateau and at least two deep tests have drilled through more than 3000m of granite to reach oil reservoirs in Upper Palaeozoic strata (Gries, 1983). The recognition that faults previously thought to be normal were in fact overthrusts has stimulated an intensive search for oil beneath Precambrian crystalline rocks, something totally unexpected a few years ago. If the Uncompahgre Precambrian is now known to be in reversed fault contact with Pennsylvanian comglomerate fans containing boulders of the same rock, how do we explain the apparent contradictions? This can only be done by arguing that the faulting is a young feature, and that the Precambrian was in a normal source to depositional area relationship in Pennsylvanian times.



Text-fig. 10 Diagram of the salt intrusions in the Paradox Basin (modified after Baars).

Precambrian rocks have limited outcrops in the Colorado Plateau area and few deep boreholes have reached them in concealed areas (text-fig. 10). They span a chronological interval at least three times longer than the Phanerozoic, and their complex tectonic and metamorphic deformations compound the problems of interpretation. Two groups of Precambrian rocks are present: an older crystalline group of gneisses, schists and granitic intrusions, and a younger group of unaltered sediments. Space does not permit a detailed discussion and only a few salient paradoxical points can be outlined here.

From the mineralogical composition, these crystalline rocks are clearly of continental crustal character. Radiometric dates range from 1900 Ma to 1400 Ma clustering around 1700 Ma (Babcock et al., 1978; Tweto, 1980). The earliest of these may represent the time of original sedimentation, i.e. early Proterozoic, with the main episodes of metamorphism and deformation culminating around 1700 Ma, and some late intrusions being as young as 1400 Ma. The main outcrops are in the bottom of the Grand Canyon (Babcock et al., 1978), the San Juan and Needle Mountains of southwest Colorado (Barker, 1969) and the Black Canyon of the Gunnison (Hansen, 1971) on the eastern margin of the Plateau. In all these the rocks are broadly similar in character and age and it seems likely that they represent a largely buried southwesterly extension of the Canadian shield. In



Text-fig. 11 Sketch map of Precambrian outcrops (shaded areas) in the Colorado Plateau are.

fact, the foliation, distribution of metamorphic grades and major faults have a general SW-NE trend which can be matched with similar trends seen in the Great Lakes area. These observations indicate that the Colorado Plateau has been part of the North American plate since at least early Proterozoic times and has not been directly involved in any plate collisions, break-up or subduction. One paradox does, however, arise. The lineament along the SW-NE trend seen in the Grand Canyon and Black Canyon is at right angles to that seen in the San Juan Mountains and to the trend of the block-faulting beneath the salt anticlines of the Paradox basin. The NW-SE trend of such a lineament has been suggested to link with the Olympic Mountains of the Washington State to the northwest and to the Ouachita Mountains to the southeast. Warner (1978) and Baars and Stevenson (1982) have argued that the SW-NE trend of the Colorado lineament and that the combination could only have come about as a result of north-south compression, at right angles to the stresses of Mesozoic-Cenozoic times. This Precambrian compression may have been due to the collision of North and South American plates (Kluth and Coney, 1981). The intersecting pattern may be the underlying cause of the basins and upwarps within the Plateau. However, as we shall see later, the general trend of folds within the Plateau is N-S, e.g. the Raplee anticline and the Kaibab upwarp mentioned above in connection with drainage anomalies.

The younger Precambrian rocks are unmetamorphosed sediments, again with widely scattered outcrops and presenting many difficulties in dating and correlation. Generally ranging in age from 1100 Ma to around 800 Ma the main outcrops are in the Grand Canyon (Ford & Breed, 1973b, 1978), the Uncompahgre Uplift (Tweto, 1980), the San Juan Mountains (Barker, 1969) and the Uinta Mountains north of the Plateau (Wallace and Crittenden, 1969). In the Grand Canyon some 4000 m of generally quiet, shallow water argillaceous sediments with some sandstones and limestones belong to the Unkar and Chuar Groups, with basaltic lavas between them (Ford and Breed, 1973b, 1978). The higher beds have yielded Precambrian stromatolites (Plate 30A, microfossils (Ford and Breed, 1973a; Hoffmann, 1977, Vidal and Ford, 1984) indicative of late Proterozoic (Riphean) to Vendian age — 700-800 Ma. They are capped by coarse breccias and conglomerates of the Sixty Mile Formation, which Elston (1979) demonstrated to have been derived from a nearby fault scarp. Elston and McKee (1982) have shown that this tectonic activity can be correlated with other regions of North America as the Grand Canyon Disturbance. Palaeomagnetic and radiometric dating studies have also been linked by them with the palaeontological evidence so that the Grand Canyon Supergroup probably ranges from 1250-820 Ma, and is at least partly correlative with the Uinta Mountain Group. The micropalaeontological evidence (Vidal and Ford, 1985) suggests that the higher parts of the Grand Canyon Supergroup and the Uinta Mountain Group may be younger than the palaeomagnetic and radiometric arguments of Elston and McKee (1982) suggest. The Grand Canyon Supergroup rests with profound unconformity on the crystalline basement with granitic intrusions as young as 1400 Ma.

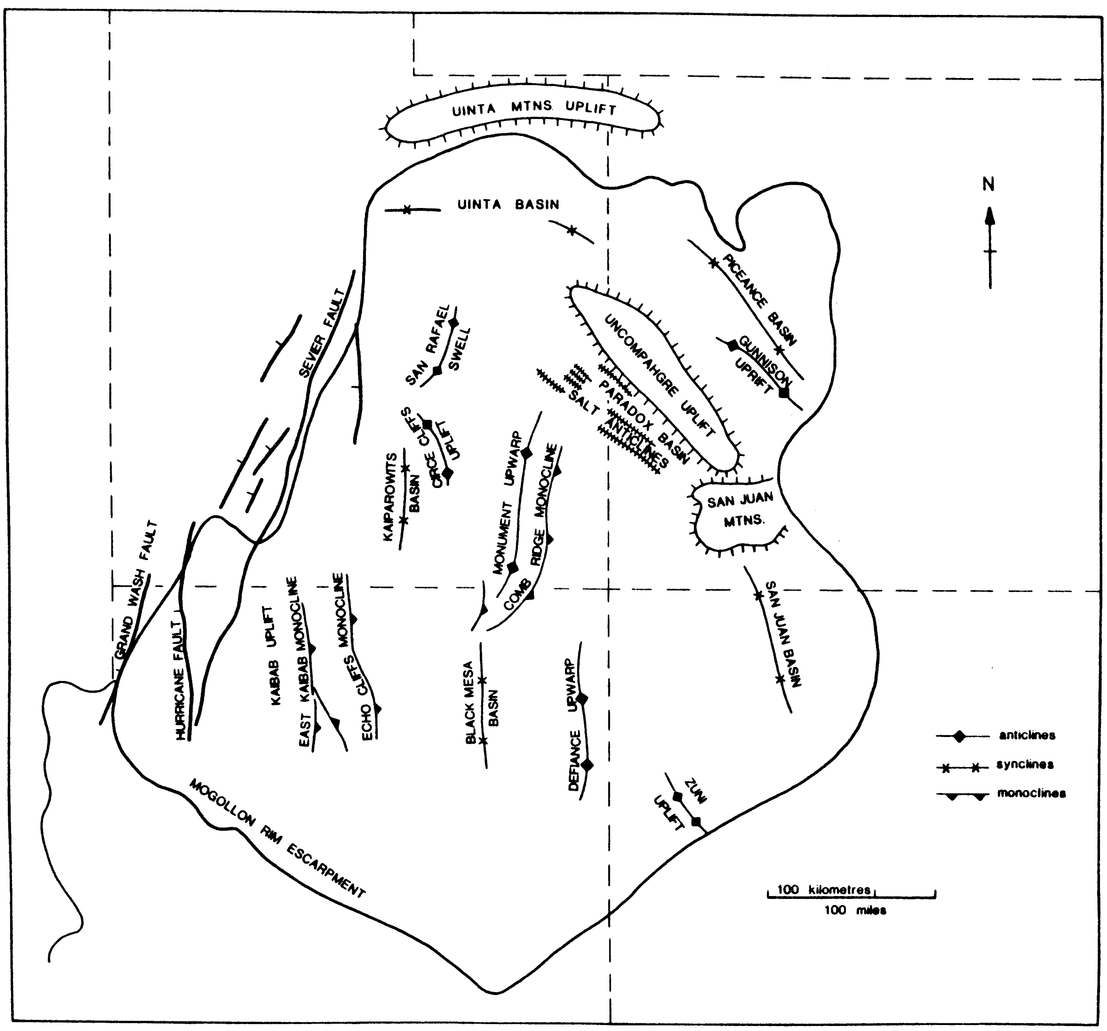
In the Needle Mountains and the subsurface of the Uncompahgre Uplift the dominantly quartzitic Uncompahgre Group is tightly folded and metamorphosed to chlorite grade (Hinds, 1936; Barker, 1969). The Group rests unconformably on the Twilight and other gneisses dated at around 1700 Ma, and it is intruded by a granite 1400 Ma old, making the Group older than the Grand Canyon Supergroup and the Uinta Mountain Group. A conglomerate at the base contains no local clasts and the nearest possible parent rocks are in central Arizona (Tweto, 1980). Though of limited extent today, the Uncompahgre Group, if palinspastically unfolded, would have occupied a much wider area at the time of deposition.

The Uinta Mountain Group, though strictly outside the Plateau, has similar quartzitic sandstones (Hansen, 1965) but it is only gently folded and largely unmetamorphosed, as seen in the Flaming Gorge of the Uinta Mountains (Wallace and Crittenden, 1969). Argillites near the top have yielded microfossils (Hofmannm, 1977) and palaeomagnetic data suggest a late Proterozoic date.

The problem is that there is an age bracket from around 1400 Ma to 700 Ma to accommodate all three of these major rock groups and there is no reliable radiometric data to help correlation. Palaeontological data (Hofmann, 1977; Vidal and Ford, 1984) confirms that at least the higher parts of the Chuar and Uinta Mountain Groups are contemporary, but that still leaves the more deformed Uncompahgre Group without clear correlatives in the Plateau area. When it is remembered that the time available for all three Groups is longer than the whole Phanerozoic, it can be seen that the Precambrian history of the region is far from fully understood.

Attention has already been drawn to some prominent folds; these and others are portrayed on text-fig. 12. The paradox is why are there folds at all on the plateau of generally flat-lying strata resting on a solid foundation of ancient Precambrian crystalline rocks? Furthermore, how are they related to the faulting? When did folding and faulting occur?

The general trend of both folds and faults is north-south, and their general form can be typified by the east flank of the Kaibab Uplift as seen in a monocline facing eastwards; in the Painted Desert to the east it is clear that Mesozoic strata were involved in the same fold and thus the structure as seen today is of Tertiary, probably late or post-Eocene, age. But in the Grand Canyon the monocline is seen to be underlain by faulted Precambrian. The Butte Fault can be traced for some 30 km and the monocline for well over 100 km. Nothing unusual in having a faulted core of competent rocks beneath folded higher strata, one might say, but when the details of the Precambrian rocks on either side of the fault are examined, the downthrow is demonstrably in the opposite direction to the monoclinal downwarp, i.e. westwards. The Butte Fault has moved twice, a pre-Cambrian downthrow westwards of 1300 m, partly cancelled out by the Laramide flexing of the monocline 600 m down in the opposite direction (Ford & Breed, 1973b; Elston & McKee, 1982). Similar reversals of movement have been detected on other monocline-cum-fault systems in the Grand Canyon, though the evidence is less well-exposed (Huntoon, 1978; Hamblin, 1984). There has thus been eastward pressure followed by tension. If such reverse-faulted monoclines can ever be demonstrated to lie above faults in the Precambrian, one has the situation of east-west tension with westward downthrow in the Precambrian, east-west compression in the Laramide movements (late Cretaceous to early Eocene) followed by east-west tension again, perhaps in middle Cenozoic times.



Text-fig. 12 Sketch map of the main folds and faults in the Colorado Plateau area.

Striking monoclines, such as that at Comb Ridge, border many of the major upwarps in the Plateau area, usually on the east flanks (Woodward, 1973) and these may well overlie complex basement structures as in the Grand Canyon. Within the upwarps Woodward has noted that gently north-south to northwest-southeast folds are common though with dips rarely exceeding 2°-3° on each limb. These, including sharp folds such as the Raplee anticline (text-fig. 5), show no apparent reason for their presence. Even the Monument Valley upwarp yields little evidence of the nature of its core. In eastern Utah, the hypothesis of basement fault-blocks in the cores of salt anticlines has already been noted (Baars and See, 1981).

The Plateau appears to show some evidence of crustal (sialic) thickening in contrast to the Basin & Range province to the west. Woodward (1973) considered that this explained the Plateau's apparent resistance to eastward-directed orogenic pressures. An alternative explanation could be put forward for some of the paradoxical anticlines—*décollement*, where the Phanerozoic cover effectively slides and crumples disharmonically over the basement, as has been demonstrated in the Jura Mountains of Europe. However, no evidence to support such a hypothesis has been brought forward, and the sequence of events deduced by Baars & See (1968) involving repeated up and down movements of a horst at Coalbank Pass, southwest Colorado, cannot be explained by a *décollement*.

The Colorado Plateau is bordered to the east by the Front Ranges, where repeated block-faulting and filling of depressed areas by Phanerozoic sediments can easily be demonstrated. To the west lies the Basin and Range Province where multiple eastwards thrusting has been deduced (Smith, 1978).

Recoil from the thrusting pressure has left down-faulted blocks in the Basin and Range country to the west of the Plateau. As noted above, the Plateau has a history of alternating compression and tension giving the faulted monoclines and simpler anticlines ahead of the Overthrust Belt. To the east the resistant Rocky Mountains seem to have been a buffer zone.

One anomaly of the folding is the occurrence at Mexican Hat on the Utah/Arizona border of a synclinal oilfield (Huber, in Baars, 1973). Whilst this unusual oil reservoir might be thought to be due to a lack of water in the petroliferous horizons to buoy the oil up, current thought is that the oil is trapped by changes in facies and permeability close to the synclinal axis.

Igneous Activity

Leaving aside Precambrian meta-volcanics, granites and basaltic lavas, igneous activity was almost absent from the Colorado Plateau until Cenozoic times. Throughout this era, however, extrusion and intrusion of magma was common (text-fig. 13). Space does not allow a detailed review. The latest Cretaceous and Eocene saw widespread extrusion of rhyolitic lavas and ashes in the San Juan Mountains (Baars, 1983), in northwest Arizona and a scatter of other localities. Caldera collapses, as at Silverton and elsewhere in the San Juan mountains, were accompanied by the emplacement of microdioritic dykes and sills and much mineralization (Romberger, 1980). By Miocene times these calderas and many other igneous rocks were mineralized and became important mining centres in the 19th century. Places with famous names such as Cripple Creek, Telluride and Ouray owe their existence to the mineral deposits in early Cenozoic igneous rocks.

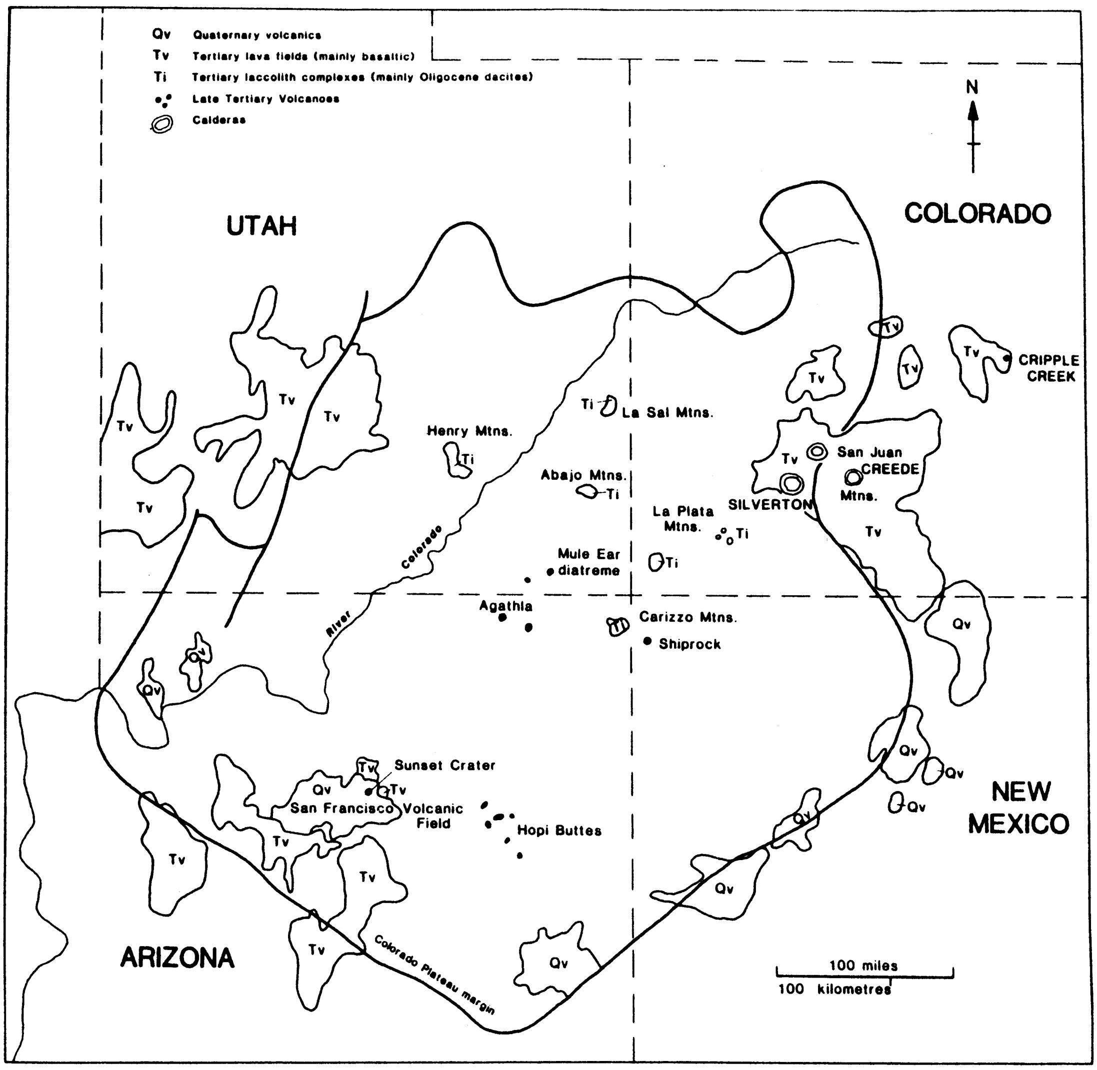
Also in the early Cenozoic magma rose in other parts of the Plateau but largely failed to reach the surface. Bulbous sill complexes and laccoliths dot the Plateau and make prominent but local mountain ranges. The Henry, La Sal, Carizzo, Abajo, La Plata and Ute Mountains of south east Utah fall into this category; some have associated extrusive rocks, but generally they are laccolithic in form.

Late in the Cenozoic isolated volcanoes rose in northeast Arizona and northwest New Mexico only to die and leave greatly denuded wrecks as prominent features today. Shiprock, with its radial dykes, and Agathla in Monument Valley (Plate 30B) are the two largest but there are others in the Hopi Buttes and Church Rock near Kayenta.

Of uncertain age are a scatter of diatremes of ultrabasic rock with abundant xenoliths. Some have so little igneous matrix that they are effectively fossilized explosive gas vents filled with a mixture of igneous and metamorphic basement blocks brought up from below and subsided sedimentary blocks. The Mule Ear diatreme in southwestern Utah (Stuart-Alexander et al., 1972; Ellingson, 1973) has blocks up to 30 m across of granite, richly garnetiferous rock, lamprophyres and ultrabasic rocks in a matrix of pulverized rocks derived from all these. The presence of blocks of kimberlite, dunite, eclogite and serpentinized schist suggests that the source of at least some of the material was near the crust-mantle boundary. The kimberlite has not yet yielded diamonds!

The last phase of igneous activity is the very widespread eruption of mostly basaltic lavas and ashes from numerous vents, notably in the western Grand Canyon (Hamblin, 1978) and near Flagstaff in northern Arizona with about 400 vents and cinder cones (Colton, 1967). Amongst these are some dacite domes such as Elden Mountain at Flagstaff and olivine-bearing andesites. Olivine and sanidine crystals occur amongst the ash of Red Mountain. These rock types have been shown to be related geochemically and a mechanism of magmatic differentiation has been proposed by Wenrich-Verbeek (1979). Equivalent volcanic fields are near Bryce Canyon in the west, along the Sevier fault system in the northwest, near Gunnison and Salida, and in northwestern new Mexico. Basalt lavas poured from vents on the rim of the western Gran Canyon and dammed it only 1.2 million years ago, and again later 0.75 Ma. The river has re-excavated its gorge through these since then. The last known eruption was at Sunset Crater near Flagstaff in 1065 A.D.

Together these manifestations of igneous activity should link together to tell us something of the plate tectonic and crustal evolution story of the Plateau, but the paradox is that they don't! No clear magmatic compositional trend has been worked out; no relation to structural patterns has yet been deduced; no relationship to a progressively changing subduction system has yet been deduced.



Text-fig. 13 Sketch map of igneous features of the Colorado Plateau area.

Mineral Deposits

Gold, silver, copper, lead, zinc and other metals have been mined in many of the igneous terranes of the Plateau, though activity is moribund in these days of recession. This address will not attempt to discuss them in detail; one can just say that they are an enigma in themselves: where did the metals come from? From magmas or sequestered from the country rocks? Mantle origin or concentrated from the surrounding rocks during metamorphism and igneous activity? Also, just beyond the northeastern margins of the Plateau, the Front Ranges have widespread mineral deposits in Precambrian crystalline rocks—are these too of the same mineral suite and age as those in the Plateau, i.e. Tertiary? Where do the great porphyries of Climax and Henderson with their molybdenum deposits fit into the story? There are obviously enough paradoxes in these questions to keep an army of geologists busy for years (see Dickinson and Payne, 1981; Romberger, 1980).

Uranium is another story. It is widespread as a group of cementing minerals such as carnotite in sandstones of the Plateau and is currently being mined from some (e.g. Chenoweth, 1980). The chief uraniferous sands are in the Triassic Chinle Formation and the upper Jurassic Morrison Formation: mainly the occurrences are in lenticular channel or sand-bar bodies, but their distribution has been an enigma for many years (Williams, 1964). Whence comes the uranium and how is it deposited? Two main hypotheses are current: one derives the uranium from hidden magmatic sources and would have it deposited as the fluids move upwards through zones of greatest permeability. More recent studies (Sandford, 1982) suggest that the uranium may have been derived either from the weathering of igneous rocks to the west of the Plateau or leached from the Palaeozoic strata of the western Plateau. In either case groundwater moved eastwards (down-dip then) across the Plateau through aquifers, in particular through the more porous channel sands. When such groundwaters met the structures associated with salt anticlines or with buried Precambrian massifs they were deflected upwards by hydraulic pressure, mixing with upwelling brines containing traces of hydrocarbons. The reducing properties of the brines when they met cool meteoric water then caused the precipitation of the otherwise rather soluble uranium salts.

This second hypothesis seems to fit the observations best but has a rather critical requirement of timing: the mechanism could only work at a time when the Sierras were uplifted with a continuum of sedimentary formations declining eastwards across the Plateau, i.e. before the faulting along the Sevier and Owens Valley systems between the Plateau and the Sierras cut off the continuum, and after the development of the salt anticlines. Dating of the uranium minerals by radio-active means should yield the same answer. Fortunately these various requirements agree with the dating result—in the early Cenozoic. But then, that is the date one would expect if the deposits came from a magmatic source when igneous activity was at its peak. Perhaps this paradox can be resolved if one postulates that the igneous activity provided a little heat to help drive groundwater movement and reactions. It is worth noting that the postulated mechanism would work best at the same time as the ancestral Colorado river was flowing northeast across this sedimentary accumulation in Eocene times as hypthesized by Young (1981).

The Colorado Plateau and Plate Tectonics

The Colorado Plateau has been a part of the North American plate since the earliest observable rocks therein were formed, i.e. early Proterozoic, and it has not been directly subject to subduction, obduction or rift movements. Yet, paradoxically it lies within the western Cordilleran mountain belt. Simplistically, the Colorado Plateau lies between two main branches of the Cordillera, the Front Ranges to the east and the High Sierras to the west. Current thought on the origin of the west coast ranges of North America accepts long continued subduction but adds a grand scale hypothesis of the lateral movement of parts of the orogenic belt (Dickinson, 1978; 1981; Coney et al., 1980; 1981). This leads to a concept of "suspect terranes", blocks of crust which have been shuffled laterally along large wrench faults so that they are no longer in contact with contemporary rocks or structures. Unravelling these is in its infancy, and whilst it is possible to say that some part of the Sierras lay to the west of the Plateau at various geological peroids, it is not possible to say exactly which was there or when. Dating the granite plutons in the Sierra Nevada indicates that subduction started there at least as early as Triassic times, and that pieces of mobilized granitic crust have risen at intervals at least until early Tertiary times. Massive faults bound the Sierras, and the San Andreas fault is but the latest and most spectacular of these with demonstrable dextral movement of several hundred kilometres. Some parts of the Sierras and the Coast Ranges now lie above the East Pacific Rise—a mid-ocean ridge with sinistral transcurrent faults displacing the northern extension of the rise towards the Pacific. Reconstruction of events in California suggests that a small Farallon plate has been overridden in these processes (Dickinson 1978). But how do these features relate to the Colorado Plateau? That is the largest paradox of all. At best one can say that there have been periods of subduction of an oceanic plate under the continental margins to the west of the Plateau. Subduction was in an eastward direction and has operated at intervals since at least Triassic times. The multiplicity of granite plutons in the Sierra Nevada suggests that the subduction zone there was long lived and in much the same place.

Subduction in California has resulted in eastward lateral pressure in the Basin and Range Province of Nevada and western Utah. Indeed many of the faults bounding the Ranges, once thought to be normal faults, are now known to be listric overthrusts (e.g. Allmendinger et al., 1983). Whilst the Sevier Fault system bounding the northwestern margin of the Plateau appears at first to combine normal and wrench fault effects, recent studies have shown that these can be explained just as easily by oblique shift on the upturned end of a listric thrust. Much of Wyoming to the north of the Plateau has similar overthrusting (e.g. Blackstone, 1983) but little sign of such movements has been detected in the Plateau itself. Monoclinal folds and scattered reversed faults show that the eastwards pressure was maintained for most of the Cenozoic, but with some recoil as indicated by the reversed faults on monoclines in the Grand Canyon (Huntoon, 1978; Hamblin, 1984) an unexpected result of seismic reflection profiling, subsequently confirmed by drilling, has been the discovery of underthrusting or reversed faulting on the western margin of the Uncompahgre Uplift, north of Moab in Utah (Gries, 1983). Here a borehole penetrated some 3000 m of Precambrian granite before entering Mississippian limestones. Similar phenomena are well known in Wyoming, north of the Plateau (Blackstone, 1983) and it raises an as yet unknown problem of how widespread such a relationship could be within the Plateau.

The eastward compression associated with the Mesozoic-Cenozoic subduction in California is paradoxically in contrast to the NE-SE and NE-SW lineaments crossing the Plateau and extending far beyond its margins (Baars and Stevenson 1982). But, as discussed earlier in this contribution, the lineaments are basically ancient, Precambrian features, which have affected sedimentation at intervals throughout the Phanerozoic. Indeed, east-west compression directed against such obstacles has, in the view of Baars and Stevenson (1982) been responsible for the development of the intervening sedimentary basins. The origin of the lineaments themselves is, however, still a mystery probably associated with the tectonic evolution of the Precambrian craton, largely concealed from view.

Conclusion

My review of the paradoxes of this vast region of the southwestern United States has attempted to focus attention on some of the problems still facing geologists. Exploration for natural resources, oil, coal and uranium to mention but a few, will doubtless unravel a few of the mysteries in years to come, though such exploration is hampered by the constraints imposed by vast areas dedicated to National Parks and Monuments, Forests, Recreation Areas, Indian Reservations and Military areas, in most of which any form of commercially inspired investigations is forbidden.

Can we in Britain learn any lessons from this review? Apart from the obvious knowledge of the formation of sedimentary rocks and basins, and of mountain ranges, my main conclusion is that we are too insular in looking at our local geology. We must see it in a wider context. Our oil geologists are, of course, doing this, but we have a long way to go. We can learn lessons from far-flung areas such as the Colorado Plateau and apply them here in Britain. To take one paradox as an example, how did the deep Carboniferous sedimentary basin of the south and central Pennines become a positive area of uplift by Permian times, and a land area and geographic barrier through much of Mesozoic and Cenozoic time? A broad relationship of this stratigraphic inversion to the compression of the plate collision of the Armorican orogeny has been proposed, but the paradox here is that the compression would have been directed northwards, whereas many of the structures in the Pennines suggest east-west compression. Knowledge is steadily accumulating, but, like the southwestern United States, the search for geological knowledge is constrained. Much of what we seek is hidden beneath younger rocks and geophysical study followed by drilling is the only way to find answers to geologial problems. But such investigations are subject to strict planning control, sometimes refused, and the target of ill-informed conservationists, and even when boreholes are sunk the data obtained is often concealed in government or oil company files for years. The final paradox I would offer here is that the search for geological truth would be best served if all the geological facts were freely revealed to all who can make use of them — without unnatural constraints. They are not so revealed and I wonder what we are missing!

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Explanation of Plates

Plate 26, Fig. A

The eastern Grand Canyon, seen from Desert View, showing the incision from the Permian plateau surface down to younger Precambrian bordering the River Colorado on the left.

Plate 26, Fig. B

The Grand Canyon seen from the lower slopes, showing the Tonto Platform of Cambrian shales in the foreground, the vertical cliff of Mississippian Redwall Limestone, the cyclic sandstones and shales on the Pennsylvanian Supai Formation and relic caps of Permian Coconino Sandstone.

Plate 27, Fig. A

The rugged red sandstone cliffs of the Mogollon Rim above Sedona in Oak Creek Canyon.

Plate 27, Fig. B

The east flank of the Raplee anticline in southwest Utah; the main fold on the left is in Pennsylvanian cyclothems; Permian and Triassic strata occupy the low ground with the San Juan River meandering across it, the jagged scarp of Comb Ridge on the right is in uppermost Triassic to Lowest Jurassic Navajo Sandstones.

Plate 28, Fig. A

The incised meanders of the Goosenecks, near Mexican Hat, Utah.

Plate 28, Fig. B

Pennsylvanian mudstone which formerly blanketed the ancient karstic tower of Mississippian Limestones in the foreground, Molas Pass, southwest Colorado.

Plate 29, Fig. A

Angel's Landing in Zion Canyon with its high cliffs of aeolian Navajo Sandstones.

Plate 29, Fig. B

Onion Creek, east of Moab, Utah, showing the flank of the gypsum cap to a salt intrusion on the left, with upturned conglomerates of the Cutler Formation, (Pennsylvanian) on the right.

Plate 30, Fig. A

The tops of silicified and dolomitized algal stromatolite columns, probably *Collenia columnaris* in the younger Precambrian Chuar Group, Nankoweap Canyon, eastern Grand Canyon.

Plate 30, Fig. B

Agathla Peak at the southern entrance of Monument Valley—a denuded basaltic volcano.

Plate 26, Fig. A

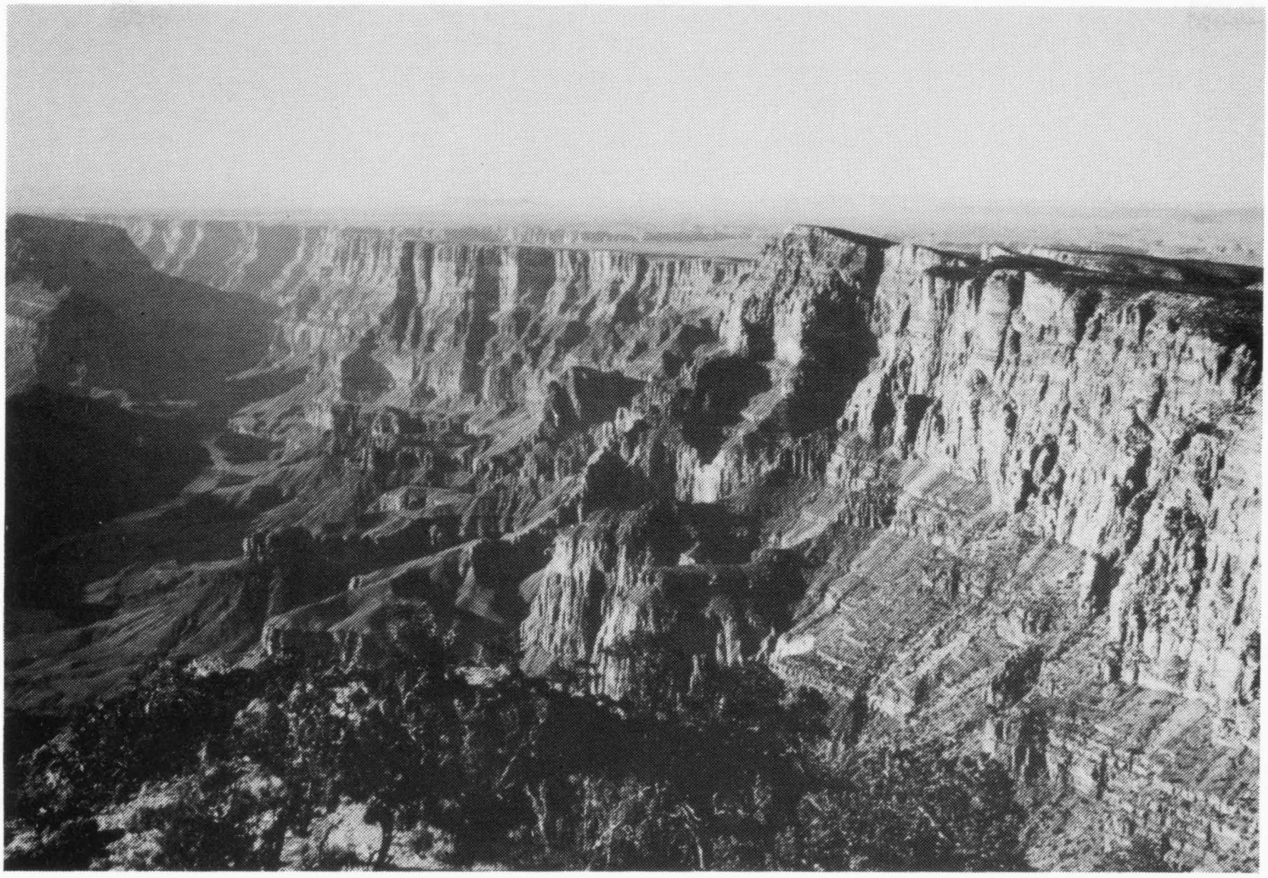


Plate 26, Fig. B

Plate 27, Fig. A

Plate 27, Fig. B

Plate 28, Fig. A

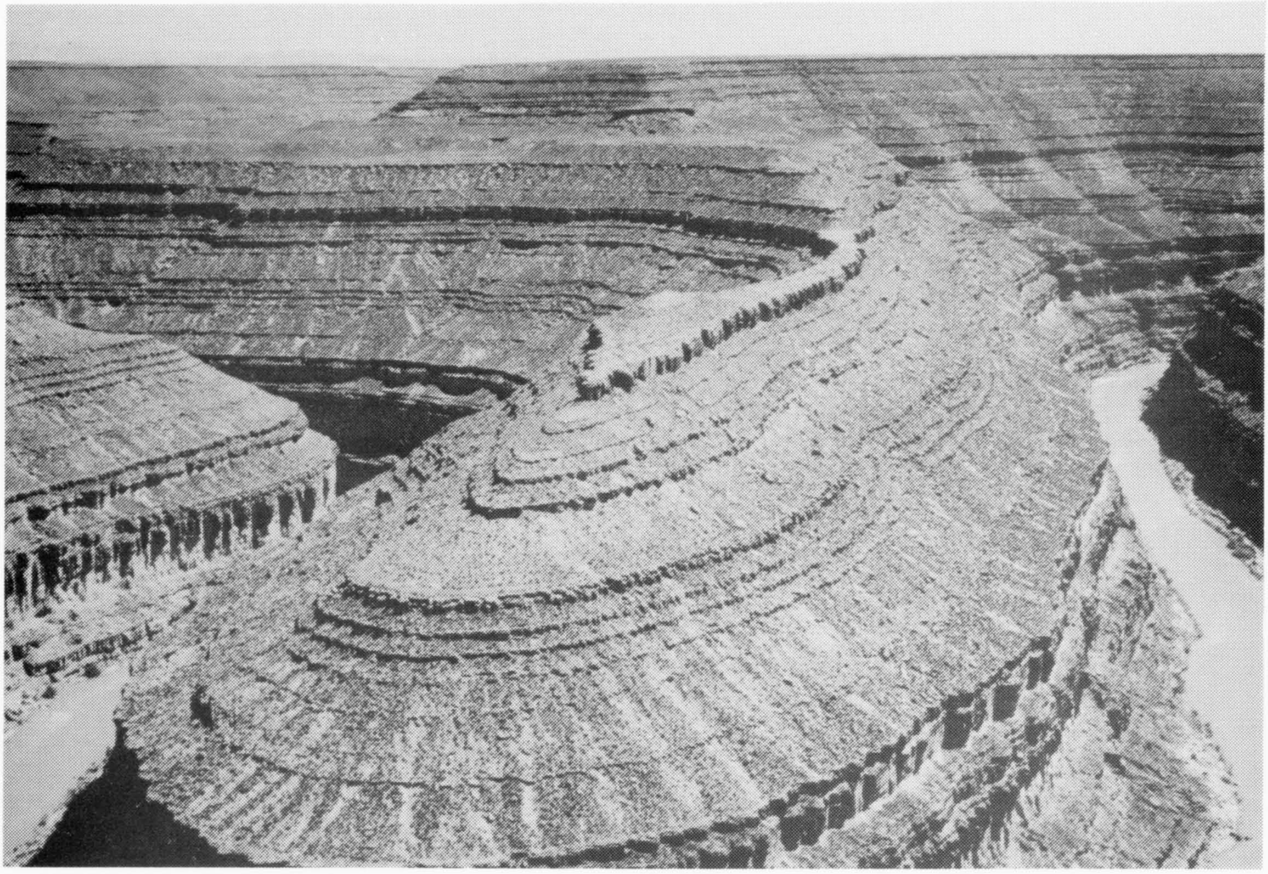


Plate 28, Fig. B

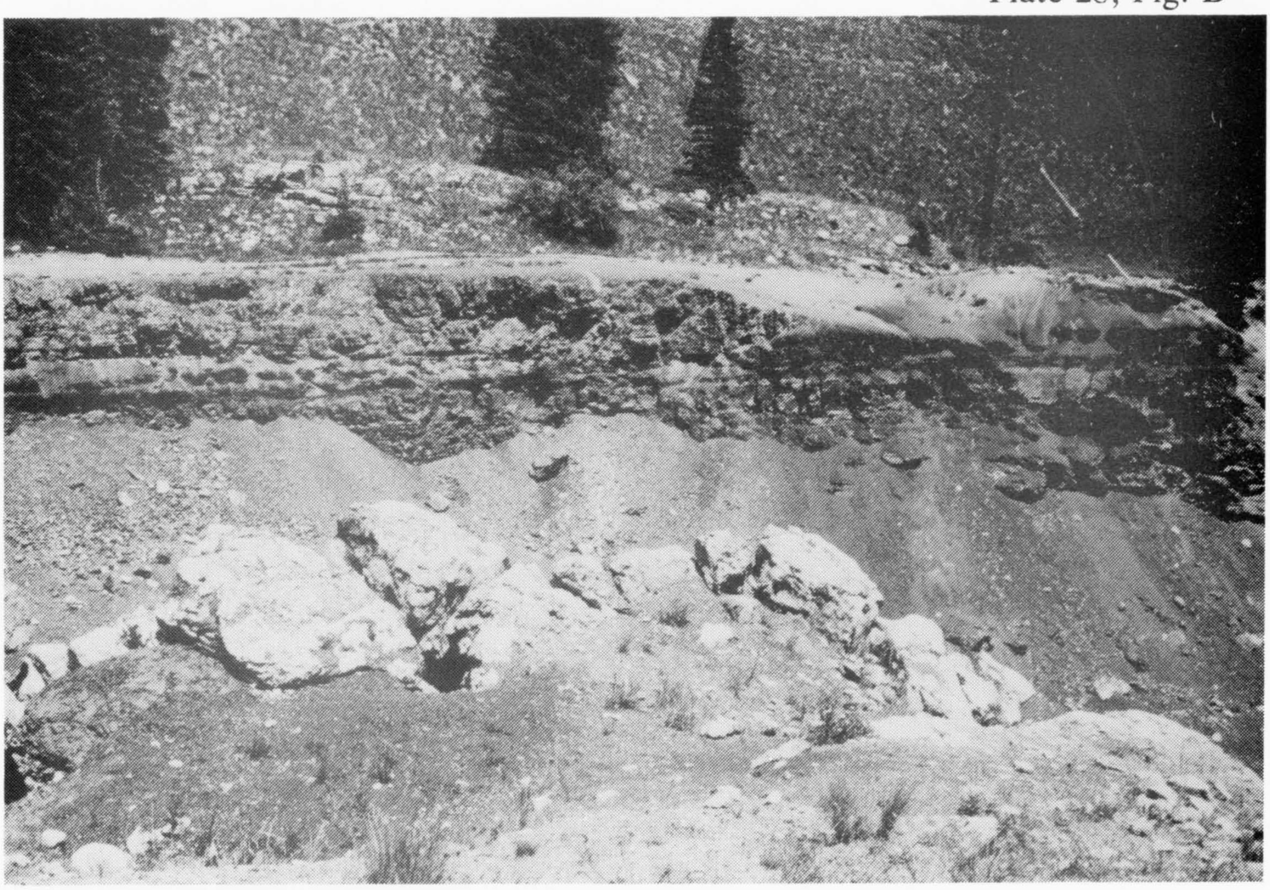


Plate 29, Fig. A

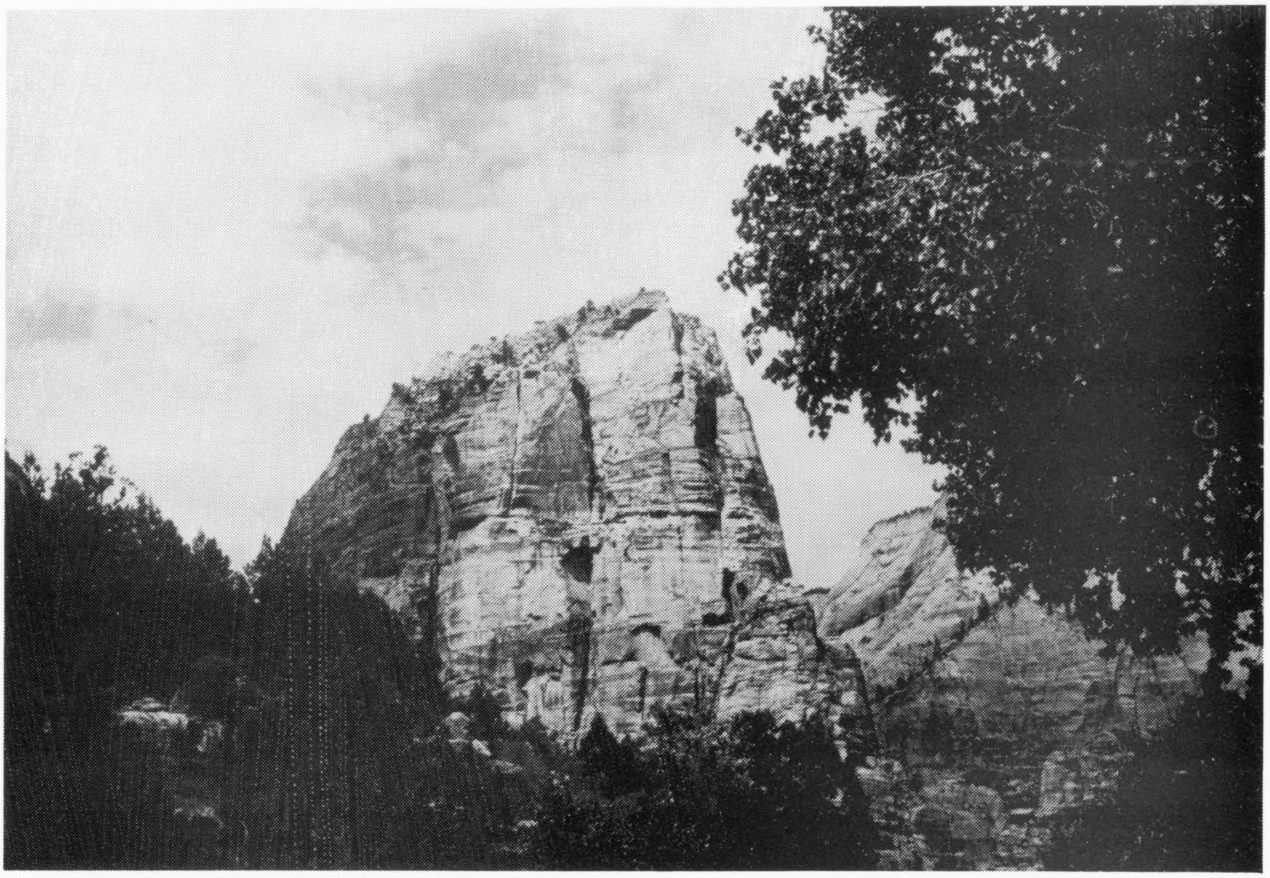


Plate 29, Fig. B

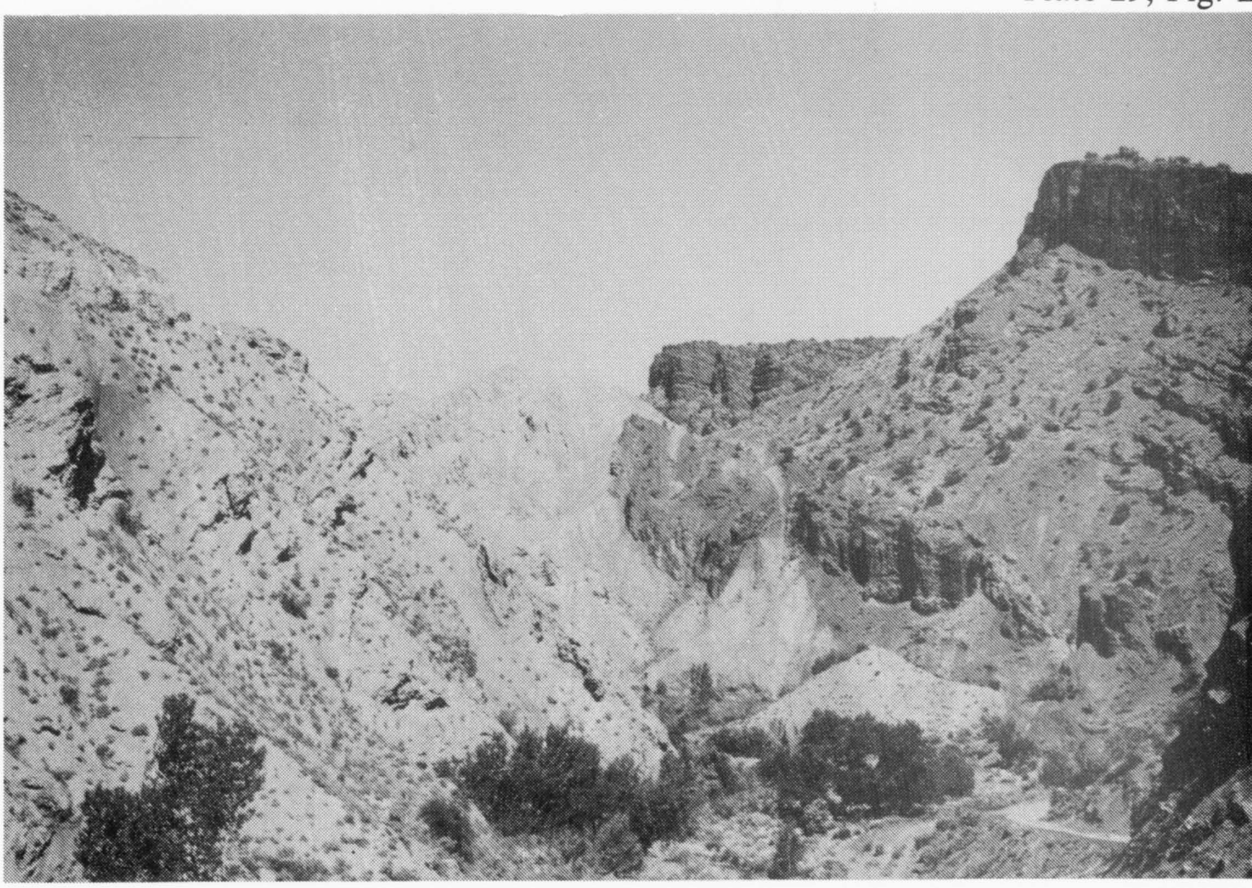


Plate 30, Fig. A

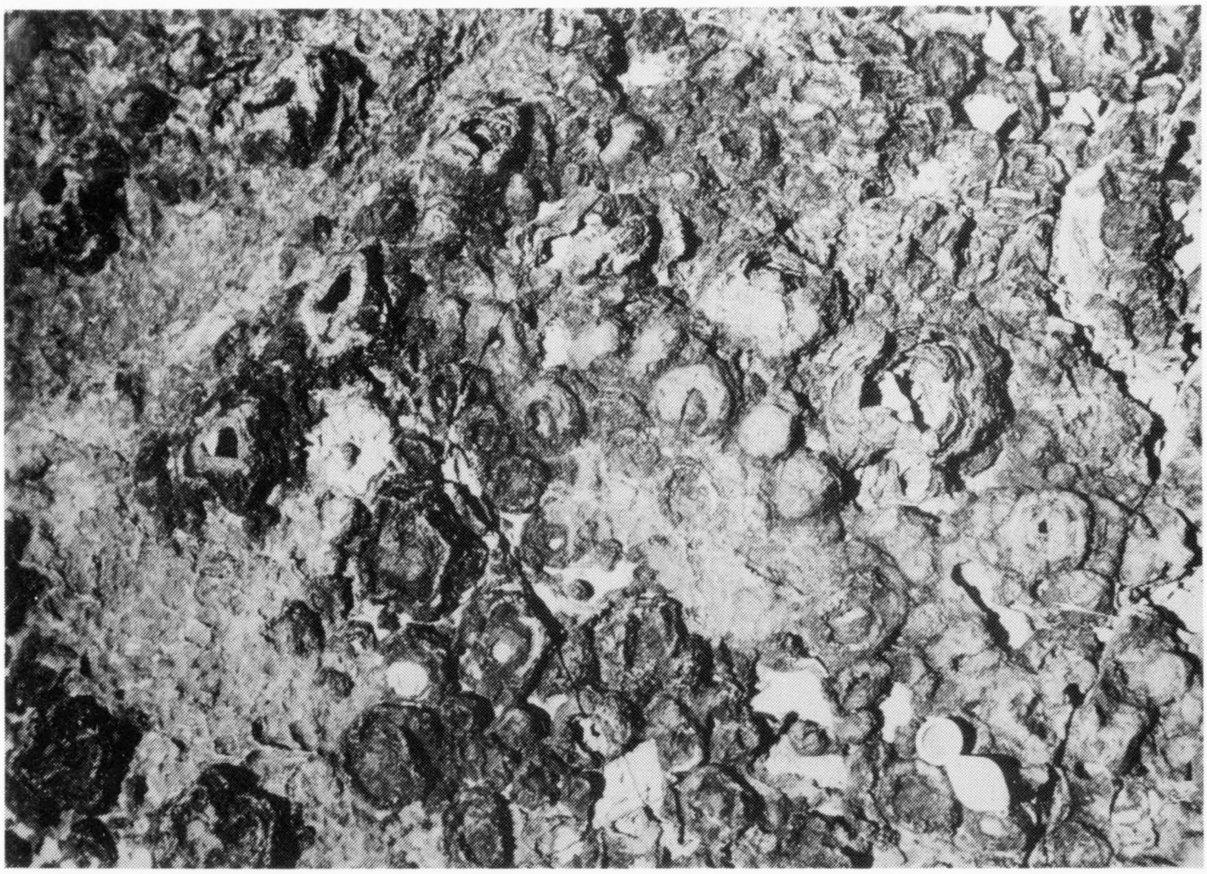
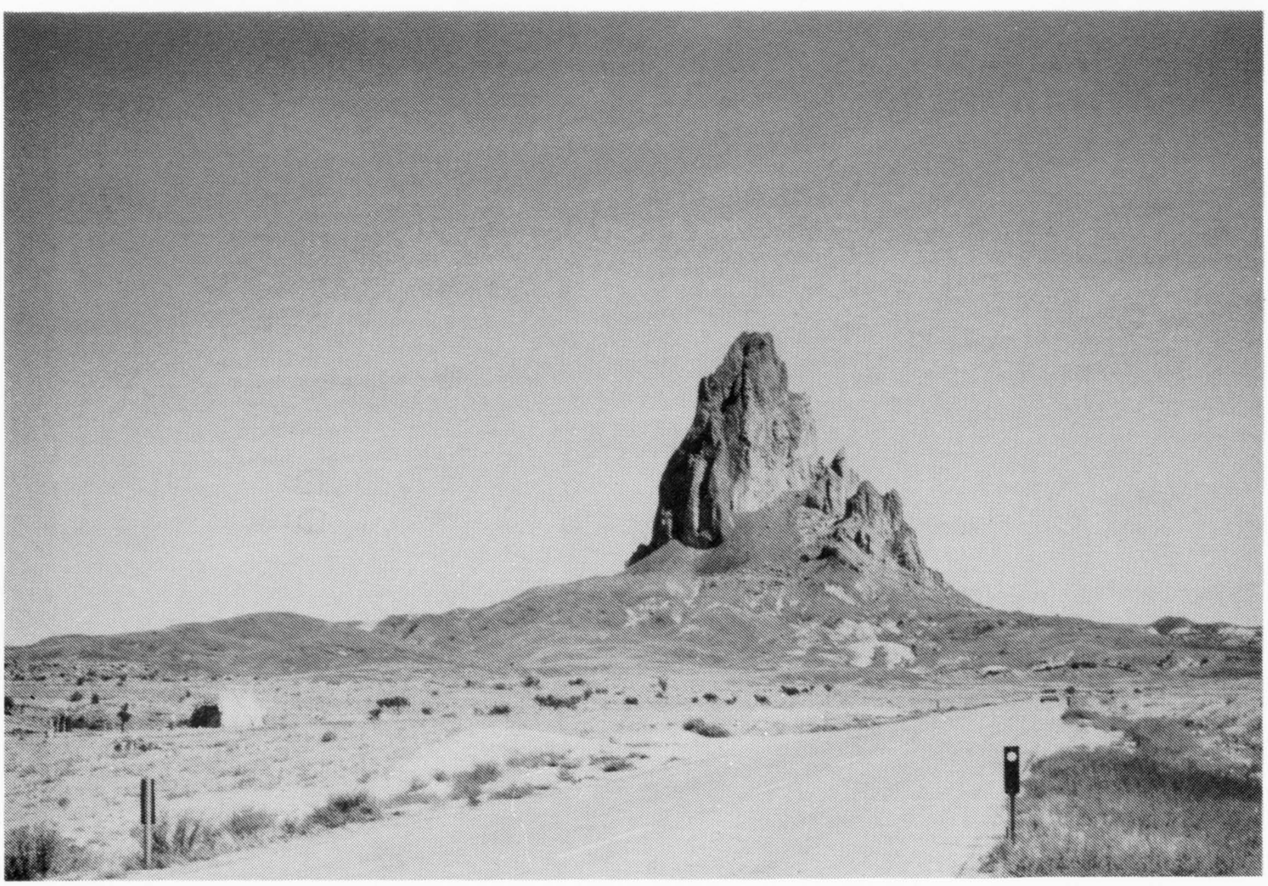


Plate 30, Fig. B



A PALAEOMAGNETIC REVERSAL IN EARLY QUATERNARY SEDIMENTS IN MASSON HILL, MATLOCK, DERBYSHIRE.

by

M. Noel, R.P. Shaw
and T.D. Ford

Summary

A section of fluvio-glacial sediments in Old Jant Mine, Masson Hill, Matlock, shows a palaeomagnetic reversed to normal transition which it is argued is most likely to have occurred at the Brunhes/Matuyama event of 730,000 years ago. The sediments thus appear to be the oldest record of Pleistocene glaciation in Britain.

Introduction

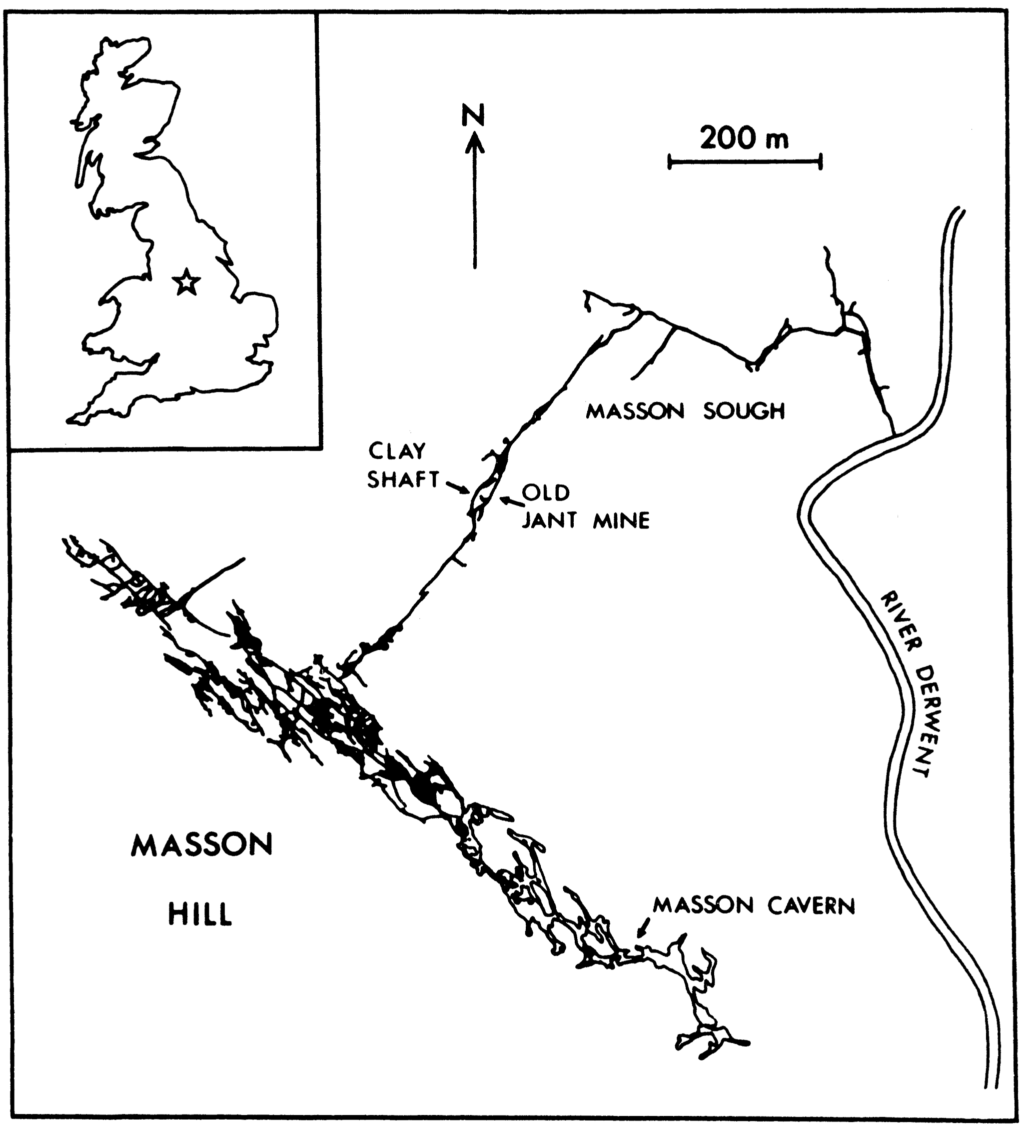
The feasibility of applying high-resolution magnetostratigraphy to the regional correlation and dating of Quaternary deposits has been demonstrated in palaeomagnetic studies of European and North American lake sediment cores (Stober and Thompson, 1977; Creer, 1981, 1982; Creer and Tucholka, 1982a, b). However, the use of lacustrine deposits to extend the timescale beyond about 15 kyr BP is hampered by the difficulty of retrieving deeper core material and by scouring during the Devensian glaciation which affected the majority of upland lake basins. In contrast, many caves contain extensive deposits of fine-grained sediments that are largely protected from surface erosional events, weathering or bioturbation (Bull, 1980; Bögli, 1980) and which may have ages up to or in excess of 350 kyr BP (Atkinson *et al.*, 1978; Gascoyne *et al.*, 1981; Schmidt, 1982). These sediments can retain a reliable record of the geomagnetic field and hence offer the potential for extending the existing lake sediment magnetostratigraphy into the Middle or Lower Quaternary (Creer and Kopper, 1976; Noel, 1983; Noel and St. Pierre, 1984).

This paper describes the palaeomagnetism of a 4 m section of natural cave fill exposed in Old Jant Mine, Matlock, Derbyshire. The sediments provide the first British record of a geomagnetic polarity transition whose age and significance can be discussed in relation to recognised global polarity events and both continental and marine palaeoclimatic records.

Mercian Geologist, vol. 9, no. 4,
1984, pp. 235-242, 5 text-figs.

Geological Setting

Old Jant Mine is situated to the west of the Derwent River Gorge, within Masson Hill (text–fig.1) forming part of a complex system of disused lead and fluorspar mines which worked ore deposits in the form of fissure, pipe and flat veins in the Carboniferous Limestone. The layout and history of the mine-workings were described by Warriner *et al.* (1981). At the same horizon post-mineralisation cavernisation has occurred by solutional enlargement of voids left by the hydrothermal fluids and these then acted as pathways for groundwater movement. This phase is thought to have been initiated during the late Tertiary or early Pleistocene when incision of the Derwent Gorge commenced and the necessary hydraulic gradients became established (Ford and Worley, 1977). Most of the phreatic network was subsequently filled with a mixture of autochthonous and allochthonous sediments after which the cave passages were permanently abandoned by active streams. Because many of these sediments contain alluvial galena, much has been removed by past mining activity but some relics still remain. The narrow Clay Shaft in Old Jant Mine penetrates vertically through about 4 m of alternating sands, silts and clays which fill a calcite-lined pipe vein cavity (text–fig.2). The sediments are compacted and partly desiccated but are uncemented. Because these sediments comprise the longest undisturbed section in the mine they were selected for a detailed palaeomagnetic and sedimentological study.

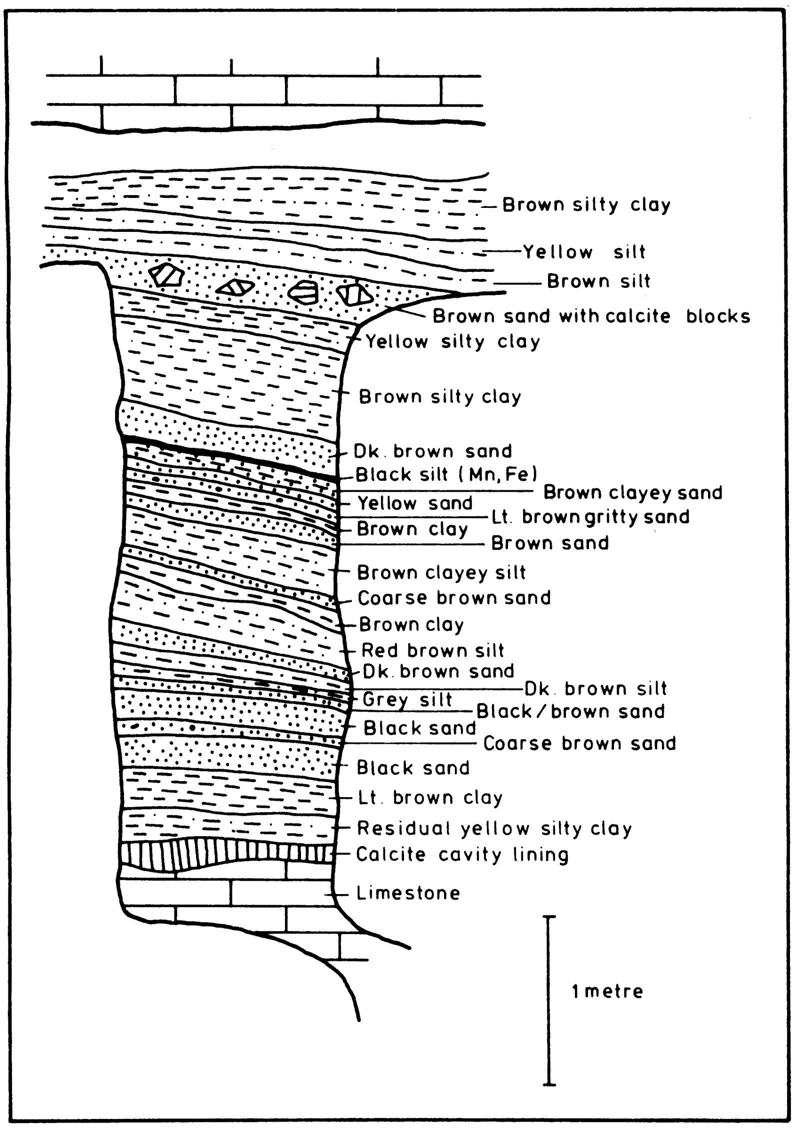


Text–fig.1. Location of the Clay Shaft and Old Jant Mine within the Masson Mines complex, Matlock, Derbyshire. Redrawn from Warriner *et al.* (1981).

Sampling and Measurement

A clean sediment surface was first prepared using non-magnetic tools. A vertical set of seventy-eight samples were then obtained from the section by forcing 5×5 cm plastic cylinders into the sediment using a hydraulic jack. The orientation of each specimen was recorded using a spirit level and magnetic compass. Multiple samples were taken from six horizons to assess the precision of the palaeomagnetic record. The sediment section contains several coarse sand layers which could not be sampled and hence it was impossible to obtain a regular sample spacing.

The direction and intensity of the natural remanent magnetisation of each specimen were measured using a fluxgate spinner magnetometer (Molyneux, 1971). Samples representing typical lithologies were then selected and their stability of magnetisation examined using stepwise partial demagnetisation (Creer, 1959). As a result of these tests, it was decided to partially demagnetise the remaining samples in an alternating magnetic field of 15 mT to remove secondary components of magnetisation after which their remanence was remeasured.



Text–fig.2. The sedimentary sequence exposed in Clay Shaft, Old Jant Mine, Matlock, Derbyshire.

The orientation of the magnetic susceptibility anistropy (magnetic fabric) was measured in the groups of multiple samples by using a modified spinner magnetometer (Singh *et al.*, 1975). This technique is analogous to optical fabric measurement and provides evidence for the extent of post-depositional disturbance in a deposit (Hamilton and Rees, 1970). A magnetic separate was also prepared from the sediment and its Curie temperature measured using a thermomagnetic balance.

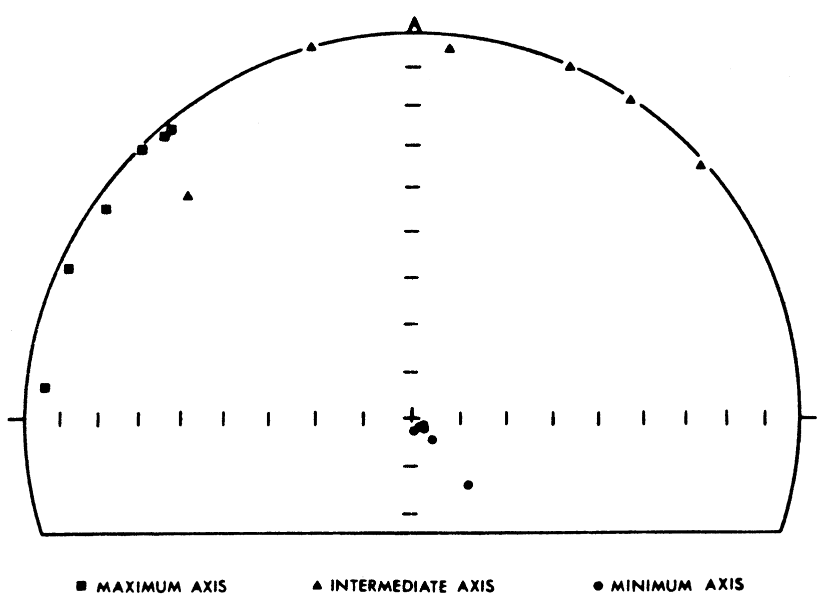
A total of 250 quartz grains were examined under a scanning electron microscope and their surface features compared to the classification scheme of Margolis and Krinsley (1974) in order to assess the palaeoenvironment of the sediment source.

Results and Discussion

The sediments were found during the demagnetisation tests to contain an original stable magnetisation. An undisturbed, depositional style of magnetic fibre (Hamilton and Rees, 1970) was revealed by the susceptibility anisotropy measurements (text–fig.3). The Curie temperature analysis indicated that the principal sedimentary magnetic mineral is magnetite. Therefore it is concluded that the sediment magnetisation has arisen from the alignment of magnetic particles by the earth's magnetic field during deposition. The consistent directions of multiple sample vectors (text–fig.4) support the conclusion that these sediments contain a reliable record of the geomagnetic field at the time of deposition.

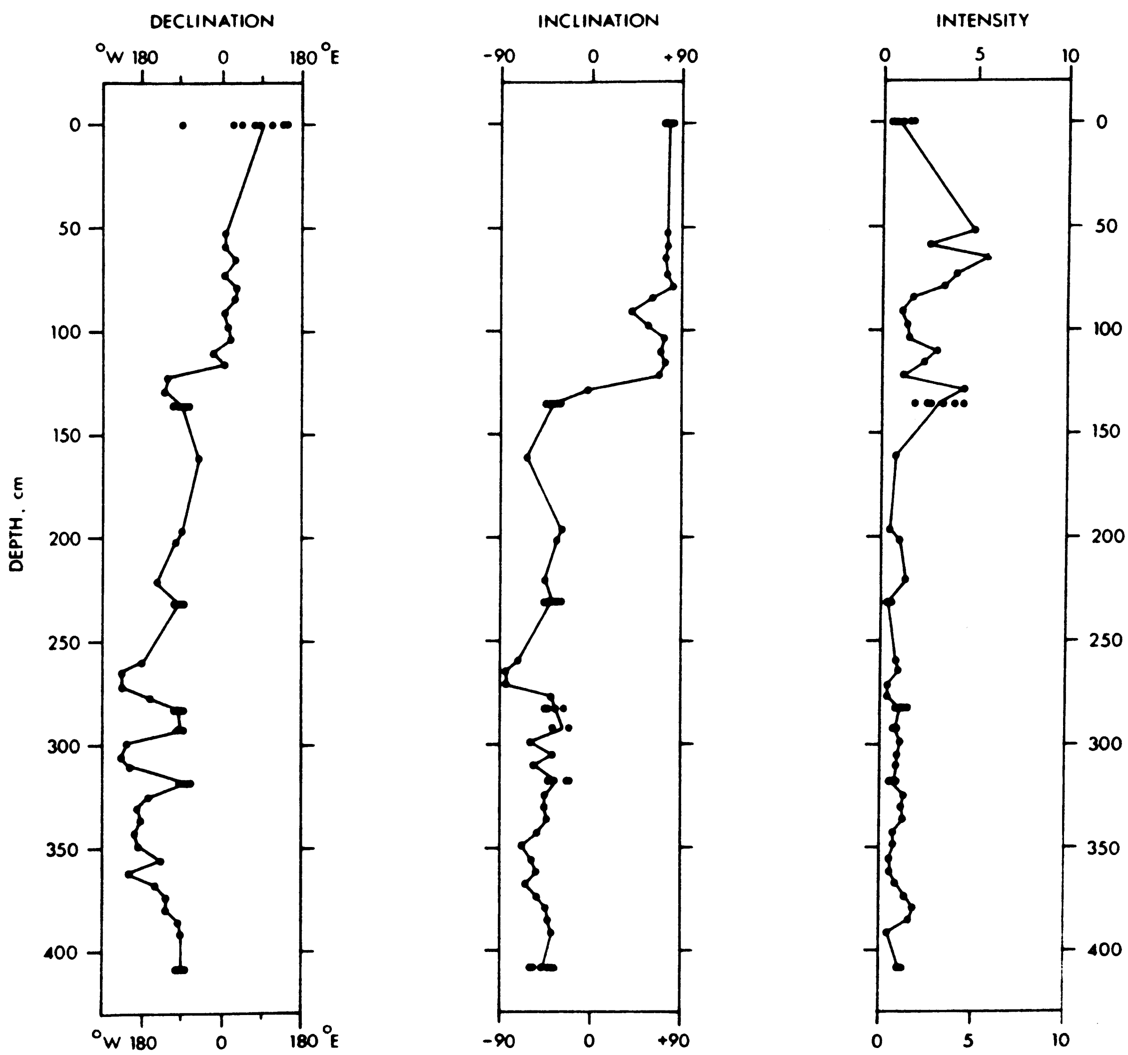
The profile can be considered in three parts: (a) lower, 400–250 cm from the top of the measured section (text–fig.4), the sediment records a period of reversed geomagnetic field as shown by the negative (upward) remanence inclinations and oscillating, southerly declinations. A pilot sample from this unit produced an initial rise in remanence intensity on partial demagnetisation, confirming the removal of normal polarity, secondary components from a reversed polarity primary magnetisation; (b) middle, from 250 up to 140 cm there is a steady trend in declination associated with diminished variability in inclination; (c) upper, at 130 cm from the top of the section there is an abrupt swing to positive inclination and northward declination values signifying a transition to the normal geomagnetic field polarity recorded by the remainder of the section. The lack of a marked intensity decrease previously associated with polarity transitions (Ninkovitch *et al.*, 1966; Hillhouse and Cox, 1976) may be due to variations in sediment lithology masking dependence of remanence intensity on the field strength.

Sediments in the Clay Shaft are not interbedded with any radiometrically datable speleothem material and preliminary assays indicate an exceptionally low content of indeterminable pollen. Thus conclusions concerning the age of the polarity transition are based on other factors which define chronological limits for sedimentation in the cave.



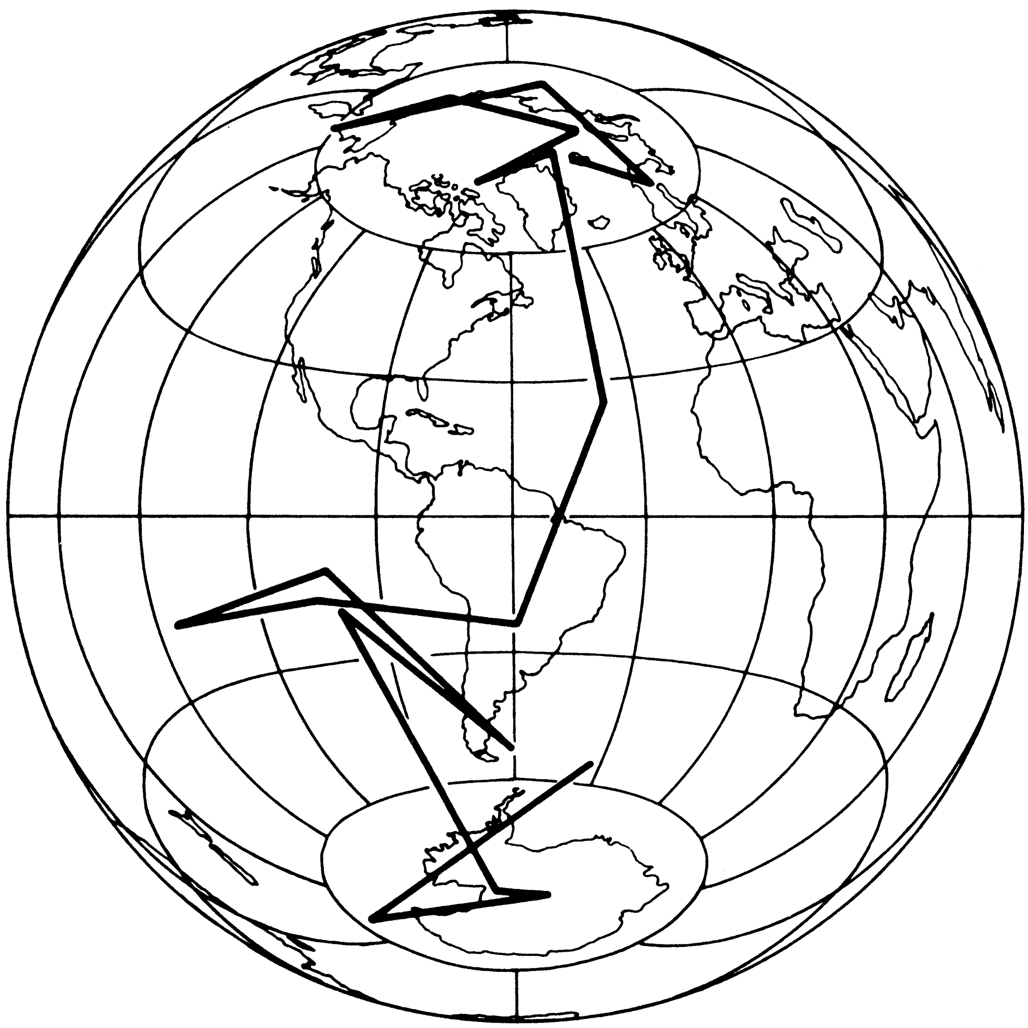
Text–fig.3. The magnetic susceptibility anisotropy of samples from a clay layer at a depth of 318 cm in the section. The anisotropy is shown in terms of the orientation of the three principal axes of susceptibility. The clustering of minimum axes normal to the bedding is typical of an undisturbed depositional style of fabric (Hamilton and Rees, 1970). Equal area projection, lower hemisphere.

An SEM study of 250 quartz grain surface textures shows some with angular chattermarks and fracture plates indicating derivation from a glacial environment; some with mechanical V-pits and subrounding suggesting a fluvial environment, and some with both. Although the fluvial characters could have been inherited from the primary source rock, the Millstone Grit deltaic sands, the overall implication is of a pro-glacial environment with grains derived from a glacier and transported into the cave by melt-water streams (Shaw, 1984). Though largely obscured by mining activities and the sedimentary fill the caves throughout Masson Hill show only phreatic forms, i.e. the caves were formed by solution beneath the water-table and it is quite possible that the sedimentary fills were also deposited below the water-table by relatively slow-moving melt-water streams (Ford & Worley, 1977) before the full incision of the Derwent Gorge. The Clay Shaft site is perched 140 m above present river level and so both cave and fill must predate the final incision of the Gorge, which Ford and Burek (1976) argued was during or immediately after the Late Wolstonian. A Wolstonian or earlier age for the cave sediments is also suggested by the absence of any local till which can be ascribed to the Devensian glaciation (Burek, 1977). On this basis, the polarity transition in the sediment of Old Jant Mine must predate the Laschamp, Mungo and Blake geomagnetic events (Bonhommet and Zähringer, 1969; Barbetti and McElhinny, 1972; Smith and Foster, 1969). The Biwa I and II events at 180 kyr BP and 295 kyr BP (Kawai *et al.*, 1972) are also improbable candidates since the marine $0^{18}/0^{16}$ record shows that these would have terminated under the full glacial conditions of stages 6 and 8 respectively (Shackleton and Opdyke, 1973).



Text–fig.4. Palaeomagnetic results from the Clay Shaft section after partial demagnetisation in a peak alternating field of 15 mT. Remanence intensity in units of $Am^2\ Kg^{-1} \times 10^{-5}$.

Records of the Brunhes/Matuyama polarity transition are available from several sites in central Europe (Hoffman, 1979); the most reliable data are probably those from clays at Brüggen, Germany (Koci and Sibrava, 1976). In these sediments the polarity change corresponds to a virtual pole which crosses the equator near 40°W in close proximity to the path shown in text–fig.5. An age of 730 kyr BP for the polarity transition is also supported by the results from DSDP Hole 552A (Shackleton *et al.*, 1984) which show that the Brunhes/Matuyama transition occurs near the stage 19/18 boundary which would provide the proglacial climate conditions required for cave sedimentation. However, we do not rule out the possibility that the sediments may record an earlier event within the Matuyama chron although their age is probably less than 2.37 Myr, the estimated date for the first major northern hemisphere glacial event (Shackleton *et al.*, 1984). The combination of palaeomagnetic results and SEM grain textures in these sediments implies an earlier episode of full glaciation than any previously recognised in the British Pleistocene which may correlate with one of the pre-Cromerian cold phases in East Anglia (West, 1980).



Text–fig.5. Virtual geomagnetic pole path during the polarity transition. Data correspond to samples from 73 to 277 cm depth in the section shown in text–fig.2. Lines of latitude and longitude at 30° intervals. Zenithal equal area projection.

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FIELD EXCURSION TO THE ISLE OF MAN

Leader: T.D. Ford May 25-28th, 1984

A small and very select party of 11 members enjoyed three days of magnificent weather and geology over the Bank Holiday weekend. A high-speed drive to Liverpool was followed by a rather crowded voyage on the ferry across the submerged Triassic basin of the Irish Sea and members had a view of the platforms of the Morecambe Bay gas field. A short drive then took us to our accommodation at Castletown, appropriately situated on the Carboniferous Limestone, with outcrops barely 10m away on the beach. Some members were even seen looking for fossils before breakfast!

The first day's field work was a traverse of the Carboniferous Limestone outcrops of the south coast. The fault-bounded outlier at Port St. Mary showed thin-bedded Castletown Formation limestones with abundant corals, bryozoa, *Zoophycos* feeding trails and scattered gastropods. Sparse quartz pebbles suggested that land was not too far away at the time of deposition. Bedding plane surfaces raised questions as to why some were flat and others were hummocky. Both ends of the section are faulted against Manx Slates, and tight folds in the Lonan Flags division were examined in the bay west of Kallow Point.

Moving to Strandhall shore, large Caninid corals were abundant, and a complex of faults, dykes and a thin mineral vein at Poyll Breini caused discussion. Raised beach gravels with sub-fossil limpets were partly covered by tufa. Moving eastwards, up the succession, the reef limestones of the Poyllvaaish Beds were soon reached at Salt Spring and fossil-hunting started in earnest. Beds packed with goniatites almost made some members forget lunch! Across the inlet of Ghaw Gortagh, close to Poyllvaaish Farm, exposures caused a lot of discussion. What appeared at first sight to be isolated small reefs turned out to be fallen blocks of reef limestone in a matrix of thin black shaly limestones distorted by compaction round the blocks. Geopetal fabrics demonstrated that the blocks were locally overturned.

On the east side of Poyllvaaish Bay, a petrographic diversion was had on the reject offcuts of various granites, diorites etc. from a small monumental masonry works. Close by, the highest Dinantian beds are black shales with occasional calcareous bands, with crushed goniatites and bivalves scattered on bedding planes of the Close ny Chollagh Formation. Numerous dolerite dykes of presumed Tertiary age cut the succession in the Poyllvaaish area, but these were coincidental with the passage of the Carboniferous limestones up into the pene-contemporary Scarlett Volcanics. Lenses and tongues of black limestone passing into agglomerates demonstrated their relationship at Close ny Chollagh point. The volcanics outcrop continuously for a mile of shore, with spectacular exposures of pillow lavas, amygdaloidal basalts, coarse agglomerates, fine tuffs and a wall-like intrusion, with a probable vent showing radial columns at the Stack of Scarlett. Adjacent to the Stack, the volcanics' contact with the limestones was obscured by faults and much dolomitization before dykes were crossed on to well-developed folds in the Castletown Formation again.

A short drive took us round to Langness Point where the basal Carboniferous breccias are seen resting on weathered Manx Slate in Dreswick inlet. Eroded into impressive stacks and arches, the breccias along the west side of Langness are cut by a fault, several dykes and a mineral vein.

The second day took us north across the Manx Slate country. A diversion was made into the "spar" quarry in the Foxdale granite to see the massive quartz-feldspar and quartz-mica pegmatites cutting the rather kaolinized granite. "Spar" here means vein quartz!

At Peel, immediately outside the seaward Castle walls a shallow quarry on the wave-cut platform showed tight, small folds, with faults and a contemporary dyke in the Niarbyl Flags division of the Manx Slate. Microfossil evidence has shown that the Manx Slate Group is of uppermost Cambrian to lowest Ordovician age, though details of the succession of stratigraphic units within the Manx Slate are still controversial.

North of Peel a short climb over a headland took us via a cliff path down into the Traie Fogog bay for magnificent exposures of the Peel Sandstone. Generally regarded as of Old Red Sandstone age (though it has yielded no diagnostic fossils) features of fluvial sandstones are well-displayed in the steeply dipping sandstone. These pass up into red mudstones and finally into thick cornstones (= calcretes) with a gravelly matrix, representing an ancient series of soils. The overlying fine breccias by The Stack have yielded limestone pebbles with Ordovician and Silurian fossils of unknown provenance. Sources in Ireland were thought most likely.

After lunch, a move was made a mile north along the coast to walk down into Whitestrand Bay. Very similiar lithologies of Peel Sandstone are well-exposed here but the details suggest that they are a repetition of depositional facies rather than a faulted recurrence of the same beds as in Traie Fogog. At the north end of Whitestrand Bay the headland shows the Peel Sandstone Beds in wild disarray and much discussion ensued. The consensus was that primary slump folds showed overturning towards the east, i.e. away from the present Irish Sea basin towards the Manx Massif, with a Devonian palaeoslope in the opposite direction to that seen today. Current-bedding directions and the fossilferous pebbles supported the hypothesis of a westerly source for the sandstones. Subsequently these primary structures had secondary, tectonic, shears superimposed in the form of numerous sub-horizontal fault planes. Shearing and shattering became more pronounced on the north side of the headland as the strong fault in the Wills Strand Bay was approached. This threw Peel Sandstones against Manx Slates with a small intrusion of much altered dolerite.

On the return journey to Castletown, a stop was made briefly at Niarbyl Point to see the crush breccias, and another stop was at the ruined Glen Rushen mines, were lead and copper had been produced from a major east-west vein complex cutting both Manx Slate and Foxdale Granite. Relics of the miners' ingenious devices for winding, pumping and ore-processing were pointed out.

The third day was largely on the Pleistocene. After a drive to Kirkmichael, the cliffs adjacent to Glen Wyllin were examined. The succession of Devensian tills and outwash sands and gravels was pointed out and questions were raised about the presence of *Turritella* shells in glacial sediments. To the north, kettle holes dated at around 18000 BP yielded peat infills and calcareous marls with *Chara*. They demonstrate that glaciation finished here rather earlier than in some nearby regions, but soliflucation deposits across the kettle holes showed that cold climate persisted for a time. A drive across the rolling hills of the Bride terminal moraine took us to the Point of Ayr at the northern tip of the island to see the fine storm beach ridges, with their abundant derived pebbles of riebeckite microgranite from Ailsa Craig in the Firth of Clyde. Lunch was taken on the prom at Ramsey before a drive across the hills to Laxey, stopping briefly at one of the island's many archaeological treasures—King Orry's Grave, actually a Bronze Age burial chamber.

At Laxey, a pilgrimage was made to the giant water-wheel, Lady Isabella, 72 ft. in diameter. Installed in 1852, it helped to pump the lead-zinc-copper mines dry to a depth far below sea level. A walk upstream took the party to the turbine house and the water-pressure engine shaft, further evidence of the miners' fight against their old enemy, water. Here the President demonstrated that he could still get into an old boiler but no members were willing to follow.

Apart from getting lost on the motorway complex round Manchester, the return journey to Nottingham was uneventful, and the party was left with memories of a highly varied weekend, with many geological problems both solved and unsolved.

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EHLERS, J. (Editor). *Glacial deposits in North-West Europe.* 1983. Balkema, Rotterdam. 482 pp., index. £29, hardback.

Jürgen Ehlers of the Hamburg Geological Survey has compiled this volume by persuading 45 other European scientists to contribute papers (all of which are in English) and as most editors will appreciate this is a remarkable achievement in itself! What is perhaps even more remarkable is the coherent nature of the resulting publication, so that despite the widely varying lengths of the 53 chapters, a uniformly high standard of presentation and consistent style is present throughout. The test is profusely illustrated by 409 figures and 300 photographs, of which 95 are in colour. A bibliography at the end of the book combines over 700 references, whilst the index is unusually comprehensive.

The aim of the book is to review recent developments in the study of glacial sediments, particularly their lithological characteristics and their association with depositional landforms, in North-West Europe; which is defined in this context as Norway, Sweden, Denmark, northern West Germany and the Netherlands. This rather restricted definition is in many ways regrettable since glaciers and their deposits tend to pay little heed to political boundaries, however one can sympathise with the editorial problems involved in trying to produce a more comprehensive synthesis. Whilst the geographical scope of the book may be restricted, its scientific content is most certainly not and various chapters consider glacial stratigraphy, glacio-tectonics, till deposition, associated marine, lacustrine, fluvial and aeolian sediments together with applied aspects such as mineral prospecting in glaciated regions and the engineering properties of glacial deposits. The book is subdivided into five sections, one for each country, and after an introductory chapter on the glacial history of each area, a number of selected topics are discussed in the succeeding contributions. Clearly the subject matter of these latter chapters varies depending upon which area is being considered, e.g. the Norwegian section is concerned largely with the effects of the last glaciation (since this is best represented in the Norwegian Quaternary record) whilst more extensive consideration is given to glaciofluvial and glaciolacustrine sediments of several glacial periods in the section dealing with the Netherlands. Some of the papers are extremely short (in one case consisting of only a one page summary) whilst others, e.g. those considering the stratigraphic use of palaeosols and the stratigraphy of Schleswig-Holstein, represent comprehensive reviews of their subject areas.

The declared intention of the book is "to show the glacial deposits of Northern Europe to all those who have neither the time nor the possibilities to see them all by themselves", particularly those "interested in Quaternary or Sedimentology Research, amateurs as well as students or professionals". Most of us, amateurs or professionals are unlikely to ever get the opportunity to visit all the localities illustrated in this book, or (even if we did get there) we would be fortunate to see the sequences as well exposed as they were when photographed for this volume since many of the exposures occur in working quarries or other temporary excavations (the illustrations of ice contact deltaic sequences are more striking than any which I have ever seen over several summers of working in Norway, whilst the illustrations of glacio-tectonic structures are only equalled in the United Kingdom by those exposed in the cliffs near Cromer). The book therefore provides an invaluable opportunity for anyone with an interest in this subject to broaden their horizons, by simply examining the excellent illustrations of these diverse deposits and on this basis the book is strongly recommended to amateurs and professionals alike. Additionally, for anyone studying glacial deposits in Europe the up-to-date bibliography will be a valuable source of information. At a time when standard paperback textbooks often cost over £15 this book will be reasonably priced solely on the basis of the quantity of material it contains, however the informative colour photographs and extensive bibliography ensure that the book is a bargain which many glacial geologists will wish to purchase for themselves.

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COLLINSON, Margaret E. (1983) *Fossil Plants of the London Clay*. Palaeontological Association Field Guide to Fossils No. 1. London: The Palaeontological Association. 121 pp., 242 text figs. £7.95.

The fossil flora of the London Clay is one of the most varied fruit and seed floras known, and the only rich flora of lower Eocene age in Europe. Remains of some 500 types of plant are known from the London Clay, including about 350 named species. Seeds, fruits and other macrofossils can readily be collected from coastal exposures and more temporary sections inland, but their identification poses considerable problems. These difficulties of identification are due partly to the variable condition of preservation of the fossils and partly to the available monographs (principally those of E.M. Reid & M.E.J. Chandler 1933; M.E.J. Chandler 1961, 1964, 1978) being devoted to comprehensive taxonomic descriptions rather than to hints for identification of the commoner fossils.

The present book provides the first convenient guide to identification of the plant macrofossils of the London Clay. Over 250 of the commoner fossils (mainly fruits and seeds) are included, with clear photographic illustrations of 238 taxa. The keys and the illustrations cover the identification not only of whole and well-preserved material but also of internal casts of seeds and other common fossils, including a number whose botanical identity is uncertain.

Although the greater part of the book is devoted to keys, brief descriptions and illustrations, it is a compact handbook rather than merely an identification guide. Introductory sections deal with the geological setting, depositional environments, an annotated list of fossiliferous localities, hints on collection, conservation of fossils, systematic studies and their evolutionary implications, states of preservation and palaeo-environmental and palaeo-climatic implications. In addition there are lists and a table summarising the stratigraphical ranges of all genera recorded from the London Clay.

Only about one-third of the London Clay plant macrofossils are placed in living genera (e.g. *Magnolia, Vitis, Rubus, Sabal*), and all of these are considered to be represented by extinct species. Others can be assigned to living families although not genera, and still others cannot be placed in living families. Amongst the plant fossils that can be identified are palms, mangroves, and others that imply a palaeo-climate much warmer than the modern climate of southern England. Trees, shrubs and vines are considerably more strongly represented than herbs, implying that it was predominantly forest vegetation. The remains of this vegetation were deposited in the inshore marine environment in which the London Clay accumulated.

Although this richly varied flora has receieved a great deal of detailed study it is evident that much remains to be discovered. Many of the plant taxa are still known from only a few remains, so that their ranges of variability are poorly understood and hence their taxonomic delimitation is unsettled.

Short-lived exposures of the London Clay occur commonly in both the London and Hampshire Basins, and these offer frequent opportunities for collection of seeds from new sites. The few professional palaeobotanists cannot study more than a fraction of these ephemeral sites so that much of the material that is potentially available remains uninvestigated.

This well produced little book offers a great deal of assistance to those wishing to join in the study of a difficult but fascinating group of fossils. It is also a convenient source of reference to the Eocene flora. The author and publishers alike are to be congratulated on an attractive and useful addition to the literature.

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(Copies of this book are obtainable from Dr R.J. Aldridge, Department of Geology, University Park, Nottingham, NG7 2RD at £7.95 inclusive of postage and packing).

GALLOWAY, W.E. and HOBDAY, D.K. *Terrigenous clastic depositional systems. Applications to Petroleum, Coal and Uranium Exploration.* 1983. Springer—Verlag, New York. 423 pp., index. £29, hardback.

This book has been produced with the expressed aim of integrating modern developments in sedimentology with the more traditional economic geology of mineral fuel deposits. Following a very brief discussion of the fuel mineral resource base the authors outline their approach to 'genetic stratigraphic analyses', i.e. the use of sub-surface exploration techniques, particularly downhole wire-line log data, to determine the way in which sediments, deposited in a variety of environments, are combined by tectonic processes to form parts of the earth's crust. The major part of the book (chapters 3 to 10) is devoted to reviewing sedimentary environments in terms of the processes which act within them and the sedimentary successions which result. This section of the book is comparable to '*Sedimentary Environments and Facies*' (edited by H.G. Reading) and the more recently published A.A.P.G. Memoir '*Sandstone Depositional Environments*' (edited by P.A. Scholle). Galloway and Hobday's discussion of environments and facies is more concise than that contained in equivalent chapters of the volume edited by Reading and as such will no doubt appeal to many economic geologists. The brevity of this treatment has inevitably led to somewhat uneven emphasis on the various facies models, e.g. in discussion of deep sea turbidite fan models, only the model proposed by Walker being presented in any detail. However, a strong point of the book is the integration of examples of economic deposits into each chapter : an approach which I found much more satisfactory than the way in which examples of economically important sediments are rather awkwardly appended to each chapter in the A.A.P.G. Memoir.

In chapter 12 the authors consider basin hydrogeology, emphasising the important interaction between depositional and groundwater flow systems in determining the location of potentially economic fuel reserves; whilst the remaining three chapters consider economic reserves of coal, sedimentary uranium and hydrocarbons in the context of the preceeding chapters.

The book is well illustrated with 237 figures, most of which are line drawings. Most figures are reproduced from other publications and in some instances insufficient attention has been paid to redrafting them, e.g. Figure 10-1 contains an arrow mystically labelled 'Z→X': the caption of the figure fails however to tell us is that this represents the prevailing wind direction! Such errors are infrequent and the drawings are for the most part clear and concise. A feature which will particularly appeal to industrial geologists is the inclusion of schematic wire-line log motifs alongside many of the more conventional diagrams depicting facies sequences. Detailed illustrations of the various structures and textures described in the text are clearly beyond the scope of the book and emphasis is placed on the larger scale features recognisable from geophysical data or at a basin-wide scale and as such the book is unlikely to replace Reineck and Singh's '*Deposition Sedimentary Environments*' as a student text. The book ends with a comprehensive bibliography although somewhat frustratingly several of the key citations refer to unpublished North American theses which are not easily accessible to readers based on this side of the Atlantic.

In summary, this is a book written for the practising exploration or production geologist and as such deserves to find a place on the bookshelves of almost every company involved in mineral fuel exploration. Whilst the text assumes too much knowledge to be easily understood by a newcomer with no background in sedimentology, it does provide an excellent introduction to the application of sedimentology to the search for the fuel resources of the future.

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London illustrated geological walks. Book One, 1984. Robinson, E. Scottish Academic Press Ltd., for the Geologists' Association, i-iv + 98 pp including 95 photos, 1 line drawing, 11 street maps, references and 2 pp glossary, plus 10 blank pp for readers notes. £4.95p.

This excellent guide to London's East End was published to celebrate the 125th anniversary of the Geologists' Association: it is the first of a series of illustrated London walks. If subsequent publications are as good as this they will give much pleasure and profit to many geologically inclined London residents and visitors.

The writer has personally walked three of the five itineraries and can consequently testify from first hand experience that this guide is very easy to follow, maps and photographs appearing in the text just when required to reassure the reader he is really looking at what is described in the text. Users should, however, be warned to check the captions of photos against the maps. The writer has found only one ambiguity but since this concerns the first building mentioned after leaving St. Paul's in the first walk described it creates an altogether false impression of otherwise almost faultless editing. This photograph on page 7 labelled "Juxon House from the West Front" (of St. Paul's) is in fact a picture of Bancroft House and the building bordering the east side of Paternoster Square with a small part of Juxon House appearing in the left hand foreground. The careless reader, with whom the present reviewer must be numbered, can all too easily examine the building stones in Bancroft House, which are similar to Juxon House, and become increasingly disturbed by the mis-match between the text and his observation until he turns over the page and finds a map which tells him that he has been looking at the wrong building.

Other problems may arise through no fault of the author due to the rapidity with which London property is bought and sold and perhaps refaced or even demolished. For instance, the Burnley Building Society premises on Ludgate Hill were sold shortly after this guide was published and it seems unlikely that the new owners will retain the name even if they keep the granite cladding. Fortunately the author gives the address (30-32 Ludgate Hill) so this particular site should be easily identifiable.

At first sight the care, attention to detail and sheer hard work which has gone into producing this slim volume is not obvious. Only when one actually follows the itinerary is it realised that these have been selected to demonstrate a very wide range of building stones with as little duplication as possible. To do this so successfully many more buildings other than those mentioned in the guide must have been examined. Moreover the identification of the source of unusual building stones is no easy task for adequate records are rarely kept by architects or clients. The author gives due credit to Eva Wilson's fascinating detective work in tracking down the probable source of the black marble formerly used in the steps of St. Paul's, but he modestly does not discuss his own painstaking efforts.

As a user of the booklet I found 115 mm × 225 mm a convenient size for slipping into a pocket and the cover and pages stood up to 6 hours wear and tear exceedingly well. A London map showing the general location of these walks would have been welcome. More mention of building materials other than stone would have added to my enjoyment, particularly since the area abounds in brick, terracotta and brushed aggregate concretes from a great variety of geological sources. Also I felt that since the first walk started from the steps of St. Paul's it was a pity not to look at decorative materials used in the interior fabric and monuments in the cathedral. This diversion merely confirmed my lack of knowledge and a companion guide to the ornamental stones of St. Paul's itself would admirably complement the present volume. Doubtless readers new to geology will derive as much benefit from Dr. Robinson's explanations of the genesis of building stones as I did from his comments on architecture, conservation areas and environmental politics. His affirmation that a Shap Granite bollard in front of St. Paul's provides "the best example you could find anywhere for the molten origin of granites" caused me wry amusement since in my student days such feldspathised xenolits were cited by many geologists as strong evidence of granitization without recourse to a magmatic stage—a salutary reminder of how drastically geological interpretation can change.

Such minor criticisms must not be allowed to detract from a booklet with its lucid text, excellent maps and first class photographs (by Mike Gray and Colin Stuart) which has given me much pleasure and information and moreover has provided an excuse to visit parts of London which I would not normally frequent.

I strongly recommend this guide and can assure would-be users that visitors and residents take scant notice of an idiosyncratic geologist examining the stone facings of buildings with a hand lens. I was accosted only once and that by an over zealous security guard who, on reading Eric Robinson's words of wit and wisdom, was almost persuaded to buy a copy and certainly now knows more about the building he was guarding than he did before.

I look forward to more illustrated London walks describing other parts of the metropolis which I am sure, if produced by the same team, will be at least as good as Book One.

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EAST MIDLANDS GEOLOGICAL SOCIETY

SECRETARY'S REPORT FOR 1981

Now in its 18th year the membership of the Society remained at around 500, with Ordinary membrs from as far afield as Canada, France and Norway, and Institutional members spanning the globe. The programme of both indoor meetings and field excursions, attracted good attendances with speakers and leaders continuing to give excellent service on every occasion.

There had been 15 meetings consisting of 9 indoor, 5 field and one Joint meeting with the Matlock Field Club.

The first of each season being the Annual General Meeting, on 7th March, was attended by 50 members. Comments from the floor had been made regarding delivery and frequency of circulars, whether one every two months might not be sufficient, but it was felt that many people preferred their memories to be jogged before each meeting. Increasing postage costs were now an annual event, but kept lower by the group of members who accepted responsibility for delivering material in their own area. Both the Editor, with the Journal, and the Secretary, with the circular, greatly appreciated their zeal.

Following the AGM, Steve Penn of the Trent Polytechnic, Nottingham, talked of the Geology of Iceland with numerous photographs, and discussed the ways in which geysers and hot springs were being utilised with the resulting difficulties of corrosion of the equipment.

The Joint meeting with the Matlock Field Club at the Peak District Mining Museum, Matlock, started as it meant to go on, in pouring rain. In the morning Dr. Lyn Willies lectured on Mines of the Peak District to about 50 people, and then those that had fortified themselves with a hot lunch at the Fishponds Hotel across the road, faced the rigours of Magpie Mine and Meerbrook Smelting Works, 15 souls persevering to the bitter end.

The April meeting was held on Saturday 4th when Dr. G.C. Brown of the Open University lectured on the Origin of Granite (with particular reference to Great Britain) the previous Autumn having led the party on the Lake District week-end.

As the Annual Dinner had had little support recently, a Social Evening at a local hall was suggested, but this too suffered the same fate. Luckily it was realised in time and the 16 people who had shown interest, were invited to Nancy Mulholland's house on 11th April, and she, Mrs. Moss and the Secretary provided the collation. It was a pleasant and enjoyable evening in good company.

The University of Nottingham celebrated its Centenary, and to mark the occasion, opened its doors to the general public, but on a day when members would be away on the week-end excursion. Professor Baker most kindly allowed the Society the privilege of looking around the Department of Geology on Thursday 14th May instead. About 30 members took advantage and after a lightening tour to show what was where, everyone wandered at will throughout the various sections, but finding that as usual, there was insufficient time to do justice to the hard work involved in mounting such an exhibition.

The week-end excursion was spent on Anglesey from the 15th-17th May, being led by Dr. A.M. Evans, Department of Geology, University of Leicester. The Holborn Private Hotel in Holyhead was used as base. Twenty two members joined the excursion, Saturday being spent on Holy Island and Sunday, North Anglesey, Parys Mountain and by special request, the exposure of glaucophane schist.

The first day excursion of the summer was led by Dr. John Moseley to look at the Precambrian and Lower Palaeozoic geology of Church Stretton and Shelve area of South Shropshire. A longer distance than usual, the party of 28 met the leader at 11.40 am at Hope Bowdler, and finishing the day at the Stiperstones for a superb view of the surrounding countryside, the coach arriving back in Nottingham for 9.00 pm exactly.

On 5th July the Ashover Grit of the Stanton Syncline, Derbyshire, was led by Mr J.I. Chisholm of the Institute of Geological Sciences, Leeds, 27 people travelling to meet him and joined by several cars. Starting from the vantage point of dolomitised limestone near Winster, the party were able to see the area to be visited. At Birchover, 3 quarries at different levels and later the massive sandstone at Rowtor Rocks.

Dr. F.M. Taylor was kept to the promise he had made to lead a week's excursion based at St. Andrews. On 1st August a party of 26 including Dr. Taylor, met at St. Andrews, the main party staying in Lindsey House, David Russell Hall, University of St. Andrews, a self-contained wing ideal for our purpose. The previous evening to each excursion, a briefing session was held to make sure the drivers knew where and at what time the first location should be reached.

Sunday 2nd August, the shore section from Petty Cur north towards Kirkaldy with an almost continuous sequence of Lower Carboniferous rocks visible, especially as the tides had been forecast correctly. Following lunch, eaten when and where convenient, the Lomond Hills, inland from St. Andrews. The view from the top could have been clearer, but an added bonus of a hang-glider provided a diversion. Monday 3rd August was spent on the East Coastal section of St. Andrews. First a walk along the cliff top, where synclines and anticlines were plainly visible from above, unfortunately in rain, then dropping to the shore to examine them more closely. One or two reluctant seaweed rock-hoppers were again provided with a diversion as an Air Sea Rescue helicopter deposited and 'rescued' a 'casualty' from the Rock and Spindle.

Tuesday 4th August — a longer journey, visiting Arbroath for the unconformity between the Upper and Lower Old Red Sandstone. Northwards to Crawton Bay where the Boulder Beds were most impressive. From Stonehaven a 'quick' walk over the Devonian Sandstones to see the Highland Boundary Fault, a marvellous view from the cliff top at Craigeven Bay, and all in glorious sunshine.

Wednesday 5th August — a morning spent inland at Drumcarrow displaying the Olivine-Dolerite Sill, then to Ladeddie Hill with its volcanic vent and view over the site of glacial lakes at Pitscottie and Ceres. On to Dura Den valley for rocks of Upper Old Red Sandstone and Lower Carboniferous before a short lunch stop south at Elie car park. The party then walked along the cliff path to Ardross Cottages, the return being along the shore to examine the 4 volcanic necks, complicated not only by the Ardross fault but also the abundant seaweed.

Thursday 6th August — the Wormit Gap with quarrying in Devonian Volcanics, sandpit in Pleistocene deposits and from where the line of the esker could be seen. The party were fascinated by the variety, size and distance travelled by the boulders. After lunch eaten at the top of Newton Hill overlooking Wormit Gap and the Tay Bridge, the shore of the Tay was traversed examining the Devonian igneous rocks.

Friday 7th August the party travelled to Edzell where the leader for the day, Dr. N.F.C. Hudson, was camped nearby. The walk along part of Glen Esk was spectacular both for scenery and the rocks the river had exposed, the gorge cut into the Jasper and Greenrock Series, the Garnet and Biotite zones and finally an enormous boulder of mica-schist found in a stream bed, from which numerous specimens were taken. Unfortunately Dr. Hudson was unable to return to St. Andrews, but after dinner the rest adjourned to the 'local', Rufflets Hotel, for a drink together on the last evening.

A memorable week's geology in georgeous sunshine.

A morning was spent on Sunday 13th September at the Carsington Reservoir Scheme, meeting the Project Manager, Mr. P.G. Davey, who first outlined the reason for its being built and the manner in which it would function. The geologist, Mr. Rick Rogers, then escorted the party of 30 to the various areas of progress, and the cores which had been taken before work began, were examined. After lunch no other excursion had been arranged, but the coach party spent a pleasant hour at Harborough Rocks, where the view was much appreciated.

An excursion to South Leicestershire was organised for Sunday 27th September led by Dr. J. Rice, Department of Geology, University of Leicester. Only 15 plus 4 from Leicester University joined the excursion, which was an excellent day looking at the Pleistocene deposits of the Avon/Soar drainage areas.

The first indoor meeting of the winter session was held on Saturday 7th November when Mr. J. E. Matthews of the Department of Civil Engineering at Derby Lonsdale College, talked about Limestone Extraction in Derbyshire, a lecture on the development of the industry up to the present day. It was followed by a lively discussion especially its encroachment onto the Peak National Park.

The Centenary of the Natural History Museum was celebrated by a day excursion to London on Wednesday 18th November. Societies had been invited for a 'behind the scenes' look, 14 people taking advantage of this. The basement of the Musuem was opened to visitors and nearly every room had mounted a display. The staff proved to be extremely helpful, keen and went to a great deal of trouble to explain their exhibits to all who showed interest. It was agreed on the coach returning to Nottingham that it had been a very well worthwhile visit, but unfortunately, could only be a unique occasion.

At the end of November — the 28th — Professor A. Hallam, Department of Geological Sciences, University of Birmingham, visited Nottingham to lecture on the 'Growth of the Atlantic'. A large gathering listened as he discussed the accuracy with which the continents would fit together, taking the 1,000ft depth as the point of juncture and by numerous diagrams was able to postulate that pole reversal and its effect could account for the expected presence or absence of fossils in certain areas.

The last meeting in 1981 combined a lecture and most enjoyable social occasion. Dr. G. Tresise from the County Museum in Liverpool, gave members a memorable talk on the 'Geology and Wine'. Unfortunately icy conditions prevented all but 50 people attending, but they sampled with gusto the 6 different wines and various cheeses, which were set out in the Swinnerton Laboratory.

1982 started with a lecture on 'Glaciation of the Midland Valley in Scotland' by Mr. J. Rose of Birbeck College, University of London, an appropriate subject as the temperature had only risen above freezing that day after a long period of glacial conditions. This area of Scotland had been covered by 4 Society Week Excursions since 1976 and was well known to those who had attended and a recap of the times in Scotland.

The last meeting of the Society year was the Foundation Lecture on 6th February, when Dr. Jane Plant of the Institute of Geological Sciences, London, spoke on 'Regional Geochemical Mapping in Britain: some economic and environmental applications'. Again as at the January meeting, the rail strike necessitated a change of plan at the last minute, but Dr. Plant arrived on time and gave an excellent talk on the use of computers to build pictures of chemical element distribution and the relevance to disease in both man and animals.

Dr. Plant's enthusiastic lecture ended the year in grand style. Our thanks to her and all the lecturers, Mr. S. Penn, Dr. L. Willies, Dr. G.C. Brown, Mr. J. E. Matthews, Professor A. Hallam, Dr. G. Tresise and Mr. J. Rose. Also the leaders of field excursions, Dr. A.M. Evans, Dr. J. Moseley, Mr. J.I. Chisholm, Dr. F.M. Taylor, Dr. N.F.C. Hudson, Mr. R. Rogers and Dr. J. Rice. The Society benefits from their knowledge and we are always grateful for the time and trouble they take in providing us with excellent meetings and field excursions.

Ten circulars had been sent during the year providing information and news. This was one less than usual as the 2 September excursions were published together. The coloured duplicating paper had still been in use and was considered an asset as its colour was readily distinguishable from other papers.

During 1981 Council had met 5 times to discuss and arrange the Society's affairs. I will continue to remind members that all suggestions will be welcome, for the year's programme, the *Mercian Geologist* or anything relating to the Society, and should be sent to the Secretary. This will be put on the agenda for the following Council Meeting which is always notified in the circular.

The membership of the Socity remained steady and was as follows:

Honorary	Ordinary	Joint	Junior	Institutional	Total
2	260	120	3	111	496

The *Mercian Geologist* had been published twice, Vol. 8 Numbers 2 and 3, as usual the Editor had been ably assisted by his band of helpers, both in collating and distribution of the Journal.

The Society Exhibit had just completed a tour of the North Nottinghamshire Branch Libraries, bringing the existence of the Society, its activities and publications to the notice of many more people. It would then be ready for up-dating and refurbishing, having been 'on the road' for 10 years.

Both the University of Nottingham and Professor P.E. Baker had, as always, allowed the Society free use of facilities in the Department of Geology for which we are continually grateful. Our thanks, although repeated many times, are nevertheless sincere.

In conclusion, appreciation of the support given to me, especially from Members of Council, their fund of knowledge and accessibility as such a help on all occasions, as is the tolerance of the general membership.

W. M. Wright

LETTERS TO THE EDITOR

Origin of alabastrine gypsum

6th Sept, 1984

Dear Sir,

I write first of all to congratulate Dr Firman on his most interesting and valuable review of the history of English alabaster and its uses (Firman, 1984). His careful combination of historical and geological evidence can only increase our enjoyment, admiration and appreciation of one of the more beautiful ornamental stones to be found in this country.

However, there is one point with which I wish to take issue with Dr Firman; this concerns the origin of the alabastrine textures commonly found in gypsum rocks around the world. In this regard Dr Firman kindly quotes the work of myself (Holliday, 1967, 1970a) and Mossop and Shearman (1973), in Spitsbergen and Arctic Canada respectively, and draws the conclusion that alabaster in Britain has resulted from the hydration of anhydrite under periglacial conditions. However, in modern polar areas, hydration of anhydrite is generally limited in extent, even shallow penetration of groundwater commonly being prevented by permafrost. The importance of such areas is the clear proof they supply that alabastrine textures form near the surface and not necessarily at significant depth, as claimed by Ogniben (1957). The typical disordered textures of alabastrine gypsum result from rapid hydration of anhydrite at temperatures well below the equilibrium transition temperature (42°C) (Holliday, 1970a, Mossop and Shearman 1973) rather than as a result of mechancial crushing (Ogniben, 1957). That periglacial conditions are not essential for the formation of such gypsum is shown by a number of examples in modern tropical and sub-tropical areas where this explanation cannot apply; the extensive Eocene gypsum of Jamaica is one with which I am particularly familiar (Holliday, 1970b). The thickness and extent of English alabastrine gypsum thus points to non-glacial periods of formation, of which the Quaternary Interglacials or the later Tertiary period immediately spring to mind. Perhaps the most potent times of English alabaster formation were the periods of climatic and amelioration when the Quaternary glaciers became stagnant and rapidly washed away. At these times very large volumes of water were produced which, no longer inhibited by permafrost, could penetrate into the subsurface and quickly bring about the hydration of near surface anhydrite.

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25th September 1984

Dear Dr. Bryant,

I am grateful to Dr. Holliday for his kind remarks on the content of my paper (Firman, 1984). I am also most grateful to him for clarifying an ambiguity in my text which seems to have arisen from my ill-advised use of the word periglacial and the implicit, though unintentional, suggestion that alabastrine textures can only form in periglacial conditions.

That small quantities of alabastrine gypsum have formed by hydration of anhydrite in the active zone above the permafrost table has been amply demonstrated by Holliday (1967) and Mossop and Shearman (1973). I readily agree that this process cannot take place at depths comparable to that of much of English alabastrine gypsum unless and until the permafrost zone melts.

To extend the use of the term periglacial to environments in which the permafrost has wholly or substantially melted is, I agree, misleading although it might be noted that the presence of permafrost or even glaciers are not a necessary part of the definition of the term (Black, 1966). Dr. Holliday's reminder that alabastrine textures can form in modern tropical and sub-tropical areas is salutary but I hope he will agree that periglacial weathering (i.e. frost action), although not an essential pre-requisite, was nevertheless likely to have been more potent than Tertiary weathering in facilitating the subsequent formation of alabastrine textures.

In the absence of any accurate methods of dating the products of hydration interpretation of the chronology of hydration is difficult but the distribution of alabastrine textures and their inter-relationship with porphyroblastic gypsum in the East Midlands (Aljubouri, 1972) is consistent with an early phase (possibly Tertiary) of porphyroblastic gypsum formation followed by subsequent exhumation and deep weathering leading to the formation of alabastrine gypsum from anhydrite which had previously escapted hydration. The exhumation seems most likely to have been associated with the valley widening of the proto-Trent and its tributaries either before the onset of glaciation or during an interglacial period and the deep weathering seems to me to have most probably been periglacial.

Thus like Dr. Holliday I favour one or more interglacial periods as the most potent time for the formation of alabastrine gypsum differing only in believing that its formation was initiated, albeit on a small scale, in peri-glacial conditions, proceeding concomittantly with the melting of ice-sheets and was completed earlier rather than later in the succeeding interglacial period.

I trust this clarifies my views both for Dr. Holliday and for readers who may have been misled by my original all too brief statement.

Yours sincerely,

R.J. Firman
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ERRATUM

The editors wish to apologise to Sir Kingsley Dunham for a number of typing errors in his field excursion report "The geology of the Durham area" which was published in vol. 9, no. 3, pp. 179-181. The most serious error was the change from *feretory* (where St. Cuthbert is buried in the cathedral) to *refectory* in the final printed version. For example at the top of p. 180 "*the refectory behind the High Alter*" should read "*the feretory behind the High Altar*".

Apologies are also due to Dr. Frank Moseley for mis-spelling his name and omitting the name of the publishers (the Macmillan Press Ltd.) when reviewing his recently published book, *The volcanic rocks of the Lake District* (reviewed in the Mercian Geologist vol. 9, no. 3, pp. 185-186).

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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 36 parts, comprising 9 volumes have been issued; the last, Vol. 9 No. 3 in Mar., 1984. The Mercian Geologist publishes articles especially on the geology of the Midlands of England, but other articles have been published which are of current interest to geology generally. Contents include original papers, review articles, biographies, bibliographies, excursion reports, book reviews and the Secretary's report on Society activities.

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