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Front cover picture: *Dunbarella papyracea* Specimen 1979.88.A; an example of a non-marine bivalve from Ravenhead Quarry, Upholland near Wigan (see page 17) in the fossil collection of National Museums Liverpool.
Photograph: Wendy Simkiss, © National Museums Liverpool.

THE NORTH WEST GEOLOGIST
(Formerly THE AMATEUR GEOLOGIST)
Number 18

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Editorial

This issue of North West Geologist has been particularly difficult to put together due to incredibly challenging circumstances. It is made up of a small number of larger articles and I am very grateful to the authors Derek Brumhead, Geoff Tresise, Jane Michael and Tom Metcalfe. I would also like to apologise to Duncan Woodcock for an error in the last issue (number 17) in which a formatting error meant the wrong diagram was inserted into the article. The correct one can be found at the end of this issue.

Wendy Simkiss

Circumstances beyond her control have prevented Wendy Simkiss from completing the editing of this issue of North West Geologist. Sue Plumb (MGA) and Jennifer Rhodes (LGGA) have completed the task.

Notes for Authors

Articles and suggestions for future issues are most welcome and should be sent to either Chris Hunt, Department of Earth Sciences, The University, Liverpool L69 2BX or Wendy Simkiss, Earth Sciences, World Museum Liverpool, William Brown Street, Liverpool, L3 8EN,
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Articles should preferably be emailed, or if very large files, be presented on disk in MS Word. They may be up to 3,000 words in length. Figures should be designed for reduction to fit a maximum frame size of 180 mm by 125 mm.

Cover pictures can either be photographs or digital images and must include the name of the photographer or owner, the society to which they belong and information about the image including the location. The cover picture will be around 92 mm by 72 mm and, if sent as a digital image must be at least 300 dpi.

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RATES OF SEDIMENTATION IN THE NAMURIAN AND WESTPHALIAN: A REVIEW

by Derek Brumhead

This paper was presented at the Manchester Geological Association's first Fred Broadhurst Memorial Lectures at Manchester University on 12 November 2011.

Studying the rates of sedimentation is rather like serving as a soldier – hours of boredom interrupted by brief moments of terror.

Namurian

This observation is well illustrated in the High Peak in Derbyshire. In the late Namurian of the Pennines, deep marine basins were inherited from Dinantian bathymetry, involving tilt blocks and basins (**Figure 1**) which played a major role in controlling deposition. The mudstones of the basins record a period when deposition of suspended sediment in quiet, relatively deep (a few hundred metres) conditions, generally out of range of any coarser clastic supply, took hundreds of thousands of years. Underlying the Hope valley of the High Peak, the Edale Shales are 800 ft. thick and extend over four goniatite zones, E, C, N and H (Stevenson and Gaunt, 1971). As will be shown later these zones could represent a total period of approximately 732,000 years, i.e. a rate of deposition of one foot every 915 years (one metre every 2,975 years).

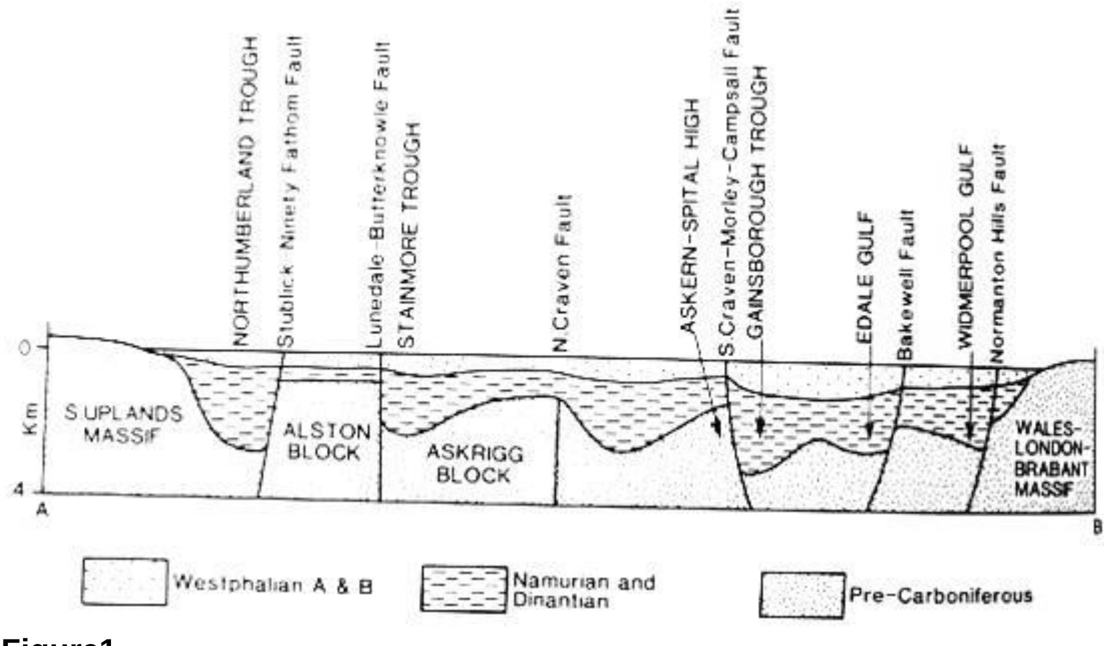

Figure1
North-South section of the Pennine Basin showing major basins and tilt blocks which influenced Westphalian A and B sedimentation. (Guion and Fielding Fig 13.5: Besley and Kelling 1988)

These deep marine tectonic basins came to be filled with enormous volumes of igneous and metamorphic material brought by the erosion of a large mountain range to the north. During the Kinderscoutian in the Vale of Hope the long period of boredom was supplanted by moments of terror with the arrival of a turbidite-fronted delta, fed by large delta-top distributaries transporting coarse sands directly to submarine feeder channels (**Figure 2**). A bed deposited by a single turbidity current may be decimetres or even metres thick but takes only a matter of hours to form (**Figures 3-6**). For instance, in 1929 following the Newfoundland earthquake, 12 North Atlantic telegraph cables linking North America and Europe were broken. Subsequent studies demonstrated that a turbidity current, triggered by the earthquake, was responsible. From the known times and positions of the cable breaks, the track and speed of the current was reconstructed, amounting to 60-100 kph (38-63 mph) (Fine et al., 2005). Between the pulses of the turbidite flows, hundreds or thousands of years might pass with very slow sedimentation from suspension of the hemipelagic deposits (**Figure 3**).

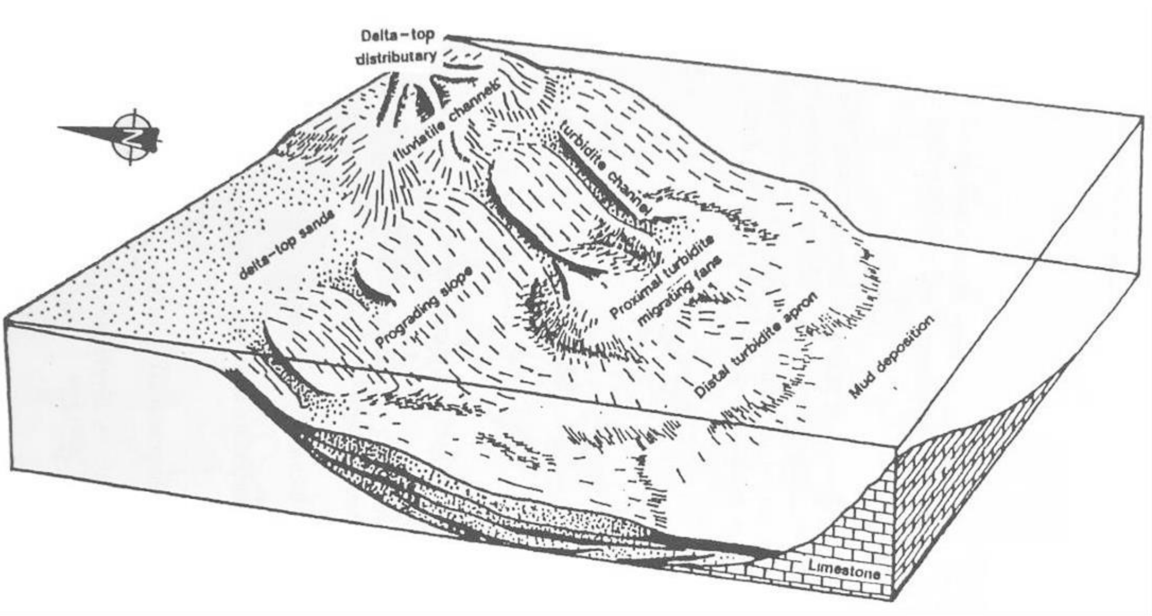

Figure 2
The approach of a Namurian turbidite-fronted delta towards the Derbyshire limestone massif in Dinantian times.

This turbidite-fronted delta sequence constituted a major basin-filling sequence of the Namurian (**Figure 4**). These coarsening-upwards sequences of the prograding delta slope sequences are capped by a delta-plain system with major fluvial distributary channels and by marine bands or perhaps thin and low quality coals (**Figure 5**). The water discharge on the delta-top was at times very large and the apparent rapidity of these progradations demonstrated the sediment-transporting capacities of the rivers with the rapid dumping of sand during floods during lateral migration of the channels. The thick regressive sandstones associated with a falling sea-level are up to several hundred metres in the Kinderscoutian and Pendleian and it can be shown that that they occur within a single cyclothem, so confirming the rapid deposition. For the deposition of individual sandstone units, we are probably talking of days.

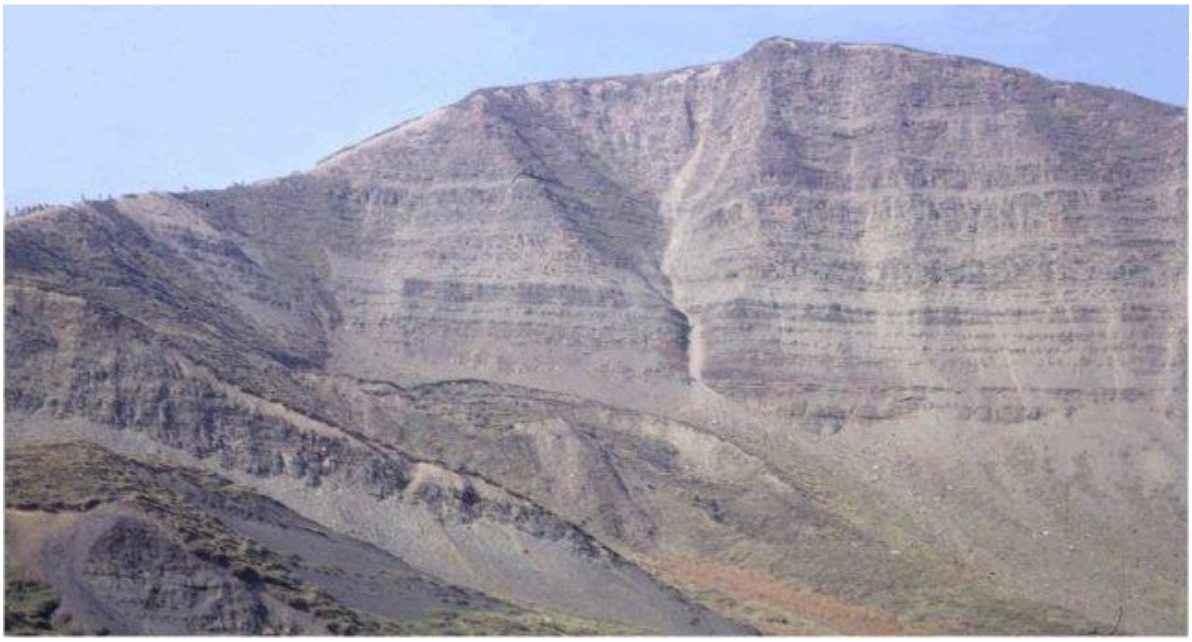

Figure 3
Turbidites of Mam Tor overlying the Edale Shales (bottom left)

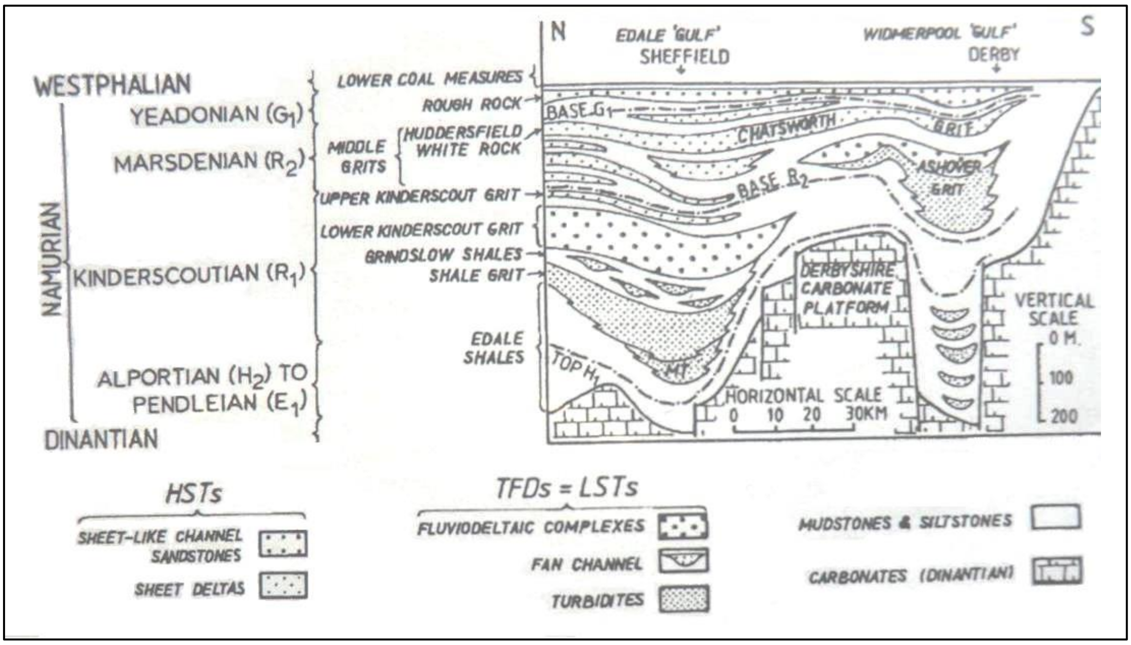

Figure 4
Cycles of fluvio-deltaic complexes in the Edale Gulf with intervening mudstones due to fluctuating eustatic sea-levels (Read, 1991, after Collinson, 1990)

In considering the rates of sedimentation, a number of parameters of sedimentation have to be taken note of – the rate of sea-level change, rate, subsidence, compaction and the available accommodation space (defined as the space in which sediments may accumulate and be preserved). Strata vary laterally in thickness, hence there must be a variable rate of sedimentation laterally in these beds, so that measuring say, one graphic log, is not a way of finding a regional result. This is well shown in the main sandstones of the Millstone Grit where sandstone units not only vary considerably in thickness but have limited south-north extent (**Figure 6**, Waters and Davies, 2006). Graphic logs show considerable differences in the thickness of the sandstones yet the goniatite zones, which are isochronous, show that they were deposited in the same total time. Hence, there were great variations in the rate of sedimentation.

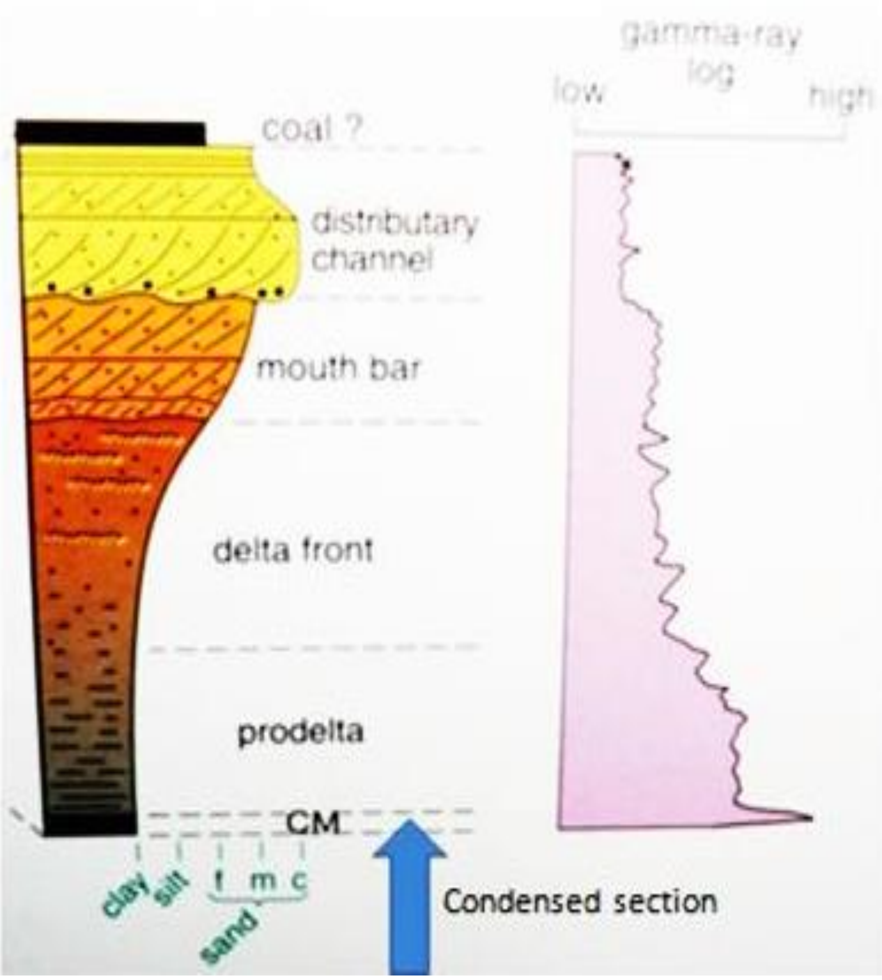

Figure 5
Typical Namurian coarsening-upwards deltaic cycle, CM is a marine band (condensed section) (Coe 2005)

The deposition of succeeding bedding may also be preceded by the removal of underlying sediment. For instance, the Crawshaw Sandstone in the East Midlands (the lowest sandstone of the Westphalian, equivalent to the Manchester region's Woodhead Hill Rock), responding to a falling sea-level, is a highly incised valley fill into the underlying Rough Rock Group, cutting through several underlying marine bands and earlier delta systems (**Figure 7**). It thus produces an erosional unconformity or sequence boundary which, unless it was deposited in an area of varied topography, marks the removal of strata at a scale which forms an identifiable time gap. Five goniatite zones could cover c.915,000 years.

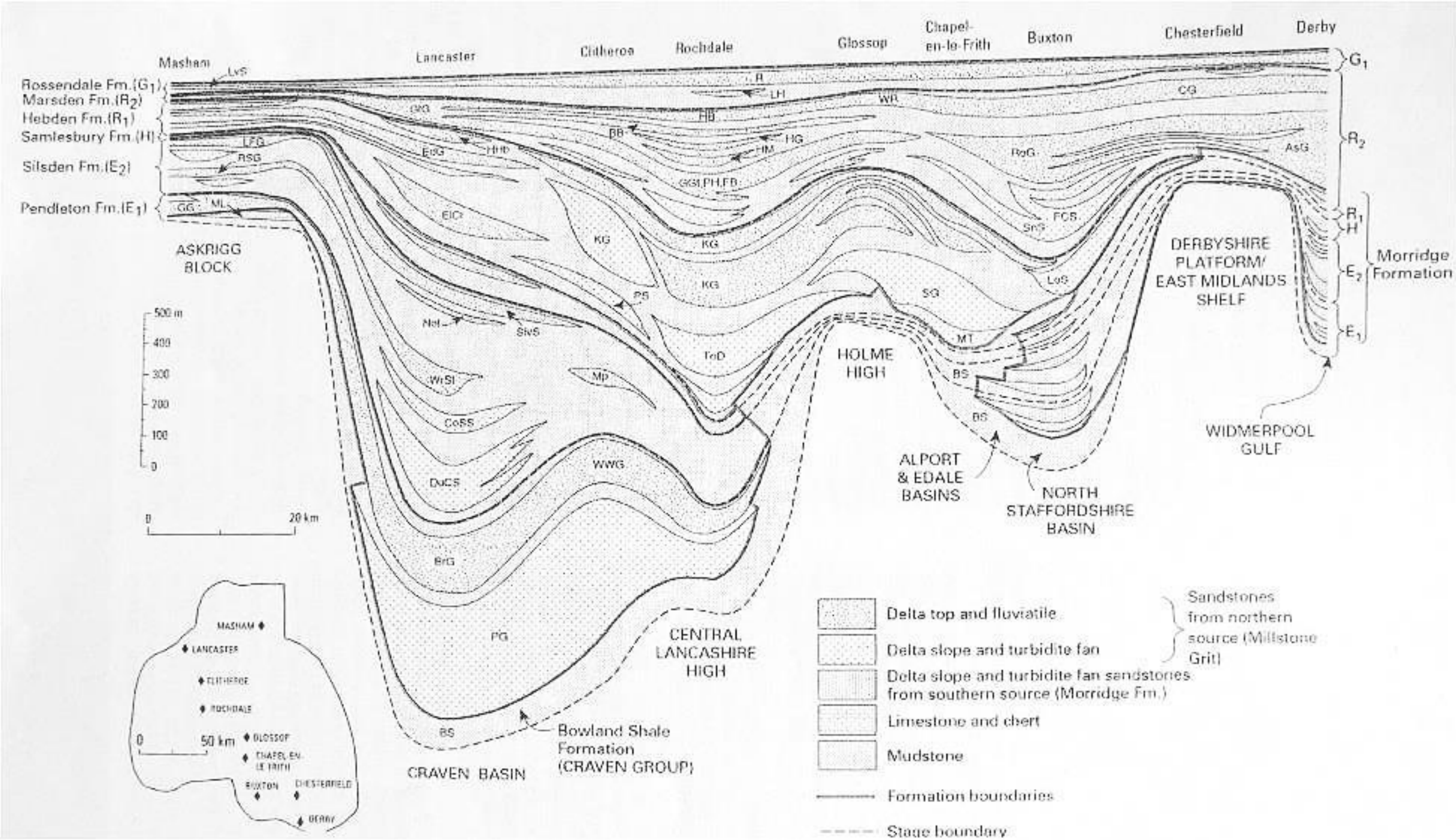

Figure 6
Distribution and lithofacies of the main sandstones of the Millstone Grit Group of the central Pennines showing lateral variation in thickness (Waters and Davies: Brenchley and Rawson, 2006)

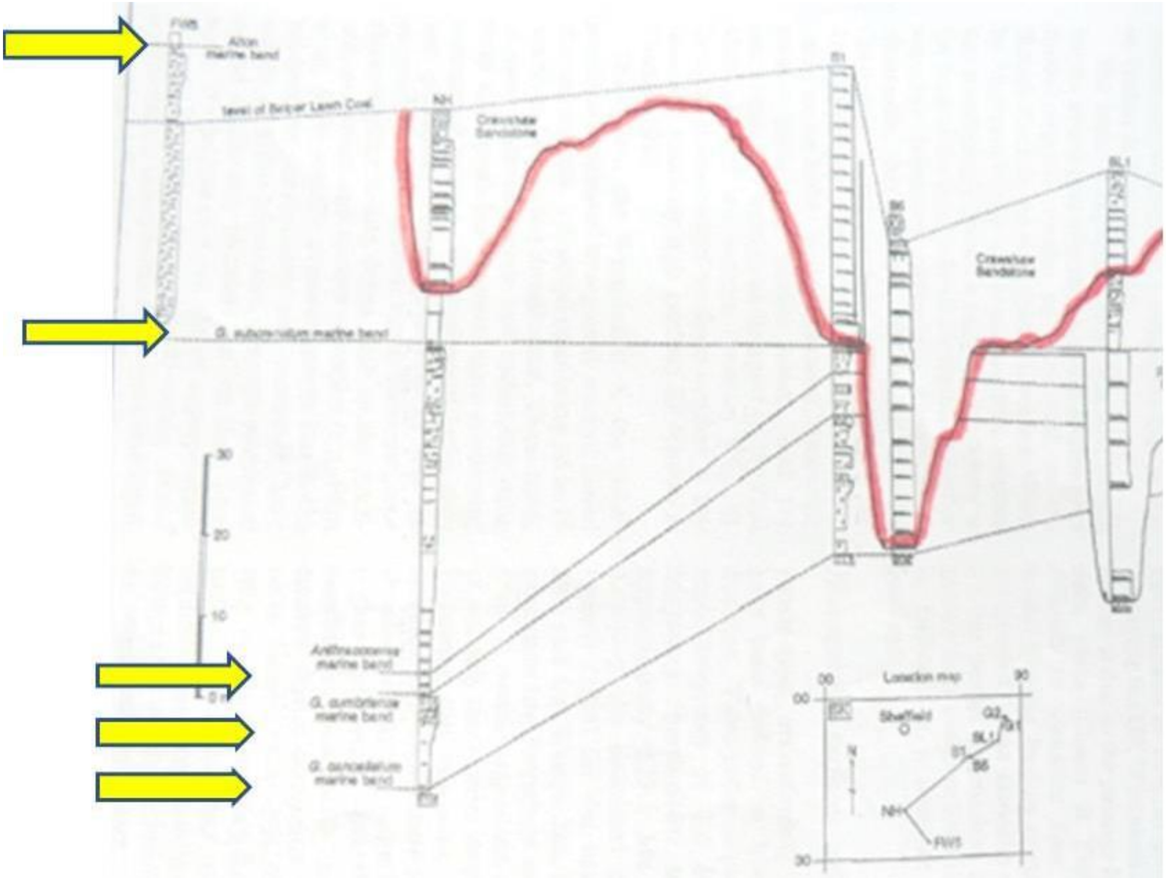

Figure 7
Cross-section through the south-east of the Central Pennine Basin showing the Crawshaw Sandstone complex (base of the Westphalian) incised into underlying deposits and removing almost the entire uppermost Namurian Rough Rock group succession including five marine bands. The marine bands shown by the arrows are from the top: Alton marine band: *Gastrioceras subcrenatum: Anthracoceras: Gastrioceras cumbriense: Gastrioceras cancellatum* (Flint, Aitken and Hampson, Fig. 8: European Coal Geology, Geol. Soc. Spec. Pub., No. 83, pp. 1-16, 1995)

Each of the upwardly-coarsening deltaic cycles was followed by marine transgressions and delta abandonment and in the Namurian there were at least 60 of these cycles or cyclothems (Ramsbottom, 1979). A major ice cap in Gondwanaland prevailed during the Namurian, having commenced in the Visean and traditionally it has been considered that the waxing and waning of ice produced glacio-eustatic sea-level changes which were responsible for the cycles. This underlying concept of eustasy as an influence on sedimentation, particularly with respect to widespread marine transgression, is widely accepted. But several geologists insert a word of qualification. Not all are agreed that these depositional cycles are only due to glacio-eustatic changes in sea-level. It has been suggested that in the Carboniferous the Gondwana ice sheet was highly sensitive to orbitally forced variations in solar insolation, tied to Milankovitch cyclicity which caused the sedimentary cycles. The periodicity, magnitude and widespread nature of the sea-level changes and the associated marine transgressions can be assigned to a non-random cause operating within the range of those expected from orbitally-forced glacio-eustasy (Maynard and Leeder, 1992). Falcon-Lang in 2004 demonstrated that plant assemblages in Pennsylvanian tropical rain forests recorded in the Sydney Mines Formation in Cape Breton Island concentrated and expanded in response to glacial-interglacial rhythms recorded in cyclic sediments which record orbital forcing.

A number of workers have attempted to calculate the average duration of these 60 Namurian cyclothems of which almost every one of the marine incursions had its own diagnostic goniatite species. Ramsbottom (1979), who anticipated the advent of sequence stratigraphy, postulated that a new goniatite fauna and associated cyclothem occurs every 250,000-200,000 years, i.e. making a total of between 12 Ma and 15 Ma years for the Namurian.

This traditional biostratigraphical method of dating has been supported by radiometric methods. Hess and Lippolt (1986) used radiometric dating ($^{40}Ar/^{39}Ar$) of tonsteins (weathered volcanic tuffs) and sanidine (a variety of orthoclase feldspar) interdigitated in the Carboniferous sediments to calculate a figure of 11 Ma for the duration of the Namurian. This date was later confirmed by biostratigraphical methods (Holdsworth and Collinson, 1988). That would mean that a cyclothem occurred every 183,000 years. This age of the Namurian was later confirmed by Gradstein et al. in 2008 (**Figure 8**). One could add that Ramsbottom's 1979 estimates were not far off the mark.

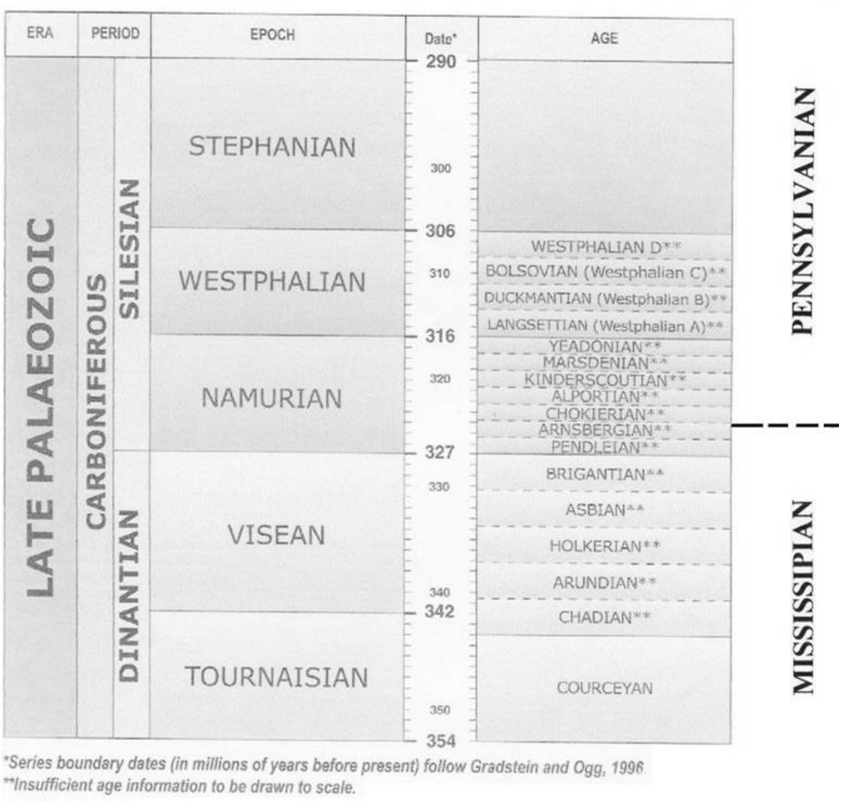

Figure 8
Ages of Namurian (11Ma) and Westphalian (10Ma). Concise Geological Time Scale (Gradstein, Ogg, and Van Kranendonk, 2008)

Westphalian

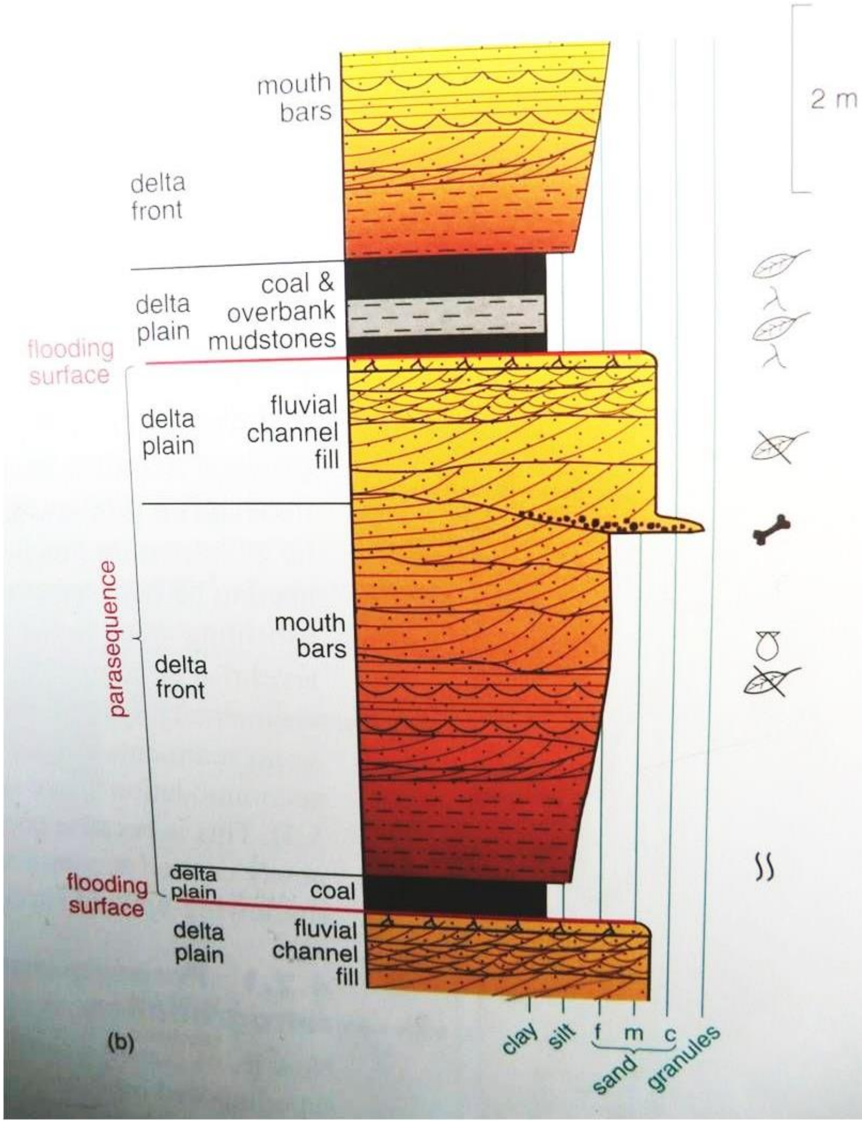

Figure 9
Typical Westphalian deltaic succession (A. Coe, 2005, Fig. 4.5 (b))

Westphalian A strata sediments are similar in character to the underlying Namurian but continued to be less influenced by the blocks and troughs and more by thermal sag (Leeder, 1982). A gradual transition from lower to upper delta plain environment took place. In general, the Westphalian rocks in NW Europe represent flood-plain deposits of mudstones, diachronous sandstones which show much lateral variation in thickness, siltstones and coals (**Figure 9**), with marine transgressions that became less common through time. The Westphalian contains approximately 100 cycles but only five widespread marine bands, the chief being the Vanderbeckei widespread across N W Europe, all of which were due to eustatic rise in sea-level. The cyclothems are thinner than in the Namurian, the deltas are not so laterally extensive, they do not have turbiditic aprons and have proportionally thicker fluvial-deltaic sediments which indicate deposition by major low-sinuosity distributary channels in a lower alluvial/upper delta plain environment.

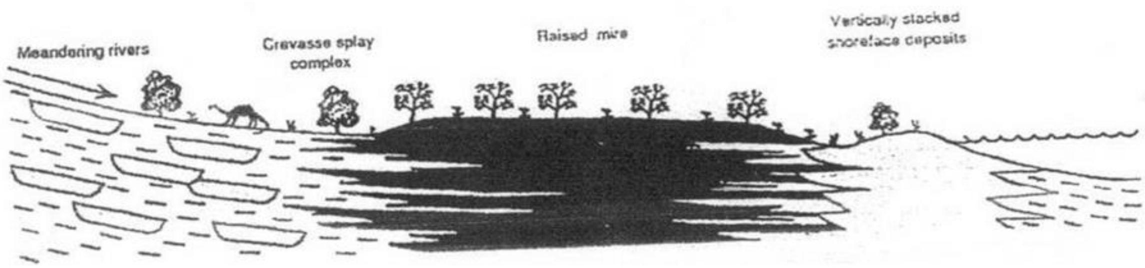

Figure 10
The creation of peat mires in the Westphalian. Peat mires are maintained through several thousands of years by a slowly rising base level and high water table. Accommodation space of hundreds of square miles is created. Clastics from the interior do not reach the mire. There was a high rate of creation in the Westphalian mid A to late B – hence thicker and more abundant coals. (Flint, Aitken and Hampson, 1995 from McCabe and Shanley, 1992)

The humid tropical climate resulted in a largely waterlogged plain. Lakes were a common feature, tens of km in diameter and 5-10m deep. They were slowly infilled by suspension fallout, bedload material from small lacustrine deltas, crevasse splays and overbank deposits. Gradual vertical accretion (aided by channel distributaries) raised the delta surface until vegetation was able to get a hold on abandoned channels and infilled lakes and established swamps or raised mires (non-saline wetlands) where peat accumulated.

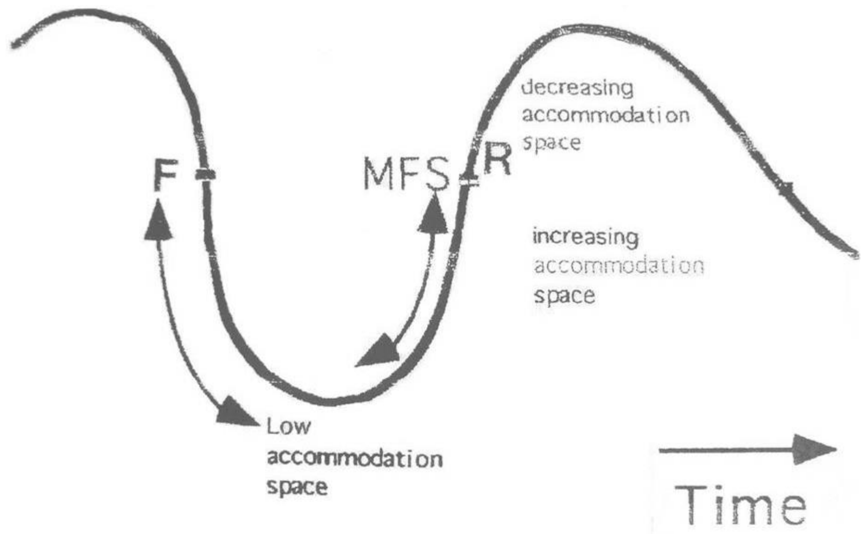

Figure 11
Sinusoidal conceptual sea-level curve of eustatic sea-level oscillations showing maximum rise of sea-level at inflection point 'R' and creation of space landward up to that point. (Flint, Aitken and Hampson, 1995, Fig. 2)

Coal seams**,** derived from the peat**,** accumulated more slowly than any other rock types in the Westphalian. They accumulated as raised mires or swamps where clastics were excluded (due to the reduction in the gradient of the fluvial system) and maintained through several thousands of years (**Figure 10**). They depended on a widespread slowly rising water table, achieved by a base level rise on a regional scale, (maximum rise of sea-level at inflection point 'R' on graph, **Figure 11**) and the creation of accommodation space. This led to the occurrence of mires, often evolving into raised mires (they maintained their own water table), and the preservation of peat as the waterlogged conditions promoted anoxia, thus reducing the chance of the organic matter being oxidised. With the next relative sea-level fall, fluvial channels deposited siliciclastic sediments on the peat and following burial the peat was preserved as coal.

In the early Westphalian, marine flooding events were greater and the time available for peat accumulation principally as low-lying mires, was shorter, resulting in thin 'cannel' coals of poor quality e.g. the Yard (Bassy) seam overlying the Woodhead Hill Rock, the lowest sandstone of the Westphalian (**Figure 12**). With substantial subsidence rates, high rate of creation of accommodation space and fresh ground water, coals are more abundant, thicker and more laterally continuous in mid-Westphalian A to late Westphalian B. The duration of the Westphalian is calculated as 10 Ma (**Figure 8**). If this is the case, the maximum thickness of the Coal Measures of 7,425 feet (2,283m) in the Manchester-Oldham region means an overall sedimentation average rate of the order of 1,347 years per foot (4,380 years per metre). Since it was all deposited at or near sea-level, it follows that the subsidence rate was huge. The vast, flat, swampy, low-lying lands or mires developed at or near sea-level, covered a very large aerial extent, lying in several different structural basins and as much as 2,000 km E-W and 600 km N-S. For instance, the coalfields of northern England represent one continuous depositional area, which has since been separated by the Variscan orogeny and later erosion.

It is difficult precisely to convert rates of peat accumulation to coal because considerable compaction (perhaps as much as 5:1) takes place within peat in a mire environment. Ratios have been calculated to be between 1.4:1 and 30:1. Assuming a median average ratio of 10:1, McCabe (1987) calculated that 1 metre of coal represents peat accumulation in the tropics over a period between 4,000 and 10,000 years. Mudrock partings in coals probably represent events with a periodicity of thousands or even tens of thousands of years.

Mires therefore maintained themselves through many thousands of years. The Limestone Coal Group (Pendleian) of Scotland attains a thickness of some 200-450m, of which 4.2-9.2% is coal resting mainly on sandstones and seat earths with some mudstones (Read, 1988). Since this group has been shown to occupy the upper part alone of one goniatite zone (E1a) taking c.183,000 years, the time for the accumulation of up to 40m of coal is c.1m in 4,575 years. In 1986, Fred Broadhurst and Tony France in their article on 'Time represented by coal seams in the Coal Measures of England' calculated 1m in 7,000 years (Broadhurst and France, 1986). Both these figures fall into McCabe's range.

Coal seams are characterised by lateral changes, mostly seam splits. They represent greater subsidence and higher rates of sedimentation in the direction of the splitting and so allow a direct comparison of the rate of coal formation with that of interseam sediments. It is generally agreed that peat formation was continuous during a given length of time on one side of the split (where the parent seam occurs), while subsidence occurred on at least one occasion during the same time interval on the other side of the seam split. Hence, the length of time for the sedimentation between the split seams is equivalent to that of the parent seam.

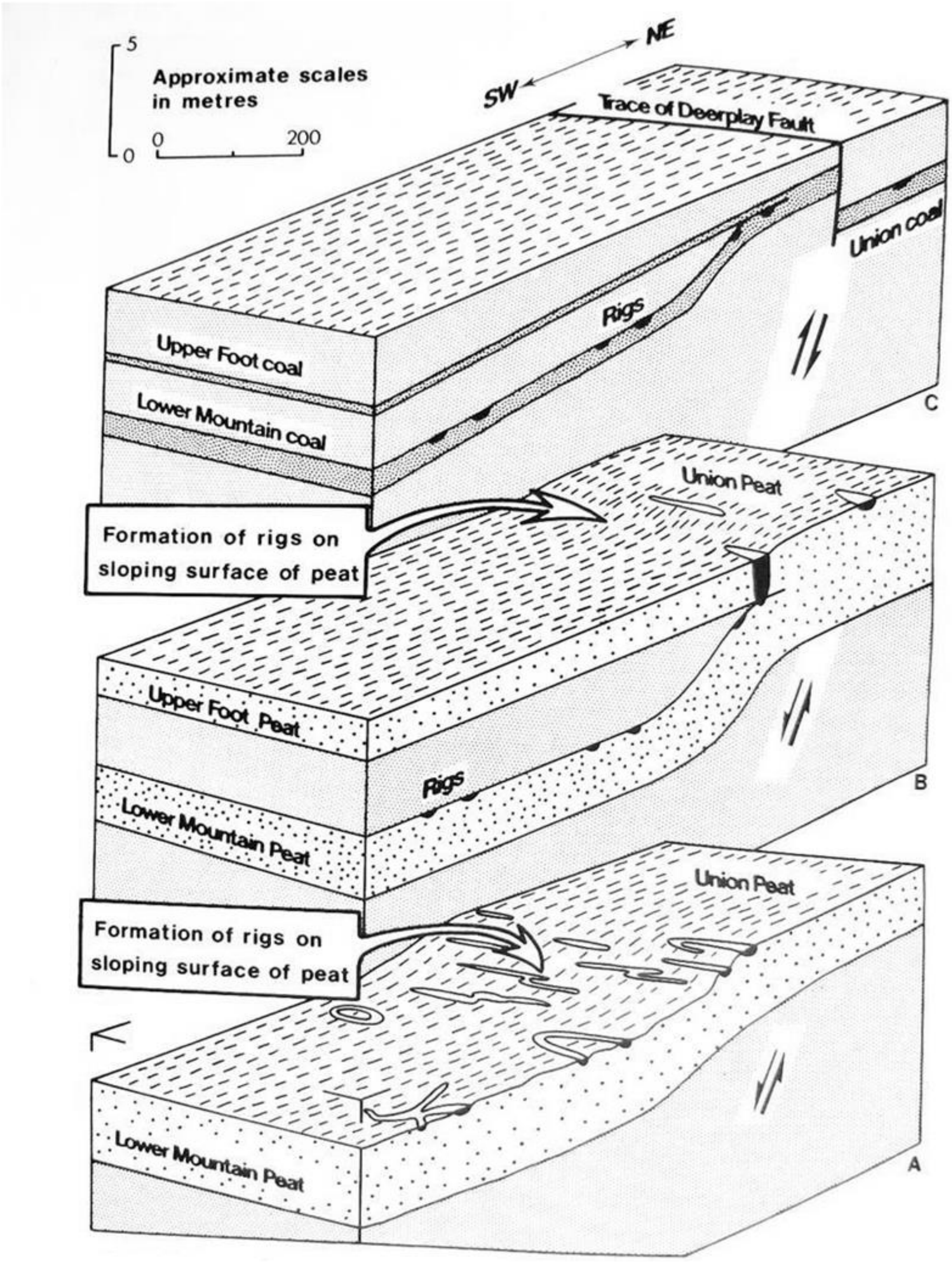

Figure 12
Diagrammatic reconstruction of events associated with the formation of the split of the Union Mine in the Burnley area of Lancashire. (Broadhurst, Simpson and Williamson, 'Seam Splitting', Figure 4.)

An article by Fred, Morven Simpson and Iain Williamson (1968) refers to the split of the Union Mine coal of the Burnley area to form the Lower Mountain and Upper Foot Mine coals, first described in 1916.The split develops in a south westerly direction so that in less than half a mile the two members are separated by some 60ft (18m) of predominantly arenaceous strata (**Figure 12**). The rate of sedimentation was rapid, since occasional trees were found in the position of growth. The *Gastrioceras listeri* marine band overlies the coal before the split and the Upper Foot Mine after the split, so providing a widespread datum level. It is also suggested that the seam splitting was due to movement along a buried fault which ran parallel to the line of the seam split during the time of peat formation.

Another celebrated case is that of the Thick Coal of the South Staffordshire Coalfield (Mitchell, 1942). This coal splits laterally into several seams separated from each other by varying thicknesses of clastic sediments. The Thick Coal varies between 6m and 10m in thickness whilst the corresponding sequence of coals and sediments totals approximately 50m. This confirms that the deposition of interseam sediments was a much more rapid process than was the accumulation of peat. Another example is provided by the splitting of the Barnsley seam. Raistrick and Marshall's somewhat dated but underrated book (1939) has a chapter of 15 pages on the splitting of coal seams.

Marine Bands

Marine bands are condensed sections due to the marine incursions, referred to in modern terminology as maximum flooding surfaces. They occur at the point of maximum rate of base level rise ('R' inflection point on the graph of the sinusoidal curve of eustatic sea-level oscillations) not at the eustatic sea-level highstand (**Figure 11**). The rapid rise in sea-level above the shelf margin means sedimentation rates are very slow in response to the great distance from sediment supply, and the great area of accommodation space exposed to sedimentation on the sea floor made available on a regional or continental scale. Thus a condensed section results when the last fine-grained widespread transgressive sediment collects. They may be in total less than a metre in thickness. For instance, the *G*. *cumbriense* band of the central Pennines does not generally exceed 60cm in thickness (Wignall, 1987). The time taken for their deposition will be of the order of tens of thousands of years, of the order of ten times that of the rest of the deltaic cycle. Sediment supply is re-established when fluvial sedimentation ends at abruptly at the 'F' inflection point on the graph, the sea retreats rapidly and the next cycle starts. The erosion and palaeosol surfaces resulting are just as important as the marine bands, being associated with potentially significant strata omission (C N Waters and S J Davies, 2006).

The transgressions brought with them marine bands containing a concentration of diagnostic goniatite faunas each of which form approximately isochronous marker horizons, i.e. they represent the same marine transgressions. They were extensive within and between basins on a continental scale, for instance, the *Gastrioceras subcrenatum* band at the top of the Namurian extends from northern England across Europe to the Donetz Basin in Russia. From **Figure 5**, it can be seen that the progradation of each mudstone layer is recognised from the high uranium concentrations showing as 'spikes' on the gamma-ray logs, because the marine mudstones are enriched in radioactive isotopes. Low carbon/sulphur rates also point to low sedimentation rates.

The intervals of strata in between the marine bands are rarely constant in thickness traced laterally over any appreciable distance so that the overall rate of sedimentation is variable laterally. Some evidence for this is provided by certain faunal characteristics. Changes in the rate of sedimentation have been related to lateral changes in thickness of bands of non-marine bivalves together with change in population density. Features of the size-frequency distributions of non-marine bivalves and the grain size of enclosing sediment have also been related, at least in part, to different rates of sedimentation (Broadhurst, 1964). Absence of fauna has been related to a high rate of sedimentation.

Almost the only evidence for fully marine salinity comes from the marine bands indicated by thick-shelled goniatites, the subject of an article by Fred and a colleague in 1970 (Broadhurst and Loring, 1970, Calver, 1968). The salinity of each marine band shows: advance, acme, retreat. The highest concentration of goniatites is in the centre of the marine bands, There is a preponderance here of small goniatites due to infant mortality arising from stagnant conditions indicating slow sedimentation. Less extensive marine bands with *Lingula* and other marine or brackish fossils are indicative of lower salinity. Successive deltaic progradations would reduce the volume of water in the basins and the fresh water proportion would increase. Trace fossils (e.g. *Pelecypodichnus*) which become progressively more important upwards through the Namurian between marine bands suggest overall decreasing salinity (Eagar *et al* 1985).

Upright trees are evidence of very rapid sedimentation of the enclosing sediments. The trunks were surrounded by sediment before the interiors were decomposed, otherwise the trees would have fallen over. The Fossil Grove in Victoria Park, Glasgow, is a famous locality. A fossilised tree has been described in position of growth from the Coal Measures at Blackrod near Wigan. Fred and a colleague (Broadhurst and Magraw, 1959) refer to a 13ft (4m) cast, probably once 38ft (12m), completely buried in sediment and rooted immediately above the underlying coal seam. This and other fossil trees had been broken off not more than six feet above the coal seam. He calculated that the rate of sedimentation round the tree was very high involving a rate of sedimentation of 4½ inches per year.) DiMichele and Falcon-Lang's paper of 2011 quotes this paper. Tree casts are not rare in coal-bearing rocks and many fossilised trees in the position of growth have been recorded in literature in Lancashire (**Figure 16**). Fred records one in Jumbles Country Park (his photograph of it is illustrated on the rear cover of Eagar and Broadhurst, 1991). Perhaps the earliest examples were in 1830 when a fossil tree was observed in a Northumberland colliery (Wood, 1830) and 1839 when some fossil trees were found standing on coal on the line of the Manchester and Bolton Railway.

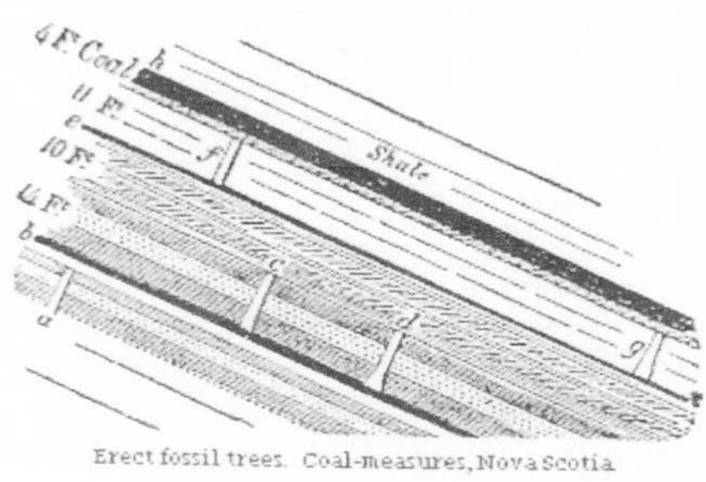

Figure 13
Sketch of the outcrop of fossil trees at Joggins, Nova Scotia, Canada (Lyell 1845) (*a,c,d,f & g* are erect trees)

More recently, stands of *Calamites* stems have been found in a small area of Coal Measures at Brymbo, north Wales (Appleton et al., 2011). But cases like these pale into insignificance when compared with the 66 fossil tree horizons exposed along the Joggins cliffs, Nova Scotia for 35 miles (Lyell, 1843, Davies et al., 2005, Calder et al., 2006, Falcon-Lang, 2006, and DiMichele and Falcon-Lang, 2011). The discovery of these horizons of upright fossil trees rooted in coal seams convinced Lyell that coal was the product of a peaty soil (**Figure 13**) (DiMichele and Falcon-Lang, 2011). Burial must have taken place in a single event or a small number of such events and the magnitude of the burial events and the rate of provision of accommodation space must have been very high. For instance, trees may have been buried by coastal flooding in a matter of days or weeks (**Figure 14**).

They also noted that there appeared to be a relationship between the existence of fossil trees in coarser grained sediments and the absence of shell beds (bivalves), suggesting that the rate of sedimentation was a possible factor in the control of the form of the size-frequency distributions of bivalves. Shale environments where sedimentation was slow (and hence fossil trees absent) and the water more clear, would be suitable for pelecypods, but once the rate of sedimentation was too high, as in mudstones, to allow the establishment or growth of pelecypods, it would then be approaching a value appropriate to the entombment and fossilisation of trees. Periods of slow sedimentation corresponded with faunal bands alternating with periods of faster sedimentation and the existence of fossil trees.

Seasonal Sedimentation

Evidence for seasonal controls of sedimentation in the Westphalian is best sought in sediment sequences formed in environments with seasonal changes in rainfall and fluctuating rates of sediment supply. The sequence of sediments between two coals in the Lancashire Coalfield (Westphalian A) is described by Fred and colleagues (Broadhurst et al., 1980) with particular reference to Ravenhead Quarry near Wigan. Part of this succession consists of regularly-bedded laminated sandstone/siltstone units containing non-marine bivalves and their escape shafts. The sandstone/siltstone units were due to cyclic sedimentation controlled by monsoons. The sandstone accumulated during wet seasons, the intervening siltstones during dry seasons, so that the rate of sedimentation is measured in days (**Figure 15**).

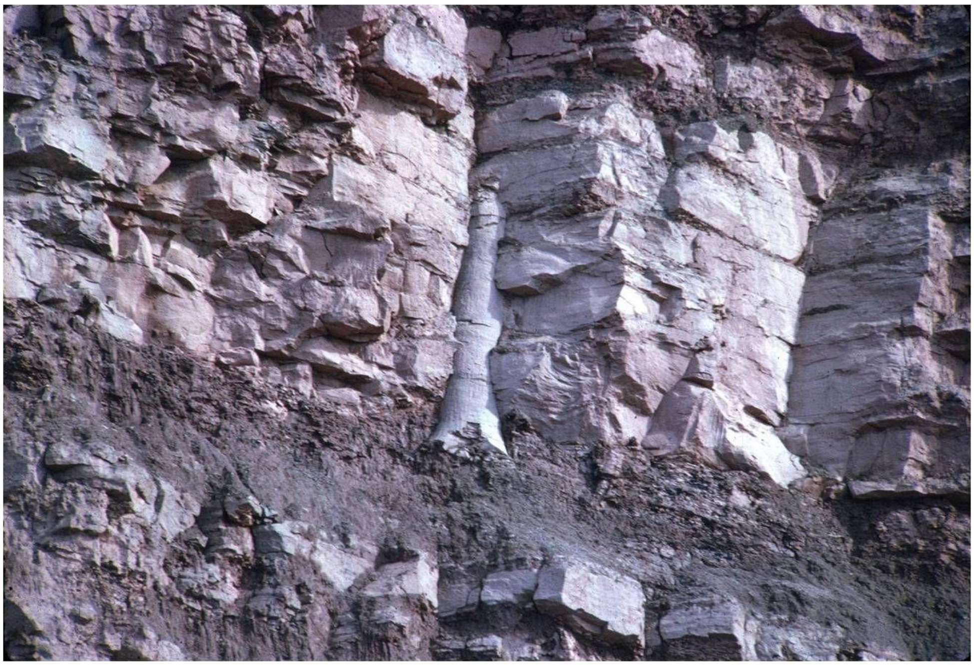

Figure 14
A fossil tree found in situ at Joggins, Nova Scotia, Canada, standing in a coal seam. The deposition of the sediment (sandstone) around it can be measured in days, weeks or months (Compare with coal seam, taking thousands of years). (Photograph Dr J E Pollard).

Ravenhead then lay within a few degrees of the equator and as a result enjoyed a tropical climate subject to monsoons. The increasing importance of sand at the expense of silt seen upwards through the lower part of each sandstone unit can be explained by the progressive development of floods with the onset of the wet season, each flood producing one sand lamina. The final loss of sand laminae towards the top of each sandstone unit can be interpreted as due to a progressive failure of floods towards the end of a wet season.

The escape shafts of the non-marine bivalves are evidence of rapid sedimentation. Prior to the deposition of the rhythmic succession, the sediments were colonised by a community of non-marine bivalves (*Carbonicola*). Once deposition of the sedimentary couplets commenced the bivalves escaped upwards to maintain contact with the water above. Mortality took place and the community progressively aged until it finally disappeared from the record some 7 or 8 couplets above the base (**Figure 16**). The time of deposition of 9-10 couplets was therefore less than the maximum life span of individual bivalves, some twenty plus years (modern examples). It is difficult to avoid the conclusion that the couplets represent one year's sedimentation, the sand formed by successive floods in the wet season and the silt/clays in the dry season. There are also cases where *Carbonicola* burrowed obliquely indicating a lower rate of sedimentation (**Figure 16**).

Tidal sedimentation

There is a paucity of examples of tidal deposition in the European Westphalian. In the Francis Creek Shale of Westphalian D in NE Illinois, the laminated succession of the silty clay rock includes clay bands forming couplets or pairs. Variation in the thickness of the silty clay layers within and between the clay rock pairs appear to be cyclic. The development of alternating thin and thick groupings of the paired-clay sequences has been interpreted to result from deposition during neap and spring tidal cycles. Spring tides associated with larger tidal ranges and greater water velocities thus explain the deposition of thicker silt bands. Neap tides, on the other hand, result in the deposition of thinner silt bands (**Figure 17**).

It is considered that in Westphalian times the range in the number of tides per lunar cycle was similar to that of today. The thin-thin or thick-thick cycles therefore represent approximately 14 days' accumulation of sediment and accordingly the tidal regime would be diurnal. The above sedimentary characteristics cannot be explained in any other way.

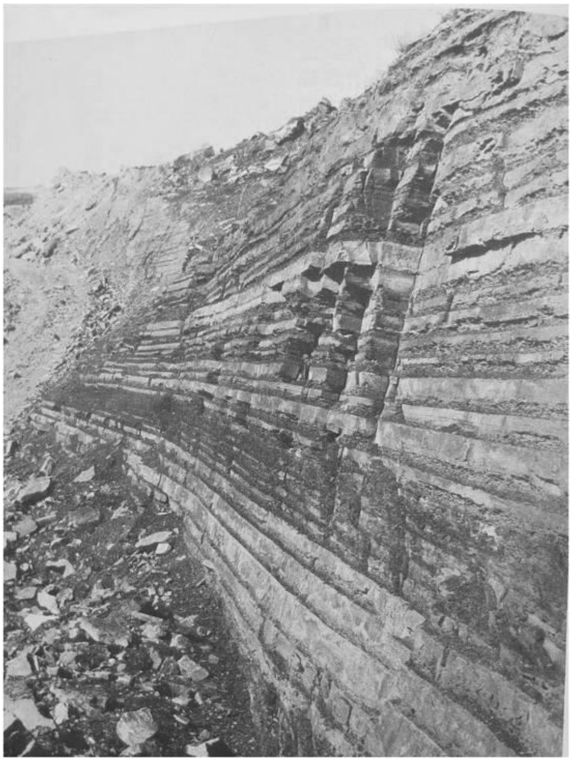

Figure 15
Field appearance of rhythmic laminated sandstone/silt-clay rock couplets in Westphalian succession, Lancashire.
(Broadhurst, Simpson and Hardy, 1980, Fig. 3)

It is possible therefore to measure the rate of sedimentation which appears to have averaged 1m/yr (i.e. 34 years to deposit a total maximum thickness of

34m). But this includes compaction, reworking and subsidence so that the minimum time of deposition may be significantly longer.

As said, there is a paucity of examples of tidal deposition in the European Westphalian. It is possible that evidence of tidal controls of sedimentation may be found in the sediments associated with the marine beds developed during transgressions and regressions of the sea across the Namurian and Westphalian deltas, i.e. some sequences of tidal origin have been misinterpreted as fluvial. However, findings by Wells et al., (2005), predict a very low tidal range (less than 10cm) in the epi-continental seaway which covered most of NW Europe during the late Carboniferous. The resultant weak tide and wave currents might be unrecognisable in the geological record.

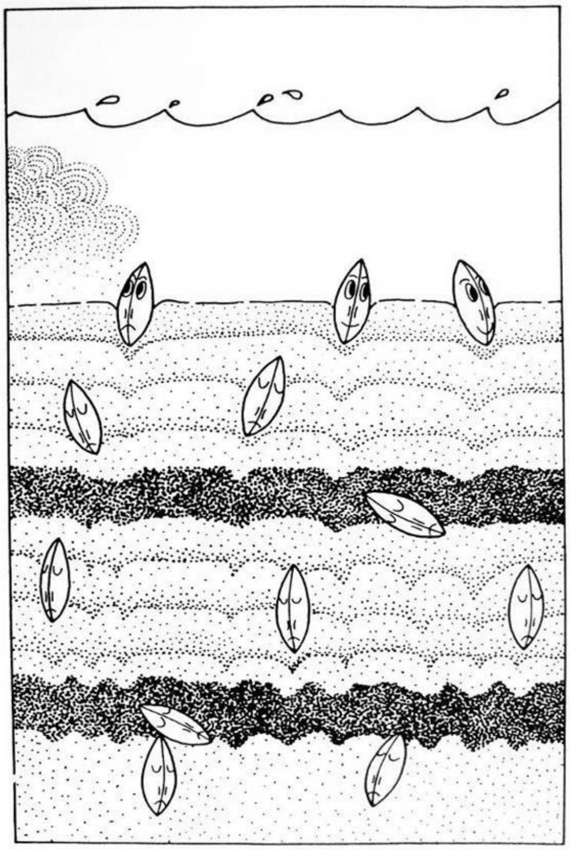

Figure 16
Cartoon by P G Hardy to show the response of bivalves to periodic deposition of sand (Broadhurst, Fig 19.4; Besley and Kelling 1988)

Conclusion

So, in conclusion, the rate of sedimentation can vary with very many factors - with the environment of deposition, climate, rate of sea-level change, supply and type of sediment, compaction, source, uplift, subsidence, tectonic movement (difficult to distinguish from compaction), erosion, hiatuses (is a bedding plane a hiatus?) and available accommodation space. More time may be represented between beds than by the beds themselves. So what about diachronous lithologies so common in the Westphalian and Namurian, giving rise to lateral variation in sedimentation? This can be on a vast scale. As we know, for any part of the stratigraphical column in one place, in another the same division may be hundreds or even thousands of times thicker yet represent the same time, something which Darwin in 1859 observed:

> Some of the formations, which are represented in England by thin beds, are thousands of feet in thickness on the Continent. Moreover between each successive formation we have...enormously long blank periods. So that the lofty pile of sedimentary rocks in Britain gives but an inadequate idea of the time which has elapsed during their accumulation...

A compilation of nearly 25,000 rates of sediment accumulation from over 700 references shows that they are extremely variable, spanning 11 orders of magnitude. Much of this variation results from compiling rates determined for different time spans. Whether or not it is due to measurement error there is a consistent trend of falling mean sediment accumulation rates with increasing time span (Sadler, 1981).

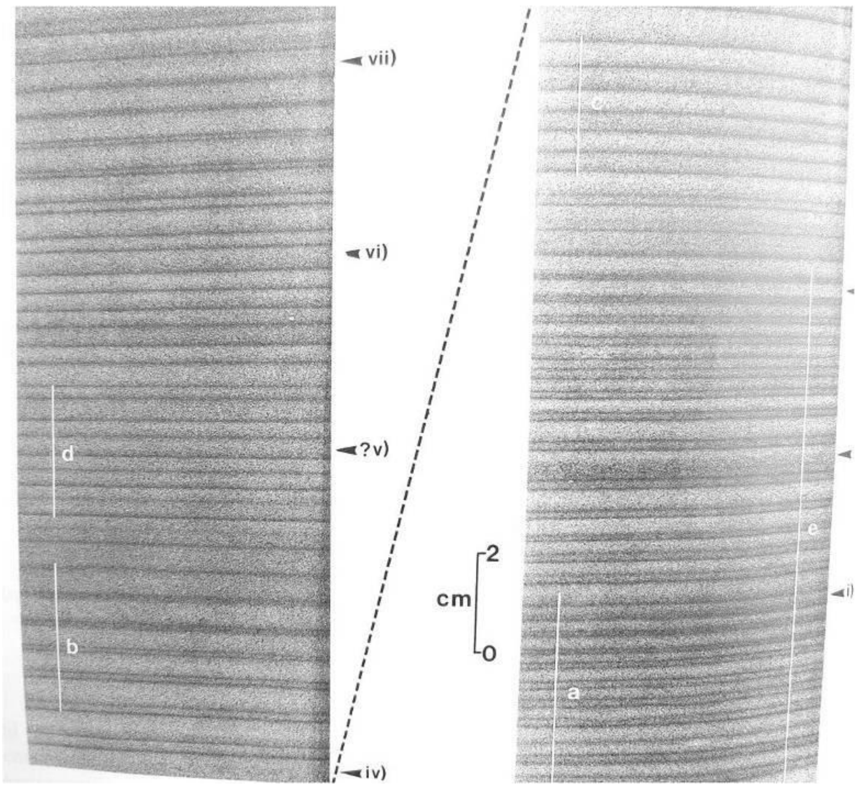

Figure 17
A spring-neap tide sequence in the Francis Creek Shales, Illinois, in which paired clay bands and variations in the thickness of associated silts and sands are clearly evident. Thin bands are neap tides, thick bands are spring tides. One couplet is deposited per 14 days, giving a rate of 1m per year. (Kuecher, Woodland and Broadhurst, 1990, Fig. 5.0)

Finally, of course, one of the objects of the meeting at which this paper was presented was a means of reminding ourselves of Fred Broadhurst's contribution to our subject. A trawl through the literature and the references in this talk show that Fred together with his colleagues were at the forefront (and certainly, as far as British literature is concerned, on their own) in attempting to calculate rates of sedimentation using a variety of parameters and observations, particularly in the Westphalian. His work, some of it over thirty to forty years ago, is still referred to even in recent articles, which reminds us that Fred, as in many things geological, was ahead of his time (**Figure 18**).

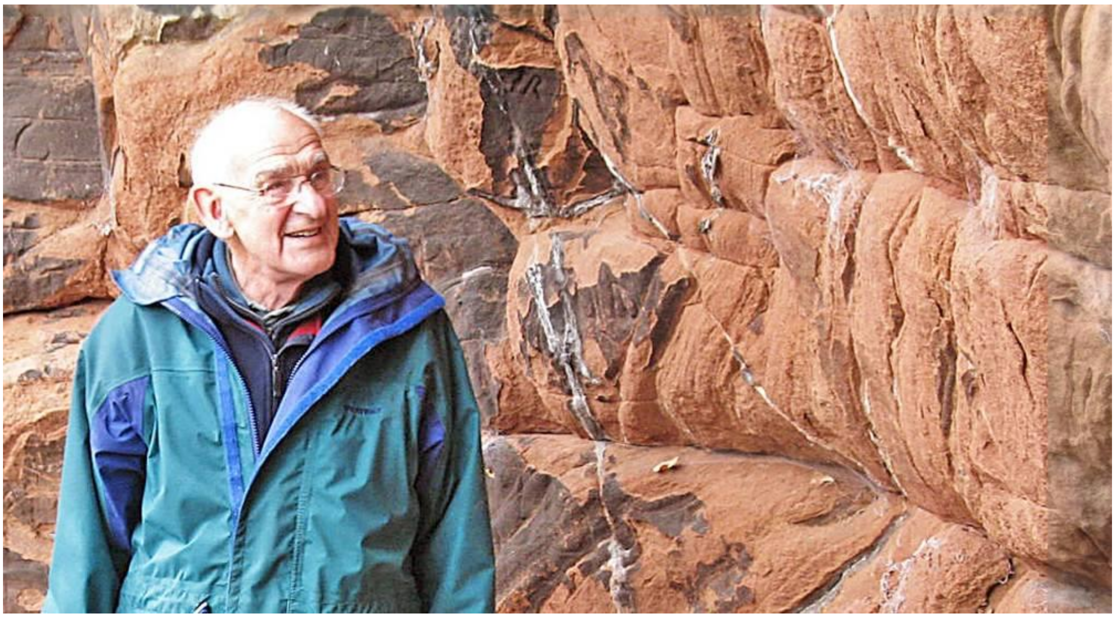

Figure 18
Fred Broadhurst (1928 -2009)
(Courtesy of Fred Owen MGA)

ACKNOWLEDGEMENT

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THE LIVERPOOL GEOLOGICAL ASSOCIATION: 1880 – 1910

by Geoff Tresise

2010 marked not only the sesquicentenary of the Liverpool Geological Society but, in addition, the centenary of the merging of this Society with the Liverpool Geological Association. The Association, now almost forgotten, had held its inaugural meeting on 13 December 1880, twenty-one years to the day after the Liverpool Geological Society was founded.

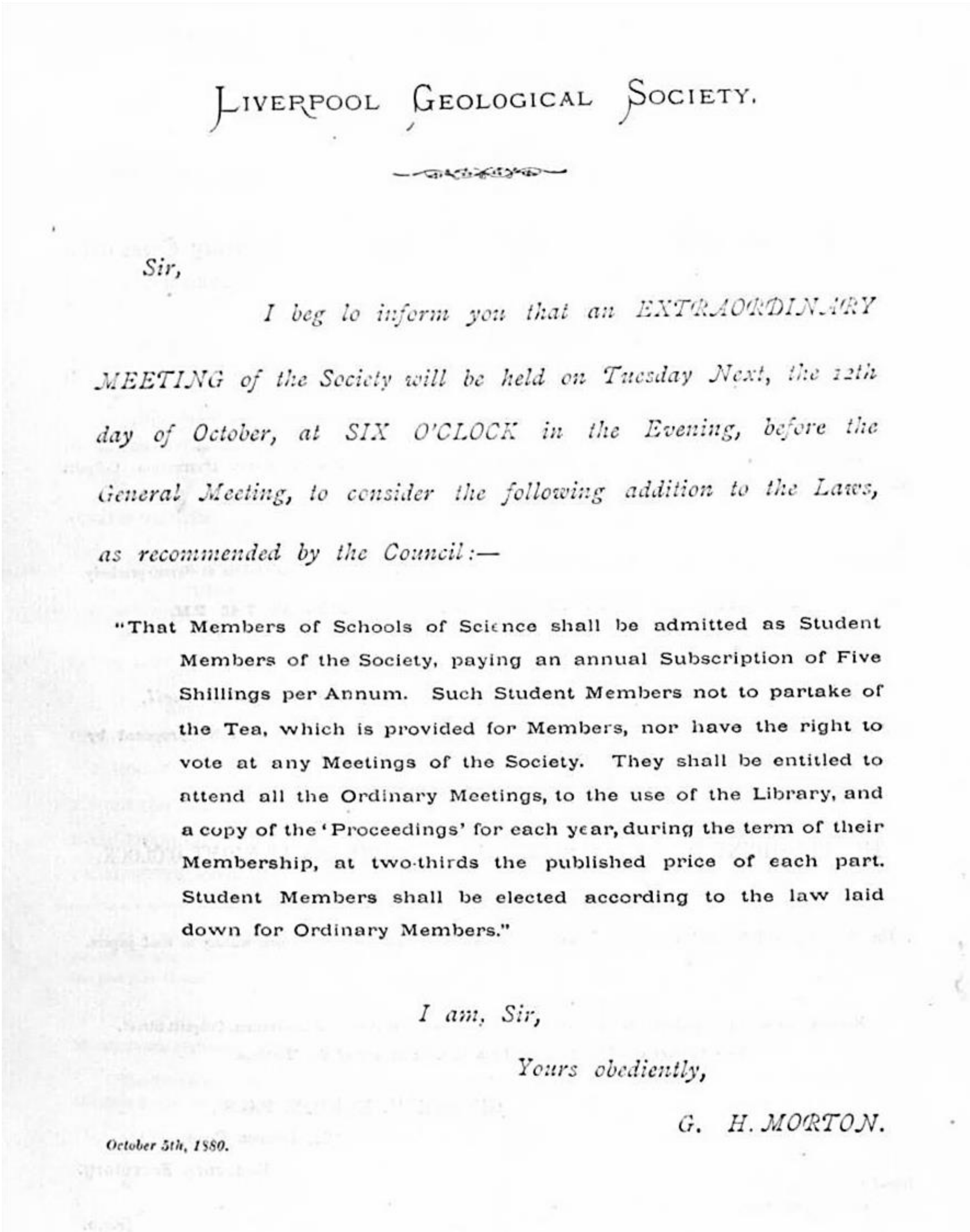
Somewhat surprisingly, the Association came about as the result of a copper broker, William Semmons, deciding to leave Liverpool to set up business in London. Semmons (1841-1915) had used his business and mining connections to help build up a mineral collection. Since 1870, he had run a very successful series of classes at the School of Science – the forerunner of the Liverpool Technical College and hence of John Moores University. According to one of the students who had attended his classes in geology and mineralogy:

> Permeated by a love of these sciences, of which he had made a lifelong study, and possessing an excellent collection of specimens, Mr Semmons had also the gift of kindling the enthusiasm of his students. It was with feelings of regret that the Students heard the announcement that, owing to business arrangements, Mr Semmons would have to sever his connections with his classes, and a very general desire was felt that some means should be devised to extend and develop the knowledge already acquired, and to cultivate the study of Geology and its allied sciences. There being already in existence in Liverpool a Geological Society, the most obvious means of accomplishing the desired object was by the formation of a new class of Members, to be termed 'Students', and such a proposal was made to the Council of that Society, but was rejected by them. (Bramall 1881, pp. 1-2).

The reasons for the Council's rejection of the proposal were not set out but the sequence of events is clear. On 3 June 1880, twenty-eight of Semmon's students (twenty-three male, five female) decided to form 'The Liverpool Geological Students Association'. This was to consist of 'past and present students of the Liverpool School of Science Geological and Mineralogical classes'. A subscription of two shillings [10p] was levied to fund the Association until October, by which time they confidently expected to be affiliated to the Liverpool Geological Society.

They had good reasons for optimism since the Society's President for the 1879-80 session was William Semmons, whose support could be relied upon. G.H. Morton, still Secretary of the Society he had founded twenty years before, was equally supportive. He led the members of the Students Association on a field trip to Dingle Point in June 1880 and invited them to join the Society's excursion to Storeton Quarry in July. He lectured to them on the geology of Storeton Hill in August and, on two evenings in October, invited the group to his house to inspect his geological collection. During the same period, three other members of the Society Council, Hugh Hall, Charles

Ricketts and Thomas Mellard Reade, also led field trips or read papers to the student group.



LIVERPOOL GEOLOGICAL SOCIETY.

Sir,

I beg to inform you that an EXTRAORDINARY MEETING of the Society will be held on Tuesday Next, the 12th day of October, at SIX O'CLOCK in the Evening, before the General Meeting, to consider the following addition to the Laws, as recommended by the Council:—

"That Members of Schools of Science shall be admitted as Student Members of the Society, paying an annual Subscription of Five Shillings per Annum. Such Student Members not to partake of the Tea, which is provided for Members, nor have the right to vote at any Meetings of the Society. They shall be entitled to attend all the Ordinary Meetings, to the use of the Library, and a copy of the 'Proceedings' for each year, during the term of their Membership, at two-thirds the published price of each part. Student Members shall be elected according to the law laid down for Ordinary Members."

I am, Sir,

Yours obediently,

G. H. MORTON.

October 5th, 1880.

Figure 1
Calling notice for the Society meeting in October 1880. The motion was withdrawn at the meeting.

In addition to such practical support, it was unanimously agreed at a meeting of the Society Council on 10 August 1880:

> That the student members of Schools of Science be admitted as Student members of this Society, paying an annual subscription of five shillings [25p] per annum. Such student members shall not partake of the tea which is provided for members at meetings, nor have the right to vote at any meetings of the Society. They shall be entitled to attend all Ordinary meetings of the Society, to the use of the Library and a copy of the 'Proceedings' at two-thirds the published price of each part.

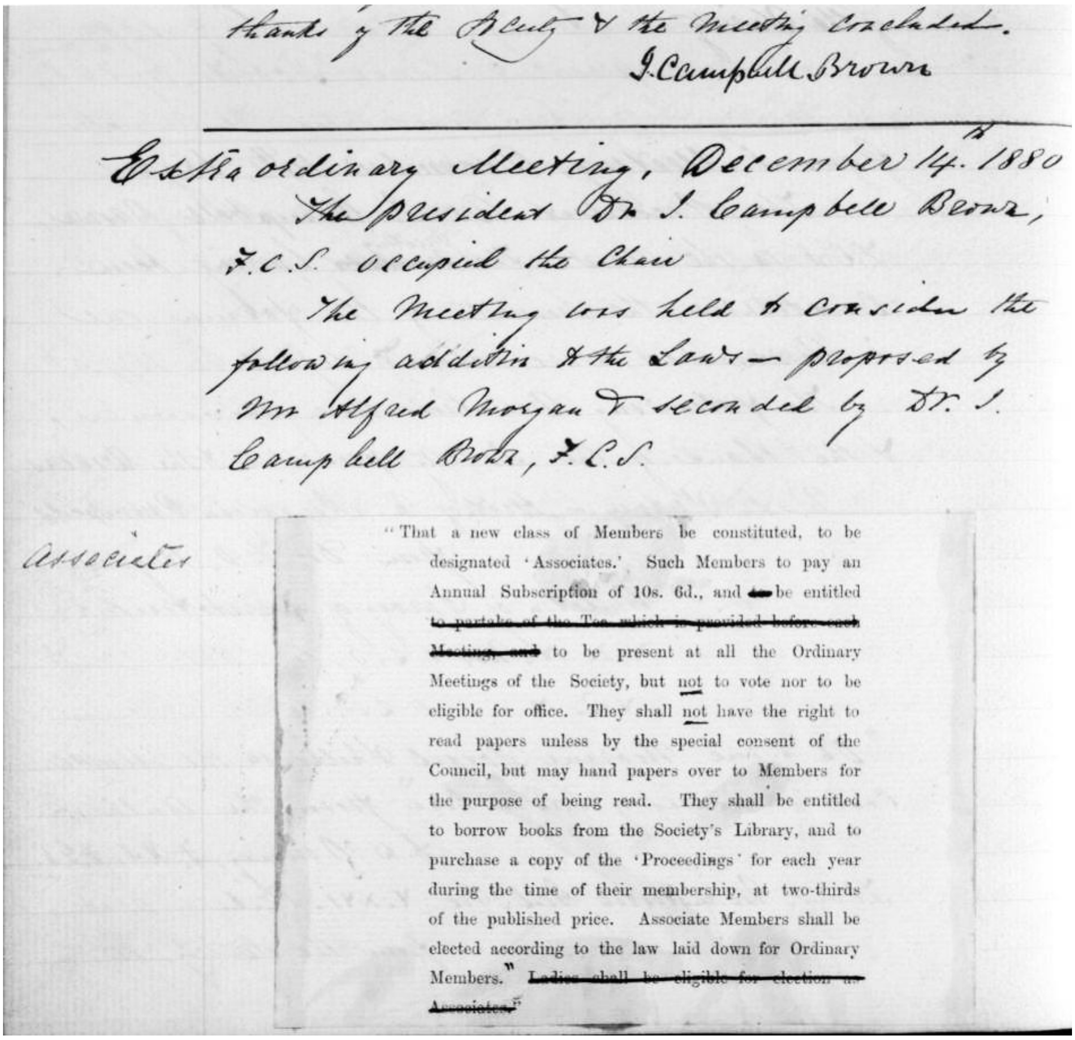
The Secretary was instructed to call an Extraordinary Meeting before the Society meeting on 12 October so that this proposal could be put to the membership.

All seemed to be going smoothly. However, only four members of the eleven-strong Council had attended the August meeting. Morton was the only officer present along with three committee members – Edwin Foster, Thomas Moore and Isaac Roberts. Consequently the 'unanimous' decision had been taken by a minority of the Council. The absence of the Honorary Treasurer was to prove particularly unfortunate.

The Treasurer, Alfred Morgan, had real cause for concern. In 1873 the Society's annual subscription had been raised to one guinea [£1-05] – but only for new members. The existing members continued to pay at the former half-guinea rate. By 1879, the annual expenditure was exceeding the income from subscriptions and the Society only remained solvent by drawing on its slim financial reserves. Two remedial measures were promptly introduced: donations were solicited for a special 'Printing Fund' and it was suggested that members still paying the pre-1873 subscription should be invited voluntarily to increase this to one guinea. These measures achieved some measure of success and the impending financial crisis seemed to have been averted.

Nevertheless it was understandable that, the following year, the Treasurer should view with concern the proposal to create a new class of members who would pay less than a quarter of the full subscription rate. In the event, the calling notice for the meeting on 12 October 1880 announced that a vote would be taken on the recommendation passed by the depleted Council in August (**Figure 1**). However, at the meeting itself, this resolution was withdrawn and a very different one put forward in its place. Proposed by Alfred Morgan, seconded by Dr Campbell Brown, this read:

> That a new class of members be constituted to be designated 'Associates'. Such members to pay an annual subscription of ten shillings and sixpence [52.5p], and to be entitled to partake of the Tea which is provided before each Meeting, and to be present at all Ordinary Meetings of the Society, but not to vote or be eligible for office. They shall not have the right to read papers except by special consent of Council, but may hand papers to members for this purpose. They shall be entitled to borrow books from the Society's Library and to purchase a copy of the 'Proceedings' at two-thirds of the published price… Ladies shall be eligible to be elected as Associates.



thanks of the Society & the meeting concluded.
J. Campbell Brown

Extraordinary Meeting, December 14th 1880
The President Dr J. Campbell Brown, F.C.S. occupied the Chair
The Meeting was held to consider the following addition to the Laws — proposed by Mr Alfred Morgan & seconded by Dr J. Campbell Brown, F.C.S.

Associates

"That a new class of Members be constituted, to be designated 'Associates.' Such Members to pay an Annual Subscription of 10s. 6d., and ~~to~~ be entitled ~~to partake of the Tea which is provided before each Meeting, and~~ to be present at all the Ordinary Meetings of the Society, but not to vote nor to be eligible for office. They shall not have the right to read papers unless by the special consent of the Council, but may hand papers over to Members for the purpose of being read. They shall be entitled to borrow books from the Society's Library, and to purchase a copy of the 'Proceedings' for each year during the time of their membership, at two-thirds of the published price. Associate Members shall be elected according to the law laid down for Ordinary Members." ~~Ladies shall be eligible for election as Associates."~~

Figure 2
Motion carried at the Society meeting in December 1880. The clause 'Ladies shall be eligible for election as Associates' has been deleted.

Since the members had had no prior notice of this resolution, a vote was postponed until the November meeting, when it was again postponed for a further month.

At the meeting on 14 December: 'After some discussion it was decided that the words "to partake of the Tea which is provided before each Meeting" and "Ladies shall be eligible for election as Associates" should be left out'. In this abridged form (**Figure 2**) the motion was put to the meeting and was carried unanimously. However, even after the deletion of the clause that ladies be eligible for election, the three Associate members who were elected in the months that followed were all female. There were no other applicants. The Society had offered the Students Association too little, too late. The withdrawal of the resolution passed by the Council in August had been an unexpected blow as had been the more than doubling of the proposed membership fee. Buoyed up by the success of their group to date, the students had decided to go their own way. On 11 October 1880, their acting

Committee was asked to draw up a set of rules for a permanent Association and these were accepted at a meeting on 15 November.

The name was changed to 'The Liverpool Geological Association' and the stipulation that members should have attended a School of Science course was abandoned. The annual subscription was set at five shillings [25p]. Meetings were to be held in the Derby Museum (now the World Museum Liverpool) 'on the first Monday of each month at eight o'clock in the evening'. The renamed Association had its first official meeting on 13 December 1880, it being pointed out that: 'Since June we have had five meetings, four papers read, six excursions and two visits to a museum' – the "museum visits" presumably being those to view Morton's own collection. Relations with the Liverpool Geological Society remained cordial; many members of the senior Society joined the new Association, providing both moral and financial support even if they did not normally attend meetings.

There was no lack of activity in the new Association's first year. In the period from January to September 1881, papers were read on the Giant's Causeway, salt deposits in a St Helens colliery, "Croll's Theory" of climate change, the progress of geological discoveries (this last from Osmund Jeffs who would give talks and lead field meetings for the Association until his death in 1897), the history of escarpments, the Brixham Bone Caves, Isomorphism & Dimorphism, and the geology of Anglesea (sic). In addition there were field meetings to Matlock, Llandudno, Storeton Hill, the Wrekin and Thurstaston.

This full and varied programme set the pattern for the years that followed. 1881-82 saw an increased emphasis on mineralogy and petrology with papers on diamonds, iron pyrites and volcanoes. Thomas Shilston spoke on fossil footprints, a topic of local interest, but with the emphasis on finds in the U.S.A. and Australia. The session also included visits to Owens College Museum in Manchester and the museum of the Chester Society of Natural Science.

The 1882-83 session was enlivened by a more controversial topic spread over two meetings. On 4 December 1882, Hugh Hall, a member of the Association, read a paper on 'Some Observations on the Darwinian Theory of the Evolution of Species'. Although he expressed an admiration for Darwin's scientific work, he went on to comprehensively dismiss his conclusions. In Hall's view, Darwin had completely failed to resolve the problems he posed and "the only solution is that of revelation, a Creator and Universal Orderer" (Hall 1882, p. 52). The following meeting, on 8 January 1883 was wholly devoted to a discussion of Hall's paper. The three speakers (Thomas Brennan, I.E. George and Frederick Marrat) strongly contested Hall's views and his dismissive assertion that "Mr Darwin does not support his theory of evolution by known facts". Brennan, in particular, considered the stratigraphical record at some length, pointing out that the sequence in which different groups of animals appeared matched that which Darwin's theories would predict (Brennan 1883).

The Association maintained an active field work programme and in August 1883 held its first three-day field meeting in Shropshire. There were also six one-day trips that year together with three evening excursions to Tranmere, Toxteth and Eastham. These last were noted to have been "among the most enjoyable gatherings of the session". In the winter months, when field trips were less attractive, there were regular Saturday afternoon study sessions in the galleries of the Derby Museum.

Each year the Association produced a slim volume of *Transactions* (later renamed the *Journal*). 1883-84 was notable for a paper by T. Ward on 'The subsidences in the salt districts of Cheshire and their geological cause'. In April 1889, James Wilding spoke on 'The Building Stones used in Liverpool' – anticipating a topic which would become a favourite in Liverpool and elsewhere a century or so later.

The 1890s brought an important paper on Triassic footprints from Osmund Jeffs. However, prior to this, James Hornell read a paper which, with the benefit of hindsight, can be seen to have been wrong in almost every particular – even its title 'The Hand-footed Labyrinthodont' (Hornell 1889). Almost half a century earlier in 1842, Richard Owen had indeed suggested that the *Chirotherium* tracks found on Storeton Hill were those of the giant amphibians he had named *Labyrinthodont,* arguing that these were the only large land-living animals known from the Trias. At the time, it did not seem an unreasonable suggestion but Owen was to repeat this theory in his famous text-book *Palaeontology* which appeared in 1860 and thereafter in numerous reprints throughout the nineteenth century. This was unwise since, by the 1860s, much more was known about the Triassic fauna and it was clear that the dominant land animals then had been reptiles not amphibians, making it more likely that the *Chirotherium* footprints too must be reptilian. Despite this, Hornell declared, astonishingly, "Since Owen put forward his conclusion, all subsequent discoveries and researches have but tended to confirm this correlation" – a statement that could hardly be further from the truth!

The *Transactions* do not include any comments on Hornell's paper but it is fair to assume that his conclusions would have appalled Osmund Jeffs. However, it was not until 1894 that Jeffs put forward his own views in a paper on 'The Storeton Series of Footprints'. This was illustrated by 18 specimens from his collection. Having described these in some detail, he turned his attention to the originator of the *Chirotherium* prints. He began with a tactful tribute to Hornell's "able paper" before making it very clear that he did not support the views expressed therein. "It is remarkable that the correlation of Owen… being based on what now appears to have been evidence of too scanty a nature, should continue to be quoted as if it were in no way disputed by modern authorities" (Jeffs 1894, p.20). He pointed out Labyrinthodonts "had been most minutely and elaborately investigated by a Committee of the British Association, reported upon by Professor Miall". This Committee had reported that, while Labyrinthodonts had thrived during the Carboniferous (at least thirty-one genera and many more species were known from this period), by Triassic times they were few in number and close to extinction. Damningly for Owen's view, they concluded that "Nor is there a single distinctive

Labyrinthodont feature about *Cheirotherium*" (Miall 1874, p.244). Jeffs himself put forward the tentative suggestion that the footprints might be those of dinosaurs.

This paper was a valuable one, not least because the footprints displayed and described at the meeting are now in the collections of Chester's Grosvenor Museum. Following Jeffs's death in March 1897, his widow offered his collection – said to include "some 32 different specimens of footprints, some of them unique examples" – to the Museum. The following month the Museum made a not over-generous offer of £10 and the purchase was agreed.

In 1885, at the peak of its success, the Association had 148 ordinary and six honorary members but this was followed by a long, slow decline. One reason was that members of the Liverpool Geological Society no longer chose to become members of the junior Association. By 1901 Association membership had dwindled to 34 ordinary and seven honorary members but soon thereafter came a modest revival. The new Central Technical School (forerunner of John Moores University), which opened alongside the Museum in 1901, offered evening classes in Geology "and many young and ardent students, after finishing the course of instruction provided there, became active members of the Association, preferring it to the Society, no doubt on account of the much lower annual subscription" (Jones 1944, p. 35).

Membership rose to 55 ordinary members in 1907 but thereafter once again began to decline. It was becoming increasingly apparent that a merger with the Liverpool Geological Society would be advantageous and a joint working group was set up to discuss amalgamation. At a special meeting of the Association held on 1st June 1910, it was unanimously agreed that: The two Societies amalgamate under the name of the Liverpool Geological Society. Such an amalgamation was to take effect from the first day of October 1910. For the first year the words 'including the Liverpool Geological Association' were to be added to the title of the Liverpool Geological Society.

This resolution was ratified by the Society on 10 June. It was agreed that meetings should be held in the Royal Institution, Colquitt Street and that the annual subscription should be half a guinea [52.5p]. Although it seems almost unbelievable today, the subscriptions of both bodies had remained unchanged since the abortive discussions of 1880 – one guinea for the Society, five shillings for the Association. At the time of the merger, the Association had 48 members while the Society had 45 Ordinary members and 6 Associate members, one of the latter also being a member of the Association. The Society thus had the potential to double its membership, and so offset the halving of the subscription rate. Unfortunately, following the merger the Society gained only 29 new members and so suffered a substantial loss of revenue.

Association lectures in the final 1909-1910 session remained an alternation of aspects of local geology (the Magnesian Limestone of Skillaw Clough) with briefings on topics of more general interest (Vitreous Volcanic Rocks). The Association ran its own weekend fieldtrip to the Arenig Mountains in March but the day-trips, 7 in number, were now organised in conjunction with the Liverpool Geological Society.

In the course of its 30-year history, the Association had held rival meetings for and against controversial topics – on Darwin's theory of evolution in the 1882-83 session and, albeit with a 5-year interval, on Owen's correlation of *Chirotherium* footprints with Labyrinthodont amphibians. But it was the controversy over their members' gender which can now be seen as the Association's most significant achievement. The proposal to convert the members of the Student Association into Associate Members of the Society had foundered, partly on financial grounds and partly on the eligibility of women to become Associate Members. The clause which would have permitted this was deleted before the Society accepted the proposal. Nevertheless the three Associate members elected to the Society in the following year were all female. Each of the three had a close link with an existing member: Miss S.E. (Sarah Elizabeth) Morton was the eldest of the four daughters of the Society's founder and Secretary, while Mrs Morgan and Mrs Roberts were the wives of the Honorary Treasurer and a past President. The process of female assimilation into the Society thereafter was to be an agonisingly protracted one.

A tiny number of women remained Associate members for the next 20 years but on 13th December 1900 Miss Morton was elected a full member of the Society. No doubt this was partly in tribute to her father who had died in the spring but the more cynical could argue that Miss Morton's gift to the Society of a number of her father's possessions (most notably the much-prized William Smith map) might also have played a part. Miss Morton would remain the only female Ordinary member for a further 10 years until the election of Miss H. Stevenson, a member's daughter, in 1910. However, Miss F. Lloyd, elected on Valentine's Day in 1911, had the distinction of being the first who appears not to have been related to a male member.

Miss Morton's pioneering progress continued with her election to the Society's Council in 1913 but she was never to read a paper to the members. That innovation came more than a decade later still. Stella Harris B.Sc., elected on 14th December 1920 was not only the first graduate among the female members but also the first to hold a salaried post as a geologist. She was employed as Geological Assistant at Liverpool Museum and led the Society on a field meeting there on 6th June 1925. In the same year, her paper on the Museum's geological collections was published in the *Proceedings* (Harris 1925). Then, on 13th April 1926, now Mrs Stella Alty M.Sc., she read a paper to the Society (on the Keuper sediments seen in a boring at Wilmslow) which was printed in the *Proceedings* (Alty 1926). Meanwhile Gertrude Ellis M.B.E., D.Sc., F.G.S., the acknowledged authority on graptolites, had been elected an Honorary Member in June 1925. One final bastion remained: it was not until 1971 that Elizabeth Bailey became the first of the four female Presidents of the Society who have held that post to date. Conversely the posts of Honorary Treasurer and, perhaps more surprisingly, Honorary Secretary have invariably been held by men.

The Liverpool Geological Society, founded in the nineteenth century, was modelled in the tradition of the 'gentlemen's club' and has been male-dominated throughout its history. The Liverpool Geological Association, by contrast, was ahead of its time in welcoming female members on an equal basis and deserves due credit for so doing.

ACKNOWLEDGEMENTS

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THE MUSEUM, THE BEACH AND "THE HORSEBOX": MANCHESTER GEOLOGICAL ASSOCIATION'S TRIP TO PEMBROKESHIRE

by Jane Michael

Manchester University's Dr John Nudds and National Museum of Wales' Dr Cindy Howells led a group of MGA members to investigate the Geology of Pembrokeshire and the Glamorgan Heritage Coast over August Bank Holiday 2011. This four day trip covered a lot of ground both literally and geologically and, unlike other MGA trips in 2011, was blessed with fine weather.

Day 1 Friday

The trip began at the National Museum of Wales in Cardiff where Cindy guided the 13 party members round the award-winning Evolution of Wales gallery. This was spectacular, not just for the variety of the exhibits, but their quality and the interesting way the story was told. Whilst many of the younger visitors were only interested in dinosaurs, the MGA party were fascinated by the smaller fossils.

Display of Silurian reef reconstruction

Cindy and John had prepared an excellent guide/field notes for the trip and these were handed out at the evening's briefing. John outlined the basic geology of the area, explaining that the rocks of this part of Wales covered a time period from the Precambrian to the Jurassic (the Permian is missing). No Mesozoic rocks outcrop in Pembrokeshire**,** though they are found in the sea bed to the south. Any later deposits have been eroded away following uplift. The Quaternary ice-age is represented by tills, raised beaches and erosional features plus Pleistocene animal bone fossils in caves. This reflects the movement of the continents from the far south of the equator to their present position around 50°N.

Precambrian rocks include extrusives (lavas, ashes), intrusives and sedimentary rocks of the Ediacaran Period (trace fossils are found in

Carmarthenshire). Cambrian rocks are sedimentary reflecting a gradually deepening ocean - the Welsh Basin - with a shallow marine platform alongside. Fossils such as large *Paradoxides* trilobites occur in the Middle and Upper Cambrian.

The Welsh Basin was much deeper in the Ordovician, the rocks being characterised by muds and shales rich in a variety of fossils: brachiopods, trilobites and graptolites. Volcanic activity during this time produced rhyolites, pillow lavas and sills. The Silurian was a time locally of shallow, warm seas and volcanic islands. The fauna was more diverse with corals, brachiopods and bryozoans. Structurally, north Pembrokeshire shows the effect of the Caledonian orogeny as Iapetus closed.

Much of South Wales is covered by vast thicknesses of Devonian/Old Red Sandstone (ORS): coastal sediments with primitive land plants and some trace fossils of fish and amphibians. The Lower Carboniferous is represented by limestones (fossil corals, brachiopods, crinoids, molluscs). Local graphic logging has revealed fluctuating relative sea-levels and some extreme stormy episodes. The cyclic Millstone Grit Series, with its terrestrial and deltaic conditions and the Coal Measures, are both represented. Pembrokeshire had its own coalfield though not mined on a large scale. The Variscan orogeny at the end of the Carboniferous gives an east-west trend to the structure of South Wales which is seen in south Pembrokeshire.

The Triassic, found in south-east Wales, has dinosaur and other reptile footprints. There are some Lower Jurassic limestones with ammonites, bivalves, corals and echinoids. Fissures in the Carboniferous Limestone have been filled with Mesozoic early mammal and dinosaur bones representing flooding episodes. The Quaternary ice-age covered the whole of South Wales at times, resulting in raised beaches, glacial till and erosional features including caves containing Pleistocene animal bone fossils.

John's plan was to travel up the succession, starting with the Pre-Cambrian and finishing on Monday afternoon in the Triassic.

Day 2 Saturday

Our first locality on Saturday was St Non's and Caerfai Bay on the north Pembrokeshire coast. Whilst walking to the coastal path, we stopped at St Non's Chapel which is built in the purple Cambrian Caerbwdy sandstone. St Non was St David's mother. The views of the coast from the Chapel were spectacular. From the coast path we could see the Precambrian Pebidian Supergroup represented by volcanic banded tuffs and rhyolites (some of which were creamy). Locally some of the tuff is silicified, a greeny-blue rock known as halleflinta, representing ash washed into the basin rather than an airfall deposit. The Pebidian is overlain unconformably by the Cambrian Caerfai Group comprising St Non's Sandstone, Caerfai Bay Shales, Caerbwdy Sandstone, Solva Beds and Lingula Flags. The basal conglomerate contains quartzite, tuff and halleflinta. This formed around 540/535Ma when the Pan-African orogeny broke up Pannotia into Laurentia, Siberia and Baltica in the north, leaving Gondwana in the south. There was a marine transgression as Iapetus opened. Continuing round the coastal path, we came to the overlying green St Non's Sandstone, then the red Caerfai Shales (tuffs), elsewhere containing trilobite body fossils, and the red/purple Caerbwdy Sandstones. The colour differences were quite marked especially in the sunshine.

View from St Non's Chapel

The group climbed down to the first of several beaches on the trip. This was Caerfai Bay where we examined the Lower and Middle Cambrian sediments comprising tuff beds within the red shales of the Caerfai. Here we could also see two faults and their effect on the structural geology of the bay. Some rough measurements were taken and an apparent dip to the south of 50° was found yet there was a distinct 'bend' in the rocks of around 35° to the north as shown in the photograph. As can be seen from the photo, there was quartz veining running through the red shales. John also pointed out some trace fossils on those bedding planes we could see.

Abereiddi Bay, our first stop after lunch, is the Ordovician type locality for the Llanvirn Series. It is formed within the centre of an asymmetrical syncline. The Llandeilo and Caradoc shales form the centre of the syncline, but are unseen. We investigated the underlying Upper Llanvirn in each limb. The syncline is trending north-east/south-west and is the result of the Caledonian orogeny. The beds dip north to the north, but on the south side are overturned and still dip north. The rocks young towards the centre of the bay. We were looking at the Caerhys Shales plus the Abereiddy Tuff in the quarry. The latter have been dated to about 465Ma. The main fossils found here are graptolites. These have been fossilised by carbonisation and are seen as white markings on the rock. Our fossil hunting exploits were successful with good examples of *Didymograptus murchisoni* found amongst other graptolites.


Structures at Caerfai Bay

On our return to the car park, we crossed an outcrop of the Castell Limestone and saw a good exposure of the Caerhys Shales plus an outcrop of the Abereiddy Tuff and the underlying Cyffredin Shale. We made our return to Pembroke via Marloes Sands. Here we reached the Silurian/Devonian boundary. Unfortunately the tide was high, leaving us unable to visit the whole of the locality; a good coastal path along the cliff top enabled us to see the main geology. The Llandovery and Wenlock strata dip steeply and pass up into the Ludlow of the ORS facies. We managed to reach the beach to see the Skomer Volcanic Group, comprising rhyolite and basalt flows plus sediments containing corals, brachiopods, crinoids and bivalves, all of which were collected by the party.

Day 3 Sunday

Sunday was spent in south Pembrokeshire. Freshwater West, a spectacular expanse of sand with some shingle, which had featured in some scenes in both Harry Potter and Robin Hood, was our first stop. The bay is part of an anticline. We were looking at Silurian and Devonian rocks, but the older Ordovician occasionally outcrops in the centre of the bay when beach erosion exposes it. *Didymograptus murchisoni* can then be found at low tide.

John explained that here the rocks covered the period from the Silurian through the Devonian into the Carboniferous in a southerly direction. We walked south along the beach stopping initially to look at marine Silurian Wenlock beds. These deposits comprise cobble-sized conglomerates, sandstones, mudstones and a fossiliferous limestone at the unconformable 'top' of the sequence. The red and green mudstones of the Moor's Cliff Formation followed. The green colouration is due to iron reduction. These are floodplain deposits, thus terrestrial, and are an ORS facies. Several tuff beds could be found including the Townsend Tuff Bed, which is 3m thick and weathers very easily as it is extremely soft.


Freshwater West Bay

We saw the Chapel Point Calcrete, a fossil soil which is the result of high rain, high evaporation and a source of calcium carbonate. It represents a terrestrial environment and can be found either infilling burrows or as solid layers. This raised the question of where the Silurian/Devonian boundary was. The Chapel Point Calcrete correlates to Downtonian/Dittonian boundary and was formerly considered to represent the boundary. John explained the problems of drawing boundaries in a continuous sequence. The Townsend Tuff bed, somewhat older than the calcrete, has recently been dated at 416Ma and is now taken as the base of the Devonian in this area. The onset of terrestrial conditions is thus diachronous. The terrestrial deposits of ORS facies commenced before the end of the Silurian and continued into the Carboniferous.

The group discussed the reasons for the change from a marine environment to terrestrial. This was post-Caledonian orogeny; the Welsh Basin was inverted with huge mountains to the north which were eroded in a southerly direction onto vast flood plains with braided river systems as the Rheaic Ocean opened to the south. We moved round the headland into the next bay, noting the dextral strike-slip Flimston Bay Fault running sub-parallel to the cliffs at their base. This was the Freshwater West Formation (Lower Devonian) comprising the Rat Island Mudstones with beds of coarse grained Conigar Pit Sandstones. The latter represent the channels of braided rivers with floodplain deposits. The various cycles of the Conigar Pit Member were so clear to see. There was cross-bedding at different scales, red/white colour differences, including more green iron-reduced deposits and enormous trace fossils of Beaconites.

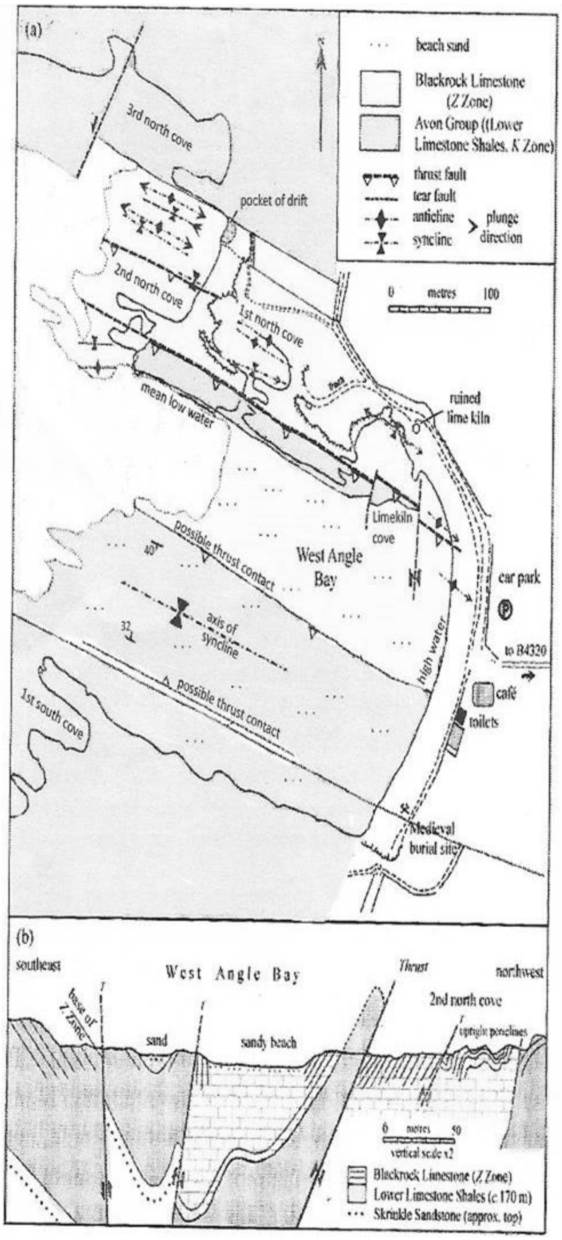
The Rat Island Mudstones were exposed at the south end of the bay beyond which the Ridgway Conglomerate was seen. This multi-layered conglomerate had a finely grained matrix and contained quartz, mudstone and both Cambrian and Ordovician volcanic clasts. It is thought to represent an alluvial fan with the deposits coming from the south – the higher ground which is now the Bristol Channel. We turned to look at the cliff and the effect of the faulting. The date of the fault is not known, but it was clearly active during sedimentation. There does appear to be an unconformity/disconformity between the Ridgway Conglomerate and the Gupton Sandstone (containing Upper Devonian *Holoptychius* fish scales) indicating a major break although little angular change.

Freshwater West: Conigar Pit Sandstones

Our second location was West Angle Bay, a designated SSSI for its marine flora and fauna. It is important for its geological structures and the rock succession from the Devonian Ridgway Conglomerate to the Lower Carboniferous limestones. Just off the coast is Thorn Island, once a Napoleonic fort protecting Milford Sound, then a hotel and now disused awaiting redevelopment. From the cliffs opposite Thorn Island we had a great view of the Ridgway Conglomerate and Gupton Sandstones steeply dipping away from us. We also had excellent views of the Upper Devonian West Angle Formation. This is a fluvial, semi-arid flood plain deposit. The lower Conglomerate Member is red containing exotic clasts as well as calcretes. The sandstone horizons contain similar clasts. Above this is the Heterolithic Member. This is finer grained, fines upwards and contains shark teeth and plant debris. It reflects minor marine incursions due probably to eustatic changes in relative sea-level as the Rheaic Ocean closed.

The Heterolithic Member has been dated palynologically (fossil pollen and spores) as Upper Devonian in age. The top of the adjacent sea stack has been dated as Lower Carboniferous. The Devonian/Carboniferous boundary is in the middle of the gully with no obvious change in lithology. The structure is synclinal with periclinal folds. The basal Carboniferous (Lower Limestone

Shale) forms the headlands and a prominent ridge between the Third and Second North Coves. The Main Limestone forms the centre of the main bay. This has the most folding and is light grey.



a) Generalised geology and structural map of West Angle Bay
b) Simplified northwest-southeast cross section across West Angle Bay
Both modified from Dixon 1921, Hancock *et al* 1982

In Lime Kiln Cove crinoids can be found including a new species of *Hylodecrinus* which will be published this year by Cindy. MGA Member Lisa Abbott did her Third Year Project here and by detailed logging interpreted the facies and history as a shallow muddy inner carbonate ramp. We could also see evidence of a thrust complex. The cliffs exhibit some interesting late Pleistocene deposits including glacial outwash from the Irish Sea ice sheet.

Our third locality was the Green Bridge of Wales. This is a sea stack archway carved out of the Pen-y-Holt and Stackpole Limestones of Arundian and Holkerian age. The view was wonderful in the sunshine, although the wind was quite strong and most members kept well away from the edge of the cliffs.

The Green Bridge of Wales

Finally, some members of the party visited the tiny St Govan's Chapel and holy well on the coast by Trevallen Downs which gave pause for thought about the builders, being located halfway down a steep cliff.

Day 4 Monday

The final day of our field excursion saw us visiting three locations on our return route. Firstly, we visited Ogmore-by-Sea. During the Triassic most of this area was a low lying arid landscape: hills to the north and the sea to the south. The climate was tropical with droughts and extreme storms which is reflected in the Triassic rocks seen. However our first location was in the Carboniferous. We descended from the car park to an area of low cliffs. These were in the High Tor Limestone, dated as lower Arundian (mid-Dinantian). The bedding was almost horizontal and this locality was almost fossil heaven! We found rugose and tabulate corals such as *Caninia gigantia* and *Syringopora,* and brachiopods such as *Delepinea.* Most exciting were the very large colonial rugose corals, previously identified from this locality as either *Lithostrotion* or *Siphonodendron,* but which John has recently re-identified as the rare coral *Solenodendron horsfieldi*.

This species is usually restricted to Courceyan and Chadian rocks, so to confirm the age John and Cindy had collected limestone samples above and below and contacted a Czech colleague who has confirmed that the foraminiferans in the limestones are indeed Arundian in age. Therefore they have found the youngest example of *Solenodendron* yet discovered! Trace fossils were also in abundance: *Zoophycus* and *Thalassinoides* together with other corals such as *Michelinia megastoma* and *Zaphrentis* sp.

The rare coral *Solenodendron*

Many of the corals are overturned. This together with the thick-shelled brachiopods and gastropods indicates a high-energy environment. There are vertical fissures in the limestones of speliothermic origin and filled with Triassic sediments together with occasional bones and teeth from a variety of fauna. John pointed out the change in general grain of the area from post Caledonian north-east/south-west to post Variscan east/west. This effect is seen throughout Europe although mid-South Wales is the northern limit of the Variscan front.

We walked along the cliffs noting the thickness of poorly sorted breccias which overlie the limestones. They are flash flood deposits of Triassic age, and the size of some of the boulders (up to 1.5m diameter) caused more than one member of the party to say they were glad they weren't around during that flooding episode! Included in the deposits are limestone blocks ripped from the sides of the wadis as the flood water passed through.

On our return we crossed the Fairy Cave Mudstone which is in between the Arundian High Tor Limestone and the bioturbated Chadian Gully Oolite. We entered a small quarry to see the lowest Jurassic rocks which sit unconformably on the Carboniferous. The Sutton Stone is a massive, creamy freestone with a small layer of Carboniferous pebbles at its base. It is overlain by the thinner bedded Southerndown Beds which represent the marginal facies of the Lower Jurassic in South Wales. The unconformity reflects marine transgressions that eventually drowned the Triassic deserts.

Our next stop was Dunraven Bay at Southerndown. The group walked part way down the cliff path for a view of the bay and the marginal facies of the Southerndown beds at the base of the cliff. Here they are represented by conglomeratic limestones and thin shales. These pass up into the fully marine Blue Lias which comprises alternating beds of limestones and shales. This is mostly within the *bucklandi* ammonite zone. There are no belemnites found here as these do not occur in the Blue Lias. We saw the effect of the Dunraven Fault bringing the older Sutton Stone alongside the younger Blue Lias in the opposite headland. The group spent some time collecting fossils of *Gryphaea* and some ammonites alongside the recent road cutting within the Blue Lias.

After lunch, we moved to our final location of the trip. And what a location! After a tortuous journey through an industrial estate at Barry, we arrived at Bendrick Rock. Fighting our way through brambles and a thorn thicket, we made it to the beach. We were in the desert facies of the Mercia Mudstones: red sandstones and mudstones deposited on low lying plains in and around playa lakes and seasonal watercourses. More particularly the area was a playground for dinosaurs and their footprints and trackways were there for the whole world to see and marvel at!

Dinosaur footprints

This was a suitable place to finish our excellent and informative trip. John Nudds and Cindy Howells were exceptional leaders, being patient both in explaining the same point several times and also with the less fleet of foot members of the group. We thanked them warmly for giving up their August Bank Holiday (and its great weather) to show us an area they clearly love to bits.

A note should also be made about Phil Spencer's patience and forebearance in driving 'The Horse Box' round the single track roads of Pembrokeshire. It must have been like being a *Gigantosaurus* in the world of the *Velociraptor!!*

The Horse Box

LIVERPOOL GEOLOGICAL SOCIETY FIELD EXCURSION TO WENLOCK EDGE AND THE ERCALL

by Tom Metcalfe

Leader: Graham Sherwood

The final field excursion of the Liverpool Geological Society's 153rd Session was led by our President for the session, Graham Sherwood M.A., Ph.D., to a part of Shropshire renowned for its fascinating geology. The party met in a car park near Presthope by the B4371.

The company assembles

The Day; an overview

Leaving aside the Quaternary (Pleistocene) deposits which are present in varying thickness over much of Shropshire, the county has representatives of the geological record from the late Precambrian (Protoerozoic) through the Palaeozoic to the early Jurassic (Mesozoic).

The society was in Shropshire to examine the geology at two sites, the late Precambrian, Cambrian and Ordovician geology of the Ercall area and the Silurian geology of Wenlock Edge.

The Precambrian geology of the Ercall is dated at 570-560 Ma. The rocks are lavas and ashes (tuffs), the Uriconian volcanics, erupted by volcanoes probably associated with rifting along the Pontesford - Linley and Church Stretton faults, on what was then an active plate boundary. The activity appears to coincide with the beginning of the Avalonian orogeny, when what we now call Shropshire was on the edge of Gondwana, in latitude 60°S and to the north was a widening Iapetus Ocean. Some time after the eruption of the lavas and tuffs, which are mainly rhyolites, i.e. essentially granitic in composition, they were intruded by the Ercall granophyre, a fine-grained pink rock, also of granitic composition.

Perhaps worth noting at this point, is that the Uriconian volcanics take their name from the nearby Roman town of Uriconium, or to give it its full title, Viroconium Cornoviorum. The Cornovii were the indigenous British tribe. It was a Roman town of considerable size and importance, the fourth largest in Britain, the local capital of central Britain. It lies just a short distance to the west of the Ercall and part of it is now occupied by the small village of Wroxeter. On the exit of the Romans from Britain it was eventually abandoned. Shortly afterwards, its stone was plundered by the Anglo-Saxons as they built what was to become Shrewsbury, about 8km to the northwest. This was a more readily defended position on raised ground within an almost closed meander of the River Severn.

During the Cambrian the Iapetus Ocean continued to widen and the first deposit in the Ercall area was the Ercall Quarztite, a shallow water sandstone, which at its base is a conglomerate containing some pebbles from the underlying Uriconian Volcanics. As the Cambrian seas continued to deepen a succession of sandstones was laid down, termed the Upper and Lower Comley Sandstones. With a proved unconformity between them, they mark the end of Cambrian deposition in this area. Because of faulting, the Upper Comley Sandstones are not exposed in the vicinity of the Ercall. Here, the next exposures are early Ordovician in age, the Shineton Shales outcrop on the southern flank of the Ercall at Maddock's Hill. The shales, now with a near vertical dip at this site, have been intruded by a sill, described as camptonite by the BGS. The shales and the sill have been affected by late Ordovician folding, hence the dip.

The next geological period to interest our members on this day is the Silurian. Tectonic processes meant that after the Shineton Shales, there was no deposition of Ordovician sediments in this part of Shropshire, east of the Church Stretton Fault, until later in the Caradoc. The Silurian Basal Unconformity lies upon mudstones and sandstones of the Acton Scott Group, the penultimate stage in the Ordovician. The early Silurian sea spread from the west, depositing first coarse then finer sandstones, then shales as water deepened; this first transition marks the Llandovery Series. Above this lies the Wenlock Series, first a succession of shales. This used to be called the Wenlock Shales, but which we must now call the Coalbrookdale Formation. Towards the top of the formation, layers of limestone nodules become increasingly common (Tickwood Beds or Farley Member). As the proportion of limestone in the rock increases, the base of the Much Wenlock Formation is reached, much of which is made up of quite thin alternating bands of a nodular limestone, clays and shales. Within all of this there are layers of limestones which contain a large proportion of shell debris and reef limestones, which we know must have formed in a clear subtropical sea.

Indeed, by the mid-Silurian this part of Britain had moved from 60°S, on the edge of Gondwana in the late Precambrian, to 20°S of the equator. They are not the barrier or fringing reefs with which some of us might be familiar. These are sometimes described as patch reefs because they grew as separate patches on the sea bed. Their exact mode of formation in ancient seas is still the subject of discussion and it may be better if we simply referred to this type of structure as carbonate buildups. In the Much Wenlock Limestone they are present between Ironbridge and Easthope but not further west where they are larger and more numerous towards the top. They are lens shaped, massive and consist of corals with sponge, bryozoan and crinoid fragments.

It is worth noting that the reefs, known in this area as 'ballstones' are quite pure limestones ($CaCO_3$) which played a part in the early industry of Coalbrookdale and surrounds. The local ironstone contains fine-grained silicates, which are impurities in the iron making process and must be removed.

In simple terms, the limestone is added to the furnace to remove the silicon which at the temperatures of the furnace has become an oxide and similarly the calcium carbonate has become calcium oxide.

So

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

and

$$CaO(s) + SiO_2(s) \rightarrow CaSiO_3(l)$$

The calcium oxide reacts with the silicon dioxide to form calcium silicate known in the trade as slag, which is a liquid lighter than molten iron and so floats on top and can be tapped off separately.

Above the Much Wenlock Formation the Silurian rocks of Shropshire become soft shales and mudstones again, the Elton Formation, the lowest unit of the Ludlow Series. These rocks form the valley of Hopedale visible to the south of Wenlock Edge, beyond which one can see the escarpment formed of the Aymestry Limestone. This rock spans the Bringewood Formation and Leintwardine Formation boundary, but is still within the Ludlow Series. There are further Silurian rocks in Shropshire but they won't concern us on this field excursion.

Locality 1

A short walk, on good paths, through pleasant woodland brought us to our first locality, a fault plane, in a quarry in the Much Wenlock Limestone. Here we were able to examine at close hand an example of what we quickly determined was a strike slip fault, i.e. the displacement of the fault was parallel to the strike of the plane of displacement. Our conclusion was greatly assisted by a fine example of slickenside lineation. In places the fault plane was coloured by a red mineral, which most agreed was probably an iron compound.

Strike Slip Fault

Locality 2

A short step across the quarry we were faced by a totally different wall, much of which consisted of bedded nodular limestones, separated by thin beds of clays and shales, which we were told make up most of the Much Wenlock Limestone. Clearly some kind of regular event was controlling sediment flow into this subtropical Silurian sea. Within the bedded limestones we could see lenticular masses of limestone, which we were told were the famous 'patch reefs' of the Much Wenlock Limestone.

Small Patch Reef in the Much Wenlock Limestone

Locality 3

Another short hike through this pleasant woodland setting brought us to an interesting relic of bygone days, lime kilns. The Lime Kilns of Knowle Quarry have been restored by the National Trust with locally produced lime; the small modern kiln built for this production has in the past produced lime for the Trust's work in other areas. It was argued that the use of lime mortar may well be 'greener' than the use of cement mortars. Lower temperatures in production and its absorption of carbon dioxide as it hardens were cited.

Reconstructed Limekilns of Knowle Quarry

Locality 4

The group moved on to find itself overlooking Lea Quarry. No longer producing limestone, this large hole in the Much Wenlock Limestone gave us an insight into the great volumes of the rock which have been removed from this part of Shropshire. On our way back to our cars we took time to search for fossils in the debris beside the footpath. There were many fragmental examples, but no museum quality exhibits. The members then enjoyed a pub lunch at the Huntsman Inn in Little Wenlock and left for the afternoon session suitably refreshed.

Searching the debris

Locality 5

The company regrouped in the Forest Glen Car Park, an old roadside quarry, and were introduced to the Uriconian Volcanics. We were faced with a rather complicated wall of rock most of which was tuff or agglomerate (rock containing larger particles than the tuffs) of granitic composition.

Within this were examples of rhyolites some of which showed banding, indicating flow and therefore that these rocks may have been erupted as lavas. Progressing towards the western end of the quarry we were confronted by a rather more obvious piece of geology in the form of a dolerite dyke. These intrusions, we were told, are commonly associated with late stages of volcanic activity and that this example was one of a number associated with the Uriconian rocks of this area.

Dolerite Dyke in the Uriconian Volcanics

Locality 6

The group now proceeded to the Ercall Quarry. Here it was explained that we were examining the Ercall Granophyre, best described as a fine grained pink rock which was granitic in composition and intrusive in nature. This rock had been dated at 560Ma. At the south eastern end of the quarry and dipping steeply in that direction was a rock that was, despite the dip, clearly sedimentary in origin, with very distinctive bedding planes. This we were informed was the Wrekin Quartzite, quartzite strictly speaking now being a misnomer since the rock was not of metamorphic origin but merely a pure quartz sandstone. The Wrekin Quartzite is Cambrian in age and since in this locality it represents the base of the Cambrian, then somewhere in front of us was the Basal Cambrian Unconformity.

It seems that the Cambrian transgression was rather later here in Shropshire than in other parts of Britain, the base of the Wrekin Quartzite is dated at approximately 533Ma from the occurrence of primitive algae taken from shale layers in the basal conglomerate of the Wrekin Quartzite. Getting up close the group were able to examine pebbly layers, the pebbles of which could well have originated in the Uriconian Volcanics. We could not however, find any that we were able to relate to the underlying Ercall Granophyre.

Ercall Quarry; Bedded Wrekin Quartzite lying unconformably on the Ercall Granophyre.

Pebble beds at the base of the Wrekin Quartzite

A short walk took the group to a bedding plane which displayed a fine set of ripple marks. Given the note earlier that the bedding dipped to the south east and since the ripples were at near right angles to the dip, this should indicate water, almost certainly a marine environment, somewhere to the south-east. Before leaving the Ercall Quarry we were introduced to the Lower Comley Sandstone, a glauconitic sandstone, containing the green clay mineral glauconite, and a distinct change from the Wrekin Quartzite. This would be the last example of a Cambrian rock that we were to examine this day.

Locality 7

We moved on again, another pleasant walk though woodland bearing the scars of man’s early industrial efforts and so to Maddock's Hill Quarry. Here we entered a deep linear gash in the earth, from which a large amount of rock had been removed. That which had been removed, we were told, was an intrusion, a sill. The rock into which the intrusion had been emplaced was the Shineton Shales. Formed during the early Ordovician Period and although horizontal during formation and emplacement of the sill, the shales were folded later in the Ordovician. This explains their near vertical present day dip and the 'vertical' sill. The shales take their name from the small village of Sheinton, about six kilometres to the south-west of Maddock's Hill and yes, there is a spelling mistake in there, but not by me! The group had walked through minor exposures of the shales on the way to the quarry and so were keen to examine the intrusion, but the excavation was very overgrown and whilst there were exposures on the south-eastern wall of the quarry, they were deemed not safe. The hunt began for fallen blocks. Eventually some were found, it was we were informed, an alkali lamprophyre. On closer examination it was a medium grained grey rock with distinctive pink and black crystals. The hammers came out and the wise backed off. When informed that the shales had given up a few specimens of a dendroid graptolite the company moved as one to the north-western wall and searched the piles of debris at the foot of the wall. Sadly none was found but it was noted that the shales at this locality were baked, because of proximity to the sill. They were much tougher and prone to splinter.

Ripples on bedding plane of Wrekin Quartzite

We learned that much of what was now missing from Maddock's Hill had vanished in the 1970s, when the lamprophyre intrusion had been carried off and used as roadstone in the construction of the M54 linking Telford to the M6. The day over, we made our way back to our cars at the Forest Glen car park where we thanked Graham in our customary way, for what had been another excellent day out with the Liverpool Geological Society.

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Maps
Church Stretton 1:50,000 BGS

Telford 1:25,000 BGS

Erratum for Woodcock *The North West Geologist* No. 17 2010 pp 28-32

THE EL TIME GROUP: A THICK SEQUENCE OF FLUVIAL CONGLOMERATES ON LA PALMA, CANARY ISLANDS

by Duncan Woodcock

Apologies are necessary for the wrong map being inserted for **Figure 1** due to an error in reading the formats. Please find the correct map for the article shown here.

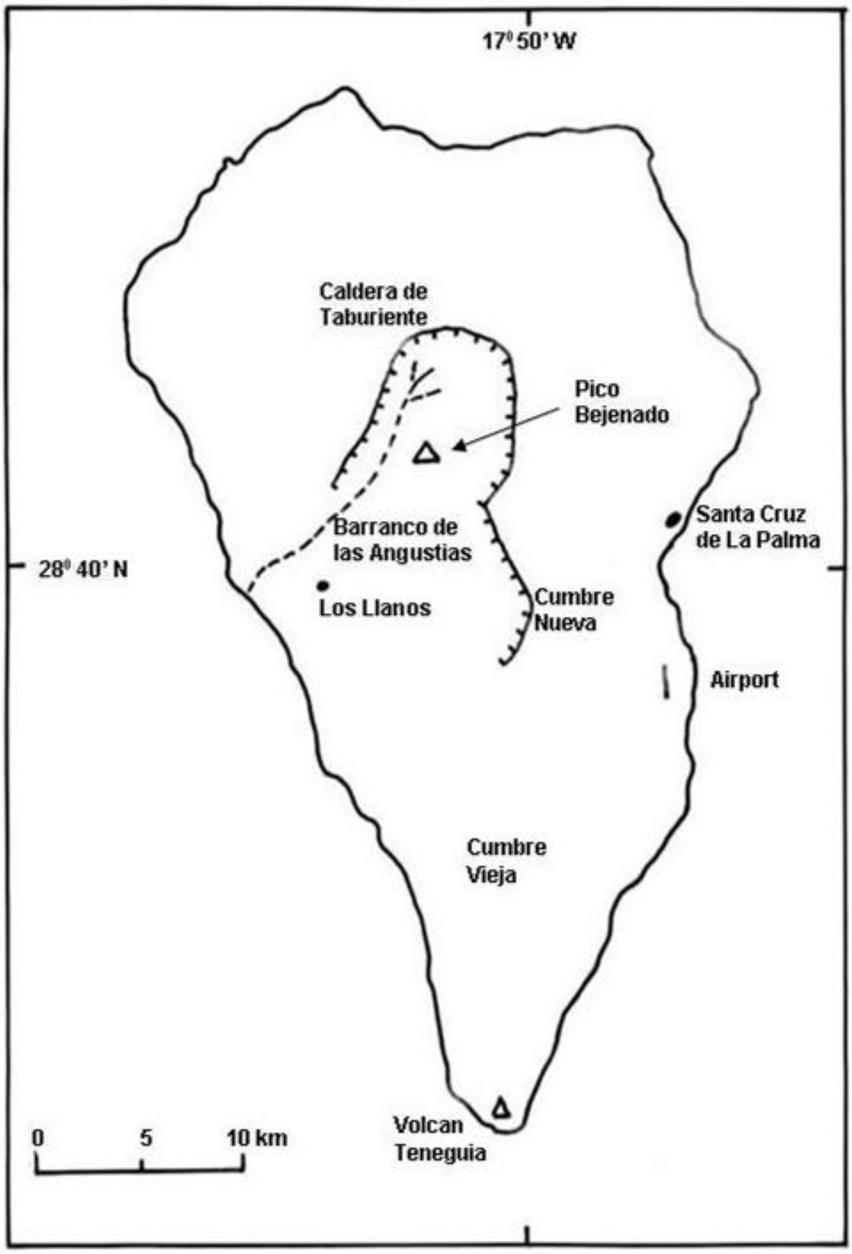
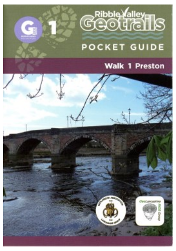
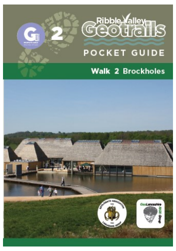
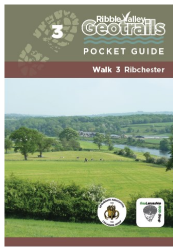
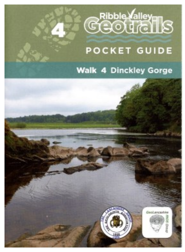


Figure 1
Sketch map of La Palma, showing locations mentioned in the text









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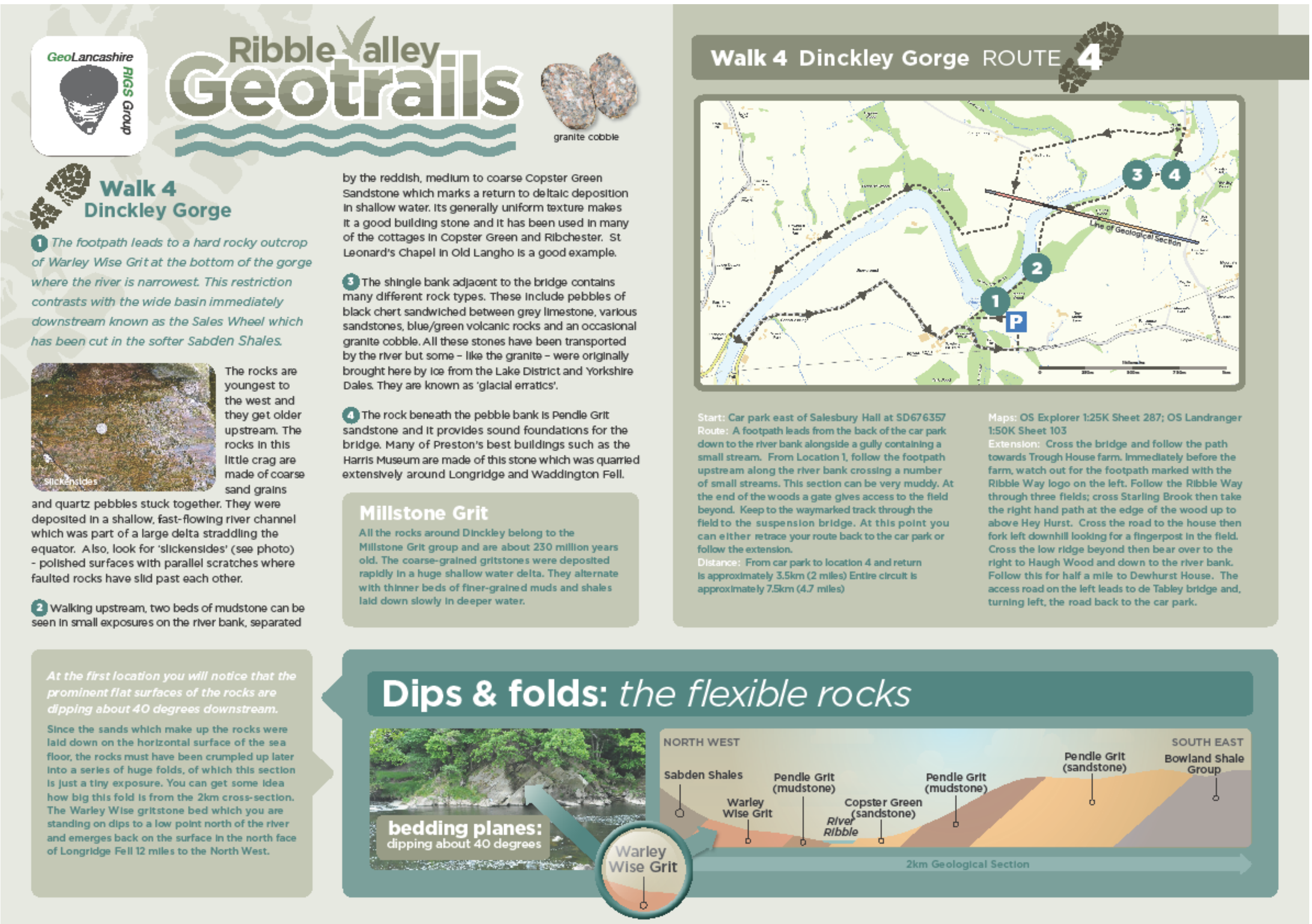
The Ribble Way provides a ready-made excursion into many of the geological landscapes of Lancashire and the Yorkshire Dales. These short geotrails provide a way of exploring the area and a geological guide to the whole route is planned.

Four trail guides are now published, the Clitheroe trail is imminent and more are planned for the upper reaches of the valley around Settle, Horton-in-Ribblesdale, Stainforth and Ribblehead.

Each guide contains a circular walk of about 4-6km, giving information about aspects of geology and landforms. QR codes enable the use of smart phones to access additional information from the GeoLancashire website at www.geolancashire.org.uk

The guides can be downloaded and are also available from outlets including Lancashire Wildlife Trust's Brockholes reserve, Clitheroe Castle Museum and Ribchester Roman Museum.

GeoLancashire *and the* ***Lancashire Group*** *of the* ***Geologists' Association***



GeoLancashire RIGS Group

Ribble Valley Geotrails

granite cobble

Walk 4 Dinckley Gorge

1 *The footpath leads to a hard rocky outcrop of Warley Wise Grit at the bottom of the gorge where the river is narrowest. This restriction contrasts with the wide basin immediately downstream known as the Sales Wheel which has been cut in the softer Sabden Shales.*

Slickensides

The rocks are youngest to the west and they get older upstream. The rocks in this little crag are made of coarse sand grains and quartz pebbles stuck together. They were deposited in a shallow, fast-flowing river channel which was part of a large delta straddling the equator. Also, look for 'slickensides' (see photo) - polished surfaces with parallel scratches where faulted rocks have slid past each other.

2 Walking upstream, two beds of mudstone can be seen in small exposures on the river bank, separated by the reddish, medium to coarse Copster Green Sandstone which marks a return to deltaic deposition in shallow water. Its generally uniform texture makes it a good building stone and it has been used in many of the cottages in Copster Green and Ribchester. St Leonard's Chapel in Old Langho is a good example.

3 The shingle bank adjacent to the bridge contains many different rock types. These include pebbles of black chert sandwiched between grey limestone, various sandstones, blue/green volcanic rocks and an occasional granite cobble. All these stones have been transported by the river but some – like the granite – were originally brought here by ice from the Lake District and Yorkshire Dales. They are known as 'glacial erratics'.

4 The rock beneath the pebble bank is Pendle Grit sandstone and it provides sound foundations for the bridge. Many of Preston's best buildings such as the Harris Museum are made of this stone which was quarried extensively around Longridge and Waddington Fell.

Millstone Grit

All the rocks around Dinckley belong to the Millstone Grit group and are about 230 million years old. The coarse-grained gritstones were deposited rapidly in a huge shallow water delta. They alternate with thinner beds of finer-grained muds and shales laid down slowly in deeper water.

Walk 4 Dinckley Gorge ROUTE 4

Line of Geological Section

Start: Car park east of Salesbury Hall at SD676357
Route: A footpath leads from the back of the car park down to the river bank alongside a gully containing a small stream. From Location 1, follow the footpath upstream along the river bank crossing a number of small streams. This section can be very muddy. At the end of the woods a gate gives access to the field beyond. Keep to the waymarked track through the field to the suspension bridge. At this point you can either retrace your route back to the car park or follow the extension.
Distance: From car park to location 4 and return is approximately 3.5km (2 miles) Entire circuit is approximately 7.5km (4.7 miles)

Maps: OS Explorer 1:25K Sheet 287; OS Landranger 1:50K Sheet 103
Extension: Cross the bridge and follow the path towards Trough House farm. Immediately before the farm, watch out for the footpath marked with the Ribble Way logo on the left. Follow the Ribble Way through three fields; cross Starling Brook then take the right hand path at the edge of the wood up to above Hey Hurst. Cross the road to the house then fork left downhill looking for a fingerpost in the field. Cross the low ridge beyond then bear over to the right to Haugh Wood and down to the river bank. Follow this for half a mile to Dewhurst House. The access road on the left leads to de Tabley bridge and, turning left, the road back to the car park.

At the first location you will notice that the prominent flat surfaces of the rocks are dipping about 40 degrees downstream.

Since the sands which make up the rocks were laid down on the horizontal surface of the sea floor, the rocks must have been crumpled up later into a series of huge folds, of which this section is just a tiny exposure. You can get some idea how big this fold is from the 2km cross-section. The Warley Wise gritstone bed which you are standing on dips to a low point north of the river and emerges back on the surface in the north face of Longridge Fell 12 miles to the North West.

Dips & folds: *the flexible rocks*

bedding planes: dipping about 40 degrees

NORTH WEST
SOUTH EAST
Sabden Shales
Warley Wise Grit
Pendle Grit (mudstone)
River Ribble
Copster Green (sandstone)
Pendle Grit (mudstone)
Pendle Grit (sandstone)
Bowland Shale Group
Warley Wise Grit
2km Geological Section

www.gaiagraphics.co.uk

Other Publications

Liverpool Geological Society

The Geological Journal
Rock around Liverpool
Rock around Wirral
Rock around Chester
The William Smith map
A field guide to the continental Permo-Triassic rocks of Cumbria and North West Cheshire
Contact: Bob Bell, 5 Brancote Gardens, Bromborough, Wirral CH62 6AH (0151 334 1440)

Michel Levy Charts
Stereographic Projections
Contact Mr N C Hunt, Department of Earth Sciences, University of Liverpool, PO Box 147, Liverpool L69 3BX or email: scfc@liv.ac.uk

Manchester Geological Association

A Lateral Key for the Identification of the Commoner Lower Carboniferous Coral Genera (£2.25)
Available from Niall Clarke, 64 Yorkdale, Clarksfield, Oldham, Lancashire OL4 3AR

Geology Trail of Knutsford's Buildings and Cobbles (£1.50)
Available from Fred Owen, 29 Westage Lane, Great Budworth, Northwich, CW9 6HJ

A Building Stones Guide to Central Manchester
Available from Rosemary Broadhurst, 77 Clumber Road, Poynton, Stockport SK12 1 NW

Lancashire Group of the Geologists' Association/GeoLancashire

Ribble Valley GeoTrail Guides
- **1 Preston**
- **2 Brockholes Nature Reserve**
- **3 Ribchester**
- **4 Dinckley Gorge**

Available from Jennifer Rhodes, The Rough Lee, Naylor's Terrace, Belmont, Bolton, Lancashire BL7 8AP or from www.geolancashire.org.uk

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