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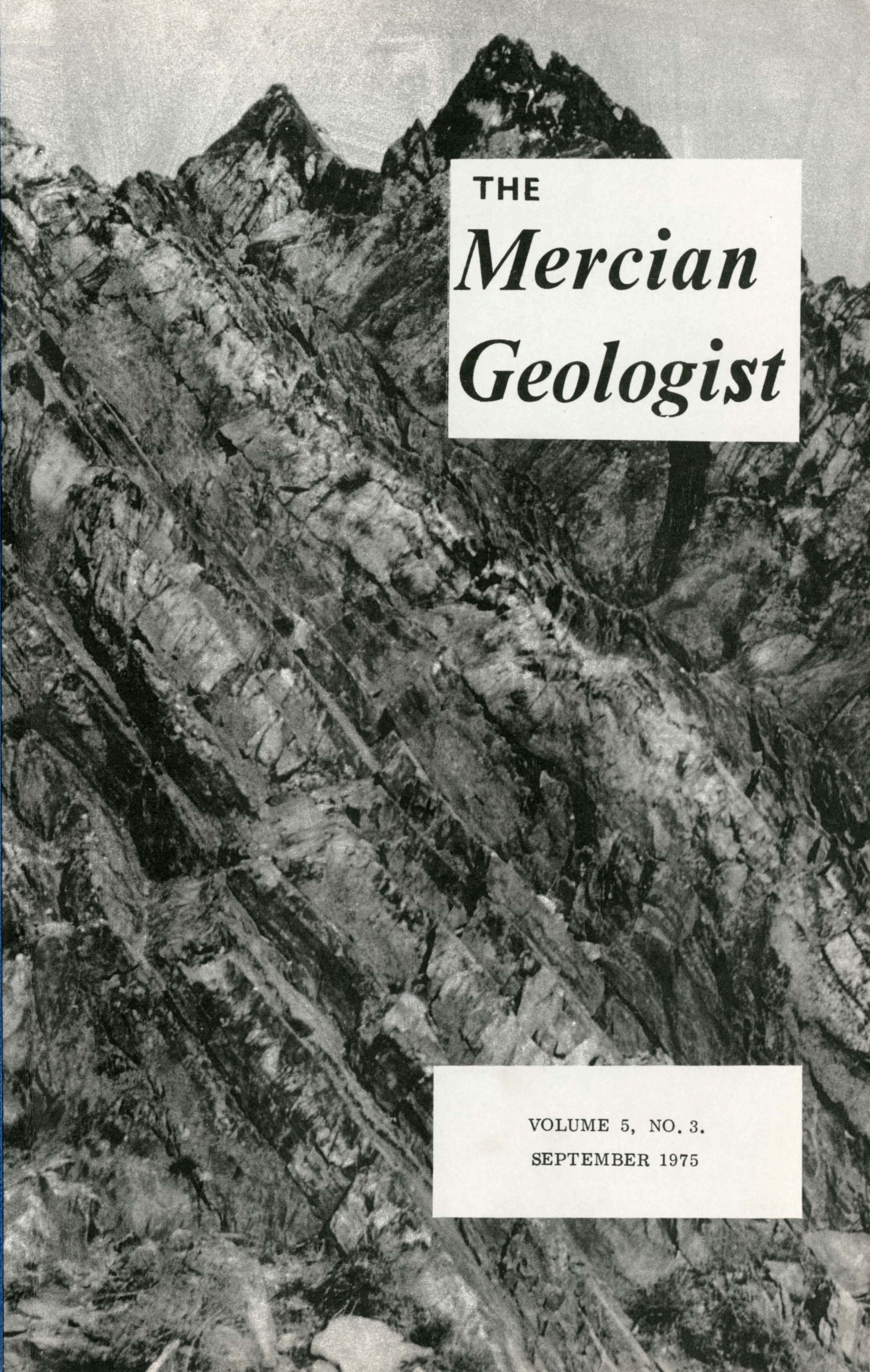

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GEOLOGICAL INVESTIGATION OF SITES FOR A PROPOSED M42/M1 MOTORWAY BRIDGE CROSSING, NEAR STANTON-BY-DALE, DERBYSHIRE

by

D.S. Buist and F.M. Taylor

Summary

The geology of alternative sites for a bridge crossing for the proposed M42/M1 intersection are described. The results of the first investigation suggested the possibility of old coal workings in the north of the site, artesian water and shattered rocks in the south and a varied lithology for the foundation over the site generally. The second site, 300 m to the south, is underlain by a more constant lithology for the foundations and there is an absence of complex structure; it is therefore to be preferred.

Introduction

The possible route of the M42 Nottingham to Birmingham Motorway, as outlined by the Midland Road Construction Unit in 1971, would entail the construction of a number of major bridges, one of which would span the M1 motorway between the Trowell Service Station and M1 exit 25 (A52 crossing) in the vicinity of the Erewash Golf Course (SK 477378), close to the village of Stanton-by-Dale, near Sandiacre, Derbyshire. A detailed geological survey was initiated because of the known occurrence of a major east-west fault, the Stony Clouds Fault, separating Coal Measures rocks to the north from Permo-Triassic strata to the south. The area was geologically surveyed by the authors on the 1/2500 scale, information being available from the original M1 survey (Le Grand Adsco 1962), from publications which resulted from the M1 excavations (Taylor 1965; Frost 1968) and from nine new boreholes (A - J) drilled for the present survey. Information was also obtained from trench excavations along the west margin of the M1, which were dug for a mains water pipe-line for the City of Nottingham Water Department in 1968 and recorded at the time by Mr. A.E.R. Houldsworth.

Text-fig. 1 is a reduction from the completed 1/2500 plan and indicates the geology of the area and the position of two possible bridge sites; the first, situated north of the major fault, is entirely underlain by Coal Measures strata and the second one, currently under consideration, is on Permo-Triassic rocks. Text-fig. 2 summarises the rocks found in the area.

Site 1; 200 m south-west of the Erewash Valley Golf Course M1 underpass (SK 475368)

Situated entirely on Coal Measures rocks, this location was considered to lie north of the Stony Clouds Fault and south of the outcrop of the lowest potentially exploitable coal seam, the Alton Coal. The site should therefore be free from old coal workings and would avoid the extensive rock fracturing that might be found close to the main fault. The geological sequence below the Alton Coal proved to be mainly mudstones and siltstones with thin weathered coals, possibly the Smalley Coals. A layer of mudstone containing the brachiopod shell, *Lingula* sp above the upper of these two coals proved a convenient marker horizon in some of the boreholes. The Coal Measures sequence ends with the Crawshaw Sandstone, a coarse-grained rock up to 32 m in thickness. In the borehole cores of this rock, the iron oxides had not been oxidised and it was light to medium grey in colour. The base of the sandstone was not attained in the boreholes.

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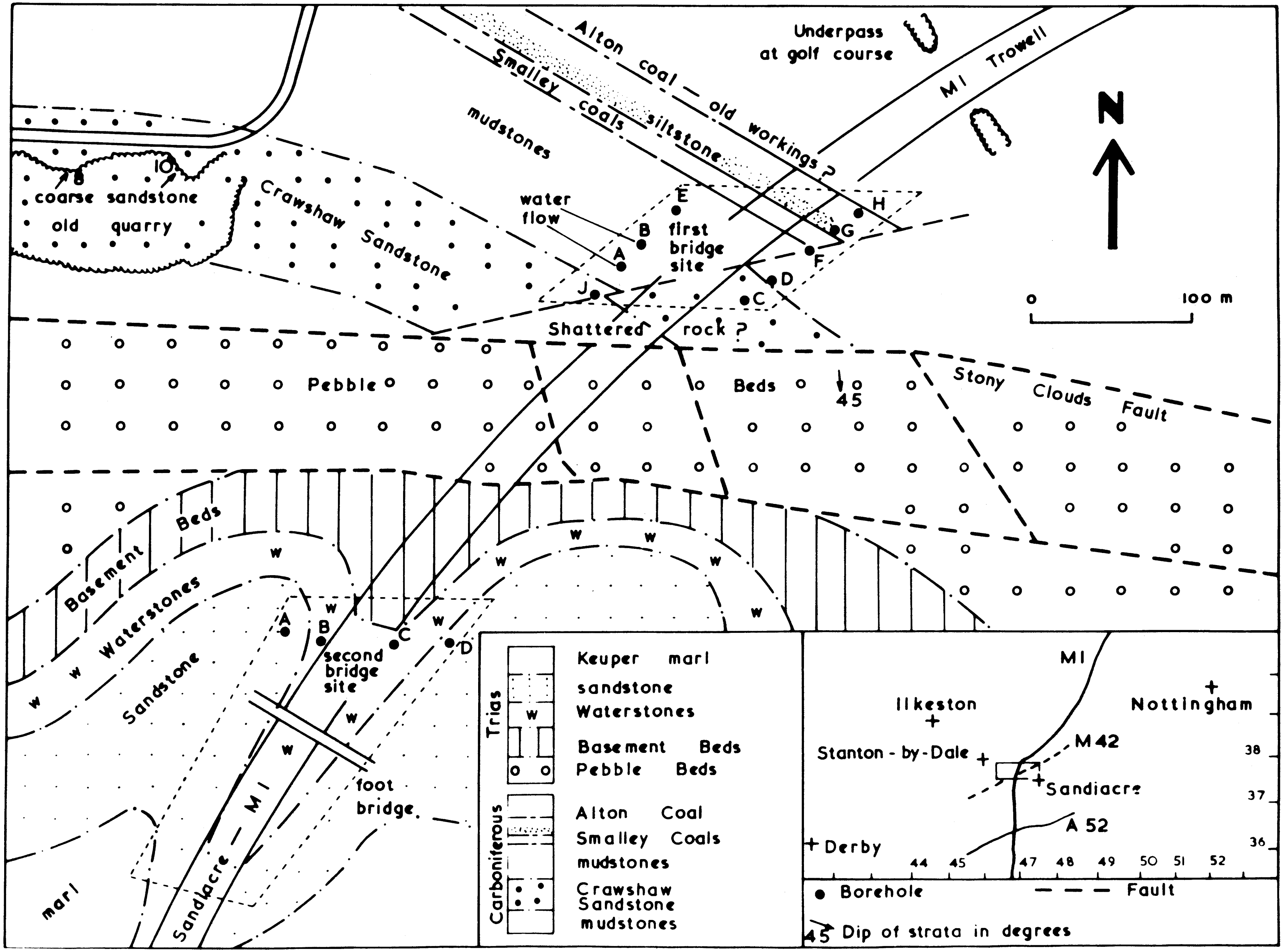


Text-fig. 1. Geological plan of proposed M1/M42 bridge sites

It can be seen from text-fig. 1 that the alignment of the bridge, at approximately N 80°E, would differ from the strike direction of the rocks at N 135°E by 55°. The maximum inclination of the rocks is 25°, direction N 45°E, whilst the dip is frequently about 10°. This, considered with the varied rock types of the Coal Measures mentioned above, means that there would be no constant lithology for any of the bridge pier footings. On the west side of the site, the Crawshaw Sandstone is the most suitable founding material, but the rock can only be located close to the surface at the southern end; at the northern end the sandstone could be up to 30 m below ground level. The rocks above this sandstone are mainly weathered clays. On the east side of the motorway, a compact siltstone or fine sandstone was located in boreholes G and H, at the north end of the east pier, but a thin, weathered coal separated the rock into two thin layers. These rocks could not be located at the south end of the pier position, where boreholes D and F contained the mainly weathered clays, considered to occur above the Crawshaw Sandstone, which was encountered in borehole C. It was concluded that a fault separated boreholes F and G; the shattered state of the rocks in borehole F suggested that the fault would be close to this position.

On text-fig. 1, this fault has been drawn across the motorway to borehole J, which after considerable difficulty in drilling produced a core of shattered black mudstone with highly polished shear faces. It is considered that this borehole is situated too far north for it to have encountered the Stony Clouds Fault.

The shattered, weathered mudstone from borehole J may well have formed an hydraulic barrier for water draining from higher ground to the west through crevasses and pore spaces in the Crawshaw Sandstone, for artesian water conditions were proved in boreholes A and B. Although nothing in this water, or ground water from other boreholes indicated potential sulphate attack on concrete, some joint surfaces of the Crawshaw Sandstone were coated with gypsum, which suggests that sulphate resistant concrete should be used in any foundation work on this site.

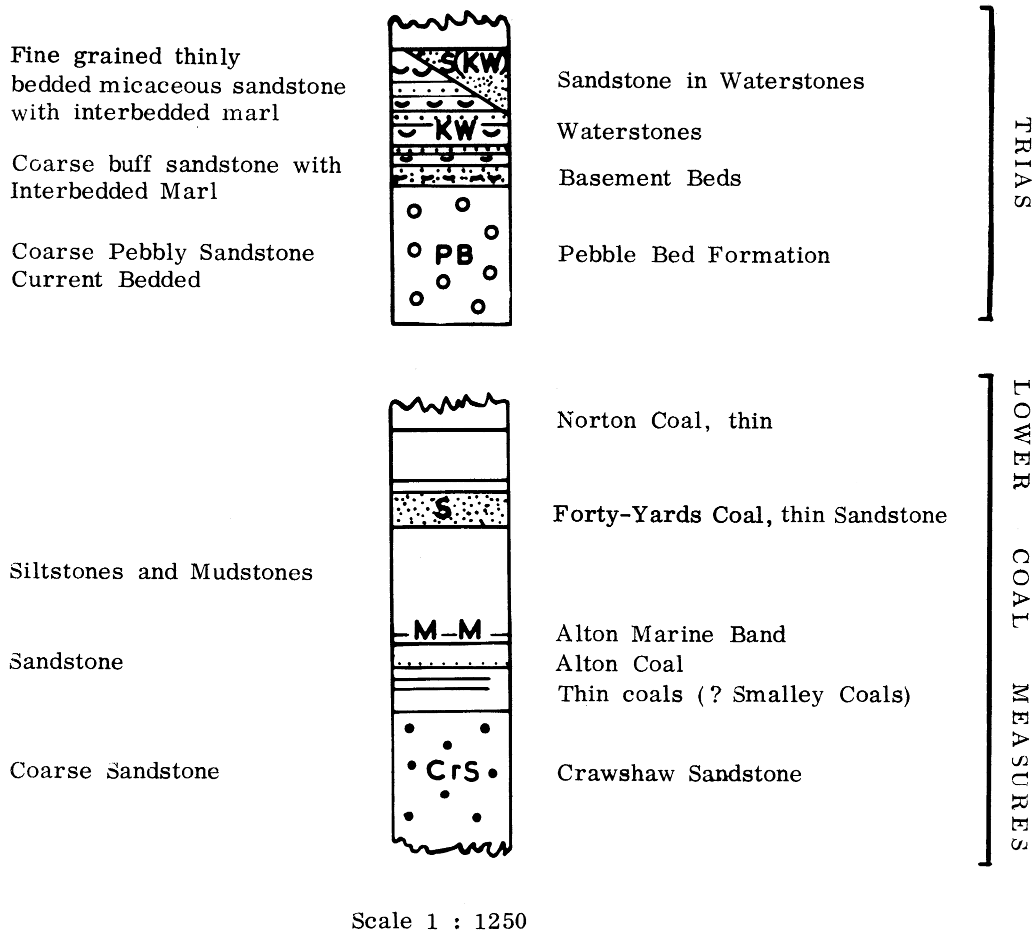
Thus, although the general geology of the area indicated initially that a possible site occurred at this point, the subsequent detailed investigation proved that foundation engineering would be complex. There would be not only the risk of constant flooding of the site but also of failure to locate consistently competent strata on which to build the bridge foundations. A second site, some 300 m to the south-west, was therefore investigated.

Site 2; close to the accommodation footbridge (SK 472375)

During the construction of the M1 Motorway, the Triassic rocks immediately south of the Stony Clouds Fault were exposed in a deep cutting and the details recorded. In particular, it was noted that the Waterstones Formation contained thick fine-grained compact sandstones with a minimum amount of interbedded marl. The sandstones and marls were essentially unweathered below a position 5 m from the original surface. The site investigation boreholes of this site (A - D) confirmed the original observations.

The sandstones should form excellent strata for all the foundations of the M42 bridge and the Waterstones Formation below, consisting of thin sandstones and marls, would also be suitable. If necessary the foundations could go deeper to the level of the Pebble Beds but, as the higher rocks are unweathered, the deeper foundations are unneceessary. There were no faults recorded from the area outlined on text-fig. 1 as the second bridge site, and there were no water problems.

Optimum utilisation of the sandstone would mean that the bridge-crossing would be sited just to the south of the footbridge indicated on text-fig. 1. This would mean that the line of the motorway would be undesirably close to a housing estate to the south-east. Advantage might be taken of the unweathered state of the marls and thin sandstones below the main sandstones to site the bridge north of the footbridge, keeping the motorway as far as possible from the houses. The road would be situated in a cutting at the closest point. The differences in



Text-fig. 2. Generalised Vertical Section shear strength of weathered and unweathered Keuper Marls and similar rocks is considerable, as noted, amongst others, by Chandler (1969) and it would be necessary to ensure that weathering of these rocks is kept to a minimum by sealing the foundations from surface-water and water which may gain access from the M1 cutting.

The unweathered Triassic rocks contain both dolomite and gypsum and sulphate resistant concrete would be essential.

Conclusion

Geological knowledge of the area of the Erewash Valley Golf Course, Sandiacre, along the line of the M1, suggested two possible sites for the proposed M42/M1 crossing. Detailed investigation indicated that the first site, on Coal Measures rocks, would result in complex and costly foundation engineering with problems of water, shattered rock, a mixed lithology and others to be solved. The second site, although closer to urban development, is, from the geological point of view, to be preferred, as foundation work would be restricted to the same lithology, with an absence of structural complications.

Acknowledgements

The authors would like to thank Mr. J. A. Jukes, Director, General Highways, for permission to publish the foregoing paper. The work was carried out in the Midland Road Construction Unit (Director: Mr. A. N. Brant) in the offices of the Derbyshire Sub-Unit (Chief Engineer: Mr. Underwood) The records of the M1 in the area have been made available by Sir Owen Williams and Partners, Consultant Engineers to the then Ministry of Transport. The City of Nottingham Water Department has allowed access to records and Mr. A. E. R. Houldsworth has generously assisted in determining the position of certain geological horizons.

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EXPLANATION OF PLATES

Plate 9

fig. 1. General site area of M42/M1 first bridge site, taken from Stony Clouds (outcrop of Lower Triassic Pebble Beds in the foreground). The M1 motorway is in the centre of the photograph with the Erewash Golf Course, Club House and Stanton Iron Works beyond. The motorway underpass can be seen on the far right of the fig.

fig. 2. General site area of the M42/M1 second bridge site as proposed, to be sited to the right of the footbridge. Taken from Stony Clouds with the Erewash Golf Course beyond the M1 motorway cutting.

Plate 10

fig. 1. Stony Cloud outcrop of Pebble Beds from the Erewash Golf Course, looking east. The escarpment is controlled by a fault separating the Pebble Beds from Upper Carboniferous Rocks.

fig. 2. View from Stony Clouds looking approximately west. The thick belt of trees marks the position of the old quarry in the the Crawshaw Sandstone.

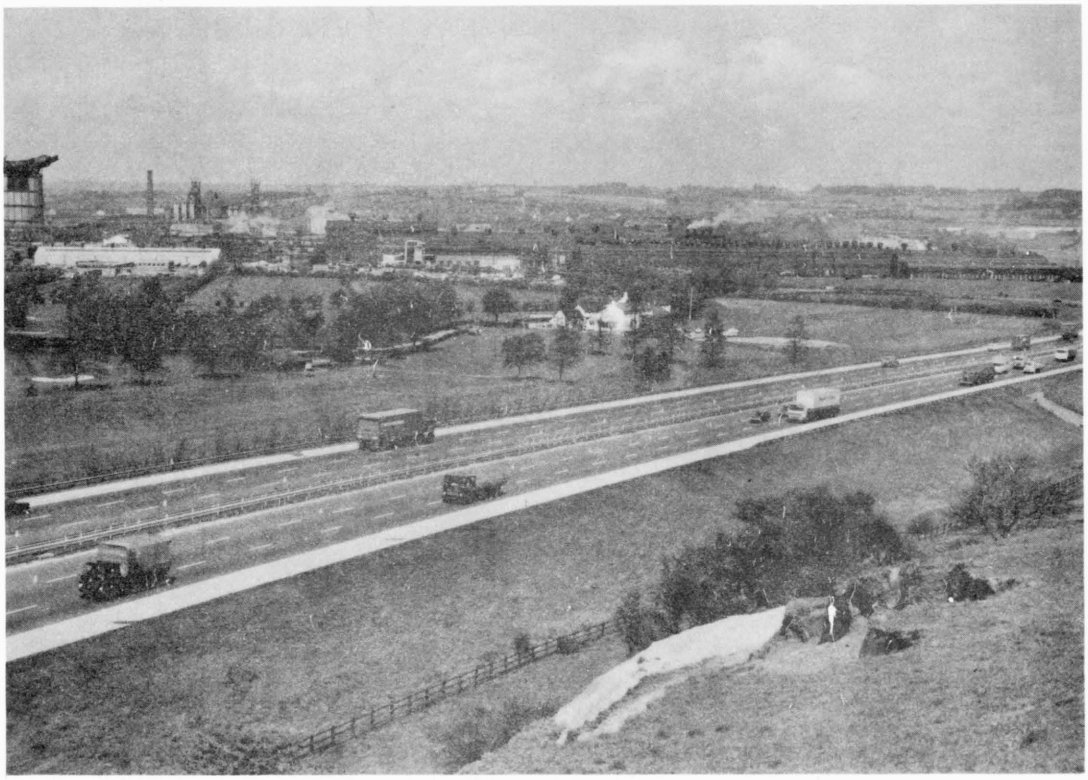


Fig. 1. First Bridge site.

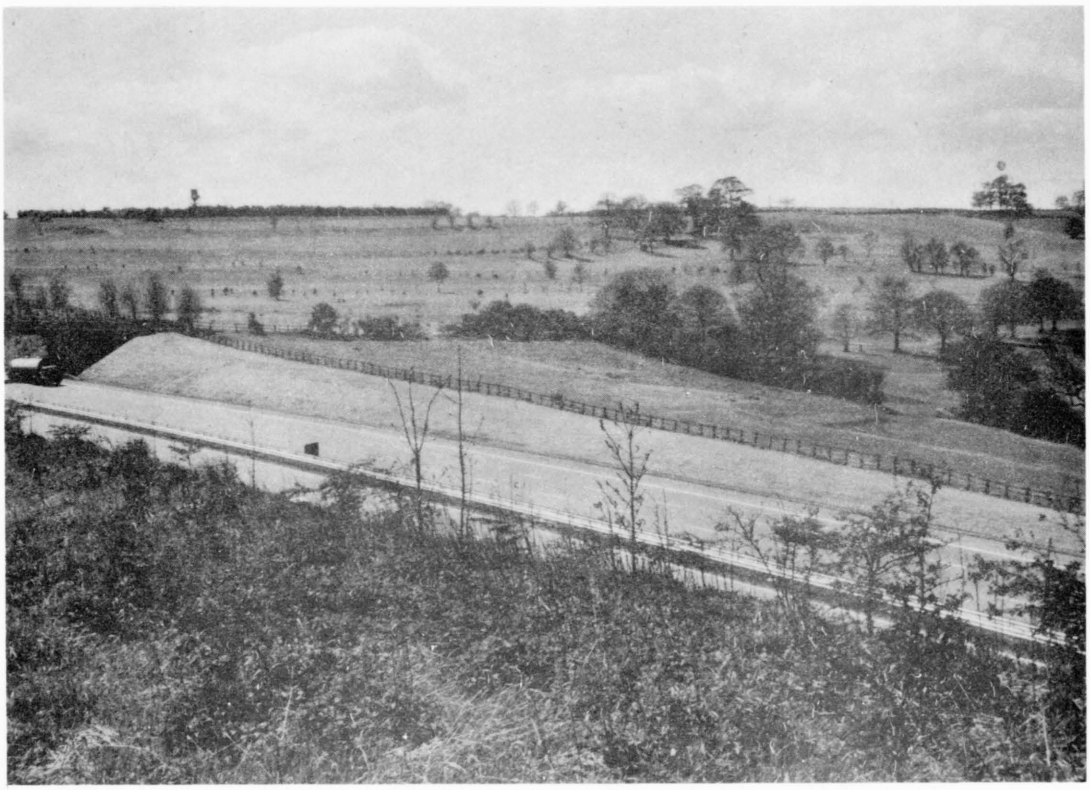


Fig. 2. Second Bridge Site.

Fig. 1. Stony Clouds, Sandiacre.

Fig. 2. Crawshaw Sandstone Outcrop, Stanton-by-Dale.

A REVISION OF PART OF THE MATLOCK GROUP AT MASSON HILL, MATLOCK, DERBYSHIRE

by

R. A. Ixer

Summary

Detailed mapping of the sedimentary and volcanic rocks along the summit of Masson Hill, and new borehole evidence, has led to a revision of the stratigraphy of the area. The sequence of rocks is shown to include a tuff at the base of the Matlock Lower Lava, and at least four volcanic clay horizons within the Matlock Lower Limestone Formation.

Introduction

Masson Hill is a prominent topographical feature, rising to about 335 metres, and situated 1500 metres west of Matlock, Derbyshire. Masson Hill contains extensive mineralization and especially an intermittent fluorspar flat which was exposed within opencast workings on the summit (SK 284591).

The first geological sections of the Matlock area were given by Farey (1811, p. 29) and Green *et al.* (1887, p. 22). Later Wedd (1907, p. 12) sub-divided the limestones on faunal evidence. More recently the stratigraphy of the Matlock area has been divided into four local groups (Eden *et al.* 1959, p. 33):

Cawdor Group
Matlock Group
Hoptonwood Group
Griffe Grange Bed

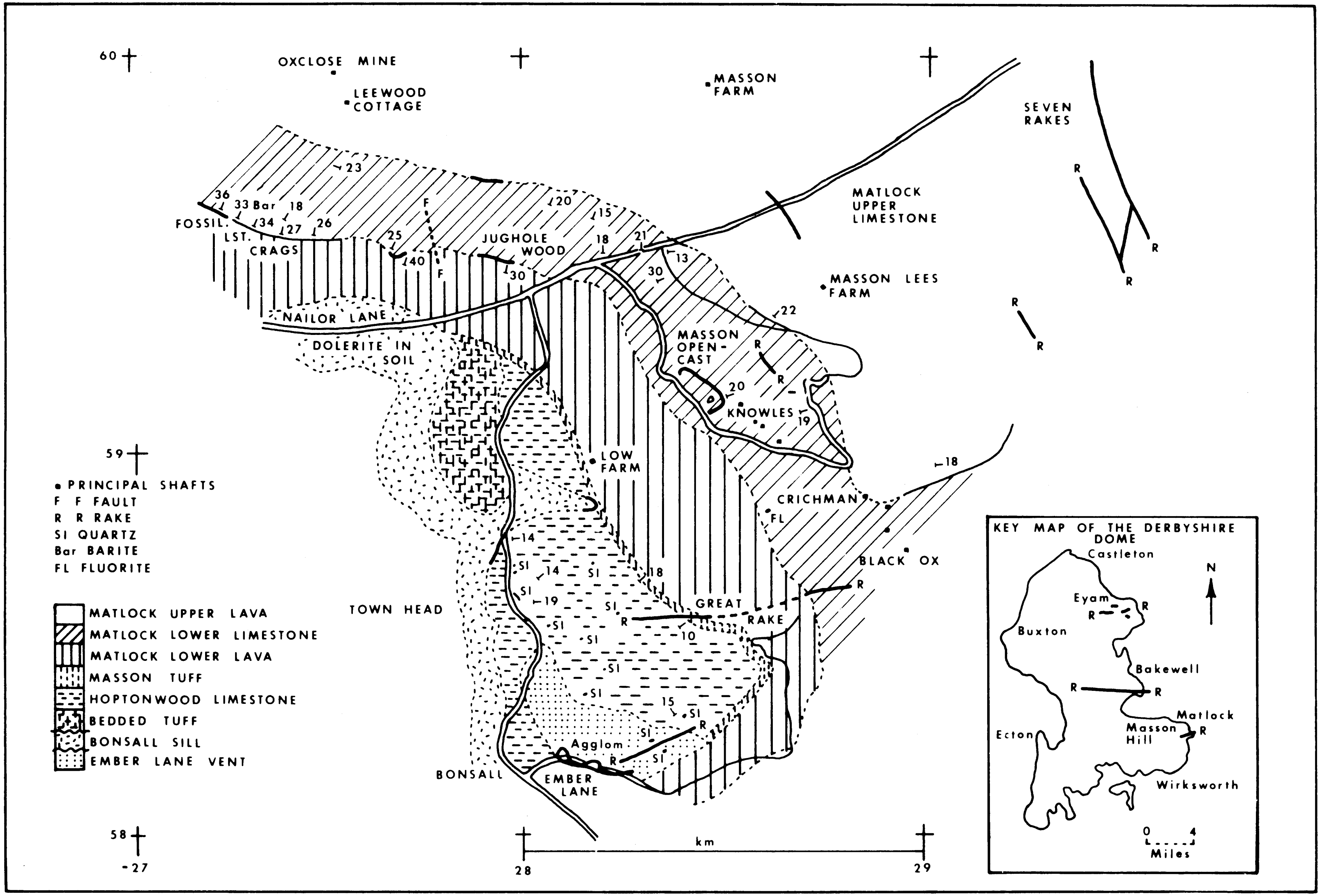
At Masson Hill only the middle two groups, the Hoptonwood Group and Matlock Group are present at outcrop. The limestones of these two groups are irregularly dolomitized, silicified and mineralized, whilst a wide variety of interbedded volcanic rocks occur, including basaltic lavas, tuffs and bentonitic clays, colloquially called wayboards. The stratigraphy of the Hoptonwood and Matlock Group has been especially studied because of the controls that varying lithologies have exerted on the mineralization. The detailed stratigraphy of the Matlock Group has been given by Dunham (1952, p. 97-101), and both the Hoptonwood and Matlock Group by Smith *et al.* (1967, p. 15-20).

The Masson Hill area was mapped in detail, especially the continuous 300 metre outcrop within the Masson Opencast, of the Matlock Lower Limestone Formation. Together with information obtained from a borehole drilled by Laporte Industries Ltd., the mapping has provided new evidence to modify the stratigraphical interpretation of Eden *et al.* 1959, 1967). The borehole was drilled within the opencast site, starting at the junction of the Matlock Lower Limestone Formation and Matlock Lower Lava and continued until the underlying Hoptonwood Limestone Group was penetrated. Core was only obtained of the Masson Tuff.

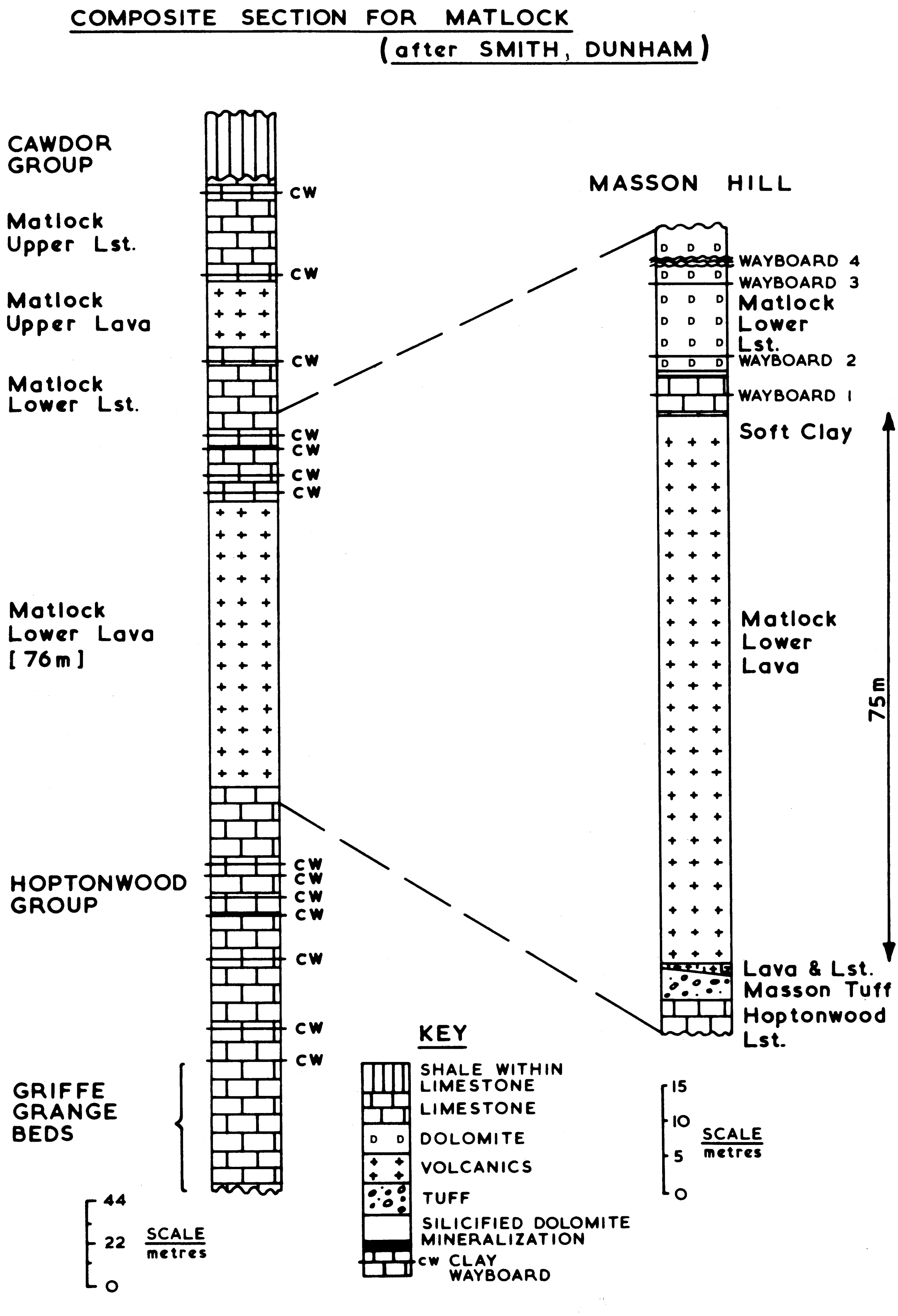
Stratigraphy

The general geology is shown in text-fig. 1 and the present interpretation is essentially similar to that of Smith *et al.* (1967, p. 9-27). An area of uncorrelated tuffaceous limestone, now only located in field walls (SK 279591) is, however, again reinterpreted as a bedded tuff (Arnold-Bemrose 1907, p. 265) rather than as a vent agglomerate (Smith *et al.* 1967, p. 27).

Mercian Geol Vol 5, No 3, pp. 181-188, 2 text-figs.



Text-fig. 1. Geology of Masson Hill, Derbyshire.



Text-fig. 2. Vertical sections of rocks, Matlock and Masson Hill.

Essentially, the interbedded limestones and lavas of the Matlock Group occur on the northern flank of an anticline. Their dips are variable but at the opencast site are 18° - 20° to the north-east.

A composite sequence for the Matlock area based on the sequences of Dunham (1952) and Smith *et al.* (1967), together with the present revised sequence, is given in text-fig. 2. The detailed stratigraphy of the revised sequence measured at the Masson Opencast Quarry and from the borehole is given in table 1.

TABLE 1

			metres
	Lava		
	No measurements		
	Dolomite	approx.	8.0
	Dolomite & limestone lenses		5.50
	Clay wayboard 4		0.30
	Dolomite		2.65
	Clay wayboard 3		0.10
	Dolomite and sporadic mineralization		10.40
Matlock	Clay wayboard 2		0.05
	Dolomite		2.10
Lower	Partially silicified and dolomitized limestone		0.90
Limestone	Fluorite and galena metasomatic mineralization		0.15 - 0 30
	Bioclastic limestone and fluorspar flat		2.45
	Clay wayboard 1		0.05
	Bioclastic limestone and fluorspar flat		3.05
Matlock	Soft altered lava or clays		3.95
Lower	Hard basalt with soft clays		74.35
Lava	Lava with limestone blocks		0.90
Masson Tuff	Tuff with grey limestone		3.05
Hoptonwood Limestone	Massive grey limestone with rare tuff fragments seen down to		5.00

Description of Formations

The Masson Tuff

The tuff is made up of dark green volcanic lapilli and limestone fragments in highly variable proportions set in a foraminifera-rich biomicrite. The lapilli are composed of greatly altered olivine-basalt, with calcite and chloritic pseudomorphs after olivine, 200 - 800μ in length, and plagioclase, 150 - 300μ in length; they are set in a chloritic or indeterminate brown groundmass. Vesicles are commonly infilled with spherulitic chlorite, calcite spar or calcite mud. No primary oxides have survived; however, secondary haematite, anatase and goethite are common.

The limestone fragments are very similar to the matrix but show less intense silicification.

The tuff is exposed along Great Rake at Low Mine (SK 283585), where the limestone fragments and matrix show replacement by fluorite.

The Matlock Lower Lava

No core was taken of the Lower Lava. The indicated borehole thickness is 79·2 metres, much nearer to the previously measured thickness of 76·2 metres (Dunham 1952, p. 98) than the calculated thickness of 115·8 metres (Smith *et al.* 1967, p. 17). Examination of specimens of Lower Lava collected from the Masson Opencast site and from along Great Rake (SK 287587) has confirmed previous descriptions (Arnold-Bemrose 1894, 1907 and Harrison, in Smith *et al* 1967, p. 261) of the lava as a calcitized, chloritized, vesicular olivine-basalt. X-ray diffraction has shown the 'chlorite' to be a mixture of kaolinite, mixed illite-montmorillonite and mixed chlorite-montmorillonite clays. Similar results for other Derbyshire 'chlorites' have been obtained by Sarjeant (1967, p. 85) and Walkden (1972, p. 156).

Progressive hydrothermal alteration has increased the calcite and silica content of the lava until finally a pseudotuff has resulted. This consists of haematized basalt 'fragments' in a matrix of calcite spar, quartz and chalcedony. Pyrite and occasional chalcopyrite are associated with the calcite spar.

The hydrothermal alteration differs markedly from that caused by weathering. The junction of the Lower Lava and Lower Limestone within the opencast site locally contains a perched watertable, which has converted the lava into a mixture of montmorillonite, kaolinite, illite-montmorillonite, with accessory calcite, albite, anatase and quartz.

Matlock Lower Limestone

The basal limestone is thickly bedded and poorly jointed, containing noticeable fossil debris and with calcite veining. Incipient dolomitization, especially common within brachiopod fragments and the calcite mud matrix, has subsequently recrystallised as calcite. The euhedral dolomite rhombic crystals, 180μ in length, are now transformed to a random mosaic of calcite crystals.

Above the limestone, dolomite occurs in beds 0·60 - 1·80 metres thick. Textural evidence in thin section shows that the dolomitization is totally epigenetic. Its intensity is related to the proximity of the clay wayboards and to the grain size of the original limestone. The amount of dolomitization is substantially reduced adjacent to the wayboards and to a distance of 0·30 - 0·50 metres away from these clay horizons. In addition, within the dolomite, isolated limestone beds occur, generally one or two metres thick and 5 - 10 metres wide, comprising light grey, poorly jointed biomicrite. These limestone beds are generally enveloped in a thin (0·05 - 0·10 metre) skin of metasomatic mineralization.

Petrographically the dolomite contains a biomodal distribution of small, 50μ, euhedral dolomite crystals in a subhedral to anhedral dolomite groundmass of average grain size 270μ. Subhedral to euhedral quartz is common often partially replacing relict calcite. Chemically the dolomites, remarkedly uniform throughout the sequence, can be classified slightly calcitic, following the classification of Chillinger *et al.* (1967) with a Ca/Mg ratio of 1·7 to 2·0.

The junction between the basal limestone and overlying dolomite is marked by a persistent horizon of mineralization which has the generalized sequence:

		Dolomite
Replacement	{	Silicified dolomite with fluorite and barite
Void		Banded barite and fluorite
Infilling		Void
		Banded barite, galena and fluorite
Replacement		Barite and galena with silicified limestone
		Limestone

The mineralized horizon varies in thickness between 0·10 - 0·15 metres and is probably due to the entrapment of the mineralizing fluids between the well jointed dolomite and more impermeable underlying limestones.

The Clay Wayboards

The presence of volcanic clay wayboards within the Matlock Lower Limestone has been discussed by Dunham (1952, p. 98) and Ford (1967, p. 67). Dunham paid particular attention to the 'Little Toadstone' a 0·80 metre thick clay horizon lying 5·5 metres above the base of the Lower Limestone. This thickness of impermeable clay appears to have been responsible for the massive replacement deposit described by Dunham. The wayboard is not exposed in the open pit and does not appear to correlate with wayboard 1.

Four wayboards of varying thickness were established within the Lower Limestone sequence. Wayboards 1 and 3 are orange-brown, slightly laminated pyritic clays, lying on a reddened mammilated surface that has an average relief of 0.03 - 0.10 m and hollows 0.12 - 0.12 m wide.

Wayboard 2 is a thin, 0·05 metres, clay parting, present in all the measured sections, making correlation between these sections possible.

Wayboard 4 is more complex than the others and has the following subdivisions:

Dolomitized Limestone	
Yellow laminated clays	0·07 - 0·08 metres
Dolomitized limestone rich in brachiopods	0·05 - 0·09 metres
Blue laminated clays	0·10 - 0·13 metres
Reddened mammilated surface.	< 0·01 metres
Dolomitized limestone	

Within the included dolomitized limestone horizon, the brachiopod shells, up to 0·08 metres across, lie concave upwards amid shell debris and compacted clay. The undersurface of the layer is extensively pseudo-mammilated with abundant goethite pseudomorphs after pyrite.

Goethite is also responsible for the reddened appearance beneath the wayboard. The junction of the wayboard clays and underlying dolomitized limestone is marked by an 80 - 100μ thick aggregate of goethite replacing pyrite with relict pyrite in the core.

The mineralogy of the four clay horizons is largely uniform, although the relative proportions vary. The mineralogy of the clays was determined by X-ray diffraction techniques The clays are composed of a mixed illite-montmorillonite fraction, kaolinite, quartz with accessory calcite, dolomite, anatase and chlorite. This mineralogy is typical of Derbyshire bentonites (Walkden 1970, 1972) except for their high carbonate and silica content. Much of the carbonate may be adventitious but the quartz forms part of the wayboards and reflects the strong silicifaction of the Masson area.

Conclusions

The borehole and field mapping has provided additional information on the stratigraphy of the Matlock Group. The borehole data has confirmed the thickness of the Matlock Lower Lava as given by Dunham (1952) and has proved the presence of an undiscovered tuff horizon. The detailed mapping and petrographic studies of the Matlock Lower Limestone Formation has shown it to have a varied lithology including four typical Derbyshire bentonite clay horizons.

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THE PLEISTOCENE SUCCESSION IN THE SOUTHERN PART OF CHARNWOOD FOREST, LEICESTERSHIRE.

by

J. F. D. Bridger

Summary

A succession of drift deposits for the Pleistocene period in south Charnwood Forest, based upon motorway and quarry exposures, indicates that the area was twice covered by ice. The first glaciation was by ice of north-eastern origin, whereas the second involved ice advancing, initially from the north-west and, subsequently, from the north-east. The latter ice movements are ascribed to that part of the Wolstonian stage associated with glacial lake Harrison; an earlier Wolstonian age is favoured for the first glaciation. There is evidence for local proglacial lake development at over 190 m O. D. during both glaciations and also for three phases of periglacial activity, two being dated as Wolstonian with the third, more complex period, being placed in the Devensian stage.

Introduction

Charnwood Forest is essentially the hilly ground within a triangle formed by Leicester, Loughborough and Coalville (text-fig. 1). This part of the Midlands is famous for its Pre-Cambrian and Triassic rocks but the Pleistocene deposits were not studied in detail until the nineteen-sixties when numerous sections, rich in glacial and periglacial material, were exposed during the construction of the M1 motorway which runs almost centrally through the Forest.

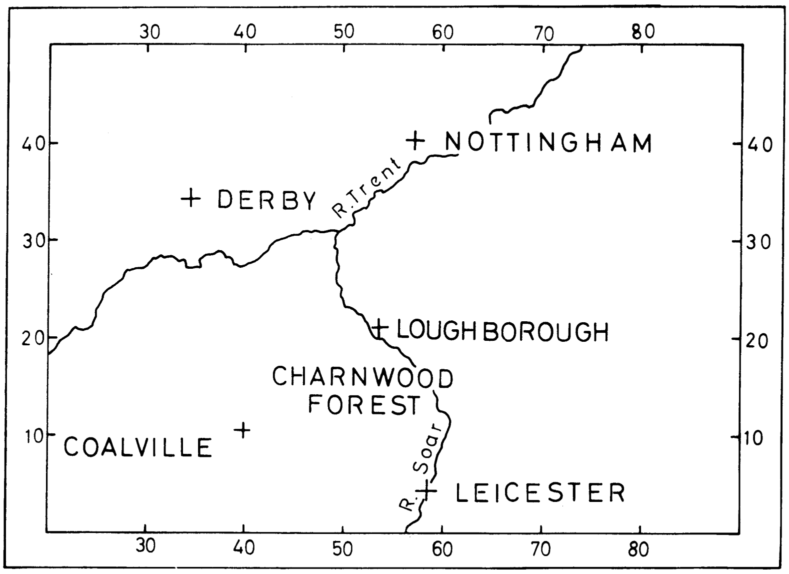
Lucy (1870) had described a surface spread of quartzite pebbles and flint and suggested that it had been laid down as drift. From 1899 onwards Geological Survey maps (Sheet Nos. 141 and 155) have shown boulder clay and glacial sands and gravels covering various parts of the area. However, the significance of these observations was largely overlooked for, prior to recent work, it was generally accepted that ".......... the Forest was never completely overwhelmed by an ice sheet from outside....." (Watts. 1947, p. 115).

Ford (1967 and 1968) has briefly described glacial and periglacial phenomena observed in motorway cuttings and also in quarries. Motorway sections were treated in more detail by Poole (1968) who included reference to rootlet beds underlying till. Both Ford and Poole concluded that ice had covered parts of Charnwood previously believed to have escaped glaciation.

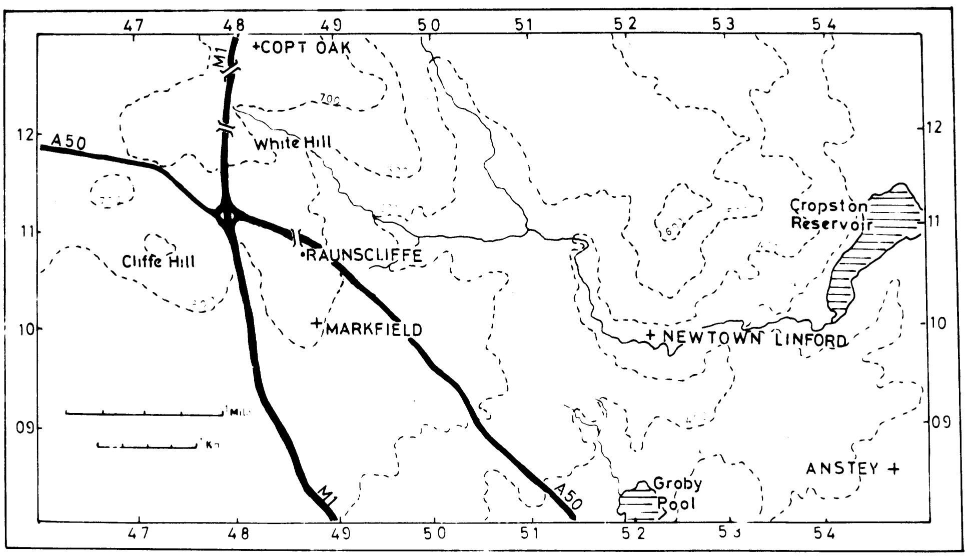
Pleistocene deposits have been examined in detail over virtually the whole of Charnwood Forest (Bridger, 1972). This paper is principally concerned with south Charnwood for it is here that the stratigraphically more important sections occur, notably temporary exposures at the following three localities:

1. The cutting for the A50 Markfield By-pass (text-fig. 3) to the north of Raunscliffe (SK 487107).
2. The site of the excavations for the bridge carrying the local road across the M1 near White Hill (SK 479121) (text-fig. 4).
3. In the quarry at Cliffe Hill (SK 477104) where a cutting (text-fig. 5) in the south-eastern corner takes a new road to the lower working level.

Mercian Geol. Vol. 5. No. 3, pp 189-203, 7 text-figs.



Text-fig. 1. Location of Charnwood Forest, Leicestershire



Text-fig. 2. Localities mentioned in the text

Although the three sections are less than 2 km apart and all extend down to bedrock they exhibit considerable differences, in lithology and stratigraphy, of the superficial deposits. Correlation has been based mainly on lithological and carbonate characteristics supplemented by a study of derived micro-fossils, in particular, ostracods. The latter have been particularly useful for, unlike most macro-fossils, the ostracods have not been crushed by ice during transportation and, in certain circumstances, meltwater has carried them beyond the range of other erratics. The most abundant material is till of which three separate types have been distinguished. One, the lowest stratigraphically, is the brown calcareous Raunscliffe Till with a predominantly Liassic suite of erratics. A second, the Newtown Linford Till, comprises a reddish non-calcareous deposit characteristically containing Coal Measure and Lower Triassic rocks. The third and upper of the three types, is the calcareous Anstey Till, a greyish chalky boulder clay with Liassic erratics in addition to its distinctive component of Cretaceous material.

The account of the succession given below includes a consideration of the genesis of the members and their local correlation. The following discussion covers chronology and relationships to successions further afield.

The Pleistocene Succession in South Charnwood

The sequence of Pleistocene deposits in the southern part of Charnwood Forest is here divided into the following members:

NEWER DRIFT

- Upper Head

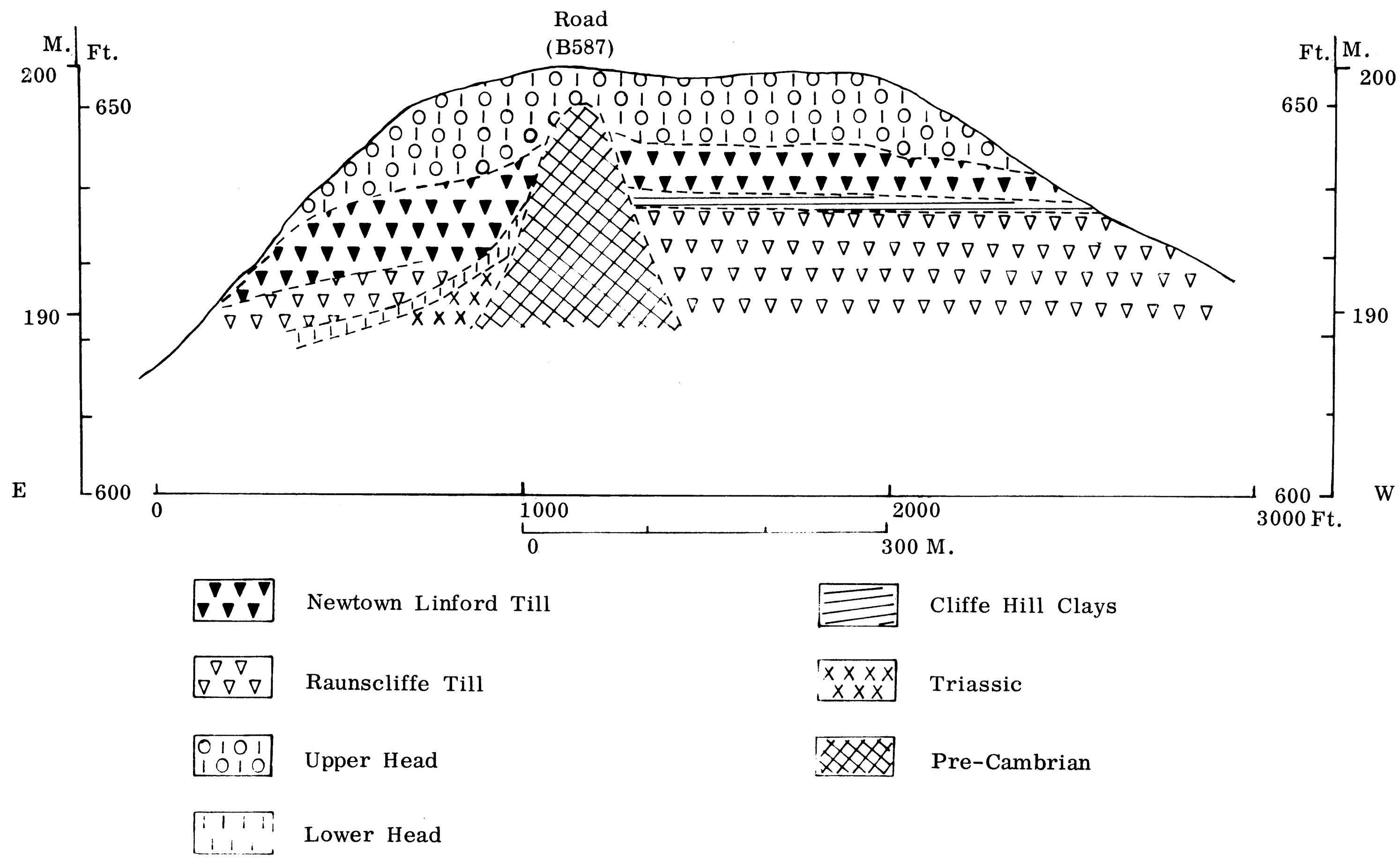
OLDER DRIFT

- Anstey Till
- Newtown Linford Till
- Markfield Clay with Middle Head
- Cliffe Hill Sand and Gravel
- Raunscliffe Till and the White Hill Clays and Silts
- Lower Head

The Lower Head

At two localities solifluction or head deposits underlie the drift that is associated with the earliest recorded ice to enter the area. In the Markfield By-pass cutting (text-fig. 3) the Lower Head rests on Keuper Marl and is overlain by a calcareous till, rich in Jurassic erratics. The Lower Head is over a metre thick and is composed of a non-calcareous reddish-yellow clay with numerous angular to sub-angular blocks of rock, in size-range up to large boulder. Usually the latter have a weathered skin and are derived from the Charnian Maplewell Series which outcrops at the foot of the bridge carrying the B 587 (SK 486109) and also at the "Altar Stones" (SK 485108) a prominent crag rising to 213 m, a hundred metres to the west of Raunscliffe. A deposit of this type does not compare lithologically with any noted in the local Keuper succession (Bosworth 1912) and, although the possibility of it being the product of a restricted local glaciation cannot be entirely ruled out, it is more satisfactorily explained as a solifluction deposit.

Motorway bridge excavations near White Hill (text-fig. 4) exposed Lower Head resting on an uneven projection of Charnian Slate-agglomerate and its flanking beds of Keuper marl and breccia. Above these rocks are calcareous proglacial silts into which the head deposit passes without disturbance. The head has a maximum thickness of over 1·5 m and is in part stratified.



Text-fig. 3. Generalised section showing succession exposed above road level in the southern face of the Markfield By-pass cutting (SK 487107) recorded in 1967.

Its main constituents are brown and brownish-yellow gritty clays containing many sub-angular fragments, up to pebble-sizes, of often highly weathered Charnian-type rocks which could not be matched with the contiguous slate-agglomerate or other local Pre-Cambrian outcrops. The crucial evidence for a periglacial origin is the gradual vertical transition into proglacial silts. The presence of Charnian-type rock not identified locally may be interpreted as material derived by solifluction from nearby, formerly exposed outcrops, now buried under drift.

The Raunscliffe Till and White Hill Clays and Silts

Raunscliffe Till has only been recorded in the Markfield By-pass, where it exceeds 5 m in thickness and has a maximum altitude of close to 193 m O. D. (text-fig. 3). In the vicinity of the B 587 bridge the till rests either on Lower Head or on Charnian rock. To the west of the bridge it is overlain by Cliffe Hill Clay; however, to the east, where observation was difficult, the overlying deposit is believed to be Newtown Linford Till. Coloured reddish-brown to dark-brown, the Raunscliffe Till includes beds and lenses of silt and sand. It is, invariably, highly calcareous with calcium carbonate values of up to 17%. The erratic suite contains some Triassic and Charnian rocks but the majority are Liassic in origin. Fragments of echinoid spines and valves of the Liassic ostracod *Hungarella* sp. are not uncommon in the sand fraction. Since Jurassic beds do not outcrop to the west of the Soar valley (text-fig. 6) the predominance of Liassic erratics in the Raunscliffe Till indicates that the ice carrying them moved across Leicestershire from the north-east.

The White Hill motorway bridge site (text-fig. 4) showed over 3 m of inter-stratified clays and silts resting on Lower Head with Newtown Linford Till above. Apart from the upper half metre, the White Hill Clays and Silts are calcareous with a maximum of 17% calcium carbonate. At irregular intervals horizons with rootlet holes lie within the silts, but pollen has not been preserved. A few small quartzite pebbles and fragments of Keuper and Charnian rock are present at most levels; in the upper beds more numerous pieces of Coal Measure shale, coal, ironstone and sandstone appear. Evidence of Jurassic material is in the form of *Hungarella* valves found in most of the silts and also small fragments of echinoid spines restricted to the silts at the base of the sequence.

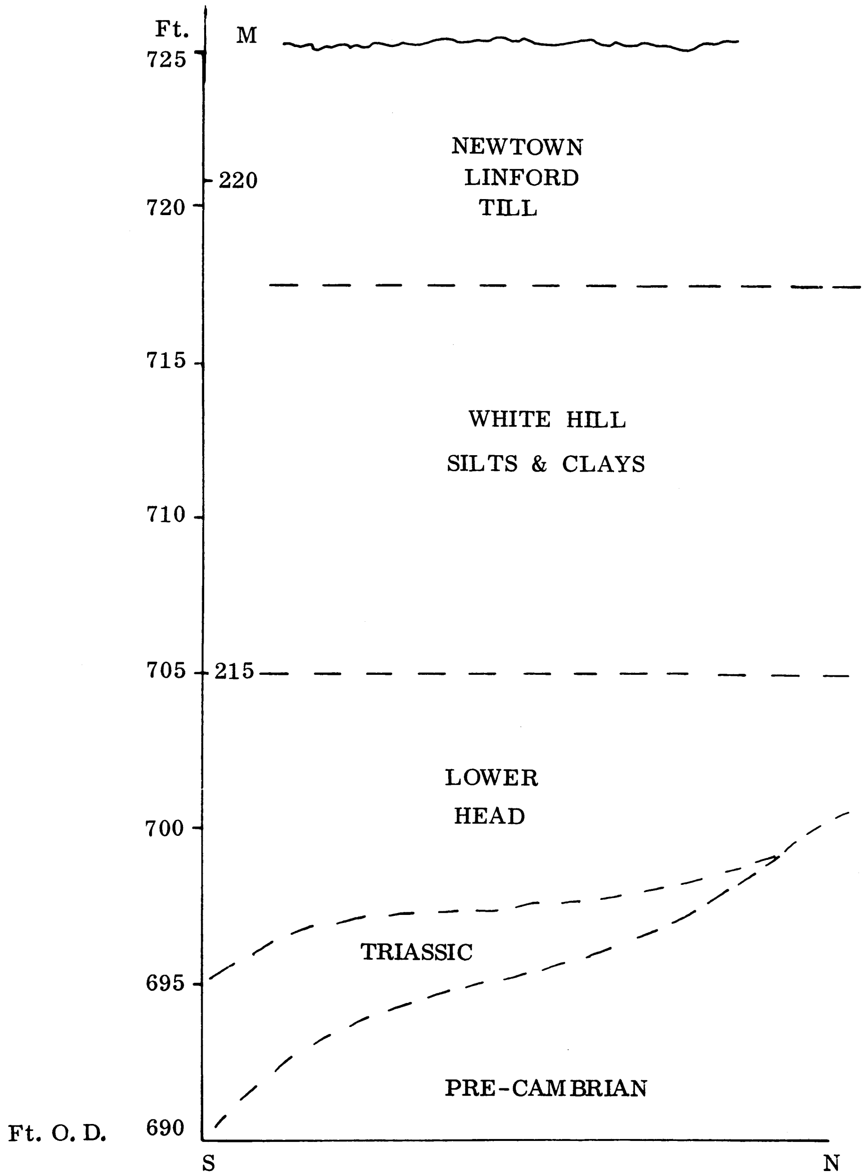
In this area, the most satisfactory explanation of sediments bearing Liassic micro-fossils at 215m O. D., is proglacial deposition. The proximity of the Raunscliffe Till confirms the former presence of ice which may account for both the character and the formation of these deposits. Accordingly the Raunscliffe Till is correlated with the White Hill Clays and Silts (text-fig. 7), although it is accepted that the lake in which these deposits accumulated may have survived until the arrival of north-western ice early in the next glaciation.

The Cliffe Hill Sand and Gravel and the Markfield Clay

Temporary faces in the south-eastern corner of Cliffe Hill quarry (text-fig. 5) revealed an uneven, sloping surface of partially rotted micro-diorite overlain successively by beds of gravel, sand, clay, clay with head and Newtown Linford Till.

The Cliffe Hill Gravel has a brownish non-calcareous clayey sand matrix and contains up to cobble size sub-angular fragments of Coal Measure rocks and so-called Bunter pebbles with lesser amounts of Keuper and Charnian rocks and a little flint. This bed passes abruptly into an overlying layer of reddish-brown sand which has thin interstratified bands of clay in its upper part.

At approximately 192m O. D. this sand is succeeded by a near horizontal bed of red Markfield Clay thickening southwards from 0·5m to over 3m. Above the point where the gradient in the bed-rock surface is steepest and for several metres to the south-west the clay is divisible into two zones, the lower being undisturbed pure clay whereas the upper contains sand from rotted igneous rock in the form of streaks, lenses and rectangular inclusions.



Text-fig. 4. Generalised succession from the foundation excavations for the motorway bridge new White Hill (SK 479121) recorded in 1964.

The upper zone also contains, up to boulder size, angular blocks of micro-diorite exhibiting, with a few exceptions, various stages of rotting. In places thin bands of silt split to envelope the clasts. This debris laden layer passes horizontally into pure clay some 10 m to the south-west. There is no disturbance at the contact with the overlying Newtown Linford Till.

Sections seen at various temporary faces during the excavation of the cutting for the Markfield By-pass displayed up to 5 m of essentially stone-free clay with interstratified silt resting upon Raunscliffe Till and overlain, at about 195 m O. D., partly by Newtown Linford Till and partly by Upper Head. At the base, the reddish-brown to reddish-yellow beds of clay and silt are calcareous and stoneless passing upwards into a zone with a few quartzite pebbles and fragments of Jurassic rock. Towards the top the sediments become non-calcareous and stones are again absent. Apart from disturbance at the contact with the overlying head, evidence of cryoturbation occurs within the clay at depths of one metre or more below its upper surface.

The composition of the Cliffe Hill Gravel strongly suggests that it is outwash from the ice which later laid down the Newtown Linford Till. The succeeding sand and clay indicate the hydrological changes, culminating in proglacial lake formation, associated with this ice as it approached the southern part of Charnwood Forest. An explanation for the presence of the rock and sand in the Markfield Clay at Cliffe Hill quarry is given below.

The altitude of the clays at both sites is close to 195 m O. D. a relationship which coupled with their close proximity, suggests that they have a common lacustrine origin. If this correlation (text-fig. 7) is accepted, chemical differences may be seen as a reflection of local variations in the depositional environment, involving the shore and bed of the lake, being easily worked calcareous till at one point and mainly igneous rock at another.

The Middle Head

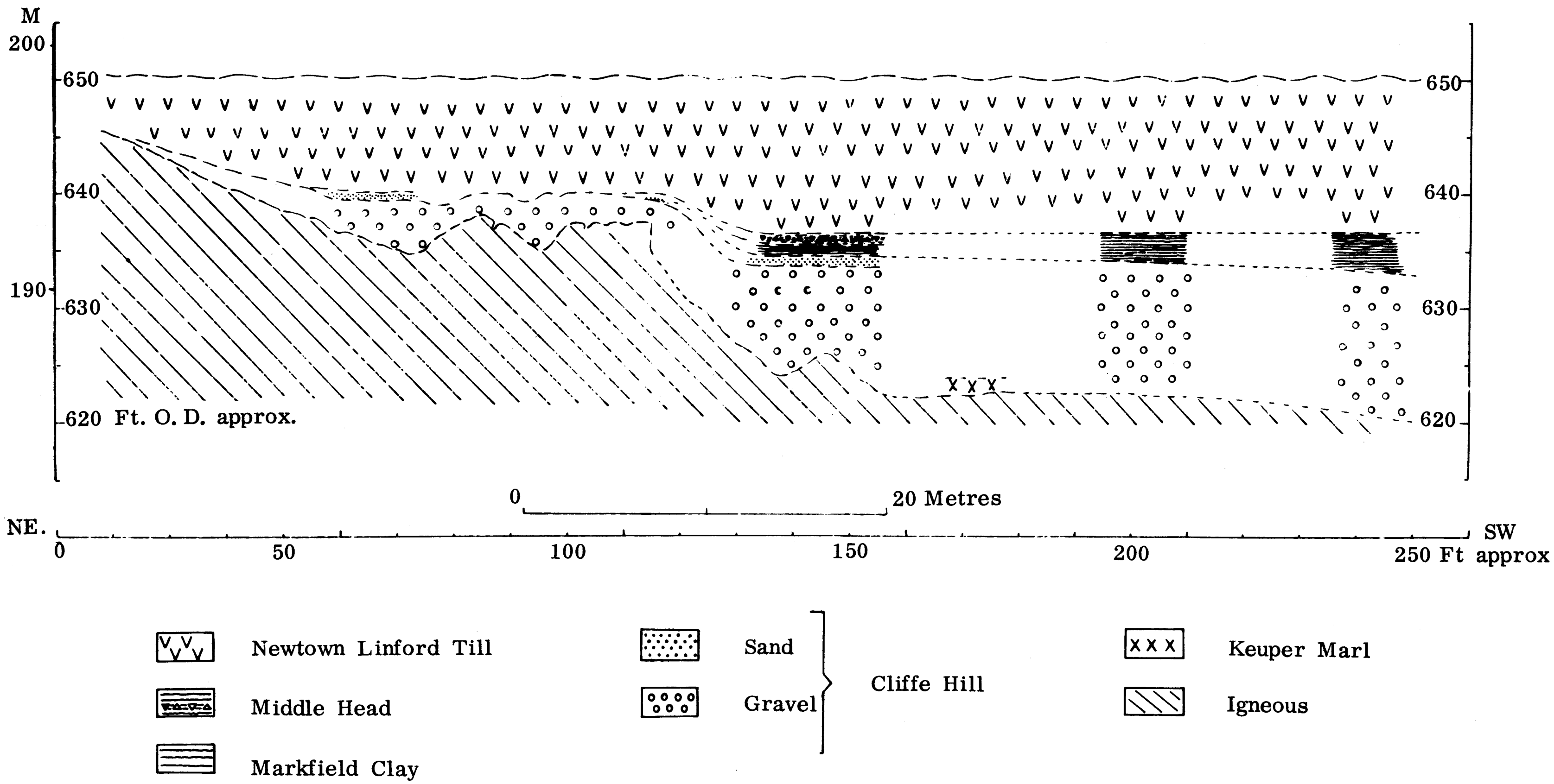
The stoney upper layer of Markfield Clay at Cliffe Hill quarry is explained as head, moved by solifluction from the shore on to the surface of adjoining lake ice which, on melting, deposited rock on the lake floor. The deposit contains a few unweathered clasts of micro-diorite with an angular outline indicating that the blocks were sound when they were incorporated into the sediment as this type of rock, where weathered, produces rounded core-stones. The sand may result from the disintegration of rock on the lake floor but equally it could involve solifluction from weathered outcrops above the shoreline.

Cryoturbated zones within the clay at the Markfield By-pass cutting indicate that the level of the lake was not constant and that periglacial processes were able to disturb the sediments.

The Newtown Linford Till

The Newtown Linford Till, in contrast to the Raunscliffe Till, is characteristically a reddish-brown non-calcareous clay with Coal Measure and Lower Triassic (Bunter) rocks as well as Charnian and Upper Triassic (Keuper) material and a little flint. It is wide spread and shows considerable variation in composition over short distances. At Newtown Linford (SK 519099) the till is very stoney and virtually structureless whilst in the Markfield By-pass cutting and also at Cliffe Hill quarry it usually has fewer stones and often shows conspicuous stratification with the local development of beds and lenses of silt and sand.

The erratic suite of this till is not inconsistent with deposition from ice which had crossed the exposed portion of the Leicestershire-Derbyshire coalfield lying to the north-west of Charnwood Forest (text-fig. 6) but the precise route taken by this ice is uncertain. The extensive cover of Newtown Linford Till at altitudes of over 200 m O. D. shows conclusively that the associated ice ultimately covered the greater part, if not the whole, of Charnwood Forest.



Text-fig. 5. Generalised section showing succession exposed in the south-eastern face of the road cutting at Cliffe Hill quarry (SK 477121) recorded in 1969. The unshaded areas in the section represent parts which were obscured by downwashed spoil.

The Anstey Till

The Anstey Till was not revealed in any of the three major sections and its stratigraphical position has been established by the evidence of smaller temporary exposures and by augering. Although this till is the upper member of the Older Drift succession it is, in general, found in topographically low positions as, for example, at Anstey Green (SK 545088) where it does not rise above 85 m O. D. In this locality drainage trenches displayed over a metre of greyish-brown calcareous till packed with small pieces of chalk in addition to flint, quartzite pebbles and discrete lumps of Lias clay. A similar chalky till, sometimes with Lias fossils and large flints occurs between Anstey and Newtown Linford at an altitude of over 100 m O. D. On the eastern outskirts of the latter village patches of chalky till are incorporated in a red-brown till with flint and quartzite pebbles. Augering into a badly slumped stream bank about 0·5 km to the north-west of the same settlement (SK 515104) revealed over a metre of greyish-blue chalky till passing downwards into Newtown Linford Till.

The Cretaceous-rich Anstey Till clearly has an eastern provenance. Its distribution is not extensive in Charnwood Forest but there is a wider spread of red-brown, non-calcareous till containing flint, to which it may be related. Although this red-brown till has not been recorded in contact with other glacial deposits it has been seen, in shallow sections, to overlie Keuper bed-rock. It is possible that the till in question is a highly weathered and decalcified Anstey Till, alternatively it may be the equivalent of the red-brown till noted near Newtown Linford to contain patches of Anstey Till. In the absence of stratigraphical evidence these relationships remain problematical.

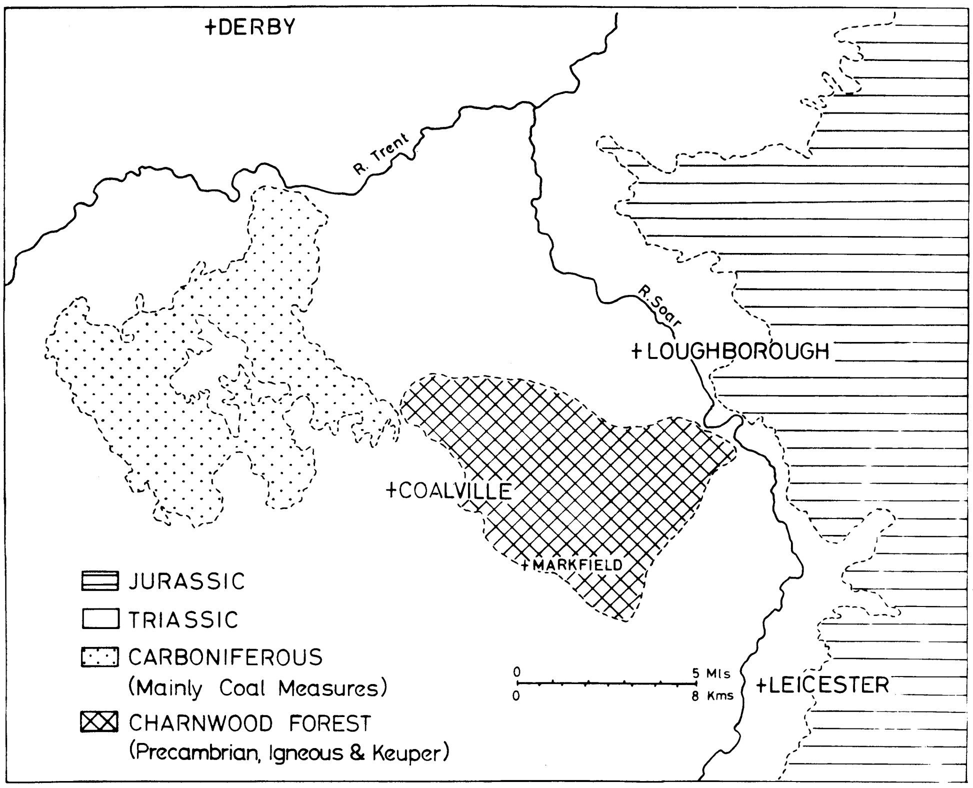
The Upper Head

Sectioned slopes in south Charnwood Forest invariably show solifluction deposits close to the surface, sometimes over 3 m thick. They rest on till or bed-rock with inter-facial trends closely following the slopes of the present day topography. The texture of the Upper Head is extremely variable. Around tor-like outcrops of igneous and most Charnian rocks periglacial processes have produced a very coarse deposit. Where till is the parent material the soliflucted product contains smaller stones varying in type and number with the erratic content of the till; in the case of Keuper Marl the derived deposit may be stone free. It is not unusual for the Upper Head to be of composite derivation. Commonly it shows vertical zonation with a virtually stone free clay at the base passing upwards into coarser layers. Additionally the head exhibits evidence of cryoturbation in the form of frost wedge casts and stones rotated into an "on end" position.

Discussion

In his account of the Pleistocene deposits in the area between Coventry, Rugby and Leamington, lying some 30 km to the south-west of Charnwood Forest, Shotton (1953) gives the following Older Drift succession:

Dunsmore Gravel	
Wolston Series	Upper Wolston Clay Wolston Sand Lower Wolston Clay
Baginton Sand	
Baginton-Lillington Gravel	
- Long time interval -	
Bubbenhall Clay	



Text-fig. 6. Outline solid geology of northern Leicestershire and parts of adjoining counties.

On the evidence of the Wolston Series, Shotton argues that, in the Midlands, the Wolstonian (Saalian) Glaciation started with the advance of ice from the north-west and subsequently ice from the north-east became dominant. These ice movements together with the presence of Welsh ice in the Severn Estuary formed glacial Lake Harrison which at its maximum covered the greater part of the Midland plain. The glaciation culminated with north-eastern ice over-running virtually the whole of the area at one time occupied by the lake.

Against this background the Cliffe Hill Sand and Gravel, the Markfield Clay and the Newtown Linford and Anstey Tills may be seen as the depositional representatives in south Charnwood Forest of Shotton's Older Drift succession and sequence of events. Yet, Shotton's interpretation presents difficulties when the Raunscliffe Till and White Hill Clays and Silts are considered, for there would appear to be no place for early north-eastern ice in his scheme.

It is assumed that the now isolated deposit of Liassic-rich till at Raunscliffe is a relic of what was originally an extensive and homogeneous spread of calcareous eastern drift. On this basis it becomes necessary to postulate a phase of sub-aerial erosion before the entry of north-western ice to account for the regional absence of Raunscliffe Till and also the dearth of eastern material in the overlying Newtown Linford Till.

If this denudation was accomplished during a long interval it would not be unreasonable to assign it to the interglacial predating the Wolstonian i.e. the Hoxnian, with the glaciation associated with the Raunscliffe Till being placed in the Anglian stage. This view however is given little support by research workers in other parts of the Midlands where glacial deposits of Anglian age are generally accepted as being of north-western or Welsh origin (e.g. Shotton 1953 and 1973) an exception being Poole (1968) who believed that an Anglian age should be applied to a Cretaceous bearing lower till found in the Market Harborough area, about 35 km to the south-east of Charnwood Forest.

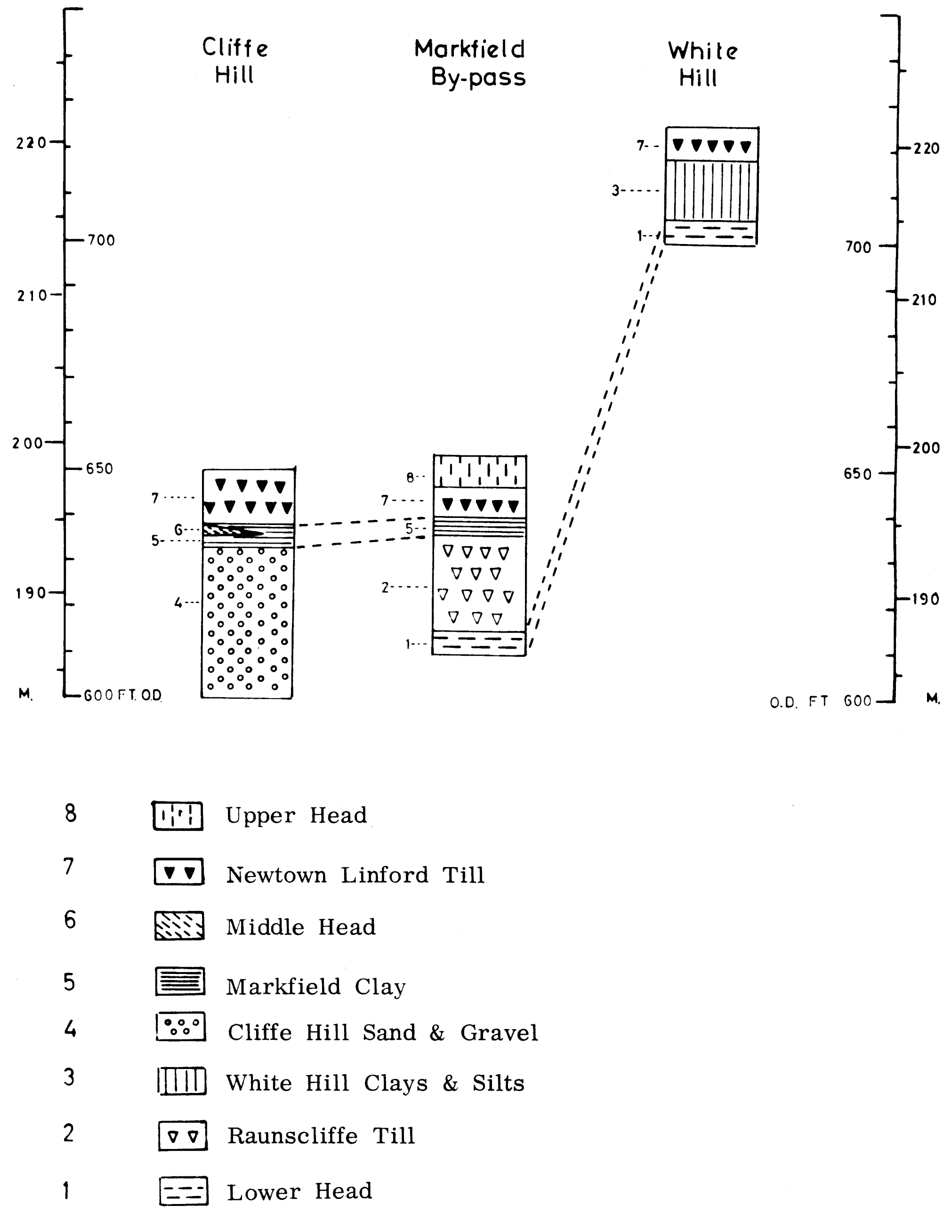
Alternatively, should the erosion have been completed during a shorter period of inter-stadial dimensions it might, together with the preceding glaciation, be positioned in the early part of the Wolstonian. In the Itchen valley, Bishop (1958) has recorded a till with eastern erratics underlying the Wolston Series. Bishop explains the till as the deposit from a Wolstonian ice-lobe which advanced and retreated before the entry of the north-western and eastern ice involved in forming Lake Harrison. Shotton (1968) has expressed uncertainty on the precise position within the Wolstonian for the formation of the lake. The placing of this event in an equivalent of the continental stage Saale II would solve many problems for it would allow the postulated erosion to be placed in the Saale I/II interstadial and the earlier north-eastern glaciation to correspond with Saale I.

It should be noted that Poole (1968), whose foremost argument is for a Hoxnian inter-glacial interval between the lower and upper tills of Market Harborough, does not rule out the possibility of these tills being related to separate minor glacial phases within a single stage but, in his case, an Anglian age is preferred.

In the southern part of Charnwood Forest deposits which may be unequivocally dated as Hoxnian have yet to be observed and therefore an interstadial episode of Wolstonian age is favoured for the period between the deposition of the Raunscliffe and the Newtown Linford tills. Although the acceptance of such an interpretation would require a revision of existing British schemes it would not be at variance with evidence from the continental mainland where a two-fold division of the Saale stage is well established (Woldstedt, 1955).

It follows that an early Wolstonian age is applicable to the Lower Head for there is nothing to suggest that it was formed in other than a periglacial phase related to the advance of the ice which laid down the Raunscliffe Till.

Later members of the succession are more easily related to Shotton's scheme for the Wolstonian, although some exhibit features reflecting exceptional local environments of deposition. For example, whilst the composition of the Cliffe Hill gravel confirms the dominance of north-western



Text-fig. 7. Height relationships and correlation of the successions at Cliffe Hill, Markfield By-Pass and White Hill.

ice at the beginning of the glaciation associated with Lake Harrison, the altitude of the Markfield Clay indicates Charnwood Forest proglacial lake levels 60 m or more above those recorded elsewhere in the Midlands (Bishop, 1958). Notwithstanding this discrepancy, the absence of evidence showing any influence of north-eastern ice in the formation of the Charnwood lake justifies the correlation of the Markfield Clay with Shotton's Lower Wolston Clay, but there was, of course, no physical continuity between Lake Harrison and the proglacial ponding around Charnwood Forest.

The age of the Middle Head is therefore established for it lies within the Markfield Clay. It is hardly surprising that this head has no recorded counterpart in the Midlands as the shoreline conditions leading to its formation were probably unique to south Charnwood Forest.

Although the Newtown Linford Till shows a variable composition it characteristically contains some Coal Measure erratics. This trait may be taken as an indication of south-easterly ice movement over the topographically unobstructed ground lying between the exposed portion of the Leicestershire-Derbyshire coalfield and south Charnwood Forest. There was, however, an additional route open to ice from the coalfield via the low terrain north of Charnwood Forest and the valley of the Proto-Soar (Rice, 1968). Support for the utilisation of the latter course by north-western ice is found in the Thrussington Till mapped by Rice in the northern part of the Soar Valley and it therefore seems probable that both routes were used by lobes of ice which had initially advanced over the Coal Measure outcrop. Although their respective contributions to the Newtown Linford Till are not understood this interpretation goes some way towards explaining its variability.

The youngest member of the Older Drift in south Charnwood Forest, the chalky Anstey Till, supports evidence from other parts of the Midlands for the dominance of north-eastern ice in the closing phases of the glaciation.

The relationship of the Upper Head to valley slopes developed on Wolstonian drift demonstrates that the head is younger than the main period of valley formation. The greater part of the erosion was probably effected during the Ipswichian interglacial and the origin of the Upper Head has accordingly been attributed to the periglacial environments of the following Devensian cold stage.

Cryoturbation disturbances of the head indicate more than one periglacial phase but it has not been possible to work out the sequence. Some indication of the number of phases involved and their position within the stage may be gained from Shotton's observations around Brandon where four Devensian cryoturbation periods have been provisionally dated, with three being placed in the early Devensian and one in the Upton Warren interstadial.

Conclusion

In the light of the above discussion the pattern of Pleistocene events for south Charnwood Forest may be summarised as follows:

A. Wolstonian

i. Early period of periglacial environment (Lower Head).

ii. Entry of north-eastern ice (Raunscliffe Till).

iii. Formation of proglacial lake (White Hill Clays and Silt).

iv. Erosion of glacial deposits laid down in stages ii. and iii.

v. Advance of north-western ice (Cliffe Hill Sand and Gravel).

vi. Formation of proglacial lake (Markfield Clay).

vii. Periglacial environment with head becoming incorporated into proglacial lake sediments (Middle Head).

viii. Entry of north-western ice (Newtown Linford Till).

ix. North-eastern ice becomes dominant (Anstey Till).

B. Ipswichian

i. Erosion

C. Devensian

i. Several phases of periglacial activity (Upper Head and cryoturbation).

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THE EARTH, THE MOON AND TIDAL SEDIMENTS :

AN ANALYTICAL REVIEW

Lecture, East Midlands Geological Society, 12th April 1975

by

J. G. Ford

Summary

An attempt is made to relate contemporary tidal sedimentation to that of the past. The causes of the tides are considered at an elementary level, and it is shown that their magnitude depends on a number of factors which may have varied over geological time. The validity of theories in which these variations are implicit are considered, while the scale of the implied fluctuations is investigated semi-quantitatively. One theory is found which dominates all others in its effects on tidal magnitude variation. This is the theory associated with tidal-friction. The implication is that, on descending the stratigraphical column, preserved tidal deposits should show increasing tidal ranges. Recent tidal sediments are examined and apparently offer adequate criteria for identification of fossil deposits of similar origin. Palaeozoic quartzites and tilloids are both suggested as evidence for higher tides and this places a possible question mark against Hutton's Principle of Uniformitarianism. The quantitative studies carried out by geologists on Phanerozoic rocks seem to show that, although tides were higher then, they were not sufficiently high to satisfy the astronomers. The astronomers require tides that are kilometres high and, unless the deposits left by these tides are unrecognised by geologists for what they are, such tides have not occurred. It is possible that the moon is of recent origin, but no theory fits the facts and this conflict between astronomy and geology remains to the end. The only solution offered is that the radioactive decay constants vary with time, which solves the underlying time-scale difficulty, that prevents the geological and astronomical theories from being compatible. But the cure seems to be worse than the disease.

Introduction

This paper is an attempt to compare tidal sedimentation today with that of the geological past. These investigations have two main aims. Firstly, after giving a brief general review of tidal sediments, to examine tidal ranges in Palaeozoic and older rocks in order to see what evidence is available for or against Hutton's Principle of Uniformitarianism, which postulates that the present is the key to the past. Secondly, to throw some light on the history of the earth-moon system, which has an important bearing on the whole of earth history. In order to achieve these aims, a preliminary insight into tidal theory is necessary. An analysis of present day tidal deposits will follow, combined with a search for criteria that can be used to identify tidal deposits in the sedimentary record.

A number of current astronomical and cosmological theories predict, either explicitly or implicitly, that tidal magnitudes have previously been higher. These theories are contrasted with the sparse results available from the rock record of tidal ranges in various geological

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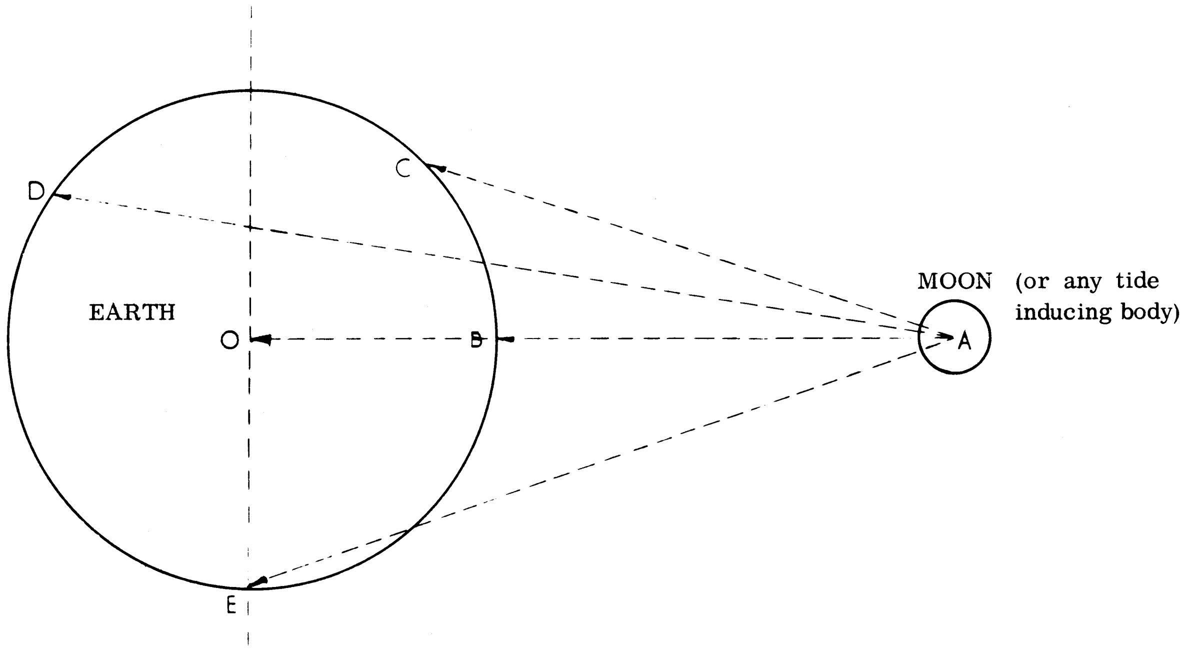
pp. 205-239, 15 text-figs.

epochs. This paper does not set out to solve the problems associated with tidal action in geological history but rather to pose clearly the dilemmas and to suggest a tentative route towards their resolution.

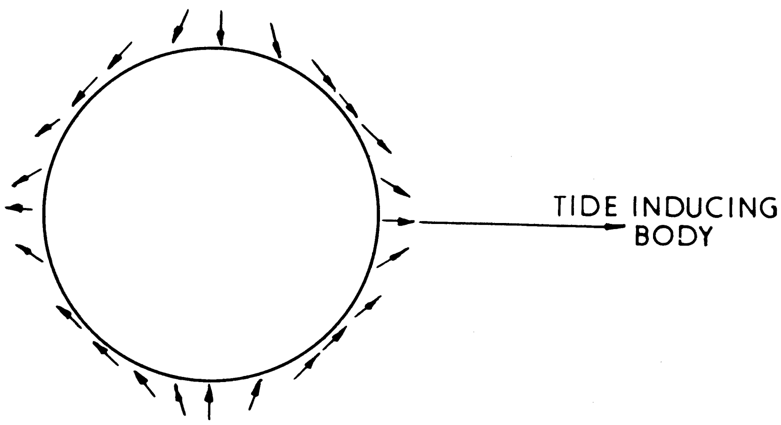
The causes of tides

Tides are caused by the varying gravitational attraction of the sun and the moon upon the individual particles of the earth. The directions along which the gravitational forces act are not uniform, as the earth is a sphere and the particles on it are therefore at varying angles to the tide inducing body. These angles are of similar magnitude but the small variations are significant. The magnitude of the forces also varies, to a similarly small but important extent, as some particles are further away from the tide inducing body than others and the magnitude of the gravitational force is dependent on the separation of the bodies. These two effects can be seen in text-fig. 1 : for example, the angle BAC is greater than angle BAD, while the distance AB is less than distance AC. The average force on the particles is that along the line ABO at a distance AO.

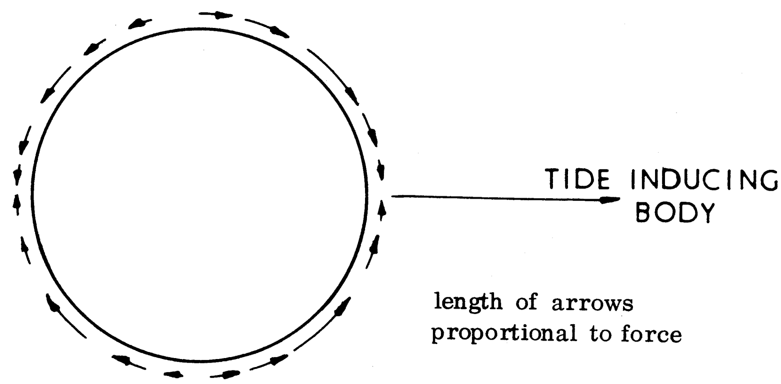


Text-fig. 1. The variation in gravitational force due to distance and position on the earth's surface.

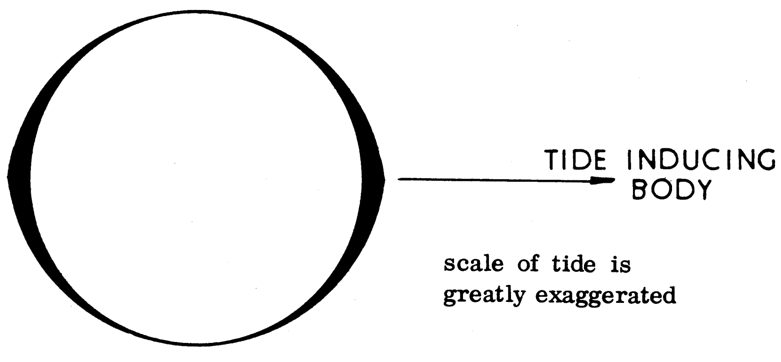
Therefore if the average force on each particle due to gravitational attraction is subtracted vectorially from the actual force on each particle, a system of residual forces remains which vary systematically in strength and direction over the earth's surface (see text - fig. 2). These residual forces can be resolved into horizontal and vertical components with respect to the surface of the earth. The vertical component can be neglected as it simply adds to, or subtracts from the weight of particles by an insignificant amount. The resulting horizontal forces are shown in text-fig. 3, and these are the effective tide generating forces, producing what is known as the 'equilibrium' tide (see text-fig. 4). This tide is to a large extent conceptual, bearing only a limited correspondence to the hard facts of observation with regard both to timing and to magnitude.



Text-fig. 2. The residual tide inducing forces remaining after subtracting the average force from the actual force.



Text-fig. 3. The horizontal tide generating forces.



Text-fig. 4. The 'equilibrium tide', resulting from the horizontal tide generating forces.

While the explanation above is for only one tide inducing body, the earth has two such bodies acting upon it - the sun and the moon. The moon exerts a stronger tidal influence on the earth than the sun, inducing tides that are 2.17 times as strong.

One point which must be clarified is that these tidal forces act on the whole body of the earth and while the aqueous layer of the earth responds noticeably to these, the solid earth is also affected to a lesser degree. These tides within the solid earth hold no further interest in this paper.

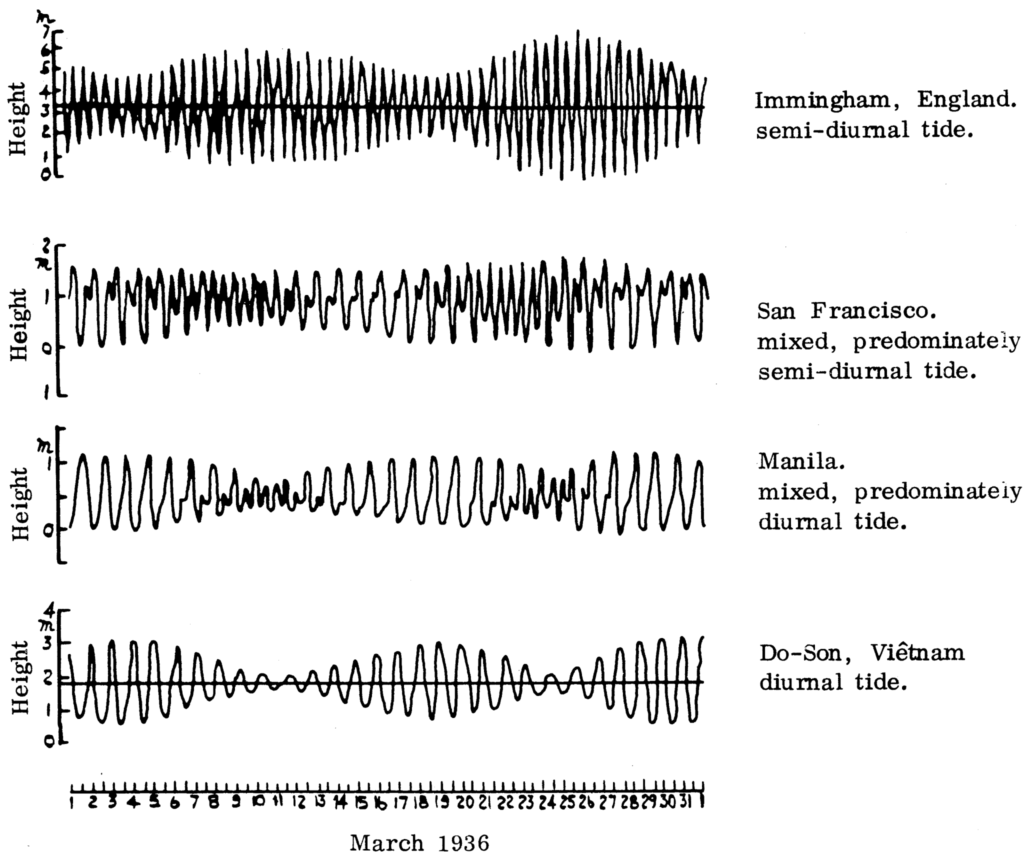
The 'equilibrium' tidal theory was first developed by Sir Isaac Newton in his book "Principia". Galileo had, prior to Newton, given a good empirical account of tides but his theoretical analysis was faulty. Bernoulli vindicated the Newtonian theory in the eighteenth century and the accepted theory became the Newton-Bernoulli equilibrium theory of tides. Since this time the theory has been challenged by Laplace, with his dynamical theory of tides and by Kelvin, who attempted to modify severely the Newtonian theory. Both these challenges were endeavouring to reconcile the huge discrepancy between theory and observation, but both failed. The Newtonian model is, however, sufficient for the purposes of this paper and further details can be found in Darwin (1898, pp. 135-147) and Tricker (1964, pp. 4-13). The latter offers a particularly good elementary mathematical treatment. More modern tidal theory is dealt with at a popular level by Russell and Macmillan (1952, pp. 214-251), and more rigorously by Dean (1966). Reservations as regards the whole of present-day tidal theory have been expressed by Michelson (1974).

Tides in practice

Tides are, in reality, waves with a typical period of twelve hours twenty-five minutes, and with a wavelength of half the circumference of the earth, about 21,300 kilometres. From the equilibrium tidal theory of Newton the maximum and minimum tidal ranges at the spring and neap tides can be calculated as seventy-nine cms. and thirty-one cms. respectively (Pattullo. 1966, p. 917). The spring tide is that which occurs when the tides induced by the sun and moon reinforce each other, while the neap tide occurs when the two tides are in opposition. These extremes should only be found where the sun and moon can be directly overhead; elsewhere the variation in tidal range should be more restricted. Values similar to the calculated ones are found on isolated oceanic islands, where the tidal range is between ninety and sixty cms (Darwin, 1898). Elsewhere in the world the observed tides have little in common with those of theory.

Two classes of effects lead to the departure from theory. First, physical conditions and constraints on earth act in ways that create diversity; amplification of tidal range due to resonance effects takes place, for example, in the Bay of Fundy (Swift, 1966); amplification due to water depth shallowing is found in narrow seas, estuaries and on broad continental shelves, while meteorological tides can arise from high winds. All these agents act in localised areas, whereas the second class of effects, contributing to worldwide tidal variations, are more systematic. These are astronomical effects, caused by the complex motions of the sun and the moon, coupled with geographical variations due to the tide inducing bodies being at different elevations with respect to different latitudes on earth. The forces causing the tides can therefore be broken up into numerous separate components. These components can be classified into three groups on the basis of their periodicities: long-period, diurnal and semi-diurnal. The relative importance of these groups varies geographically, with a tendency for low latitudes to exhibit semi-diurnal tides (Pattullo, 1966, p. 914, his fig. 3), so monthly tidal curves show markedly different patterns from one place to another. For example, text-fig. 5 shows tidal curves from four different areas of the world illustrating these variations. Marmer (1926, pp. 61-75) considers the above variations at greater length.

The totality of the above effects results in worldwide variations in tidal range of two orders of magnitude: from twenty cms in enclosed basins such as the Mediterranean Sea to nearly twenty metres in the Bay of Fundy (Pattullo, 1966, p. 919). Variations in tidal



Text-fig. 5. Tidal curves for various tidal groups. The heights refer to arbitary zero points for each location. (After Pattullo, 1966).

periodicity along the complete spectrum from diurnal to semi-diurnal tides also exist. With such variability being found today, any changes in tidal range over geological time would obviously have to have been of several orders of magnitude to be picked up unambiguously in the geological record.

Tidal sediments today

Tidal sediments are those sediments which possess a majority of depositional and sedimentary features which are the result of tidal action. Environments in which tidal sedimentation is important are beaches, tidal flats and shallow marine deposits. Beaches are strongly overprinted with the effect, however, of wave action. More importantly, the dominant waves which rework sediments on beaches are produced by storms and therefore of meteorological origin. Shallow marine sediments are influenced by the interaction of waves, tides and oceanic circulation (Allen, 1970, p. 150; Kukal, 1971, p. 210). Tidal flats are usually protected from both wave action and oceanic circulation due to their situation in bays, and represent the only areas where sedimentary patterns are almost solely attributable to tidal causes.

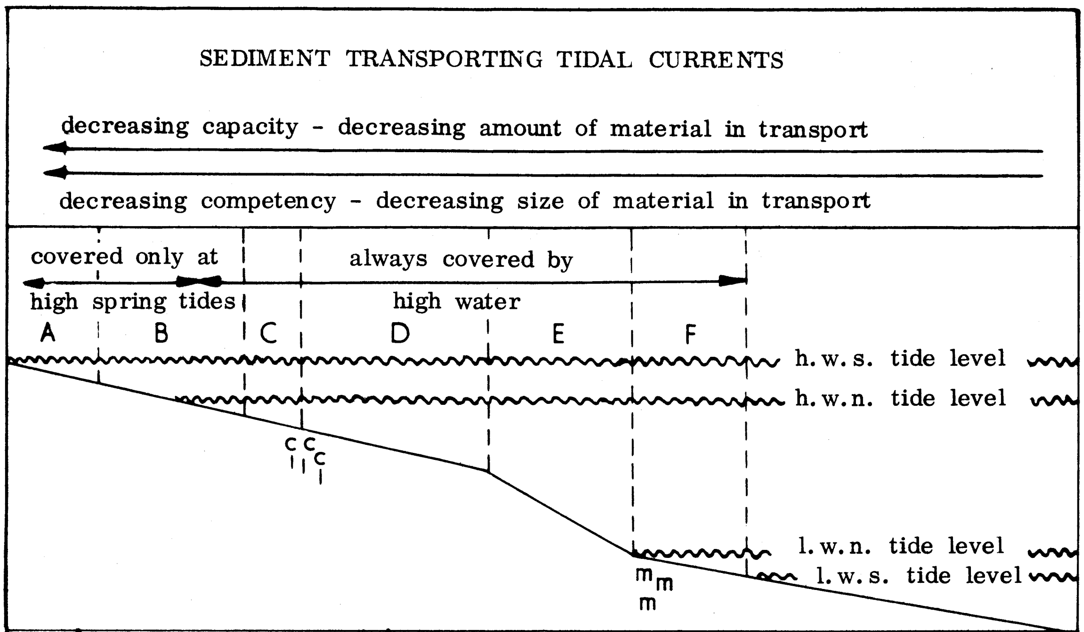
Tidal flats are marshy or muddy areas which are covered and uncovered by the rise and fall of the tide. They occur today only on submergent coastlines with a constant or recurrent positive movement of sea-level (Kukal, 1971. p. 264). Examples of modern tidal flats include the Wash of eastern England (Evans, 1958, 1965), the Bay of Fundy in Nova Scotia (Klein, 1963a., 1970a) and the Wadden Sea of the Netherlands and Germany (Van Straaten, 1961; Reineck, 1969). All other areas of tidal flats lack comprehensive study. The Wash and Wadden Sea show very similar tidal ranges, whereas the Bay of Fundy is dissimilar in this respect and so may be expected to exhibit markedly different sedimentary characteristics.

These areas are all clastic dominated sedimentary environments, little work having been done on those with carbonate precipitation. Both Klein (1967) and Evans (1970) consider that, despite the great differences in origin of clastic and carbonate sediments, the patterns of dispersal and the resulting sedimentary facies patterns show striking similarities for like tidal ranges. In the case of the carbonate environments, the tidal marsh zone appears to be replaced by broad sabkhas and supratidal areas in which penecontemporaneous dolomite is formed. Since this paper was prepared, Lucia (1972) has presented his work on carbonate shore-line sedimentation. Both clastic and carbonate areas show a general decrease in grain size landwards. Table 1 lists the rock equivalents for clastic and carbonate rocks in tidal flat environments.

Table 1 Comparative clastic and carbonate rock types found in tidal flat environments

Clastic	**Carbonate**
Sandstone	Limestone consisting of sand-sized particles
Siltstone	Limestone consisting of silt-sized particles
Mudstone	Dolomite
Coal	Evaporites

Research on the above named areas indicates that intertidal sedimentation is characterised by a distinct zonation of sedimentary environments from high to low tide level. The sedimentary zones are crosscut by deposits associated with tidal creeks. The sediments of each zone can be distinguished on the basis of composition, texture, sedimentary structures and included organisms. Evans (1965) identified six sub-environments in the intertidal environment of the Wash, excluding tidal creeks. These are shown in text-fig. 6, where brief characteristics of the sedimentary environments are also given. In the southern North Sea of the Netherlands and Germany four sub-environments have been distinguished (Van Straaten, 1954a; Van Straaten and Kuenen, 1958; Reineck, 1963, 1967). These two classifications are



A	salt marsh	no reworking by waves or organisms; fairly slow sedimentation; sediment bound by plants; filter effect on plants
B	higher mud flats	very limited reworking by waves & organisms; fairly rapid sedimentation; sediment bound by algae.
C	inner sand flats	limited reworking by waves; extensive reworking by *corophium*; slow sedimentation.
D	*Arenicola* sand flats	extensive reworking by waves & *arenicola*; slow sedimentation.
E	lower mud flats	little reworking by waves or organisms; rapid sedimentation.
F	lower sand flats	little or no organic reworking, minor wave-action; strong tidal currents slow sedimentation.
c	*Cardium edule*	organisms extracting suspended clay from seawater (i.e. filter feeders).
l	*Lutraria elliptica*	
m	*Mytilus edulis*	

h.w.s. - high water spring
h.w.n. - high water neap
l.w.s. - low water spring
l.w.n. - low water neap

Text-fig. 6. A schematic representation of the six sub-environments and the dynamics of sedimentation in the Wash. (Source Evans (1965), with permission of the Geological Society of London).

compared in text-fig. 7 and shown to be broadly similar. Each sub-environment grades into adjacent ones. Text-figs. 6 and 7 show the relationship of the sub-environments and the tidal levels.

The mechanism of tidal sedimentation was divided by Van Straaten (1961) into two types: 'lateral' and 'vertical'. The former occurs predominately in lower tidal flat areas on the sides of migrating channels and gullies and results in beds that are gently inclined. Deposition is rapid, but ephemeral due to subsequent erosion. Reineck (1960) estimated that only 1/10,000 to 1/100,000 of sediment deposited in tidal flat areas is, in fact, eventually preserved. Vertical sedimentation is found mainly on the higher parts of tidal flats, outside the influence of the shifting gullies and channels, and consists of a slow accumulation of sand and mud, the sand often being supplied by current ripple migration from gullies. The two mechanisms are shown in text-fig. 8, which also illustrates other facets of the tidal flat environment. Lateral and vertical processes of sedimentation are not mutually exclusive; both often occur together.

Klein and Sanders (1964) consider the distinctive features of tidal flat sediments result directly from the intensity of the reworking mechanisms, which consist of Van Straaten's lateral sedimentation and organic activity. The importance of bioturbation in the zone of vertical sedimentation should not be disregarded. Van Straaten (1952) estimated that the entire layer of sandy sediment above the feeding level of organisms is reworked every twenty months.

Van Straaten and Kuenen (1958) postulated two mechanisms which work in tandem to explain the seaward coarsening of sediments mentioned above. These two mechanisms are *settling lag* and *scour lag*. The first is particles settling out from a waning current, which are not deposited vertically but carried along in the current direction a distance proportional to the settling velocity of the particle in question from the point at which the current is no longer competent to carry the particle. Scour lag occurs because the maximum current velocity which allows sedimentation is lower than the minimum current velocity needed for erosion of the same material to take place. This means that once a particle is deposited on a waning current it will not become re-entrained when a current sweeps over it with the same velocity as that of the current which allowed deposition to occur.

The Wadden Sea and Wash having been compared, the Bay of Fundy can now be shown to be notably different. Klein (1967) went as far as to divide intertidal sediments into two distinct groups, Wadden-type and Fundy-type. The tidal flat environment in the Bay of Fundy consists of four sub-environments (Klein, 1963a). These sub-environments will be briefly described as, unlike those of the Wash and Wadden Sea, they cannot easily be represented diagrammatically. The four sub-environments are as follows:

1. Wave-cut Benches

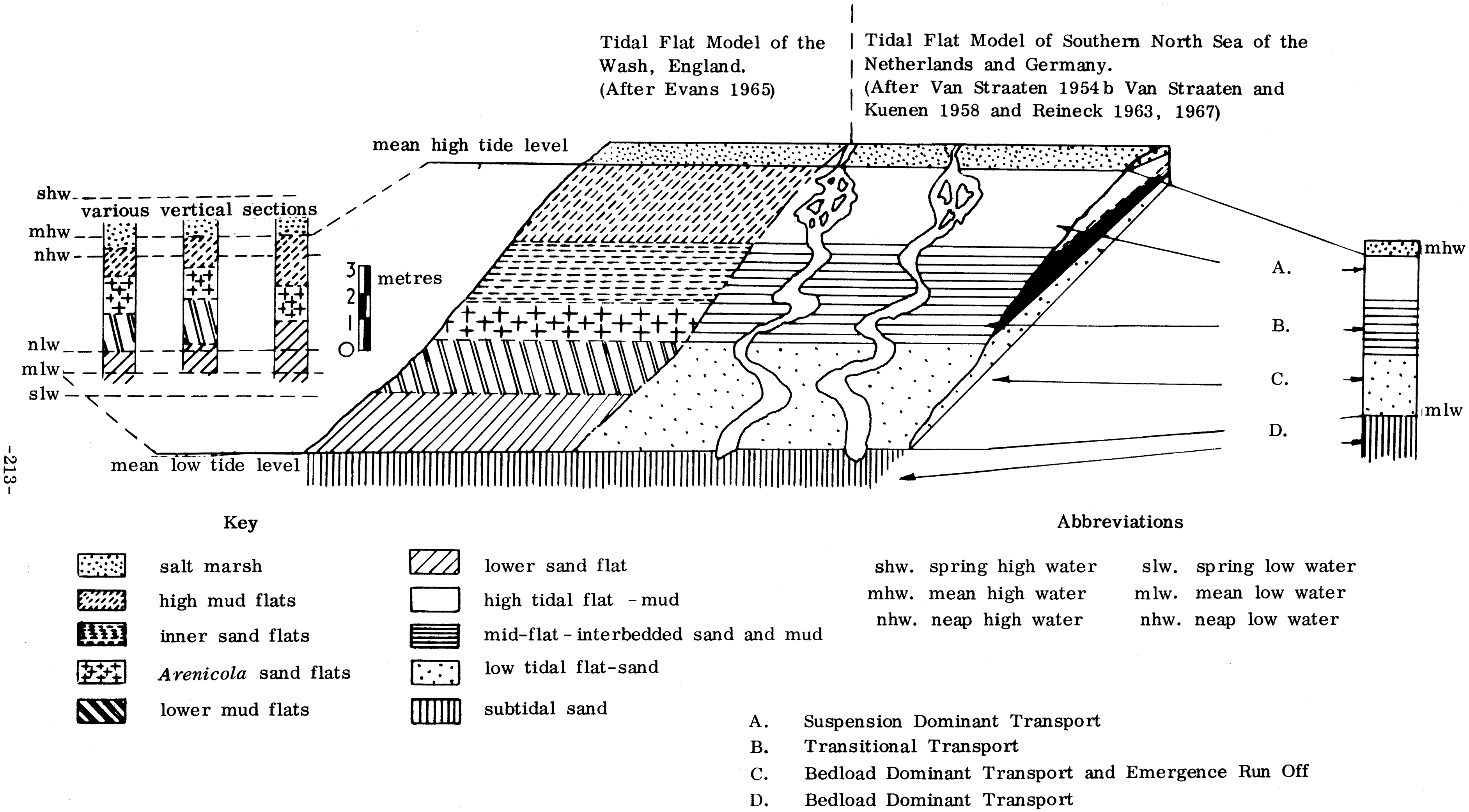
Tidal sediments in this environment constitute seventy-five per cent of the total and are formed by the undercutting of sea cliffs. Only a thin veneer of sediment is present on the benches and this correlates very closely in type with the underlying bedrock. The dominant action here is wave motion and this results in the widespread occurrence of oscillation ripples. Rhombic shaped interference ripples are also characteristic, with near shore clay accumulation. (Van Straaten and Kuenen, 1958).

2. Estuarine Clay Flats

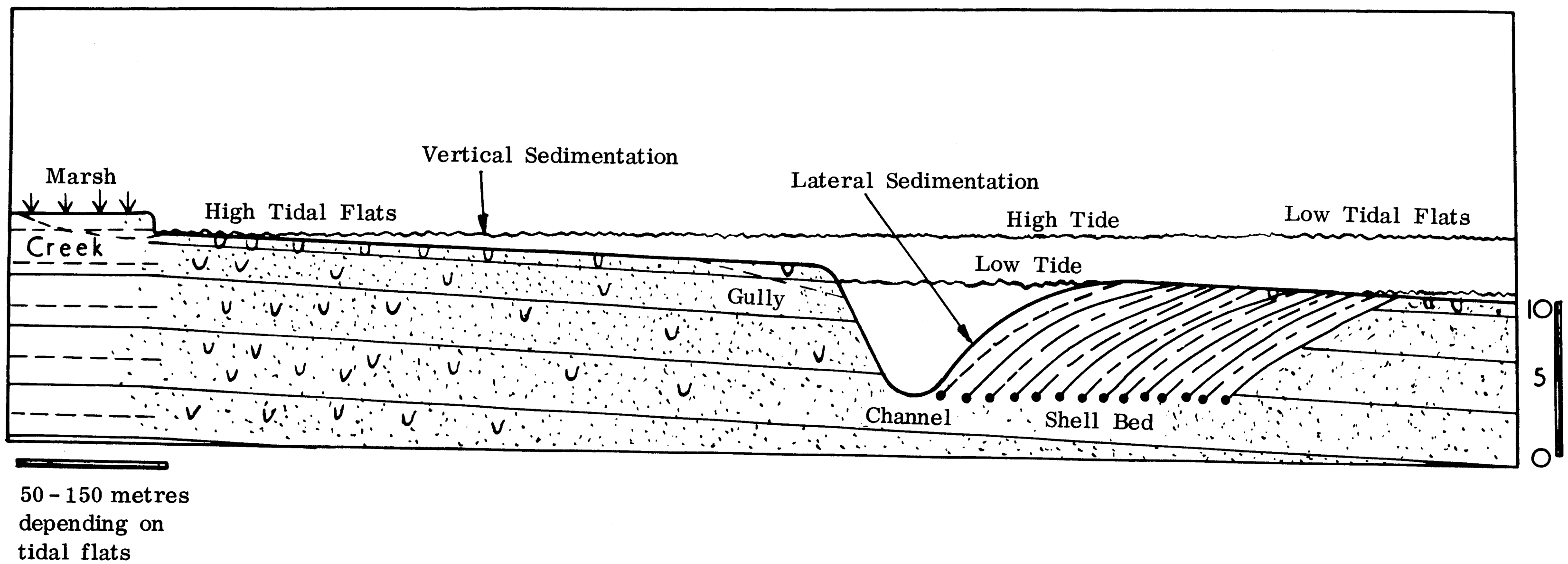
These sediments consist of clay and silt with rare shells. No stratification or ripples can be seen, except for a few oscillation ripples near the high tide mark.

3. In the lee of bedrock islands

The sediments of this environment are closely analogous to the tidal flats of the Wadden Sea, and sediments similar to both the high and low tidal flats of the Wadden Sea can be distinguished. In this environment are found the only examples of lateral sedimentation in the whole Bay of Fundy area.



Text-fig. 7. A sedimentary model for determining tidal range in the past. Clastic intertidal sedimentation models of the north sea coast of the Wash and the Netherlands and Germany. (After Klein 1971, with permission of Geological Society of America).



Text-fig. 8. Vertical and lateral sedimentation in tidal flats; in this idealised cross-section of a tidal flat environment, V shows the varying intensity of bioturbation on sediment structure in high parts of flats (with slow, continuous deposition), and in low parts of flats, where sediments are frequently reworked by shifting gullies.

4. Tidal Marsh

The Bay of Fundy tidal marsh sediments exhibit little evidence of stratification, but otherwise resemble those of the Wadden Sea.

The differences between the Wadden Sea tidal flats and those of the Bay of Fundy are manifest but the underlying cause of these differences is not quite so obvious. The traces of what appears to be Wadden-type sedimentation on the sheltered sides of bedrock islands suggest that a large part of the explanation can be attributed to the higher current velocities in the Bay of Fundy which result from the higher tidal range. Klein (1967) lists a number of factors thought to influence sedimentation in coastal areas, such as bottom slope, tidal range, fetch, coastal morphology, climate, organisms, and long term position of the sea. These factors and also provenance are compared for the three areas of the Wash, the Wadden Sea and the Bay of Fundy in table 2.

The table illustrates clearly that tidal-range and provenance are the two factors which differ markedly between the areas. The tidal range is over two and a half times larger in the Bay of Fundy than in either of the other two areas, although the provenance does show a minimum correlation as Pleistocene sediments are present in all three areas. The tidal range is related to current velocity, as the higher the range the greater the volume of water which must be moved in a fixed time, therefore the higher the current velocities. Klein (1970a) records tidal current surface velocities of up to 280 cms sec^{-1} and bottom velocities of 110 cms sec^{-1} in the Bay of Fundy, and concludes that tidal current transport is the dominant process of sand deposition.

Klein and Sanders (1964) in their comparison of tidal flat sediments in the Bay of Fundy and Dutch Wadden Sea did not isolate one factor as determining the differences between the two areas, rather suggesting that the differences were explicable on the basis of the interaction of a number of factors. But the sedimentary environments are so different in the two areas that there seems to be strong support for the hypothesis that tidal range and hence current velocity are the primary factors in determining sedimentary facies in intertidal areas. Obviously other factors do come into play to a limited extent and these may reinforce or weaken the influence of tidal range on the environment: for example, emergent coastlines would reinforce tidal influences.

Table 2 A comparison of the factors effecting sedimentation in three areas of intertidal sedimentation

Factor	The Wadden Sea	The Wash	Bay of Fundy
Bottom Slope	All shallow and similar: 1:100 to 1:450		
Tidal Range	2.8 - 4.5 M (1)	6.7 M (2)	17.0 M (3)
Fetch	All fairly restricted in length		
Coastal Morphology	Low-lying	Low-lying	More prominent
Climate	All cool temperate maritime		
Organisms	As far as known, all similar		
Provenance	Pleistocene from floor of the North Sea (4)	Pleistocene from floor of the North Sea (2)	Pleistocene, Carboniferous and Triassic rocks (5)
Long term position of the sea	Slight transgression	Moderate regression	Slight transgression occurring today

(1) Van Straaten (1961) (3) Swift (1966) (5) Klein (1970a)

(2) Evans (1965) (4) Van Straaten (1954b)

The dominance of tidal influence is very important when looking at tidal deposits in the geological record and this fact will be used later. Swift (1966) concluded that the reason the Bay of Fundy has an atypical tidal range of high magnitude is that the shape of the Bay is such that tidal resonance takes place, enhancing the tidal height by strong reinforcement. This means that the Bay can be considered as a relic tidal flat environment of a past time when, if ever, the tidal range throughout the world was an order of magnitude higher than it is today.

Criteria for identifying tidal sediments in the past

The most obvious way of identifying tidal sediments in the stratigraphical column is by the use of diagnostic sedimentary structures, coupled with other available evidence for origin. Unfortunately there is no unique structure or set of structures which will result in a reliable identification. The best single criterion was considered by Van Straaten (1961) to be the presence of tidal channel deposits. Klein (1963b) distinguished between river, estuarine and tidal channel deposits in the geological past by means of the composition of the coarse grained material or lag found in the channel bottom. River channels contain lag deposits which consist of chips of clay eroded from semi-consolidated clay beds at the time of deposition; estuary channels contain both 'clay-chip' and shell lag deposits, while in tidal channels only shell lag deposits are found.

However, Van Straaten (1961) pointed out that there are few, if any, sedimentological features which taken alone could prove that sedimentary rocks originated in a tidal environment. He concluded that it is necessary to study all the characteristics of a rock, both organic and inorganic - and if possible, the underlying, overlying and adjoining rocks - before coming to a final decision. Klein (1971) holds similar views to those of Van Straaten and considers that sediments deposited by tidal currents can only be identified by a combination of features. In his process-response model, Klein identifies ten phases of tidal sediment transport, in both clastic and carbonate environments, which he considers are characterised by a distinct combination of sedimentary structures, vertical sequences, textures and lithologies. In his table 1, Klein gives in all fifty-nine criteria for recognising tidal sediments. Tidal sediments are subdivided on the basis of structures indicating exposure, evaporation and late-stage emergence run-off prior to exposure.

Other criteria besides those above have been advanced as aiding in the establishment of a tidal origin for certain rocks. Van Straaten (1954b, pp. 88-93) lists factors useful for distinguishing between sub-environments in modern tidal flats, but many of these are equally applicable to indurated rocks. Klein (1970b, his table 2) lists thirty-six factors in a comparison of the lower fine-grained quartzite (Dalradian) of Islay and other rocks from tidal environments. Klein (1970a) and Swett et al. (1971) give thirteen and nine criteria respectively for the characterisation of tidal sediments.

Besides sedimentary structures, other corroborative criteria are available. Palaeontological evidence is often useful, but the reliability of this evidence falls in the Paleozoic, and all but vanishes in the Pre-Cambrian. Trace fossil communities provide another approach. Seilacher (1967) considers trace fossils useful tools in paleobathymetry, suggesting that in very shallow environments protective burrows, which are deep and vertical, predominate over other kinds of trace fossils. These protective burrows constitute Seilacher's skolithos trace fossil facies, characteristic of littoral environments. Two specific trace fossils, *Corophium volutator* and *Callianassa* burrows, thought by Seilacher to be specifically intertidal, however, can be also subtidal.

Geochemical analysis of the trace-element content of rocks is a recently introduced technique, which is thought to indicate paleosalinities. Shaw and Bugry (1966) consider that the higher the boron content in a rock, the higher the salinity of the water in which the sediment was deposited. Other trace-elements besides boron have been proposed as better discriminants, but the state of the art at the moment is such that whichever discriminant is used, great caution is required in interpretation. Krejci-Graf (1964) said of these techniques, " . . theoretical difficulties are not always practical obstacles. . " but these difficulties do tend to be rather disconcerting.

With the above variety of criteria available, there would seem to be little difficulty in unambiguously identifying tidal environments in the geological record. However, a number of problems do arise. Firstly, ancient and modern environments cannot be studied in the same way (table 3); secondly, diagenetic modifications of sedimentary rocks with age may have

Table 3 Limitations inherent in research methods for comparing ancient and modern environments

Recent Sediments	Ancient Sediments
Mainly occur as thin layers over large areas	Mainly vertical sections of restricted horizontal extent
Environment studied in a horizontal sense	Lateral facies variation is limited by size of outcrop
Time correlation of sedimentary deposits by age is easily established	Time correlation is virtually impossible
Environment is complete in the spatial aspect	Environment normally found as sporadic outcrops which may grossly misrepresent original proportions of various facies

(Modified from Kukal ((1971, his table 200))

altered the characteristic features beyond recognition; thirdly, organic activity has changed over geological time; and fourthly, tidal variations may, with time, have been such as to cast doubt on the applicability of the Huttonian Principle of Uniformitarianism. Nevertheless, bearing in mind these reservations there does at least seem to be a reliable base of criteria for the identification of tidal sediments.

Paleotides from theory

The basis of tidal theory is Newton's Law of Gravitation which is encapsulated in equation (1), F being related to tidal height, as explained in the section concerning the causes of tides.

$$F = \frac{GMm}{r^2} \qquad (1)$$

F = force
G = the Universal Gravitational Constant
M = the mass of the tide inducing body
m = the mass of the particle being affected
r = the distance away of the tide inducing body

If m is assumed to be a constant of unit mass, it can clearly be seen that a change in any of the other physical properties on the right hand side of the equation will affect property F. A number of theories have been proposed which imply changes in the physical parameters in question. These will now be considered and the resulting effects on paleotides evaluated.

G - the Universal Gravitational Constant

Variation in G was first proposed by Dirac (1937, 1938) who suggested that G was inversely proportional to the age of the universe. Since then, further research has led to a position where four alternatives need consideration: first, G is constant; second, Dirac and Jordan's hypothesis that G is decreasing by 1 or 2 parts in 10^{10} per year; third, the Brans-Dicke and Hoyle-Narlikar hypotheses which require a decrease of between 1 and 5 parts in 10^{11} per year (Wesson, 1973); and fourth, that G varies as a function of both time and space (Steiner, 1967). This last suggestion implies that an oscillation in the value of G, occurs superimposed on its secular decrease.

From astronomical data available of solar eclipses in the Pre-Christian era, Dicke (1966) calculated that, at the earth's present rate of deceleration, allowing for tidal friction which will be discussed later, G was decreasing by 3.8 parts in 10^{11} per year. Stewart (1970, 1972) suggested a number of gravity sensitive geological indicators, including sediment compaction, diaper movement and change in depth of fossil footprints, but all he could conclude was that if G was changing, it had been changing by less than 4 parts in 10^{8} per year over the last twenty-six million years. Wesson (1973), in a lengthy review article concerning cosmologies with implicit G variations, was unable to conclude that G was even varying. It therefore seems that, if G has been decreasing, the rate has been very low - around 3 or 4 parts in 10^{11} or less.

Table 4 illustrates the effect, changes in G of this rate, would have had on tides in the past. The results given in the table are based on equations (2) and (3). The first is given by Dicke (1962a, p. 46) and the second by Alfvén and Arrhenius (1969).

$$r \alpha 1/G \qquad (2)$$

$$f \alpha (Ro/R)^3 \qquad (3)$$

r is the distance away of the tide-inducing body

f is tidal height

Ro is distance away of the tide-inducing body today

R is distance away of the tide-inducing body in the past

Table 4 Paleotides compared with those of today, assuming G to be changing constantly at the rate postulated by Dicke (1966)

	Today	0.6 aeons ago (1)	3.0 aeons ago
G	1.00	1.02	1.11
Earth Moon distance	1.00	0.98	0.90
Earth-Sun distance	1.00	0.98	0.90
Tidal height	1.00	1.07	1.38

(1) Throughout this paper 1.0 aeon equals 10^{9} years
Today's values are all taken as unity, and the tidal heights derived are those of the theoretical equilibrium tide

The assumption made in deriving the figures in table 4 is that the contraction of the earth's radius in the past due to G being higher was negligible. This assumption is supported by Dicke (1962b) who gives equation (4):

$$dr = 0.1 \, ((Go - G)/G) \qquad (4)$$

dr is change in earth's radius compared to today

G is value of G in the past

Go is value of G today

With the rate of change of G postulated, the change in radius of the earth would have been negligible in its effects on tides. Therefore, accepting the value postulated by Dicke as indicating an upper limit as regards the rate of change of G, it has been shown that tides in the past are unaffected on a significant scale.

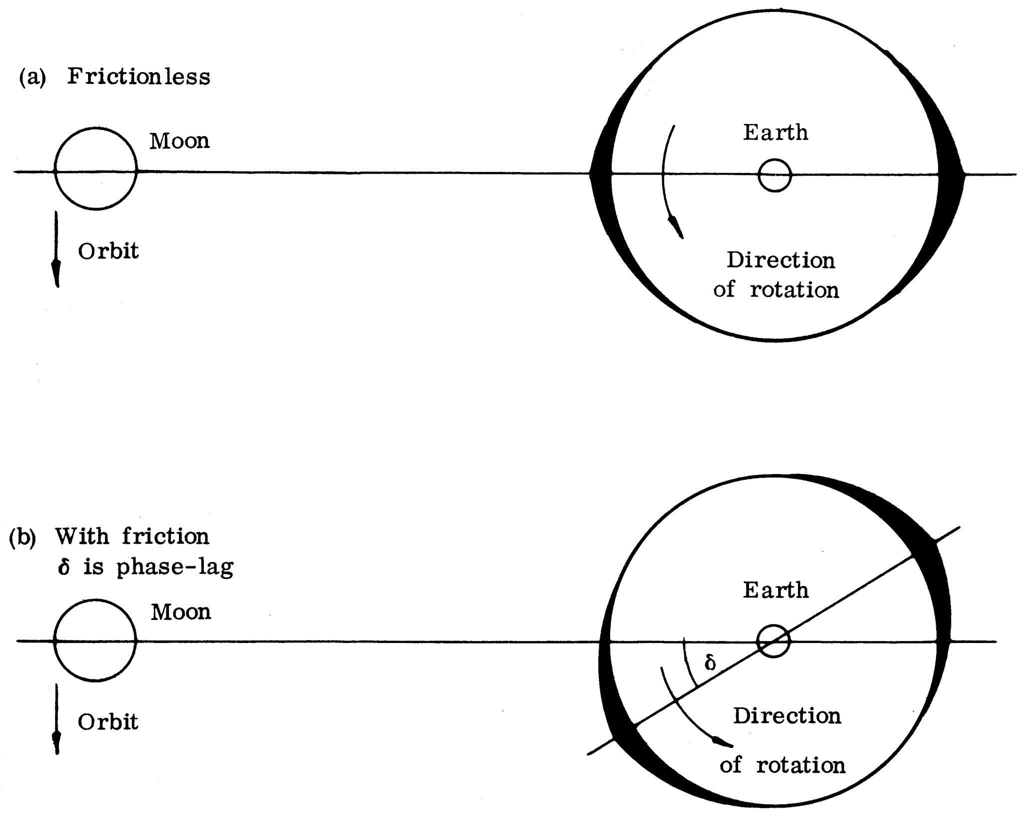
M - the mass of the tide inducing body

A significant increase in mass of any of the bodies in the solar system due to meteoric bombardment and cosmic dust settling has been discredited by Garrels and Mackenzie (1971, p. 111). Kapp (1960) put forward a theory which suggested all mass concentrations in the universe were losing mass fairly rapidly due to a constant creation of matter per unit volume and a constant extinction per unit mass. The rate proposed meant that the earth, sun and moon would have had masses of between ten and one thousand times their present mass four aeons ago. Holmes (1965, p. 985) pointed out that the implied volume change was far too high to be geologically acceptable. Wesson (1973, p. 9) neatly summarises present opinion when he says Kapp's theory is almost certainly wrong, while other theories postulate rates of continuous matter creation which are insufficient to affect the mass of the moon or earth noticeably. Hence mass changes with time have not significantly affected tides.

r - the distance away of the tide inducing body

Theory

Since George Darwin's work (1879, 1880) it has been known that the distance between the earth and the moon has been changing, at least on the geological timescale. The reason for this change is illustrated in text-fig. 9. The upper diagram shows the situation which would prevail if the earth was perfectly elastic in its solid parts and perfectly fluid in its liquid parts. The tidal bulges would then be in perfect alignment with the line between the centres of the earth and moon, and no torque would be introduced into the system. However, as friction accompanies tidal deformation, the rotation of the earth causes the tidal bulges to be carried forward, resulting in the situation as shown in the lower diagram. This means that tides are not highest when the moon is directly overhead but at some earlier time.



Text-fig. 9. A schematic representation of the mechanism causing tidal friction. The diagrams are greatly exaggerated.

The gravitational attraction of the two bulges is therefore asymmetrical to the line of centres. There is a stronger forward attraction from the bulge nearest the moon than a retarding one from the bulge furthest away and this results in a torque on the earth and an equal and opposite torque on the moon. This main pair of torques is supplemented by subsidiary ones, induced in the system by the mutual interaction of the earth, sun and moon. The net result of all these torques is that the earth's rotation is slowed but, more significant from the paleotidal aspect, the moon is hurried on in its orbit, in consequence spiralling very slowly out into space. As the moon retreats from the earth, the tidal range will decrease in consequence. Two popular accounts are given by Darwin (1898, pp. 238-284) and Kopal (1971) of tidal friction; its occurrence within the solid earth has been proposed by Bostrom (1971) as a mechanism for continental drift.

Results

Attempts have recently been made to extrapolate back from the present in order to sketch the dynamic history of the moon's orbit. The calculations indicate that at some period in the past a close approach of the moon to the earth took place. When this happened, it is thought that the inclination of the moon's orbital plane to that of the earth increased rapidly, resulting finally in the orbital plane of the moon passing over the earth's poles - an event which would convert the moon's prograde orbit into a retrograde one. Once in a retrograde orbit, tidal friction begins to work in reverse and so, as extrapolation back continues, the moon recedes from the earth. This can be seen by imagining that the moon's orbit, as shown in the lower part of text-fig. 9, is the reverse of that shown. Then the closer tidal bulge would be slowing it down while the more remote bulge would be attempting less successfully to accelerate it.

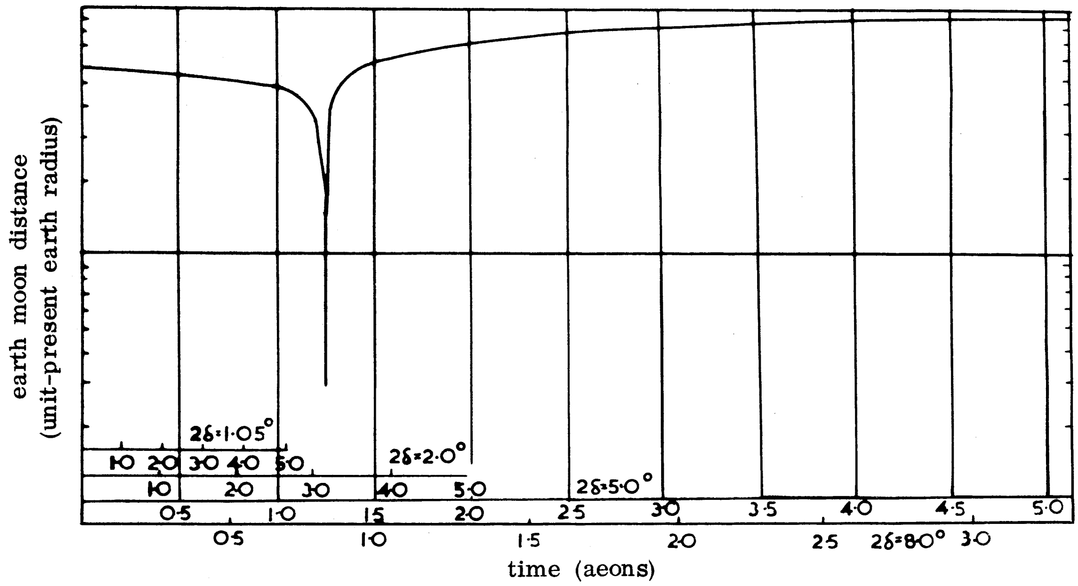
Gerstenkorn (1955, 1967), MacDonald (1964), Goldreich (1966), and Chevallier and Cailleux (1972) all accept the concept of a close approach by the moon, differing only in regard to when and at what distance this happened. Gerstenkorn (1955) stated that the calculations indicated that the moon must originally have been captured in an extended retrograde orbit. The results of Gerstenkorn's and MacDonald's calculations are shown in Table 5. Text-figs. 10 and 11 show the earth-moon distance and the length of the month in the past from some other calculations by MacDonald (1966). The tidal heights have been calculated by the author from the distance data using equation (3). The results cited in the table correspond closely with those of Goldreich (1966) and Gerstenkorn (1967), the main reason for the differences observed being the various

Table 5 Parameters postulated for the close approach of the Moon

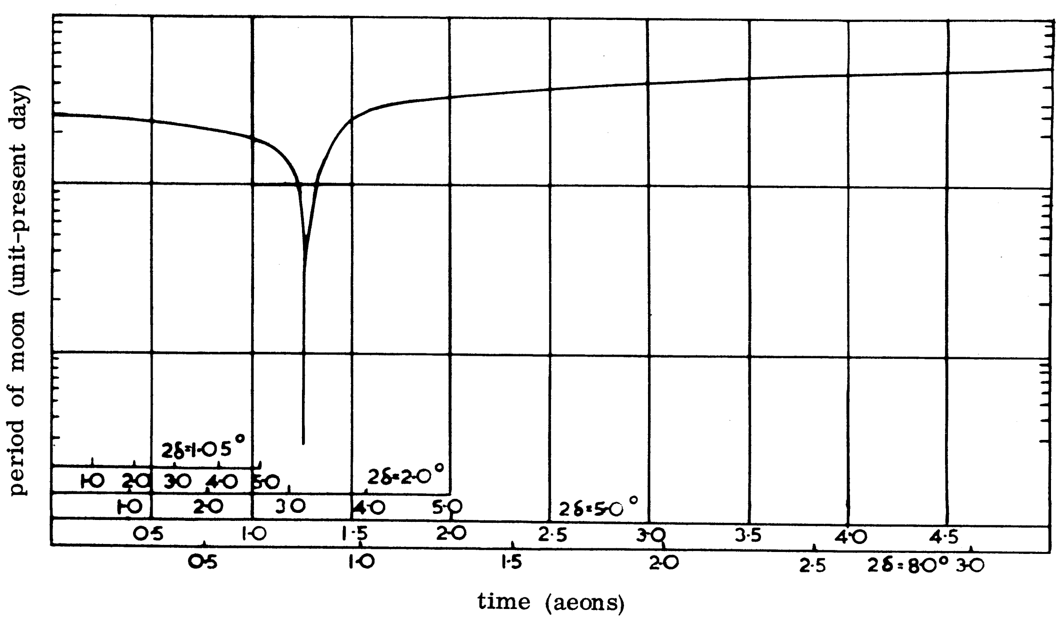
	Time of closest approach (in Aeons)	Distance at this time (in earth radii)	Length of day (in hours)	Length of month (in hours)	Tidal height (today's equilibrium tidal height taken as unity)
MacDonald (1964, his table 2)	1.8	2.72	4.9	30.2	11,300
Gerstenkorn (1955)	1.4	2.89	4.8	6.8	9,400

assumptions made about the past value of the phase lag. This is the angular amount by which the tidal bulge is ahead of the moon in its orbit. This is shown in the lower half of text-fig. 9 as the angle δ.

The only arguments that have been advanced against tidal friction are those of Engels (1880), which today would be considered invalid, and that based on magnetohydrodynamic theory. This is the study of the motions of electrically conducting fluids in the presence of electric and magnetic fields, and it does suggest that it might be possible for energy transfer to take place between parts of the solar system without affecting the angular momentum of the



Text-fig. 10. The earth-moon distance in the past. (After MacDonald, 1966).



Text-fig. 11. The length of the month in the past. (After MacDonald, 1966).

individual bodies. This theory is described fairly simply in Dungay (1958), but the implications for tidal friction are obscure. Observation apparently shows that tidal friction has occurred at the rates postulated and astronomers working on the earth-moon system continue to ignore magnetohydrodynamic theory.

The work of Wells (1963), Scrutton (1964) and others on growth rings in fossils lends credence to tidal friction (text-fig. 12). This shows the length of the day based on paleontological evidence since the Cambrian, along with theoretical values derived on the basis of a number of alternative sets of assumptions. The reason these results are important is that the earth's rotation is arrested simultaneously with the acceleration of the lunar orbit, and so evidence of the former supports the hypothesis of tidal friction being an agent in altering the moon's orbital radius.

Problems

Two points of criticism arise: firstly, a common supposition is that the phase lag was always constant in the past. Different values are put into the calculations (text-figs. 10 and 11) but not ones that vary with time. Today's value is thought to be 2.25°. (MacDonald, 1966, p. 180). The phase lag depends on the amount of friction occurring at any one time and this is attributable to two components: that due to bodily tides, and that due to tidal dissipation in shallow seas. Munk (1968, p. 357) considers two thirds of tidal friction today to be that occurring in shallow seas, and suggests that this proportion might change in step with the variation in the area of shallow seas throughout the world. Pannella *et al.* (1968) produce evidence for a variation in phase lag with time (text-fig. 13), showing that the rate of change of the synodic month has not been constant, the synodic month being the interval between two successive full moons. If the phase lag had been constant, it would have been expected that the rate of change of the synodic month would also have been constant. Therefore the time-scale could be significantly in error. Alfvén and Arrhenius (1969) suggest that phase lag today is an exceptionally high value.

The second point of criticism is that the moon may have joined the system more recently than the postulated time of close approach. If this was so, that awesome period in earth history, with 7 km. high tides sweeping round an earth with a five hour day and accompanied by a moon having a seven hour polar orbit obliterating half the sky, may have been avoided. This would imply a non-catastrophic origin of the earth-moon system, as there are no signs in the geological record of a recent catastropic origin. A number of these non-catastrophic theories are considered, along with their implications for paleotides, in Table 6, (p. 225).

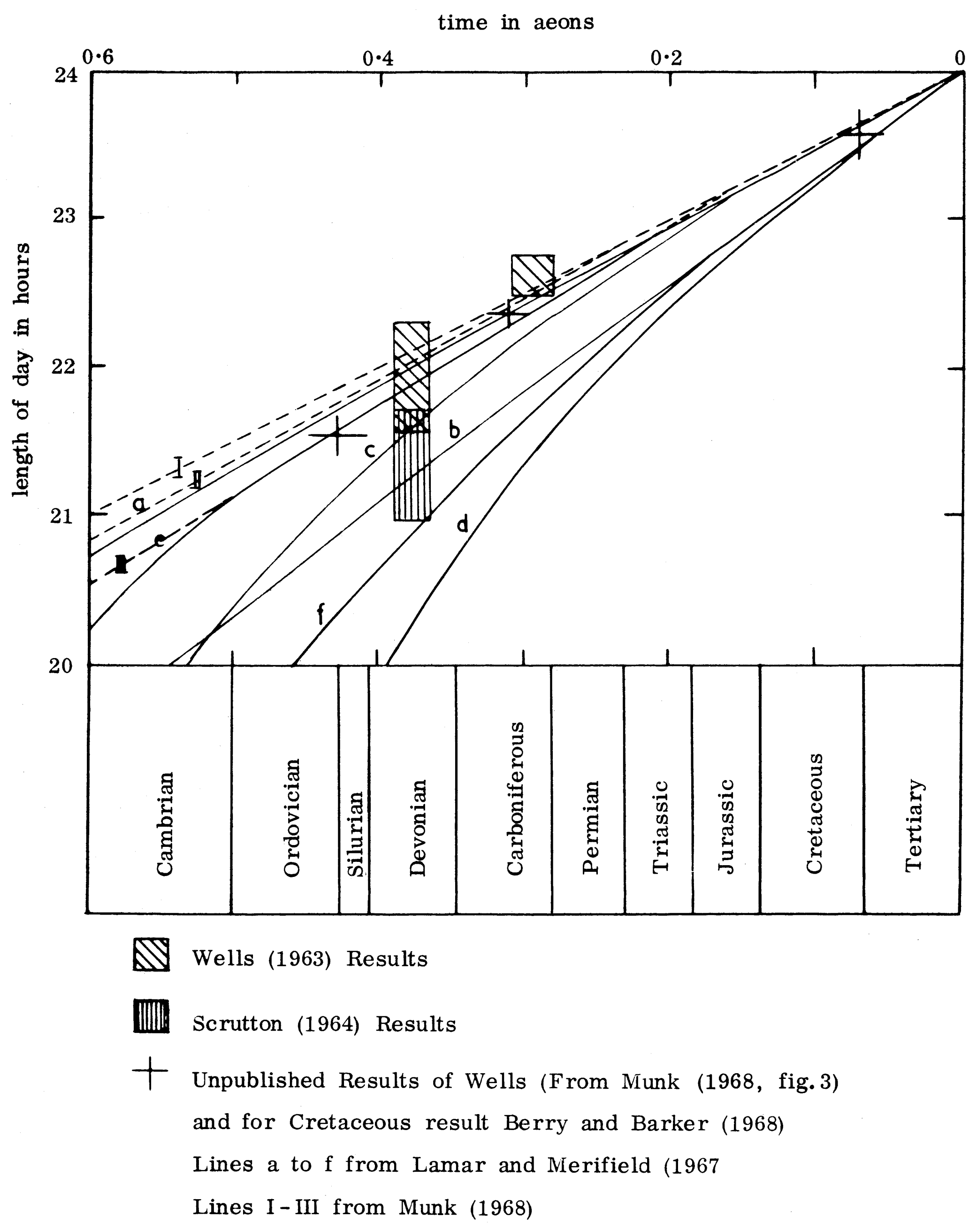
The tidal ranges given in Table 6 are obviously at a maximum at the time or origin of the system, and begin to decay immediately with the action of tidal friction.

All the variable factors in equation (1) have now been considered, but one other factor needs examination:

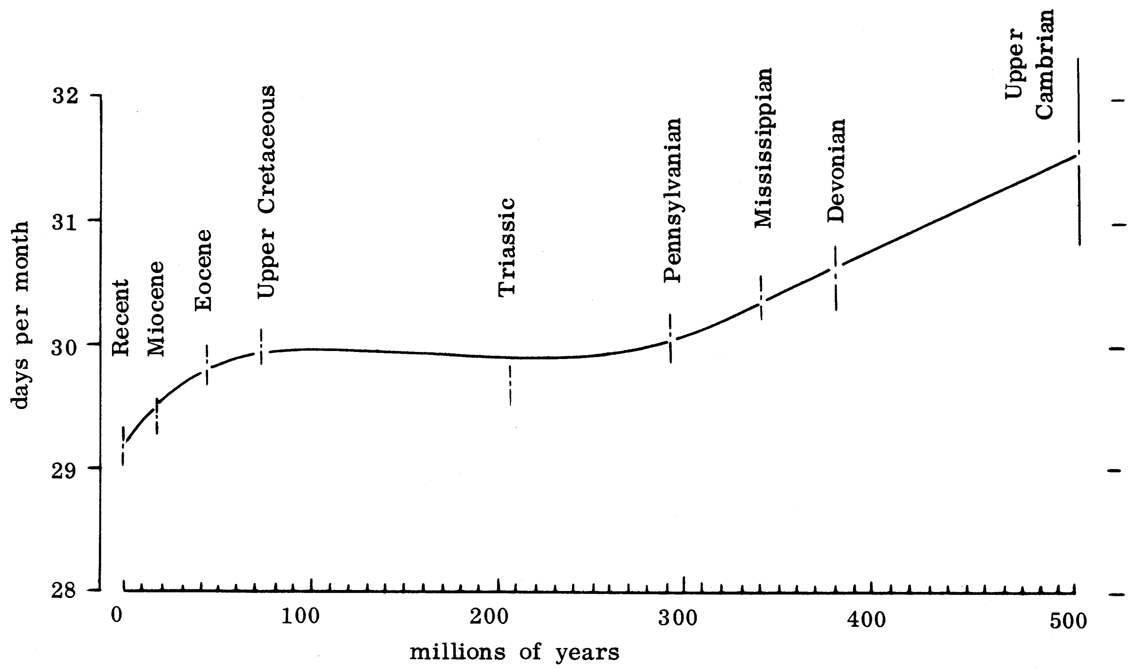
Variation in tidal force due to an expansion of the Earth

The explanation why earth expansion is a factor influencing paleotides can be seen by looking again at text-fig. 1 (p. 206). Should the earth expand with time, the distance AB would decrease while the distance AE would increase, combined with an increase in the angle OAE. These effects would result in an increased equilibrium tidal height, as the horizontal tide generating forces shown in text-fig. 3 would be strengthened, provided the orbits of the tide inducing bodies remains unchanged.

Two hypotheses have been proposed which require an expansion of the earth. First, Halm (1935) suggested that the earth's original density was much higher than today's and, since the time of formation, the material constituting the earth has been expanding in volume and decreasing in density. Geological evidence in support of this hypothesis was given by



Text-fig. 12. The length of the day from fossil evidence, with some plots of the theoretical variation with various tidal friction models. (After Lamar and Merifield 1967) (With permission of the Geological Society of America).



limited eperic seas: wide continental shelves large Atlantic Ocean.	limited eperic seas with no Atlantic ocean: change (in Cretaceous) to widespread eperic seas bordered in part by narrow Atlantic Ocean	very extensive eperic seas adjacent to Pacific Ocean
Cenozoic	Mesozoic	Paleozoic

Text-fig. 13. The variation in the length of the synodic month. (Source: Pannella *et al.* (1968), with permission of *Science*. Copyright 1968 by the American Association for the Advancement of Science).

Table 6. Some non-catastrophic theories concerning the origin of the earth-moon system and the implications for paleotides

		Time ago (in Aeons)	Distance (in earth radii)	Tidal height (1)
GOLDREICH (1966)				
Formation of the moon by the accretion of many small satellites	...	1.5 (a)	10 - 30	150 - 5.0
MACDONALD (1966)				
(a) Captive in an extended prograde orbit	...	1.0	40 - 45	2.5 - 2.0
(b) Moon formed by accretion of 6 - 10 small satellites	...	1.1	40	2.5
GERSTENKORN (1967)				
Capture, without the aid of tidal friction in a prograde orbit	...	1.0 (2)	30 - 45	5.0 - 2.0
ALFVÉN and ARRHENIUS (1969)				
Protracted evolution of the orbit, as close approach prevented by resonating periods of orbit of moon with earth's rotation period	...	1.0 - 2.0 (2)	10+	less than 150

(1) Tidal height compared to today's equilibrium tidal height, which is taken as unity, the height in the past being determined by equation (5).

(2) Not given in paper in question, but estimated by author.

$$f = 5/16 + 11/(16r^3) \qquad (5)$$

f = tidal height in past

r = distance of tide inducing body from the earth, if today's distance is considered as unity.

Egyed (1956). If expansion had taken place, the length of the day would be increasing, and Holmes (1965, pp. 972-974) uses Wells' (1963) data on growth rings in corals, which suggests a 401 day Devonian year as support for the expanding earth model above. The work of Wells and others on growth banding in fossils is now considered as evidence in favour of tidal friction, and Halm's hypothesis has now been superseded by the second hypothesis in favour of earth expansion.

This second hypothesis is that previously examined under the heading "G - The Universal Gravitational Constant'. Any decrease in G would result in an expansion of the earth accompanied by a partially counterbalancing expansion in both the moon's orbit and the earth's orbit around the sun. But, as was noted in the above-mentioned section, Dicke (1962b) concludes that changes in G were too small for this effect to be noticeable in changing tidal heights. The question as to whether or not the earth is expanding is of no concern here. Even accepting that G is varying at the rate suggested by Wesson (1973), for instance, tidal heights are unaffected to the extent required for unambiguous recognition of this quantitative change in the geological record. This can be seen by comparing the tidal heights given in Tables 4 and 5. If variations in G led, in total, to increases in tidal heights of ten or one hundred times greater than those envisaged in Table 4, they would still be barely distinguishable from tides of today. This expansion would, however, produce a whole range of other effects on the rock record. Jordan (1971) has discussed these at length.

In conclusion, it can be seen that, of these theories which have been discussed with regard to their effects on tides, the one with the major effect is that related to tidal friction. The various theories on the origin of the earth-moon system involved a change in the height of the tides ranging from 2.0 to 11,300 times today's value. Although it would be impossible to detect changes at the lower end of this scale, it should be possible to put some constraints on these figures from geological evidence of paleotides.

Ancient Tidal Sediments

The preservation potential of tidal sediments is thought to be very low (Kukal, 1971, p.386). Despite this, numerous examples are known of tidal sediments preserved as rocks. Klein (1970c) states that at least 428 different rock exposures have yielded evidence of being of a tidal or intertidal origin. Here is not the place to discuss these in detail. The vast majority of them have features very similar to those found in the Wadden-type area today (Klein, 1967). The only two ancient counterparts of the Fundy-type area are the worldwide transgression of Cambrian shelf sediments on Pre-Cambrian crystalline rocks, and the shallow marine transgression of Upper Llandovery age in the Welsh borderland (Klein, 1964). A comparison of thirty-one ancient tidal deposits is given by Klein (1970b, his table 2). This great predominance of ancient tidal sediments of a similar type to the Wadden Sea type of today is borne out in the literature (Van Straaten, 1954a; Pannekoek, 1960; Klein, 1967 and Wunderlich, 1970)

The conclusion could be drawn that tidal sedimentation has remained virtually unchanged throughout time. But this may be an over-simplification as two alternative conclusions are possible. First, there exists today a very large spectrum of tidal intensities, evidenced by tidal range variations; this was probably true in former times (Table 8, p. 229), but a certain portion of the spectrum could have a high preservation potential while other parts are rarely preserved. Thus, even if the spectrum of tidal ranges changes, the type of sediments preserved may remain the same. The second alternative is that tidal sediments, which were laid down by exceptionally high tides, are preserved in the rocks record, but that a quantitative change in tidal height leads to a qualitative change in sedimentary features, and hence these deposits fail to be recognised for what they are.

The first possibility, by reason of its negative nature, is not open to discussion, but the second can be examined. The great predominance of quartzites in the early Paleozoic and late Pre-Cambrian could provide evidence of much greater scouring power at this time - the result of higher tides. Klein (1970a); Hargreaves (1970) and Swett *et al.* (1971) all consider these quartzites to be of tidal origin. The genesis of many mineralogically mature marine sandstones could be related to paleotidal processes, in that these sandstones, by being subjected to greatly enhanced scouring action, would rapidly attain maturity (Swett *et al.* 1971). Until recently no satisfactory mechanism was available, but now higher tides in late Pre-Cambrian or early Paleozoic times offer a solution. These quartzites are by no means limited to this part of the geological column, but what has been difficult to explain is their greater abundance at this particular time. Tidal scour is inversely proportional to the sixth power of the distance of the tide inducing body (MacDonald, 1964). So, if at this time the moon was only half as far away as now, the scour would be sixty-four times greater. It is probable that a smaller increase in scouring power than this would be sufficient to solve the quartzite problem.

Paleotides

Initial Research

The first workers to gueest, for geological reasons, that tides might have been higher in the past were Ball (1881) and Hull (1881). Ball's suggestion was that higher tides, owing to their enhanced erosion capacities, would explain the thicknesses of sediments in the Lower Paleozoic; while Hull considered higher tides, for a similar reason, would explain the unconformities at the base of the Cambrian, Devonian and Triassic - although the latter two unconformities are not considered today to be very conspicuous. Eckermann (1937) investigated the possibility of higher tides in the Pre-Cambrian, with inconclusive results.

Recent Work

Olson (1968, 1970, 1972) suggested a close approach of the moon to the earth at the end of the Pre-Cambrian, based on measurements of gravel thickness in the past, implying tides of up to three km. in range. This is illustrated in text-fig. 14, where it can be seen that the trend in conglomerate thickness reaches a peak about six or seven hundred million years ago. Olson, in his 1972 paper, moderates his value for tidal range in the late Pre-Cambrian to 100 m. These conglomerates, thought by Olson to represent tidal deposits in extremely fast currents of up to fifty $m. sec^{-1}$, have in many cases been described as tillites or tilloids. A tillite deposit is thought of as a deposit of definite glacial origin, whereas a tilloid is a deposit of unknown or questionable origin closely resembling a till.

Schermerhorn and Stanton (1963) give a good example of a late Pre-Cambrian conglomerate in a paper re-interpreting a supposed tillite deposit in the West Congo geosyncline as a tilloid submarine mudflow deposit, but much of their evidence would lend itself to an interpretation along the lines Olson envisages. This would necessitate a re-examination of evidence for a worldwide late Pre-Cambrian glaciation.

One of Olson's other suggestions is that the close approach of the moon would explain the Lipalian interval, an interval immediately preceding the Cambrian which is supposedly missing throughout the world in the geological record. Cloud (1968a) criticised this work for a number of reasons, while Munk (1968) dismissed it by recording that the Lipalian interval has now been bridged in a large number of areas. Olson's papers are the only ones which postulate tidal ranges of anything near the height required for a lunar approach along the lines the tidal friction model gives, but at the moment Olson's work has little support.

Cloud (1968b) suggested that paleotidal heights were around five or six metres in the early Pre-Cambrian. Table 7 shows an updated version of Cloud's results, which were based on stromatolites, domed sedimentary structures of algal origin.

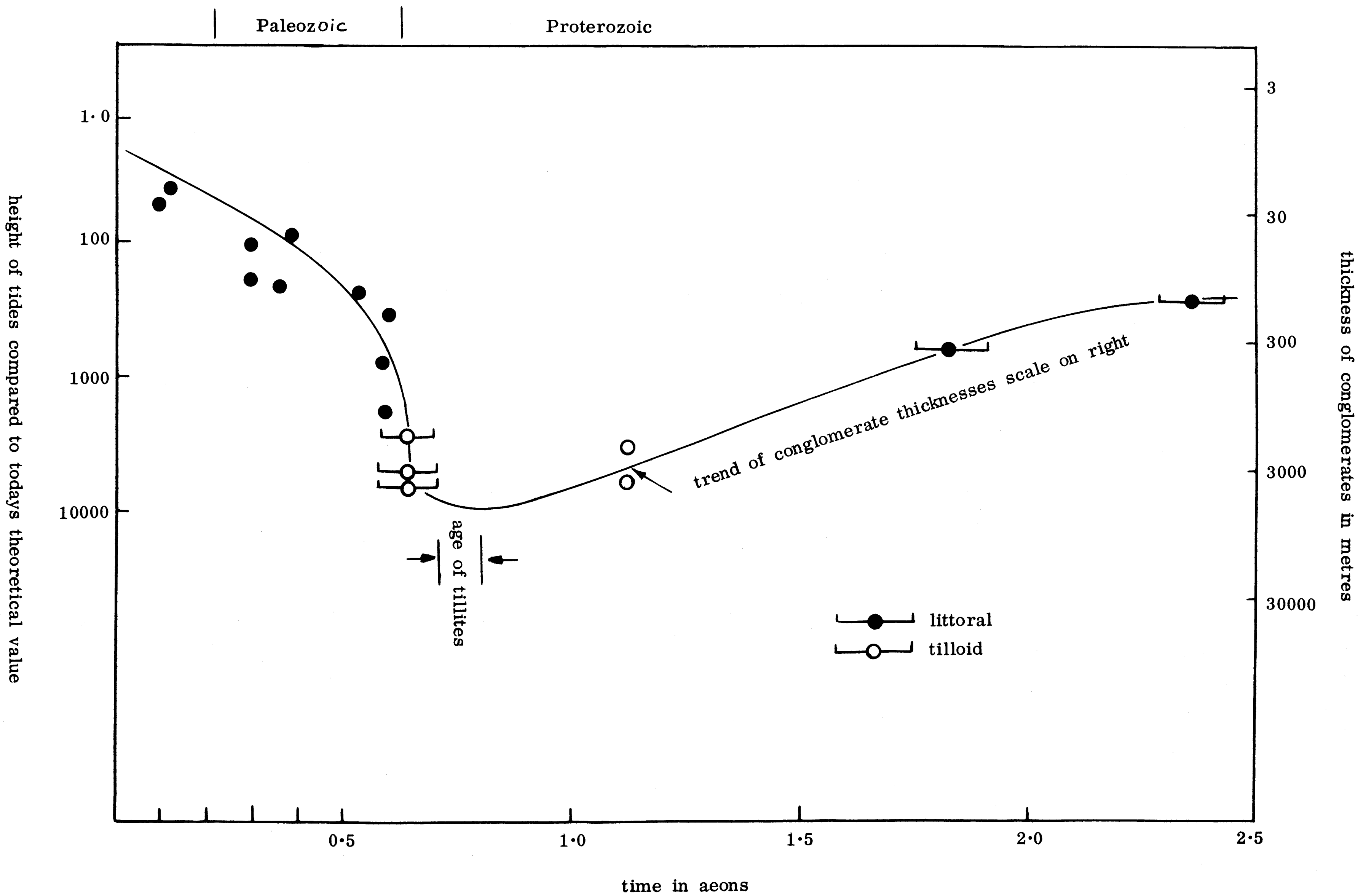
Table 7 Maximum stromatolite heights in the past (after Cloud (1968a)

Age (aeons)		Height (metres)
0.0		0.7
0.5 - 1.1	(1)	6.0
Older than 1.1		5.0
1.5 - 1.7		2.5 - 3.00
Older than 2.0		2.5 - 3.00
1.95 - 2.3	(2)	0.1 - 0.4
Older than 2.7	(3)	0.04 - 0.6

(1) This result comes from the Otavi Series which Cloud (1968b) dates as Proterozoic. Alfvén and Arrhenius (1969) give the age quoted.

(2) Additional result from Button (1971)

(3) Additional result for which Engel et al. (1968) give a figure for the height of 0.04 m, while Walter (1970) disagrees, giving a value of 0.6 m.



Text-fig. 14. Tidal heights in the past, from conglomerate thickness after Olson (1970), his figure 3. Reprinted with permission of the New York Academy of Sciences.

Both Cloud and Kukal (1971, p. 63) assume stromatolites to be intertidal. Caution is needed in the interpretation of Cloud's results for although he claims they are obtained from areas of stromatolites too great to be due to local exceptionally high tides, other objections arise. Walker (1970) argued that stromatolites are sub-tidal and further, he reports a stromatolite fifteen metres high in the Middle Cambrian from near Lake Baikal in Russia. If the specimen is not exceptional, the postulated tidal height should be corroborated in the Cambrian from other sources.

Another problem with using maximum stromatolite heights as a measure of tidal range is that some of these results could be spurious as the area the specimens came from could have been a submergent coastline, which would indicate anomalously high tides. Evidence of English stromatolites on submergent coastlines has been reported by Dr. M. R. Leeder (personal communication). Cloud's results seem therefore to be of use only as a broad guideline, since the criticisms above and the wide spectrum of tidal ranges found today suggest that the fine variations shown by Cloud should not now be taken too literally.

Klein (1972a) has reported some preliminary results of paleotidal ranges, obtained by using the model he published in 1971; these are given in Table 8 :

Table 8 Paleotidal Ranges (after Klein, 1972a)

	Range (in metres)
Late Pre-Cambrian	0.3 - 13.0
Cambrian	1.1 - 7.9
Silurian	3.3 - 6.1
Devonian	1.0 - 8.9
Jurassic	0.8 - 4.1
Holocene (Today)	0.0 - 17.0

The table was based on 428 samples, whose time-stratigraphical distribution was correlated with the length of time represented by various geological periods, i.e. the proportion of samples in any particular period was proportional to the length of the period and nothing else. This suggests that tidal sedimentation has existed since earliest Pre-Cambrian times, 3.2 aeons ago (Klein, 1970c) as this is as far back the sampling went. The results in Table 8 show that tidal range has changed little, if at all, over the period investigated, although Klein does consider that the results show a narrower spectrum of tidal ranges in the past than today (written communication).

Klein's model is illustrated in text-fig. 7 (p. 213). A fining-upward sequence, in prograding tidal-flat deposits, contains a record of tidal range at the time of deposition. The position of the mean low tide is considered to be represented by the sandstone member of the sequence and is found at the contact between sandstones showing features indicative of bedload transport only, and those indicating a combination of bedload transport and late stage emergence run-off features. The mean high water mark is the contact of the sandstones with the overlying tidal marsh. The vertical distance between these two is the mean tidal range. As sandstones compact little, later burial by other sediments should not greatly alter this vertical distance. Olson (1972) and Klein (1972b) discuss this at length.

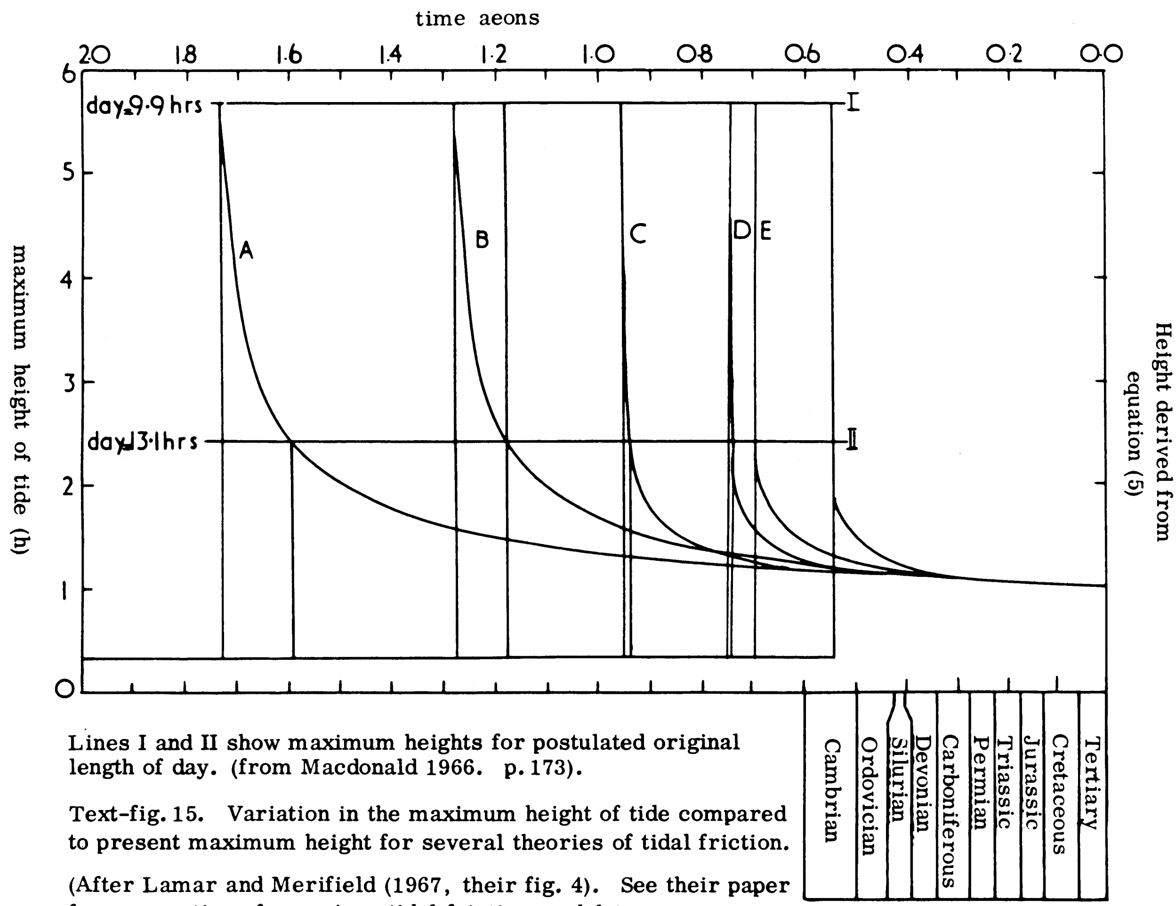
Tides higher than those found today have been postulated as occurring around the end of the Pre-Cambrian (Lamar and Merifield, 1967; Merifield and Lamar, 1968, 1970). In the first of these papers the suggestion is made that the evolution of hard shelled organisms in the Cambrian was a response to the sudden onset of strong tidal currents and exposure at low tide, caused by lunar capture. Text-fig. 15 shows the variation of tidal height with time deduced. The data in the 1967 paper has been slightly modified by Lamar *et al.* 1970.

Support for the idea of higher tides in former times is given by Oparin (1952, p. 98) who suggested that tremendous bodily tides in the Archean caused very deep seated rocks to be erupted, and Trechmann (1955) who suggested that mountain building was linked with lunar gravitation.

The next steps

Klein (1971) has supplied a model for clastic paleotidal ranges, and recently a model has been proposed for carbonate paleotidal ranges. Ginsburg *et al.* (1970) have reported that a zonation of carbonate intertidal areas can be obtained on the basis of organisms, textures, structures and stromatolite morphology. This zonation is linked to the percentage of the year which an area is exposed to the atmosphere, with ninety per cent exposure being considered the high water mark and fifteen per cent the low water mark. Thus, in prograding carbonate intertidal areas, a vertical succession is produced, which like the model for clastic intertidal areas, contains a measure of the tidal range at the time of deposition.

Another approach which offers some hope for the determination of paleotide ranges



Lines I and II show maximum heights for postulated original length of day. (from Macdonald 1966. p. 173).

Text-fig. 15. Variation in the maximum height of tide compared to present maximum height for several theories of tidal friction.

(After Lamar and Merifield (1967, their fig. 4). See their paper for assumptions for various tidal friction models).

(with permission of The Geological Society of America) is by the inspection of growth rings in fossils. Tidal rhythm cycles have been reported by a number of scientists. Barker (1964) identifies five cyclic groupings of growth layers in molluscs, three of which were said to be tidal. These are shown in Table 9:

Table 9 The various rhythms in mollusc growth rings (based on Barker, 1964)

Order	Environmental periodicity reflected
First	Annual changes in temperature and salinity
Second	Equinoctial tides and storms
Third	Fortnightly tidal cycle
Fourth	Day and night
Fifth	Daily tidal rhythm

The work on the periodicities exhibited in the shells of the various fossil phyla can be paralleled by similar studies on stromatolites, which show a characteristic lamination in cross-section (Kukal, 1971, pp. 62-63). In recent forms the laminae consist of either consolidated layers, or fine and coarse alternating layers, indicating a periodicity control. Pannella (1972) claims that monthly tidal growth patterns are recorded in fossil stromatolites as old as 2.2 aeons, indicating that the earth-moon system has been in existence at least since the early Proterozoic. Pannella's results at a more detailed level were inconclusive but the hope remains that stromatolites could become important tools in geochronometry.

This method does have difficulties associated with it. Stromatolites apart, the technique is confined to the Phanerozoic, whilst tides are not quite as beautifully periodic as first imagined (text-fig. 5, p. 209) and mixed tidal areas or an eccentric lunar orbit might yield anomalous results. Finally, in all this work, the length of the year is used as a frame of reference for lower order periodicities and considered implicitly to be constant, whereas it is likely that tidal friction between the earth and the sun is slowly lengthening the year.

Summary and conclusions

The first few sections of this paper are simply reviews of present knowledge in a number of areas associated with the geology of tides. It is only when paleotides and the history of the earth-moon system are considered that the paper departs from being simply a review. This latter section has been approached very much as Rubey (1951) approached his work on the geological history of sea-water. It is primarily intended here to ask the questions, while trying to put some constraints on the answers. The lack of research in the field of paleotides, and the complex interactions between scientific disciplines which are rarely considered in conjunction, means that the conclusions reached should be treated with a degree of scepticism perhaps not normally associated with geological work.

Bearing in mind the above caveat, it can be said that tidal sediments today are sufficiently well documented for their identification in the geological column to be possible with a reasonable degree of certainty. Little is known in quantitative terms of the tides which produced them. The possibility arises that not all past tidal sediments are recognised for what they are, as quantitative changes in tidal range have led to qualitative changes in sedimentary structures, due to enhanced current velocities. Olson's work (1970) suggests that tilloid deposits of great age may be of tidal origin. Experiments with flume tanks using very high flow velocities might support Olson's hypothesis, or could lead to the formation of other sedimentary structures which could be looked for in both the literature and sedimentary rocks.

The research work which has been done, results in two apparently incompatible results being obtained. The geologists, apart from Olson, suggest that although tidal heights in the past were apparently higher at times than those of today, this was only by a factor of two or so, whereas many of the astronomers' theories require tidal heights four orders of magnitude greater than those of today.

If the evidence of the geologists is accepted, no close approach of the moon can have occurred within the last three aeons, but the theory of tidal friction demands that a close approach to the earth should have happened within the last two aeons. It therefore seems that the moon cannot have been in orbit round the earth since early in earth history, implying that the earth-moon system must have had a non-catastrophic origin along the lines of one of the theories proposed in Table 6, (p. 225).

Three basic theories of non-catastrophic lunar origin late in earth history have been postulated. Firstly, an aggregation of a number of smaller satellites over a period of time as proposed by Goldreich (1966) and Alfvén and Arrhenius (1972). This aggregation would imply some lunar rocks with ages around the time of supposed aggregation, but Mason and Melson (1970, pp. 76-77) report only ages between 2.7 and 4.4 aeons, while Tera *et al.* (1974) fix the date of the moon's terminal cataclysm around 3.9 aeons. Therefore aggregation is excluded as a viable theory on the same grounds as the above. If the moon was formed by aggregation more than two aeons ago in orbit round the earth, it must have endured a close approach to the earth, for which there is no evidence.

The second theory - capture at a distance - has been criticised on many grounds by both Goldreich (1966) and Gerstenkorn (1967), whilst a third theory (Alvén and Arrhenius, 1969) suffers from a complete lack of theoretical and observational backing.

If, instead of accepting the evidence of the geologists, that of the astronomers is preferred, the consequences are that evidence of tremendous tides should exist and needs to be found; but more importantly, one of the philosophical groundrules of geology has been violated. The Lyellian version of uniformitarianism states that geological processes have always proceeded at the same rate as those observable today. This will no longer be true and a great deal of geological work will have to be re-evaluated.

One way out of these difficulties is to attempt to solve the time-scale problem which lies behind all the difficulties, as then both geological and astronomical theories are congruent. The time-scale problem can be solved by postulating that the radioactivity decay constants are dependent on the age of the universe. Dicke (1959) suggested a similar relationship but only for the beta-decay constant, while the alpha-decay constant was invariant. Kanasewich and Savage (1969) attempted to test this hypothesis of Dicke but found no evidence in its favour. However, should both constants vary at the same rate, the techniques used by Kanasewich and Savage would not have been capable of detecting the change.

If, in fact, the two constants vary in unison, catastrophical theories of the evolution of the lunar orbit can be revived but the implications for the scientific world would be traumatic. The evidence to support the assertion that the radioactive decay constants may vary with the age of the universe is that sedimentation rates throughout the geological column increase the closer to the present day that they are measured. Kay (1955) gives the following figures: sedimentation rate from Cambrian to today is average of 0.004 mm $year^{-1}$, while the sedimentation rate for the last million years is 0.3 - 0.4 mm $year^{-1}$. Holmes (1965, p. 227) also gives the theory some support when he gives figures of movement rate along the San Andreas fault since the late Jurassic. At that time the rate of movement was 1.20 km per million years, whereas the rate today is 16.0 km per million years.

If it is assumed that sedimentation rates and movements along the San Andreas fault have been approximately constant throughout geological history, then time was apparently passing faster than today in earlier epochs, on the basis of radioactive dating, suggesting a slowing of decay rates with time.

This paper does reveal that geologists and astronomers need to co-operate more closely in the future in order to give each other a sense of perspective. Today the two disciplines seem to be at an impasse with respect to each other, a situation which bodes ill for both. How this impasse is going to be overcome is not clear at the moment but cracks are appearing in the facade of scientific unity, and pressure seems to be building up which may shatter asunder both geology and astronomy. The ad hoc nature at the moment of theories of lunar origin, such as those of Singer (1972) and Alfvén and Arrhenius (1972), involving chains of interlocking coincidences of extremely low probability, are reminiscent of astronomical work in the pre-Keplerian age when more and more epicycles were continually added to an already over-ponderous astronomical world view. If Kuhn's (1970) vision of how science moves is correct, geology and astronomy may need a revolution.

Tides may seem to have been forgotten, but the above discussion should illustrate how important the study of the tides of antiquity could be to geology and other sciences.

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WEEKEND EXCURSION TO THE LLANGOLLEN AREA

Leader: Dr. F.M. Taylor — 11th - 13th May 1973

The party travelled independently to Llangollen, booking in at the Eirianfa Hotel. On the Friday evening, after dinner, the leader gave a brief outline of the geology of the area visited, including, with the aid of maps, the regional geology of the Llangollen area. The town is situated almost in the centre of a Lower Palaeozoic syncline (Wills 1920, 1922) the axis of which trends east - west, approximately along the line of the River Dee. To the east, Carboniferous rocks overly the older strata with marked unconformity or faulted contacts (Wedd *et al.* 1927). The Saturday excursion was centred on the Horse-shoe Pass examining the northern limb of the syncline, whilst the Sunday excursion was mainly concerned with the Carboniferous rocks but would also complete the study of the Lower Palaeozoic rocks north of Llangollen.

The following sequence of Carboniferous, Silurian and Ordovician rocks was seen during the week-end:

Upper Carboniferous	Coal Measures	Chwarelau Coal and associated rocks
	Cefn-y-Fedw Sandstones	Aqueduct Grit Upper Shales Dee Bridge Sandstone Lower Shale Middle Sandstone Cherty Shale Lower Sandstone and Conglomerate
Lower Carboniferous	Carboniferous Limestone	Sandy Limestone Upper Grey Limestones White Limestones Lower Grey and Brown Limestones
Carboniferous or Devonian		Basement Beds
	- Unconformity -	
Silurian	Ludlow	Dinas Bran Beds Vivod Beds Nant-y-Bache Beds Glyndyfrwdwy Beds
	Wenlock	Moel-y-Faen Slates
	Valentian (Llandovery)	Mudstones and siltstones Green-grey and maroon slates
Ordovician	Bala	Plas Uchaf Grit Cyrn-y-Brain Beds

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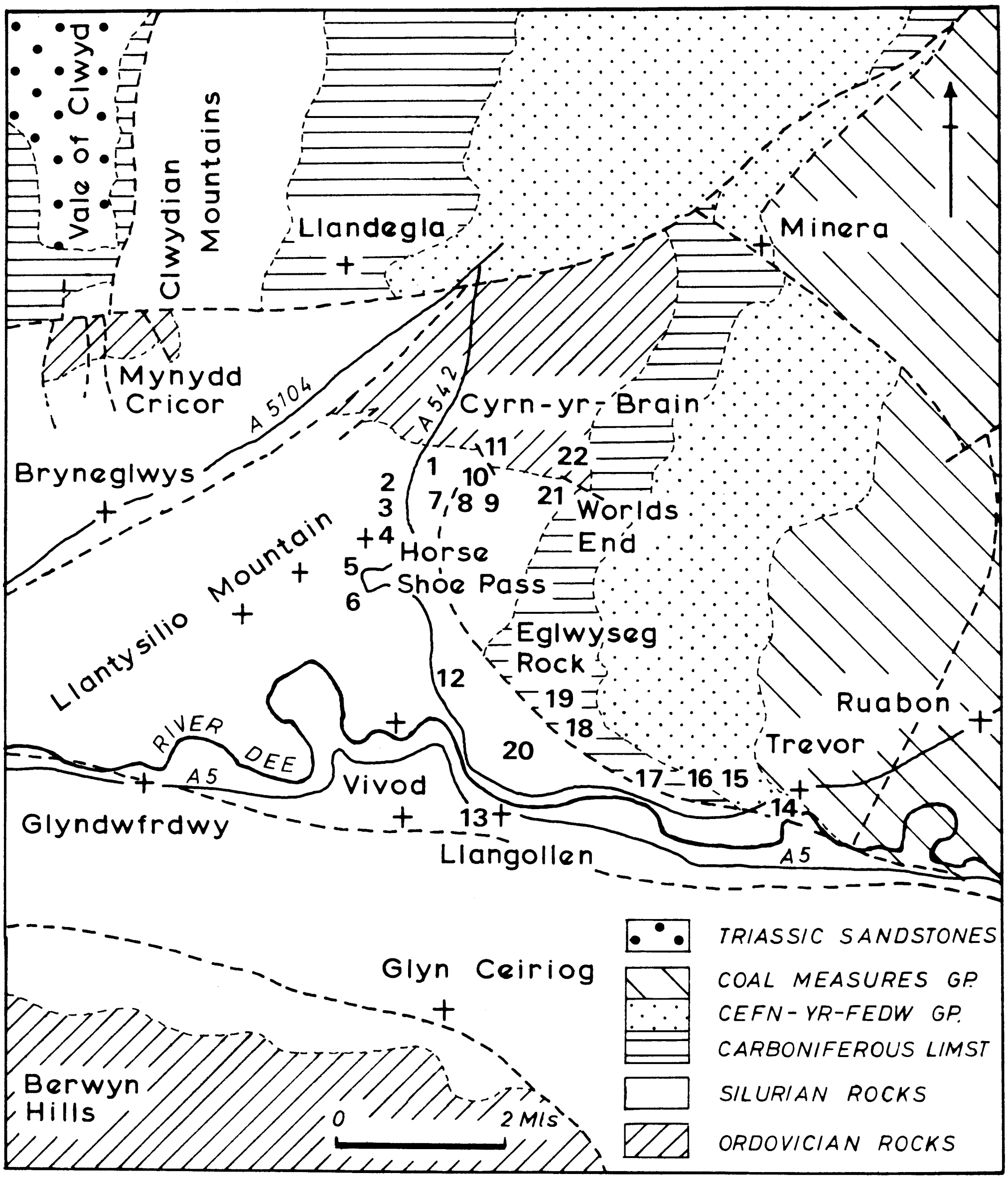
pp. 241-247. 1 text-fig.



Text-fig. 1. Outline geology of the Llangollen area. Numbers 1-22, refer to the localities visited.

Text-fig. 1 illustrates the outline geology of the area and the localities visited are numbered 1 - 22. The oldest rocks outcrop on Cyrn-y-Brain. From this mountain southwards to Llangollen, successively younger Silurian rocks are encountered all striking approximately east - west. The Carboniferous rocks, striking north - south, overly the Lower Palaeozoic strata unconformably in the east. The Aqueduct Fault forms the junction to the south-east and south.

The geology and outcrop pattern of the northern part of the Llangollen syncline is complicated by intense folding. Regional metamorphism has changed the mudstones and shales to slates but in the sandstones and siltstones, cleavage is much more variably developed, having little effect on the sandstones. There are no igneous rocks exposed in the area visited. Mineral veins occur in many places, with lead, zinc and calcite minerals in the Carboniferous Limestone and a quartz-copper mineralisation in the Silurian rocks.

Saturday, 12th May

1. Horse-shoe Pass

From Llangollen, the party travelled from the hotel by car northwards to the summit of the Horse-shoe Pass (SJ 193481) where other Members of the Society joined the excursion. A short walk further north brought Members to the southern slopes of Cryn-y-Brain immediately west of Tai-Newyddion, where in old excavation (SJ 192488) (1) the lowest Silurian rocks were examined. They are poorly cleaved silty mudstones, medium grey in colour and a number of brachiopods were obtained from one of the excavations. From this point, looking generally in a southerly direction the slopes of Moel-y-Faen can be seen with excavations in the slate belt aligned east - west. In front of the quarries (to the north) are the very extensive tips of the inferior slate material.

2. At Hafod-yr-Abbot (SJ 187486) blueish grey and blueish black cleaved mudstones where examined to locate Llandovery graptolites (*Monograptus crenulatus*), at the locality recorded by Wills. On this occasion only small fragments, broken by the cleavage, were recovered.

3. Moel-y-Faen. The party then climbed the northern flank of Moel-y-Faen skirting round the tips and then ascended the steep incline into the quarries (SJ 188477), situated below the summit of the mountain. A number of excavations were visited allowing detailed examination of the lithology and the structure. In the passage-ways leading into the main quarries hard beds of sandstone interbedded with the slate indicated the dip of the beds. The amount varied from almost vertical where the beds were slightly overturned to gentle, where the beds were the correct way-up. Quartz veining, also involved in small intense folds, occurred throughout. The best Moel-y-Faen slates are dark blue in colour and of the local slates, the best quality were obtained from these quarries and mines. The variable quality of the slates is indicated by the size of the tips.

4. Despite the cold wind and overcast sky, most Members continued to the summit of Moel-y-Faen (SJ 185475) for the view. Once on the top, 1510 ft., it could be seen that the summit is situated at the north-eastern end of a ridge - Llantysilio Mountain - extending south-westwards including the high points of Moel-y-Gamelin (SJ 176463) and Moel Morfydd (SJ 166458), both at about 1, 800 ft. Llantysilio Mountain is composed of various parts of the Wenlock and Ludlow sequence. To the north, lies the broad Bryneglwys Valley extending south-eastwards to Corwen. Further north are the rounded hills of the Clwydian Range and the Ordovician inlier of Mynydd Cricor. Visibility did not allow a view of the North Wales coast or, in a westerly direction, the Snowdon Range of mountains. To the north-east, across the Ruthin road, the position of Ordovician rocks is marked by the television mast on Cyrn-y-Brain. Eastwards the Carboniferous Limestone escarpment of Eglwyseg Mountain formed of grey rocks with scree deposits, could be clearly seen and a little to the south the isolated hill of Dinas Bran indicates the position of the highest Ludlow rocks. Still looking south, the present course and the abandoned incised meanders of the River Dee were pointed out. Further south, the sky-line is made up of rocks representing the southern limb of the Llangollen syncline extending to the west and the Berwyn Hills.

5. Oernant Slate Quarries. The summit party, then descended rapidly to the disused slate quarries on the south side of Moel-y-Faen, at Oernant (SJ 183470) to examine the Pentre Dwr Slates. They are grey in colour and as this slate band was more variable in lithology and of poorer quality than that of Moel-y-Faen there was less exploitation and the excavations are smaller. The trend of the quarries is parallel to those of Moel-y-Faen indicating that the fold axes are parallel with the strike of the beds. The presence of small scale folding can be seen in the more westerly of the Oernant Quarries where shallow southerly dips are followed by steep dips to the north.

6. Clogau Quarry. Continuing further south along an old tramway and up a steep incline, the old slab quarry on Clogau was next visited (SJ 185464). The rocks at this locality are a sequence of rapidly alternating thinly bedded siltstones and mudstones. The siltstones have generally resisted cleavage which has changed the mudstones to slates. The dip of the beds and the cleavage in the main quarry are steep and almost parallel. In the passage leading into the quarry variation in dip can be detected by coarser beds indicating the presence of small folds. Rock creep has affected the top section of the north quarry face. In the main quarry, some of the exposed bedding surfaces are covered with *Orthoceras*, somewhat distorted by the cleavage; other surfaces are covered with small concretions. The quarry used to specialise in the production of large slabs of slate used for billiard table tops, stone cisterns, boundary and walling stones.

7 - 9 South side of Cryn-y-Brain. The party returned briefly to the car park at the top of the Horse-Shoe Pass and then took the footpath to Bryn-yr-Odin (SJ 201481) (7). On either side of this footpath exposures of pale grey, green-grey, and purple slates were examined. The slates seem to be cut by two cleavage planes set at an angle to produce blocky fragments. Small orthid brachiopods were found in the green-grey bands. Attempts were made to trace some of the purple bands for short distance up the steep slopes, for with the absence of coarser beds in this part of the sequence, the colour changes were the only clue to the bedding. Maps produced by L.J. Wills show that the distribution of the purple slates illustrates folds in the strata and that they fit into the general structural pattern determined elsewhere on more reliable evidence. The track towards Caer Hafod (8) allowed the party to examine the varied lithologies that occur between the purple slates and the blue slates at Pant Glas Quarry (SJ 214476) (9), the lateral equivalent of the Moel-y-Faen Slates. The quartz veining seen previously was again noted and as at the Moel-y-Faen quarries, the veins were folded.

10 - 11 Cryn-y-Brain. A route was next projected that would eventually reach the summit of Cryn-y-Brain, the northerly traverse descending the sequence. A number of steep valleys were crossed, in one of which, a band of purple slates within the green-grey slates could clearly be seen at outcrop and in scree debris. After crossing a flat marshy area, outcrops of siltstones situated above the Plas Uchaf Grit were examined in the rising ground towards the television mast. Finally close to the mast blocks of the typical white coarse sandstone, the Plas Uchaf Grit, were discovered at about the right outcrop point but none were thought to be in place.

From the view point (10), the terrain described previously from Moel-y-Faen was again observed.

The return journey to the cars was made along the track from the T.V. relay station to the Horse-Shoe Pass. In an old cutting (SJ 200483) (11) adjacent to the track a few feet of black graptolitic slates were exposed interbedded with dark grey silty slates. The horizon has yielded *Monograptus crenulatus* but the blocky slate fragments rarely produce good specimens. On this occasion fossil collecting was made difficult by the gale force freezing wind blowing through the cutting.

12. Valle Crucis Abbey. From the car park, the party returned to the Eirianfa Hotel noting on the way the coarser sandstones and siltstones of the younger Ludlow rocks, particularly at the old quarry near Valle Crucis Abbey (SJ 202445). The Abbey is situated in an old abandoned incised meander of the River Dee.

Sunday, 13th May 1973

13. Llangollen. A visit was made to the rocks exposed in the bed of the River Dee at Llangollen, 200 yds. west of the town bridge (SJ 214421). The coarse greywackes are thickly bedded and are more or less horizontal forming the upper part of the Vivod Beds in the centre of the Llangollen Syncline.

14. Trevor. From Llangollen, the cars were driven along the Ruabon road to Trevor for the commencement of the study of the Carboniferous rocks. At the works of Roberts and MacGinnis (SJ 265426), part of the Millstone Grit and Lower Coal Measures strata are exposed. The Aqueduct Grit was first examined on the western side of the site. About 40 feet of coarse felspathic sandstone, with occasional pebbly layers were exposed in the quarry. Members of the excursion felt quite at home in dealing with this rock and comparing it with Millstone Grit exposures of Derbyshire.

Moving round to the east side of the site some of the higher beds of the Aqueduct Grit could be seen and the lowest members of the Coal Measures. The entrance to the Ganister Mine (Wills 1922, now closed) was seen and the rocks exposed here and in the adjacent face were examined. The following sequence was established:

Sandstone

Clays and siltstones

Coal, 18 inches ? Chwarelau Coal

Ganister - the original material for the works

Sandstone

Plant fossils were obtained from most of the horizons including the upper sandstone.

In a stock pile behind the works, the present stocks of ganister, eventually to be crushed and used as the raw material for the manufacture of refactory bricks, had been obtained from quarries well to the north of the works.

Garth. From the Brick Works, the cars followed the minor road to Garth and then an even narrower road in a westerly direction towards the 'Panorama Walk'. On the way, exposures and escarpments formed by the Middle Sandstones could be seen. The sandstones are similar in lithology to the Aqueduct Grit. One of them is the source of the stone for the famous Pont Cysyllte Aqueduct.

15-17 Panorama Walk. Rocks below the Middle Sandstones were next examined in old quarries (SK 248429) (15) about 800 yards west of Garth. The quarries are mainly in cherty mudstones but exposures of the overlying and underlying sandstones were seen. The cherty rocks are a rather unique type of lithology, resembling a very fine-grained, well bedded ganister. The party moved westwards to the main escarpment (16) formed by the Lower Sandstones and Conglomerates, above the Carboniferous Limestone. The sandstones are very coarse with large white quartzite pebbles. The effect of the Aqueduct Fault cutting across successive escarpments of limestones and sandstones was demonstrated.

Continuing westwards along the Panorama Walk, the top beds of the Sandy Limestone were next examined (SJ 241429) (17). The structure exhibited by one of the rock faces immediately drew attention. At first glance, the structure was an apparent unconformity with horizontal beds cutting across others dipping at 45°. As there was no satisfactory explanation for this phenomena on the regional scale, an explanation was sought in conjunction with the Aqueduct Fault, indicating movement along the fault during deposition of the Sandy Limestone. Finally the previous explanation (Wedd *et al.* 1927) was put to the party that these were giant cross-bedded units. The exposed part of the cross-bedded unit is almost 6 feet in height a scale outside the experience of those present. The explanation was eventually reluctantly accepted. Lunch was then taken during a heavy rain period.

18-19 Trevor Rocks. The afternoon commenced still 'in the wet' but with the promise that the rain would show up the corals in the Carboniferous Limestone to perfection. Sure enough, at the old quarries towards the top of an old incline, (SJ 234433) (18), the coral beds were quickly located. Various species of *Lithostrotion*, *Lonsdaleia*, and *Palaeosmilia* were seen with occasional specimens of *Dibunophyllum*. Gigantoproductids, other productids and spirifers were amongst the brachiopods noted. Extensive collections of corals and brachiopods were possible not only in this quarry but in the succeeding continuous exposures towards the Eglwseg Rocks. A route was taken, mainly along an old tramway which allowed a gradually descending sequence to be looked at, through the White Limestones to the Lower Grey and Brown Limestones. At one point (SJ 228434) (19) close to the base of the White Limestone, possibly in the Grey Limestones a bed of red, yellow, and brown shales dipping at 45° at the outer edge of the tramway evoked a certain amount of discussion. Limestone could be seen below the exposure of the shales in the lower part of the escarpment and a bed of shale could be seen higher in the cliff face. It was eventually concluded that a slip had taken place, either along a joint or possibly a fault parallel with the Aqueduct Fault which is quite close to the escarpment at this point. The idea, that the steep dip was the result of drag against the fault plane of the Aqueduct Fault, was made and on the evidence available at the time, could not be disproved. The party continued along the tramway until a point was reached opposite Castel Dinas Bran.

20. Castel Dinas Bran. Some encouragement was then necessary to attempt the precipitous descent to the base of the escarpment, the crossing of the fault hollow eroded along the Aqueduct Fault and the equally precipitous ascent to the summit of Castel Dinas Bran (SJ 222431). The point about the erosion along the fault hollow having been made, the highest Ludlow Beds in the Llangollen area were then examined. *Saetograptus* (*Monograptus*) *lientwardinensis* has been recorded from these beds along with other fossils (Wills 1927) but little was obtained on this occasion. From the top, there were excellent views, the rain having cleared away, across the Vale of Llangollen and the old river valleys of the Dee, abandoned as a result of ice blockage during the Pleistocene and water finding a new outlet and eventually eroding a valley to a lower level than previously. Northwards, the ground walked over on the previous day could be seen and the magnificant escarpment of the Carboniferous Limestone continuing northwards in great arcs towards Worlds End.

Returning to the cars, red soils and blocks of red sandstones and breccias were pointed out at the foot of the limestone escarpment (SJ 226432) and the brown limestones, occurring above the red beds were available for study at a number of places.

21-22 Worlds End. (SJ 233478) Along the very narrow road to Plas Uchaf and Worlds End, there are continuous views of the Carboniferous Limestone escarpment. Just off the road, beyond Plas Uchaf, in the stream below the limestone, grey-green mudstones (Llandovery) are exposed. The Carboniferous Limestone outcrops a few feet above in the hillside. At Worlds End, a footpath leads up through a small valley eroded along a fault, which can be seen in a number of places as a result of small mining excavations and intense calcite veining.

Further along the narrow road to Minera, a few forestry road, on the left has been cut across the Nant Craig-y-moch and westwards towards Fron Lŵyd. This road cuts through the highest part of the Cyrn-y-Brain Beds, below the Plas Uchaf Grit. The beds are calcareous and fossiliferous with corals, trilobites and brachiopods. The rocks were examined by the party in the same stream section but above the forestry limit (SJ 230485) (22) in somewhat older strata but similar fossils were obtained indicating the Upper Ordovician age of the group. The excursion was declared closed when the third cephalon of *Platycalymene* was disclosed.

After a vote of thanks to the leader, the party dispersed some to explore the old mine tips at Minera and others returning to Llangollen.

References

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FIELD MEETING IN SHROPSHIRE

Leader: I.D. Sutton. Sunday, 3 June 1973

The excursion here reported (by the leader) was the second East Midlands Geological Society excursion to Shropshire. Previously a week-end excursion took place in May 1969. [Sutton and Sarjeant 1970].

The journey to Shropshire was one of sunshine and showers but approaching Much Wenlock the skies cleared and the day promised to be kind to the party. The main purpose of this visit was to examine the Upper Ordovician and Silurian fossiliferous shelf facies in the area from the Wrekin to south of Church Stretton.

The first stop was made at Shadwell Quarry (SJ 626007) just outside Much Wenlock. This quarry was visited on the previous excursion but since then a great deal of quarrying has taken place. A wide variety of fossils were obtained including the tabulate corals *Favosites* sps, *Heliolites* sps, *Halysites* sps, *Thecia swinderniana*; the rugose corals *Kodonophyllum* sp, *Phaulactis* sp, *Acervularia* sp, the brachiopods, *Atrypa reticularis*, *Camarotoechia nucula*, *Leptaena rhomboidalis*, *Rhipidomella* sp. and *Plectodonta* sp. In addition stromatoporoids, gastropods, bryozoans and crinoids were also abundant. The lithological variation of the limestone was shown very well in the quarry faces with thin bedded argillaceous limestones, massive bedded purer limestones and also the small reef structures known locally in Shropshire as "Ballstones".

After lunch in Much Wenlock the party took the Ludlow road out of Much Wenlock crossing over the Aymestry Limestone which could be seen well separated from the Wenlock Limestone. In Corve Dale are a large number of exposures in the Upper Ludlow and two were visited by the party.

The first was a small quarry behind the school at Brockton (SO 578939) where the typical brachiopod fauna of *Camarotoechia nucula* and *Protochonetes ludloviensis* was well displayed with additional lingulids and orthoceratid nautiloid fragments. These fossils were found in a lithology of siltstones with coarser sandstone bands and where the brachiopods were abundant they were responsible for the development of thin limestone bands.

Further along the Ludlow Road a second exposure of the Upper Ludlovian near Broadstone Farm (SO 543898) was looked at quickly. This was a small roadside exposure which exhibited a very similar fauna to that at Brockton.

From here the party travelled to Craven Arms and then along the main A49 road northwards towards Church Stretton where two exposures in the Upper Ordovician (Caradocian) sequence were visited. The first was in a small roadside cutting near to Marshbrook (SO 442898). Here the Cheney Longville Flags yielded typical Upper Ordovician trilobites, brachiopods, crinoids and tentaculites.

The Harnage Shales are exposed on the south side of Ragleth Hill SO 446915) resting uncomfortably on the Pre-Cambrian. The fauna in the shales was rather sparse but the nature of the relationship with the underlying rocks and structures within the shales themselves provoked some discussion.

The ensuing journey from Ragleth Hill to Church Stretton and then to Much Wenlock took us through some delightful country. Initially with the Longmynd to the west and the volcanic hills of Caer Caradoc and its neighbours on our east, and then the journey along Wenlock Edge was in conditions suitable to show us the full glory of the limestone escarpment and the relationship of the topography to the south easterly dipping Silurian Strata.

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pp. 249-250.

The last stop of the day, after negotiating many diversions due to road works was made at Maddock's Hill Quarry on the Wrekin (SJ 645087) where an intrusion of camptonite into the Tremadocian Shineton Shales can be seen. Time was rapidly running out and in the limited amount available members were able to collect specimens of *Dictyonema* sp. from the shales together with one complete but unidentified trilobite, and quickly look at the intrusion.

The return journey to Nottingham was uneventful and everyone returned dry and refreshed at least by the Salopian air.

On a one day excursion of this nature a considerable amount of time is taken in travelling and really to make the trip worthwhile and allow suitable time to be spent at the various exposures an earlier start would be a great advantage.

Reference

SUTTON, I.D., and SARJEANT, W.A.S. Week-end excursion to Shropshire. *Mercian Geol.* vol. 3, no.3, pp. 291-303.

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FIELD MEETING IN CHARNWOOD FOREST

Leader: A.M. Evans

Sunday, 1 July 1973

Introduction

This upland area of considerable scenic interest has long attracted geologists with its wide variety of pyroclastic, igneous and sedimentary rock-types. These ancient rocks were designated as the Charnian System by Lapworth, Watts and Harrison in 1898 and their Pre-Cambrian age has been generally accepted for many decades. It was not until 1963 however that this age was confirmed by Meneisy and Miller (1963) who obtained radiometric ages indicating that some of the igneous rocks are about 700 million years old.

Broadly speaking, the Charnian rocks form a south-eastward plunging anticline, much faulted and obscured by the overlying mantle of Triassic rocks (Keuper Marl). The oldest rocks, the Blackbrook Series, crop out in the centre and north of the Forest whilst the younger rocks appear to the north-east, the south-east and the south-west forming a horseshoe-shaped distribution around the Blackbrook Series. In addition to the large anticlinal fold there are a number of other secondary structures. These include minor folds, cleavage and jointing. The cleavage does not show a close relationship to the major anticline, but usually crosses the fold-axis obliquely. In the south-east, however, (e.g. in Bradgate Park) it strikes parallel to the fold axis. The cleavage and some of the minor folds, which have a parallel trend, may therefore represent a later phase of deformation than that which gave rise to the main anticline. Further details of the structural geology and the stratigraphy appear in Evans (1968).

Excursion details

Bradgate Park (SK 5310). The party gathered in the car park of the Hallgate entrance (SK 542114) to the Park. Here the leader gave a brief résumé of the geology and warned the party that no hammering of the outcrops was permitted in the park. The party then proceeded to the first outcrop (SK 542112) where rocks near the top of the Maplewell Series are exposed. The Maplewell Series is the second of the three series into which the Charnian is divided. Over most of the Forest it is composed dominantly of pyroclastic material mainly of coarse to dust tuff grade. In this outcrop the bedding is fairly obvious and can be seen to dip at 24° to the north-north-east. The cleavage and jointing were also demonstrated.

Proceeding due south, outcrops around SK 541109 were then examined. The most important feature here is the reversal of dip which indicated that the party had just walked over the crest of a fold or a series of folds. In a small old quarry graded bedding was seen and in some crags to the east of the quarry a minor synclinal fold was inspected. Here deformation of the cleavage was demonstrated and some of the tectonic problems of the area were discussed.

The next stop was at the Stable Pit (SK 534100) where the middle quartzite unit of the Brand Series crops out. The Brand Series is the uppermost and dominantly sedimentary series of the Charnian. A synclinal fold is present in the main part of the outcrop and in the northern limb current-bedding is clearly visible. Some of the bedding surfaces are slickensided as the result of bedding slip during concentric folding. In the southern limb a prominent strike-slip fault is present and in it a much altered intrusion of diorite was inspected.

The party then proceeded to the nearby exposures of markfieldite (granophyric diorite) close to the walls of Bradgate House. Then followed a climb of a kilometre to the outcrops just below the War Memorial (SK 524111) where specimens of *Charniodiscus*, one of Britain's oldest fossils, were seen on a prominant bedding surface. Passing through Old John Spinney

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to the tower of that name incipient slumping was demonstrated in more outcrops of the Maplewell Series at SK 526112. Continuing eastwards the effects of severe sub-aqueous sliding were seen in the slump breccias of outcrops around SK 528112. An even more spectacular example of a slump breccia was demonstrated at SK 531113. These are the rocks incorrectly described as agglomerates by previous workers. The party then returned to the coach which carried it to the Reservoir Hotel where sandwiches and liquid refreshments were consumed beneath a hot sun.

Swithland Wood (SK 5312). From the Waterworks we followed a well-marked path into the wood to examine an outcrop of the Swithland Slate which occurs beside one of the old flooded slate quarries. This is a well cleaved siltstone in which the bedding cannot readily be discerned.

Church Quarry, Woodhouse Eaves (SK 531141). In this abandoned quarry a seam of slate in the middle unit of the Brand Series was once exploited. At the Staple Pit this unit was seen to be a well sorted quartzite but now, just over 2 km along the strike, the unit is a subgreywacke containing bands of pebbles and seams of slate.

Windmill Hill (SK 526143). After admiring the view over the Soar Valley to the Jurassic scarps of eastern Leicestershire the group turned their attention to a coarse-grained, non-stratified unit of the Maplewell Series. This is an ignimbrite (nuée ardente deposit) consisting of devitrified pumice-tuff in which flattened chloritized pumice fragments can be seen.

Beacon Hill Park (SK 5114). We entered the park at SK 523145 and almost immediately came to some outcrops of Beacon Hill Beds the most important unit of the Maplewell Series. In these outcrops about 10 m of tuffs are exposed and the party discovered a number of good examples of graded bedding. The long climb to the summit of Beacon Hill was then undertaken. This is the type locality for the Beacon Hill Beds which form rugged crags more in keeping with mountainous terrain than with the rolling Midland shires. Eschewing the attractions of one of the Midlands' finest views (Beacon Hill is the second highest point in Leicestershire) the party examined the well laminated buff and green tuffs which are folded into a syncline the hinge region of which is exposed.

The party then rejoined the coach in the car park and returned to Nottingham.

References

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MENEISY, M.Y. and MILLER, J.A. 1963. *A geochronological study of the crystalline rocks of Charnwood Forest.* Geol. Mag., vol. 100, pp.507-523.

Excursion references to localities in Charnwood Forest published previously in the Mercian Geologists can be found in:

Vol. 1. No. 1. p. 69
Vol. 2. No. 4. p.419
Vol. 3. No. 1. p. 85
Vol. 3. No. 2. p.190

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Secretary's Report for 1973-74

1973-74, the tenth year since the founding of the Society, might be regarded as its first landmark. To the 28 Founder Members who paid a first subscription at the inaugeral meeting on February 1st 1964 it was astonishing and gratifying to consider the great mushroom which had grown from such a tiny spore. The Society owes a great deal to the industry and enthusiasm of early Officers and Councils, and to the unflagging loyalty and support of the first Ordinary Members.

The tenth year was a good year. Fifteen meetings were planned, and it was with the deepest regret that a geological film show had to be cancelled at the last moment because of the consequences of industrial strikes. There was a weekend field meeting, four day excursions and a halfday excursion; there were three indoor meetings in Nottingham, one in Derby, and one in Matlock; there was a Presidential Address, an Annual Dinner and an Annual General Meeting combined with a Collectors' Meeting.

The Annual General Meeting in March was attended by over 60 Members, and was notable for a change in the management. Dr. F.M. Taylor had held office as President for three years and was due to retire and become Vice-President. Mr. P.H. Speed had been Treasurer for six years and felt that it was time to pass on his burden. Dr. W.A. Cummins had been appointed to the Editorial Board of the Geological Society of London, and had resigned from his office of Editor of the Mercian Geologist. In consequence of this, Mr. H.R. Potter was elected President, Mr. E.H. Marriott was elected Treasurer, and Dr. F.M. Taylor was elected Editor.

Seven vacancies had occurred on Council, as members retired after a three year term, and a new Council was elected by ballot.

The Collectors Meeting began long before the A.G.M. and continued as soon as the business was concluded. As on former occasions, the exhibitions prepared by members were varied and original, and this very popular meeting was as lively and enthusiastic as ever. After such a long series of annual exhibitions, it is admirable that members should find it possible to keep up the standard and proliferation of their exhibits.

A list of exhibits follows:

1.	D. Manning and D. Kelsey	The Geology of the Island of Rhum.
2.	W.A. Cummins	Neolithic Stone Axe Petrology.
3.	E. Taylor	Chart: Science in the Search for Oil.
4.	R. Bright	Ammonite Collection.
5.	H.B. Briggs	Outdoor Gear suitable for the Practical Geologist.
6.	J.C. MacDonald	Mineral Collection.
7.	M. Beaumont	a. Science and Geology at the Open University. b. Geology and Environment. c. Experimental Kit for Course S 223.
8.	R.C. Gratton	Collection of Fossils and Minerals.
9.	C. Champion	Ordovician Fossils.
10.	D.M. Morrow	Specimens from the Pleistocene Crag, Dunwich.
11.	H. Manning	Semi-precious Stones from Australia and New Zealand.
12.	M. Boneham	The Annesley Conglomerate.
13.	F. Russell	Fossils from the Red Crag of Shottisham, Suffolk.
14.	R.W. Morrell	Collection of Rocks and Fossils.

15.	J. Fletcher	Inlaid Marble Tabletop made in Bakewell.
16.	P. Spencer	Books, Postcards, Transparencies and Journals of Geological Interest.
17.	A. Houldsworth and F.M. Taylor	a. The Permo-Triassic Unconformity at Trowell. b. Barite of the Trowell and Bramcote Area.
18.	The Editor	Complete set of the Mercian Geologist.

During the meeting, Mr. J. H. Sykes held his second specimen sale, and his increasing competance and business acumen was rewarded by the amazing profit of £24. 50, which he later donated to the Society's Trust Fund.

At the final meeting of the indoor session in April, Mr. D.N. Robinson Tutor-Organiser for South Lindsey, Lincolnshire, W.E.A. and a newly-elected Member of Council, described to a large audience the geology and scenery of the Lincolnshire Wolds. Mr. Robinson had led a most successful weekend field excursion to this area in 1970, and his lecture was closely associated with it. His description of the area was illustrated by splendid slides, and was particularly appreciated by those members who had taken part in the excursion.

The first field excursion of 1973 was the weekend in the Llangollen area, led by Dr. F.M. Taylor. A party of 26 assembled in Llangollen, most of whom found themselves lodged in unaccustomed starkness in a hotel "chalet block". Saturday, a refreshing, windy day, was spent most pleasantly on the hills among the slate quarries, but Sunday was very wet, and it was a heroic little band that grimly followed the Carboniferous sequence in the teeth of cold wind-driven rain. In the afternoon, however, the sky cleared, and the excursion ended charmingly at World's End in a blaze of bright sunshine.

Later in May, Dr. F.M. Taylor and Mr. A. Houldsworth led an afternoon excursion to examine the cutting which had been made at Kimberley for the new motor-way by-pass. Members had been asked to meet at Kimberley, and although it was a fine Bank Holiday Sunday, some 20 members were present. Impromptu excursions such as this have an urgent vitality all their own, and it is clear that members appreciate the opportunity to visit temporary exposures when these present themselves.

In June, Dr. I.D. Sutton led a large party to Shropshire. The coach travelled through heavy rain to Much Wenlock, but at the first quarry, the clouds parted, the sun appeared, the ground dried, and incredibly the dismal morning transformed itself into a beautiful summer's day. This fitter setting for the rich geology of Shropshire crowned a most rewarding and enjoyable excursion.

During June, an exhibition was held in Derby Museum, entitled "200 years of Derbyshire Geology". In association with this, a series of lectures was arranged and the Society was invited to hold a meeting in the museum to co-incide with one of the lectures. The meeting was accordingly held on the last day of June, when two eminent members of the E.M.G.S. were to speak. In the afternoon Dr. F.M. Taylor of Nottingham University described the Permo-Trias in Derbyshire, and after a break for tea, Dr. T.D. Ford of Leicester University gave an account of the Quaternary in Derbyshire.

Next day, the July excursion took place, and Dr. A.M. Evans of Leicester University escorted a very large party around Charnwood Forest. Since quarries in Charnwood were disinclined to accept geological parties, and since the use of hammers in Charnwood was in general frowned upon, Dr. Evans laid his emphasis on aspects of topography and structure. On such a lovely hot day the walking and the viewpoints delighted the party, many of whom had formerly regarded Charnwood only as an interesting sequence of quarries.

The September visit to the Ladybower and Derwent Reservoirs was quite unlike any other excursion held by the Society. The members who took part were exceedingly grateful to Mr. J. Bullivant, the Chief Draughtsman, who patiently described the geology and drainage of the area, the construction of the dams, and the manner in which the reservoirs were manipulated. It was an intriguing experience to follow underground passages and to climb vertical iron ladders, and to emerge, surprisingly into a dam tower.

The last excursion of the season was held in October in the Walsall area. There were three leaders, Mr. L.A. Riley, now at Robertson's Research Laboratories and Dr. Taylor and Dr. Cummins of Nottingham University. Mr. Riley, with permission from British Railways, first took the party down into a railway cutting to collect Wenlock Shales - which they did nonchalantly as locomotives shunted at speed, back and forth alongside. After lunch, Dr. Cummins led a visit to a road metal quarry which held many other interests than road metal. Lastly, Dr. Taylor took the party into an Etruria Marl Pit. This fine triple field meeting was a worthy ending to a splendid outdoor season.

The first indoor meeting was held early in November. Mr. D. Sears, a Research Student from Leicester University described to an immense audience his researches on the luminescence of meteorites. There was great appreciation of his demonstration of luminescence, and great delight as his apparently white-hot stones were passed in darkness from hand to hand round the room. But an even greater joy was evident when he described the components of his simulated "moon-dust" - not, as might be thought, green cheese, but soot, talcum powder and cocoa.

The December meeting was held on a bitterly cold evening, but a good audience braved the sleet to hear Dr. R.J. Aldridge of Nottingham University describe conodonts. The conodont mystery was unfolded from a description of odd parts, of assemblages, and associations to the controversial "conodont animal" recently discovered, and so captured the interest of those present that they later flocked to examine an exhibition of conodonts which had been arranged under miscroscopes.

According to annual custom, a January meeting was held in Tawney House, Matlock, jointly with the Matlock Field Club. Mr. P. Wilkinson of Sheffield University spoke to a crowded room on the subject of Derbyshire Volcanoes. He describes various types of volcanic activity and related the products of these to the rock types found in Derbyshire. More than 120 people attended this meeting, a record even for Matlock.

The ninth Annual Dinner was arranged by Dr. I.D. Sutton and was held in the Nottingham University Staff Club. As always, it was a very pleasant social occasion, and a very happy party assembled.

At the last meeting of the year, the President, Mr. H.R. Potter gave his first Presidential Address, and took as his subject the Sediments of the Henmore Brook Catchment Area. As the University had cancelled weekend bookings because of the power crisis, the meeting was held in the Adult Education Centre, Shakespeare Street, Nottingham. Members were received in the entrance hall by candlelight, and conducted to the lecture room with torches to hear the President describe in a room, with electric light, the series of observations which he had made at Henmore Brook near Carsington in Derbyshire, and to see demonstrated his gauges and measuring instruments. It was an extremely interesting lecture, and a fascinating glimpse into the field of Hydrology.

In all, we have had a splendid year of activities, and our members have supported excursions and activities most enthusiastically. We give our grateful thanks to our excursion leaders, Dr. F.M. Taylor, Dr. I.D. Sutton, Dr. A.M. Evans, Mr. J. Bullivant, Mr. L.A. Riley and Dr. W.A. Cummins, and to our lecturers, Mr. D.N. Robinson, Dr. F.M. Taylor, Dr.T.D. Ford, Mr. D. Sears, Dr. R.J. Aldridge, Mr. P. Wilkinson, and to our President, Mr.H.R.Potter. They have given us great pleasure, and taught us a great deal.

Eleven monthly circulars were sent out to members during the year, and the high cost of postage was reduced considerably by the kindness of members who delivered circulars by hand to people who lived nearby. This is a real service to the Society and deserves appreciation.

Membership continues to be satisfactory. During the year a pruning operation was carried out, and members who had allowed their subscriptions to lapse were served with final notices. As a consequence, a good many subscription arrears were received, and there were some resignations. In 1973, however, there was a total of 60 new members, and the state of membership at the end of the year was as follows:

Ordinary	Joint	Institutional	Junior	Honorary	Total
244	86	130	25	2	487

During 1973, two issues of the Mercian Geologist were produced and distributed. Volumn 4, No.3 was prepared by Dr. W.A. Cummins, the retiring Editor, and was published in March. Volume 4, No.4 comprised the Bibliography of the Geology of Leicestershire, compiled by Dr. T.D. Ford, Mr. R.J. King and Mr. G.J. Snowball, and was published in December. The Society acknowledges with gratitude the generous donation of £150 from the Department of Civil Engineering, University of Loughborough, granted through the kind offices of Mr. W.S. Moffat, which made it possible to produce the Bibliography at little cost to the Society.

A tenth annual report cannot end without a deep acknowledgement to Professor Lord Energlyn for the infinite support he has given to us over the ten years. During all this time the Society has been made to feel welcome at the Department of Geology, whether holding a meeting or collating the journal or in making the numerous business calls which seem to be necessary. We, the Society, are grateful for this privilege.

We are also grateful to the University of Nottingham who allow us the use of their premises without making a charge, so enabling us to hold our meetings in the most advantageous surroundings, with the use of their excellent equipment.

As Secretary, I must acknowledge the tremendous co-operation and kindness I have received from Society members on all occasions. It has indeed been a most rewarding service.

D.M. Morrow

Secretary.

REVIEW

ALLEN, J. R. L., 1975. *Physical Geology*. Edited by J. A. G. Thomas, published by George Allen & Unwin Ltd., 139 pp. incl. index: 88 figs: 37 plates. Softbound £1.85.

The publication of another book in the 'Introducing Geology' Series has, no doubt, been eagerly awaited by many teachers of G. C. E. Ordinary Level Geology. Physical Geology by J. R. L. Allen may, however, prove something of a disappointment as much of the text is far too advanced for the majority of 14 - 16 year old pupils.

As a teacher's reference book it will be very useful, as it summarizes the origin of sediments; the chief physical agents of sedimentation and their products; earth movements and their effects on sedimentation and strata. J. R. L. Allen has also included many useful suggestions for simple experiments which can be carried out to develop insight into many of the points discussed in the text.

Following the introductory chapter in which the structure of the earth and geocycle are explained the book continues with the explanation of weathering and the agents involved in entrainment, transport and deposition of sediments. The following six chapters take each of the agents and describes the relevant features and resulting sediments involved in the work of rivers, wind, seas and oceans, and ice. The work of the sea is discussed, understandably and of necessity, in great depth.

Chapter 10 'The Restless Lithosphere' is most welcome as it will hopefully encourage many geology teachers to become more aware of modern theories in structural geology as J. R. L. Allen makes particular reference to the use of strain markers and compressional and tensional folds. The text ends with a very useful chapter which summarizes continental drift theories together with the newer theories of sea-floor spreading and plate-tectonics.

The main criticisms of this book are that it is in the main too advanced and too detailed for use by fourth and fifth year 'O' level pupils but it will be a useful text for pupils studying for G. C. E. advanced level Geology. Many of the photographs are of rather poor quality, several of them having no real value. The diagrams are, in many cases, rather complicated and often not fully explained in the text.

In conclusion, this third book in the 'Introducing Geology' Series will be a useful addition to the series as a teachers, or advanced level text, but not for use by 'O' level pupils. The cost, £1.85, may also prohibit many schools from acquiring more than a few copies.

J. M. A.

REVIEW

L. BEVERLY HALSTEAD and JENNIFER MIDDLETON 1972: *Bare Bones. An exploration in art and science*. Edinburgh: Oliver & Boyd. Toronto: University of Toronto Press 8 Unnam. + 119 pp., many illus. $7-95.

Bones have, for most people, a sinister, graveyard context; the very word evokes visions of death and dissolution. It needs an effort of thought to recognise that bones are also the framework for life and to remember that bone has long been the material of tools and a medium for art.

This book must surely be the first ever to try to assess bones in all their contexts and uses and, indeed, to convey the fascination of bones. Its authors are well fitted to do this: one of them, Beverly Halstead, is a vertebrate palaeontologist holding a dual appointment in the Departments of Zoology and Geology of Reading University; the other, Jennifer Middleton, is a medical artist. (Appropriately enough, the portrait of the authors (p. 3) is a radiograph!) Together they have produced a thoroughly fascinating book, excellently illustrated, surveying bone as a living material in action, bones and disease, bones as tools and in toolmaking, bone as a material for carving (and, in particular, the beautiful scrimshaw work of French prisoners-of-war in England during the Napoleonic period), and the representation of bones in cartoons, sculpture and paintings.

The first five chapters all contain much of interest to paleontologists. It is interesting, for example, to learn that growth rings in dinosaur bone indicate life spans of up to 120 years; that the short, "functionless" fore limbs of *Tyrannosaurus* were sufficiently well muscled to allow that reptile to rise from a prone position; that plesiosaurs were incapable of diving; that pterodactyls were furred and that the big pterodactyl *Pterarodon* could fly at 15 to 35 m.p.h. and was highly manoeuvrable. After seeing many reconstructions of Neanderthal man as a stooping, shuffling "inferior species", it is salutary to be reminded that the reconstruction was based on the skeleton of a 70-year-old, affected by arthritic diseases - a man who had survived to that age at a time when his contempararies rarely lived past 30 and who thus was definitely exceptional!

The authors stress the need for vertebrate palaeontologists to avoid similar misinterpretations by studying the effects of bone disease. They also give a qualified defence of Dr. Raymond Dart's much-criticised "osteodontokeratic" cultural interpretation of the bone accumulations found with the remains of *Australopithecus*; and they provide fascinating accounts of the origin of bone and of earbone evolution in mammals.

All in all, this is a unique and very readable book, that can be highly recommended.

WILLIAM A. S. SARJEANT

THE MERCIAN GEOLOGIST

Journal of the East Midlands Geological Society

The journal first appeared in December 1964 and since that time, 18 parts, comprising 4 volumes have been issued; the last, vol. 5, no. 2 in March 1975. The Mercian Geologist publishes articles especially on the geology of the Midlands of England, but other articles have been published which relate to Midlands geology or are of current interest to geology generally. Contents include original papers, review articles, biography, bibliographies, excursion reports, book reviews and the Secretary's report on Society activities.

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