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PROFILE

A brief autobiography by Dr Richard Hamblin, new President of the EMGS

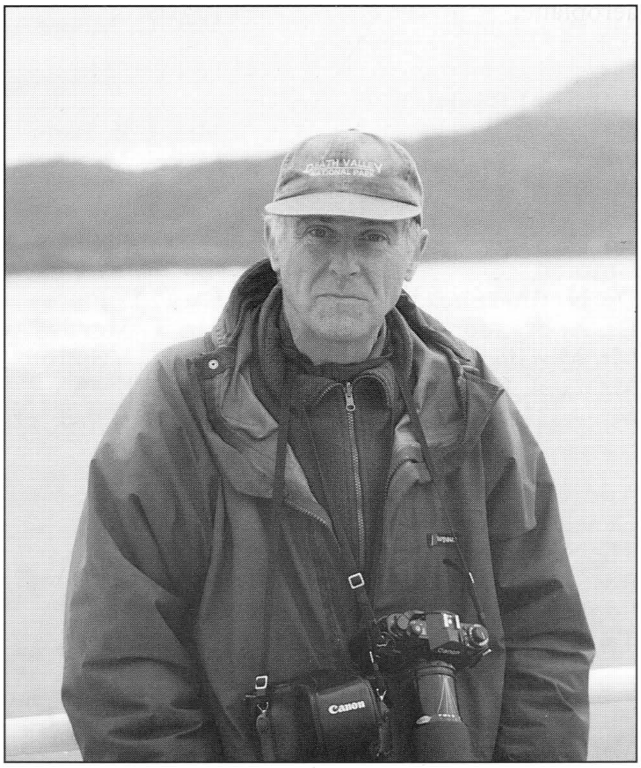
Unlike Sue Miles, my predecessor as President, I cannot claim an East Midlands origin, nor to have been born post-war! However, I am from the Midlands, having been born in south Birmingham. At King Edward's School I gravitated into science, but by the time I had passed the traditional three A-levels of maths, physics and chemistry I had become rather bored with 'indoor' science so I stayed on an extra year to add A-level geology. My interest in geology stemmed partly from a fascination for maps (and the discovery that geological maps were the most colourful) and partly from my experiences with the boy scouts. Whilst I never quite mastered the difference between a reef knot and a fisherman's bend (or a triangular bandage, come to think of it), the scouts did take me to lots of interesting places such as the Isle of Arran and the Bavarian Alps, which back in the 'fifties would otherwise have been out of reach.

I did a degree in geology at Durham University, and although I had left school with the intention of becoming an airline pilot, I found that I could not resist carrying on in geology, so I took up a three-year post as a research assistant at Exeter University. This was to work on a NERC contract to re-map the Teignmouth 1:50,000 sheet for the then Institute of Geological Sciences (now the British Geological Survey). This work led to a PhD on the geology of the Haldon Hills, which was mainly concerned with early Tertiary Haldon Gravels. I had met my wife Sue at Durham and we married a year after I moved to Exeter. I had also learned to fly at Durham, courtesy of the University Air Squadron, and I continued flying with the Plymouth Aero Club: my aerial photographs of the Haldon Hills are generally accepted as the most boring slides ever produced . . .

Since my professor from Durham, Kingsley Dunham, had in the meantime become Director of IGS, I had always been hopeful of a post with the Survey, and thus in 1969 I found myself joining the Central and South Midlands Field Unit, and attempting to 'join up' my maps with those of Albert Horton! After a brief season on the Abingdon sheet I moved to Telford and embarked upon three years of continuous field work in the new town. We rented a house from the New Town Corporation and our son David was born while we were living there.

I had hoped that, by the end of this period, the IGS would have completed its move to Nottingham, but in 1972 I was finally obliged to return to the London office, and we lived for seven years in Hitchin, Hertfordshire. This was the right side of London for travelling to the field in the Midlands and also to my in-laws in Essex. Our daughter Elizabeth was born in Hitchin in 1974. Finally, the geological mapping units of the IGS started to move to Keyworth, and we were in the first group to move, in October 1979.

After writing up Telford I found myself mapping on the Redditch and Birmingham sheets, and having become a geologist partly to get away from Birmingham I decided that it was time to request a move. This led to a brief and rather incomprehensible period in which I was in charge of the Keyworth branch of the Highlands and Islands Unit, mapping the Dalradian around Aberdeen, after which I settled into the Marine Geology Unit for seven years. The unit was short of staff with experience of producing maps, and I was mostly involved in the 1:250,000 solid and sea bed sediments maps of the English Channel and Thames Estuary, followed by the English Channel regional guide. However the offshore surveys were by now concentrated off Scotland, and I had some fascinating visits to such remote outposts of the empire as St Kilda, Lerwick, Stornaway and Cardiff. I thoroughly enjoyed working at sea, involving driving winches and drilling equipment as well as logging cores, but I did wish I could remember the difference between a reef knot and a fisherman's bend . . .



In 1990 the Keyworth section of the Marine Geology Unit became the Coastal Geology Unit, and I produced a 1:50,000 map of the inner Bristol Channel. Tracing the course of the Hercynian Front through Palaeozoic rocks proved an interesting but brief return to hard rock geology. However I still felt in my heart that I belonged in onshore mapping, and in 1991 I transferred to what is now the South and East England survey unit. Since then I have been concerned with surveys of north-eastern Suffolk and north Norfolk, involving around 16 weeks fieldwork each year. I have been very successful at avoiding being transferred or promoted into an administrative position, and hope to continue doing fieldwork until I drop!

I joined EMGS as soon as I moved to Keyworth, and served for a year on Council in the early eighties, although I have not been as active as I would have liked because of long periods in the field or at sea. However my spare-time geological interests have broadened now that the children have grown up and we can take more interesting holidays, and in recent years we have paid several visits to the western states of the USA and Alaska, looking at glaciers, volcanoes and deserts — unlike anything I have found in Norfolk! Sue still does not admit to an interest in geology, but she does admit that my geological friends are more interesting that my aeronautical friends.

I have always maintained my pilot's licence and have recently bought my first share in an aeroplane, a small two-seater based at the Rolls-Royce airfield at Hucknall. I also represent the East Midlands on the national council of the Popular Flying Association, and my ambition is to build my own aeroplane, although this will clearly have to wait until I retire. We have now lived in Keyworth for eighteen years and have no plans to move since it has taken us this long to get the garden under control. Gardening on Oadby Till is very much harder than on the Upper Chalk of Hertfordshire, but we have at last produced a reasonable show of roses!

MERCIAN NEWS

OBE's for EMGS members

Two of our longest serving members, Trevor Ford and David Robinson, have been awarded OBEs in the 1997 Queen's Birthday Honours list.

From his earlier years exploring the innermost parts of Speedwell Cavern, Trevor Ford has emerged as the primary authority on the geology, mineralogy and karst geomorphology of the Peak District. However, his services to geology extend well beyond his research. He was a founder member of the EMGS in 1964, serving for several terms on Council including President in 1982-85, and continues to be a prolific supplier of engaging articles and papers for *Mercian Geologist*. He has also played a leading role for many years in both the Peak District Mines and Historical Society and the British Cave Research Association, including the thankless task of editing journals for both these bodies. Throw in his years of service at Leicester University, research on Charnian fossils, primary geological mapping in the Grand Canyon and his massive knowledge of all aspects of geology, and we have in Trevor a true credit to the science of geology.

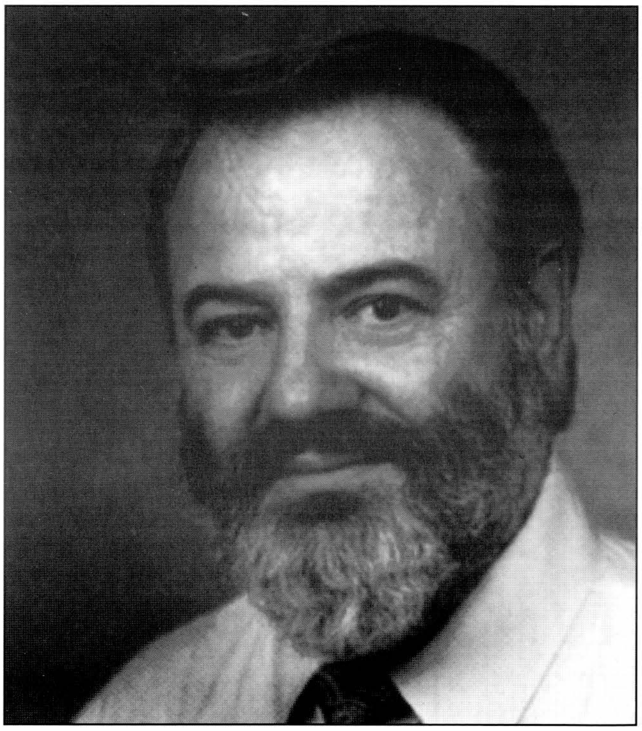
The geological community will be familiar with David Robinon's expertise on the Quaternary of Lincolnshire and Humberside, but he is also a widely-acknowledged authority on Fen conservation issues, being Secretary of the Lincolnshire Trust for Nature Conservation and having made numerous TV appearances. David has been an EMGS member since 1965 and served on Council from 1974-77, many members will have fond memories of several excellent field excursions to the Lincolnshire Wolds and Fens led by David in the 1970's and 80's. He continues to be a highly active supporter of field research and teaching in Lincolnshire, playing a central role in the setting up of both the field study centre at Gibraltar Point and the Lincolnshire Regionally Important Geological Sites (RIGS) Group.

The Society extends its warmest congratulations to both Trevor and David. Everyone will agree that their awards are in well-deserved recognition of their services to geology, and of their contributions to broadening the appreciation of the earth sciences by the wider community.

New Director at BGS

Dr David Falvey has been appointed as the next Director of the British Geological Survey. Dr Falvey, 51, has been Director of the international Ocean Drilling Program (ODP) at the Joint Oceanographic Institutions (JOI) in Washington DC, USA, since 1994.

Dr Falvey was born in Sydney, Australia. After gaining a PhD in Marine Geophysics from the University of New South Wales, he worked as an exploration geophysicist for Shell from 1972 to 1974. He then returned to academia as a Senior Lecturer in Geophysics at the University of Sydney from 1974 to 1982, where he organised the first



systematic programme of palaeomagnetic research in the Pacific Islands, focusing on the tectonic evolution of the south-west Pacific.

Like the present Director of BGS, Dr Peter Cook, Dr Falvey has held senior management positions at the Australian Geological Survey Organisation (AGSO). In 1989 he became an Associate Director of AGSO and Head of the Petroleum and Marine Geosciences Group. Since taking up his current post in Washington, Dr Falvey has worked to broaden the membership of the Ocean Drilling Program, and has promoted the Program's achievements to a wider scientific and public audience.

'I am pleased and excited to be taking up the highly prestigious position of Director of the British Geological Survey', says Dr Falvey. 'I look forward to the challenge of leading the Survey as it moves into the 21st century. My priorities include the preparation of digital, three-dimensional geoscientific data models and the development of relevant applications, aimed at providing solutions for the needs of government, industry and the community. I will continue to support strongly the Survey's core programme and its contract programmes, both at home and abroad'.

Dr Peter Cook retires at the end of 1997, after which Dr Falvey will take up the post of Director in January 1998.

Nottingham hosts major international groundwater conference

In September 1997, Nottingham was the venue for the 27th Congress of the International Association of Hydrogeologists, which focussed on the search for solutions to the growing resource management and engineering problems associated with groundwater in the urban environment. Most of the earth's freshwater reserves lie underground, and groundwater provides the drinking water for more than 1500 million urban dwellers around the world. Usage is growing rapidly in the expanding cities of some developing countries, where excessive pumping not only threatens the future security of the resources but also causes serious ground subsidence problems. Conversely, in many longer established cities, for example Nottingham and London, rising groundwater levels are a problem due to a decline in water abstraction. Additionally, most urban solid wastes and large volumes of urban wastewater are disposed of either on or in the ground, posing a serious threat to groundwater quality.

The Congress was attended by over 400 of the world's foremost experts on groundwater, from 40 countries, and was held at the impressive facilities of the East Midlands Conference Centre on the Nottingham University campus. Nottingham was an appropriate choice of venue, given the importance of groundwater was a major component of its water supply. The Congress included a detailed case study modelling the impact of Nottingham on the quantity and quality of its underlying groundwater, together with field excursions to demonstrate the local geology and environment.

Papers presented at the Congress will be published in two volumes in early 1998.

It's never too late to learn . . .

The University of Derby is offering a new accecss route for mature students wishing to study geology in higher education. The Geology Department, in conjunction with the University's Centre for Access and Lifelong Learning, has designed new courses to introduce geological concepts and practical skills to students with little or no background in science. Four new study modules are available, which can be taken on an individual basis or as part of a full-time Access or Foundation programme. These are: From Crystals to Continents; Investigating the Earth; Geological Time; Interpreting the Geological Record.

These modules are not only suitable for students wishing eventually to progress to a degree course in geology, but also for those who enjoy outdoor pursuits and simply want to learn more about the ground beneath their feet. Further details may be obtained from Mrs Barbara Marsh, School of Environmental and Applied Sciences, University of Derby, Kedleston Road, Derby DE22 1GB.

BGS Nottingham and Grantham maps now available

Running out of ideas for unusual Christmas presents? Then drop in to the British Geological Survey shop at Keyworth, which stocks a broad range of earth science maps, books and guides catering for all ages and levels of knowledge, plus attractive gemstones, souvenirs, field equipment and (not forgetting!) model dinosaurs.

While you're there, why not treat yourself to the new, 1997 editions of the BGS 1:50,000 scale maps of Nottingham (sheet 126) and Grantham (sheet 127). Both maps are based on new, state-of-the-art detailed geological surveys, and incorporate the latest geological information and stratigraphical nomenclature. They are available as flat or folded copies, both good value at £9.95.

The Sandstone Caves of Nottingham

A completely revised and expanded 56pp edition of Tony Waltham's *Sandstone Caves of Nottingham* with full colour cover, 28 photographs and 22 two-colour maps is available to society members at a reduced rate of £3.00 plus £0.65 p&p from Judith Rigby, 233 Mansfield Road, Redhill, Nottingham NG5 8LS.

REPORT

The Christmas Day landslide at Nottingham Castle

Newspapers and television news programmes featured the landslide at Nottingham Castle on Christmas Day, 1996. Initial impressions of a demise of the sandstone crag on which it stands, or of any involvement by descendants of Robin Hood, were unfounded.

Nottingham's real castle was of Norman origin. Sadly for expectant latter-day tourists, it was almost completely destroyed in 1651 at the end of England's civil war. It had stood on a steep crag of Triassic Sherwood Sandstone which rises nearly 40m above the floodplain of the River Trent. The commanding site was subsequently occupied by the seventeenth century mansion, which survives in modified form today as the Castle Museum, and is often incorrectly referred to as the Castle. The mansion, splendid and spectacular in its own right, is firmly founded on solid sandstone, but is surrounded by a wide paved terrace.

At the outer edge of the terrace, a perimeter wall, built in about 1700, retains a soil fill which is capped by the terrace paving. To make space for the terrace, this wall had to be founded out beyond the flatter top of Castle Rock, and it probably rose from narrow ledges cut into the steeply sloping sandstone of the upper cliff. The height of this wall reached about 7m on the corner at its southernmost tip, where it projected farthest out from the museum building and where it crossed a shallow gully cut into the sloping top of the Castle Rock sandstone.

Prologue

A corroded iron water main within the terrace fill chose Christmas Eve to finally burst, just after everyone had packed up and gone home. At 9 o'clock that evening, water and soil was seen pouring down the cliff; a small fan of sand and silt had formed in the garden below, and the occasional rock came crashing down through the darkness.

On Christmas Day morning, Castle staff found the flagstones of the paved terrace had been disturbed due to the raised water pressure in the soil fill around the broken main; some flags had even lifted a little. Yet water was also pouring out from the bottom of the perimeter wall, taking the odd piece of masonry with it. The water main was closed off at the entrance to the Castle grounds, but back pressure on the ring main ensured that water continued to flow at a significant rate.

Leakage of the water through the base of the wall provided the outlet for yet more of the finer components being washed out of the fill. Piping cavities must have been developing; these characteristically expand in the upflow direction, so that some grew just beneath the paving and close to the break in the water main. At about 1pm, two of the paving flags collapsed into a small crater. A potential hazard was perceived, and the Castle grounds were closed. But the water was switched off, the Council engineers were off on holiday, and there did not seem to be much else that could be done.

Down below, the alluvial fan at the foot of the cliff continued to grow, in mute testimony to the amount of fill being washed out from behind the wall. By mid-morning, it had spread across the 7m of the Castle's lower gardens, so that silt and sand were being washed through the paling fence and across Peveril Drive. The water could be seen to be pouring from the foot of the wall, mainly where it sat on the rock on its western edge; it was also weeping out of the lower two thirds of the wall's height.

Collapse

Early in the afternoon, water, sand and masonry were still falling down the cliff. From his home on Castle Boulevard, a man had seen and heard the debris coming down at various times since first light. Some time between 2 and 3pm, an increase in the noise of the falling debris made him look up. He stood almost mesmerised as the whole wall slowly

The site of the failure seen from the foot of the cliff on 27th December, before the loose debris was removed, and with the fallen tree and lamp post still leaning across Peveril Drive (photos by Tony Waltham).

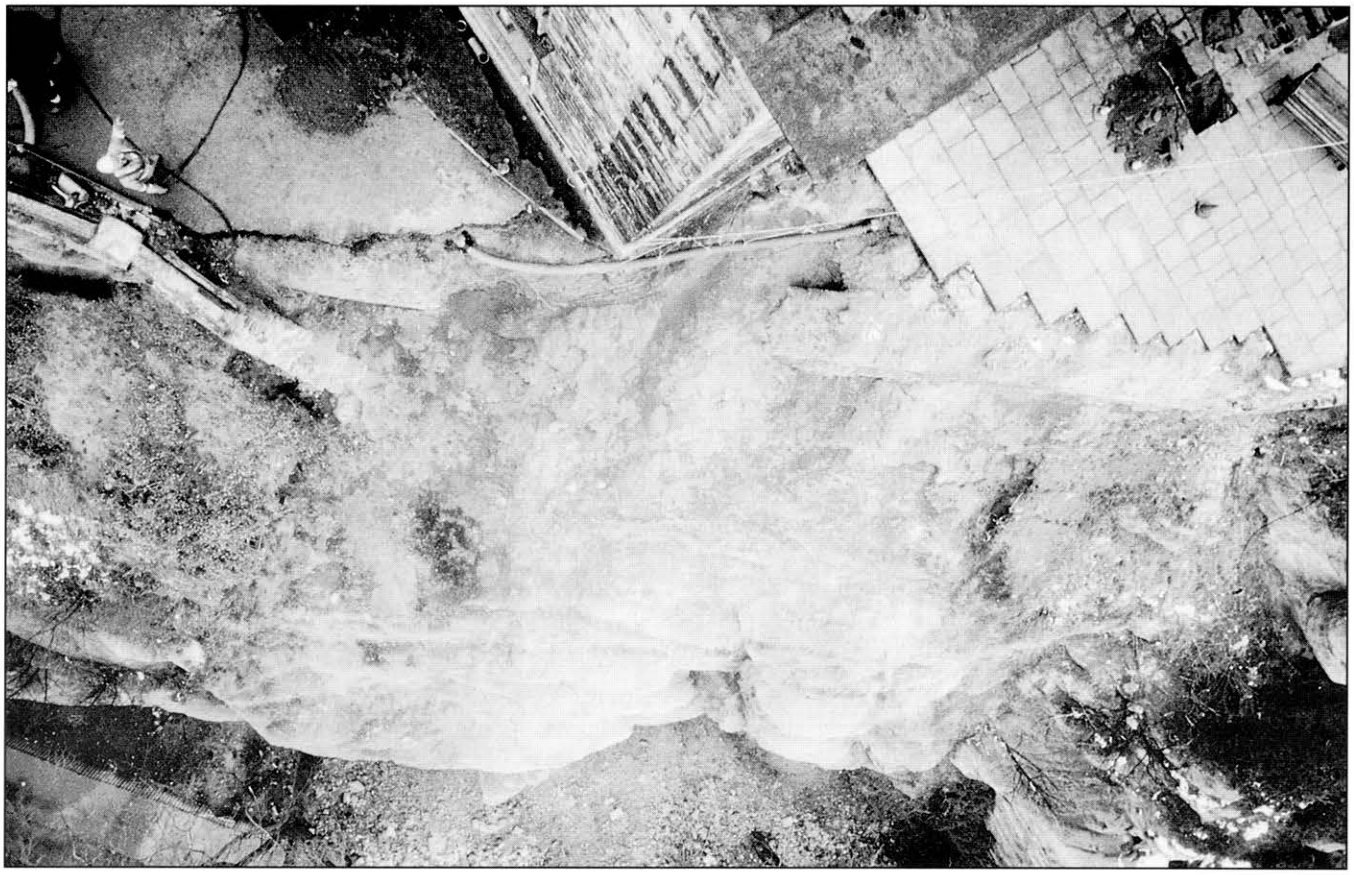
bulged out at mid-height; then its lower section failed and burst outwards, followed by total collapse of the whole structure. It was all over in a few minutes, and the observer only cursed that he had not had a camera to hand. There were no dramatic sound effects, and people inside nearby houses heard nothing. The museum duty attendant was in his office 50m away, when he heard a whooshing noise, and went outside to find that the terrace had gone.

The wall, the fill and the paving all fell to the foot of Castle Rock. Nearly 100 cubic metres of soil and masonry, weighing around 200 tons, lay piled on the strip of garden below. Most of it remained behind the iron fence, though the odd block of stone had bounced across Peveril Drive, where a sheet of sand and silt was also washed out. A plane tree was hit by the debris, so that it was laid across the road, where it bent a lamppost to a bizarre angle.

Up above, there was a yawning gap where about 10m of the wall had fallen away. With it had gone most of the soil and old masonry that had originally been held behind it. None of the bedrock sandstone had failed. The wall and artificial fill, and perhaps some remnants of natural soil, had merely slipped off the rock, with a slip surface at the rockhead. Fortunately the massive stone foundations of the Castle Museum had been built up from solid sandstone bedrock behind the rim of the steeper cliff, and the mansion stood unharmed. The museum foundations are bonded with only a weak lime-clay mortar, which is best not exposed to rainwash or frost for long. A good spread on the foundation masonry has ensured that there is no danger of further failure before the constraining terrace is replaced.

The Christmas Day collapse provided a classic example of the failure of a retained soil which had become saturated by a sudden input of water from a broken pipeline. Water has a devastating influence on a soil structure, and increased water has three separate effects. First, the raised water pressure within the ground acts laterally as an increased force pushing the retaining wall outwards. Second, the raised pressure of the interstitial water within the soil forces the soil particles apart; soil strength is largely due to its internal frictional resistance to shear, which depends on the force pressing the grains together, so the strength is reduced by increased water pressure, and yet more load is cast onto the retaining wall. Third, flowing water washes the finest particles out of the soil, in a process which increases until all the soil is washed out along the drainage route to create a piping cavity, which ultimately collapses. The sequence of events at the Castle clearly shows that all three processes were active through the 18 hours between first sight of the water leak and the final collapse.

Closer view of the slide scar, with the masonry of the Norman wall visible beneath the overhanging terrace paving; undisturbed sandstone is exposed at the foot of the picture.



The landslide site seen from almost vertically above, after the loose debris had been cleared off. The straight line of the Norman wall is clearly exposed, as very little of it had fallen away; the gap in it dates almost entirely from about 1680, when space was created for the mansion foundations.

It is likely that irreversible damage was done to the terrace structure during the night when the water was flowing unchecked for over 12 hours. Large piping cavities were formed in this early phase, as indicated by the amount of fines washed down the cliff by Christmas Day morning. The total collapse may have been prevented if the water had been completely stopped early in the day; but the terrace would have remained as a distressed structure demanding rather tricky remedial engineering.

Epilogue

A veneer of loose material remained on the sloping rock of the slide scar; this was soon cleared off, to add to the debris pile far below. The newly exposed sandstone appeared devoid of any joints or open bedding planes which could be regarded as contributory to the failure; one niche across the rock face looked as if it had been artificially cut as a footing for the wall structure. The rock's bare surface had been scoured by the passing debris, but otherwise appeared to have remained intact. The bedding is nearly horizontal, so could contribute little to slip surfaces. Almost vertical joints are aligned mainly to the northwest; one underlies the landslide scar, but was not involved in the failure. It appears that practically none of the water drained into the rock; the nearest part of Mortimer's Hole is almost beneath the slide scar, offset just a few metres to the east, and no water entered it. The intact weathered sandstone has very low permeability at the rockhead surface, there are no open joints or fissures at the site, and the steep slope encouraged rapid run-off.

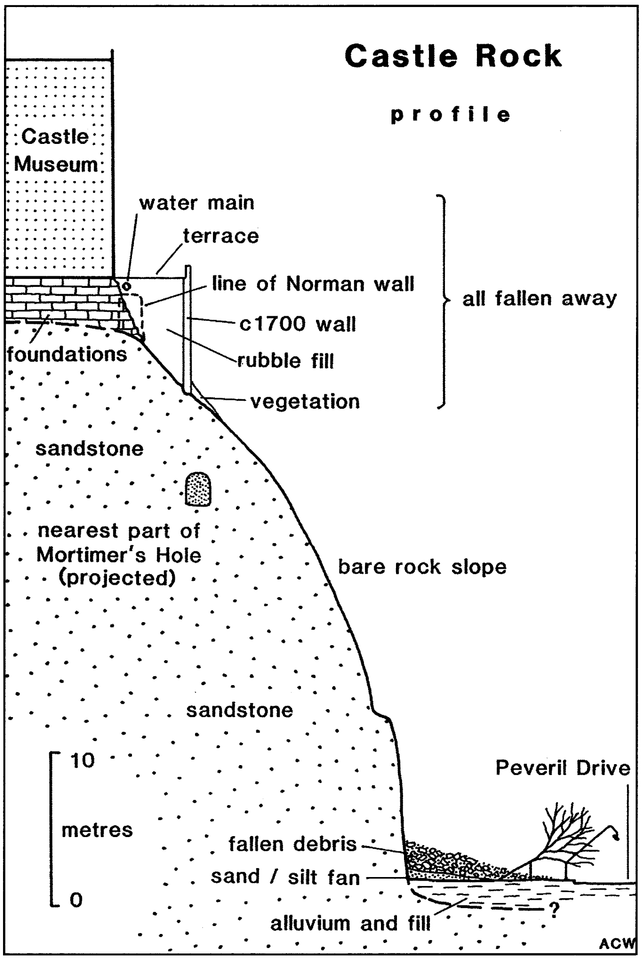
One incidental benefit of the landslide has been the exposure of a medieval wall, perhaps of Norman origin, which had lain buried under the paved terrace for over 250 years. A section of this was removed in about 1680, to make room for the foundations of the new mansion. A little more seems to have fallen away in the new landslide, but two cross sections through the rough sandstone stonework remain in either side of the slip scar. Repair work started in January. A temporary platform is supported on scaffolding columns which stand in vertical holes drilled a metre into the exposed sandstone. This working platform allows placement of rock anchors to tie the remaining walls and the museum foundations back to the sound sandstone. Designs for the renovated terrace have come down to two options. One has a new concrete wall, standing on and anchored to the exposed sandstone; behind it, a rubble or gravel fill re-buries the Norman wall, and carries the flagstone paving of a restored terrace. The concrete wall is faced with masonry blocks from the original wall, rescued from the debris below, so that the restored site will look as before. Alternatively, the hole in the terrace is left open to expose the different foundations and wall remnants, now stabilised, and a cantilevered viewing platform will complete the terrace walkway by spanning the gap. Aesthetics and costs are the two factors which must determine the choice, hopefully to be made in time to complete the main works before the 1998 summer visitor season.

The only map of the original castle is that by Smithson, drawn in 1617. An overlay of this on a modern plan of the site, correlated with features excavated at the north end of Castle Rock, aligns two medieval walls on the southern rim of the rock crag; the wall exposed by the landslide lies exactly midway between these. This indicates an error in the overlay. It remains uncertain that the exposed wall is the original outer wall, set back a little from the lip of the cliff; traces of rendering on its outer face may be relics from the time when it was known as the White Tower. In the unlikely event that it is the original inner wall, then the outer wall has completely gone, and the whole cliff face must have retreated by about 6m — with some interesting implications for geomorphology.

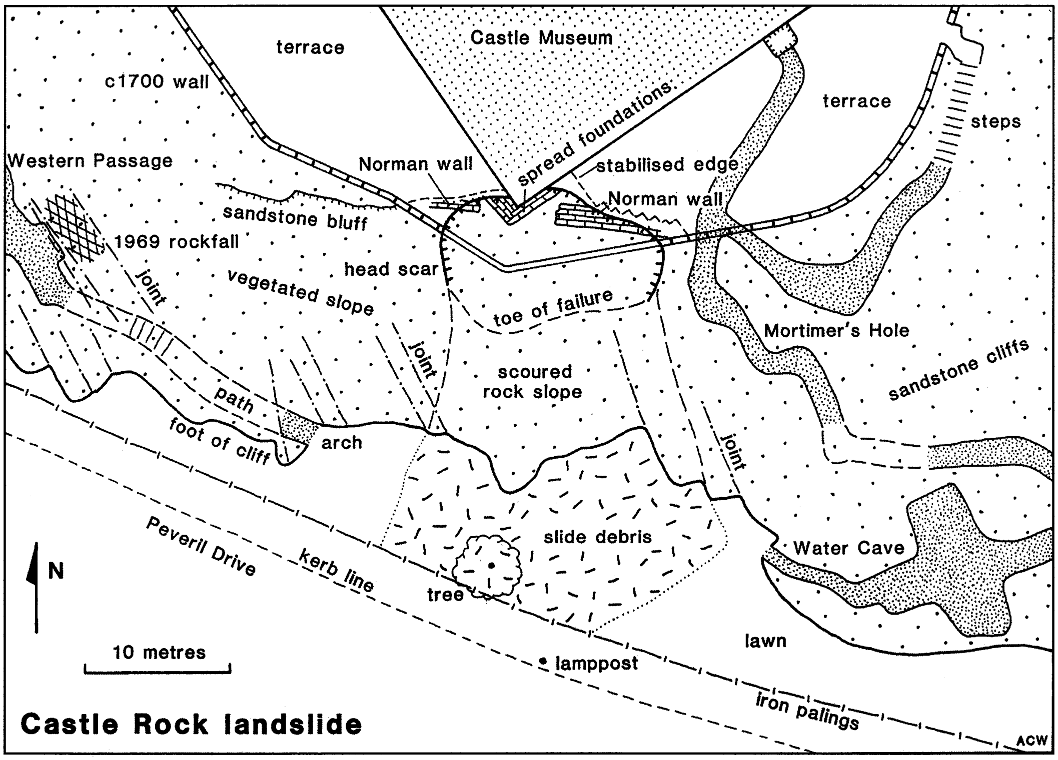
Peripherals

Castle Rock does have a history of rockfalls and failures, most of which were small and in styles not directly related to the latest event. The iron cross at the head of a masonry anchor was visible on the section of wall which fell on Christmas Day; but this was at least 100 years old, and was unrelated to the latest failure.

Beside one of the old cave entrances at pavement level on Castle Road, a slab of sandstone, measuring



Profile of the southern end of Castle Rock, on the line of the 1996 landslide. The wall and terrace fill around the edge of the museum building fell away to expose the foundation, while the rock slope remaind intact.



Plan view of the landslide site on the southwestern corner of Castle Rock.

about 3 tons, became unstable during 1996. Tree roots were growing in an inclined joint in the rock, forcing it open at a rate measured at over a millimetre per day in the summer growth season. This movement created new fractures in the adjacent rock, and a slab failure became a serious threat. The tree has since been removed, and concealed bolts now lie through the rock to restore its stability.

Trees and other vegetation do improve stability on soil slopes, by removing water, reducing erosion and providing tensile strength with their root mat; but those benefits are trivial on rock slopes, where roots are detrimental because they weaken sound rock by opening up the joints. Individual rockfalls are mostly small, but tree roots are a significant hazard on many of the sandstone cliffs. Clearance of the trees from the cliffs above Castle Road, in January 1997, is the best possible thing to have happened to them. Total removal of the trees, and killing of their root systems, would clearly lengthen the life of the rock faces around Castle Rock. There is a strong case for removing all the trees on the cliffs around the southern tip of the Rock, and this would also improve the visual appearance of this very distinctive geological feature.

The largest recent rock fall was in January 1969, on the southwestern face of Castle Rock. This is recognisably the least stable zone around the Castle, as the main cliff is parallel to the dominant set of joints, aligned northwest to southeast; there is little instability on the southern tip of Castle Rock, where the main joints are aligned straight into the cliff. Almost above the lower entrance to Western Passage, a pillar of rock rose 9m but had little support; more than 7m of it was separated from the main rock face by an open joint. The top of it appears to have fallen off in a separate failure 30 years previously. The main pillar failed by shearing through only about 1 metre of rock at its base, and about 20 tons of large sandstone blocks landed in Peveril Drive. This fall was of the type triggered by rising water pressure and frost action during the winter months, in contrast to the falls due to tree roots which occur in the summer months. With the outer slab gone, new support was necessary to prevent the next parallel slab of sandstone subsequently failing as the joint behind it opened due to stress relief; remedial works included concealed rock anchors, the large concrete buttresses which still stand against the rockface, and concrete grout seals in the exposed open joints.

Rockfalls are a component of the long-term erosion and denudation of Castle Rock. Records of earlier events are sparse, and it is difficult to make estimates of the overall rates of erosion and cliff face retreat. At the foot of the Rock, there are various caves which appear to be only the remnants of a more extensive group of artificially cut rooms and passages; their fragmentation is evidence of the cliff's retreat. Weathering and collapse of the caves accelerated the rates of face retreat on many of Nottingham's sandstone cliffs, notably when one generation of caves became unsafe and were therefore intentionally destroyed when the cliff was cut back to a new stable profile. This may have been a significant factor in creating steep cliffs in place of more gently graded natural buffs, and Castle Rock was probably no exception. Higher up the cliff, erosion rates would have been closer to natural levels, and could reasonably be expected to be in the order of 1 metre per 1000 years. Retreat of 6m since Norman times appears to be untenable, except that larger landslides could have created major anomalies in the retreat patterns. There is still much to learn of processes on Castle Rock.

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Developments in Nottingham's Sandstone Caves

A. C. Waltham and T. J. Cubby

Abstract: The sandstone caves cut beneath Nottingham are part of the city's heritage, and the recorded list of them is growing steadily. Most but not all of the partial cave roof failures are related to water input or tree root growth. Intact sandstone forms arches successfully for 11m across the largest single cave room under the city, though it is being given extra support following a small roof fall. Weathering of the sandstone inside caves is greatest in those with free air circulation through open doors, and survival of the fine carvings in the Park caves may be dependent on new doors being fitted in their entrances.

The many hundreds of artifically excavated caves beneath the streets and buildings of Nottingham are now a well-established part of the city's structure. Their existence is due to geological factors, in that the Triassic Sherwood Sandstone is such an ideal tunnelling medium — easily excavated due to the low rock strength, but then stable over an underground void due to the high rock mass strength. Beyond this influence, the nature and distribution of the caves were largely determined by man's needs for a little more space in a once crowded town (before Nottingham became a city).

Nottingham's caves were described earlier in the pages of the *Mercian Geologist* (Waltham, 1992). That paper was published as a separate booklet, until it was replaced by the new book on the caves (Waltham, 1996b), also published by the Society. The book is a more user-friendly presentation designed for the wider audience, and therefore has less detail on some pure and applied aspects of the cave geology. This short paper reviews some recent events, developments, discoveries, research and literature that are more relevant to the ethos of the Society.

The changing face of the caves

Most of the caves lie beneath the city centre of Nottingham, where continuing redevelopment of the commercial buildings is the main means by which previously unsuspected caves are revealed, perhaps for the first time in many hundreds of years. Consequently, the latest map of the caves (Fig. 1) has numerous additions to the data recorded on the earlier map, published in the *Mercian Geologist* in 1992, but equally it will be outdated in future years.

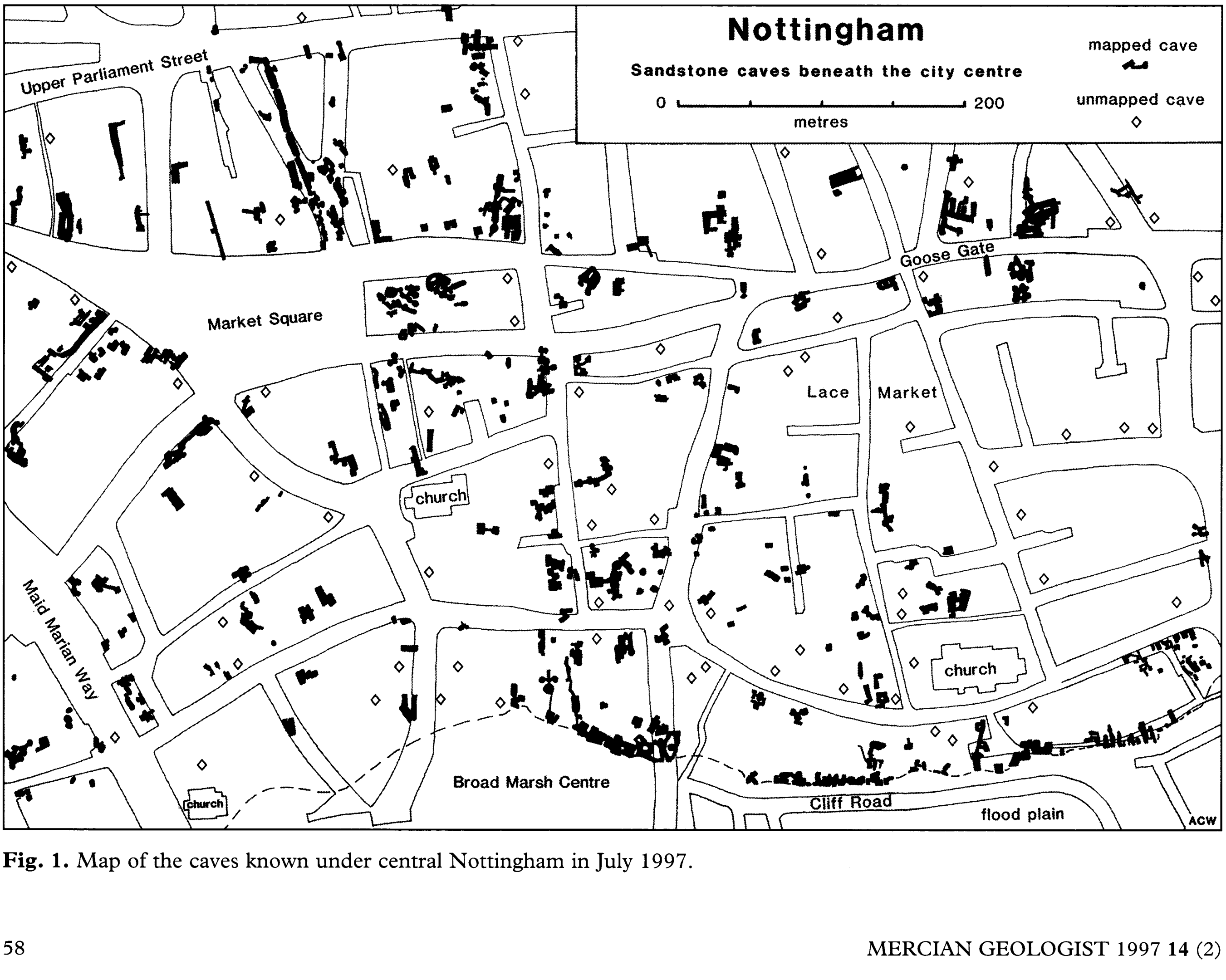

Fig. 1. Map of the caves known under central Nottingham in July 1997.

Most exciting of the recent discoveries was the complex group of caves, named after the bygone Black's Head Inn; these were found in the section of sandstone cliff now tucked away behind the Broad Marsh Centre. Pub cellar caves, a malt kiln cave and a cave tannery were all found literally on top of each other, when the upper caves partially collapsed into the lower caves, to the detriment of the buildings above (Waltham and MacCormick, 1993). Furthermore, the caves also yielded some fine pottery fragments, a slate tool from the tannery, and a pair of gold coins.

Recent cave discoveries also include the remains of two more malt kiln caves, bringing the total to twenty within the city. One of the new ones lies beside Huntingdon Street, and is therefore the first one outside the old town limits. In the cliff below Malin Street, the bricked-up caves were briefly re-entered, and proved to be a series of old beer cellars that had also seen various other phases of use. A complex group of caves and passages on two levels, found behind brick walls beneath the old Shire Hall (now the Galleries of Justice), include one room 7 metres wide and another smaller round cave that appears to have been an ice house.

The sand mines along the Mansfield Road have been a little better understood, and another site of old sand mining was recognised across the road from Rouse's well known mine (Waltham, 1994). Large amounts of loose sand within Rouse's mine probably originated from the excavation of the two air raid shelter exists up to Peel Street; members of the Nottingham Historical and Archaeological Society have recently cleared a new route that loops through the old air raid shelter. New office blocks have been built above the mine; they were positioned carefully with reference to the mine pillars, so that there was no need for disturbance within the galleries. Similar shallow mines in the Permo-Triassic sandstones have required extensive concrete filling beneath housing developments at Castleford (Baldwin and Newton, 1988) and at Redcliffe in Bristol, but the Nottingham mines are fortunately more stable than both these sites.

Activity related to the 1996 Christmas landslide at Nottingham Castle (see this volume, pp. 53-57) provided the opportunity to inspect parts of Castle Rock from a crane bucket. A cave found on a thin, ivy-clad ledge 5m below the footings of the old walls proved to be natural. It is just 4m long, though only about 700mm high and wide, except at its flare onto the cliff face. The cave has formed where a bed of pebbles and mud flakes is intersected by one of the main set of vertical joints aligned just west of north; its enlargement has been by frost action and granular spalling, aided by groundwater seepage (though it is now dry), and perhaps by loose sand being brushed off the walls by the foxes who now visit it. This appears to be the longest natural cave in Nottingham at present; it probably indicates the style of many small fissures and natural caves in the sandstone cliffs all along the south side of Nottingham, before the artificial caves were cut and the cliffs were repeatedly cut back by man.

While new sites add to the inventory of Nottingham's caves, there have also been some losses. A cave system beneath shops on Goose Gate was reported to be quite extensive, but was just one of a number of caves whose entries were bricked up before they could be properly mapped, photographed and documented. The city's twentieth malt kiln cave was found close to Broad Street, but only half the kiln remained and even this has since been filled. On the Mansfield Road frontage, a new office block has been built partly over the extensive caves that date from the old Nottingham Brewery. Only a few metres of cave were totally filled and lost, but there are some massive partial fills of concrete where columns were founded on bases above the caves. These were the cheap option, but the shuttered fills are larger than they needed to be, producing results that are seriously unsympathetic to the city's heritage. Bored piles into the caves, similar to those supporting the adjacent York House, were not used because their added costs were too high for a very tight budget.

Greater publicity and wider knowledge about the caves have raised their profile within Nottingham. The benefits are slow to mature, but caves are being preserved, or at least documented, where they may have been lost in the past. The best publicity of all has derived from the commercial development of the caves under the Broad Marsh Centre. Now known simply as The Caves of Nottingham (James, 1995), the site offers an excellent presentation of the caves to visitors from Nottingham and farther afield. The informal guided tours that used to run in the Broad Marsh caves have now been displaced to Rouse's sand mine (often known as the Peel Street caves), where some sand clearance has made a better route through the section fitted up as the air raid shelter. The register of caves published by the British Geological Survey (Owen and Walsby, 1989) remains the key source of documentation; one of its authors, Jenny Walsby, is still at the BGS, where she fields enquiries and also aims to produce a register supplement when time and funding permit.

Instability and failure of the caves

Though many of Nottingham's caves have remained intact for over 500 years, there are various ways in which failures can occur. Simple cave roof failure due to imposed loading is a permanent threat where new buildings are placed over old caves, but the hazard is minimised by careful adherence to loading limits. A critical zone can be recognised within the ground beneath any foundation (Fig. 2), where caves have to be searched for and then either avoided or provided with appropriate support.

Research at Nottingham Trent University has investigated the dimensions of the foundation critical zone, by destructive test loading of numerous scale models of caves and also one full-size cave

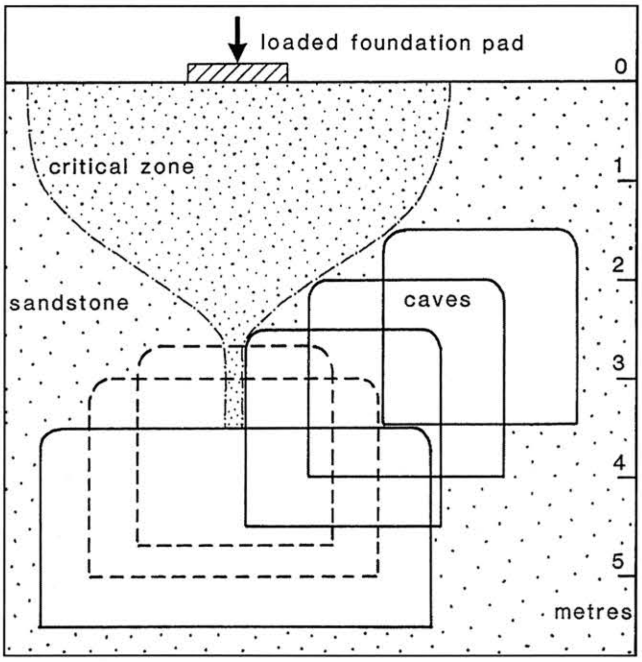

Fig. 2. Cross section showing caves in Nottingham's sandstone, which are acceptable below a foundation pad. Sound rock has to be proven within the critical zone to avoid the threat of a punching failure, except where the caves shown with broken lines are stable due to their modest widths. Caves wider than 4 metres are uncommon, and may require a greater cover to ensure stability.

(Waltham, 1992; Froggatt, 1992; Lonsdale, 1995). Failure occurs by punching, where a plug of rock bounded by shear planes is pushed into the cave; only very thin cave roofs are seen to collapse as beam failures. Results have broadly justified the 3m of sandstone cover required in general foundation design for Nottingham buildings; they have also justified some flexibility in design with respect to caves where shapes and passage intersections render strict guidelines difficult to apply. Mathematical modelling of cave failures by finite element analysis (Roodbarkay *et al.*, 1994) is being employed to cross-check the results from the physical modelling; when this programme is complete, a comprehensive overview of all the test results will be published, to succeed the interim review (Waltham, 1996a).

Many cave roof failures have been a consequence of water reaching the rock, usually from a broken drain or pipeline. The sandstone loses 40-80% of its strength when saturated, and the normal result is therefore the progressive failure of the roof beds, perhaps through to the surface as a typical crown hole (Waltham, 1993). Any drainage failure, and saturation of the rock, can cause progressive cave roof failure regardless of any load imposed by a surface building. The saturated and overstressed sandstone breaks into beds, each typically 10-40mm thick, and upward stoping and cavity migration occurs when single beds fall away consecutively. A

Fig. 3. Tree roots hang from the failure zone where a crown hole developed beside North Sherwood Street. The roof sandstone was little more than 1 metre thick, and tree roots had grown into it from a thin soil cover. The fallen debris on the floor is broken blocks of sandstone capped by a cone of completely weathered sand and soil. The brickwork in the background is not related to the failure (photos by Tony Waltham).

cave 4m wide with a gently arched roof is likely to develop a stable arched profile after about 2m of sandstone has fallen away in the centre; no arch or failure rising more than 1.3m has yet been observed. Though the local building design guidelines are based on a cover of sound and dry sandstone over a cave, the 3m requirement does therefore also protect against crown hole failures in saturated rock.

Water may be the dominant factor in cave roof collapses, but some failures in dry rock have had other causes. Tree roots are a significant factor in many roof failures in the caves. Roots cannot penetrate the unjointed sandstone, but they find their way into even the narrowest of fractures. Their growth then forces the joint faces apart and may cause lateral extension of the initial fracture; the rock deformation also opens up bedding plane weaknesses and creates new fractures in massive sandstone. Fine root ends hanging into a cave are fair warning of an incipient failure, and rather thicker roots are commonly exposed by a failure (Fig. 3).

The caves cut into the foot of the cliff along Castle Road have experienced a number of roof falls over the years, all near the cliff face where tree root growth has been active. The single most unstable piece of rock became detached above a steeply dipping joint that intersected the cliff face at its toe (Fig. 4). This joint was being heaved wider at a rate of 1mm per day in the summer growing season, and it cut obliquely through the entire thickness of the wall and roof of a cave immediately inside the rock. Tree roots hung down inside the cave, while blocks were falling away into the cave, and the whole arch of the wall and roof was disintegrating (Fig. 5). The tree has now been removed and long dowels reinforce the thin sandstone wall. In January 1997, all the trees were cut down along these cliffs; this should eliminate any further deterioration of the caves, as long as the roots are completely killed and any subsequent regrowth is prevented.

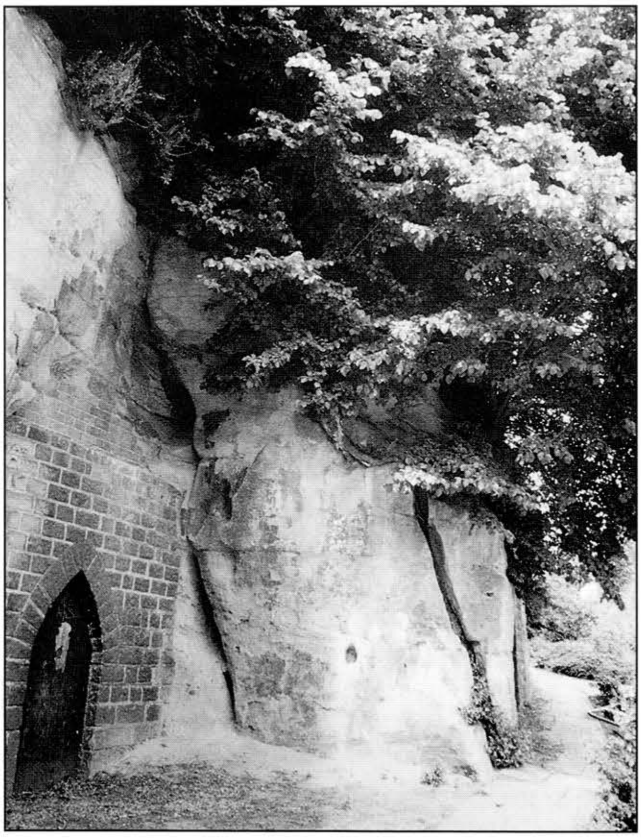

Fig. 4. The widening fissure beneath the unstable sandstone slab beside Castle Road, before the trees were removed and the rock was bolted.

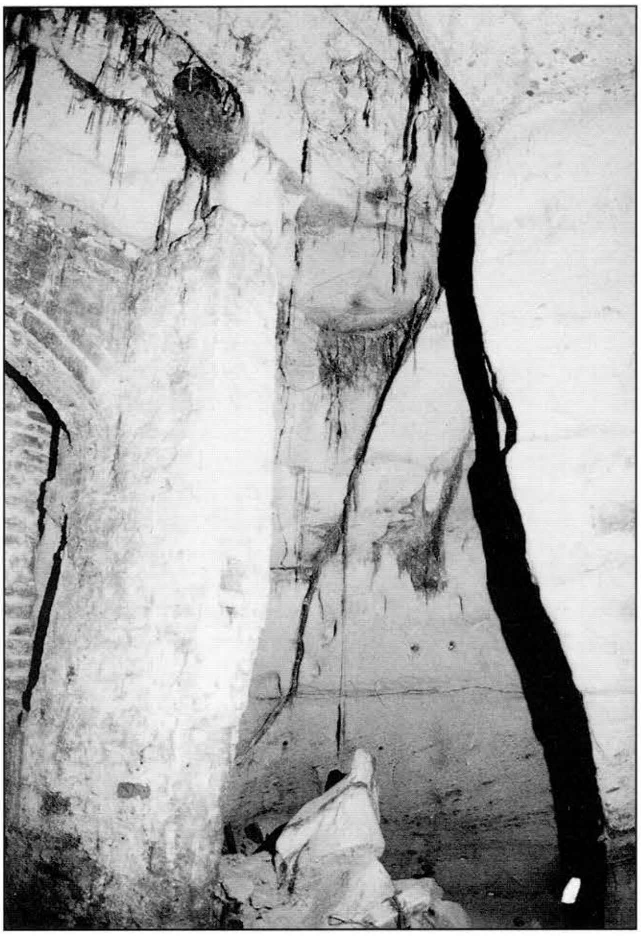

Fig. 5. Interior of the cave beside Castle Road, with the fissure seen in Figure 4 descending diagonally towards the left. The fine tree roots which hang from many bedding planes and joints have caused the roof falls whose debris lies on the cave floor.

While most cave roof failures can be attributed to water ingress or tree root expansion, there have been other events unrelated to either of these factors. A slab of sandstone, over a metre across, fell away from the roof of a cave under the north frontage of Goose Gate, where the rock remained dry and there were no trees. The fallen slab broke away from a bedding plane which had been 150mm above the cave ceiling. Long-term deformation of cave roof beds has not yet been measured, but hundreds of years of creeping sag of an unsupported bed of sandstone could cause de-lamination at a bedding weakness; the consequent loss of all tensile strength at the bedding plane would then hasten a failure.

The Brewhouse Yard caves are part of the museum visitor route, and have had numerous very small falls of roof sandstone, mostly where bed edges have broken back to their overhead bedding planes. In May 1996, a larger slab of sandstone fell away from the roof immediately in from the entrance arch, but this was a different style of failure. Within the cave roof, a vertical tension fracture developed parallel to the vertical maximum stress; as a feature of stress relief, this opened by about 3mm, as the rock moved towards the exposed cliff face, which receives no support or restraint from the museum building. The fissure opened only within the rock above the roof bed, so that it was not visible within the cave; its western end ran into a shaft, which was yet another weakness within the roof rock structure. The roof bed immediately above the cave did not move, so that bedding plane shear separated it from the moving block above (Fig. 6). The outer section of the roof bed was therefore held only in cantilever, until it failed completely. Initial deformation of the rock may have been aided by sagging across the span of the cave entrance, and this would have accelerated opening of the bedding plane.

The whole cave roof has now been reinforced by an array of 42 dowels. Holes 720mm deep were carefully bored into the cave roof, using a rotary drill to avoid vibration disturbance; steel bars, 700mm long with a load capacity of nearly 4 tons, were then inserted into each hole and cement grouted over their whole length. Grout covers the bar ends, and there is no face plate, so that the dowels are not easily seen. The reinforced unit of rock, 700mm thick, now acts as a coherent entity. Tensile strength of the Sherwood Sandstone is low perpendicular to the bedding, and is negligible across significant bedding planes, but the dowels effectively prevent bed de-lamination within their length.

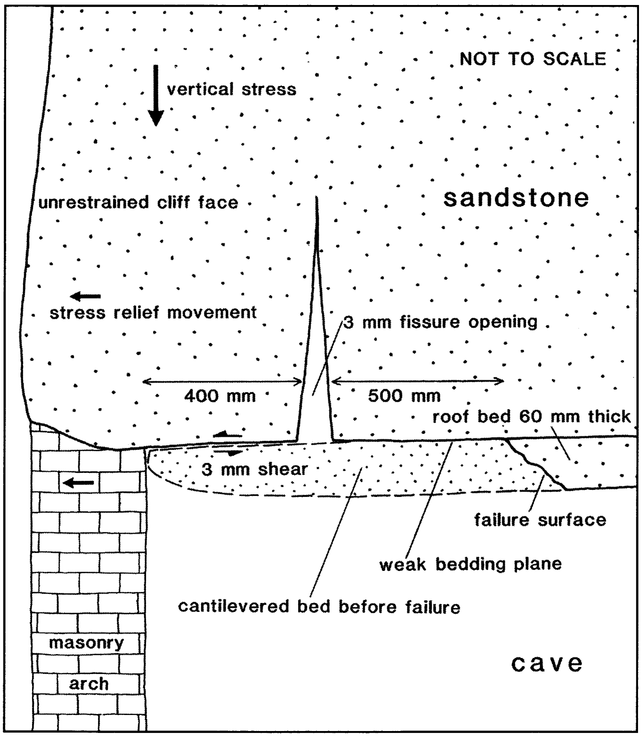

Fig. 6. Diagrammatic cross section of the failure of the sandstone bed which forms the roof in the cave behind the Brewhouse Yard Museum.

The Wollaton Street cave

Early in January 1997, a partial roof failure drew attention to the largest cave room in Nottingham. The cave's length of over 20m is not exceptional, but its width varies from 8 to 11m, and it is a full 3m high (Fig. 7). No other cave approaches the width of this unsupported span; the walls are curved into a partially arched profile, but the flat section of the roof is 6 to 7m wide (Fig. 8). The cave lies directly beneath the traffic lanes of Wollaton Street, and its huge roof span is probably just less than 3m thick. The original purpose of the cave is in doubt, though it may have been a wagon maker's workshop (Nix, 1984b), cut behind an old building on Derby Road, which was at a lower level in the eighteenth century. It is unrelated to Wollaton Street, which was an old sunken trackway cut down to its present level in 1852. The garage caves above the eastern end of the large cave were probably excavated in 1870 as store rooms, also reached by a shaft up to the rear of buildings on Talbot Street.

The size of this cave puts it beyond all known empirical data on stability assessment of the Nottingham caves. Structural analysis of the cave roof is hindered by not knowing the exact fracture patterns within the sandstone — which remain obscured until they are revealed by collapse. The roof gains strength through its part that is arching and is therefore in compression, yet it suffers weakness through lateral tension in the underside of the flat section, which behaves as a beam. The unknown balance of the components makes it difficult to estimate a reliable safety factor. The cave roof is also weakened by a drain trench through practically its whole thickness (Fig. 7).

In the recent roof fall, a slab of sandstone nearly 5 by 3m, tapering from 20 to 200mm thick, broke away from a pebble bed horizon that dips gently eastwards to pass just above most of the flat cave roof. No water or tree roots were involved, and the failure can only be ascribed to long-term de-lamination and creep of the roof bed; this may have been accelerated by traffic vibration. The main fall was probably triggered by the collapse of a wall on the north side of Wollaton Street, when the debris fell down the rock cliff and landed almost above the cave. After the main failure, small chunks of sandstone continued to fall away from the broken edge of the unsupported bed beneath the weak bedding plane. All the fallen rock has been from the zone of the roof left in tension, beneath a theoretical arch in compression; it is clear that the arch must be the mechanism that provides integrity in the cave roof, so the loss of rock from beneath the arch causes no direct reduction of the stability.

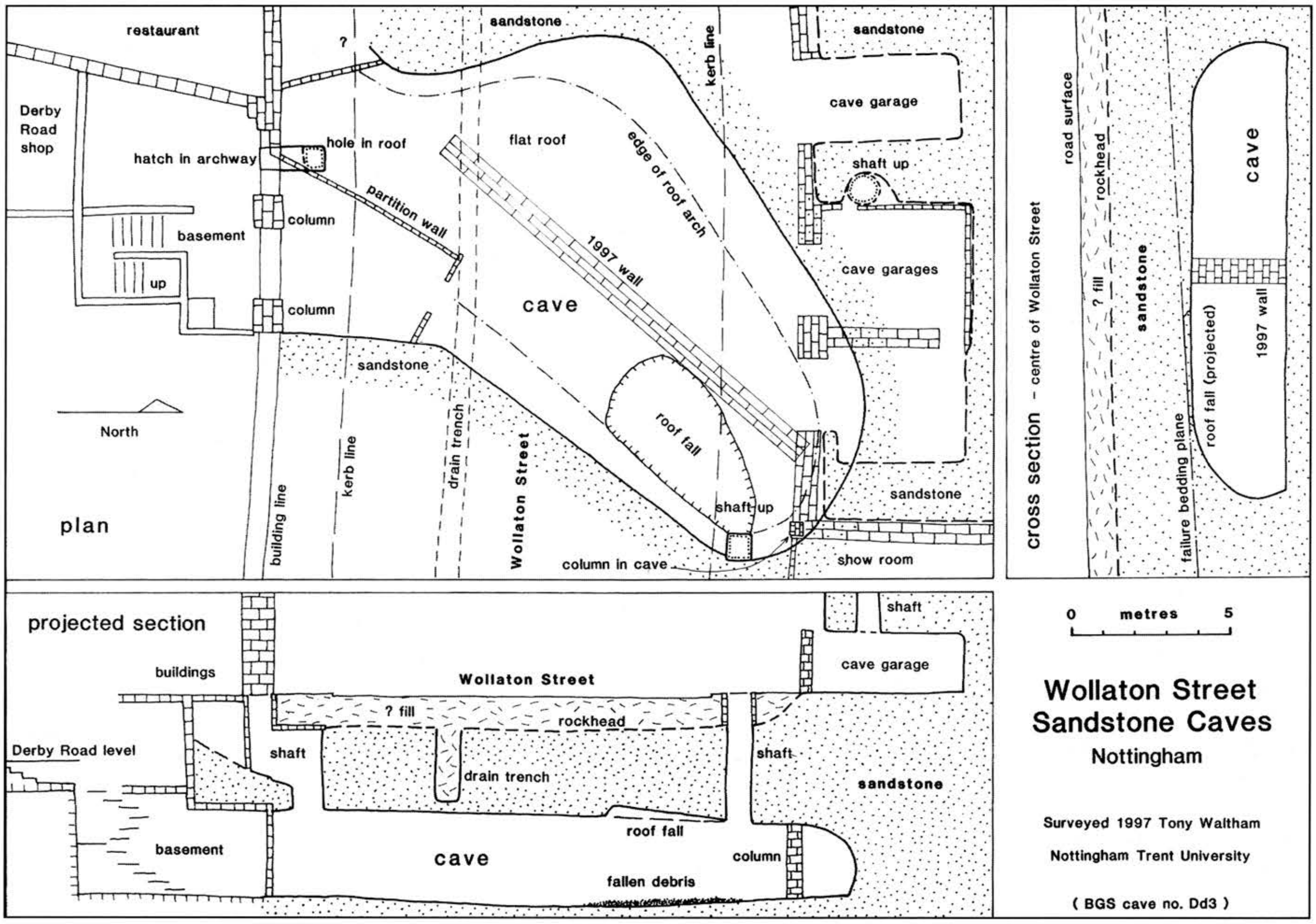

Fig. 7. Plan and profiles of the large cave beneath Wollaton Street.

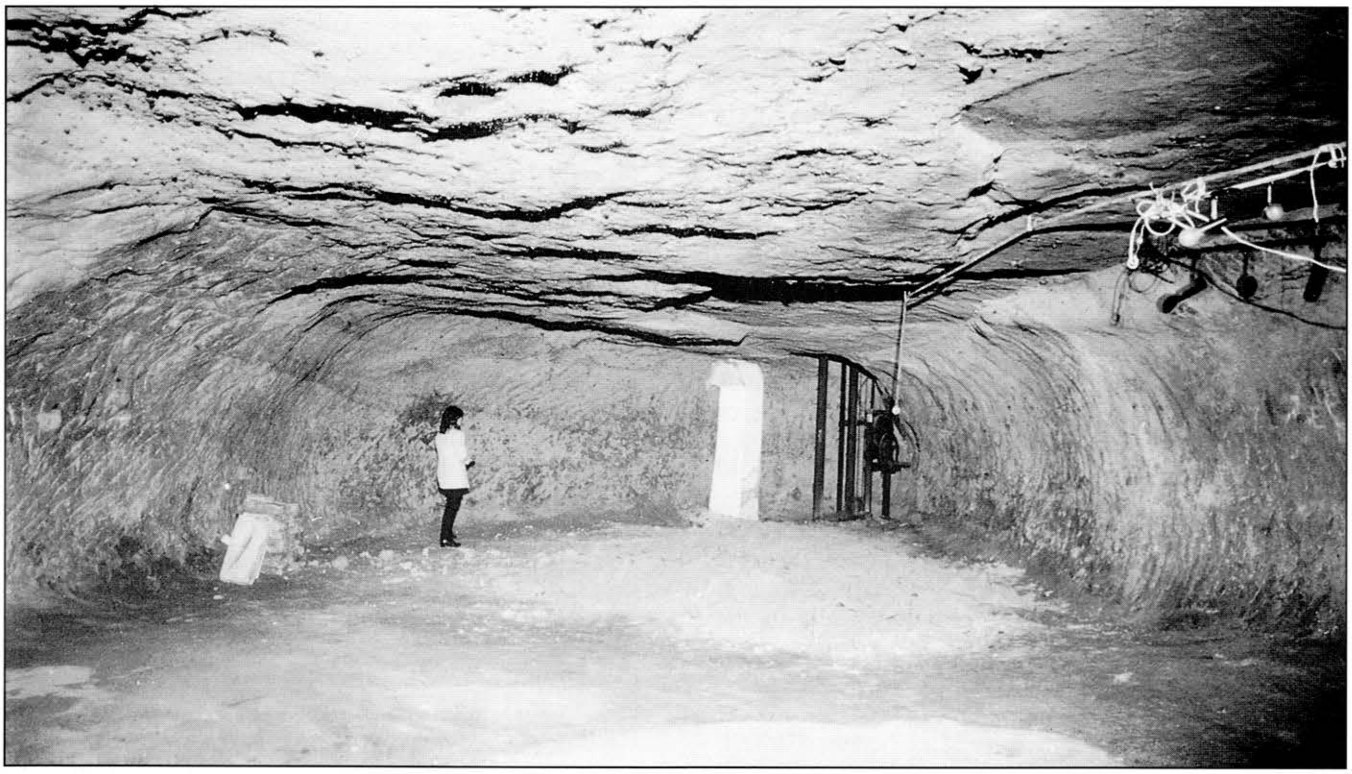

Fig. 8. Part of the Wollaton Street cave, looking towards the northeast, before construction of its central support wall. Beyond the light patch of concrete in the foreground, the low pile of debris is the sandstone which fell from the roof early in 1997.

Fig. 9. The statues of Daniel in the Lion's Den, in their cave within The Park. All surfaces are losing sand grains due to weathering, and unswept loose sand is visible at the foot of the two columns. The view is from the open cave entrance.

A consensus of opinion on the cave was that it was only marginally stable. Consequently, temporary internal supports were installed in March, before a load bearing wall was built along the centre of the cave in April 1997 (Fig. 7). This eliminates any threat of total collapse, and Wollaton Street is now safe from its unseen hazard. Meanwhile, concern may be directed to the possible existence of any other equally large caves, as the current building guidelines (Fig. 2) are based on caves up to about 5m wide.

Sandstone weathering inside the caves

Most of Nottingham's caves are entered by stairways that lead down from the basements of buildings. Their microclimate is therefore very stable, and weathering of the sandstone walls is negligible or absent. In contrast, caves that are open to the outside may experience cyclic changes of temperature and humidity within their atmosphere. This may cause weathering of the rock, irrespective of any effects due to moisture movement through the sandstone. Caves that have open entrances, and are not regularly swept out, are distinguished by the miniature scree banks of loose fallen sand grains along the bases of their walls (Fig. 9). Closed caves lack these scree slopes. Additionally, many closed caves that are damp have a layer of mould on their walls, and this appears to further prevent weathering, as loose grains on the surface cannot fall away.

This scale of weathering rapidly destroys any detail or features carved into the sandstone. The caves that have suffered most are those excavated at the behest of Thomas Herbert, and which contain the splendid statues carved into the underground bedrock (Nix, 1984a; Waltham, 1996b); they now lie within The Park. Daniel in the Lion's Den is the finest of the statues (Fig. 9), and it is steadily shedding sand grains, thereby losing much of its finer detail. Rates of wall decay have been measured by catching the fallen sand grains at the foot of the cave walls, and up to 20 grams of sand per week have been collected in trays just 700mm wide (Cubby, 1997). This translates into a mean rate of wall retreat of over 0.3mm per year. The wall disintegration varies in different parts of the caves (Table 1), and the mean retreat rate at the statues is about 0.1mm per year. Under uniform conditions during the 160 years since they were carved, in about 1837, the bare rock surfaces of the statues would have retreated by about 16mm.

cave	*3m in*	*14m in*	*worst site*	*at statues*
Daniel's	0.057	0.029	0.354	0.110
Fishpond	0.014	0.019	—	—

Table 1. Mean weathering rates in the sandstone caves over four months, November 1996 to February 1997. Rates are expressed in millimetres per year of wall retreat, based on fallen debris collected in trays. Daniel's Cave is open to the weather, but the Fishpond Drive cave is closed by doors and windows. Measured sites were 3 and 14 metres in from the entrance of each cave, and also at a notably weathered zone beside the statues in Daniel's Cave.

Caves carved into the more conglomeratic facies are distinguished by resistant quartzite pebbles which protrude from the walls where the matrix sandstone has weathered back (Fig. 10). Mean pebble protrusion in the area around the Daniel statues is 22mm, and the unweathered zone at the rear of Daniel's Cave has pebble protrusion of about 7mm. The latter figure may represent the cave wall profile as it was originally cut, in which case subsequent weathering has removed about 15mm from rock surfaces in the statues area; this value for wall retreat matches closely that calculated from current rates of wall degradation.

Microclimates are being monitored at various points inside these carved caves, and also in caves that have comparable front entrances in the gardens of houses along Fishpond Drive; some of these are like Daniel's Cave, with open entrances, but the monitored cave has doors and window glazing, which reduce or prevent air circulation.

Air temperatures inside the caves fluctuate in response to external changes, but the ranges of temperature fluctuation decrease further into caves, and are lower on caves without open entrances. Across the different sites within the various caves, weathering rates correlate broadly with the ranges of temperature variation (Table 2). The reduction of temperature variation and weathering within the less ventilated caves indicates the benefits of doors and windows on their entries. Periods of freezing and frequency of freeze and thaw may be expected to influence weathering, but during the programme of monitoring, freezing conditions have not reached even to the measured sites which lie only 3m inside the caves with open entrances.

location	*Temperature range, °C*	*Weathering mm/year*
outside	9.5	—
3m into Daniel's Cave	6.1	0.057
14m into Daniel's Cave	5.3	0.029
3m into Fishpond Cave	2.6	0.014
14m into Fishpond Cave	2.0	0.019

Table 2. Temperature ranges recorded at sites during December 1996, correlated with the mean rates of weathering (in millimetres per year) measured over a period of four months. The temperature range at 14 metres into the Fishpond Drive cave is only approximate, as it is based on fewer readings.

Fig. 10. The heavily weathered wall of the Herbarium Cave, which has its unprotected entrance in The Park close to Daniel's Cave. Pebbles protrude from the rock due to the loss of weathered sand grains, some of which are still banked along the foot of the wall.

The role of water in the weathering of the cave walls is not yet clear. The monitored caves lie beneath open ground with just a thin soil cover and discontinuous garden paving, yet weathering rates show no recognisable correlation with overall rainfall patterns (Table 3). Individual storm events may have an impact if the rock becomes saturated, but this has not been identified. Water does not drip into either of these caves, even though the Fishpond Drive cave intersects several fissures. Humidity inside the caves is always high, and contrasts between the monitored sites have not been recognised. Moisture contents of the sandstone surface layer in the cave walls have been measured approximately with an electric probe dampmeter (originally designed to measure moisture in timber). Moisture values show very little variation deep inside the caves. The greatest variation was found in the rapidly weathering zone in Daniel's Cave, at the same time that moisture levels were found to be closer to constant both farther inside the cave and nearer to the entrance.

Preliminary results from the monitoring programme do suggest that the fitting of good doors and windows on all the entries should be an effective way of prolonging the survival of the splendid Daniel statues. It appears that, without new doors, the statues will be lost sooner rather than later. There is however a possible disadvantage to such action; in a more stable cave environment, the statues may eventually acquire a covering of mould and lose their very clean appearance. Waterproof sealing of the sandstone above the caves would be expensive, and the potential benefits appear to be minimal. Modern methods of preservation of stone statues are based on injection with some form of resin or silicate gel; this would prove difficult and expensive for the Daniel and the Lions statues, due to the fragile nature of their remaining sandstone.

Geological variations are among other factors that influence weathering in the caves. Some beds and zones of the sandstone weather at higher or lower rates than the mean, but susceptible areas do not just follow the bedding, are not visually identifiable (except by their weathering rates), and the material is not available for sampling. In contrast to the zone within Daniel's Cave which has the highest weathering rate, the Summerhouse Cave, adjacent to Daniel's, has almost no deterioration by weathering of its carvings in the sandstone. This cave now lies beneath the protective umbrella of a house, but this has only been there since 1968, and the cave has probably had open doorways and windows for nearly as long as has Daniel's Cave.

Rainfall, mm/day		1.5	1.7	2.2
Daniel's	3m in	0.034	0.087	0.048
	14m in	0.003	0.022	0.053
	worst	0.328	0.385	0.235
Fishpond	3m in	0.004	0.025	0.013
	14m in	0.004	0.040	—

Table 3. Variations of rates of weathering of the cave walls (in millimetres per year) at various sites within the caves, correlated with mean daily rainfall over three periods, each of 4-6 weeks, in differing weather patterns.

While weathering is a significant problem in the open caves, the sandstone is also prone to slow disintegration within almost any cave; this is well known to drinkers in the Trip to Jerusalem bars, where beer mats are best placed on top of the glasses to protect the amber nectar from the rain of sand grains. The adjacent Brewhouse Yard caves are suffering from numerous small roof falls, mostly of a few hundred grams of sandstone at a time. These cannot be stopped, as the surface zone of the rock is just too weak; probably the only response is to clean the cave roofs by picking them over lightly with a bar and chisel, to create a new stable profile in better sandstone, but this raises conservation issues in the older caves.

At exposed sites, the sandstone weathering may contribute to an even larger scale of roof deterioration, and eventual cave collapse. The admittedly incomplete historical records do indicate a disproportionate number of collapses in the caves along the cliffs reaching from Castle Rock, past Broad Marsh and onto Sneinton Hermitage, where more caves were open to the cliff instead of being protected under buildings. Nottingham's caves may be regarded as part of the urban heritage, but it does appear that not all of them can survive into perpetuity.

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Llanvirn-Llandovery activity on the Llangranog Lineament in Southwest Ceredigion, Wales

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Abstract: A new course is proposed for the Llangranog Lineament between Corris and Strumble Head. Evidence of major contemporary down-to-northwest movement is lacking in the Arenig, fairly firm in the Llanvirn volcanic sequences and weak in the early Llandeilo. Further evidence is provided by both the presence and distribution of turbidites in the mid(?) Llandeilo-Caradoc west of Cardigan, which are absent across the Lineament to the southeast. Later, the Lineament footwall determines the northwestern limit of a non-sequence at the base of the Ashgill around Crymych. Recurrent movement on the Lineament together with movement on the Central Wales Lineament controlled the distribution of turbidites in the early Ashgill around Newcastle Emlyn and in the mid Llandovery around Pencader. Intensity of movement probably increased in the late Llandovery when the Llangranog Lineament controlled the eastern margin of the depotrough of the Aberystwyth Grits.

The Llangranog Lineament

In recent years it has been increasingly appreciated that a distinct zone of relatively high tectonic strain and rapid sedimentary facies changes extends along much of the coastal area of Ceredigion. Important structural elements of the zone include the Sarnau vergence divide south of Llangranog (Craig, 1985) and the Glandyfi vergence divide northeast of Aberystwyth (Cave and Hains, 1986). These were correlated by Craig (1987), on the basis of detailed structural studies, as elements within a major Llangranog Lineament, continuous from Cardigan to the Llyfnant valley. The Lineament was considered to represent the surface expression of a zone of tectonic adjustment between basement blocks. Indeed it overlies a possible deep-seated fracture, the Corris-Llangranog Fault, postulated by James and James (1969) largely on the basis of sedimentological studies in the Ashgill strata of the region.

The Lineament has been referred to variously as the Corris-Llangranog Lineament (Smith, 1987a; James, 1991) and, in the north, as the Glandyfi Lineament (Wilson *et al.*, 1992). Assuming physical continuity, it would be helpful to stabilise on one simple terminology, namely the Llangranog Lineament (e.g. Smith and Anketell, 1992). It has been suggested recently (Wilson *et al.*, 1992) that the Lineament is not continuous along the line suggested by earlier workers and thus a new synthesis of its location and continuity is needed, although not all workers accept the Lineament as a major structure (e.g. Pratt, 1992, fig. 1). This paper attempts to provide such a synthesis and to assess over what timespan the Lineament can be demonstrated to have exerted influence on sedimentation. The synthesis requires integration of sparsely distributed modern and classic published work with data from several unpublished postgraduate theses and with my own field work, much of which is of a reconnaissance nature in poorly exposed areas not studied this century. Parts of the synthesis are therefore speculative; however, they do fit within a self-consistent model which is offered for future testing.

Figure 1 illustrates the concept that the Lineament is continuous between Strumble Head and Corris and that its eastern margin is defined by major faults at the present day surface. In the north of the area these are the Corris Fault and, in agreement with Craig (1987), the Brwyno Fault. Inland from Aberystwyth, the Brwyno and Allt-y-Crib Faults of the Glandyfi tract (Cave and Hains, 1986) and possibly also the Dinas Mawddwy Lineament appear to merge with the major Bronnant Fault (Wilson *et al.*, 1992). Farther southwest, this in turn is here correlated with the Bwlch y Fadfa Fault mapped by Anketell (1987). This latter correlation arises from the coincidence of the Bwlch y Fadfa Fault and the incompletely mapped portion of the Bronnant fault system between SN 440 500 and 470 520. Moreover, the Bwlch y Fadfa Fault marks the southeastern margin of the regional fold vergence divide (Anketell, 1987) in obvious similarity to the Bronnant-Glandyfi fault system (Wilson *et al.*, 1992; Cave and Hains, 1986). Between Newcastle Emlyn and Eglwyswrw there is a gap in published mapping; however, the most plausible Lineament-bounding correlative fault would appear to be that defining the northern extremity of the Fishguard Volcanic Group around Newport (see Figure 1 and Lowman and Bloxam, 1981). The trace of the fault to the west of Fishguard is not clearly recognisable on published geological mapping. If present, its continuation probably lies southeast of the Fishguard Volcanic Group within the Arenig-Llanvirn sequence of the southeast limb of the Goodwick syncline in the Strumble peninsula, before entering Cambrian strata and passing out to sea immediately south of Abercastle (see map in Bevins *et al.*, 1989). A fault in this position could merge with the fault near Newport via a WNW-facing relay ramp, centred about 1.3km east of Fishguard, which contains the Carn Fran and Carn Gelli Faults (see Lowman and Bloxam, 1981, fig. 1).

Between Newport and Machynlleth the position of the Llangranog Lineament argued in this paper shows good to fair correlation with the zone of strong Euler gravity anomalies identified by

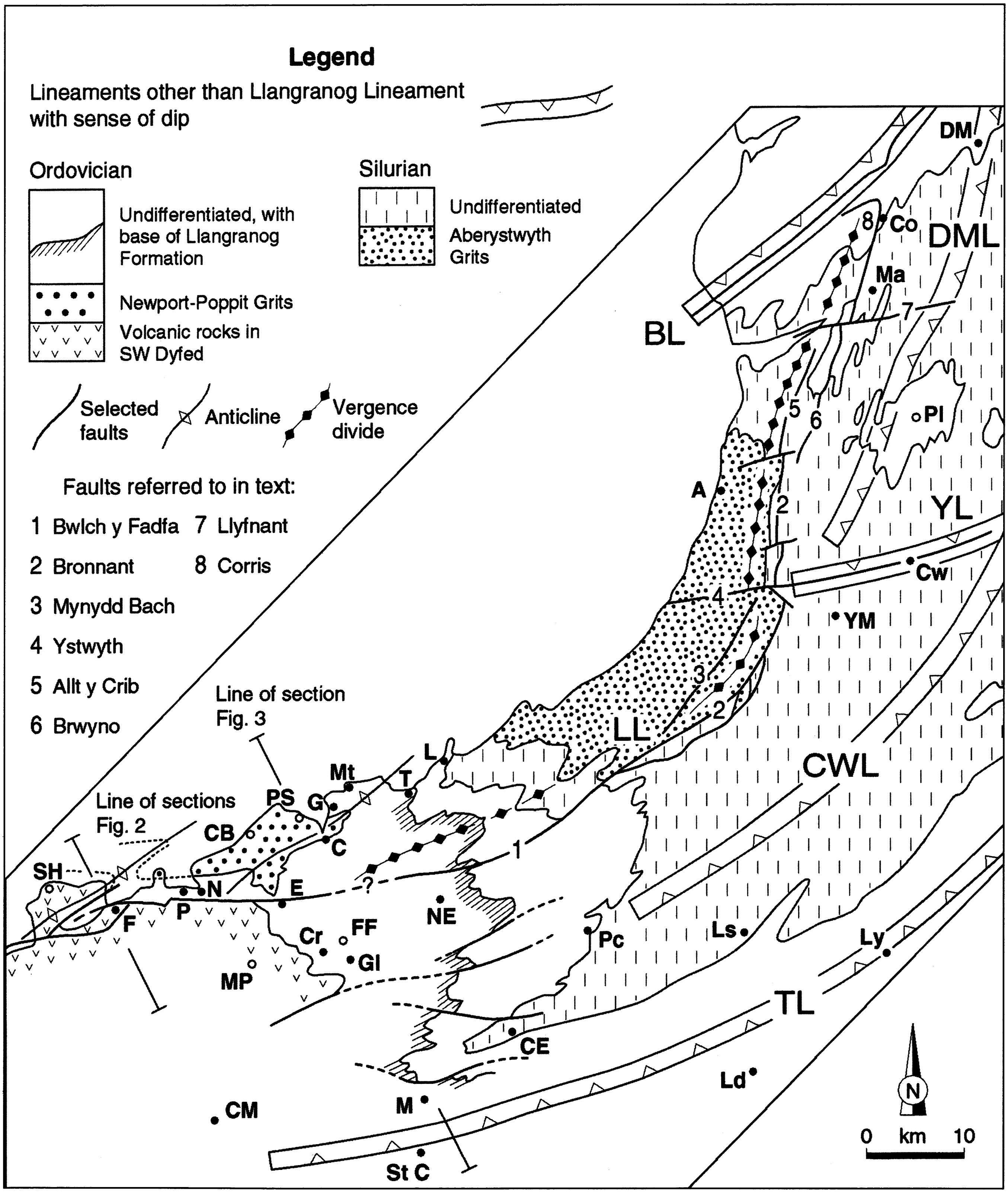

Fig. 1. The Llangranog Lineament as defined by vergence divides and bounding faults on its eastern margin: also shown are other established lineaments.
Legend to localities: A, Aberystwyth; C, Cardigan; CB, Ceibwr Bay; CE, Conwil Elfed; CM, Cotland Mill; Cm, Carmarthen; Co, Corris; Cr, Crymych; Cw, Cwmystwyth; DM, Dinas Mawddwy; E, Eglwyswrw; F, Fishguard; FF, Freni Fawr; G, Gwbert; Gl, Glogue; L, Llangranog; Ld, Llandeilo; Ls, Llansawel; Ly, Llandovery; M, Mydrim (Meidrim); Ma, Machynlleth; MP, Mynydd Preseli; Mt, Mwnt; N, Newport; NE, Newcastle Emlyn; P, Parrog; Pc, Pencader; Pl, Plynlimon; PS, Poppit Sands; SH, Strumble Head; St. C, St. Clears; T, Tresaith; YM, Ystrad Meurig. Key to Lineaments: BL, Bala; CWL, Central Wales; DML, Dinas Mawddwy; LL, Llangranog; TL, Tywi; YL, Ystwyth. Data from Anketell (1987), Cave and Hains (1986), Craig (1987), James (1991 and unpublished), Lowman and Bloxam (1981), McCann (1992) and Wilson *et al.* (1992).

McDonald *et al.* (1992, fig. 6), although the interpretation of basement fault positions shown by these authors does not correspond wholly with that of this paper. Inland of Llangranog, the newly-argued eastern margin of the Lineament lies some 5-7km southeast of the position of the Corris-Llangranog Lineament as depicted by James and James (1969, fig. 1).

Stratigraphical changes across the Lineament

Arenig. Recent study by Traynor (1988) indicates that the sub-Arenig foundation across the trace of the Llangranog Lineament as drawn here is, wherever exposed, formed by the Ogof Velvet Formation (Cambrian). In view of the variable nature of the sub-Arenig foundation elsewhere in South Wales, this suggests quiescence of the Lineament in the early Moridunian. Traynor (1988, p. 289) suggested rapidly increasing localised subsidence in the late Moridunian to early Whitlandian but his palaeogeographical maps (1988, fig. 8) are inconclusive with respect to the influence of fault-control, both with his own positions of basement lineaments (1988, fig. 1) and with those of this paper. It is thus likely that the structural grain of the Llangranog, the Central Wales and, less certainly, the Twyi Lineaments was not strongly developed in the early Arenig and that either inherited regional pre-Arenig structure or local contemporaneous volcano-tectonic structure was still predominant.

Llanvirn. The Fishguard Volcanic Group immediately south of the Lineament is about 90-220m thick around Mynydd Preseli (Evans, 1945) and 65-220m in the equivalent Llanrian Volcanic Formation at Abereiddi Bay (Hughes *et al.*, 1982), which lies to the west of the area shown on Figure 1. It thickens dramatically north of the Lineament to ca. 1800m of subaqueous lavas on the Strumble Peninsula (Bevins and Roach, 1979). This is very suggestive of differential tectonic subsidence across the Lineament and would indicate the same down-to-northwest direction of throw that will be shown below to characterise the later history of the Lineament. However, it could equally indicate differential accumulation of positive relief in a deepwater lava pile and it is plausible that both factors operated (Fig. 2). The thinning of the volcanic rocks across the trace of the Lineament is very rapid and differential isostatic subsidence across it would have been aided by a down-to-northwest fault. The Carn Gelli Fault, which may form a link fault within the Lineament, appears to have been active at this time, bounding accumulation of basaltic pillow lavas (Lowman and Bloxam, 1981, p. 64). On the other hand, any such northwest-facing relief appears to have been locally overcome and indeed reversed by up-building lavas. The evidence for this lies in the sediments of the Strumble Head Series which form thin, local intercalations within the pillow lavas of the Fishguard Volcanic Series near Strumble Head. Thomas and Thomas (1956, p. 301-303) noted that the sediments include cross-bedded feldspathic sands with well-rounded spilitic pebbles, that weathering profiles underlie some of the unconformable contacts of the sediments and that lava stacks had been 'smoothed' before onlap by the sands. These observations suggest shallowing to at least storm wave-base and possibly emergence (George, 1970, p. 27). Southeast of the Lineament, mudstone intercalations replace the intra-lava sands (Evans, 1945), indicating relatively deeper water hereabouts.

Kokelaar (1988, p.771) used evidence from the petrochemistry of the basaltic pillow lavas and of their probable ponding in a graben to propose that the Llangranog Lineament was active at this time in southwest Wales, although he found no evidence that its component faults cut the present day outcrop of the volcanics. He also considered that the volcanics did not form significant positive topography on the sea floor — a view not accepted here. The model illustrated in Figure 2 and the bounding fault location shown on Figure 1 otherwise concur with the majority of Kokelaar's arguments for intra-Llanvirn activity.

Llandeilo. Northwest of the Lineament, Llandeilo rocks comprise the Castle Point Beds (Lowman and Bloxam, 1981) overlain by the mudstones of the Parrog Formation (McCann, 1992). To the southeast the Llandeilo is represented by the Hendre Shales (Evans, 1945). The latter overstep the black shales of the underlying *D. murchisoni* Beds about 2.3km WSW of Eglwyswrw (SN 110 385) (Evans, 1945, p. 99). Judging from the progressive northwest thinning of the *D. murchisoni* Beds over a distance of at least 5km shown by Evans (1945), it is likely that the overstep is genuine and not an artefact of faulting. The overstep suggests that the Lineament then either lay within the southeast flank, or defined the northwest margin of a submarine high north and west of Crymych. The former scenario cannot be proved if the absence of the *D. murchisoni* Beds across the trace of the Lineament in the Goodwick Syncline 1km WNW of Fishguard results from faulting rather than non-deposition, but such faulting is not apparent in the map of Thomas and Thomas (1956, pl. XIV). Absence due to pre-Castle Point Beds faulting is plausible but impossible to prove with current outcrop. The latter scenario, of deepening to the northwest across the Lineament, would be consistent with the presence of thin turbidite siltstones and sandstones in the Parrog Formation (McCann, 1992) and the absence of such deposits in the more calcareous Hendre Shales. The simplest synthesis of this data is that, after the volcanic episode, a northwest facing palaeoslope was not re-established across the Lineament until the Llandeilo (Fig. 2). Subaqueous debris flows within the Castle Point Beds at Fishguard (Lowman and Bloxam, 1981, p. 60) probably indicate proximity to the active Lineament. These debris

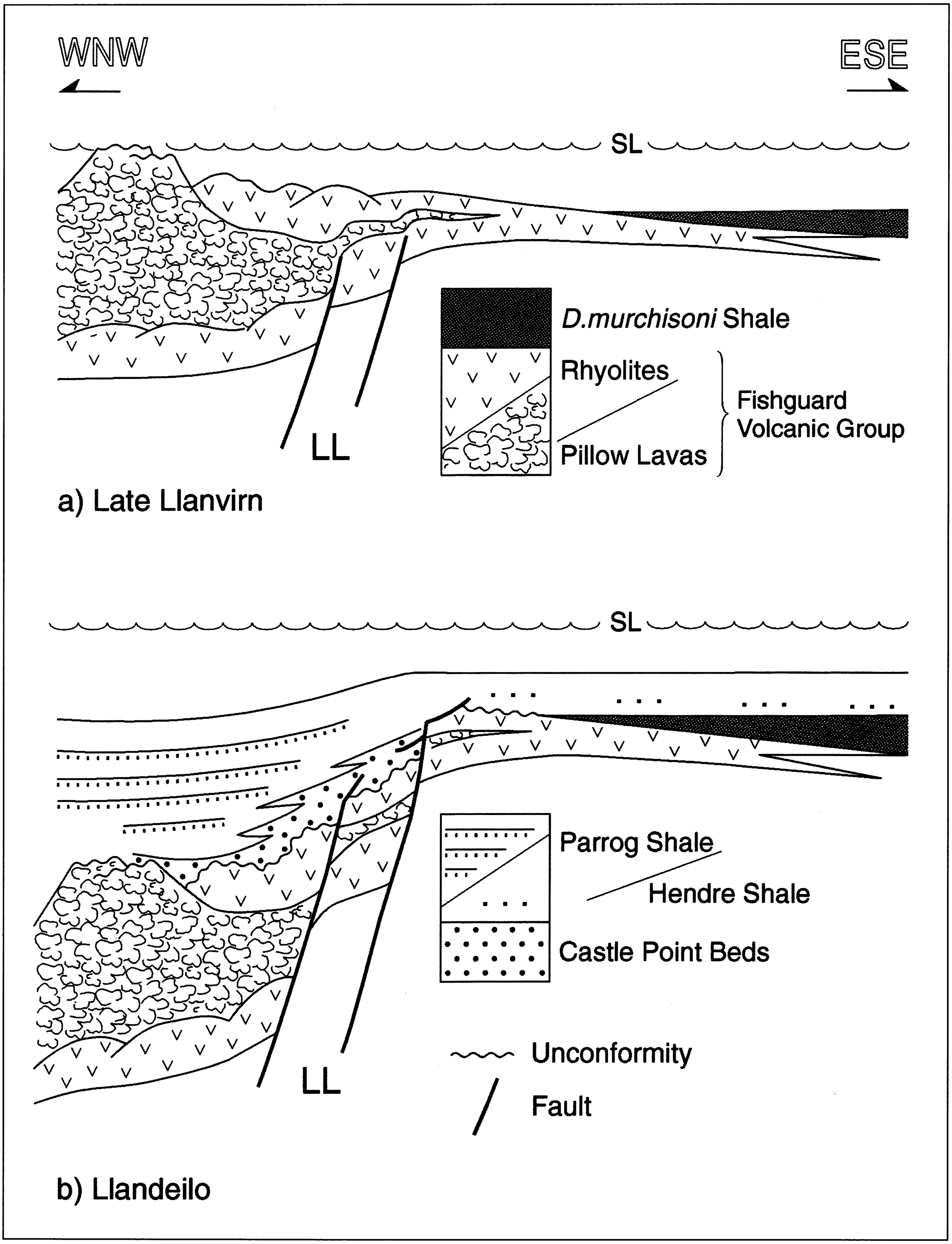

Fig. 2. Cartoon geological sections (not to scale) across the Llangranog Lineament (LL) near Strumble Head (see Fig. 1) illustrating the hypothesis that the Lineament was active in the Llanvirn-Llandeilo. Note the non-deposition of the *D. murchisoni* Shales northwest of the Lineament, a key argument for contemporaneous elevated topography there.

flows, e.g. under the northwest wall of the fort at Castle Point (SM 962 378), contain 2-20cm clasts of black shale and 3-8cm clasts of flinty volcanic rock in a sandy mudstone matrix. However, the majority of the Castle Point Beds consists of parallel laminated 0.1-0.3cm Bouma *ae* sandstone event deposits spaced at 1-2cm intervals within silty mudstone, with rare rusty weathering 3-9cm *ab* beds of high-matrix sandstone. These 'background' beds are not typical turbidites; they show no current or wave ripples, no flute casts, no interbedded mudstone and no fauna, but do contain 1-3cm vertical to inclined burrows with a sandy fill. Although the thin event deposits are commonly individually slurried, large scale mass flow phenomena are absent. Water depth during deposition of the Castle Point Beds at Castle Point is thus equivocable but is not demonstrably deep. It is likely that water depth increased appreciably during sedimentation of the Parrog Formation which is typically 'basinal' in aspect (McCann, 1990b).

Caradoc. Turbidite sandstones and interbedded mudstones of predominantly (possibly entirely) Caradoc age occur in the *N. gracilis* to *D. clingani* Biozones between Dinas Head and Cardigan (James, 1975; McCann, 1992), within a region of spectacular, albeit poorly accessible, coastal exposure and extremely poor inland exposure. In ascending sequence, the succession comprises the Newport, Ceibwr and Poppit formations as defined by McCann (1992), who estimated their thicknesses as 200m, 50m and 300m respectively. There is considerable uncertainty in the precision of these estimates, which imply average northeasterly fold plunges of between 1 and 3 degrees across the extents shown by McCann. Such plunges are at variance with McCann's statement (1992, p. 57) of 35-45 degree plunges and with my own observation of 5-20 degree northeasterly plunges in the Poppit Formation. It is very probable that the total thickness of these turbidite formations is much greater than 550m, although by how much is currently unclear. The thickness of 50m given by McCann for the Ceibwr Formation is less than the 60m height of the cliffs at the type section (McCann, 1992, fig. 7a). In his original (thesis) work McCann (1990b) gave thicknesses of 'up to 700m' for the Newport Sands Formation (now the Newport Formation) and 'c. 750m' for the Poppit Sands Formation (now the Poppit Formation).

The distribution of the Caradoc turbidites inland in sketched in Figure 1 and owes much to the reconnaissance by Challinor (1927). It is fairly clear that the turbidites thin rapidly and/or become faulted out towards Eglwyswrw and the probable WSW prolongation of the Bwlch-y-Fadfa Fault (Anketell, 1987). Across the trace of this fault the partly coeval Mydrim Shales around Crymych appear to be only c. 92m thick (Evans, 1945). No turbidites are reported here although the Caradoc may be, at least locally, incomplete as many of its contacts were mapped as faulted by Evans (1945). The Mydrim Shales are shown as c. 210m thick at Mydrim (Meidrim in current O.S. spelling) by Williams *et al.* (1972) and again, no turbidites appear to be present (D. C. Evans, 1906). There is thus no evidence of clastic supply from the southeast, consistent with (limited) palaeocurrent evidence for northeasterly transport both at Poppit Sands (James, 1975) and within the Newport Formation (McCann, 1990b). The Caradoc turbidites therefore appear to be ponded laterally by the Llangranog Lineament.

Ashgill. In the coastal sections between Cardigan and Aberporth, the Caradoc turbidites of the Poppit Formation are geographically succeeded, in a northeasterly direction, by a muddy succession comprising the Gwbert Formation (at least 380m), the Mwnt Formation (c. 350m), and the Tresaith Formation (c. 350m). These are succeeded by the more sandy Llangranog Formation (c. 140-800m) as shown by Anketell (1987) and McCann (1990a). The Caradoc-Ashgill boundary was placed, without explanation, within the Mwnt Formation by McCann (1990a, fig. 3) who considered the four formations to be stratigraphically sequential without either supporting evidence or reference to the conclusions of Craig (1985), who had earlier presented a well-argued case that the Gwbert Formation correlates with the Tresaith Formation and the Mwnt Formation with the Llangranog Formation. Craig's correlations are plausible sedimentologically but cannot yet be demonstrated directly as a distinctive 5.5m orange weathering horizon with *D. anceps*, which lies 27m below the base of the Llangranog Formation on the coast (Anketell, 1987 p.157), has not yet been found in a comparable position below the base of the Mwnt Formation. No detailed mapping is available to assess the inland extent of the Gwbert and Mwnt formations. However, unless the latter is restricted to the northwest limb of the anticline running through Aberporth (Craig, 1987, fig. 1) it should, if older than the Llangranog Formation, cross the coast between SN 250 520 and SN 270 516 around Aberporth (where exposure is good) and persist inland. My fieldwork shows that this is not the case: the Mwnt Formation is not present along the coast here and neither the Mwnt Formation nor the Gwbert Formation is obvious inland, where the presence of extensive exposures of monotonous Tresaith Formation along the lower portions of the Teifi valley argue against McCann's (1990a) stratigraphical interpretation. The Gwbert Formation is thus best thought of as a local unit within the Tresaith Formation. Both are intensively burrow-mottled, but the Gwbert Formation contains a relatively high proportion of silty/sandy Bouma *cde* intercalations.

The basal Ashgill of the Crymych area is formed by the Glogue Slates (Evans, 1945), which are well exposed in the Glogue quarry (SN 220 328). These are strongly burrow-mottled without silty/sandy intercalations and are thus more reminiscent of the type Tresaith Formation (see below) than the type Gwbert Formation. Evidence that the contact between the Glogue Slates and the Mydrim Shales near Crymych could be unconformable (Evans, 1945, p. 100-101) may be significant. Such an unconformity would lie on the footwall of the Llangranog Lineament and may equate to part of the time represented by the Gwbert Formation. Alternatively, this Formation may have been ponded laterally by the active Lineament. Table 1 illustrates the published stratigraphies.

The Tresaith Formation is a distinctive sequence of both homogeneous and cm-scale layered mudstones with a characteristic, commonly strong, burrow-mottled texture. It was defined in the coastal area by Anketell (1987, p. 157) but is clearly very similar in facies to mudstones cropping out along the Teifi valley from around Newcastle Emlyn to the Carnarvon quarries (SN 190 450) near Cardigan. Similar burrow mottling occurs in the Nant-y-Moch Formation of the Plynlimon area (James, 1971) and in the Nantmel Formation along the Teifi Lineament (Wilson *et al.*, 1993): a Cautleyan/ Rawtheyan age appears likely. In the coastal exposures near Aberporth, the Tresaith Formation contains local disrupted horizons, probably due to slumping on the downthrown side of the Llangranog Lineament. Turbidite sandbodies up to about 70m thick occur within the upper portions of the Tresaith Formation along the Teifi valley (Tata, 1985). Their principal concentration, containing the thickest individual turbidite beds and coarsest grain sizes, is consistent with ponding in the hangingwall of the Central Wales Lineament, implying uplift on the footwall of the Llangranog Lineament. Tata (1985) found that sole marks always indicate northeasterly-directed palaeocurrents, whereas current ripple lamination commonly indicates north to northwest directed flow. This would be consistent with soliton development (Kneller *et al.*, 1991) on a nearby northwest-facing slope caused by movement on the Central Wales Lineament (Fig. 3). The northwesterly disappearance of the unconformably-based shallow water Sholebrook Limestone near St Clears suggests that the Tywi Lineament may have been active in the Rawtheyan and defined the early Ashgill shelf margin. In the basin, possible time equivalents of the Sholebrook Limestone are thin, locally developed, carbonate turbidite beds (unit 3 in Figure 3), typical examples of which may be seen in the Cothi valley (SN 5330 2463), 12km ENE of Carmarthen.

The stratigraphical position of the c. 290 metre-thick Freni Fawr Beds (Evans, 1945, p. 101) is currently unclear. The sandstones and a 2 metre-thick local conglomerate reported in the Freni Fawr Beds by Evans may be a coarse member within a non-mottled variant of the Tresaith-Glogue facies (similar mudstones occur in the commonly burrow-mottled Broad Vein Formation at Corris). Alternatively, they could overlie this facies as the lateral equivalent of a coarse member within the Llangranog Formation, the mudstones of which are not typically burrow-mottled. The latter alternative requires either reversal of the dominant ENE-directed fold plunge, or down-to-southwest faulting in this area and considerable thinning of the Tresaith Formation in the hangingwall of the Central Wales Lineament. The former alternative requires such

				Llangranog Lineament
	Coast (hanging wall)			Inland (footwall)
Series	*a*	*b*	*c*	*d*
Ashgill	Llangranog Fm.	Mwnt Fm.	Llangranog Fm.	not preserved
	Tresaith Fm.	Gwbert Fm.	Tresaith Fm.	----?----?----?----?---- Freni Fawr Beds
	Mwnt Fm.			Glogue Slates
Caradoc		not studied		possible disconformity
	Gwbert Fm.			Mydrim Shales
	Poppit Fm.			
	Ceibwr Fm.			
	Newport Fm.			

Table. 1. Caradoc-Ashgill stratigraphy across the Llangranog Lineament in SW Ceredigion, including alternative correlations in the coastal area. **a**, Cardigan to Llangranog, after McCann (1990b); **b**, **c**, respectively SW and NE of Tresaith, after Craig (1985); **d**, the Crymych area, after W. D. Evans (1945).

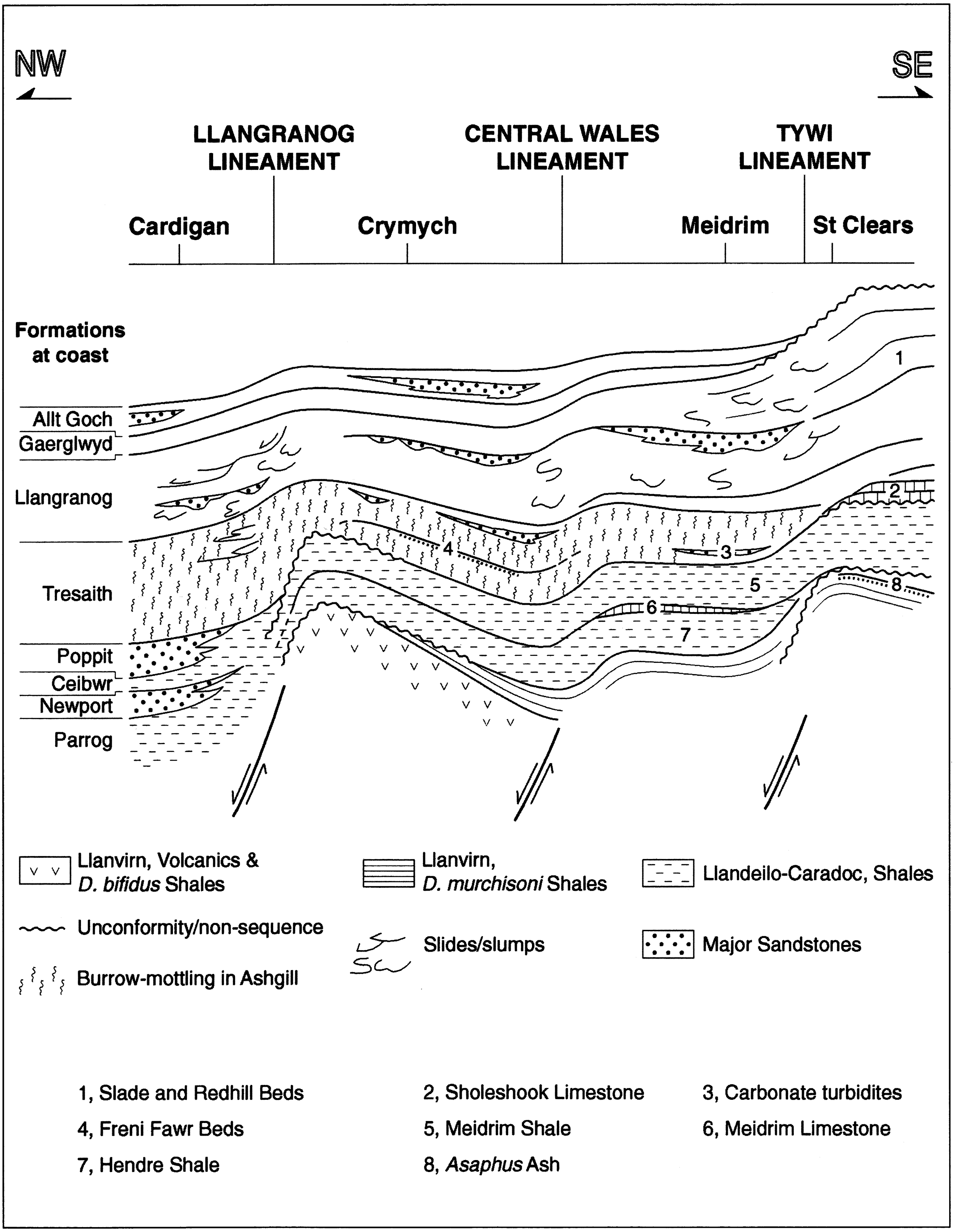

Fig. 3. Cartoon geological section (not to scale) from Cardigan to St. Clears (see Fig. 1) illustrating sedimentary relationships across the lineaments at end-Aeronian time. In the absence of detailed modern study for much of this section it is difficult and subjective to draw the diagram with a true vertical scale. Note the unconformities on footwall highs and the concentrations of major sandstones above hangingwall lows.

structural arrangement only if the Freni Fawr sandstones equate with those studied in the upper portion of the Tresaith formation by Tata (1985). However, if they are stratigraphically lower, no plunge reversal or faulting may be needed. Distinction between these possibilities awaits mapping of the area between Freni Fawr and Newcastle Emlyn. My reconnaissance sampling suggests that non-mottled mudstones with thin (<3cm) siltstones, possibly equivalent to the Freni Fawr Beds, occupy a wide area between the type locality and the Cych valley between Cwmorgan (SN 293 349), and northwest of Llancych around SN 253 832. Exposure is poor but they appear less well developed to the northwest and to lie at a lower stratigraphical level than the sandstones studied by Tata (1985). This conclusion is adopted in Figure 3. The sandstones on Freni Fawr (SN 202 350) are nowadays more sporadically exposed than in Evans' (1945) days, but where seen appear to be generally thin (2-7cm) and intercalated with somewhat thicker (5-12cm) mudstones. Sandstone samples from Freni Fawr resemble the coarser facies of the Nant-y-Moch Formation at Plynlimon (James, 1971), notably in containing re-sedimented shelly material at the base of graded units. This fauna led George (1970) to suggest a shallow water origin for the sandstones of the Freni Fawr Beds. However, the thicker sandstones show typical turbidite structures and no *in-situ* shelf fauna has yet been found in the mudstones. The Freni Fawr Beds are thus considered here to be basinal.

The stratigraphically highest portion of the Ashgill comprises the turbidite sandstones, mudstones and gritty/muddy slumps of the Llangranog Formation (Anketell, 1963; 1987, Hasso, 1974). The junction with the underlying bioturbated mudstones of the Tresaith Formation may represent a major sequence boundary related to late Rawtheyan relative sea-level fall and corresponds to the boundary between the Nant-y-moch Formation and the overlying Drosgol Formation in the Central Wales inliers (James, 1983). The boundary can be traced easily inland to Mydrim (Anketell, 1987, p. 160). Although no major thickness variation appears to occur in the Llangranog Formation across the Bwlch-y-Fadfa Fault, the greater abundance of slumping to the northwest compared to that to the southeast hints that the fault was not quiescent during deposition. Anketell (1987, p. 160) suggests a 'degree of fault control' and time equivalent sequences in the Llyfnant Inlier and at Corris certainly display the influence of the Llangranog Lineament (James, 1972; 1987). The distribution of thick sandstones in the Llangranog Formation in the Pencader-Conwil Elfed area, as shown by Hasso (1974), is further suggestive of contemporary activity on the Central Wales Lineament and on the Tywi Lineament (Fig. 3). The conglomerates at Cotland Mill west of Mydrim in the basinal facies of the Slade and Redhill Beds contain pebbles of graptolitic Caradoc shale (Pringle and George, 1948, p. 31), further indicating relative uplift/erosion immediately southeast of the active Tywi Lineament at this time.

Llandovery. There is no obvious sign of activity on the Lineament in the Rhuddanian Stage of the Silurian in the form of either sedimentary facies changes or thickness variations. The Rhuddanian sediments comprise the Gaerglwyd Formation (Anketell, 1987) and are almost exclusively mudstone within which graptolitic horizons record periodic anoxic conditions. Slow pelagic/hemipelagic deposition at this time may have allowed draping of the Gaerglwyd Formation to preserve some topographic relief across the Lineament.

In the Aeronian Stage, thickness variations and turbidite sandstone distribution in the Allt Goch Formation (Anketell, 1987; Kishimoto, 1989) strongly suggest activity on, or inherited relief across, the Llangranog Lineament in the position postulated in this paper. Kishimoto (1989) demonstrated that the principal concentration of these sandstones, with northeast-directed transport indicated by sole marks, is ponded downslope on the footwall of the Llangranog Lineament, where this may be equally regarded as the hangingwall of the Central Wales Lineament (Fig. 3). Kishimoto (1989) also recorded NNW-directed current ripples suggestive of soliton development along the slope parallel to the Central Wales Lineament. A secondary concentration of sandstones, also with NNW-directed transport, occurs at Llangranog. Kishimoto (1989) suggested that this latter concentration lay immediately adjacent to a Llangranog Lineament (*sensu* James and James, 1969) and defined a Teifi Lineament corresponding to the location of the Llangranog Lineament postulated in this paper. However, palaeocurrents in both the hangingwall and the footwall of Kishimoto's Llangranog Lineament were shown by Kishimoto (1989) to flow to the NNW and to cross this feature obliquely without deviation. The evidence for Kishimoto's interpreted position of the Llangranog Lineament is thus not strong and poor exposure of the Allt Goch Formation inland weakens its justification, at least as a major lineament.

In the Telychian Stage, palaeocurrent evidence suggestive of soliton development occurs in the Grogal Sandstones near Newquay and suggests the existence of a contemporary northwest facing slope along the Llangranog Lineament (Smith and Anketell, 1992). The Grogal Sandstones are succeeded by the Aberystwyth Grits, for which the controlling influence of the Bronnant Fault segment of the Lineament has been conclusively demonstrated by the work of Wilson *et al.* (1992). At this time there was considerable relief across the Lineament, to an extent that makes it likely that accommodation space was being created continuously during sedimentation of the Grits rather than the Grits passively infilling a static bathymetry. The Trefechan and Mynydd Bach sandstone facies of the Aberystwyth Grits are totally confined to the east by the Lineament (Wilson *et al.*, 1992, figs. 7 and 8). Later Telychian deposits are not preserved in the vicinity of the Llangranog Lineament but it has been demonstrated (Clayton, 1993; British Geological Survey, 1994) that contemporary activity on the Central Wales Lineament controlled the southeastern extent of sedimentation of the lower part of the Rhuddnant Grits. This activity may represent an intra-Telychian rejuvenation, as sea-bed relief across the Lineament was subdued in the Aeronian to the extent that it was crossed from the east by flows depositing the Ystrad Meurig Grits (James and James, 1969; Smith, 1987a). The final Telychian turbidite system, the Pysgotwr Grits, also appears to cross the Central Wales Lineament and thus records its quiescence at that time (Smith, 1987a; b).

Synthesis

The seafloor topography induced by synsedimentary activity on the lineaments of Central Wales during much of the late Ordovician/early Silurian is now generally accepted to be one of gentle southeast dipping palaeoslopes above the hanging walls of the basement fault zones and relatively steep, localised northwest-facing slopes above the footwalls (e.g. Smith, 1987a; James, 1991). Such tilt-block geometry was not identified in the early work of James and James (1969) and was first clearly set out by Davies (1981). This study provides further support for the concept.

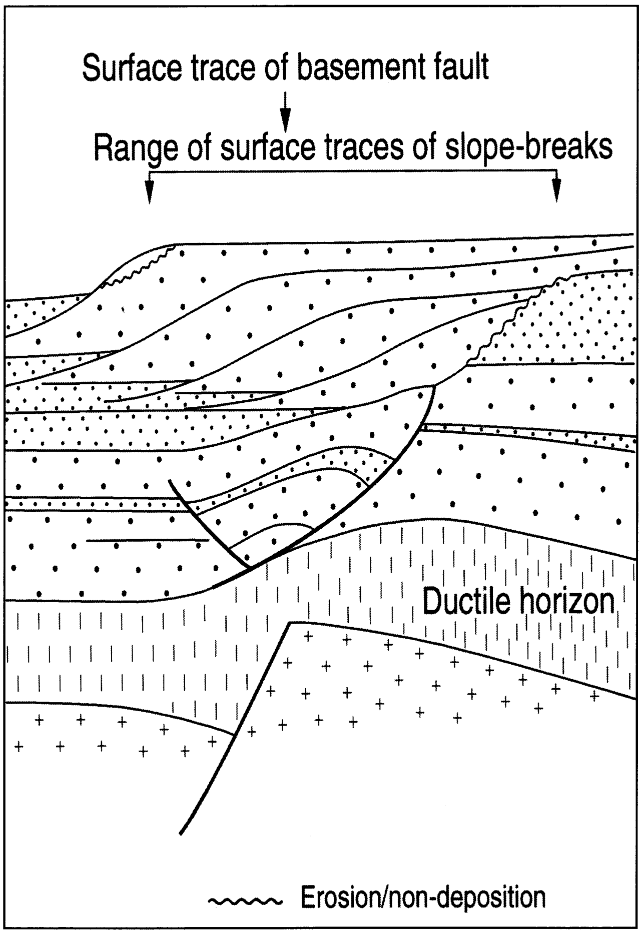

Fig. 4. Cartoon illustrating variable relationship between a basement fault and the position of localised slopes in sedimentary cover.

The exact position of the basement fault — or fault zone — is not easily or simply related to either sedimentary or structural relationships in its cover. This can be due firstly to sedimentary processes of differential lateral and longitudinal supply and accumulation leading to variation in the position of the slope break, and secondly by displacement of the slope break by ductile deformation (e.g. of overpressured shale) adjacent to the fault (Fig. 4). Moreover, at times of high sediment supply rates from the shelf to the southeast, it appears that the gentle southeast-dipping topography over the basement blocks may have been reversed. In this case the fault zone underlies a local increase of dip on a northwest prograding slope apron. This situation probably occurred during deposition of the Llangranog Formation. It is apparent from Figure 4 that the existence of a localised slope does not necessarily indicate contemporaneous activity on the lineament as sedimentary processes may sustain the existence of a slope once this has been tectonically initiated. The best evidence for contemporaneous activity is probably the rapid lateral ponding of longitudinally supplied material following an interval of minor thickness variation across the Lineament.

A further complication in the estimation of the position of the basement fault arises from tectonic deformation of the cover during inversion of the depositional half-graben, notably the possibility of thrust ramping (Schedl and Wiltschko, 1987, fig. 4) which can laterally translate the depositional margin beyond the vertically projected trace of the basement fault. The Bronnant and Bwlch-y-Fadfa Faults are not reversed as would be expected in the case of ramping, although the Brwyno Fault is reversed and might pass down into a local ramp. Experimental data (e.g. Buchanan and McClay, 1992) for non-ramping models afford little or no suggestion of the development of a vergence divide when inversion is accomplished by simple back-stacking of uni-directionally hading basement faults. The vergence divide so prominent in coastal Ceredigion is thus not easy to relate, spatially or genetically, to the sedimentologically requisite northwest-hading basement fault of the Llangranog Lineament. By analogy with seismically defined examples of inverted basins (e.g. Letouzey *et al.*, 1990, figs. 6 and 10), the divide appears to suggest the existence of a subsidiary southeast-hading fault controlling the zone of northwest fold vergence. The very existence of the vergence divide between Cardigan and Corris, and the absence of such a divide in the Central Wales Lineament and the Tywi Lineament, suggests that the Llangranog Lineament may define the central graben and associated bathymetric axis of the Welsh basin in Llanvirn to Llandovery times.

Conclusions

This paper argues for a fairly continuous record of synsedimentary activity on the Llangranog Lineament between the Llanvirn and the late Llandovery — a period of approximately 40Ma. This would extend significantly the previous (discontinuous) recognition of its activity in the Llanvirn and the late Ashgill to early Llandovery. Additionally, the strong suggestion of domino-style linkage between the basement faults of the Llangranog Lineament and the Central Wales Lineament implies that the latter was active over a similar time. This would extend very significantly the previous recognition of its activity in the early Ashgill to late Llandovery. A similar domino-style linkage may exist between the Central Wales Lineament and the Tywi Lineament. The Tywi Lineament is known to have been active from the late Llanvirn to the Wenlock, the Ordovician contrasts in facies and fauna across it having been first set out in the pioneering work of D. C. Evans (1906, p. 599).

There is still unsatisfactory knowledge of the stratigraphy and structure of the early Ashgill strata southeast of Cardigan towards Mydrim, where large areas have not been mapped this century. In particular the provisional lateral correlations of the Freni Fawr Beds deduced herein may bear revision in the event of future detailed mapping.

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Geology and engineering aspects of the Leadenham By-pass, Lincolnshire

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Abstract: This article gives an account of a non-geologist's encounter with the geology of the Lincoln Edge, as experienced during construction of a by-pass road for the village of Leadenham, Lincolnshire in 1994-95. The geology and related constraints determined during the ground investigation are described, together with their bearing on the design and construction of the road scheme.

Introduction

The village of Leadenham, Lincolnshire is situated on the A17 Newark to King's Lynn Trunk Road. The road carries a high volume of traffic between the East Midlands and the agricultural production areas of Lincolnshire, the Fens and North Norfolk, together with the East Coast ports of Boston and King's Lynn. Over 50% of the traffic is heavy goods traffic and the need for a by-pass had long been recognised.

Leadenham village lies on the junction of the A607 road with the A17 (Fig. 1). It is situated halfway up the topographical feature known as Lincoln Edge, a prominent escarpment which extends for many kilometres both northwards and southwards from Lincoln. The scarp slope is formed mainly by the mudstones and subordinate limestones and ironstones of the Lias Group, Northampton Sand Formation and Grantham Formation (Table 1). The village occupies a 400m-wide bench about halfway up the scarp slope at an altitude of approximately 50m AOD. The bench is formed by the outcrop of the Marlstone Rock Formation, which is more resistant to erosion than adjacent strata above and below. Siting of the village was no doubt influenced by the fact that the Marlstone Rock Bed is an excellent aquifer. The Marlstone Rock bench effectively divides the scarp slope into lower and upper parts. The underlying Brant Mudstone Formation forms the lower scarp, sloping steeply down to the floodplain of the rivers Brant and Witham. Above the village, the ground steepens to form the upper scarp, carved out of the Whitby Mudstone, Northampton Sand and Grantham formations. The scarp ultimately rises to an altitude of 100m AOD, and is capped by the resistant limestones of the Lincolnshire Limestone Formation, which form a long, gentle dip slope to the east.

The route of the completed by-pass is shown in Figure 1. The new road leaves the former route of the A17 about 1.3km west of Leadenham and curves in a south-easterly direction over the predominantly arable farmland of the Leadenham Low Fields. The route continues across the arable land to the south of Leadenham Park, swinging eastwards and starting to rise on a low 2-3m high embankment towards the toe of the lower scarp. Midway up the lower scarp, the road enters a cutting (the Mill House cutting, Fig. 1) which deepens rapidly to a depth of 8m beneath a new bridge carrying the A607 road over the by-pass. The by-pass continues to rise in a

Age	*Group*	*Formation*	*Former Name*	*Thickness proved on site*
Middle Jurassic	Inferior Oolite Group	Lincolnshire Limestone Formation	Lincolnshire Limestone	lowermost 5m
		Grantham Formation	Lower Estuarine Series	4.6m
		Northampton Sand Formation	Northampton Sand	
Lower Jurassic	Lias Group	Whitby Mudstone Formation	Upper Lias	45m
		Marlstone Rock Formation	Marlstone Rock Bed	2.7-3.3m
		Brant Mudstone Formation	Middle Lias	uppermost 35m

Table 1. Summary of the stratigraphy of rock formations encountered during site investigation and construction of the bypass.

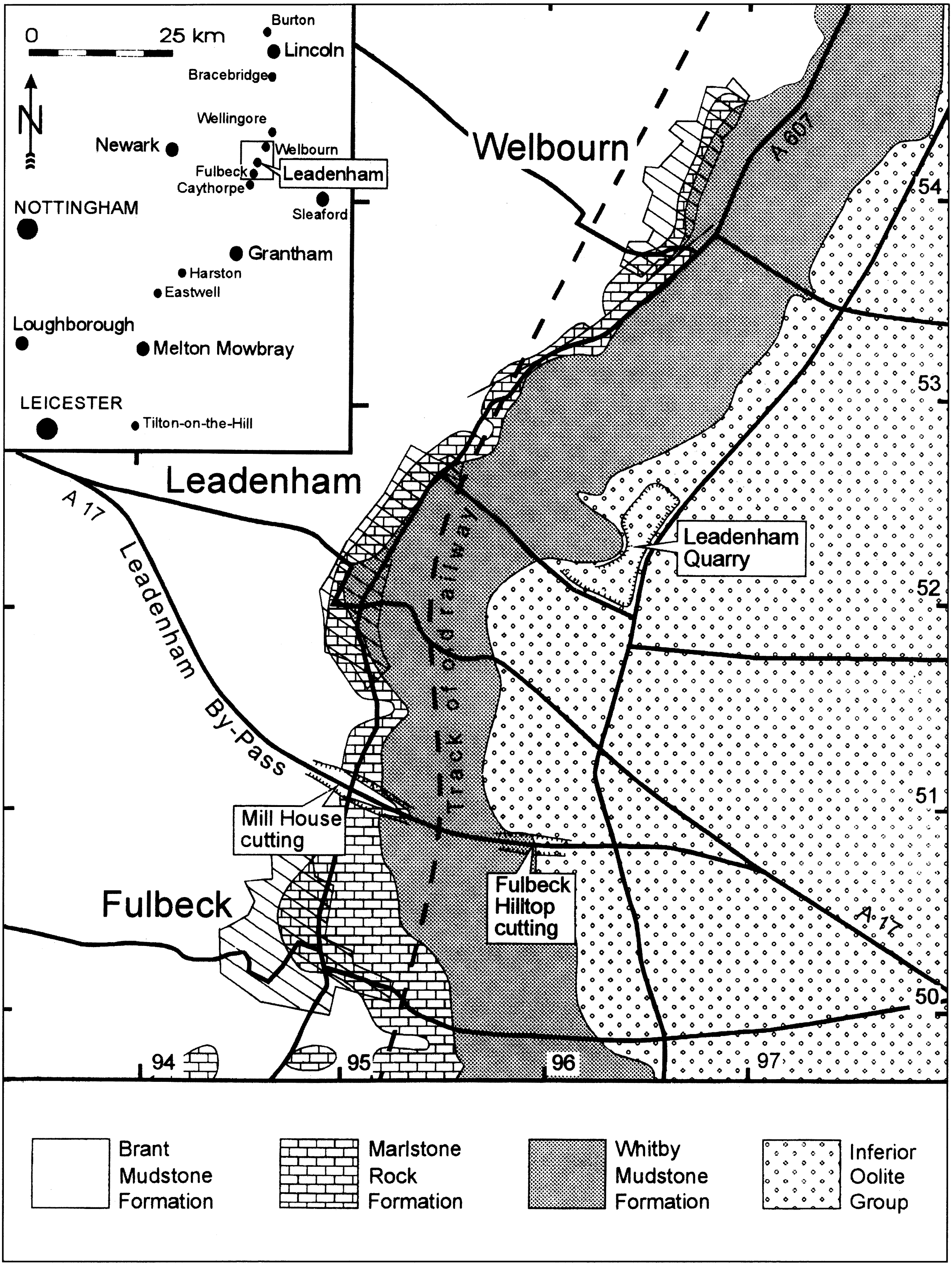

Fig. 1. Map showing route of the by-pass over the geology of the area, based on British Geological Survey 1:10,000 maps (modified after Sumbler and Ivimey-Cook, 1996).

shallow cutting through arable land to cross the disused Lincoln-Grantham railway. It then climbs diagonally across the face of the upper scarp, requiring a cutting of up to 5m depth (the Fulbeck Hilltop cutting, Fig. 1) before reaching the crest, from which the ground slopes gently away to the east at an angle of about 2 degrees.

Ground Investigation

In a roadworks scheme of this type, much ground investigative work must be carried out to determine the properties of the soils and underlying bedrock strata, so that geotechnical design criteria can be identified and recommendations for road construction formulated. The ground investigation for the Leadenham by-pass spanned a number of years. The first detailed investigation was carried out in 1971 (Chandler, 1982), augmented later by others as the preferred route was finalised. Further specialist ground investigation was carried out in 1989 along the anticipated preferred route. Major sources of documentary information used by these investigations included the geological maps, principally the 1:50,000 series Sheet 127 (Grantham) (British Geological Survey, 1972; 1996), together with MAFF soil classification maps. Ordnance Survey topographical maps and aerial photographs.

Site investigations typically involve excavating numerous trial pits to depths of 2-3 metres, supplemented in places by boreholes to depths of up to 20 metres, in order to examine the strata underlying the route and to extract both disturbed and undisturbed samples for laboratory analyses and testing. The diverse range of geotechnical tests carried out are listed in Table 2 and are designed to determine the engineering properties of the rocks and soils that would be encountered during the construction of the scheme.

Undrained Triaxial Compression Strength
One Dimensional Oedometer Consolidation cv
California Bearing Ratio
Compaction
Natural Moisture Content
Bulk Density
Plastic Limit
Liquid Limit
Plasticity Index
Particle Size Distribution
Specific Gravity
Organic matter content
Sulphate content
pH value
Point Load Index
Uniaxial Compression Strength
Consolidated Undrained Triaxial Compression Strength
Pore water pressure measurement and Value change measurement

Table 2. Principal tests to determine the engineering properties of rocks and soils (British Standards Institute 1975; 1981).

The site investigation and testing data was used to:

- determine the suitability of the various soils encountered for use as construction materials;
- determine safe slopes for cuttings and embankments;
- assess possible excavation methods;
- examine and assess foundation conditions at the bridge site;
- assess groundwater conditions and ascertain the drainage required;
- locate potentially unstable areas.

Having obtained a detailed understanding of the materials likely to be encountered, their physical properties, and more importantly how those properties would vary in response to changes in environment, the Consulting Engineer was able to proceed with the detailed design of the road scheme.

Geology

Solid Geology. The Lincolnshire Limestone Formation crops out at the crest of the upper escarpment and forms the dip slope to the east. It consists of buff grey, fine-grained oolitic limestone. Weathering along the bedding planes and joints has left a residue of yellowish sand which fills many of the joints. The Lincolnshire Limestone is underlain by the Grantham Formation (formerly known as the Lower Estuarine Series), which consists of fine sands and clay with low grade iron ore, particularly in the basal sand layer. Underlying the Grantham Formation, the Northampton Sand Formation consists of sideritic mudstones, sandstones and limestones, and constitutes a low grade, silicious iron ore. Green when fresh, the rock weathers to brown limonite exhibiting a characteristic 'box-stone' structure. The Northampton Sand lies with a slight angular unconformity on the Whitby Mudstone Formation (formerly Upper Lias), which consists dominantly of dark grey silty mudstone, weathering to silty clay. The Whitby Mudstone forms much of the steep, upper escarpment.

Towards the west, the slope of the upper escarpment flattens onto the bench formed by the Marlstone Rock Formation, which comprises a moderately strong, thinly bedded ferruginous limestone and sandstone. This formation was worked extensively for iron ore until a few decades ago. The workings in the adjacent parish of Fulbeck are at the extreme northern limit of the orefield and were of marginal economic viability. The fields from which the ironstone has been extracted are typically 1.5-2m lower than adjacent roadways and homesteads. The Marlstone Rock Formation is underlain by mudstones and siltstones with thin beds of sideritic ironstone or ironstone nodules. Formerly known as the Middle Lias, these strata have recently been included in the newly-defined Brant Mudstone Formation (Brandon *et al.*, 1990), which also encompasses the upper part of the former

'Lower Lias' subdivision. The Brant Mudstone forms the steep lower escarpment below the Marlstone Rock bench, and underlies the floor of the valley of the River Brant to the west.

Superficial Deposits. The steep surfaces of the upper and lower escarpments were affected by permafrost conditions during the Pleistocene glacial and periglacial periods. Frost shattered bedrock sheared and slipped repeatedly downslope, mantling the lower slopes of the escarpment with highly disturbed, soliflucted deposits known as Head.

As would be expected from the composition of the bedrock source materials cropping out upslope, the Head deposits generally comprise brown or grey weathered mudstone or clay containing sub-rounded to sub-angular, gravel-sized rock fragments (mainly of ironstone). Head deposits contain abundant internal shear planes with polished and slickensided surfaces. The thickness of the Head was generally expected to be up to 1.7m on the lower escarpment and up to 2.2m on the upper escarpment. Geotechnical tests showed the Head to be highly plastic and weak when wet.

Material classified as topsoil was present throughout the length of the proposed by-pass to typical depths of 0.3m and locally up to 0.4m. The topsoil was found to consist typically of a slightly gravelly, sandy clay, with limestone fragments common towards the eastern end of the route. Beneath the topsoil, the underlying Lias bedrock was weathered to a slightly sandy, very silty clay to a depth of 1.5-2m, underlain by fresh, comparatively unweathered mudstone.

Design

In designing the scheme, the Consulting Engineer had to take account of the fact that the bulk of the earthworks would be either excavated in, or constructed from, the mudstones of the Lias Group. These materials, whilst moderately strong in an undisturbed dry condition, rapidly become very plastic and weak when wet, and it was therefore essential to provide an effective drainage regime. Furthermore, it was readily apparent that the cutting design would have to allow not only for the surface water run-off after rainfall or snowmelt, but also the substantial discharges of groundwater that would otherwise issue out from the bases of the permeable rocks of the Marlstone Rock and Northampton Sand formations. The design solution involved the installation of a deep (up to 4m) cut-off filter drain around the perimeter of all cuttings. This consists of a deep trench backfilled with gravel-sized free drainage stone. At the top of the trench, a geotextile filter membrane that permits passage of water molecules but not clay or silt-sized particles is placed beneath the covering of topsoil to prevent the gravel from silting up. At the bottom of the trench, a pipe carries away any water collected. This is mostly discharged into the new road drainage system. However, for the part of the Fulbeck Hilltop cutting crossing the outcrops of the Lincolnshire Limestone, Grantham Formation and Northampton Sand, the discharge is fed beneath the new road into a 'seepaway' spillway. This was specially designed on site to maintain a natural flow downslope to water the profusion of Aconite flowers growing in the adjacent woodland (who says Engineers' do not have souls!).

In designing the earthworks, the Consulting Engineer employed a 'Factor of Safety' against failure, that resulted in cuttings in the weakest clays having sides with slopes as shallow as 1 in 5. In locations where it might be possible for seepages from minor aquifers to leak out and soften the clay slopes, the design called for lateral trench filter drains to be installed in the cutting sides. These were again protected from silting up by being enclosed in a geotextile membrane and were designed to outfall into the main longitudinal filter/carrier drains.

The main longitudinal filter drains run along either side of the new road and along the toe of the cutting slopes. They are designed to ensure that the water table beneath both the road and cutting slopes is maintained at a low level, and that the water collected is quickly discharged. They also accept and discharge any surface water shed from the carriageway.

The Head deposits masking the lower slopes of the lower scarp presented a potential problem for the road design in that they would lie beneath the approach embankment. Two options were considered:

1. complete removal, increasing the need for excavation and disposal off site and also requiring additional fill material to be imported;
2. stabilisation by installing a drainage system to maintain the material in a dry condition.

The Consulting Engineer opted for the latter solution, to be effected by a closely-spaced grid of filter drains (3.5m deep) through the Head deposits and into the mudstone bedrock beneath. These drains were also to be enclosed within a geotextile membrane and designed to outfall to the main longitudinal filter drains. The effectiveness of the filter drains was to be monitored by an array of piezometers (a device for measuring the head of water within a soil) to confirm that the water table was drawn down during and after construction of the embankment.

Whilst the above summarises the special artificial drainage measures necessitated by the geology of the escarpments, sympathetic use of the natural geological conditions permitted drainage to the east of the upper escarpments to be led down the dip slope away from the escarpment edge, before being discharged into soakaways excavated 5-6 metres into the Lincolnshire Limestone.

At the western end of the scheme, on the flat floodplain of the River Brant, a large pond was dug in impermeable Lias mudstone. The outfall from the pond was provided with a 'throttle' that restricts the rate of discharge from the road to the original natural discharge, to avoid overloading the existing roadside ditches that eventually outfall into the Brant.

Having determined the drainage required to maintain the existing soils and ground in as dry, and therefore strong, condition as possible, the design could then turn to consideration of the suitability of soil and rock materials excavated on site for construction of the embankments required by the scheme. A summary of the materials (and their properties) required for the various embankment and fill materials used during construction is given in Table 3.

From the site investigation conclusions, it was anticipated that 80% of the Lias silty clay/mudstone would, when tested again upon excavation, satisfy the criteria that would classify it as a wet cohesive or silty cohesive material suitable for use as a general fill (Class 2A, Table 3). It was anticipated that 90% of the Lincolnshire Limestone, Northampton Sand and Marlstone Rock would, upon testing on excavation, satisfy criteria to classify such material as uniformly coarse graded granular material, also suitable for use as general fill. The remaining proportions of the excavated material, including the Grantham Formation (variable sands and clays) were not expected to be suitable for use in embankment construction. The design allowed for their use as general landscape fill behind an environmental bund, to be constructed adjacent to the bypass to screen the road from Leadenham Hall. The harder limestone or ironstone beds were potentially suitable for crushing to give a graded material for use as a starter layer or fill or as a capping layer beneath the road construction (Classes 6B, 6F1, 6F2, Table 3).

At the point where the new Fulbeck bridge was to be built to carry the A607 over the new by-pass, the investigations had indicated that the foundation of the bridge would be in a very stiff silty clay/weak silty mudstone with a safe bearing capacity of 400kN/m^2. The design for the bridge foundations allowed for a worst case scenario (i.e. if all chainage measures failed and groundwater rose to within 2m of the ground level behind the abutment), providing a foundation that would induce a working load of only 190kN/m^2 with a settlement that would not exceed 15mm. The concrete to be used in the buried part of the bridge structure was designed to national guidelines set by the Building Research Establishment (1991) to resist chemical attack from groundwaters.

Construction

Upon completion of the proposed design work by the Consulting Engineer and its acceptance by the client (the Highways Agency), a contract for the construction of the works was put out to tender. The successful tenderer was given a commencement date of mid-February 1994 with a target completion date of July 1995. The Consulting Engineer was retained as Resident Engineer to oversee the construction of the road. (The author was a member of the Resident Engineer's site staff engaged upon this aspect of the scheme.) An on-site laboratory was set up and staffed to provide the Resident Engineer with materials-testing services and advice. In addition, the Resident Engineer could call upon a visiting Geotechnical Engineer for expertise on geotechnical aspects of the works.

Some minor delays in the progress of the contract were experienced in the first few months as a result of environmental protestors seeking to frustrate the works and it was not until April 1994 that earthworks got properly underway. Even so, the snowfall of February and the persistent showers of March (only 7 days without rain), meant that earthworks could only proceed upon the upland heathland of the Lincolnshire Limestone.

Attempts in mid-April to commence topsoil strip over the lowfields of the Lias clay had to be abandoned after 2 days because it was too wet; it was not possible to continue until a week later. This pattern of start-stop was to recur throughout the

Material	*Class*	*Intended Use*	*Total required (cubic metres)*
General Fill	1A, 1B, 1C, **2A**, 2D	General embankment construction	51,000
General and Landscaping Fill	1A, 1B, 1C, **2A**, 2D or 4	Noise bund construction	38,000
Topsoil	**5A**	Topsoiling	17,000
Selected granular fill	**6B**	starter layer	6,000
Selected granular fill	**6F1, 6F2**	capping layer	22,000

Table 3. Summary of the earthworks materials required during construction. Classes shown in bold indicate those encountered on the by-pass site. The classifications are determined in compliance with various geotechnical tests that measure material properties. *2A material* is a wet cohesive material, suitable for use as a general fill if it meets certain criteria with regard to its grading, plastic limit, moisture content, MCV Moisture Condition Value, and undrained shear strength of remoulded material. *5A material* is topsoil or turf suitable for re-use as topsoil provided its grading is such that it does not contain stones greater than 100mm diameter. *6B material* is selected coarse granular material suitable for use as a starter layer, consisting of natural gravel, sand, crushed rock, crushed concrete, slag etc. It must conform to a specified grading, be non-plastic and have fines with a strength characteristic of at least 50kN. *6F1 or 6F2 material* may be used as a capping material and (provided it complies with specified criteria for grading, optimum moisture content and fines strength value), is permitted to comprise any selected granular material, or combination of materials, other than unburnt colliery spoil, argillaceous rock or chalk.

earthworks programme because of the susceptibility of the Lias clay topsoil and subsoil to changes in moisture content. A rainfall of 14mm on 14th May, topped up by further rainfall of 20mm over 19th-21st May was sufficient to curtail earthworks until 6th June, when the clay escarpments and lowfields to the west eventually started to dry out. However, other works such as fencing and drainage could be continued throughout this period.

In April, the array of piezometer instruments to monitor the effect of drainage works beneath the embankment area were installed in readiness for monitoring the fall in groundwater during drainage installation and subsequent embankment construction.

In May and early June the A607 road was diverted away from the site of the new bridge. Use was made of the loadspreading capabilities of the Marlstone Rock Formation to provide foundations for the temporary 'Bailey' bridge (Fig. 2) that would carry the road over the cutting to be excavated beneath. The contractors initiative in providing this temporary bridge was a key element in shortening the contract period by several months. It enabled the A607 road traffic to be freed from conflict with construction vehicles, which could now pass from one side of the A607 road to the other by going underneath it.

The bridge excavations extended some 8 metres below the existing ground level and provided a good opportunity for examination of the Marlstone Rock Formation and the underlying Brant Mudstone Formation. The section was logged by Mike Sumbler and Hugh Ivimey-Cook of the British Geological Survey and published in an earlier part of this volume of *Mercian Geologist* (Sumbler and Ivimey-Cook, 1996). The site was visited by members of the East Midlands Geological Society as part of their excursion to the area on 3 September 1994. Fossils exposed in the lower part of the excavation included ammonites and bivalves (Fig. 3), the latter occurring in life position within a thin layer of sideritic, concretionary ironstone. These fossils were rapidly buried again as the mudstone floor of the bridge excavation was concreted over in order to maintain its dryness and strength, thus minimising the risk of wetting, softening and the potential for settlement.

As the road cuttings below the bridge were excavated down the escarpment slope to the west, three beds of sideritic concretionary ironstone were revealed in the sides of the cutting (Fig. 4), the uppermost of which corresponded to the bed uncovered in the bridge foundations (see above). Slight seepages of water were observed to emanate from these ironstones. Lateral filter drains were

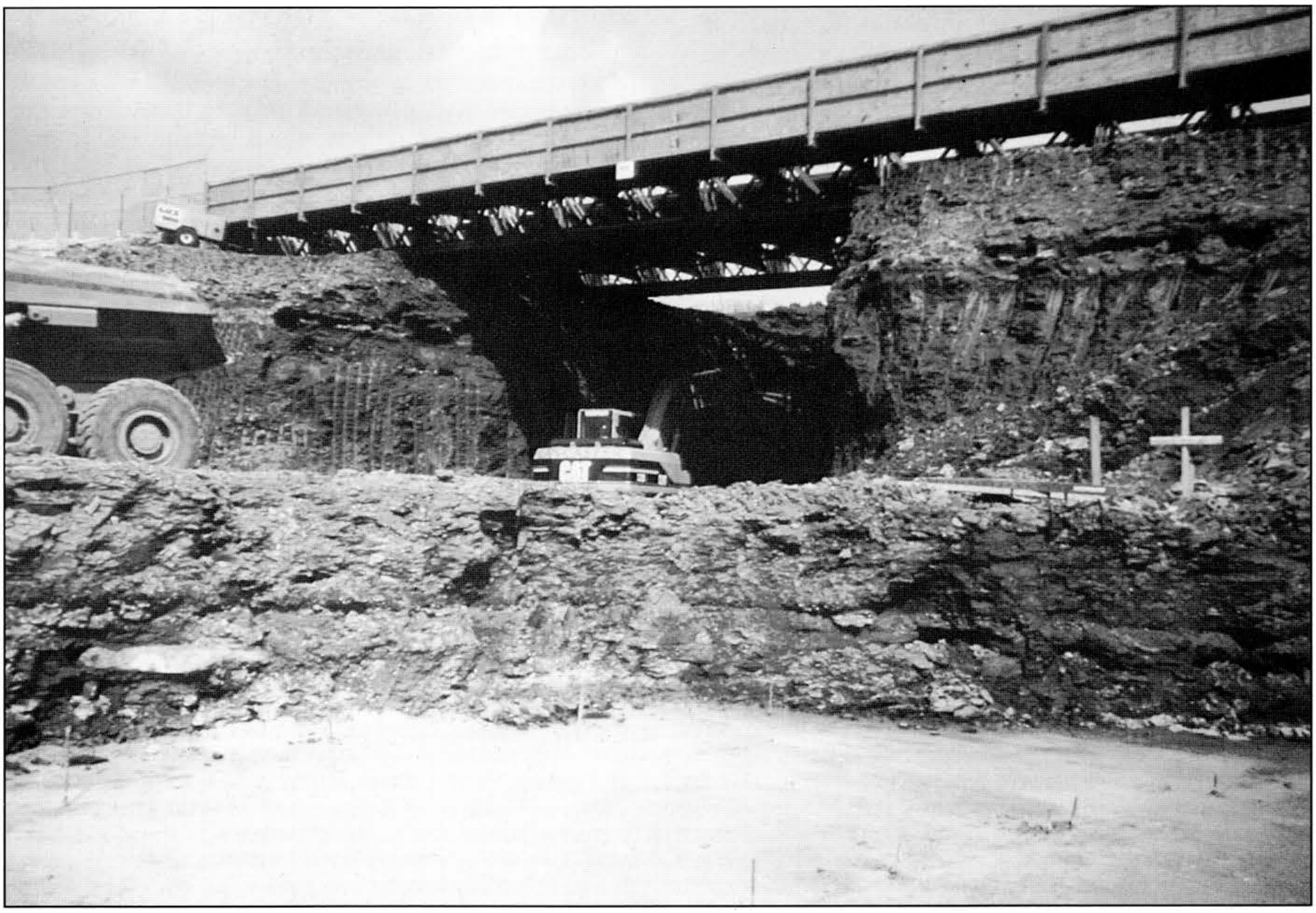

Fig. 2. Temporary overbridge of A607 road, supported on the Marlstone Rock Formation (upper strata) overlying Brant Mudstone Formation. The concreted foundation for the permanent bridge is in the foreground.

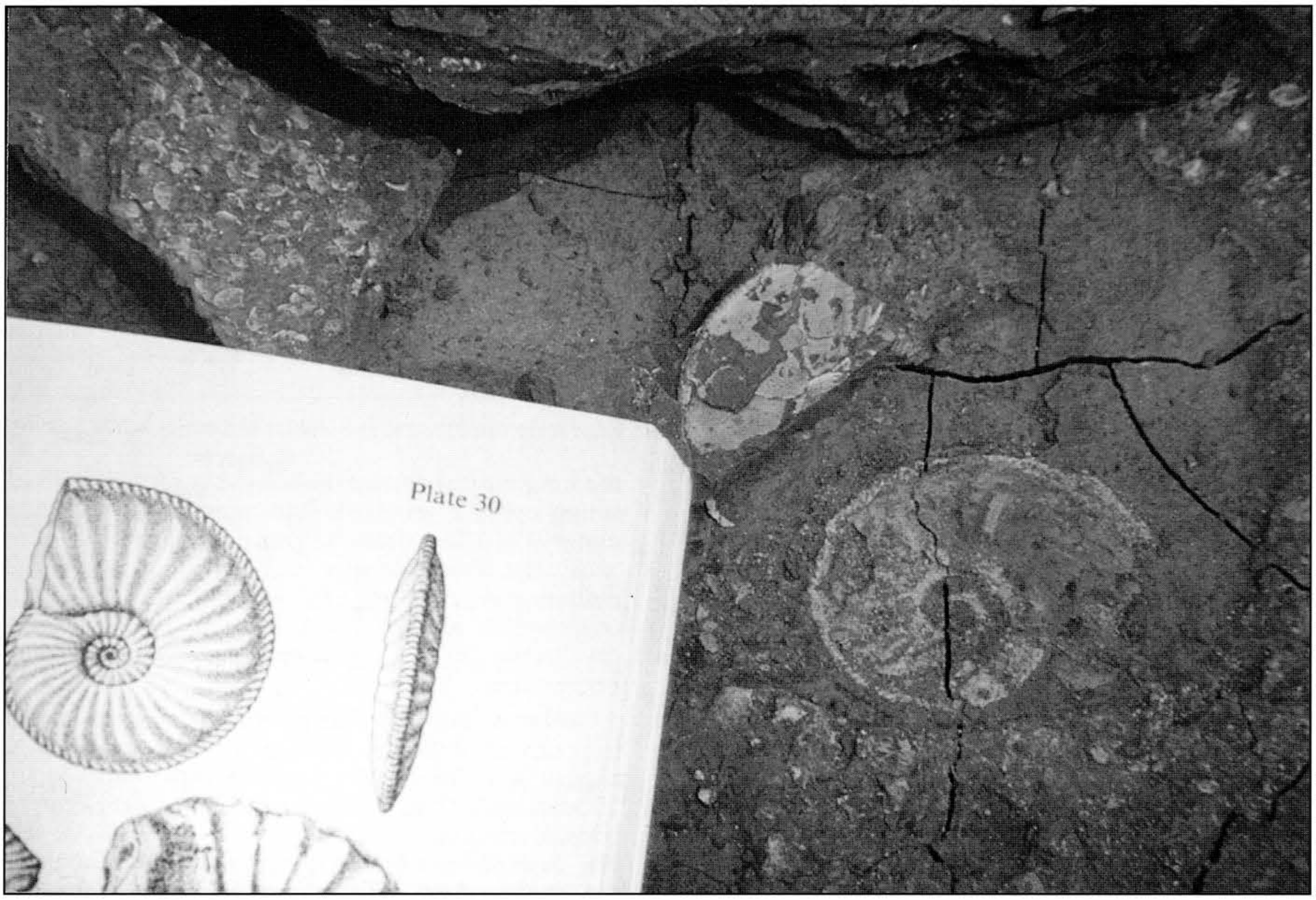

Fig. 3. Ammonites and bivalves exposed on the floor of the bridge foundation excavations before concreting over.

installed in the cutting sides to drain these spring lines and to lead the water away into the longitudinal carrier/filter drains, in order to prevent softening of the mudstone slopes and eliminate the risk of failure by slipping. Similar treatments were subsequently applied to other sources of potential spring lines, principally the Marlstone Rock Formation outcrop in the Mill House Cutting sides to either side of the A607 bridge and the Northampton Sand outcrop in the Fulbeck Hilltop cutting (Fig. 5) at the top of the upper escarpment.

During installation of the grid of transverse filter drains, designed to lower the water table below the Head deposits underlying the embankment at the foot of the lower escarpment (Fig. 6), it became obvious that these deposits were not as thick as anticipated and that the underlying mudstone was so impermeable that drawdown of the water table within it was difficult to achieve. The design was therefore reviewed to reduce both the frequency of the drains and their depth of penetration into the mudstone. This enabled acceleration of the construction works and substantial cost savings. Head deposits encountered on the side of the long, shallow cutting in the lower slopes of the upper escarpment were mostly removed during excavation,

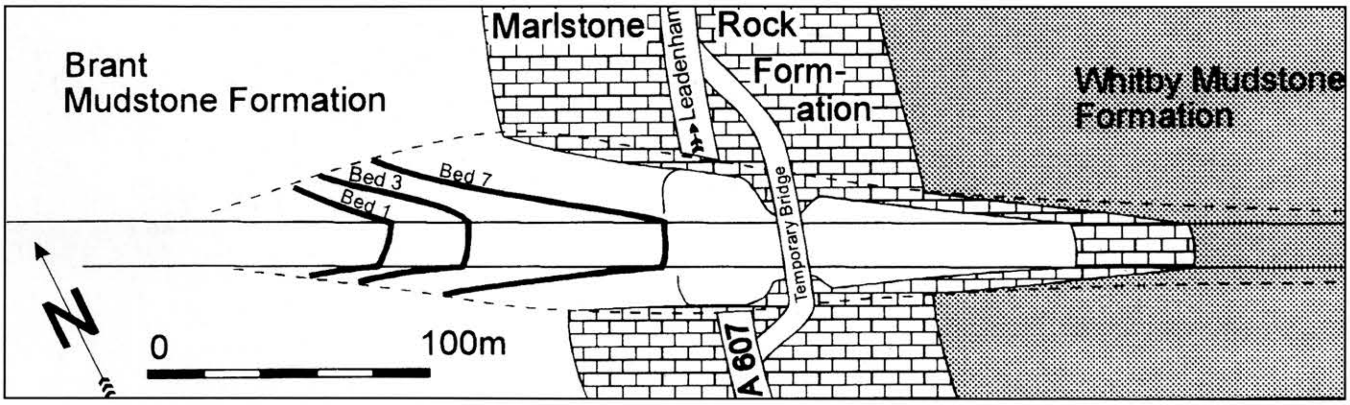

Fig. 4. Geology of the Mill House cutting in the lower Lincoln Edge scarp, showing outcrop of concretionary ironstone beds (1, 3 and 7) in banks of cutting (modified after Sumbler and Ivimey-Cook, 1996).

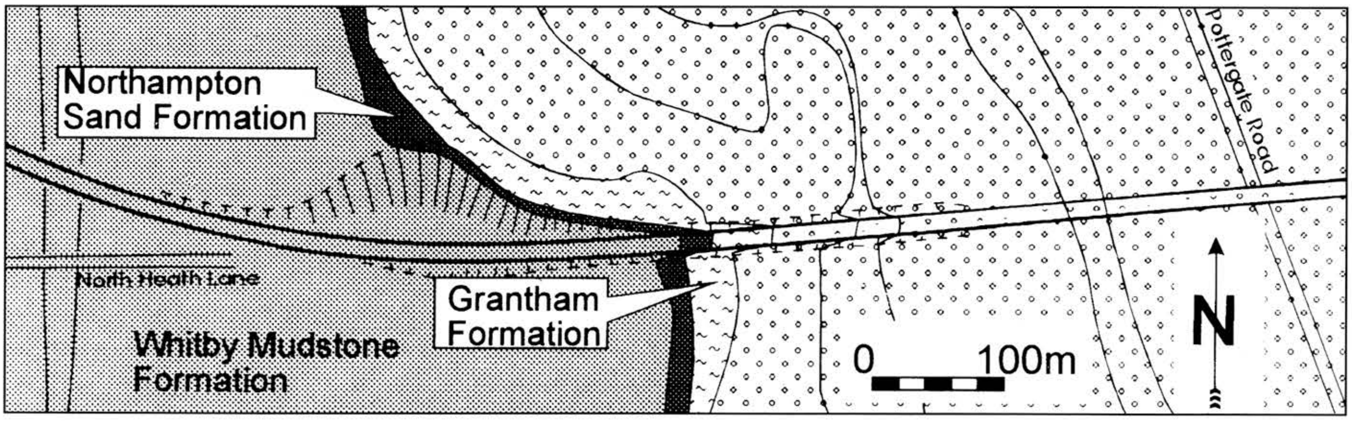

Fig. 5. Geology of the Fulbeck Hill top cutting in the upper Lincoln Edge scarp (modified after Sumbler and Ivimey-Cook, 1996).

but some further excavation in localised areas (softspots) was required before replacement with a granular fill material.

During construction, large quantitites of granular fill material (Table 3) were required as both a starter layer and capping material. Although the Consulting Engineer had been aware in his design that the Contractor could have won some of this material from the limestone and ironstone to be excavated from the site, the Contractor decided that, bearing in mind the cost of crushing, the quantities available were insufficient for cost-effective use. All granular fill material was thus imported from a local Lincolnshire Limestone quarry. The starter layer material acts as a chainage blanket to drain down the foundation of the embankment (it is connected to the longitudinal carrier drain) and is protected from silting up by a geotextile filter membrane. Capping material is a free-draining granular material used to 'cap' the floor of the cutting or top of the embankment before the layers of the road construction are laid down. It assists in providing a dry foundation to the road by being connected to the carrier drain.

On excavation, the Lincolnshire Limestone at the top of the Fulbeck Hilltop cutting proved, as expected, to be heavily fissured with joints up to 100mm wide (Fig. 7). In the more weathered upper beds, these joints were filled with a gravelly sandy clay derived from both the weathered limestone and the overlying soil. The joints were open in the less weathered, moderately strong limestone beds at

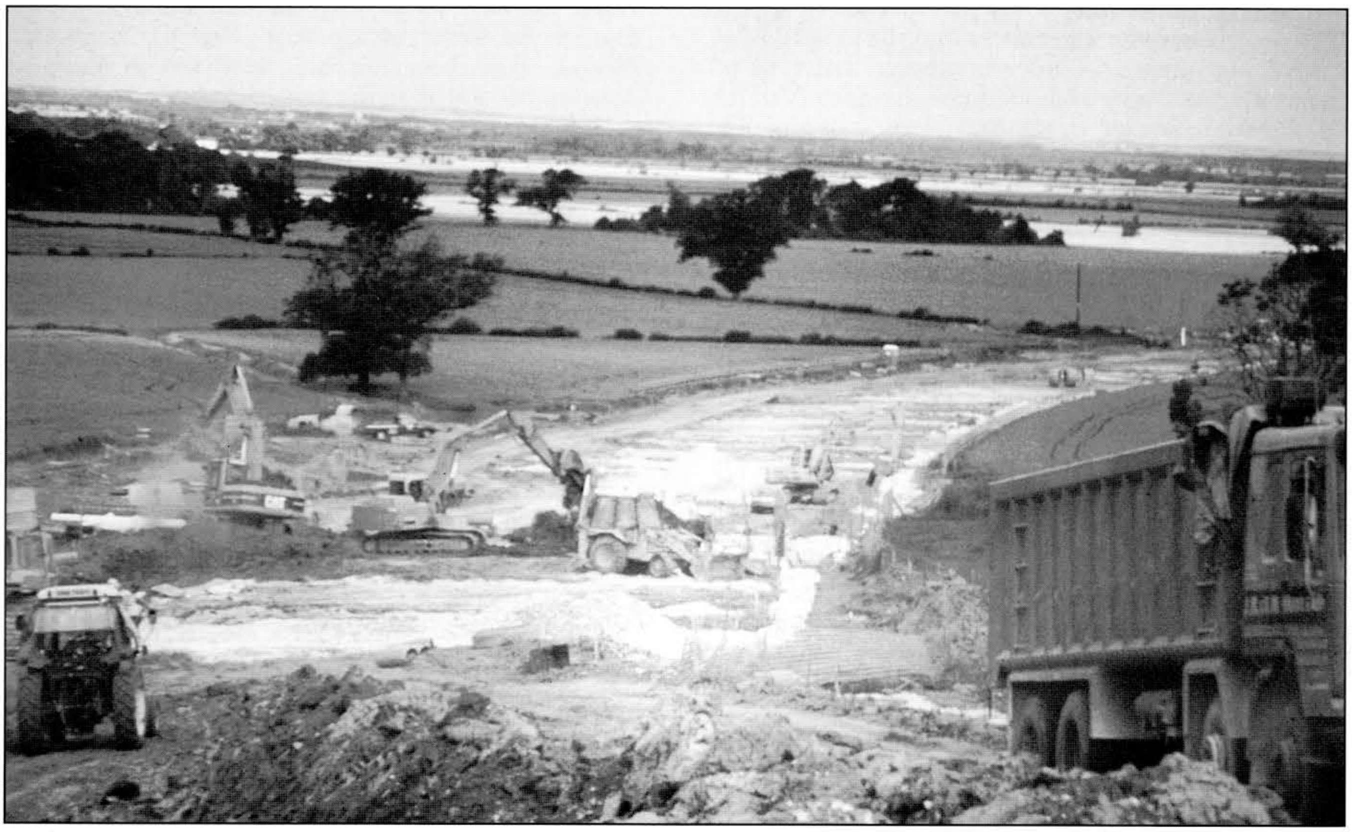

Fig. 6. Installation of the drainage system to de-water head deposits before construction of the embankment.

depth. The open joints were found to parallel the NW-SE direction of the strike of the bedding planes and the alignment of the scarp edge at this location. Here, on the very edge of the escarpment, the beds were found to dip at up to 10 degrees towards the south or south-west, whereas on the dip slope the dip was measured as 1-2 degrees to the east. This is a textbook example of cambering, induced by spring sapping of the Grantham Formation sands and clays by groundwater issuing from the base of the Northampton Sand Formation. It was concluded that the existence of the open joints was unlikely to have any effect on the stability of the cutting since they were at an oblique angle to it. However, their width demanded that they should be grouted up with weak concrete and capped over prior to road pavement construction, to avoid the possibility of localised depressions. Though this entailed a slight additional cost to the scheme, the fissuring (after soakage tests) permitted the number of large diameter 6 metre deep soakaways, designed to be constructed at the eastern end of the scheme (see above), to be substantially reduced.

Fig. 7. Joints up to 100mm wide in Lincolnshire Limestone. These trend parallel to the valley side at the top of upper escarpment, and have opened up as a result of cambering of the Limestone.

Conclusion

The author counts himself fortunate to have been involved with the engineering of a roadworks site that encountered a range of rarely-exposed strata of Lower and Middle Jurassic age. Although the differing geotechnical properties of the various geological formations demanded careful consideration and appropriate engineering solutions, these same properties could in many cases be turned to advantageous and imaginative use to solve some of the problems that arose during construction. The new road not only relieved the village of Leadenham of the nuisance and danger of heavy traffic but also provided an excellent opportunity for geological field study of these rocks by groups such as the East Midlands Geological Society and the Stamford and District Geological Society. The exposures have also provided considerable information on the otherwise poorly-exposed Lias Group strata of this part of Lincolnshire, greatly increasing geologists' knowledge and understanding of regional Lower Jurassic stratigraphy. Furthermore, it has encouraged the workforce engaged on the scheme and the local population (who have asked for a collection of the local fossils found on the site to be displayed in Fulbeck church) to take an interest in and find out more about the geology of the area.

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EXCURSION

The Wrekin, Shropshire

Leader: Susan Beale

22nd September 1996

This very well-attended field trip to a classic geological locality was fortunate to have, as leader, Susan Beale, co-author with Peter Toghill of G.A. guide No. 48; '*The Ercall Quarries*'. The EMGS party benefited considerably from Susan's expertise and local knowledge of the sections, and the geology of the localities was explained in a most articulate and interesting manner. The weather was much kinder than during a previous Society field trip to the Shropshire region, ie. Wenlock Edge in June 1995, when flippers and wetsuits would not have gone amiss.

After parking in the Forest Glen car park (SJ 639 093), which itself has much to offer in the way of interesting geology, including a dolerite dyke and andesitic tuffs, the morning was spent in the Ercall quarry complex. There, within a relatively small area, a wide range of geological features were studied. The complex consists of five quarries, of which numbers one to three, on the northern side of the access road, were visited during the morning.

Quarry No. 1 exposes Uriconian volcanics, and the party spent some time studying the rhyolitic lavas, pyroclastic rocks and a basaltic dyke, parts of which could be seen through the vegetation. *Quarry No. 2* exposes an excellent section of the Ercall Granophyre and its contact with the Wrekin Quartzite. There is another fine section of the Wrekin Quartzite on the north-west side of the Quarry, at the top of which is what is believed to be an unconformity between the Pre-Cambrian and Cambrian. A slickensided fault plane was observed on the eastern side of the quarry, close to the entrance; the direction of movement of the fault could be clearly determined by running one's fingers along the exposed fault plane, the 'smoothest' direction indicating the direction of movement. *Quarry No. 3* also displays a fine exposure of the contact between the Pre-Cambrian Ercall Granophyre and the Wrekin Quartzite. Ripple-marked bedding planes occur within the Quartzite although, unfortunately, the exposure had been damaged by so-called graffiti 'artists'.

Following a pub lunch, the afternoon's first stop was Maddock's Hill Quarry, to observe the Shineton Shales and the remains of an intrusion of camptonite, most of which has been removed by quarrying. The contact between the camptonite and the Shineton Shales, which have been baked hard adjacent to the intrusion, was seen on both sides of the quarry. The Shineton Shales dip almost vertically and contain specimens of *Dictyonema flabelliforme*, a dendroid graptolite. A couple of specimens, of which one was a particularly fine example, were found by members of the party. The final visit of the day was to Lyth Hill to examine the Pre-Cambrian conglomerates of the Bayston Group, notably including the Stanbatch Conglomerate which is well exposed at the top of the Hill. As a bonus, the view from the hilltop was breathtaking, even though visibility was not at its best, and on a clearer day it would have been fantastic.

In conclusion, the day was a great success and I am certain that all who took part enjoyed a most pleasant and instructive field excursion. This was due in no small measure to the leader Susan Beale to whom, on behalf of all who attended, I say thank you very much.

Anyone wishing to visit the quarries at Ercall or Maddock's Hill should seek permission from:

Ercall Quarries: Lord Forester, Estate office, Willey Park, Broseley, Telford, Shropshire TF12 5JJ.

Maddock's Hill Quarry: Johnson Brothers, Leaton Quarry, Leaton, Wellington, Telford, Shropshire.

Hammering is not permitted at these exposures. In addition, it would be advantageous to obtain a copy of The Geologists' Association Guide No. 48, "Ercall Quarries", by Peter Toghill and Susan Beale, published by The Geologists Association, Burlington House, Piccadilly, London W1V 0JU.

L. R. Hall

EXCURSION

The Lower Cretaceous of Speeton, Yorkshire

Leader: Dr Allistair Lomax

19th May 1996

Twenty four members travelled with Dr Lomax by coach to the Reighton Sands caravan park and walked down to the beach on a bright and sunny day. *[It should be noted that this cliff section has frequent cliff falls, climbing on the unstable cliffs can be hazardous, hard hats should be worn and care must be taken not to get caught by the incoming tide.]* Dr Lomax provided members with some excellent notes and these have been used in the preparation of this report.

Speeton has the finest continuously-exposed section of Lower Cretaceous strata in Europe and is designated as the type locality (stratotype) for several individual parts of that succession. The strata seen at Speeton range from Kimmeridgian (Late Jurassic) to Barremian (Early Cretaceous) in age and are assigned to the Kimmeridge Clay and Speeton Clay formations. The section studied was located between Middle Cliff and Speeton Beck, and is overlain by Boulder Clay deposited by the last (Devensian) glaciation.

The Speeton Clay Formation was formally subdivided by G. W. Lamplugh in 1889, unusually starting from A at the top to D at the base, rather than the usual convention in stratigraphy which is to number beds from the base upwards. The subdivisions were based on belemnite faunas; other workers have added the E and F units and further subdivided Lamplugh's beds.

A beds — *Neohibolites*
B beds — *Praeoxyteuthis, Aulacoteuthis* and *Oxyteuthis*
C beds — *Hibolites*
D beds — *Acroteuthis*
E bed — The Coprolite Bed
F beds — Kimmeridge Clay

The excursion itself consisted of a walk eastwards (up-sequence) along the beach, from the F beds to the A beds and the Red Chalk. Each of the subdivisions was located and described, and fossils were collected from many horizons. An abundance of fresh material is available due to the frequent cliff falls and erosion by the sea. Keen collectors found examples of most of the principal fossils described by Dr Lomax, although the fragile state of preservation of the fossils makes conservation for a collection very difficult.

Kimmeridge Clay Formation (F beds)

This dark grey organic-rich clay contains calcium carbonate nodules, often nucleated around one or more fossils. These strata have been substantially folded due to pressure from the overlying North Sea glacier during the last ice age.

The Coprolite Bed (E bed)

This rests unconformably on the Kimmeridge Clay and is made up of internal casts of ammonites and bivalves coated with phosphate and the winnowed remains of fossils. It represents a long break in deposition spanning several million years at the beginning of the Cretaceous.

The D beds

These contain thin beds of yellow bentonite, representing the breakdown products of thin layers of pyroclastic volcanic material. Numerous ammonites and large bivalves were seen and collected.

The C beds

These beds are divided into eleven subdivisions and are particularly highly fossiliferous, with the ammonites *Endemoceras regale, Aegocrioceras, Paracrioceras* and *Isocrioceras*. Also found were fossil wood and a fossil prawn, *Meyeria ornata*.

The B beds

These include the Cementstones, consisting of up to seven distinct layers of large calcareous nodules, often enclosing huge ammonites. The nodules were mined in the last century for use in cement-making. Below the Cementstones, the clays contain pyrite-rich laminae and, compared to the rest of the Speeton Clay, are poorly fossiliferous. This was probably due to increased water depth and the absence of dissolved oxygen in the waters close to the sea bed at the time of deposition.

The A beds

These were poorly exposed due to slipped Boulder Clay from above masking the cliff face. The A beds merge upwards into the Red Chalk, sections of which were heavily landslipped.

Dr Lomax explained how the comparisons made between the Speeton faunas and those of comparable age in North Germany and Russia had enabled early Cretaceous faunal migration routes and oceanographic changes to be interpreted.

The higher beds of the Speeton Clay and the Red Chalk were seen to contain many interesting and puzzling structural distortions. The possibility of land-slipping and other causes for these was discussed. The subsequent lecture to the Society by Dr Dave Roberts on 2nd November 1996 provided a further insight into the formation of these structures by a range of glacio-tectonic processes.

Soon after reaching the A beds the incoming tide persuaded most members to make their way back along the beach to the coach, which was conveniently parked by a tea shop. The interesting flora was studied along the path back from the beach. The really dedicated fossil hunters returned a little later along a rather muddier route, to reach the coach on time but forfeiting their tea!

The leader was thanked for a very interesting and well-structured excursion.

Inga and Alan Filmer

REPORT

Peterborough Museum and its collection of marine vertebrates from the Oxford Clay

Peterborough Museum was founded in 1871 by the Peterborough Natural History Society and Field Club (known since World War II as the Peterborough Museum Society). For many years the Society was the premier cultural organisation in Peterborough, and it still has a varied programme of evening lectures and summer outings. These are now augmented by the Friends of Peterborough Museum and Art Gallery, who arrange lunchtime lectures and outdoor meetings.

The museum building dates back to 1816 and was originally Squire Cooke's private residence until Earl Fitzwilliam bought it in 1856, after which it became the Infirmary and Dispensary. A serious fire in 1884 destroyed much of the original Georgian interior. New wings were added in 1897 and 1902. The opening of the new hospital on Midland Road in 1929 led to the vacation of the building as an Infirmary and its present use as the Museum began in 1931. A bequest by Mrs Ann Maxwell Davis allowed construction of the Art Gallery in 1938, although the war delayed its use as such until 1952. The Peterborough Museum Society handed over management of the Museum and Art Gallery to the City Council in 1968. The Museum remains a registered charity.

There are three floors of displays. The lift gives access to all floors for visitors using wheelchairs.

Ground Floor. At reception you can have a chat with our friendly receptionists, buy your souvenirs in the shop and help our coffers by dropping some money in our 'letter box'. The first gallery, opposite reception, usually has a temporary or travelling exhibit of specific topical interest.

At the far end of the entrance corridor is a display about Peterborough's most famous son, John Clare, the "Peasant poet" (there is more about Clare on the first floor landing). The Art Gallery has a constantly changing programme of exhibitions, mainly of contemporary art, but also of crafts or other aspects of our culture. Recent themes have included such diversities as cake icing and science fiction.

First Floor. Here you are greeted by Mark Noble, one of Peterborough's watchmakers, in a mock-up of his eighteenth century workshop. Through the double doors you have *Geology and Wildlife* on your left, and *Archaeology* on your right. Straight ahead and to the right there is the Period Shop display where you can see many of the household items your grandparents might have bought! Also on this landing is a display about Mary Queen of Scots, who was beheaded at nearby Fotheringhay in 1587, and about John Clare.

Geology and Wildlife takes you through the story of Peterborough since the time of the dinosaurs, 150 million years ago, when giant sea reptiles swam around eating ammonites and belemnites. Next comes the Ice Age, with creatures such as woolly mammoth and hippopotamus. The wildlife sections show glassland, woodland, urban and fenland habitats. Finally you can see the pliosaur skeleton excavated by the Museum in 1994 which is believed to be a new species (see *Pachycostasaurus* below).

Archaeology picks up in history more or less where *Geology and Wildlife* leaves off, continuing the story from the first human settlers of the Stone and Bronze ages through to the Iron Age. There are displays of the important Roman remains associated with Peterborough, together with early Christian silver, and mediaeval artefacts connected with the city's cathedral.

Second Floor. Through the door on the left is our display of bone and straw marquetry items made by the inmates of the Napoleonic prisoner-of-war depot at Norman Cross, which opened 200 years ago in 1797. Our collection is certainly one of the largest in existence, and includes the actual fire engine used at the camp. On the right is our display of Peterborough's social history, telling the story of the local industries, schools, entertainments and so forth. This gallery is very popular with school parties.

Fossil marine reptiles of the Peterborough brick pits

Major urban growth in Victorian England led to rapid expansion of the brick-making industry, requiring large scale extraction of clay for the purpose. Many clay pits were opened in the late Jurassic Oxford Clay of the Peterborough area, and brickworks chimneys remain a common sight in the district. The properties of the Oxford Clay make it ideal for the manufacture of cheap, yet strong and durable bricks. The manufacturing procedure used is known as the Fletton process, named after one of the local villages where it was first developed around the turn of the century. The illitic clay has about 20 per cent water content. This makes it sufficiently plastic to press into shape, and yet not so wet that the moulded bricks need to be dried out before firing. It is also strong enough to stack the bricks straight into the kiln without distorting. The lime content of the clay in the *jason* and *coronatum* Zones is at about the optimum to prevent shrinkage during firing. Furthermore, the carbon fuel content of the clay in these zones is about 5 per cent, which makes the clay self-firing. A very small amount of coal is necessary to control the firing temperature of 1050 degrees centigrade. Impurities in the form of fossil shell material occur mainly as soft and friable aragonite. Above and below the worked beds, the more calcite-rich shells of belemnites and *Gryphaea* abound, and if these are included in the bricks they produce pockets of quicklime after firing, with disastrous results when the bricks are wetted.

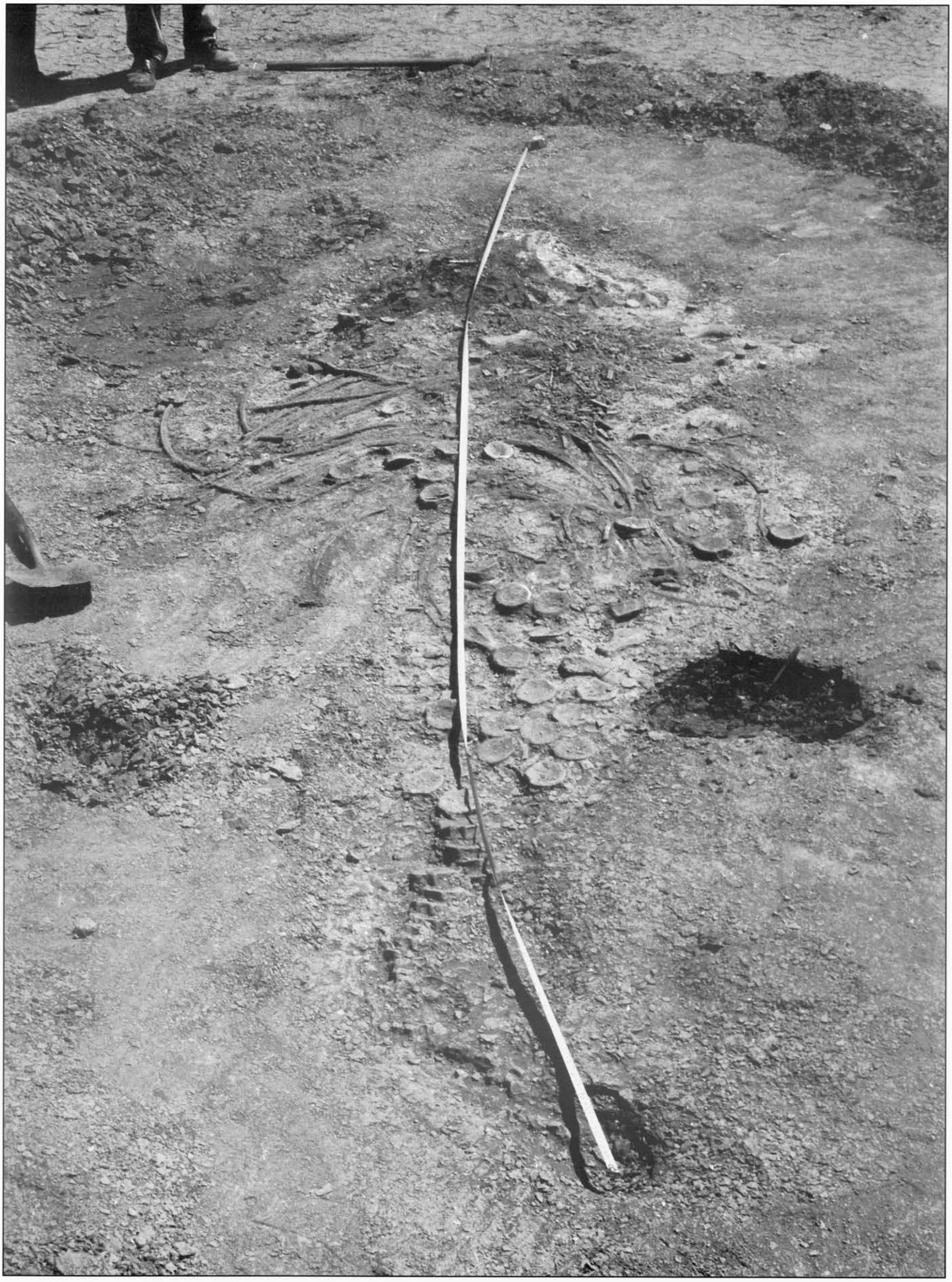

Fig. 1. Skeleton of *Ophthalmosaurus* exposed in situ in 1995. The restored specimen is 4.2m long.

Fig. 2. The author (right) and Shaun Shearman at work, mounting the specimen of *Pachycostasaurus dawni* for eventual display.

Such large-scale brick clay extraction led to the discovery of a considerable number of fossilized, large marine reptiles. Indeed the Oxford Clay of the English Midlands has been one of the most prolific sources of such fossils in the world. The clay was originally extracted by hand and transported by horse and cart. A series of benches or steps were cut into the face of the "knotholes" (the local name for the brick pits) and the cart would back up to the face. Heavy crowbars then levered the clay from the top of the bench into the cart. An experienced workman would know immediately when his crowbar hit anything harder than clay, and this led to the discovery of large numbers of vertebrate skeletons. The frequent discoveries were encouraged by two brothers who lived at Eyebury, to the east of Peterborough. Alfred and Charles Leeds were gentlemen farmers by profession but more interested in palaeontology. They would pay coins to workmen who discovered bone. Not all finds led to the excavation of a complete skeleton, but in the period up to the First World War the Leeds brothers amassed three major collections at Eyebury House. Each collection was sold when it became too large to house. Much went to the British Museum of Natural History, and some of their material may be found in museums all over the world.

The introduction of steam shovels in the pits meant that there was less opportunity to detect the skeletons and many must have been destroyed before they could have been discovered. After the Leeds brothers no more systematic collecting was done until Phillips resumed an interest after the war. He died in the 1920s and much of his collection is now stored in Peterborough Museum. Some of it has deteriorated through pyrite rot but the bulk is sound and is gradually being restored and mounted.

After Phillips' death, little serious collecting seems to have been carried out until the 1980s. Occasional finds found their way to the Peterborough Museum or brickworks exhibitions, but then Leicester University became interested in the vertebrate faunas. Dr Roy Clements and Dr John Hudson worked on the Oxford Clay and more recently Dr Dave Martill has made some important finds. Today the extraction of clay is much reduced and many quarries have been abandoned or land-filled. However, Peterborough Museum has its band of volunteers and new material is found at regular intervals.

Modern methods of strip-mining or shale planing with conveyor belts mean that potential specimens are either badly damaged or missed altogether. But the horizon which yields most skeletons is fortunately not worked for clay. The famous Bed 10 contains considerable numbers of large concretions, and it is in these that bones occur. The excavators do not go below this bed, but from time to time they skim over the top of the boulders and reveal bones. The Museum has several volunteers who scour the remaining pits at regular intervals and an average of about two skeletons per year are discovered, occasionally nearly complete.

The most recent find was made in June 1995 by Nigel Truss, who entered the museum one morning and produced several vertebrae from an ichthyosaur. He led us to the site where more bone was protruding. Permission was obtained from London Brick Company (now Hanson) to carry out an excavation. Two weeks of work revealed a near complete, partly-articulated skeleton of *Ophthalmosaurus*, 4.2 metres long (Fig. 1). Once uncovered, the whole skeleton was traced in situ on a large sheet of acetate, using a felt-tipped pen. Each bone was first numbered on the acetate trace and then, following lifting, the numbers were transferred to each bone.

The *Geology and Wildlife* gallery at Peterborough Museum contains many other fine fossil reptile specimens from the local brick pits. A crocodile (*Steneosaurus*), collected by Phillips in 1923, mounted three-dimensionally, immediately draws the eye of entering the gallery. Opposite, a near complete specimen of the plesiosaur *Cryptoclidus eurymerus* is displayed. This 1987 specimen has the most complete skull ever found for this species. In 1990 a worker unearthed bones which turned out to be a near complete specimen of *Liopleurodon ferox*. The skull is over one metre in length and the whole beast is some five metres long — and this is only a juvenile! In 1994, another small pliosaur was unearthed from the pits at Whittlesey. This has been mounted three dimensionally (Fig. 2) and is now on display. This specimen is unique — a new genus and species. It has been described by Cruickshank, Martill and Noe and has been named *Pachycostasaurus dawni*. Ammonites, belemnites and other shellfish formed the diet of many of the reptiles, as evidenced by the presence of their remains in the stomachs of articulated skeletons.

There is a sense of excitement, awe and wonder in the finding of these creatures never before seen by human eyes. Buried 150 million years or so ago, they have awaited discovery until now. Who knows what else remains to be revealed, or what previously-unknown animal will turn up to add to our gradually expanding knowledge of life in the Jurassic seas?

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REPORT

Origins and Innovations: the first 200 million years of vertebrate evolution

Vaughan College, Leicester, Saturday March 9th 1996.

Under the auspices of our good friends the Leicester Literary and Philosophical Society geology section, this one day meeting was organised by Dick Aldridge and Mark Purnell, both of Leicester University Geology Department. Its purpose was to present, through the medium of invited speakers, a synopsis of some of the more important recent advances in the study of the early vertebrates and vertebrate evolution. These timeless questions, always of great interest to we upright representatives of the phylum Chordata, have once again hit the headlines in recent times as the origins of our ancestors have been pushed ever farther back in time.

Paul Smith of Birmingham University opened proceedings with an overview of vertebrate origins and revealed a veritable Pandora's box of candidates for the earliest chordate, and then even more remarkably gave persuasive evidence of a fish that secreted vertebrate-like hard tissues in the Late Cambrian. Peter Holland of Reading University then showed how useful other disciplines can be in helping geologists unravel vertebrate origins by detailing his work on the genetic structure of vertebrate tissue. It was a tribute to Peter that, despite the complexity of genetics and its unwarranted reputation as a "difficult" subject, he lost no-one in the audience as he compared the genetic codes of primitive chordates with those of their more complex vertebrate relatives to reveal previously unsuspected similarities (and differences). Dick Aldridge has done more than most to put conodonts in their rightful places in the Chordata and his studies on the anatomy of whole-body conodont fossils from Edinburgh and South Africa are recognised as important landmarks in the recent palaeontological literature. He gave a lucid summary of his work to date and, after listening to the wealth of evidence now accumulated, surely few people in the audience (or elsewhere) were left doubting that the true affinities of conodonts lie with the vertebrates. Traditionally, bony tissue adapted for use in vertebrate structures was believed to have evolved via the protective bony armour of early fishes, but the latest work of the next speaker, Mark Purnell, indicated that its genesis was more a response to the predatory needs of those ancient and still somewhat enigmatic vertebrates, the conodonts. Mark's study of wear facets on conodont denticles demonstrates that direct analogies can be drawn with patterns of abrasion on the teeth of undoubted recent and fossil predators. The meeting then paused for the participants to digest the morning's proceedings, and their lunch.

The afternoon's talks began with Ivan Sansom of Birmingham University demonstrating how histology has thrown theories on the early vertebrates back into the melting pot. By careful thin sectioning of conodonts Ivan has discovered that in the Late Cambrian these animals were building tissue indistinguishable from some types of modern dentine and bone, those trademarks of the vertebrates. Also, sectioning of scales from a number of fishes from Ordovician horizons in North America, Bolivia, Australia and Argentina has revealed that a previously unsuspected diversity of armoured fishes (and ?sharks) were secreting vertebrate-like structures in their body armour long before their traditionally proposed radiation in the Silurian and Devonian. Peter Forey of the Natural History Museum admitted at the outset of his talk that he couldn't explain definitively how jaws had evolved, but then proceeded to present a fascinating insight into what may have been the mechanisms behind this most important advance taken by the vertebrates. What struck most forcibly during Peter's talk was the amazing variety of structures evolved by the fish-like vertebrates, past and present, to process their food, an evolution neatly demonstrated as following a line of increasing sophistication from the earliest vertebrates to modern teleost fishes with their remarkably complex jaws. After Moya Smith's (from Guy's Hospital) talk, no-one could have left the room without a considerably enhanced knowledge of lungfishes, past and present. In fact, Moya's talk was a classic example of the present being the key to the past, that most fundamental of geological observations. By comparing fossil and extant lungfish dentition, important insights into aspects of development and growth of the vertebrates were possible. On the way we also saw slides of the Gogo Formation fishes from the Devonian of Australia, surely some of the most beautiful fossils yet described. Per Ahlberg of the Natural History Museum tackled a most important, yet still baffling, aspect of vertebrate evolution when he attempted to explain the development of four-legged vertebrates (tetrapods) from fishes, a process which began in the Devonian. He showed that while some changes took place in an ordered step-by-step fashion according to text-book evolutionary theory, others happened suddenly. The latter may have been triggered by genetic signals, a mechanism harking back to the subject of Peter Holland's talk. The audience had hung on bravely through this last talk as thoughts of tea pervaded the hall, but they perked up considerably when Dave Martill, in typical lively fashion, stepped up to deliver a commendably concise and observant summary of the day's proceedings. It only remained for due thanks to be given to the organisers and their support team for a most successful day, which was well-supported by a nicely mixed audience approaching 60 in number.

Andrew Swift

REPORT

The Deeping Elephant

In July 1996, a field excursion by members of Stamford and District Geological Society visited the gravel pit at Deeping Bank, near the village of Deeping St. James about 5 miles north of Peterborough. The gravels are of fluvial origin and mainly date from the last (late Devensian) glacial period. However, a bed of clay and silt underlying the gravels is believed to have been deposited during the preceding (Ipswichian) interglacial, when the climate of the British Isles was substantially warmer than at present. One of the aims of the excursion was to find vertebrate remains; Pleistocene fossils had been found previously at the pit and, with 24 pairs of eyes searching, there was a real possibility of revealing more. Sure enough, Pauline Dawn unearthed an interesting bone fragment which proved to be part of the shattered tusk of an elephant.

Over the next two weeks, further digging by Society members revealed more of the skeleton, including a second tusk, unearthed by EMGS member Judy Small. When part of the skull and mandible were found, both with teeth *in situ*, Alan Dawn identified the beast as a straight-tusked elephant, *Palaeoloxodon antiquus*. This identification was later confirmed by Dr Anthony Stuart of the Norfolk County Museums Service. Judging from the size of the skeleton, Dr Stuart has inferred that the elephant was a female between 30 and 40 years old, and therefore not quite fully grown.

The clay and silt bed was deposited in an abandoned river channel; perhaps the animal may have become trapped when crossing the river. Work is in hand on the mollusc and insect fauna and on the palaeobotany and palynology, with the aim of determining more precisely the age and palaeoenvironment. Thermoluminescence dating of the bones themselves has yielded an approximate age of 117,000 years BP, consistent with the supposed Ipswichian age of the channel.

The remains have been placed in the Peterborough City Museum, the nearest and most appropriate place for them. The museum has the facilities and expertise to carry out the necessary conservation work. Although only 25 percent of the skeleton has been recovered, the good preservation of parts of the head mean that the Deeping elephant will rival in importance the well-known Upnor (Kent) and Aveley (Essex) skeletons. Conservation and casting of the bones is currently in progress, and it is hoped to put the skeleton on public display by the summer of 1999.

Alan Dawn

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SECRETARY'S REPORT FOR 1995/96

The year has been a very successful one for the Society. Since the last AGM 30 new members have joined and one Institutional Member has rejoined. Membership now stands at 214 Ordinary, 74 Joint, 79 Institutional. Sadly the death of one member, Mrs E. Lock, has been reported, and the Society's sympathy and condolences are extended to her family and friends.

The Secretary's job is in fact shared among a number of people and once again, I will use my review to thank the various individuals that have helped to organise such an enjoyable programme of events during the year.

The field meetings are organised by Dr Ian Sutton and we are very fortunate to have someone who has such a wide knowledge of locations and leaders. Dr Sutton and his office also save Council a lot of work by maintaining the postal address list, printing the envelope labels and posting the circular. The field trips are the best opportunity for our amateur members to do some hands-on geology. I understand that very few other societies can turn out sufficient members to make coach hire viable. This is greatly preferable to the marshalling of large numbers of cars, so please keep coming on the field trips. If you haven't this year, you have missed some excellent excursions.

In April, Dr Dick Aldridge led 44 members on a trip to the Wenlock Edge area to visit two working quarries and other localities. In spite of rain all day, many interesting fossils were seen, some intriguing reef/sedimentary relationships were observed and debated and much was learnt about the practical aspects of quarrying in that area.

In May, Dr Tony Cooper of the BGS led 36 members to Knaresborough Gorge, where an unconformity was followed through 14 locations to demonstrate how the Upper Permian strata were draped over the eroded Carboniferous land surface. Several excellent sections of the Permian Cadeby Limestone Formation (formerly known as the Lower Magnesian Limestone) were examined, providing the opportunity for members to study the range of carbonate depositional environments preserved in these rocks.

In June, Dr Ian Sutton and Mr Albert Horton led the Nottingham City building stones walk, which was attended by 34 people and generated considerable interest from passing members of the public, not all of it desirable! Many useful contributions were made by members, particularly Dr Firman. The walk was a trial run for the written version, which will be included in the Society's Field Guide to the Geology of the East Midlands (see page 96). Also in June, Alan Dawn led an evening walk to the Ketton Quarry geological trail.

The trip to the Cotswolds in July (see *Mercian Geologist*, Volume 14, Part 1, pp. 34-37) was led by Mike Sumbler and Mark Barron, both of BGS. It was attended by around 30 members and reported as excellent with very good fossil hunting. The Norfolk weekend in September, led by Martin Warren and Dr Sutton, was attended by 29 members and was also reported as excellent and very enjoyable. As always, the extra contributions by BGS staff and other knowledgeable members have enhanced the trips.

The field visits require a subsidy but Council think this is worthwhile to encourage more members to take part. We welcome guests of members on field trips where numbers are not limited. For insurance purposes, guests are made members for the day at a cost of £2.00.

The indoor meetings are occasions when most of the membership can get together. The meetings for 1995/96 were organised by Dr Neil Aitkenhead. Again the Society is very fortunate to have someone with such a large number of contacts to be able to find suitable speakers and who has the experience to be able to guide lecturers into a format that is suitable for our wide-ranging audience. This year we have once again enjoyed a varied and balanced lecture programme. The first lecture of the 1995/96 season was by Dr David Baker on the geology of the Moon and the evidence it provides to help us understand the origin of the entire Earth-Moon system. Over 80 members attended, several members commenting that this was one of the most enjoyable lectures for a long time, as evidenced by an interesting session of numerous challenging questions for the speaker.

In November, Simon Parfait admirably stood in at very short notice for Mark Roberts, who was ill. The large lecture theatre had been booked, as a large attendance was expected for the topic of Boxgrove Man, very much in the news at the time. About 150 members and guests attended and the lecture was very well received but unfortunately there were sound and heating problems which will be attended to for future lectures at this venue.

Prior to our usual cheese and wine get-together in December, Dr Brian Taylor of BGS, who is well known to most members, gave us an amusing and informative lecture on the history of the concept of geological time. In January, Dr Tony Waltham returned to a packed theatre to lecture on Katmai and St Helens in his highly individual and engaging style. For the Foundation lecture in February we were lucky enough to have Professor Joe Cann to talk about black smokers on the deep ocean floor and the fascinating creatures that live around them. The talk was illustrated with some amazing slides taken from the ALVIN minisub. The lecture was followed by an excellent meal in the comfortable surroundings of the University Staff Club.

Joan Bush is responsible for producing the circular, without which there would be no publicity for Society events. Joan has the difficult task of tactfully chasing speakers and excursion leaders for information and then collating it. There have been 6 circulars published this year.

There are many things to thank the President for but the one that I would like to mention here is for use of her office for photocopying the circular, minutes, agendas etc., thus saving the Society a great deal of time and money.

Your Council has met 6 times this year and continues to be conscious of its responsibilities in accordance with the Society's objectives of promoting interest in geology in the East Midlands by encouraging research, education and conservation. This year we continued with, or supported, several projects.

1. The EMGS Award Scheme is designed to increase the awareness of geology among 18 year old school leavers. It is a travel award of £250 for the winner and £50 for their School to be awarded to the best submission of a geological investigation proposal from a pre-undergraduate student in the East Midlands. With the assistance of members, the examining boards and the ESTA, we have refined our list of schools that are likely to have candidates, and have publicised the scheme through the ESTA and in all the relevant local papers and *Down to Earth*. Despite these efforts, however, I am disappointed to report that this year we have had no submissions and Council is therefore considering the future of the award. We made the award last year to Miss Katrena Stanhope of Skegness Grammar School, who produced a splendid report on her trip to Anglesey. She was also supported by the school. We would like to think that in a small way the Society may have helped her obtain three grade 'A' A Levels and a scholarship to Royal Holloway and New Bedford College of London University. She has written twice to say how well she is getting on and to thank the Society for its support.

2. The second initiative is the EMGS 'Field Guide to the Geology of the East Midlands', which is progressing steadily. The three 'city walks'-type excursions in the book will also be available separately as leaflets and published simultaneously. A lot of work is being done on this by Mr Horton, Dr Sutton and Dr Howard.

3. The Society has paid for the information and interpretation notices at the Ketton SSSI site. This project has been led by Alan Dawn with help from some of our members and members of the Stamford and District Geological Society. This year has seen the official opening of the much-praised site.

4. We have made our usual small financial contribution to help Derby Environmental Week, to be held in early 1996/97. As before, the Society will be represented at several events. Special thanks go to Philip Mucklow for dressing the Society's stand, which is also available for use at other events.

5. An ongoing initiative is the Nottingham Sandstone Caves booklet, an off-print of the original *Mercian Geologist* article. Thanks to the generosity of

the author, Tony Waltham and the energetic distribution team of Andrew and Judy Rigby, Judy Small and Dr Waltham, we have so far sold 3200 copies, generating a profit for the Society of over £3000. To build on the success of this booklet, Dr Waltham is rewriting it to make it more assessible to the lay reader and thus widen its appeal. The new version will be in a smaller format with a colour cover. Although there is now competition for sales in this area, we are confident that the new version will be a success both in terms of promoting the Society's objectives and providing a good financial return.

I have one final thank you to make on your behalf and that is to Nottingham University for providing us with excellent accommodation for our Council meetings and lectures. We are very lucky indeed to be able to use these facilities.

In conclusion I feel that the Society has had a very successful year and with the continuing and hopefully increased support of members, 1996/97 will be even better.

Alan Filmer

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BOOK REVIEWS

The Who's Who (or was Who) of geology

SARJEANT, W. A. S. *Geologists and the History of Geology, An International Bibliography.* Supplement II (1985-1993). Krieger Publishing Company, P.O. Box 9542, Melbourne, Florida, 32902, U.S.A. $365, 2386 pp. (in 3 volumes). ISBN 0-89464-880-2.

Our founder member, Bill Sarjeant, has extended his great bibliography again. Originally published in 5 volumes in 1980 with 6893 biographical entries for the years up to 1979, it was extended with a 2 volume Supplement I covering 1979-1984. This had 1548 entries. The new Supplement II has 1747 biographical entries of geologists. With cross-indexing by countries, subjects, organizations etc. the whole bibliography runs to nearly 45000 entries.

This is a massive work which Bill Sarjeant has compiled as a side-line from his main research subjects of palynology and reptile tracks. Over the years he has card-indexed the data contained in these bibliographies by scouring other bibliographies, reviews, obituaries and histories of science. He also scours the many libraries he has visited around the world. It is essentially an index of as many as possible of those geologists who have contributed to the historical growth of the subject. He has tried to cover all languages using the Latin alphabet, but with an estimated 30000 periodicals around the world which include some geology, doubtless there are omissions. Naturally, your reviewer looked up his own name but it was not listed, but then so far as he is aware nobody has written up his biography as yet, and it is a bit premature for an obituary!

Bill Sarjeant's biographical bibliography is a reference work which should be in every geological library. It will provide the raw material for many historical/geological studies in the future.

The original 5 volume set is still available at $535 and Supplement I is available at $195.

Trevor Ford

Leeds in Stone

DIMES, F. G. and MITCHELL, M. *The Building Stone Heritage of Leeds.* Leeds Philosophical & Literary Society, City Museum, Leeds. £9 paperback, 112 pp. ISBN 1 870737 10 5.

Building stones are somewhat marginal to geology but this nicely produced little book on our sister city of Leeds by two former officers of the British Geological Survey (Frank Dimes sadly died during the final stages of publication) is a welcome addition to the literature. It starts with an introduction to the history of Leeds and to the geology of the surrounding area before passing on to the history of its many notable public buildings. Some comments are made on the quality and durability of the stones used, mostly local Millstone Grit and Coal Measures sandstones. Comments are also made on imported ornamental stones. However, regrettably little is said on the techniques of quarrying or of shaping the stones. The main part of the book consists of itineraries for 4 walks around central Leeds plus more extended tours outside the City. The book concludes with a classification of the stones used and comments on problems of decay such as rising damp, sulphation and reaction to acid rain. A glossary and bibliography are appended.

Trevor Ford

Rock around the clock

CRAVEN, MAXWELL. *John Whitehurst of Derby; clockmaker and scientist 1713-1788.* Mayfield Books, Ashbourne, Derbyshire. £24.99, 272 pp. ISBN 0 9523270 31.

As the title indicates, Whitehurst earned his bread and butter as clockmaker and much of the book is devoted to this theme, which the author has thoroughly researched. However, EMGS members will know of him more as a pioneer geologist. His book on "An Inquiry into the Original State and Formation of the Earth" (1778 & 1786) contains the first published sections of strata across the Derwent Valley at Matlock. These were the inspiration for

White Watson's Geological Tablets, the first of which was presented to Whitehurst in 1786. He also drew sections around Coalbrookdale and gave us one of the first diagnoses of what crinoids were, from comparison of the abundant fossils in Derbyshire with modern crinoids then recently discovered off the West Indies. Whitehurst's Matlock sections incorporated information obtained from lead miners and so provide us with indirect data on the miners' knowledge of practical geology in the mid 18th century.

Whitehurst was a member of the Lunar Society, the informal gathering of mid-18th century scientists, philosophers and industrialists, and he was a close friend of such people as Wedgwood, Erasmus Darwin, Boulton, Watt and Priestley. Maxwell Craven has analyzed the correspondence of these and many others, as little of Whitehurst's own papers have survived. He shows that Whitehurst had considerable influence on the others in catalyzing their ideas on almost anything (architecture, hydraulic engineering and minerals to name but a few). He presents us with a fascinating picture of Whitehurst as a generous businessman, a philosopher, a maker of clocks and other instruments such as barometers, and in later life as Keeper of Standard Weights at the Royal Mint. He was also elected a Fellow of the Royal Society. Craven's coverage of Whitehurst's geology is somewhat limited, comprising only one chapter (No. 6) out of eleven; much of this is more concerned with Whitehurst's successors, White Watson and John Farey, as well as with the use of geological materials in ceramic manufacture.

Craven discusses Whitehurst's family history in detail. His family originated in Cheshire and he moved to Derby to avoid competition with his clockmaker father. He had only one child which did not survive infancy, but several brothers and cousins came into the clockmaking business. As well as discussing these, the author makes long digressions on the family history and contributions to industry and knowledge of Whitehurst's numerous associates and descendants, thereby going rather beyond his brief, but interesting reading nevertheless. Among these associates were the artist Joseph Wright and the cartographer Peter Burdett.

Along with Erasmus Darwin and others, Whitehurst made several explorations of Derbyshire lead mines and caves, but it is a pity that few details of where they went and what they saw appear to have survived.

The book is nicely printed with many black and white illustrations; a few of these are rather muddy reproductions and it is a pity that some are not in colour, for example the frontispiece portrait of Whitehurst and the famous painting of the Orrery (page 57), both by Joseph Wright.

Trevor Ford

NOTES TO CONTRIBUTORS

Scientific papers are accepted on the understanding that they have not been published or submitted for publication elsewhere; all contributions become copyright of the East Midlands Geological Society on publication. Two copies of papers should be submitted in a format as close as possible to that of the *Mercian Geologist* since Volume 13, Part 1 (1992); single copies of news, reports and review items are acceptable.

Abstract. Scientific papers should be accompanied by a brief abstract stating the essential information and conclusions presented in the text.

Text. Please present contributions on A4 (297 × 210mm portrait) paper, typed or word-processed on one side only, double-spaced, with ample margins.

References. All references cited in the text should be listed; the author is responsible for the accuracy of references. In the text, references should be given as: (Smith, 1992); use (Smith *et al.*, 1992) for more than two authors. In the References, list all authors and do not abbreviate journal titles.

Illustrations. Line drawings and photographs will all be included as text-figures, and should be presented wherever possible to cover or be in proportion to one column (width 84mm) or two columns (width 178mm) and up to 245mm depth. When full page line drawings and photographs are used an appropriate allowance should be made for the required caption. The smallest lettering on line diagrams should not be less than 1mm high. A full list of figures, with captions, should be submitted on a separate sheet. Approximate locations for text-figures should be indicated in pencil in the margin of the text. Tables will be typeset and should be designed to fit single or double column widths and up to the maximum depth.

Photographs. Whilst colour prints are acceptable good clear monochrone prints are preferable.

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