ISSN 0375-7846

The North West Geologist

Published under the auspices of
THE LIVERPOOL GEOLOGICAL SOCIETY and
THE MANCHESTER GEOLOGICAL ASSOCIATION
Number 3

THE NORTH WEST GEOLOGIST
(Formerly THE AMATEUR GEOLOGIST)

Editorial

Not even the most tortuous of minds could detect any links between the articles making up The North West Geologist No. 3. So let us make a virtue out of necessity and ask-where else but in the NWG could you find such extraordinary diversity of subject?

Not perhaps 'shoes, ships, sealing wax, cabbages and kings' but instead we can offer you Welsh castles and African mantle plumes, spiders ancient and modern, Wirral coastal defences, Derbyshire gold, Earth Science courses at Liverpool John Moores University plus of course, all our regular features. Some of the latter could be on their last legs as we run out of museums and as the BGS mappers move away from North West England. In part compensation geological conservation is taking on added importance these days. But ideas for new features would be much appreciated by-

G. D. Miller
Sheila Owen
N. C. Hunt
Tom Metcalfe

Notes for Authors

Articles and suggestions for future issues are always most welcome and should be sent to either N.C. Hunt, Department of Earth Sciences, The University, Liverpool L69 2BX; or to G. D. Miller, Oaklea, Diglee Road, Furness Vale, via Stockport, SK12 7PW. Articles should be typewritten if possible and up to 3,000 words in length. Figures should be designed for reduction to fit a maximum frame size of 180mm x 125mm.

Copyright

Back Numbers of the North West Geologist and the Amateur Geologist

Limited stocks of most previous issues are held in Manchester and Liverpool, and copies (at very modest prices) can be obtained by application to the editors.

A Lateral Key for the Identification of the Commoner Lower Carboniferous Coral Genera

Murray Mitchell's article in the last North West Geologist is now available from the Manchester Geological Association in offprint form, A5 in size with 10 pages and a blue laminate cover. The price is £1.95 (plus 25p postage and packing) for single copies. Orders in bulk (over 10) may be obtained at the discounted price of £1.70 per copy (plus 50p postage per 10 ordered).

Orders should be sent to G. D. Miller, Oaklea, Diglee Road, Furness Vale via Stockport, SK12 7PW. Please make out cheques to the MGA.

IN BRIEF....

Still more about radon

Recent detailed surveys by the National Radiological Protection Board have added considerably to our knowledge of the radon risk (see North West Geologist No. 1, 1991) in the English counties of Derbyshire, Northamptonshire and Somerset. In Derbyshire the proportion of homes exceeding the Action Level (200 Bq m^{-3}) was highest in an area broadly equivalent to the Carboniferous Limestone Dome (and immediate environs). A smaller proportion exceeded the level in the surrounding Namurian and also in the north-east of the county underlain by Permian limestones. It is not clear why the Carboniferous Limestone in Derbyshire should present greater problems than the equivalent strata in Staffordshire, the West Riding and Cumbria. The survey does refer to the importance of permeability due to fracturing and karst formation. But we shall have to await even more detailed area studies within the Derbyshire Dome to get a clearer idea of the situation.

In Northamptonshire the NRPB survey found that much of the area with the highest radon levels is underlain by the phosphatic ironstones, sandstones and limestones of the Northamptonshire Sand Formation and the Lower Estuarine Series. In Somerset high radon values were found over Lower Carboniferous and Mesozoic limestones in the north-east, and over Devonian rocks (mostly sandstones and shales) in the west of the county.

(Source : Documents of the NRPB, vol. 3, 1992)

But where have all the tuffs gone?

As a rock group the tuffs have had their ups and downs. Ups came mainly in the 1950's and 1960's with the discovery that rocks identified as lavas were in fact welded ash flow tuffs. But then came the downs. First a number of air-fall tuffs were found to be hyaloclastites, and then a larger number were re-classified as epiclastic rocks - with volcanic constituents redistributed by sedimentary processes as tuffites, lahars, turbidites as so forth. Such re-classification has appreciably modified our picture of the Borrowdale Volcanic Group in the Lake District - although as Frank Moseley points out (Moseley, 1990), bedded airfall tuffs "can on occasions be difficult to distinguish from volcaniclastic sediments... the field relations are often inconclusive and their interpretation can then be a matter of speculation".

In North Wales, too, airfall tuffs appear to form a surprisingly small proportion of the Caradocian rocks in Snowdonia and are far outnumbered by ashflow tuffs. The recent Memoir (Howells, Reedman and Campbell, 1991) notes that significant Plinian fall-out deposits are lacking in the sequences-subaerial and submarine- dominated by the acidic ash-flow tuffs. "This", adds the Memoir, "is in marked contrast with the numerous examples of recent subaerial ash flow tuffs which are preceded by a Plinian fall-out phase and followed by a fall-out from the attendant cloud". As for the basaltic Bedded Pyroclastic Formation, only a small part of it consists of "genuinely pyroclastic elements" and the tuffaceous sediments are dominant. But could it be that the pendulum has now swung too far in favour of the sedimentologists?

References

Howells, M. F., Reedman, A. J., Campbell, S. D. G. 1991. Ordovician (Caradoc) Marginal Basin Volcanism in Snowdonia (North West Wales). Mem. Geol. Surv. G.B. London HMSO.

Moseley, F. ed. 1990. The Lake District. Geologists' Association Guides.

Geologists At Home and Abroad

Despite the repercussions of UK currency devaluation geological field trip prospectuses for 1993 show plenty of enterprise. North America is back in business with Manchester's Extra Mural Department offering the Canadian Rockies to California (July-August), Nottingham's Adult Education Department visiting the Yukon and Alaska round the same time, and Bristol's Department of Continuing Education going to the South West USA in September. Even more adventurous perhaps is the Cardiff Department of Extramural Studies tour of the Hawaiian islands in late July-early August. The Mediterranean is as popular as ever. Durham's Department of Adult and Continuing Education offer Crete in April; Bristol return to Cyprus later that month, go to Pompeii and Herculaneum in May, and pay Santorini a return visit in October. Readers of the North West Geologist will remember the comprehensive field guide to the volcanics of Nisyros in our first number - take it with you if you are going with the Field Studies Council to Kos and Nisyros at the end of May, or with the Sheffield Division of Continuing Education to Nisyros and Santorini in September. Sheffield is also repeating its popular trip to the Auvergne volcanics in May.

At home Scotland is the most popular venue for geological field trips. Arran gets two- with Liverpool Centre for Continuing Education in April and Bristol in May. Mull has a pair too since Leeds Department of Continuing Adult Education goes there in early May, and Nottingham runs two courses in May-June. Ardnamurchan (Durham, May-June) completes the Highlands and Islands group.

Further south there's the Summer Academy Northumbria course centred on Durham in August-September, while across the Irish Sea Sheffield visit South Mayo in May. Wales is represented by Pembroke (Durham, September), Anglesey (Liverpool weekend, May) and the South Wales coast (Nottingham weekend, April). And if you don't want to travel so far you can still have a weekend in Swaledale (Hull Department of Adult Education, late March), the

Yorkshire Coast (Liverpool, late April), or the South and West Lake District (Nottingham, early October).

It's an ill wind ....

Derek Brumhead's article in the last North West Geologist referred to the Mam Tor landslip and its disastrous effects on the main Manchester to Sheffield road. According to Earth Conservation No. 30 (January, 1992) Mam Tor "shows one of the best rotational landslides in the country and forms part of the Castleton SSSI.. Movement of the road downslope shows the force and direction of the slip and remains as a testament to the power and magnitude of such natural events." The National Trust has made proposals to improve the landscape in this area, including a bridle path along the route of the former road. English Nature, however, has stepped in on our behalf and is consulting with the Trust to ensure that the slip's best features are preserved and "the debris slope morphology is not masked by excessive vegetation coverage". Will the geomorphologists show equal enterprise in preserving visual evidence of our British earthquakes, mining subsidence and other natural disasters?

Holmes redivivus

In the 1990 Amateur Geologist we drew attention to the centenary of the birth of one of Britain's greatest geologists, Arthur Holmes. Apart from Eric Robinson's note in the Geologists' Association Circular, little notice was taken of the event by the earth science establishment. This was in striking contrast to the celebrations of the centenary of the birth of Sir Mortimer Wheeler, an equally great archaeologist, which took place in Dorchester during September, 1990. A lunch in his honour was held in the town; reminiscences were followed by the guests perambulating round Maiden Castle hill fort and "pouring libations" before returning to Dorchester for tea and an 'Animal Vegetable Mineral' extravaganza. Earth scientists, however, move (like geological processes) at a much slower pace and it is only in 1993/4 that the name of Holmes is being honoured. A fourth edition of his magnificent 'Principles of Physical Geology' has been edited by Donald Duff with the assistance of an eminent team of revisers - thirty one chapters and over 800 pages. Furthermore, a Geological Society Arthur Holmes meeting is to be held in Iceland in 1994 - theme: the Icelandic Plume and its influence on the evolution of the North Atlantic.

'Send the coach forward'

This instruction was to be found in many older descriptions of geological itineraries. The coaches, point out the Geologists' Association Field Meeting Secretaries, were "full of geologists who spoke to each other (occasionally), ate at the same pub, were introduced to the geology en route by the leader..". But as the cost of coaches rose astronomically, they were soon abandoned for 'private transport'. This, continued Jim Bryant and John Evans, means "cars doing hundreds of miles, exhausting their drivers before the first exposure, isolating their occupants from other aficionados - and leaving the car-less behind as forgotten outcasts". So they are proposing in 1993 to reintroduce coaches from the London Embankment with pick-up points en route, "pub stops (geology permitting) and cream teas(?)".

As far as we know, the East Midlands Geological Society is one of very few other bodies which can still run successful coach field trips for its members. If the G.A. follows suit, will other societies take the plunge too?

CONTINENTAL FLOOD BASALTS OF THE KAROO, SOUTHERN AFRICA

by W. J. WADSWORTH

Introduction

Continental Flood Basalts have received considerable attention in recent years, largely because of their apparent association with the early stages of continental disruption, but also because of their sheer volume and relatively short eruptive time-spans. Of course, they have long been recognised as important components of continental geology, and have been intensively studied in various parts of the world. But in plate-tectonic terms they have tended to be the poor relations of the Ocean Floor Basalts, which are even more voluminous, and appear to play a relatively straightforward role in the construction of oceanic crust. Until recently, the link between Continental Flood Basalts and plate tectonics has been limited to the notion that initiation of a new ocean by continental rifting and the establishment of a zone of plate construction (incipient mid-ocean ridge), will inevitably produce a certain amount of on-land (i.e. continental) volcanic activity during the earliest stages of the process, but that this is just a prelude to the more important business of generating new oceanic crust.

However, the subject of Continental Flood Basalts has now taken on a new lease of life, as it has become clear that they represent significant magmatic events in their own right, and that they are probably the surface expressions of major upwellings of mantle material (mantle plumes), akin to the long-lived plumes believed to be responsible for strings of oceanic volcanoes such as the Hawaii - Emperor Chain. These sub-continental plumes differ from their oceanic counterparts by their much greater breadth (up to 2000 km across), and this feature is believed to be the result of the plume spreading out to form a mushroom shape as it encounters a blanket of relatively thick continental crust, compared with the oceanic situation where the thermal anomaly is more readily dissipated. In both cases, partial melting of mantle material as it is elevated and decompressed, leads to the generation of abundant basaltic magma. In the continental context, the plume produces doming of the crust, with consequent rifting and volcanic activity, and if the tectonic conditions are right (i.e. the continent is already under extensional stress), this process may lead to major fracturing and the eventual development of a new ocean. There is convincing evidence that such a series of events has occurred a number of times over the past 300 m.y., as the most recent re-arrangement of the continents has taken place. In particular, the Karoo basalts of S.E. Africa (and their counterparts in Antarctica and Tasmania) are associated with the post-Gondwana separation of the southern continents and the early history of the Indian Ocean; the Parana basalts of Brazil (and similar basalts in Namibia) are associated with opening of the S. Atlantic; the Deccan basalts of N.W. India with the main development of the W. Indian Ocean;

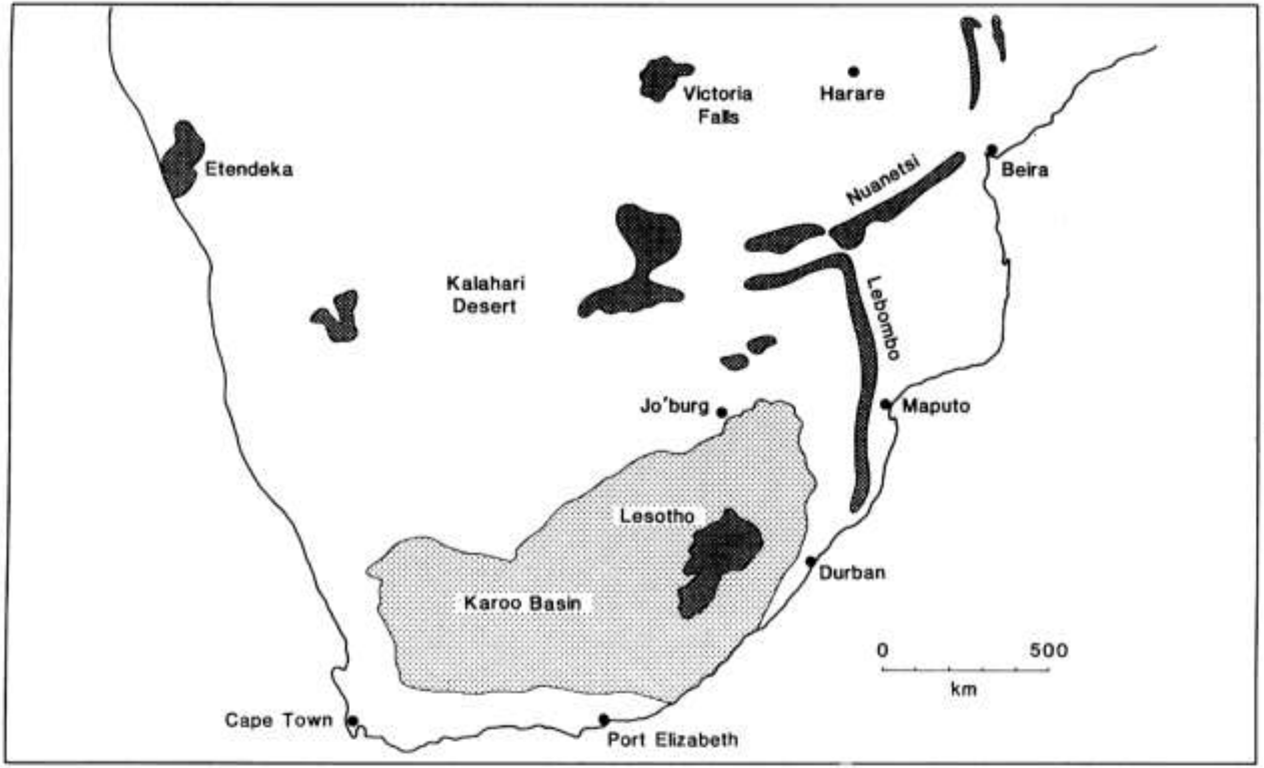


Figure 1. Map of Southern Africa, showing present distribution of Karoo lavas (heavy ornament) and the sedimentary rocks of the Karoo basin (light ornament).

and the British Tertiary Volcanic Province (and the corresponding rocks in W. Greenland) with the opening of the N.E. Atlantic. The mantle plumes responsible for the opening of the S. Atlantic, N.E. Atlantic and W. Indian Ocean may still survive as the active volcanic areas of Tristan da Cunha, Iceland and Réunion Island, respectively. Not all Continental Flood Basalts fit this pattern, however. The Columbia River - Snake River Tertiary basalt province and its associated area of current volcanic activity (Yellowstone) appear to be related to the over-riding of the E. Pacific constructive margin by the N. American plate.

Karoo Igneous Activity - General

Igneous rocks of the Karoo Province comprise both volcanic and intrusive manifestations extending over a wide area of southern Africa (see Fig. 1). They are found from the Zambesi River in the north, to Port Elizabeth in the south (2000 km); and from Namibia (Etendeka) in the west to Mozambique in the east (nearly 3000 km), although the Etendeka rocks have closer affinities with the Parana basalts of Brazil than with the rest of the Karoo province. The principal areas of volcanic rocks (mostly basalts) are Lesotho - best known for the Drakensberg scarp at its eastern margin; the various outcrops around the Kalahari desert, which may well obscure a much more extensive lava field; and the linear outcrops of the Lebombo and Nuanetsi regions close to the western border of Mozambique. The area currently covered by Karoo volcanic rocks is probably over 150,000 km^2, but the original extent may have been an order of magnitude greater. The thickness of the volcanic sequence is very variable. In areas where essentially flat-lying lavas cap the Karoo sedimentary sequence, as in Lesotho, the thickness reaches 1.5 km. However, along the Mozambique border, where the volcanics are exposed in the 100 km-long Lebombo monocline, stratigraphic thicknesses of over 10 km are encountered. The original volume of Karoo lavas and associated intrusives may have been of the order of 3,000,000 km^3.

Most of the Karoo igneous rocks can be dated as Lower Jurassic (190 - 170 m.y.). In Lesotho, the activity started at about 190 m.y. (slightly earlier in Nuanetsi), and although the extrusive episode may have been relatively short-lived (perhaps only a few million years), intrusive events probably continued until about 150 m.y. ago. Elsewhere activity continued into the Cretaceous. The Etendeka lavas have been dated at round 120 m.y. and are believed to be associated with the Lower Cretaceous opening of the S. Atlantic.

Although the greater majority of the Karoo volcanics and associated intrusive rocks are basaltic in composition, there are also significant amounts of more diverse rock types locally. Rhyolites form an important component of the Lebombo and Nuanetsi areas. At the other end of the compositional spectrum, picritic basalts and nephelinites also occur in the Nuanetsi area. The basaltic and doleritic rocks are broadly tholeiitic in character, but more subtle variations (e.g. high and low Ti varieties) can be recognised and shown to have specific geographical distributions.

Lesotho - N.E. Cape Province

The type area for the study of Karoo basalts and related dolerite intrusions is in the main Karoo basin of South Africa. Here, a thick sequence of essentially continental sediments, ranging from the upper Carboniferous to the Triassic, is conformably overlain by basalt lava (Drakensberg Formation) of Lower Jurassic age. The stratigraphic succession is as follows:-

Karoo Supergroup
- Stormberg Group
  - Drakensberg Formation
  - Clarens Formation
  - Elliot Formation
  - Molteno Formation
- Beaufort Group
- Ecca Group
- Dwyka Group

Cape Supergroup (Ordovician - Carboniferous)

The Karoo basin developed by the influx of sediments from surrounding landmasses, especially to the south where the mountains of the Cape Fold Belt (Cape Town to Port Elizabeth), were forming during the early history of the basin, and contributed material to it in Permian and Triassic times. The Dwyka Group is largely of glacial origin (Dwyka tillite), and is succeeded by the Ecca Group, mainly of deltaic facies, with local coal measures, and characterised by the *Glossopteris* flora, which first appeared towards the top of the Dwyka Group. Above the Ecca Group, and more centrally disposed within the Karoo Basin, are the deltaic/fluvial mudstones and sandstones of the Beaufort Group, reaching approximately 6000 m in thickness, and characterised by relatively abundant reptilian remains. The overlying Stormberg Group comprises a series of fluvial and deltaic sediments (Molteno Formation) with spectacular plant fossils preserved locally; a sequence of red beds (Elliot Formation); and then aeolian sandstones (Clarens Formation) immediately preceding the main period of volcanic activity which gave rise to the Drakensberg Formation. The Stormberg succession indicates progressively more arid conditions.

The Drakensberg lavas cover a wide area of Lesotho and N.E. Cape Province, approximately 300 km from N.E. to SW., and up to 150 km across. The lava succession has a maximum thickness of 1400 m, and reaches 3,500 m above sea level. The eastern scarp of the Drakensberg is a particularly impressive scenic feature. The lavas are remarkably uniform tholeiitic basalts (of lower-Ti types), and comprise a succession of mainly subaerial flows, many with pahoehoe surfaces, and characterised by abundant vesicles and amygdales. The lowest flows appear to have accumulated on an irregular surface of the Clarens

Formation (formerly called the Cave Sandstone, with its distinctive pale colour and tendency to form shallow caves and overhangs) - probably representing a rolling desert surface with a topographic relief of up to 100 m. Pillow lavas occur locally, where temporary playa lakes developed, and there are associated pyroclastic facies which may represent phreatic activity and related mudflows. Occasionally, more silicic lavas (andesite - dacite compositional range) are found near the base of the succession. However, the bulk of the Drakensberg lava pile is made up of subaerial basalt flows, generally a few metres in thickness, and uniformly basaltic. These are widely believed to represent fissure eruptions, with little evidence for the development of specific central volcanoes. Much of the succession appears to have been erupted in a relatively short time-span of 1-2 million years.

Intrusive Activity

Karoo intrusive rocks (mostly dolerites) are extremely abundant throughout most of the Karoo basin, and presumably represent the subvolcanic complement to the Drakensberg lavas. Many of them are sheet-like, both dykes and sills, but other more complex and distinctive shapes are also known. Some of the intrusions are notably differentiated, with cumulates representing concentrations of early-formed minerals such as olivine and pyroxene (also Fe-Ni-Cu sulphides), or late-stage acidic fractions forming veins or filter-pressed sheets. There is also abundant evidence of local metamorphism and rheomorphism of country rocks, as well as interaction between basaltic magma and sediments.

Further Reading

K. G. Cox (1988). The Karoo Province (in Continental Flood Basalts [Ed. J. D. Macdougall]); Kluwer Academic Publishers, pp. 239-271.

H. V. Eales, J. S. Marsh and K. G. Cox (1984). The Karoo Igneous Province: an introduction. Spec. Publ. geol. Soc..S. Afr., 13, pp. 1-26.

F. Walker and A. Poldervaart (1949). Karoo dolerites of the Union of South Africa. Bull. geol. Soc. America, 60, pp. 591-706.

W. J. Wadsworth
University of
Manchester

FROM BEDROCK TO BATTLEMENTS: THE GEOLOGY, QUARRYING AND CONSTRUCTION OF CAERGWRLE CASTLE, CLWYD

by JOHN MANLEY and WILLIAM JONES

Introduction

The remains of Caergwrle Castle stand on a hill dominating the modern village of Caergwrle, which lies to the immediate north. The castle is situated about half way between Mold and Wrexham in north-east Clwyd at SJ 306572 (Fig. 1), and the A541 linking the two towns has to turn sharply to the west to avoid the hill. In its location the castle is very much a border fortification. It stands at an altitude of 135 metres OD just to the east of the first substantial Welsh hills in the form of Hope Mountain. Any defender on the wall-walk of the castle's east curtain enjoyed extensive views north-east towards Chester, south to Wrexham and beyond, and north to Halkyn Mountain. The castle stands on a hill composed of rocks of the early Namurian Cefn-y-Fedw Sandstone. The castle itself was sited on the highest point of the hill, on sandstone and grit outcrops in the south-western corner.

Before the recent excavations the physical remains of the castle had been described by King (1974). The present plan (Fig. 2) is adapted from a new survey of the monument carried out by David Browne and David Percival of the Royal Commission on Ancient and Historical Monuments in Wales. The pre-excavation remains of the castle consisted of three substantial sections of upstanding masonry: a partly preserved north tower with an adjoining length of curtain wall on its western side; a length of the east curtain wall with a surviving exterior buttress; and a poorly preserved eastern tower with a section of the south curtain wall. The castle was defended on its eastern and northern sides by a substantial rock-cut ditch and counterscarp bank. The defences of the castle on its western side are more problematic, since there is no surface indication of either wall or ditch. Whether the absence of both is related to the steepness of the slope of the hill in this area is difficult to determine. There is, certainly, considerable evidence for post-medieval quarrying on the western side of the hill, which could have removed all archaeological indications of a defensive barrier. Some 30 metres south of the monument and about 10 metres below it there is an outlying earthwork; it is possible that this bank provided some defence for the garrison of the castle against an attack from the south. Around the summit of the hill, to the east of the castle, lie the remains of an earth-covered bank which delimit an outer enclosure. The bank is best preserved on the southern side, but elsewhere is fairly insubstantial and occasionally interrupted by later disturbances. Its date, function and relationship with the masonry castle is unclear.

The history of the castle itself is both brief and dramatic. Caergwrle Castle

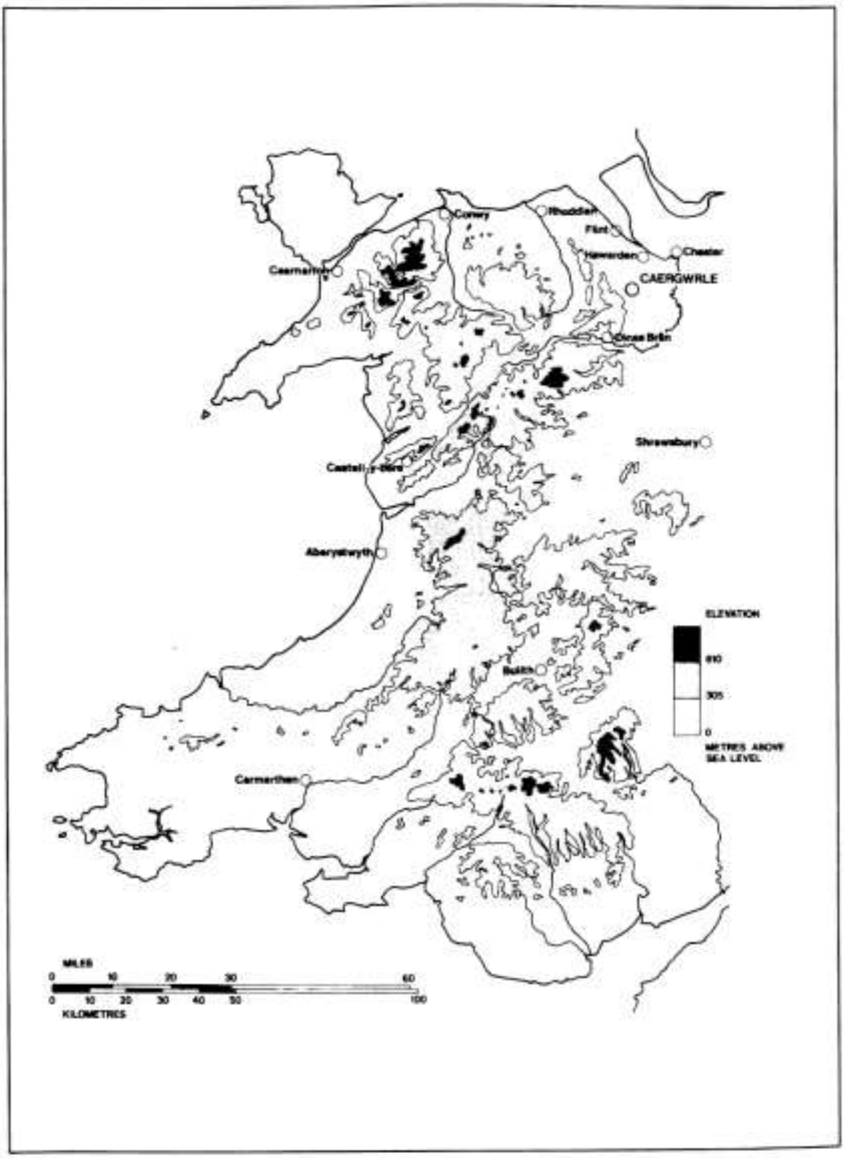


Figure 1. The location of Caergwrle within Wales

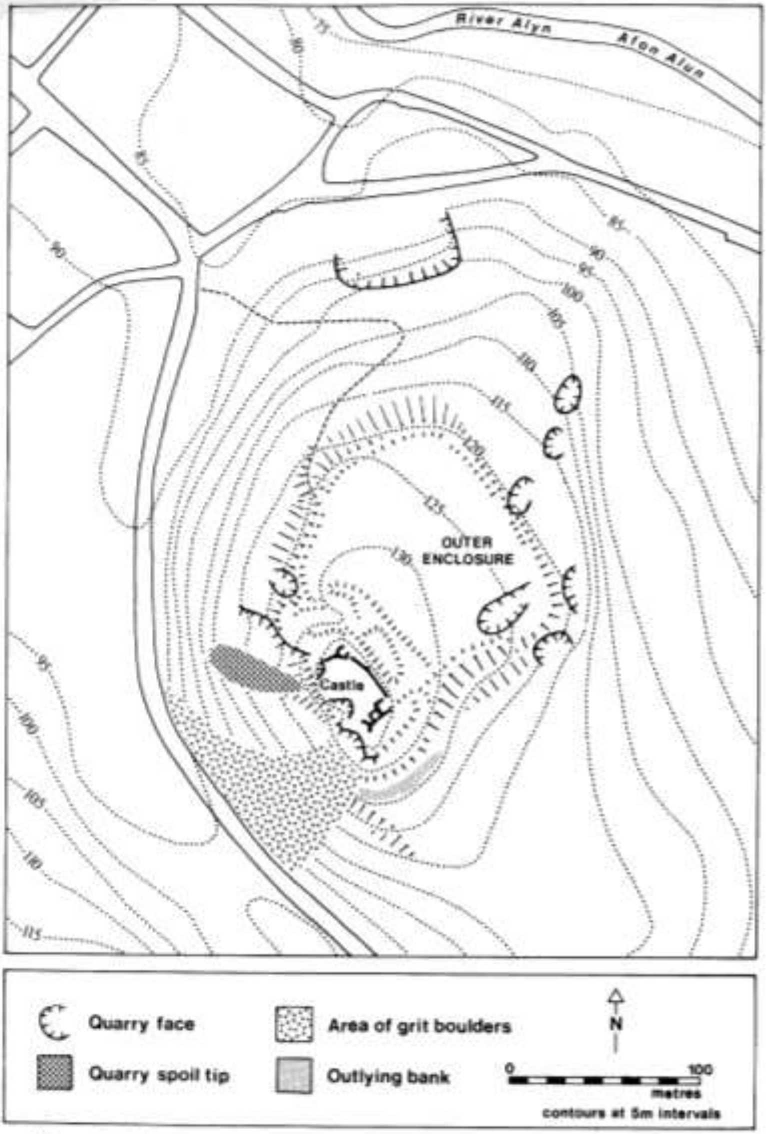


Figure 2. Plan of the castle, outer enclosure, quarries, quarry spoil tip and grit scree. Archaeological data after RCAHM (Wales). Contours after OS 1:10,000 map.

was founded in 1278 by Dafydd ap Gruffudd, who was given a donation of 100 marks for its construction in return for his loyalty to the English crown against his brother, Llywelyn, Prince of Gwynedd. During three building seasons an increasingly frustrated Dafydd must have laboured at Caergwrle until, despairing of ever claiming his rightful inheritance in Gwynedd, he launched an attack against the English, probably from Caergwrle, in spring 1282. Edward determined on a massive and final retaliation against North Wales. Reginald de Grey's forces arrived at a deserted Caergwrle on 16th June 1282 and initiated a period of 19 weeks of repair of the partially dismantled fortification. A synopsis of the English records of their building work during this period has been published by Taylor (1986). The workforce was large and comprised 340 carpenters, 600 diggers and 30 to 35 masons. Details of the layout of the castle itself are brief. Apparently the well, which Dafydd had blocked, was cleared out, and the "old keep" was demolished. We are told of the presence of an "entrance gate", while internal buildings, mainly of timber, included a "chapel", a "chamber for the pay clerks", and "another chamber and a chamber over the gate". The total expenditure by the English amounted to almost exactly £300. In the following year, on the 24th February, the king granted the castle to his queen Eleanor, by whom the building work may have been continued. On the 27th August, however, the castle - or parts of it - caught fire, causing considerable damage. The castle was subsequently conferred on Edward of Caernarfon as Prince of Wales and Earl of Chester. There is no evidence that he repaired it, however, and by 1335 it was in a ruinous condition.

Excavations were carried out by the Clwyd Archaeology Service within the masonry castle, and in limited areas outside the curtain walls, during the period 1988-90. All of the enclosed areas within the curtain walls, and the accumulated deposits inside the north and east towers, were excavated down to either bedrock or the construction levels immediately pre-dating the castle. The principal construction deposits and structural finds are illustrated in Fig. 3. From south to north these included partial remains of the large, circular south tower; a bread-oven; foundations of a rectangular building up against the inner face of the east curtain; three smithing hearths; a well and stone-working areas. Where bedrock was not exposed the area appeared to have been levelled up with a deposit of orange sandy-clay (Context 210), presumably laid by the castle builders in order to create a more even interior. Three small sample excavations were made through this deposit, two respectively against the east curtain and north tower, in order to examine the foundations of the castle.

GEOLOGY

Geological Setting

Caergwrle Castle stands on a hill composed of rocks of the early Namurian Cefn-y-Fedw Sandstone. There are two principal rock types, sandstone and grit.

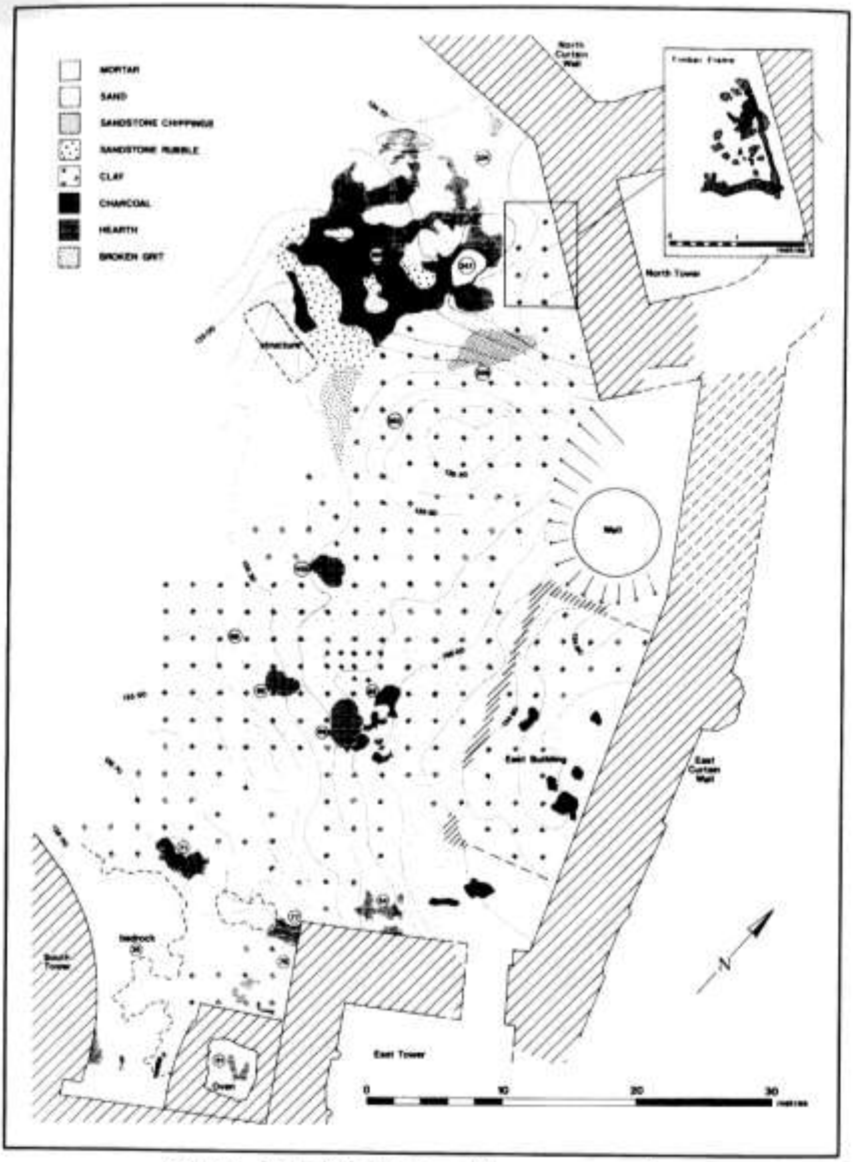


Figure 3. Plan of the interior of the masonry castle, indicating principal structures and deposits.

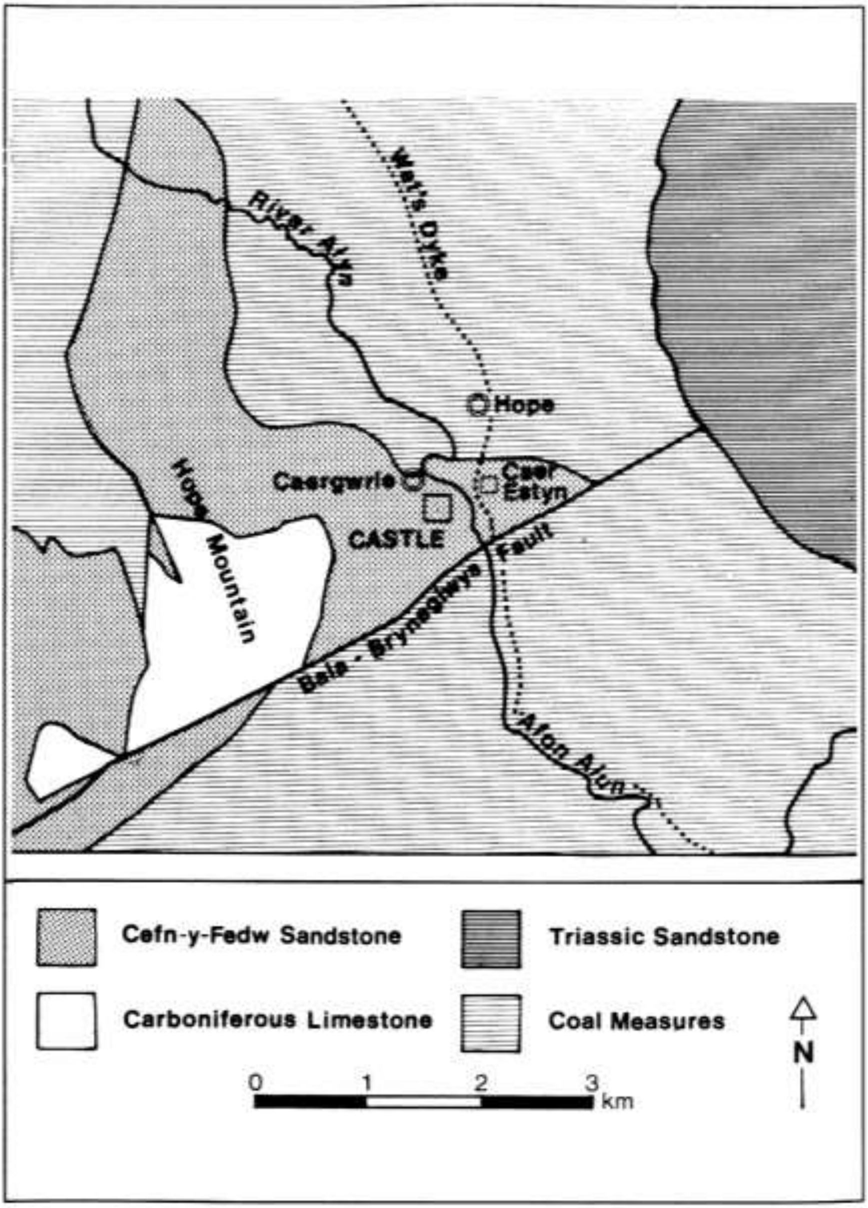


Figure 4. Regional geological setting of Caergwrle Castle.

The Cefn-y-Fedw Sandstone strikes north-south along the east side of Hope Mountain and then swings to strike east-west through the hills of Caergwrle Castle and Caer Estyn (Fig. 4); (Wedd and King 1924). At the castle the beds dip approximately northwards at about 30°. The sandstone is comparatively resistant to erosion and so forms upstanding topography. The lower lying area to the north is composed of the softer, less resistant sediments of the Coal Measures which stratigraphically overlie the Cefn-y-Fedw Sandstone. The south-east edge of Hope Mountain, Caergwrle Castle Hill and Caer Estyn are defined by the Bala-Bryneglwys Fault, on the south-east side of which the Coal Measures reappear.

During the last glaciation this area was the meeting point of ice moving eastwards out of the Welsh highlands and a major ice sheet travelling south across the Cheshire Plain from the Irish Sea. At the height of the glaciation the two ice sheets merged but during the waning stage a meltwater lake existed between the Irish Sea ice sheet and Hope Mountain. According to Peake (1961) the east-west ridge of Hope Mountain blocked the south end of this lake and the overflowing water cut a notch in the ridge. As the glacier retreated eastwards two further cuts were made in the ridge, each one lower and farther east than the last. Caergwrle Castle Hill is the remnant of the ridge between the two later valleys, while the present River Alyn runs through the most easterly cut (Figs. 4,5). More recently Thomas (1985) has suggested that the valleys were cut by subglacial streams at a time when the Hope Mountain - Caer Estyn ridge was still covered by ice. The separation of the Welsh and Irish Sea ice sheets happened between 18,000 and 14,500 years ago (Thomas 1985), so the topography of the area around Caergwrle has probably remained essentially the same for about 15,000 years.

Lithology of the Castle Hill (Fig. 6)

Sandstone is the most abundant of the two main rock types on the hill. In hand specimen it is fine to medium grained, usually pale grey and consists predominantly of quartz grains. Decomposed feldspar grains are a minor constituent, giving the rock a pale yellow colour. Iron staining by percolating ground water has given some outcrops a reddish colour. The rock is quite porous in outcrop.

The grit is a pebbly sandstone with large subrounded pebbles up to 40 mm long in a pale grey sandstone matrix. The pebbles are mostly vein quartz and quartzite with a few volcanic and granitic fragments. The grit also contains flakes of silt and shale which are very soft and are easily eroded out to leave pits in the rock face. A cylindrical hole in the vertical face below the south tower is probably a mould of what was originally a log buried in the gravel. Thin pebbly bands also occur locally in the sandstone.

The rocks dip northwards so that the oldest beds should appear at the

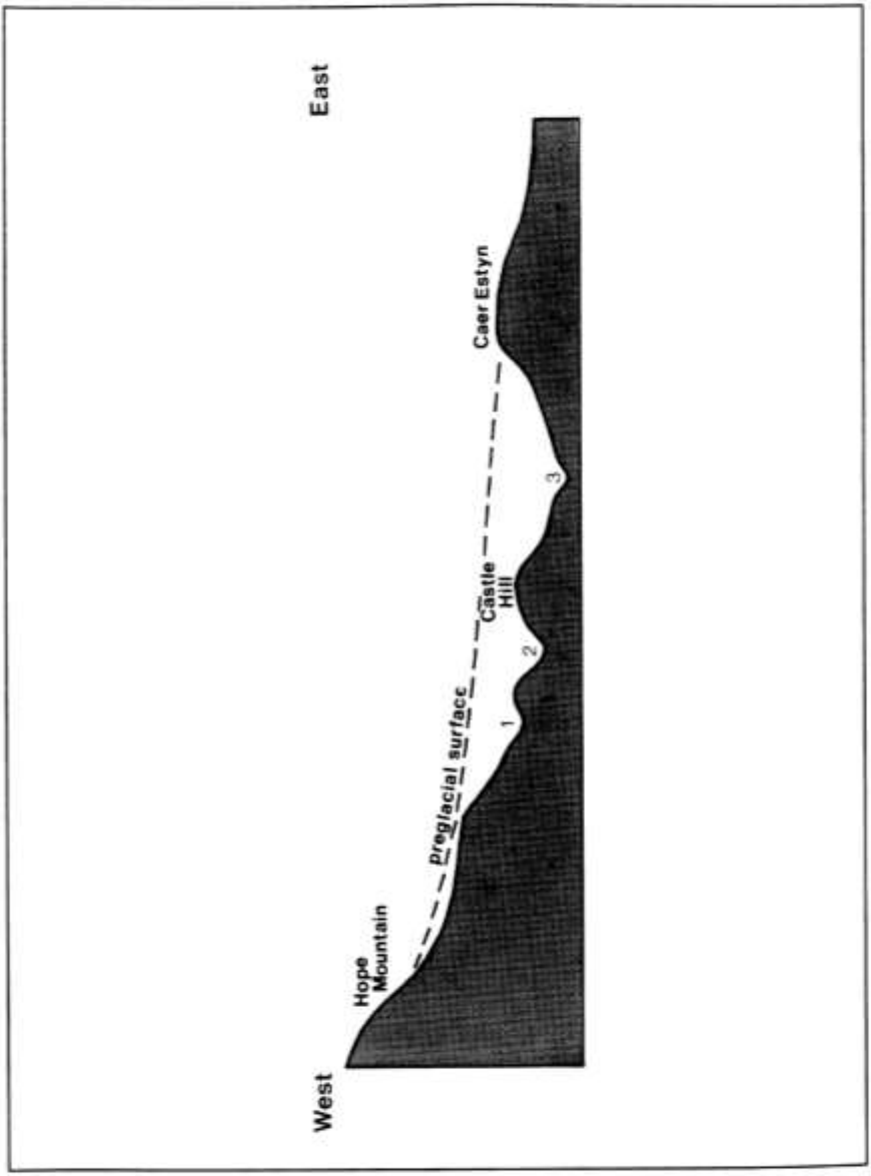


Figure 5. Glacial Meltwater Channels between Hope Mountain and Caer Estyn Ridge. Channels are numbered 1, 2 & 3 in order of formation. After Peake (1961).

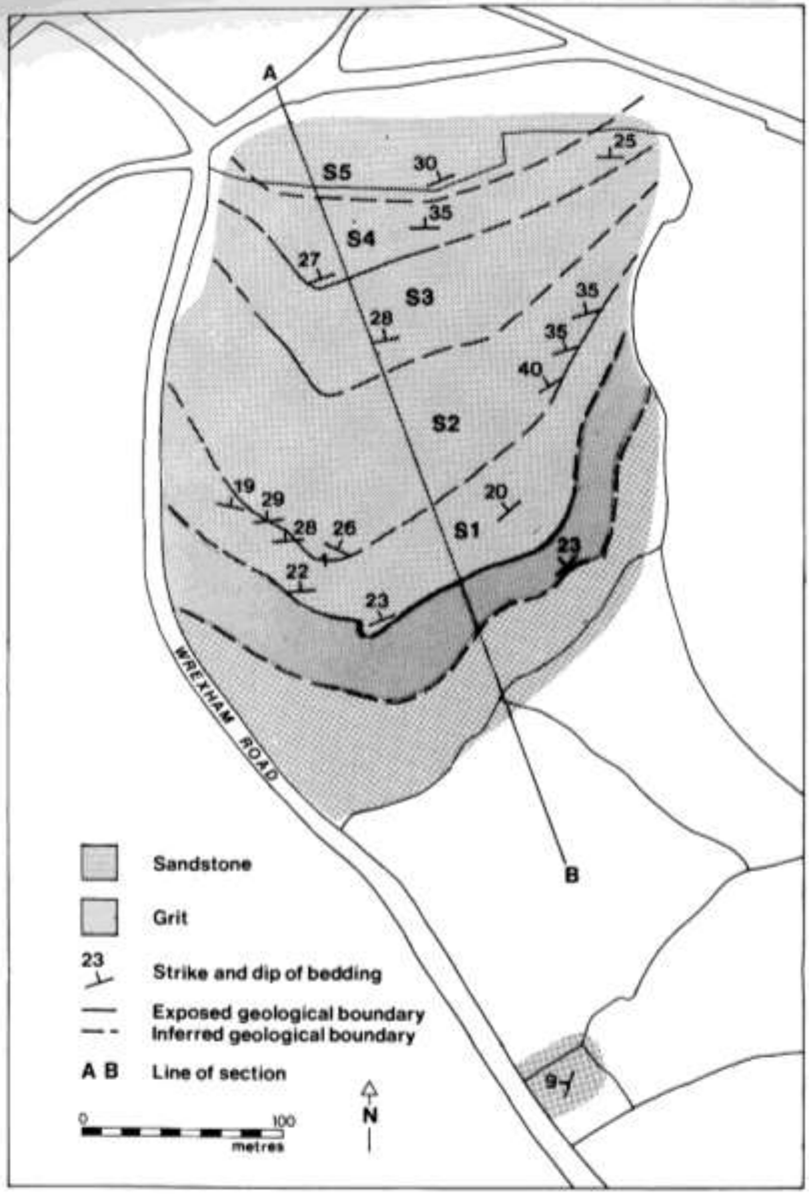


Figure 6. Geological map of Caergwrle Castle Hill

south end of the hill. In fact there are no outcrops below the grit on the hillside at the south tower. This is the highest point of the hill and it was an obvious location to site the castle. About 70 m south-west of the south tower, in the angle between the road and the boundary wall, there is a float of small to medium-grained sandstone and occasional sandy limestone cobbles. At the southern end of the next field there is an old quarry just east of the road exposing flaggy sandstone (Fig. 6). The only other exposure of rock beneath the grit is at the eastern corner of the castle hill where a quarry shows the base of the grit infilling a channel in sandstone. It seems that the beds below the grit are sandstones which are generally less massive and finer grained than those above the grit.

The grit is best exposed at the south tower where it is massive and structureless except for some crossbedding. Large boulders of the grit occur along the south-east face of the hill but there is no definite outcrop until the quarry at the eastern corner. Around the corner from here at the southern end of the north-east face, the top of the grit grades gradually into sandstone. At this corner the grit is about 10 m thick. On the south-west side of the hill there is a scree of large boulders of grit which starts at the south tower and spreads out downhill, particularly to the north-west (Fig. 2). This may be a combination of rocks displaced only slightly from the underlying grit horizon, and rocks tumbled down from the top. A minor grit horizon 1 m thick occurs at the top of the south-west hillside interbedded with the sandstone 2 m above the top of the main grit band.

The sandstone overlying the grit occurs in massive beds up to 2 m thick and also as thinner flaggy beds a few cm thick, the latter showing occasional silty partings. The more massive horizons form positive topographical features and are sometimes picked out by quarrying; five such horizons are shown on the geological map Fig. 6 and the cross-section Fig. 7, labelled S1 - S5. The northern end of the hill descends in a series of steps, the steeper slopes being the dip slopes of three of these massive horizons (Fig. 7).

Twelve rocks from Caergwrle Hill were examined in thin section. These included six representative samples of the Cefn-y-Fedw Sandstone comprising the hill, four possibly exotic specimens associated with the castle itself and two pebbles out of the soils. Descriptions of the sections are given in Appendix 1 and their original locations shown on Fig, 8.

The sandstones making up the bulk of the hill are porous, moderately to well sorted, fine to medium-grained rocks. They consist mainly of subangular-subrounded quartz grains with a subordinate amount of quartzite grains and fine grained intraclasts. Traces of leucoxene, tourmaline and zircon are usually present. There is little or no feldspar, a characteristic of the Cefn-y-Fedw Sandstone in general which distinguishes it from sandstone horizons in the Coal

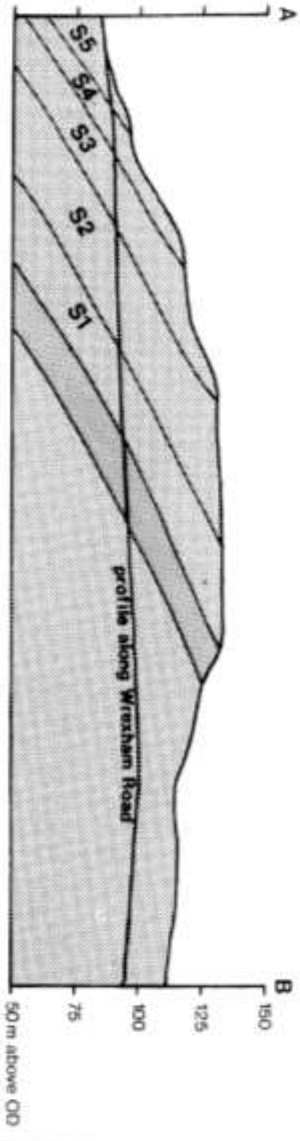


Figure 7. Geological cross-section through Caergwrle Castle Hill.
The location of the section is shown in Fig. 6 and the key is as for Fig. 6.

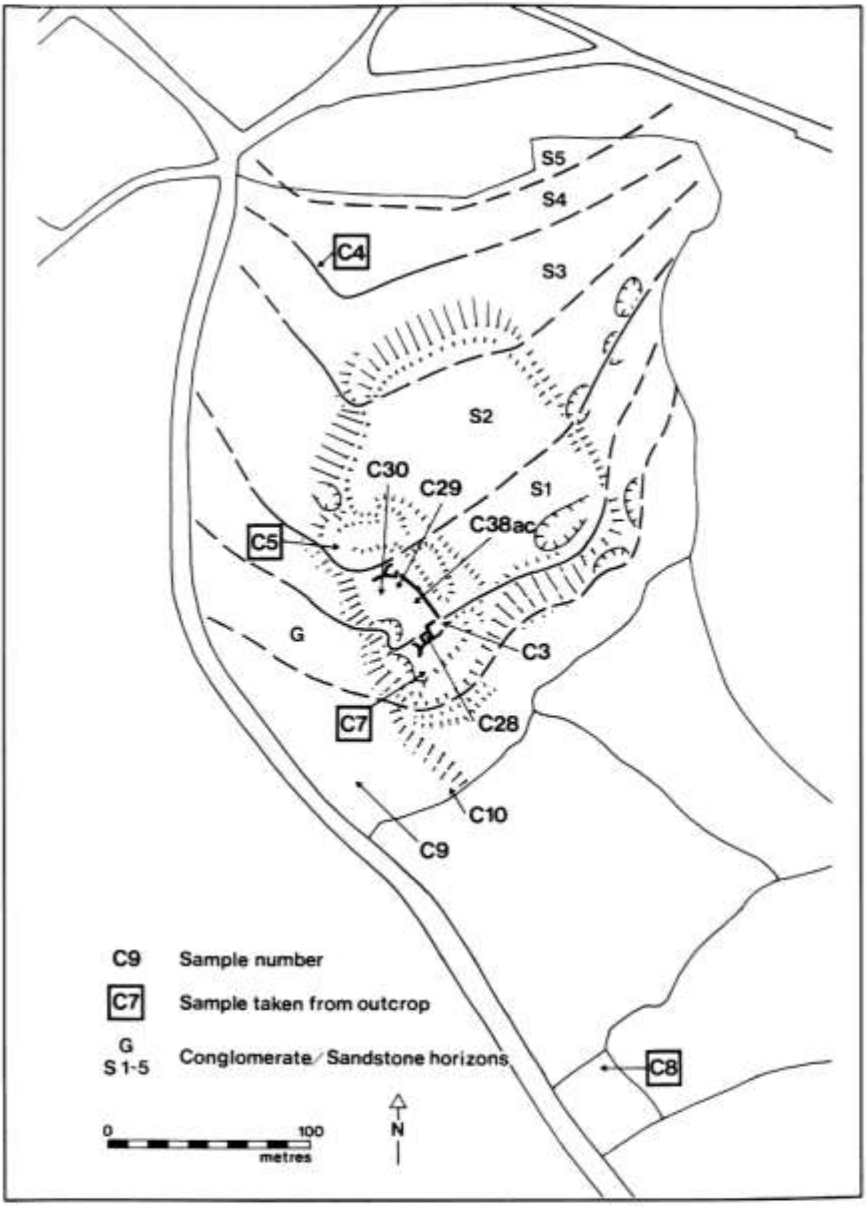


Figure 8. Locations of rock samples examined petrographically (see Appendix 1).

Measures (Campbell & Hains 1988). Well developed quartz overgrowths cement the rock together and there are occasional patches of interstitial ferruginous material. The samples all have a good porosity of 15-30%. The section of grit examined has monocrystalline and polycrystalline quartz and minor chert pebbles in a matrix which is the same as the sandstone.

Structure of the Castle Hill

The rock outcrops are cut by joints which are particularly well displayed at the south tower. The joints tend to be more prominent and more widely spaced in the grit than in the sandstone. The orientations of 42 joints were measured at the south tower and these are shown as a rose diagram in Fig. 9. The principal orientation is NNW-SSE and it is along the line of weakness due to this set of joints that the glacial meltwater carved the valley west of the castle. A less prominent joint direction is ENE-WSW which is parallel to the Bala-Bryneglwys Fault. These two directions of weakness account for the lozenge-shaped outline of the hill.

The attitude of the bedding at outcrops was measured with a compass-clinometer. A total of 49 measurements was made. These data are shown as a stereogram in Fig. 10. Several measurements were made at any one exposure and the data shown on Fig. 6 are means of 2, 3 or 4 measurements. The beds generally strike east-west and dip northwards at 30° but there is a tendency for the strike to vary from WNW-ESE in the west to NE-SW in the east. The dips at outcrops on the hill become gentler southwards and this trend is continued by the flaggy sandstone in the quarry 200 m south of the castle which has a low dip of only 10°.

BUILDING STONE

Uses of building stone

A visual inspection of the stone faces of the curtain walls, towers and internal features of the castle suggests that different styles of walling masonry were utilised at various points. All together six 'styles' were identified and these are described in Table 1, along with their principal locations on the monument, and illustrated in Figure 11.

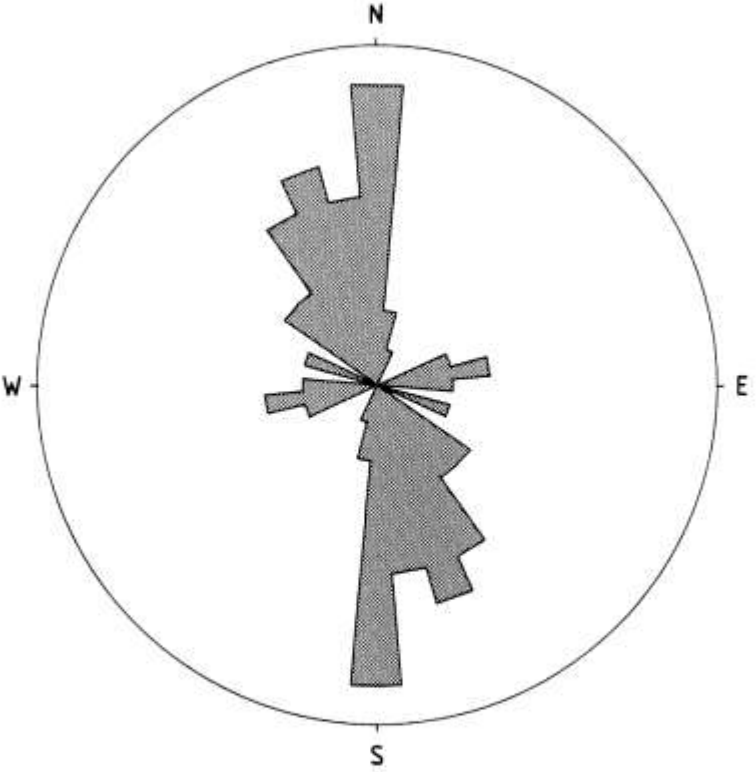


Figure 9. ORIENTATIONS OF JOINTS.
Rose diagram of the azimuths of 42 joints measured at the South Tower.
The combination of the principal NNW - SSE and secondary ENE - WSW directions is responsible for the lozenge shaped outline of the castle hill.

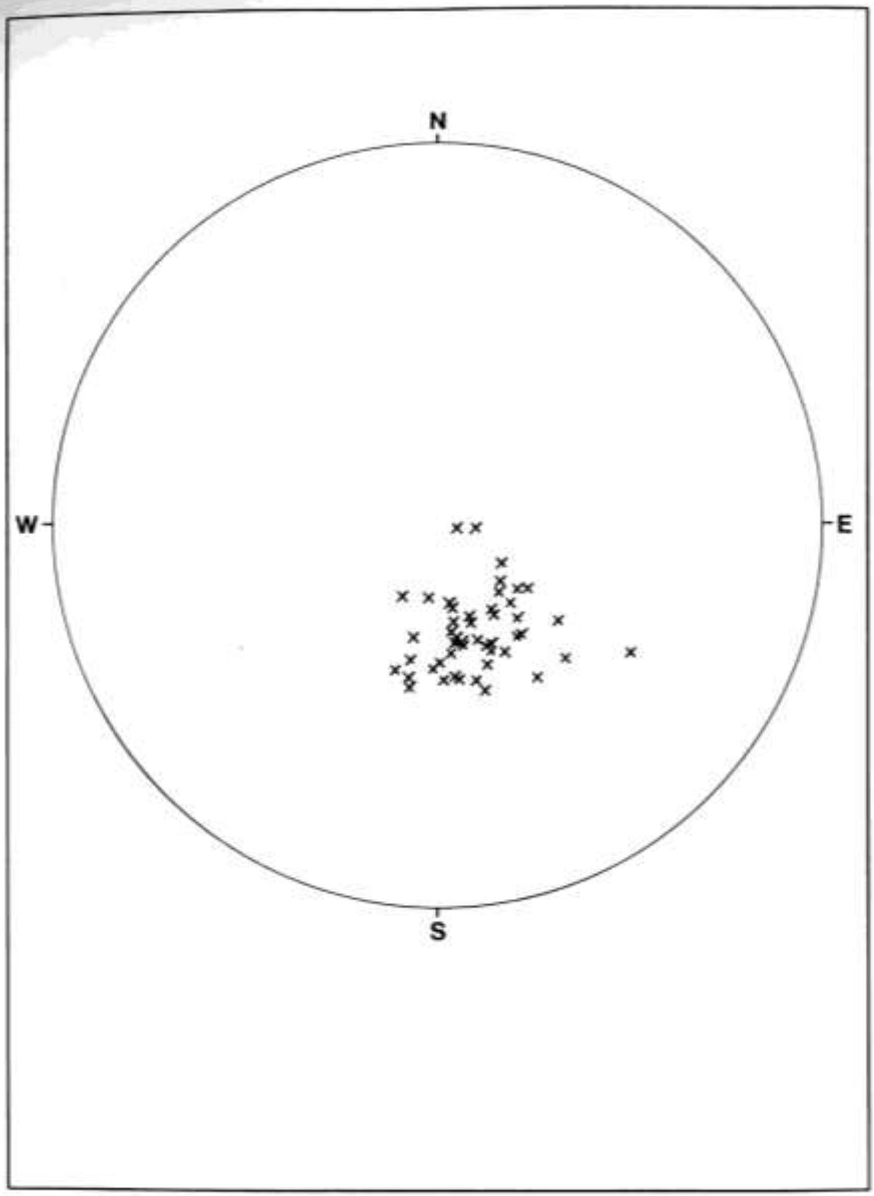


Figure 10. The attitudes of bedding planes. Stereogram of poles to bedding planes for 49 measurements on Caergwrle Castle Hill.

TABLE 1: Descriptions of the six masonry styles at Caergwrle Castle and their principal locations.

Masonry Style	Description	Principal Location
Large Regular Rock (LRB)	Finely dressed, rectangular sandstone blocks of standard heights. When laid in horizontal courses there is no need for the insertion of flags to achieve a level platform for the next course. The blocks, on average, measure 0.4 m wide by 0.25 - 0.3 m high.	East Tower North Tower
Large Block & Flag (LBF)	A mixture of large, rectangular blocks and smaller, thinner flags, both of sandstone. The flags are used as levellers. The average block size is 0.5 m wide by 0.35 m high; the average flag size is 0.09 m to 0.55 m in length, 0.05 m to 0.08 m in thickness, but prone to shattering.	South Tower (south face) North Tower Oven
Small Rectangular Block (SRB)	Almost entirely composed of small to medium sized rectangular blocks of sandstone, with very few flags. The average larger block measures 0.35 m wide by 0.25 m high, while the smaller is on average 0.25 m wide by 0.10 m high.	East Curtain (external) South Curtain (external)
Small Block & Flag (SBF)	A mixture of small sandstone blocks and flags. The general appearance is irregular but the masonry is well coursed. The flags are used singly, both to	East Curtain (internal) South Curtain (internal) North Curtain (both faces)

	level up, and superimposed in two's and three's, perhaps indicating a shortage of blocks. The average block size is 0.35 m wide by 0.15 to 0.30 m high; the flags are 0.15 to 0.25 m wide and 0.03 to 0.08 m high.	
Flags (F)	Occurs on a discrete section of the internal face of the east curtain comprised of 80% sandstone flags. Average size of flags is 0.20 - 0.25 m wide by 0.6 m high.	East Curtain (internal)
Grit Block & Flag (GBF)	Surviving two/three courses of 90% grit and 10% sandstone blocks. The average block size is 0.35 m wide by 0.25 m high. Sandstone flags and small rectangular stones are used between the blocks. The average flag size is 0.20 m wide by 0.06 m high.	South Tower (north face)

Clearly individual walls could be built in a single style or in more than one style. In the latter case changes in the masonry style can occur either vertically or horizontally. Table 2, below, gives some indication of vertical and horizontal relationships in walls which incorporate more than one style.

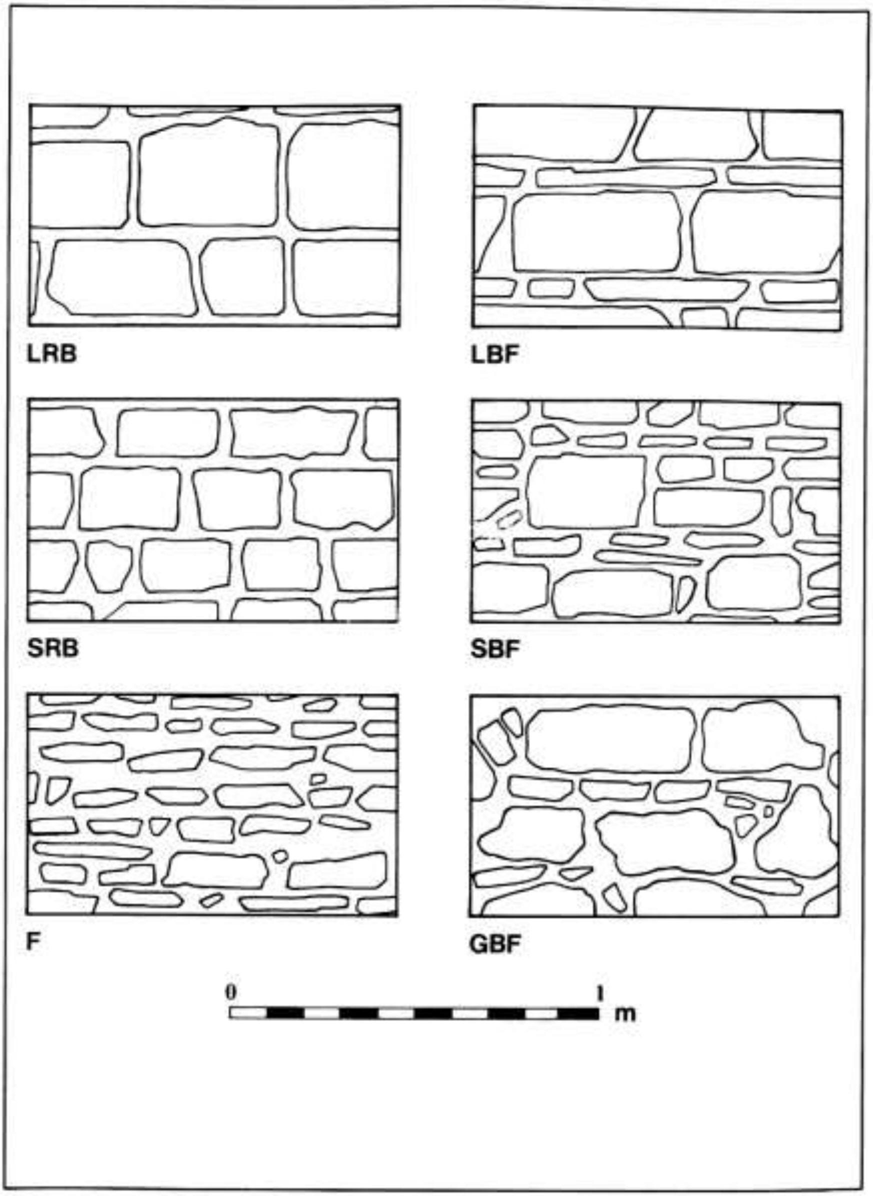


Figure 11. The six principal 'styles' of masonry at Caergwrle Castle; see Table 1 for definitions.

TABLE 2: The vertical and horizontal relationships of the six masonry styles at Caergwrle Castle.

Vertical Relationships

North Tower (external) North Tower (internal)	Small Regular Block occurs above Large Block & Flag.
East Curtain (internal)	Small Block & Flag occurs above and by the side of Flags.
East Tower (internal)	Small Block & Flag occurs above Large Regular Block.
South Curtain (external)	Small Regular Block occurs above and by the side of Small Block & Flag.

Horizontal Relationships

North Tower (external) North Curtain (external) South Curtain (external)	Small Block & Flag was built next to Small Regular Block.
East Curtain (internal)	Small Block & Flag was built next to Flags.

Preliminary analysis of the six styles indicates that they appear to represent differing degrees of sophistication of masonry, and, by implication, varying levels of cost and skill in their construction. In Table 1 the styles are listed in order of decreasing quality, from the finely dressed consistently large rectangular stones that make up LRB to the rough hewn blocks of grit that comprise GBF. The latter style was used exclusively on the north foundation courses of the south tower. The south tower was probably one of the first constructions on the site by Dafydd in 1278, since it commanded the highest point of the hill and was intended to be the keep. It was constructed on a grit outcrop and perhaps the builders experimented with the immediately available local stone. The grit, however, is coarse-grained and hard, and very difficult to work into a useful shape compared with sandstone. Certainly the southern face of the south tower was constructed in LBF, a much more impressive style. This probably implies that the masons had given up the experiment of trying to build with the grit, as a major component, and that they utilized a sophisticated style of masonry on outside faces of the castle to impress visitors.

The formula behind the spatial distribution of the masonry styles, therefore, can be accounted for by two synchronic factors: (a) the need to have the most prestigious masonry in the towers where the principal living accommodation was and (b) the requirement to have better masonry on the external faces of curtain walls. Internal walls were, of course, likely to be plastered, obscuring the masonry. However, good quality blocks would make plastering easier, and more even. It seems plausible that different groups of masons were skilled in particular masonry styles, rather than masters of all the styles. The £300 that was spent by the English at Caergwrle during the 19 weeks period in 1282 seems to have paid for a large number of carpenters and diggers, and relatively few masons. The implication is that most of the surviving masonry at Caergwrle was built following the directions of Dafydd between 1278 and 1281. The English presumably anticipated further building seasons and no doubt additional masonry (Taylor 1986, 38), although there is no indication that such plans were ever implemented.

Source of the building stone

The sandstone and grit used in the castle are clearly the same stones as are seen outcropping on the hill. The grit used in the south tower was taken from the grit horizon on which it stands. On the other hand the sandstone could have been quarried from almost anywhere on the hill.

The locations of quarries on the castle hill are shown in Fig. 2. The largest is at the northern end of the hill by Castle Street but this is a long way from the castle and is presumably relatively modern. Another large quarry lies just north-west of the castle. Here a line of south-west facing rock outcrops begins right by the castle and runs north-westwards down the hillside. The south-west side of the quarry is marked by a ridge, presumably composed of spoil (Fig. 2). The stone in this quarry looks a suitable match for the castle and this was probably the principal source of building stone. A cluster of small quarries at the eastern end of the hill might be relevant to the castle, but are more likely to relate to more recent building activity in Caergwrle village.

A few samples were taken from possibly non-local rocks at the castle for thin section examination (Fig. 2). One specimen (C29 - Appendix 1) from a large boulder (Fig. 3; Context 347) in the castle interior close to the north tower exactly matches the sandstones of the castle hill. It has probably moved only a short distance from its original outcrop position.

One section (C30 - Appendix 1) was examined from a large number of small, flattish slabs found in a pile (Fig. 3; Context [328]) in the northern half of the castle interior. This is also a sandstone like the rocks forming the hill. These stones may represent the detritus from final shaping of dressed stones before their incorporation in the walls. The stones were coated with a grey clay which is quite distinct from the usual red brown clays at the castle. This clay is probably derived from the thin clay layers interbedded with the Cefn-y-Fedw Sandstone and is not related to the glacial deposits.

A sample (C26 - Appendix 1) was taken from the interior of the oven to represent the small number of red sandstone blocks used in the castle. A similar specimen (C3 - Appendix 1) was also taken from the dump of loose stones (excavation spoil - derived from southern half of the castle) by the east tower. These two red sandstones resemble the usual pale coloured sandstone in being quartz rich and having substantial quartz overgrowths. The red colour is associated with small haematite grains enclosed within the quartz overgrowths along the original grain boundaries. These red sandstones are, therefore, just a variant of the usual rock type forming the hill and probably did not come from elsewhere.

The only stone found in the fabric of the castle which is definitely not derived from the Cefn-y-Fedw Sandstone is to be seen in the collapsed wall close to the path. It is a round green block about 100 mm long, perhaps a tuff from the Lake District, and has possible striations on its surface. It probably came out of the boulder clay.

SOILS AND CONSTRUCTION

Undisturbed and redeposited boulder clay

During the glaciation the castle hill was buried by the Irish Sea ice sheet. The hill protruded into the ice so that it would have been scoured clean, but boulder clay could have been deposited in relatively sheltered areas between the ridges of massive sandstone and grit. Boulder clay has been found in such a situation in the middle of the castle. Overlying it, with a buried soil horizon intervening, is a gritty red clay. This clay underlay the fallen masonry but incorporated pieces of slag, suggesting that it was laid down during the construction of the castle. These two distinct clay horizons are found throughout a large part of the interior of the castle and towers, and it is supposed that the lower horizon is undisturbed boulder clay whereas the upper horizon is boulder clay which was deliberately spread over the site to give it a more level surface. These two clay deposits were recorded in small sample excavations dug against the inside faces of the east and north curtain walls and from the centre of the site (Fig. 12).

To test this idea eight soil samples were investigated by particle size analysis, chemical analysis and microscopic examination of the coarsest fraction. The samples were collected mostly from the three small excavations and were chosen to represent both the presumed undisturbed boulder clay and the reworked material. Fig. 12 shows the sampling locations.

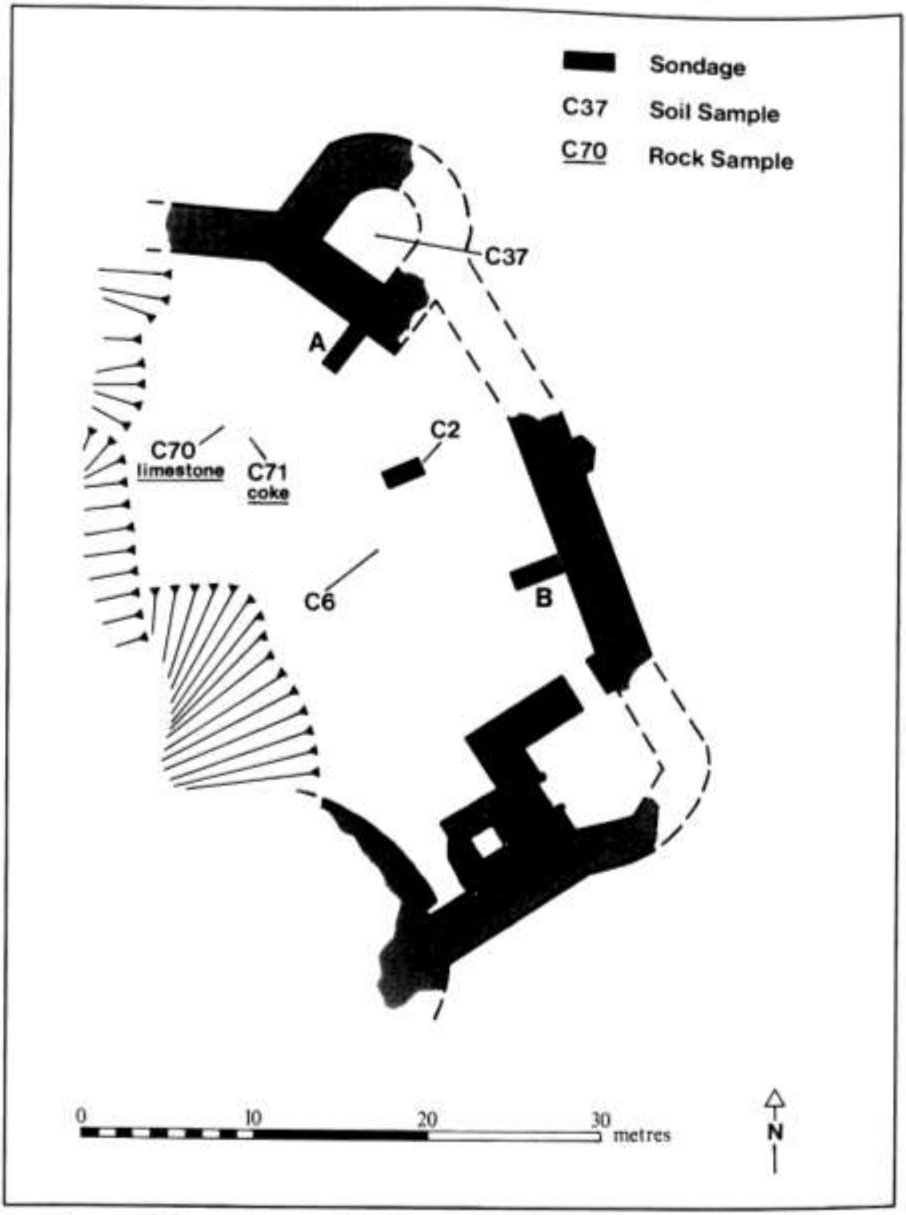


Figure 12. Locations of soil and stone samples within the castle, and the positions of the two sample excavations against the east and north Curtain Walls, and a third sondage in the interior.

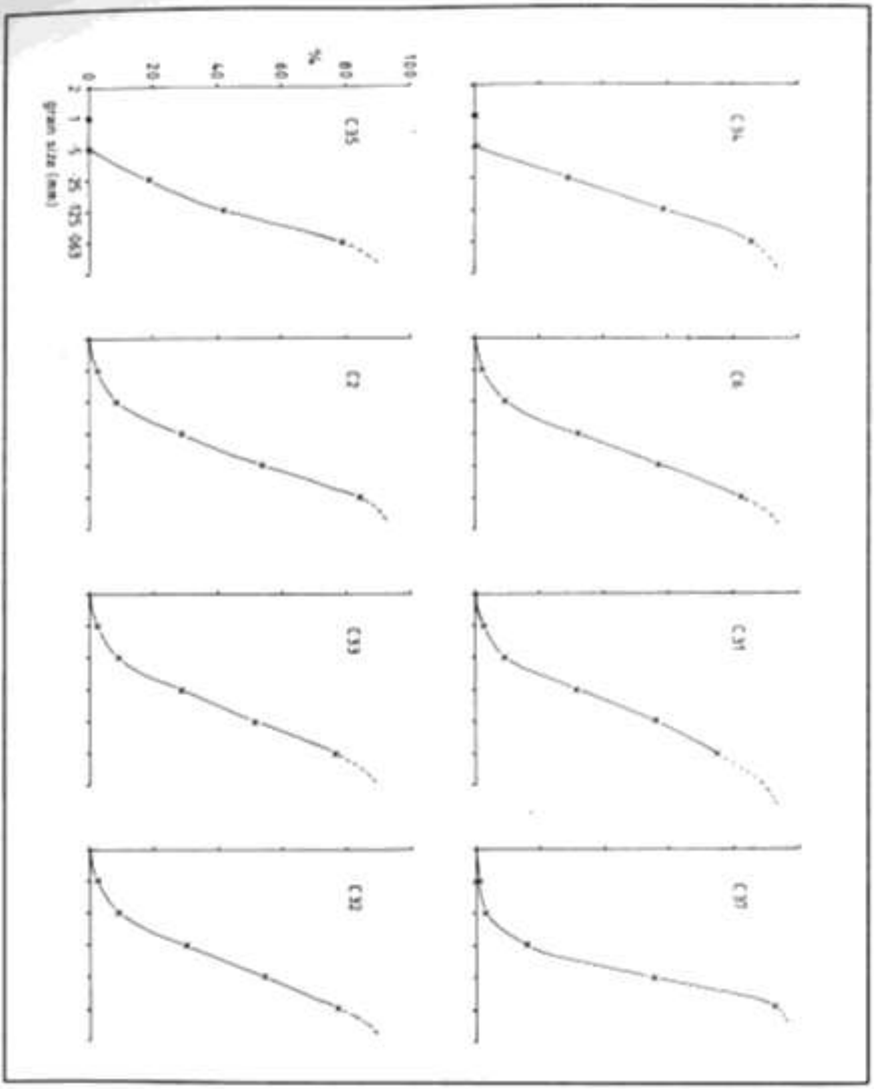


Figure 13. GRAIN SIZE DISTRIBUTION IN SOIL SAMPLES.
The vertical scale is the weight percentage of the soil sample which is coarser than the grain diameter on the horizontal scale. Material larger than 2mm is excluded and the fraction smaller than 0.063 is not subdivided. All samples have similar plots and show a broad range of grain sizes characteristic of boulder clay.

All the samples were dried at 120°C, lightly mortared and then dry sieved. The grains larger than 2 mm were separated and then from the residue each size fraction was weighed and its weight percentage calculated. The results are shown as cumulative frequency curves in Fig. 13. This Figure is laid out so that the first three columns have reworked soils (C34, C6 and C31) on the top row, and the supposed natural boulder clays (C35, C2 and C33) underlying them on the bottom row. The fourth column shows a sandy soil (similar to Context 210) from within the north tower (C37) and a presumed old soil profile (C32) overlying the boulder clay.

The most obvious feature of Fig. 13 is the similarity of all the samples, suggesting that they are all basically the same thing. They show a broad spread of grain sizes, a feature which is characteristic of boulder clay (Easterbrook 1982).

Semi-quantitative chemical analyses were carried out on all eight samples for pH, P, Mg, K and NO_3 using a soil nutrient analysis kit which detects the readily leached components. The results are shown in Appendix 2 which is laid out in the same way as Fig. 13. The most significant feature of this data is again the broad similarity between the samples. The pH is very consistent at the slightly alkaline figure of 7.2 - 7.5 which compares well with the mean pH for boulder clay locally of 7.6 (Campbell & Hains 1988) although C2 is distinctly acid at 5.9. Phosphorus shows some variation between 5 and 60 ppm (parts per million) but there is no consistent difference between the natural and reworked materials. Magnesium shows figures typical of ordinary soils but Potassium and Nitrate are comparatively low, Nitrate actually being unmeasurable by this method. These low figures for soil nutrients are again what we would expect of boulder clay.

In contrast with the broad similarity between all eight samples for the fraction smaller than 2 mm diameter, there are considerable differences in the proportion of each sample represented by grains larger than this size (Fig. 14). The higher layer consistently has more of this coarse material, which accounts for it having a more sandy texture in hand specimen. The difference between the two layers is probably because human and natural erosion breaks sandstone fragments off the bare rock outcrops and these then become incorporated in the reworked soils. The clearest example of this effect is shown by the sequence of samples C31, C32 and C33. They are all from the same section against the East Wall, C33 being the boulder clay, C32 the soil developed at its surface and C31 the overlying reworked material. C32 and C33 are nearly identical whereas C31 is similar but with much more of the fraction larger than 2 mm.

The fraction of each soil sample coarser than 2mm was examined under a binocular microscope and separated into eight different rock types which were weighed separately. The results are shown as pie charts in Fig. 14. The area of each chart is proportional to the weight percentage of the whole sample represented by the fraction coarser than 2mm. The data are laid out in the same manner as Fig. 13. The eight classes of rock fragment are:

A: Subangular to rounded fragments of porous sandstone.

B: Subangular to rounded hard iron cemented fine to medium grained sandstone.

C: Subangular quartzite and chert.

D: Fine grained micaceous sandstone.

E: Fine grained volcanic rocks.

F: Quartz grains, most milky, some showing overgrowths.

G: Buff to gey siltstone.

H: Coarse grained igneous rock fragments.

The most significant feature of Fig. 14 as of Fig. 13 is the broad similarity of all the samples. The same particle types appear in roughly similar proportions in all the soils.

Type A is probably mostly derived from the castle hill sandstones while a large proportion of B and F are also local. The content of type A is considerably higher in the reworked soils than in the natural boulder clay. This is because quartz grains and small sandstone fragments eroded from the rock outcrops would have become incorporated in the redistributed clay. E and H must have come from far away, again showing that the soils are redistributed or undisturbed boulder clay.

The undisturbed boulder clay contains small black particles up to a few cm in diameter. A sample (Fig. 12; C.36) of these was examined under a microscope and they are clearly coal, the glossy vitrain layers being particularly diagnostic. The ice would have picked up these coal fragments as it flowed southwards towards Caergwrle across the Coal Measures outcrop. It is noteworthy that similar looking coal fragments occur in the glacial gravels at Borras 8 km to the south-east, some of them up to 50 cm in diameter.

Finally two stones (Fig. 12; C38a & C) were examined in thin section from the presumed boulder clay in a trench by the east Curtain Wall. These are both

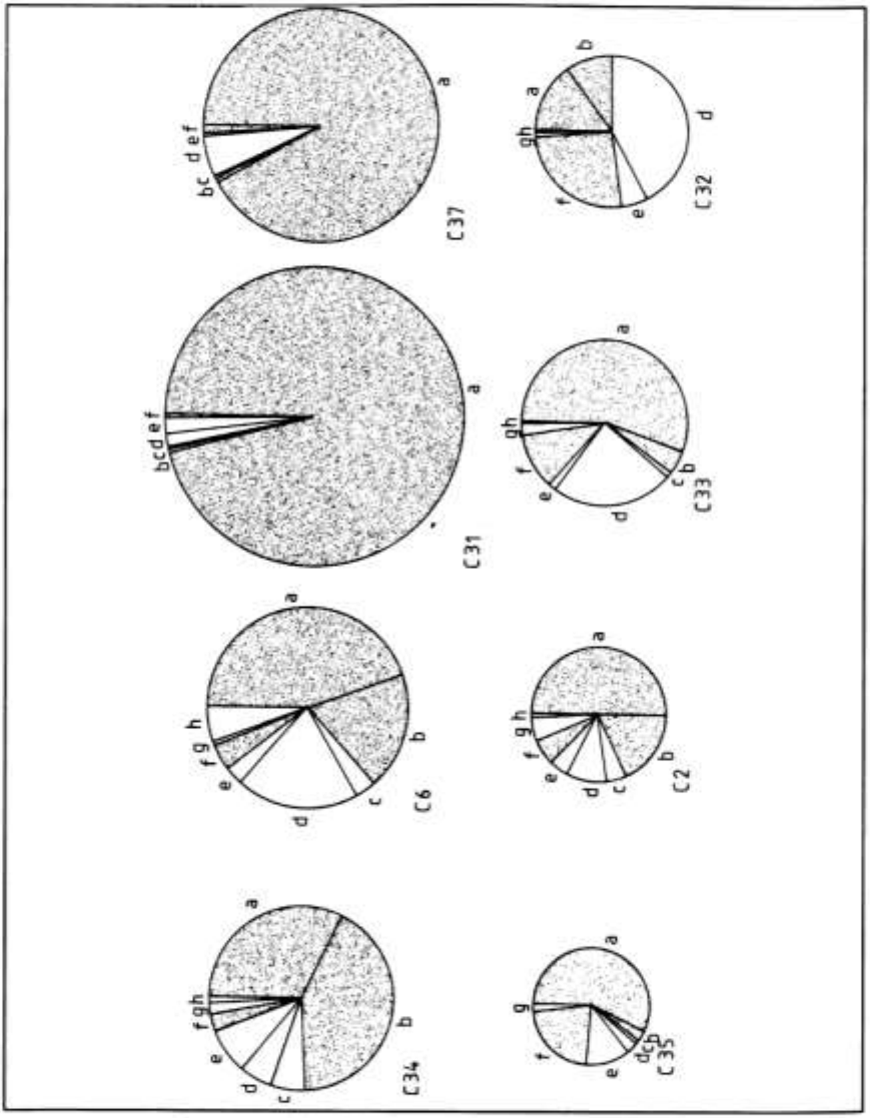


Figure 14. COARSE PARTICLE TYPES IN SOILS.
The area of each pie diagram is proportional to the weight percent of each soil sample which consists of particles coarser than 2mm. See text for explanation of particle types. The reworked soils (top row) contain a greater amount of locally derived particle types (shaded) than the in-situ boulder clay (bottom row).

very fine grained rocks, one a phyllite and the other composed of opaque hydrated iron oxide.

We may conclude from this analysis of the soils that the presumed undisturbed boulder clay is just that, and that the deposits overlying the old ground surface are redistributed boulder clay with the addition of a small amount of coarse locally derived material.

THE WEST CURTAIN WALL

A major problem in understanding Caergwrle Castle is the absence of a western curtain wall and of part of the south tower. It might be argued that there never was a western wall, but undoubtedly a large part of the south tower has disappeared. If the circular trace of the tower is extrapolated, half or more of its circumference would be beyond the edge of the crag on which it stands. Part of this crag must have disappeared, either by erosion or by being quarried away by man.

Only limited erosion has taken place on the western side of the hill, but there is considerable evidence for quarrying activity on the western side of the castle. The vertical faces under the south tower are natural joints which can be seen continuing into the rock at the corners, but quarrymen would undoubtedly have used these to prise the rock apart. The ground surface below the two main faces making an embayment in the crag is near horizontal, as through it were a working floor. There are at least two near-complete millstones on the western hillside, one close to the south tower, so quarrying for millstone production has undoubtedly occurred. This quarrying of the grit is probably partly responsible for the grit boulder scree on the western slopes of the hill (Fig. 2).

Clearance of the north-west corner of the interior of the castle during 1989 revealed a quarry in the sandstone. The back wall of this quarry truncates the west end of the north curtain wall. This end of the wall and any tower that may have stood at the north-west corner have therefore been removed by quarrying activity. A trench at the western end of this quarry exposed two horizons of boulders. The lower one has blocks up to 50 cm across with remnants of mortar while the upper layer has blocks up to 20 cm across with no mortar. The lower horizon (Context 279) may be associated with an early phase of destruction of the castle while the upper horizon (Context 277) could have formed during the digging of the quarry.

Immediately north of the south tower, in the centre of the castle, a quarry has been excavated in the sandstone immediately above the grit. If cutting stone out of the ground at the castle was worthwhile, then removing the ready dressed stone in the walls would have been an even more attractive proposition. The western side of the castle would be a more favourable prospect for robbing stone than elsewhere because of the ease of rolling the stones down the steep slope to the road. It seems entirely plausible, therefore, that the major part of the south tower and the entire length of a putative west curtain wall, could have been destroyed by quarrying in the post-castle period.

WATER SUPPLY

The sandstones forming the hill have a good porosity. They are, therefore, capable of storing large quantities of water. Porous sandstones with quartz overgrowths are also very permeable. We can, therefore, expect a plentiful supply of water to a well which intersected the water table. However, the castle is situated at the crest of the hill and there is a particularly steep slope on the western side. The water table may, therefore, be a long way below the surface, particularly in summer.

The well at Caergwrle Castle is situated in the best possible position within the walls. It is as far as it can be from the steep westerly slope and it is in a low topographical position between the grit ridge on which the south and east towers stand and the sandstone ridge carrying the north tower. It is also probably very deep since we are told that it took two months to clear out the well after the Welsh had filled it in (Taylor 1986).

MORTAR PRODUCTION

At the end of the 1989 season a layer of stones covered part of the northern interior of the castle. The stones are mostly the local sandstone but there are also pieces of limestone, a lump of coal and some small pieces of a black glassy vesicular material which is probably coke. At the southern end of this layer of stones, pieces of the conglomerate predominate. The abundance of fragments of mortar (Context 323) in this area shows that it was mixed here; lime may also have been produced by burning limestone with coal. The coarse grained friable grit would have been ground up to provide aggregate for the mortar. The nearest source of limestone is Hope Mountain, only a kilometre or two to the west (Fig. 4). The coal may have come from the Flintshire coalfield to the north or the Denbighshire coalfield to the south.

CONCLUSIONS

The castle was built from the sandstone and grit on which it stands. The principal quarry site is on the west facing hillside north-west of the castle. Six distinct styles of stonework, (possibly indicating six different work gangs), suggest selective uses of masonry styles at particular points in the castle. Coal and limestone may have been imported to make mortar. Redeposited boulder clay was used to level the area within the walls, since a depression existed between the grit outcrop under the south tower and the sandstone outcrop underneath the north tower. The well would have given a plentiful supply of water but would need to have been deep. Almost all the stonework on the western side of the castle was subsequently robbed.

Acknowledgements

The authors would like to thank Hope Community Council, the owners of the castle, for permission to examine the monument, and Cadw for allowing the archaeological excavations. Clwyd County Council and Alyn and Deeside District Council kindly funded the excavations. All of the drawings were undertaken by Tim Morgan, apart from Figs. 9, 13 and 14 which are the work of William Jones. John E. Dixon and John R. Kenyon kindly read an early draft of the report.

Bibliography

Campbell, S. D. G. and Hains B. A. 1988. Deeside (North Wales) thematic geological mapping. British Geological Survey Technical Report WA/88/2.

Easterbrook, D. J. 1982. 'Glacial Sediments'. In 'Sandstone Depositional Environments'. American Association of Petroleum Geologists Memoir 31, 1 - 10.

King, D. J. C. 1974. Two castles in northern Powys: Dinas Brân and Caergwrle. Archaeol. Camb. 123, 113 - 39.

Peake, D. S. 1961. Glacial changes in the Alyn river system and their significance in the glaciology of the North Welsh border. Q.J. Geol. Soc. 117, 335 - 366.

Taylor, A. 1986. The Welsh Castles of Edward 1. Hambledon Press.

Thomas G. S. P. 1985. The Late Devensian glaciation along the border of north-east Wales. Geol. Journal. 20, 319 - 340.

Wedd, C. B. & King, W. B. R. 1924. The geology of the country around Flint, Hawarden and Caergwrle. Geol. Survey England and Wales, Mem. 108.

John Manley, M.A.; M.A. (Econ); M.I.F.A.; Principal Archaeologist, Clwyd Archaeology Service, Clwyd County Council.
William Jones, Ph.D., C.Geol.; Geologist/Geophysicist, Wrexham, Clwyd.

APPENDIX 1

Petrographic descriptions of rock thin sections

C3 Red sandstone from loose rocks below east tower.

Fairly well sorted, fine grained sandstone. Grains subangular-subrounded, diameter 0.1-0.2 mm. Mostly monocrystalline quartz, 3% fine grained intraclasts, one crystal of muscovite. Some quartz overgrowths. Haematite forming grainy rims with an irregular distribution. Porosity 25%

C4 Sandstone from S4 horizon, forming dipping outcrop by path up from War Memorial.

Well sorted, medium grained sandstone. Grains subangular-rounded, diameter 0.2-0.5 mm. Grains mostly monocrystalline quartz, a few quartzite and occasional chert, trace of leucoxene. Substantial quartz overgrowths locking grains together and showing euhedral outlines in pores. Occasional patches of limonite matrix. Porosity 15%.

C5 Pebbly sandstone, S2 horizon, from quarry on western hillside.

Moderately sorted sandstone with subangular-rounded grains, 0.13-7 mm in diameter. Large clasts are subrounded monocrystalline quartz and quartzite. Fine grained clasts are monocrystalline quartz with a few intraclasts and several grains of tourmaline. Quartz overgrowths with euhedral faces in pores. Porosity 20%.

C7 Conglomerate, below south tower.

Large clasts up to 8 mm diameter, rounded monocrystalline quartz and quartzite. One clast of ferruginous chert. Small grains from 0.2 mm diameter, subangular-subrounded, monocrystalline quartz and some quartzite. Minor quartz overgrowths. Traces of haematite in pores. Porosity 20%

C8 Flaggy sandstone from quarry by road, 200 m south of castle.

Fairly well sorted fine to medium grained sandstone. Grains subangular-subrounded, diameter 0.15-0.35 mm. Mostly monocrystalline quartz, some quartzite. Occasional specks of haematite. Traces of leucoxene, tourmaline and zircon. A 2 mm thick horizon with porosity infilled by clay. Porosity 30% including some secondary dissolution porosity.

C9 Loose sandstone cobble on hillside south-west of castle.

Well sorted medium grained sandstone. Subangular-sub rounded grains, diameter 0.2-0.35 mm. Monocrystalline quartz with some quartzite and fine grained intraclasts. Traces of leucoxene and tourmaline. Some good quartz overgrowths. Occasional patches up to 3 mm across of haematite completely occluding pores. Porosity 25%.

C10 Sandy limestone, by wall 70 m south of castle.

30% subangular quartz grains with minor chlorite and feldspar. 70% brownish grey micritic calcite. Section through a shell, possibly a brachiopod infilled with haematite.

C28 Red sandstone from interior of front wall of oven. Context 37.

Fairly well sorted, fine to medium grained sandstone. Subrounded grains, diameter 0.15-0.35 mm, monocrystalline quartz. Traces of leucoxene and tourmaline. Haematite forms small crystals between grains. Substantial quartz overgrowths sometimes enclosing the haematite. Porosity 5%

C29 Sandstone, probably from S1 horizon, from large but loose boulder (Context 343) in castle interior near north tower.

Well sorted, medium grained sandstone. Subangular-subrounded grains, diameter 0.3-0,5 mm. Mostly monocrystalline quartz, some quartzite, traces of tourmaline. Well developed quartz overgrowths. Porosity 20%.

C30 Pebble in very stony archaeological horizon, north end of interior of castle. Context 328.

Moderately sorted, fine grained sandstone. Grains subangular-subrounded. Mostly monocrystalline quartz, some quartzite and fine grained intraclasts. Traces of tourmaline, zircon, leucoxene and feldspar. Occasional ferruginous cement, rare quartz overgrowth. Porosity 20%.

C38a Rounded stone in boulder clay (Context 332), from trench by East Curtain Wall.

Phyllite: fine grained metamorphic rock composed of muscovite, biotite, limonite and quartz.

C38c Angular stone in boulder clay (Context 332), from trench by East Curtain Wall.

Sparse tiny quartz gains in a dark red brown matrix, may be limonite.

APPENDIX 2

Chemical Analyses of Soils

	C34	C6	C31	C37
pH	7.3	7.5	7.2	7.4
P ppm	35	30	12	35
Mg ppm	100	75	75	50
K ppm	50	25	50	50
NO_3 ppm	<15	<15	<15	<15

	C35	C2	C33	C32
pH	7.3	5.9	7.3	7.4
P ppm	12	5	60	15
Mg ppm	50	100	100	100
K ppm	100	50	50	100
NO_3 ppm	<15	<15	<15	<15

Locations of samples shown in Fig. 11.

FOSSIL SPIDERS

Presidential address to the Manchester Geological Association
February 1992

by PAUL SELDEN

"If you wish to live and thrive, let the spider run alive!" as my aged aunt used to say (and probably still does). There are many legends and old wives' tales about spiders. They are creatures which we admire rather than despise, for their exquisite handiwork and general good manners in helping to rid our habitations of pestering flies. One age-old story is told by the Navajo Indians of the south-western USA, who are accomplished weavers. In Canyon de Chelly is a tall, inaccessible pinnacle of dune-bedded Permian de Chelly Sandstone called Spider Rock. The story goes that a young girl disappeared one day, and when she reappeared had learned the art of weaving which she taught to the rest of the tribe. The squaw had been captured by the Spider Woman who lives on the top of the pinnacle. To this day, genuine Navajo weavings have a hole in the pattern - the spider's lair - in recognition of the origin of their craft.

Myths abound too, where spiders are concerned. It is true that the male spider must approach the female with care in order not to be mistaken for prey, and often a morsel of food is proffered to occupy her while mating occurs. If a swift exit is not made afterwards, the female may attack the lingering male, but by now his job is done, and it makes ecological and evolutionary sense to recycle biomass within the species! The so-called bird-eating spiders do not really eat birds, although some large tree-dwelling species have been recorded taking baby hummingbirds!

Even our common or garden spiders can reveal some astounding facts and figures. W. S. Bristowe, author of the excellent book *The World of Spiders* (Collins New Naturalist, now sadly out of print), estimated that the British spider population consumes insects equivalent to the weight of the entire human population of these islands each year. A single acre of summer meadow in the south of England may provide homes for $2^1/_4$ million spiders, and the typical house probably has 2,000!

All spiders are carnivorous, some are catholic in their diet, while others are specialized. A handsome British spider is *Dysdera*, which has huge jaws (chelicerae) with long fangs for getting between the body segments of woodlice, its main food source. All spiders have a pair of chelicerae at the front of the body, followed by a pair of palps (modified in the male for sperm transfer), and then four pairs of legs. Spiders have two parts to the body: the front part which bears the appendages is called the prosoma, and the rear part which bears spinnerets at its end is the abdomen. Poisonous fangs and silk-producing spinnerets are unique features of spiders.

Not all spiders weave webs, however. Silk is used in many different ways. The wandering wolf spiders capture prey by running after it; they use silk principally to wrap their eggs, and females can be seen carrying the sacs attached to their abdomens on warm June days. Female spiders appear to show maternal instincts: the wolf spider mother continues to carry her young on her back even when hatched; and many stay with their eggs and young, warding off predators until they leave the nest. Crab spiders catch insects by waiting motionless for one to alight on a flower head or leaf, when they grab the hapless creature with outstretched forelegs. Their similarity to crabs lies in their habit of walking backwards and sideways as well as forwards, but their unusual ability is to be camouflaged by taking on the colour of the flower petals upon which they lie in wait. Jumping spiders, as their name suggests, can be seen on warm walls in the summer, leaping on flies which alight nearby. They have an enormous pair of eyes at the front of the prosoma which permit effective binocular vision for their accurate jumps.

The most outstanding achievement of spiders, to human eyes, is their ability to weave geometric orb webs. The common garden spider, *Araneus diadematus*, weaves the familiar structure with its radial lines which hold up a spiral of sticky silk. Building an orb web may take hours, and spiders are meticulous in its construction, each species producing a slightly different version; the web of the garden spider has 15° angles between the radii, for example. The true function of the web is not to act like a fishing net to tangle prey, but rather it is the sticky spiral of silk to which the insect adheres. Important too, is the tension of the web so that the spider can detect the correct vibrations which alert it to the presence of a prey item rather than, say, a predator.

Construction of an orb web is a delight to behold. First, the spider lets out a line of silk which any slight breeze will carry across the space to be filled later by the web. Once this tightrope is established, the spider walks across it, then halfway back again. Now in the middle, she drops down and thus establishes a triangle of silk with the future centre of the orb at its apex. Sides and a bottom line are laid down and the spider continues by adding radii, at the angles distinctive for the species. Once the radii are down, the spider begins to lay down a spiral starting from the centre and working outwards, being sure to tension each thread as she goes. That finished, the final stage is to remove the spiral just laid, from the outside in to the centre, and at the same time to lay down a new, sticky prey-capturing spiral. All this may seem like a great deal of hard work, as indeed it is (especially since she will take it down again the next evening to construct a new one), but then the whole survival of the animal depends on it.

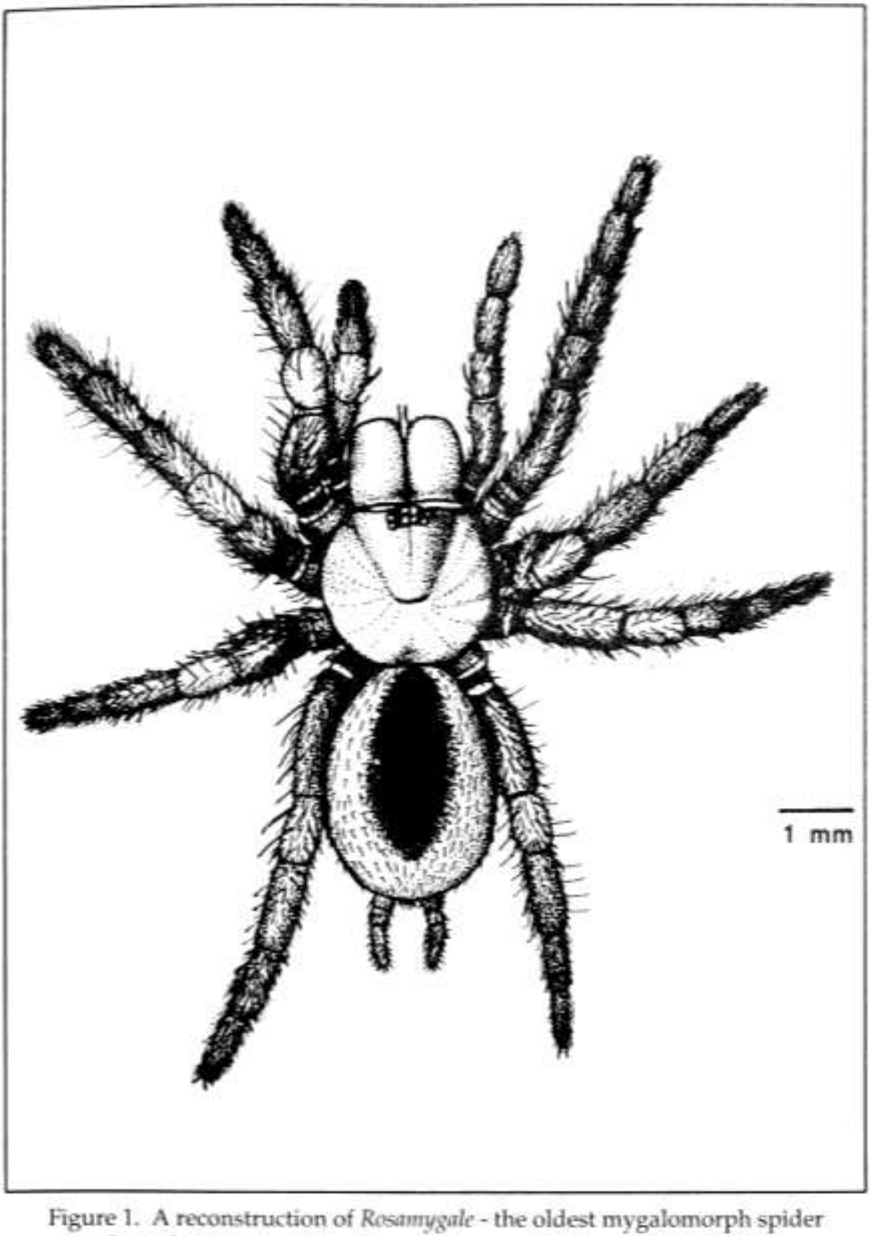


Figure 1. A reconstruction of *Rosamygale* - the oldest mygalomorph spider from the Triassic of the Vosges, France. (Selden and Gall 1992).

A major question which has taxed the minds of arachnologists over the years has been: is the orb web the pinnacle of spiders' achievements, or is it, on the contrary, a rather simple structure from which webs with different architectures have been derived? The reason for this puzzle is that there are a great many modified orb webs. Some have a zig-zag band of bright silk running across the centre in a line, or the web may have a cross woven into it (the St. Andrews cross spider from Australia, for example). Such a device, called a stabilimentum, may function to draw attention to the web and thus prevent large flying creatures such as birds from crashing through the web and destroying it. Some orb webs are elongated in one direction, forming a ladder web. Others are horizontal, rather than the more familiar vertical ones, and have a complex arrangement of scaffolding above or below. Such webs may use the scaffolding as a baffle which small flying insects hit and fall onto the orb-sheet, while others have stick droplets on threads hanging below the horizontal orb to trap insects walking underneath. All these web types could be considered specializations developed from the basic orb plan. Specialization may require reducing the orb; in some species it has been cut down to a mere triangle, and perhaps the ultimate in minimalism is the 'web' of *Mastophora*, the Bolas spider, which consists of a single thread with a large ball of glue at the end. This spider emits a chemical which mimics the pheromones put out by female moths to attract a mate. When a male moth arrives, lured by the prospect of a mate, the spider swings the ball-and-thread round and round until it the moth gets stuck to the glue. Rather than the good time he was expecting, the moth becomes a juicy meal!

Other spiders, the cribellates, use a quite different method of producing sticky silk. These spiders have a comb of curved bristles, called a calamistrum, on the last pair of legs, with which they draw silk from the spigots across a plate bearing short spines (the cribellum) situated just in front of the spinnerets. This 'carding' process produces a woolly type of silk which insects' hairs will stick to readily, in just the same way as burrs stick to a woolly jumper. Silk of the common house spider *Amaurobius* is cribellate, and has a typically bluish tinge. *Amaurobius* makes a silken tube in a wall or beneath bark, but some other cribellate spiders weave orb webs, *Uloborus* for example. Some *Uloborus* weave stabilimenta into their webs, and other cribellate orb-web weavers produce highly modified webs. *Hypiotes* makes a triangular web which is derived from one sector of an orb; it holds this taught between two twigs, letting it collapse around any insect which flies into it. Perhaps the most amazing cribellate orb web is that woven by *Deinopis*. This spider is large with long, twig-like legs. It has two enormous eyes directed forwards on the head, giving it the common name of Ogre-faced spider. *Deinopis* lives in tropical forests; at night it weaves a tiny but complete cribellate orb web between its four front legs. It stretches this out like a cat's cradle and holds it taut until an insect approaches, when it collapses the web over the insect rather like the Roman retiarius gladiator with his net.

So, just as in the araneid orb-web weavers, the cribellate forms have developed the orb web and then reduced it in various clever ways for specialized uses. The big question is: did the orb web evolve many times, in both cribellate and ecribellate spiders, or was there an ancestral cribellate orb-web weaver which gave rise to ecribellate orb-web and non-orb-web weavers? Current research based on living spiders suggests the latter, but palaeontology has some light to throw on these matters as well.

Fossil spiders are generally rather rare. They do not preserve well, and do so only under special circumstances. Perhaps the best known are those found in amber; for example that of Oligocene age from the Baltic region. Fossil spiders are also known from Tertiary rocks on the Isle of Wight, and in the Coal Measures. Few Mesozoic spiders were known until recently, when some were discovered in Cretaceous lithographic limestones in the Sierra de Montsec, a range in the foothills of the Pyrenees near Lleida, in north-east Spain. The fossil fauna found in limestones in old quarries in these hills was well known, and contained many beautifully preserved insects and plants. Excavations organized by Lleida Museum a few years ago enlisted the help of the Spanish army! During these digs, many exciting fossils were discovered, including fish, frogs, and even bird feathers and bones. Four spiders turned up as well, which were sent over to me for study, and they proved to be quite exciting.

On first examination, the spider fossils appeared simply as shapes in the rock, preserved as flakes of brown cuticle on, or just within, the slightly translucent fine limestone. A number of techniques were used to see them better. Alcohol has many uses in palaeontology, and a drop on the specimen increases the contrast for light microscopy; but to see very fine details such as the pattern of hairs on the legs, or the spinnerets, a reflected light microscope, such as that used by ore mineralogists, was employed. In this microscope, light passes down the objective lens to be reflected back up the same lens. Thus, light could be brought to the specimens at very high magnification. Inspection of one of the spiders revealed it to be an adult male of an araneoid orb-web weaver. Evidence for this was found in the nature of the bristles and claws at the tip of each leg. Three claws (rather than two) suggests a web-weaver, and specialized curved, serrated bristles indicated an orb-web weaver. Two more specimens could be identified as belonging to the modern family Tetragnathidae, also araneoid orb-web weavers. The fourth specimen was perhaps the most interesting of all. A curved calamistrum could clearly be seen on the fourth leg, together with a cribellum in front of the spinnerets. Additional evidence from the sensory hairs on the legs revealed this spider to belong to the superfamily Dinopoidea, and probably the family Uloboridae. These are orb-web weaving cribellates. Therefore, both cribellate and ecribellate orb-web weavers were present early in the Cretaceous (Montsec is dated at Berriasian–Valanginian, around 138 million years old). This does not solve the problem of which came first, the cribellum/ calamistrum or the orb web, but it places their origins back into the Jurassic at least.

All but one species of British spider are araneomorphs, *Atypus affinis* is our only representative of the mygalomorph (or bird-eating, funnel-web, trapdoor, tarantula) spiders. These spiders differ from araneomorphs in that their cheliceral fangs strike down on prey rather than clasping it in a pincer-like sideways movement. Some (the so-called tarantulas) are large, but many are small and live in burrows; they are typical of tropical and southern hemisphere regions of the world. The Isle of Wight fossil spider is a mygalomorph, and a few have been described from Tertiary rocks. A couple of years ago some mygalomorphs were described from Cretaceous rocks in Siberia and Mongolia. Then, in 1990, I spent a few days in Strasbourg working with Professor Jean-Claude Gall, studying ten specimens of spiders from Triassic rocks there. Strasbourg is a pleasant city, with a fine cathedral built of Grès à Voltzia sandstone, an excellent freestone. This stone is quarried in the northern Vosges, and many of the quarries occasionally hit clay wayboards, rather like those which are responsible for the springs in the Triassic sandstone at Alderley Edge. The claystones represent shallow pools in a deltaic setting adjacent to the western margin of the Zechstein Sea. The Grès à Voltzia had long been known to produce exceptionally preserved fossils of plants, insects, vertebrates, and even jelly fish and gelatinous strings of eggs. The ten spiders turned out to belong to a single species of mygalomorph spider, which we called *Rosamygale* (Fig. 1). This is the oldest known fossil mygalomorph, and the find more than doubled the fossil record of the group. What was particularly interesting was that the family which it belongs to, the Hexathelidae, is mainly antipodean today. It suggested that the family, and probably many other mygalomorphs, was widespread over the supercontinent Pangaea before its break-up later in the Mesozoic.

Going back in time, fossil spiders are known from Carboniferous Coal Measures in Europe and North America. All those I have seen have clearly segmented abdomens. This is a feature of the third main group of spiders alive today: the liphistiomorphs, represented by *Liphistius* in Malaysia. *Liphistius* lives in a silk-lined burrow with a trapdoor at the entrance and is considered to be the most primitive of all spiders alive today. So, the fossil record appears to mirror our concept of spider evolution, with the Palaeozoic forms being the most primitive, mygalomorphs appearing first in the Mesozoic, and araneomorphs arriving later. Are there any spiders older than this?

Carboniferous terrestrial faunas contain fossils not only of spiders but also of other arachnids in relative abundance (compared to the Mesozoic for example). Scorpions were at their most diverse then, and another group, the trigonotarbids, occur fairly frequently in some Coal Measure sequences. Trigonotarbids are extinct, but their fossil record goes back further than the Carboniferous. Our knowledge of the morphology of 'trigs' benefits greatly from their occurrence in the famed Rhynie Chert, a Lower Devonian hot-spring deposit in Aberdeenshire.

Animals and plants preserved in the translucent chert reveal their morphology in three dimensions, and serial sections can be useful as well. Study of Rhynie Chert 'trigs' showed that they are quite closely related to true spiders, and were important predators in these early terrestrial ecosystems.

Rhynie Chert arachnids had been known since 1923 but in the 1980s, trigs were discovered by palaeobotanists dissolving mudstone from the Upper Devonian of Gilboa, New York for well-preserved fossil plants. A number of trigonotarbids were described from Gilboa, but in 1989 a spider spinneret was recognized among the thousands of fragments of animal cuticle from this deposit. This was not only the earliest fossil spider but also the oldest evidence for silk production by any animal. That year I worked on the fauna with Professor Shear at Hampden-Sydney College, Virginia, and we described the fossil spider from many more fragments which had the same cuticle pattern as the spinneret. It turned out that a fragmentary animal we had described in an earlier paper as a probable trigonotarbid was actually the spider. What makes a spider differ from a 'trig' is the possession of spinnerets, but otherwise they are rather closely related.

The story of the fossil record of spiders does not quite end there. In 1990, Andrew Jeram, who was working here in Manchester on early land animals, discovered some interesting pieces of arthropod cuticle dissolved out of sediments just above the famous Ludlow Bone Bed at Ludlow, Shropshire. Fragments of fish teeth and spines have been chipped out of the Ludlow Bone Bed on the corner of Ludford Lane opposite the Youth Hostel in Ludlow by generations of fossil collectors. The danger of collapse of the overhanging rock at this corner prompted the Nature Conservancy Council to clean up the site and make it safe. Any rock removed was kept for study, and it was this material which produced the animals. One black speck turned out to be a trigonotarbid. The Ludlow Bone Bed lies on the boundary between the Ludlow and Prídoli stages of the Silurian period. This is dated at 414 million years old, and is 16 million years older than the previously known oldest terrestrial animals from the Rhynie Chert.

Trigonotarbids, spider relatives, are among the oldest known land animals, and we may yet find spiders in the Ludford Lane deposit as well. Man has been on this planet for about 2 million years, yet spiders have been weaving webs to catch insects for 400 million years. Surely, we should treat the spider with the respect she deserves!

Paul A. Selden
University of Manchester

SEA DEFENCES ALONG THE NORTH WIRRAL COAST: RIVER MERSEY TO MEOLS

by HAZEL E. CLARK

Processes Common to all Beaches

A beach is an accumulation of unconsolidated material between the highest and lowest levels of spring tides. The size, sorting and quantity of material forming the beach are significant factors in determining its final form. The gradient, height in relation to the mean sea level and resistance to erosion affect the rate of coastline development.

Waves are the fundamental force operative on a beach. They are generated by the wind and their size is determined by the strength of the wind and the distance of water over which the wind can build the waves (the fetch).

On many coastlines the dominant wave direction is oblique to the shoreline and material is carried obliquely up the beach, but is then moved, under the influence of gravity, straight down the beach by the backwash. This process is called longshore drift and moves material sideways across the beach in a down drift direction. Tidal currents may also contribute positively or negatively to this process.

Left to itself, a beach will attain a profile that is in dynamic equilibrium with its environment, i.e. little change is taking place - for example the amount of material lost through erosion is equal to the amount gained from accretion. Wave action tends to build a profile which is in equilibrium.

GAINS		LOSSES
River Sediment Supply		
Coastal Erosion		Onshore Loss
Longshore Gain	BEACH	Longshore Loss
Organic Supply		Offshore Loss
Offshore Supply		

Human interference can have a marked effect on the beach. The building of structures such as groynes, sea walls and revetments, disturbs the natural movement of the beach material and may cause profound changes in their immediate vicinity. Adjoining areas may be starved of sediment which can lead

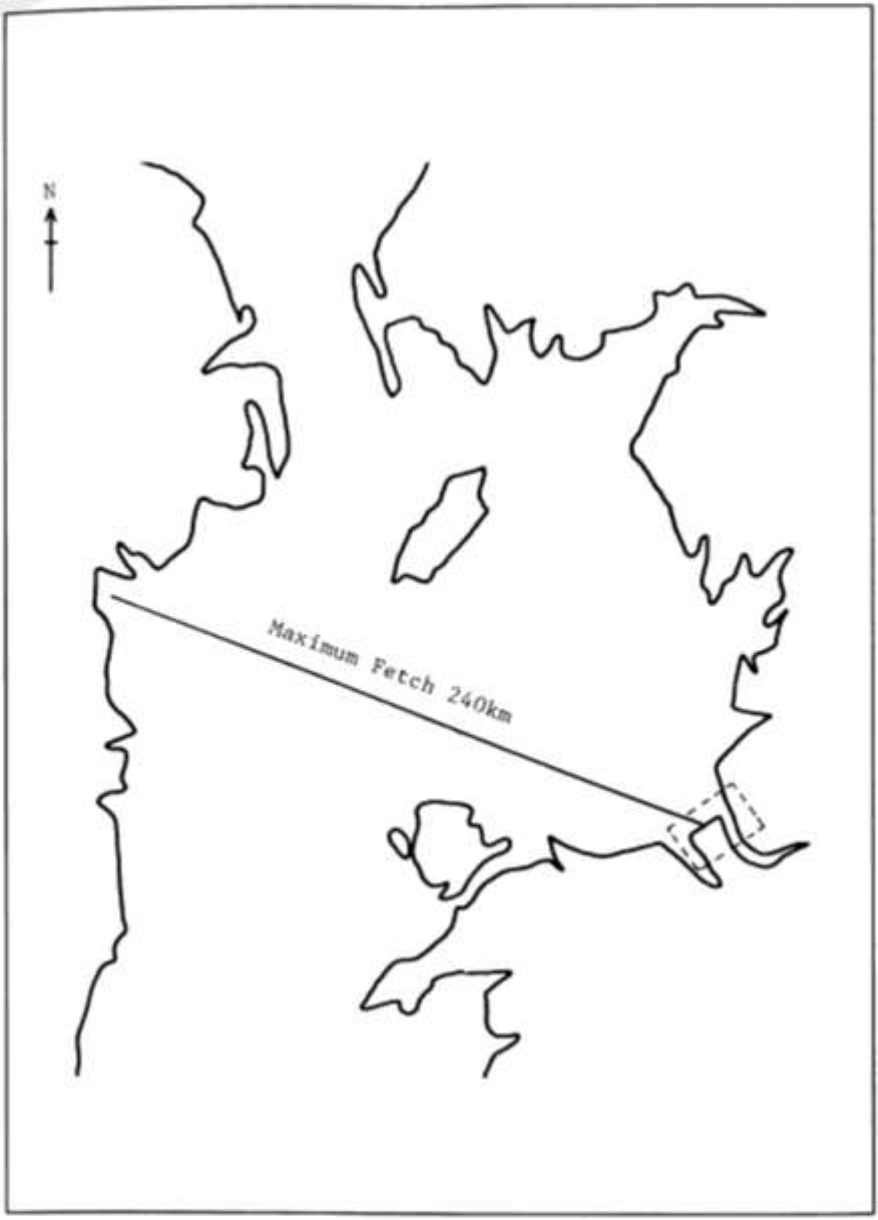


Figure 1. The Irish Sea

to the undercutting of the defences, and other areas may receive an unusually large supply which can cause siltation producing navigational problems.

Introduction to the North Wirral Coast

The north Wirral coast stretches from Hoylake in the west to New Brighton in the east. Most of the land is owned by Wirral Borough Council rather than the Crown. The foreshore is an area of sand and silt, covered twice a day by the tide which can rise up to 10 m from low to high water (depending on the time of year and phase of the moon). It was designated a Site of Special Scientific Interest (S.S.S.I.) by the Nature Conservancy Council because of the migrating and winter feeding birds.

The coast faces squarely into the prevailing north-westerly winds, exposed to 240km of open sea from Ireland which allows large waves to build up (Fig. 1). During storm conditions wave heights exceeding 6 m are common and, when combined with spring tidal maxima of 10 m, can cause severe erosion along the coast. As a result, the design, construction and maintenance of all the marine coastal structures are closely governed by the ambient site conditions.

History

Inland, the soft alluvial sediments at the northern end of the Wirral Peninsula were once protected from inundation by a continuous system of coastal dunes between Hoylake and Wallasey. On the coast the main currents cause a longshore drift of sand and mud from west to east. By the end of the eighteenth century, a deficiency in the sediment supply meant that encroachment by the sea was a real threat and a breach in the dunes was imminent. Such a breach would have caused flooding of the adjacent low-lying land and could have created a new outlet for the River Mersey, starting between Birkenhead and Wallasey and proceeding via the Wallasey Pool along the low ground towards Leasowe.

In 1794 an attempt was made to halt the erosion by forming a sloping wall along the seaward face of the dunes. This was only successful in the short term and erosion resumed. The Liverpool Corporation presented the Wallasey Embankment Bill to Parliament in 1829:-

> "For the purpose of preventing further encroachment of the sea and injury to arise therefrom to the contiguous lowlands and Port of Liverpool."

As a result a permanent commission was made responsible for the construction and maintenance of a sea defence structure now known as the Old Embankment along 2.65km of the most vulnerable stretch of the Wallasey coastline. After serious erosion around the flanks of the Old Embankment an Act of

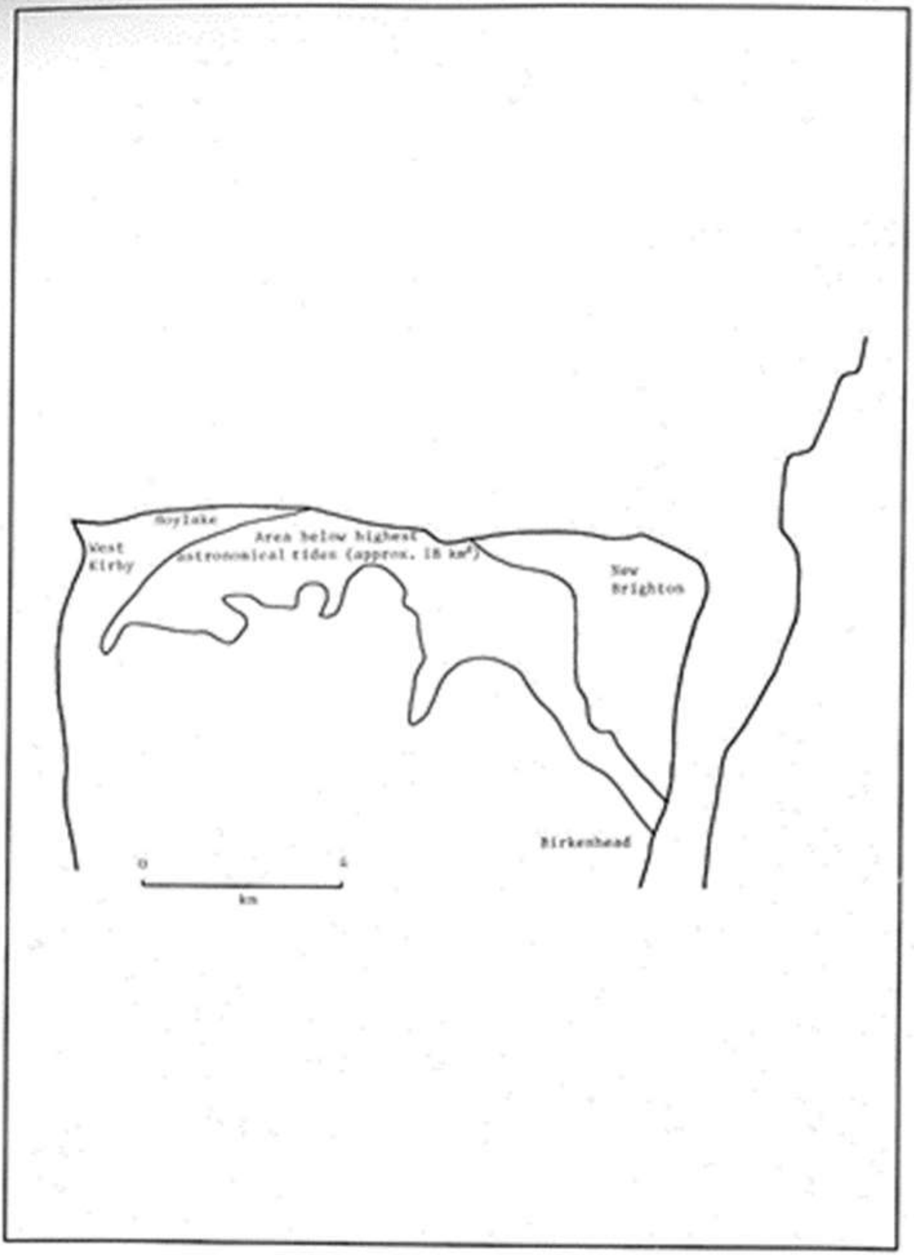


Figure 2. The Wirral Peninsula.

Parliament in 1894 extended the works to cover 3.6km of shore - the New Embankment.

The enclosure of the Wallasey Pool by the Birkenhead Dock System between 1840 and 1860 reduced the risk of the River Mersey flow being diverted. The functional emphasis of any coastal works was then shifted from maintaining the navigation into the Port of Liverpool to protecting life and property.

Today, some eighteen square kilometres of the northern end of the peninsula are below the level of the highest tide (Fig. 2) and the coastal dunes are now low, relatively discontinuous and restricted to the coastal area.

In 1981 the replacement cost of property within a threatened area just 112m wide at Harrison Drive was £2.55 million. It is, therefore, not surprising that most of the Wirral coastline has been 'protected' and that it is an area for pioneer work in coastal defence.

A brief summary of the history of the coastal protection works is given below.

End of 18th Century.	A decrease in the supply of sediment caused erosion of the dunes and encroachment by the sea. A breach in the dunes could lead to the flow of the River Mersey being diverted through the Wallasey Pool towards Leasowe.
1794	Sloping wall along seaward face of dunes to prevent erosion - only successful in the short term.
1829	Liverpool Corporation presented the Wallasey Embankment bill before Parliament. Permanent commission responsible for the construction and maintenance established; 'Old Embankment at Wallasey' built.
1840-60	Enclosure of Wallasey Pool by Birkenhead Dock System.
1859-90	Mersey River Wall - Seacombe Ferry to New Brighton Marine Lake.
1897	New Wallasey Embankment.
1897-99	Sea wall between Meols and Stanley Road (Kings Gap).
1911-57	Crosby Channel retaining walls built.
1922-23	Leasowe Revetment - Coastguard Station to Leasowe Bay.

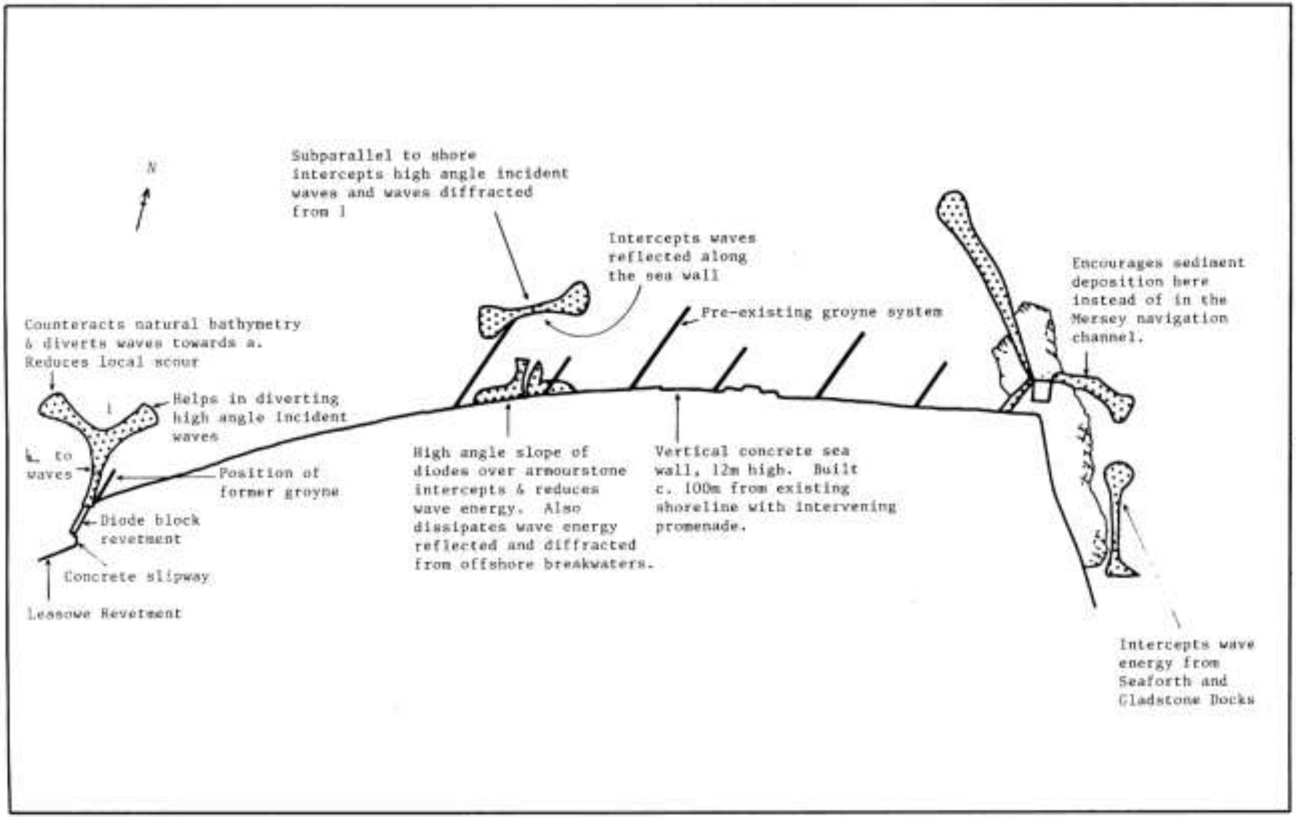


Figure 3. Coastal Defences Along Kings Parade.

1931-39 Kings Parade Land reclamation scheme. Work halted by outbreak of World War II. 'Temporary' link wall constructed to meet Leasowe Revetment.

1950's Wooden groynes constructed in front of Kings Parade.

The Sea Defences

A wide variety of coastal defences have been used on the Wirral. A walk from New Brighton Marine Lake in the east to Meols at the western end of the Wallasey Embankment will provide a spectrum of attempted solutions to an age old problem.

River Mersey Wall

This 4km of wall, stretching from Seacombe Ferry to New Brighton Marine Lake, was built between 1859 and 1890. It is composed of mass concrete faced with $0.6m^2$ sandstone blocks. This wall is still in reasonable condition but requires annual maintenance involving pressure grouting and guniting. Most of the toe of the wall is protected by sand but certain areas have shown erosion which could reduce the wall's foundation stability.

Kings Parade

Covering the 2.36km from the Marine Lake to the Coastguard Station at Harrison Drive, there is a substantial mass concrete construction which stands about 12m above present beach level. It was built between 1931 and 1939, some 100m seawards of the existing shoreline as part of a large reclamation project. The intervening land, once the upper beach, was recovered for a promenade and recreation purposes. The wall is protected by a sheet steel pile toe 5m deep, but the vertical, slightly curved profile forms a perfect wave reflecting surface which encourages erosion at the base. To minimise this effect a series of seven wooden groynes were erected in the 1950's to nourish the beach by slowing the longshore drift. They were successful for a number of years until they were damaged by storms in the early 1970's.

At Kings Parade the beach is completely covered at high water. The wall has replaced the upper beach where wave energy could have been dissipated, so the waves, still in deep water and having most of their energy, break against the wall and cause serious erosion of the beach at the base of the wall. The wall provides the only protection for land and property and as a consequence, there have to be social, ethical and financial aspects to any solution.

At first a concrete skirt to the wall was proposed. This would have been expensive and could only be a temporary measure when the rate of undercutting is considered. Additionally a concrete skirt could not prevent longshore drift.

The second (and accepted) suggestion was to build a series of offshore breakwaters.

Kings Parade Breakwaters

The breakwaters are designed to alter currents and encourage sand deposition. Their orientation, position and shape are calculated to intercept the predominant wave train patterns and each breakwater is designed to interact with the preceding and succeeding structure whilst retaining its integrity (Fig. 3). The breakwaters do not form a continuous barrier, allowing the beach to remain open for leisure pursuits.

The breakwaters, constructed between 1983 and 1985, are composed of interlocking precast concrete units overlying a skirt of armour stone and bedstone rip rap. Wave energy is dissipated by percolation through the breakwater rather than the energy being reflected away, thus reducing scour. Additionally, as the current slows on passing through the blocks, sediment is deposited in the lee of the structure. Also the offshore dissipation of energy helps to reduce run-up and overtopping of the sea wall.

The 'reef' blocks used as the higher level components of the offshore breakwaters are more elongate and vertical than the 'diode' blocks used close to shore. Their faces are oriented normal to the prevailing wave train and present an upstanding frontage to the passage of major waves. They also have a higher angle of repose, so decreasing the base width height ratio. This means that less material is needed for construction and the costs are reduced.

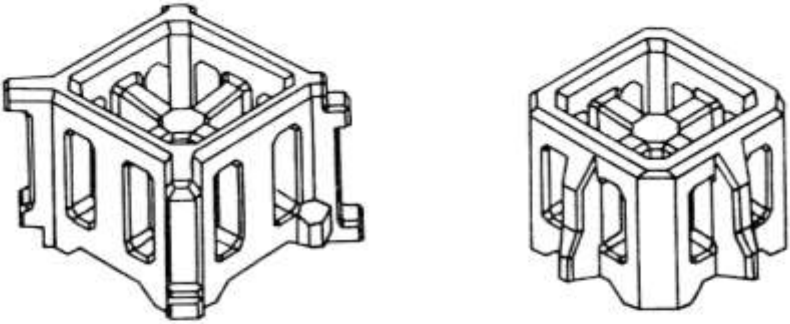
The breakwaters now provide a 'rocky shore' habitat for marine life and island sanctuaries for roosting birds.

Kings Parade - Leasowe Revetment Link Wall

Further planned construction of the Kings Parade Sea Wall had to be deferred due to the outbreak of World War II. The temporary termination, the return (link) wall erected near Harrison Drive, became a permanent coastal feature. To the west almost 2km of concrete revetment had previously been constructed in the 1920's to protect the eroding sand hills near Leasowe.

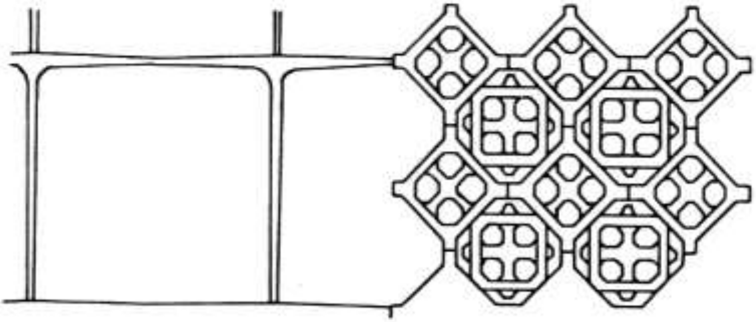
In the late 1970's a study of the environs of the link wall showed that tidal currents were deflected offshore, the prevailing wave activity was reflected by the vertical link wall and the wave energy effectively focussed onto the adjacent amenity beach. This had the effect of increasing wave height and run-up, and generating wave induced currents in a general offshore direction causing erosion.

It was thought that if the energy of waves could be dissipated at the link wall prior to any reflection, instead of later across the foreshore, beach levels



Primary Blocks

Secondary Blocks



Laying pattern using 'T' shaped units

Figure 4. Precast concrete Diode Blocks.

would increase and water depth would be reduced during any tide. A localized reduction in wave induced currents would reduce the transportation of disturbed sediment out of the area.

The benefits of wave dissipation at the link wall were established and investigations were carried out to obtain the most cost effective and acceptable method. It was decided that a sloped surface of either natural armour stone or precast concrete blocks would be used.

Armour stone requires a gradient no steeper than 1 in 6 to adequately dissipate the wave energy and remain stable. Considerable quantities of stone are required and large areas of beach are 'sterilized'. Very few local quarries were willing or able to blast and supply stone of a suitable size and quality. Possible costs were also increased by the simultaneous demand from the A55 coast road construction in North Wales.

Compared with the armour stone estimate of £1,700 per metre, the cost of a steeper (1 in 1.9) precast concrete block slope was cheaper at £1,500 per metre and could be cast on site.

The precast diodes are a development of cob (hollow cube) units used for the St. Helier breakwater on Jersey. They comprise a basic perforated cube with internal crossed solid diaphragms. The diode causes the wave to break and dissipate its energy within the block system; thus wave reflection and consequent scour is minimised. The dimensions of the blocks have to meet the overall porosity and freedom of flow criteria while at the same time inhibiting potentially fatal childrens' adventures.

Two types of block are used, primary and secondary units, which interlock into an octagonal grid pattern that avoids common faces between the units (Fig. 4).

The diode revetment was completed in November, 1982. In the winter storms of 1983 it was noted that, although spray overtopped the blocks, incident waves hardly rose above their breaking crest heights and reflection was considerably reduced. The diode's performance has resulted in limited wave run-up and encouraged beach accretion and reduced water depth.

Leasowe Bay

Leasowe Bay is not a natural feature but has developed as a direct consequence of sea defence construction on either side (Leasowe Revetment to the east and Wallasey Embankment to the west) on land owned by the local authority, while the land in the centre, owned by Leasowe Golf Club, was only defended by sand dunes. Between 1893 and 1953 there was 85m of erosion of the natural dune frontage.

Since 1950 the Golf Club has been concerned with the stabilization of the sand dunes to avoid wind blown sand on the course, and to maintain the sea defence. Rubble and clay were tipped to overlay the dune sand but this led to public objection. Between 1973 and 1978 further attempts were made to halt erosion by laying a clay slope. After the work completed, it suffered serious damage in the 1978/79 winter storms.

By 1975, because of the erosion that had been developing over the previous twenty years, it was realised that if the beaches were not stabilized the new defences under construction would rapidly deteriorate. The traditional approach of using groynes had been unsuccessful at Kings Parade, so it was agreed that a more substantial, selectively located structure would be more appropriate. As the eastern extremity of the Wallasey Embankment, on the west side of the bay, was showing increased local erosion it was chosen as a test site. It was decided to investigate the concept of a detached breakwater to control beach levels, and under test conditions it was found that a 200m long structure would reduce energy levels by 60% and protect over 400m of coastline.

The first breakwater was not designed to resist erosion directly but to exploit the distribution of wave energy. It is dog bone shaped in plan and composed of rock, lying some 150m off the western headland of Leasowe Bay, just in front of the damaged embankment (Fig. 5). The theory behind the breakwater concept comes from observing the behaviour of 'soft' coastlines which tend to wash away until hard spots are exposed. As a general rule, these hard spots encourage the formation of stable bay regime and reduce further erosion because beach accretion occurs in their lee. Thus Wallasey's offshore breakwater is an attempt to form such a hard spot by artificial means and direct wave energy away from the end of the existing embankment by building up the beach. The performance of detached breakwaters is controlled by their length and distance offshore, and they can protect a stretch of shoreline up to four times their own length.

Since the construction of this first breakwater, beach levels have been raised over a length of 600m extending east and west from the centre of the breakwater. Beach levels increased up to 1.5m during the first two years after construction.

A second, detached breakwater is located on the downdrift, eastern, side of the bay. The bay itself acts as a reservoir pushing tidal flow past the western extremity of the Leasowe Revetment. This flow used to be enhanced by wave action in the bay, which coupled with a wave-induced current, resulted in scouring of the sand from the beach. This exposed the Revetment foundations, and this caused particularly extensive damage to the corner of the Revetment. Thus it was necessary to effectively re-align the wave approach to the Revetment.

This re-alignment is achieved by a breakwater, also dog bone in shape, which is connected to the shore by a rockfill link designed to modify flood patterns after the breakwater has taken the main force of wave energy. If it were not for the link, a current parallel to the shore could have a marked scouring effect.

In February, 1983 a "once in fifty year" tide level was caused by storm conditions. As a result both breakwaters sustained minor damage but this required only three days to repair.

The breakwaters have been a success and have resulted in the development of a sandy shore which replaces the silt, mud and general debris from makeshift measures along a private frontage. The cost effectiveness of the measures can be judged by comparing equal lengths of coastline protected (1979 prices).

Conventional sea wall design unit cost including filling and paving to landward profile	£3,300 per metre
Leasowe Bay Breakwaters and ancillary works	£1,855 per metre

Wallasey Embankment

First constructed between 1829 (Old) and 1897 (New), the Embankment underwent major reconstruction between 1974 and 1983 and now covers 4.6km of the foreshore, from Leasowe Bay to Meols.

The basic form of the Old Embankment is a bank of indigenous material having a shallow seawards slope, covered by an impermeable facing. The core comprises mainly sand, silt, clay and peat, usually the natural material, trimmed to a regular profile (between 1 in 4 and 1 in 8) with any deficiency made up from the beach material.

The original facing was a 0.6m layer of local clay. This was later protected from erosion by an armour layer of interlocking sandstone blocks (0.2 - 0.4m equivalent cubes) up to the highest tide level, and cobbles in the swash zone above. The blocks within the tidal zone tapered into the embankment and are tooled on the butting faces so as to interlock. Some of this masonry was still functional at the time of reconstruction, some one hundred and forty years after it was built.

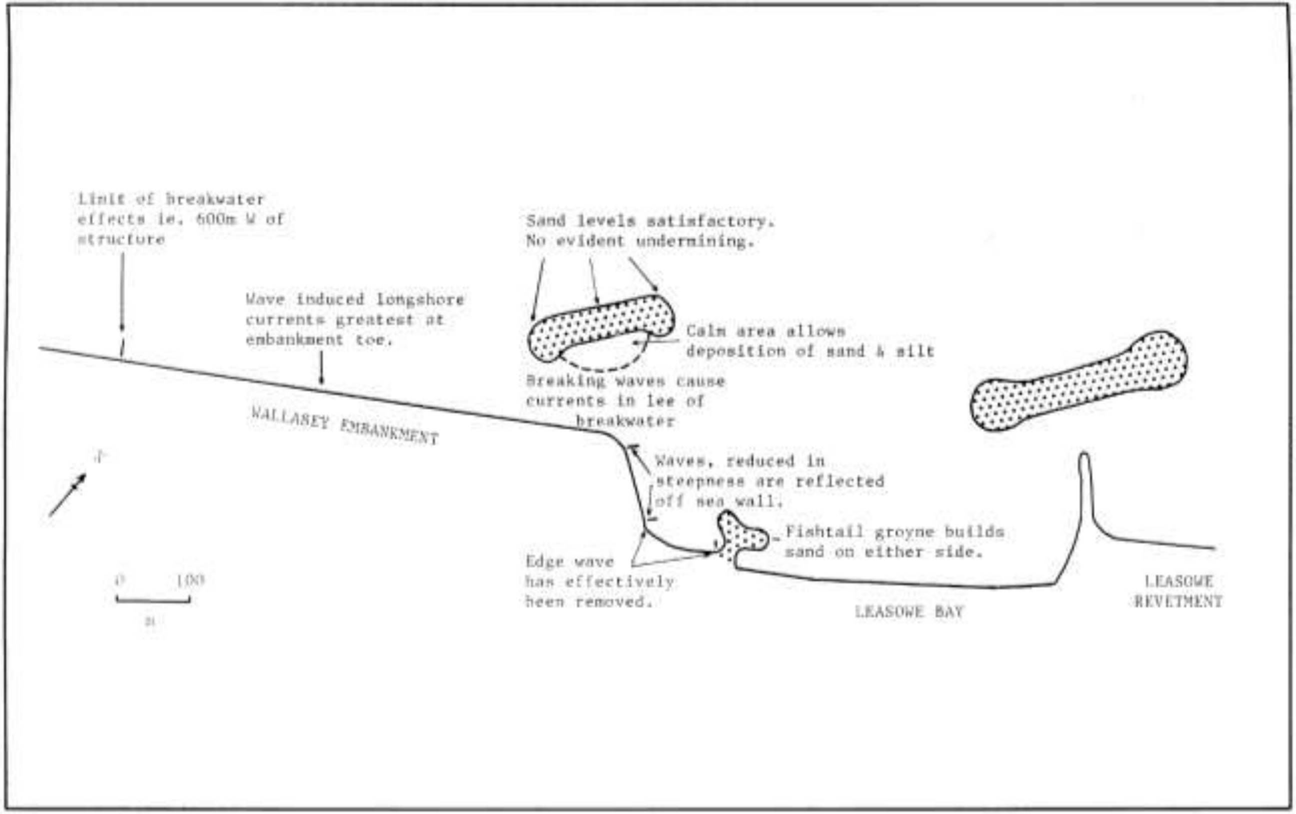


Figure 5. The Effects of Breakwaters at Leasowe Bay.

During the life of the embankment, major changes in the configuration of the sandbanks between the Dee and Mersey estuaries have occurred.

The principal change has been the migration of the Rock Channel entrance eastwards due to beach movements, influenced by the construction of the Crosby Channel training banks between 1911 and 1957.

The resulting beach erosion caused progressive failure of the toe and facing, threatening a sloping apron of stone blocks. Later, concrete was added in front of the toe to reduce scour. Beach erosion was combated by the extensive use of groynes made of inter-woven bundles of cherry tree branches.

The increased depth of water over the lowered foreshore has allowed larger waves to reach the embankment. To reduce the danger of overtopping a raised crest was added to the original embankment. More recently, in an attempt to eliminate overtopping totally, a wave return wall has been deemed necessary.

Throughout the period 1829 to 1963 a gang of men were continuously employed in the construction and maintenance of the embankment. Records show that from 1870 concrete was used increasingly instead of sandstone blocks as the material paving the structure. In 1941 a concrete cellular construction was adopted. The network of cells, approximately 4m square, was able to limit the extent of washout, in the event of failure, to an area that it was possible to repair in one tidal cycle.

After the County Borough of Wallasey assumed responsibility for the embankment in 1962, the escalation of routine maintenance costs prompted a detailed engineering inspection of the structure. Acceleration of failure of the facing was revealed, and as a result, major reconstruction began in 1972.

It was considered imperative to minimise the erosion at the toe of the embankment. The solution adopted was to provide a reinforced concrete 'beam' along the approximate line of the original toe wall in order to provide a substantial footing for the new facing. The level of the top of the toe beam was fixed so as to allow adequate formation drainage. Fix to six metres seaward of the toe beam is a continuous curtain of sheet piling, penetrating for a minimum of 0.6m into the till underlying the beach. The toe beam and sheet piling are connected by a reinforced concrete apron slab with an average slope of 1 in 4. By maintaining this slope (which is similar to that of a natural storm beach), scour on the foreshore is minimised so long as the sheet piles remain below beach level. Thus the sheet piling, apron and toe beam function as a composite unit of relatively rigid construction serving to retain the foot of the embankment.

The facing of the embankment utilizes a modified cellular structure, using precast concrete cut-off walls and in situ mass concrete infill panels designed to remain in place on a gravity basis. The weight of these panels is such that the mass of the fragments expected even after failure would be great enough to inhibit their movement by the tide.

The life of a concrete structure is dependent upon the quality of the concrete. Usually, the most severe physical conditions to which concrete is normally exposed, in the marine environment, are those involving wetting and drying. However, along the coastline of North Wales and the Wirral, abrasion is considered to be the principal cause of deterioration. The life of a structure exposed to wave action is closely governed by the detailing on the concrete, especially on the exposed edges and joints where the shock compression of entrapped air can cause spalling, and may lead to the early disruption of the concrete. To reduce this vulnerability, in the reconstruction, all significant exposed edges and joints are radiused. Away from the slab edges a ripple finish has been applied by hand tamping to provide a safer walking surface and also reduce the boundary layer run-off velocity, thus limiting beach scour of the toe of the embankment.

The design is completed by an upper wave return wall and the establishment of an access road for maintenance vehicles along the crest, and slipway access to the facing. Aesthetically, the long curved sweep of the embankment, with its gently sloping profile merging into the wide expanse of sand lying exposed at low water, limits angular intrusion into the landscape.

The Effects of the Coastal Defences on Leisure and Conservation

The primary function of the defences requires that they are substantial constructions. However, the variety of structures and the preservation of the irregular alignment of the coast helps to offset any detrimental effects of the hard structures.

Beach levels have risen substantially in some areas (viz Leasowe Bay, Leasowe Revetment and New Brighton) and thus provide large expanses of clean sand.

The combination of the permanent defences and beach accumulation have helped to improve the amenity, recreational and conservation value of the coast, attracting both visitors and wildfowl. The offshore breakwaters have become valuable roosting sites for wading birds.

Planting of Couch grass, Marram grass and Sea Lyme have helped to stabilise the sand dunes.

The primary aim and financial justification for protection works is to protect the coast from erosion and flooding which could threaten life and property. Much of the pioneering work on the Wirral defences will find application elsewhere throughout the United Kingdom.

It is recognised that no sea defences can be permanent. However, the principles of design and construction ultimately developed and proved for the Wirral Coast may help to provide viable alternatives when approaching the problem of a new sea defence.

Bibliography

ANON (1976) A Dictionary of Earth Sciences. Pan Reference Books.

BARBER, P. C. & LLOYD, T. C. (1984) The "Diode" wave dissipation block. Proc. Instn. Civ. Engrs. pt. 1, Paper 8826, pp 847-870.

BARBER, P. C. & DAVIES, C. D. (1985) Offshore breakwaters - Leasowe Bay. Proc. Instn. Civ. Engrs. 77, pt. 1, Paper 8825, pp 85-109.

BARBER, P.C. & DAVIES, C. D. (1986) Offshore breakwaters - Leasowe Bay. Discussion. Proc. Instn. Civ. Engrs.. 80, pt. 1, pp 1597-1608.

BELL, M. N., BARBER, P. C. & SMITH, D. G. E. (1975) The Wallasey Embankment. Proc. Instn. Civ. Engrs., 58, pt. 1, pp 569-590.

BYRD, T. (1981 Breakwaters for beach build up. New Civil Engineer. July 2nd. pp 14-15.

FLETCHER, T. (1982) Offshore islands build up eroding coastline. New Civil Engineer. Sept. 16th. pp 15-16.

KING, C. A. M. (1972) Beaches and coasts. Edward Arnold.

LAWTON, A. (1986) Examination of the effectiveness of the Kings Parade Beach Stabilization Project. Unpublished B.Sc. Thesis, University of Lancaster.

METROPOLITAN BOROUGH OF WIRRAL North Wirral Coastal Park Dept. Leisure Services & Tourism.

METROPOLITAN BOROUGH OF WIRRAL Coastal Protection and Sea Defences.

METROPOLITAN BOROUGH OF WIRRAL The Wirral Coast Management Policy pp 45-48.

WHITTEN, G. G. T. & BROOKS, J. R. V. (1972) The Penguin Dictionary of Geology. Penguin Reference Books.

Hazel E. Clark
Liverpool John Moores
University

APPENDIX

History of the North Wirral Coastal Protection Works

Initially the soft alluvial sediments forming the interior of the Wirral Peninsula were protected by continuous coastal dune system.

End of the 18th Century. A decrease in the supply of sediment caused erosion of the dunes and encroachment of the sea. A breach in the dunes could lead to the flow of the River Mersey being diverted through the Wallasey Pool towards Leasowe.

1794	Sloping wall along seaward face of dunes to prevent erosion - only successful in the short term.
1829	Liverpool Corporation presented the Wallasey Embankment Bill before Parliament. Permanent commission responsible for the construction and maintenance established; 'Old Embankment at Wallasey' built.
1840-60	Enclosure of Wallasey Pool by Birkenhead Dock System.
1859-90	Mersey River Wall - Seacombe Ferry to New Bright Marine Lake.
1897	New Wallasey Embankment.
1897-99	Sea wall between Meols and Stanley Road (Kings Gap).
1911-57	Crosby Channel retaining walls built.
1922-23	Leasowe Revetment - Coastguard Station to Leasowe Bay.
1931-39	Kings Parade Land reclamation scheme. Work halted by outbreak of World War II. 'Temporary' link wall constructed to meet Leasowe Revetment.

1950's	Wooden groynes constructed in front of Kings Parade.
1972-83	Reconstruction of Wallasey Embankment.
1977 - 83	Replacement of Leasowe Revetment.
1979-82	Leasowe Bay Breakwaters.
1982	Kings Parade - Leasowe Revetment Diode Link Wall.
1983-85	Kings Parade Breakwaters.

A MINE, A PUB AND SOME GOLD

Last August the 'Guardian' reported the discovery of gold in the Temple Mine, Matlock Bath, Derbyshire. The Mine is a part of the Peak District Mining Museum and Dr. Lynne Willies, Project Leader for the Museum, sent the following account to the North West Geologist -

> "The gold discovery results from re-opening of a small drive out of the ore-bearing dolomitised limestone into the Matlock Lower Lava. The lava and overlying limestone dip northwardly towards the entry to the drive, so that the tunnel gets progressively deeper in the "toadstone". The location is geologically an interesting one, since it is one of the few in the area where the contact of the slaggy top of the lava with the overlying limestone can be clearly seen without difficulty. The top of the "toadstone" is a half metre or so of a very soft clay, weathered from an ashfall which seems to have terminated the volcanic activity, with (below it) weathered lava, suffering from exfoliation. This part is very easily excavated, but during mining must have been a problem, since the soft clay acts like toothpaste in a tube, and squeezes out because of overlying pressure. Subsequently the benthonitic material has expanded from contact with air and water, the result being a passage, until it was cleared out, almost wholly filled with a most tenacious clay-sludge.
>
> At about two metres depth the lava is fairly unaltered, and very hard, causing a pick to "ring" and rapidly become blunt. The lava, projected from its dip and outcrop, may be some 100 metres thick, though it varies rapidly over quite short distances: here only a few metres of the thickness are visible, and has amygdales of calcite visible throughout the slaggy-top. Within the clay and partially altered basalt, crystals of pyrite are just visible, but most has weathered, and this reaction, with abundant lime present, has led to production of gypsum in small crystals, and to iron staining.
>
> Why the tunnel was driven is not clear, since it passes under the mineralised horizon which largely occurs just above the lava. It may have been to just penetrate the lava far enough to allow a raise to be driven up, to make it easier to get the steeply-dipping ore-body above; or it may have hoped to get below the lava, since at least one mine, the famous Millclose Mine at Darley Dale, found a huge ore-body in the 1930s at a similar stratigraphic level. In either case, like many other similar starts, it was soon abandoned".

Dr. Willies and her colleagues took samples of the weathered lava and sent them to Dr. Richard Ineson at the Department of Earth Sciences, Sheffield University. His tests found gold and the results were confirmed by the Assay Office in Sheffield. Dr. Ineson believes it may represent a micro-nugget, held perhaps in the weathered-to-clay material rather than in pyrite.

Finds of native gold have been reported from other Derbyshire localities-for example, in lava/limestone contacts near Bakewell and in the old Ible Sill dolerite quarry off the Via Gellia. But the most notorious case concerned the Lathkill Gold Mine of 1854-1856 (Grigor-Taylor 1972). A level was driven into a lead rake between Over Haddon and Conksbury Bridge and found (it was claimed) gold in decomposed lava. Samples were submitted to several assayers; some confirmed that gold was present, others could find none. However, the Over Haddon Gold and Silver Mine was launched with a capital of £5,000, and the 'Derby Reporter' wrote of a "Californian gold-digging mania raging in the north of Derbyshire". But the venture did not last long. Critics pointed out that the chief shareholder was Mr. T. Burgoyne of Eyam, late gamekeeper to the Duke of Devonshire, who had moved "from dealing in rabbits to dealing in mining shares". Mr. Burgoyne and Mr. William Wood (also of Eyam) responded indignantly to their critics, but appear to have sold out at a profit before the project was finally abandoned in April 1856.

Writing in 1964 Ford and Sarjeant concluded that in Derbyshire native gold "has not been confirmed by any modern work, although it may occur in pyrite or as a colloidal impurity in calcite etcetera". So the Temple Mine is indeed a first. The mine is open to visitors every day except Christmas Day, but opening times are naturally limited in the winter. Special visits with a geological flavour can be arranged.

Hopeful prospectors may like to note that the tuff and lava exposed in the Mine is the Matlock Lower Lava. This can also be seen to the south-west, behind the Pig O' Lead Inn at Bonsall. Here some 2 metres of lava are visible in the pub's car park; above this is the Old Basalt Quarry where another 9 metres of lava are surmounted by $2^1/_2$ metres of tuff/toadstone clay under limestone. The Ible dolerite quarry is not far away either - but take a machete to hack a way through the jungle!

References

Ford, T. D. and Sarjeant, W. A. S. 1964. The Peak District Mineral Index. Peak District Mines Historical Society Bulletin. Vol 2.

Grigor-Taylor, W. R. 1972. The Lathkill Gold Mine. Peak District Mines Historical Society Bulletin. Vol 5.

THE BRITISH GEOLOGICAL SURVEY AT WORK

North-West England and Midlands

Mr. T. J. Charsley, Regional Geologist for the area south and east of Cumbria has provided the following summary of work in progress:

The Garstang Memoir was published in 1992 to accompany the recently published solid and drift geological maps (BGS Sheet 67). Field surveying on the adjoining Lancaster Map (BGS Sheet 59) has come to an end and work is on hand to produce the 1:50 000 geological map and memoir. One further borehole is to be drilled to help clarify the lithostratigraphy and biostratigraphy of Namurian strata of Chokerian (H_1) to Kinderscoutian (R_1) age beneath the large drift-covered western part of the sheet.

The year has seen the completion of three separate urban geological mapping projects jointly funded by BGS and the Department of the Environment. Reports and accompanying thematic maps at 1:25 000 are available for Stoke-on-Trent and the Black Country; the report for Leeds will follow early in 1993.

Standard geological maps at 1:50 000 for Stoke-on-Trent and Coventry (BGS Sheet 169) are being drafted, and the memoirs are in preparation. Field surveys continue for the Wakefield (BGS Sheet 78), Birmingham (BGS Sheet 168) and Nottingham (BGS Sheet 126) maps.

Lake District and Cumbria

In the Lake District, mapping of the Lower Palaeozoic strata on the Cockermouth (23) sheet has been completed and fieldwork on the Ambleside (38) sheet is at an advanced stage. Structural studies of the shales and greywackes of the Skiddaw Group have refined the understanding of the deformational history: the early episode of major slump folding identified previously now appears to have been followed by a period of upright folding that has been subsequently modified by south-directed thrusting. Stratigraphical interpretations of the Eycott and Borrowdale Volcanic groups have confirmed that they have similar evolutional histories and support the reinterpretation of biostratigraphical evidence in favour of their coeval eruption. Detailed geochemical profiling of the lava sequences has revealed a complex history of eruption from magma chambers which, although linked in the same geotectonic setting, had individual development paths within the crust. Mapping of the eruptive products, a joint study with the University of Liverpool, further suggests that more than one original caldera may have contributed to the volcanic assemblage. Volcanotectonic faults that controlled the eruption pattern may also have influenced the subsequent fault control of the West Cumbrian Permo-Carboniferous basins.

Investigations funded by UK Nirex Ltd in the Sellafield area have accelerated progress on finalising the resurvey of the Maryport (22) and Gosforth (37) sheets. The results of these investigations are being integrated with new geophysical data to produce a three-dimensional geological model of the area. The geological maps, and thematic maps at 1:25 000 designed to meet anticipated future requirements of the continuing geological investigations, are being digitally produced.

In the West Cumbria project, funded by DOE, evaluation of existing geological records and mine plans has enabled solid and drift maps of the Coal Measures and Lower Carboniferous sequences to be compiled at 1:10 000 and 1:25 000 in more detail than was possible during the previous survey almost 60 years ago. Thematic maps illustrating aspects of particular importance for land-use planning and development, such as ground stability, location of material resources, and distribution of made and disturbed ground, are in preparation. The cored boreholes through the poorly exposed Jurassic outlier west of Carlisle have been studied in cooperation with British Gypsum Ltd. The Penarth Group (late Triassic), proved for the first time in this area, is succeeded conformably by the Lias Group, comprising rocks of latest Triassic and early Jurassic age (Hettangian and early Sinemurian). This new borehole information necessitates revision of the map of the Jurassic outlier, last surveyed in the 1920s.

(Source; Annual Report of the British Geological Survey, 1990-91).

Wales

Dr. Dick Waters, Officer in Charge, Regional Office for Wales, writes:

The mapping of the 1:50 000 sheet 177 (Aberaeron) was completed this year. It comprises the final part of a mapping transect, across the Ordovician and Silurian basinal and distal shelf sequences of central Wales, initiated in 1986 as the first phase of the Central Wales Rapid Mapping Programme. The other two sheets forming the transect, 178 (Llanilar) and 179 (Rhayader) are in press and will both be published as two editions, solid and drift. Several aspects of the results of this work have recently been published in a Welsh Basin thematic issue of the Geological Magazine (Vol. 129, No. 5). A full account of the geology of the transect is to be published as a joint memoir covering sheets 178 and 179. As a way of investigating the deep structure of mid-Wales in the vicinity of the transect, a seismic refraction survey was undertaken this year between Builth Wells and Cardigan Bay. The western end of the survey line was shot at sea, using an air-gun array on the NERC research vessel RRS Charles Darwin. Although the results of this survey are still being processed, preliminary findings indicate a major fault cutting basement near the basin margin.

The 1:50 000 sheet 209 (St Davids) was published this year as a single, solid with drift edition. Forming part of the Survey's Provisional Series the solid geology is based on published and unpublished mapping from BGS and other sources, whilst the drift geology is largely the result of an air photograph interpretation. Other maps in this series currently in press, are sheet 120 (Corwen), due to be published in 1993, and sheet 121 (Wrexham).

Maps forming part of the normal 1:50 000 series and currently in press, include sheets 108 (Flint), 119 (Snowdon), 165 (Montgomery), 149 (Cadair Idris) and 133 (Bardsey). The south-eastern part of sheet 149 and the whole of sheet 133 were mapped by Aberystwyth and Cardiff Universities respectively, under contract to NERC as part of the BGS/Academic Mapping Committee programme.

The 1:250 000 bilingual map of Wales has unfortunately been delayed in press and will now be published in 1993.

Enquiries about purchase of books and maps, or details of the various aspects of BGS work in Wales, should be addressed to the Officer in Charge, (Dr R A Waters), Regional Office for Wales, Bryn Eithyn Hall, Llanfarian, Aberystwyth, Dyfed SY23 4BY; Telephone No. 0970 611038; Fax No. 0970 624822.

Publications

The Survey's Annual Report 1990/91 was published early last year. Although it costs £8 the document offers some 83 pages, superbly produced with many colour plates and containing much of interest to amateur as well as professional geologists. In sedimentological studies, for example, present day sediment from rivers draining the Moine and Lewisian terrains of northern Scotland has been analysed and shows that the two areas produce distinctive mineral suites. So it should be possible to trace back the sources of at least some of the ancient sandstones of the north of England.

In petrology, work on the calc-alkaline Lower Borrowdale Volcanic Group has revealed systematic cycles and patterns of magmatic evolution during the development of the volcanic pile. Further analyses of these suggest that disparate magma chambers and subvolcanic plumbing systems fed the lavas extruded from numerous fissures and vents. In mineral studies, results from the South Pennines confirm the view that basinal Visean-Namurian shales were a major source of mineralisation.

Other sections of the Report refer to the Survey's work on radon hazard in collaboration with the NPRB, and on methane with the Construction Industry Research Information Association. There is a fascinating section on Geoarchaeology, too, and useful appendices on BGS structure, staff disposition, finance, publications and future plans.

Other BGS publications during 1992 include the Garstang Memoir (Sheet 67) at £27; 1:50 000 drift maps for Garstang and for Settle; and two 1:25 000 sheets in the Classical Areas of British Geology series -

SD 19 Devoke Water and Ulpha, and NG 12 Lorton and Loweswater.

CONSERVATION CORNER

English Nature and the Joint Nature Conservation Committee appear to have had a quieter year with few major developments. The JNCC's principal effort has been in GCR publications. A number have now appeared, including 'Caledonian Structures in Britain south of the Midland Valley'. This volume has been edited by Jack Treagus of Manchester University and covers the Southern Uplands, the Lakes, North Wales and the Welsh Borders. Published by Chapman and Hall it is so far only available in hardback and costs £65 for 177 pages.

The main conservation effort is now concentrated on the new RIGS groups, and it is good news that a RIGS Support Officer has been appointed for two years, operating from the Lincoln headquarters of the Royal Society for Nature Conservation. RIGS groups have started work in most North of England counties and notes on progress in the North-West are given below.

Staffordshire. (Don Steward and Keith Harrison)

Maintenance work by the North Staffs Group of the Geologists' Association continued at Brownend Quarry, Waterhouses. Work on the footpath has improved public access and steps were taken to ensure that plant growth does not re-establish itself. Gannister Quarry near Mow Cop is a notified SSSI with valuable exposures of Namurian sandstones, ganisters and shales. A working party from the N. Staffs Group visited it and plans for clearance work are being prepared by Jill Smethurst, Special Sites Officer, Cheshire Wildlife Trust. Two members of the Derbyshire Caving Club investigated the bottom of the old shaft and found of all things, an abandoned boat!

In the course of a field trip to Miry Quarry, Apedale, the party was able to examine the Vanderbecki Marine Band (Lower Coal Measures) with exposures of the Banbury Rock and Banbury Coal. It was noted for the future that the exposure needs clearing of weeds and a general tidy-up.

The Forestry Commission is not certain about the ownership of the Hanchurch Quarry part of the Butterton Dyke, and has asked us to furnish it with accurate information about the exposures and their map references. We have also made inquiries about two more exposures of the Dyke at Coldmeece and north of Yarnfield. It appears that both sites are due to be filled and landscaped. Letters to the County Council have not so far resulted in a stay of execution. Notification of another RIGS has been forwarded to Staffordshire County Council; this is Highlows Farm Quarry, Coldmeece (SJ 858334) where the Swynnerton dolerite dyke is exposed and is also historically important as the first site to be chosen (1927) to prove that magnetic surveying was a viable technique in determining concealed structures.

A geological trail booklet around the Potteries is being prepared as part of the Geologists' Association guide series, publication being timed to coincide with the British Association for the Advancement of Science meeting to be held at Keele University, 29th August - 3rd September, 1993.

Derbyshire. (Pauline Jones)

Work on the Derbyshire RIGS project started in September 1991 with the objectives of recording all sites in the country with geological interest, selecting and 'notifying' RIGS and producing a separate listing of sites that would be of use to educational users. To date approximately 1000 sites have been recorded and of those 100 have been selected as RIGS. During the coming year the search for RIGS will be extended to ensure that there is a good geographical spread of sites and also to ensure that as many areas of geological interest as possible are represented. As with all RIGS groups the Derbyshire group would welcome information on sites and suggestions for sites which could qualify as RIGS. A listing of RIGS in Derbyshire is available and can be obtained from Mrs. Pauline Jones at the University of Derby, Geology Department, Kedleston Road, Derby.

Cheshire. (Tony Browne)

Satisfactory progress is being made on the scheme as more people have offered their expertise in identifying suitable sites and writing up a preliminary recording form for each site. The initial aim is to present up to one hundred site records to the local authorities covering the project area, mainly Cheshire and Wirral, but also parts of Manchester, Stockport, Tameside and Trafford, before the end of February 1993. With the appropriate authority approval, the information will be given to English Nature with requests for RIG status.

The Project is ongoing and there is still much to be done. Any enthusiast wishing to play a part in this worthwhile scheme should contact -
Jill Smethurst at Cheshire Wildlife H.Q. Grebe House, Reaseheath, Nantwich CW5 6DA. Telephone: 0270 610180. Fax: 0270 610430

(A correction to the article in The North West Geologist No. 2. RIGS will have an equivalent status to SBIs (Sites of Biological Importance) not SSSIs as appeared on page 87.)

Greater Manchester

The problems referred to in the last North West Geologist have not yet been solved, although the likelihood is that the responsibility for geological conservation will pass to the Greater Manchester Geological Unit.

MUSEUMS ROUNDUP

In these times of governmental parsimony and local authority poverty few of our museums are safe from the threat of curtailment or even closure. It is good news therefore that Buxton's excellent museum appears to be safe - for the time being at least, and with the introduction of admission charges. Transfer of responsibility from the Education Committee budget to that of the Planning and Countryside Committee has made this possible and indeed there is hope of some expansion in facilities and services. In north-east England the Hancock and Sunderland Museums have also been reprieved, and in the south -west it is now possible that the admirable little geological museum in Bath will be re-opened.

Amongst the North-West's smaller, independent museums are -

Peak District Mining Museum, Matlock Bath, Derbyshire.

After fourteen years of operation the Museum is planning major changes to its exhibitions, mostly within the next six months. Lynn Willies, Museum Project Leader, reports -

> "Behind the scenes a new area is currently being prepared for storage of artefacts, freeing space behind the first of the current display areas for a new exhibit. This will be a very dramatic and exciting "interactive" simulated mine, allowing the visitor to experience the main elements of a lead mine, and some of its dangers. It will show how mining techniques have developed over time, and will be linked to sound and light effects and to a conversation between miners as a means of introducing the complexities of the subject. As throughout the Museum since its inception, the emphasis is on "hands-on", or perhaps more accurately, sometimes "knees-on"!

It will replace the existing geological introduction to mining, which is to be moved to a new more spacious location, and will be enhanced, to explain both the mining geology of the area, and to display the sizeable related rock and mineral collections owned by the Museum. It will include a small mining geological history display, including the "greats" such as Agricola *(De Re Fossula)*, Werner and Hutton, and local men of considerable importance such as Mawe, White Watson, and Farey.

No less important - the Museum is installing a chair lift for those with walking difficulties, allowing them to easily reach the mezzanine floor displays.

There are changes planned, too, for the Temple Mine, site of the gold discovery reported recently, which is some 200 metres from the Museum. Here a small fluorspar dressing plant of 1940-60s vintage is being installed to allow a working demonstration of the main methods of mineral treatment - it includes tipper, crusher, log washer, trommel and jigs, and there will also be a demonstration vibrating table (and flotation in the longer term). Visitors will be able to use hand-methods to achieve the same results as the mechanical, with plenty of water about to practice 'bucking', 'sieving and hutching', and' buddling'. And, of course, to practice gold-panning - you never know when it might be useful! When finished, with a number of other planned installations of appropriate equipment, it will have all the facilities of a mine of about 1950 - about the last date when the layout and working of such processes remained understandable to the non-specialist.

The Museum and Mine are open every day except Christmas Day between 11.00 and 4.00 (longer at busy times), and there is a modest charge, with the usual concessions, and a "saver ticket" for those who wish to visit both Museum and Mine. There is also Britain's best stocked mining bookshop with a selection of geology items - so allow plenty of time! Special surface and underground tours can also be arranged. Phone: (0629) 583834 if you wish to bring a party.

The Salt Museum. Northwich, Cheshire

Britain's only salt museum is situated about half a mile south of Northwich town centre and the same distance from the A56 Manchester to Chester road. Described as "small, friendly and fascinating" it is housed in the old Workhouse in Northwich and its displays combine geology, chemistry and industrial history. Free car park, toilets, coffee and publications shops are provided. There is a small admission charge to the main galleries, but entry to temporary exhibitions is free. Open all the year round - 10am to 5pm Tuesday to Friday, 2 to 5pm Saturday and Sunday. Telephone: 0606-41331.

EARTH SCIENCE AT LIVERPOOL JOHN MOORES UNIVERSITY

1. Introduction

Physical Geography and Geology have been taught to honours degree level in the Liverpool John Moores University's ancestral institutions for well over twenty years, and were integrated to form an Earth Science subject area six years ago. The Earth Science single honours degree arose as an evolutionary development of Physical Geography and Geology honours degree course dating back to 1967. A B.Sc/B.A. honours degree combining Geology and Geography was validated by the University of Lancaster in 1976. Subsequent course modifications and enhancements culminated in a complete revision and revalidation of this honours degree in 1984/85. Subsequent to the C.N.A.A's validation of Earth Science combined and joint honours in 1988, the six members of academic staff were successful in having a single honours Earth Science degree validated in 1989. Since then a Professor of Quaternary Geology and two other academic staff have been appointed enabling the course team to broaden and enhance the single honours route to include more modules.

2. The Nature of Earth Science at Liverpool John Moores University

Earth Science at Liverpool John Moores University is the study of the physical environment, including the fields of sedimentology, palaeontology, geochemistry, petrology, geophysics, geomorphology, hydrology, climatology, applied geomorphology and geology, structural and historical geology and pedology. The philosophy is that the physical environment is a single system; thus the aim is to train students to recognise the holistic nature of the physical environment and to understand the interactions within and between subsystems. This is achieved mainly by the study of the processes and their responses identified within surface and subsurface systems. Applied studies are emphasised, to produce students able to make a realistic contribution to the industrial, commercial and academic worlds.

Students are presented with the opportunity to acquire knowledge and understanding of the Earth, its systems and processes, and the impact of man upon those systems. With a strong emphasis upon applications, the acquisition of a range of practical skills is an integral component of the course. Such an intellectual and practical resource base ensures the development of students with a sound understanding of various earth materials, processes, systems and landscapes.

Synthesis of these components enables the students to integrate that information, and to create the basis for evaluation and decision-making in the exploitation and management of resources and landscape. The evolution of ideas which is a feature of current Earth Science debate reflects (and is a response to) the growing awareness of society to the finite nature of many resources in the physical environment, and the identifiable need to understand the Earth's systems to ensure appropriate exploitation and management.

3. The Earth Science Course (B.Sc. Honours)

The course is taught in small units called modules. Each module has its own examination or assessment process and credits are awarded when the module is successfully completed. So credits are accumulated through the course. The aim is to earn 30 per year and when you have 90 (usually after 3 years study) you have enough to qualify for an Honours Degree. This doesn't mean that there will be 30 examinations every year! Modules vary in length with larger ones earning more credits than short ones although still having just one examination at the end. In general the modules in the final year are long and those in the first year are short (most worth 2 credits).

A credit system is very flexible. Once credits have been earned they can be transferred to other courses should you change your mind about a career. They can even be transferred between College/Universities operating CATS schemes should you need to move to a different part of the country (or even overseas). Credits can also be stored for a while if you need to take a break from study for a year or two. On returning to study the credits are brought back with you so earlier effort is not wasted.

Another advantage of a credit-based scheme is that assessment is spread more evenly through the course than in traditional modular degrees. In the latter there is normally one examination period at the end of each year on which success or failure is decided, but in a credit scheme there are several small examination 'hurdles' instead of one large 'high-jump'.

The Earth Science Single Honours route (see table 1) enables students to develop a detailed knowledge and understanding of the Earth, its structure, the operation of its component geosystems, their impact upon human activities, and the processes by which distinctive lithospheric complexes and landscapes are formed. Such a route is attractive to students with a strong 'geological/physical geographical' bias, a desire for specialisation, and to those who welcome the opportunity for such integration offered by Earth Science.

Graduates of the course (with its well-defined practical and fieldwork orientation) can expect to gain employment in a variety of Earth Science careers, e.g. Geotechnics, Hydrogeology, Resource Exploration and

Development, Resource Management, or to continue with postgraduate studies at other institutions.

Combined and Joint Honours Earth Science (see table) allow students to unite Earth Science particularly with Countryside Management/Human Geography.

The Earth Science/Countryside Management combination fosters the development of knowledge and understanding of the Earth's system structures and processes, and their interaction with the biosphere. Such a combination provides the opportunity for broad-based, integrated analysis of all four Earth systems (Atmosphere, Hydrosphere, Lithosphere and Biosphere) and thus attracts those students who wish to gain skills and competences in environmental systems from a more diverse perspective than offered by the Single Honours route.

Such a combination proves particularly attractive to mature students, who may have experience of the application of such knowledge through local geological societies, Groundwork and Naturalist Trusts, Greenpeace, Friends of the Earth etc. Graduates with such a background would expect to gain employment in education, conservation and planning, landscape evaluation and impact assessment etc.

The Earth Science/Human Geography route offers a combination of units conducive to an understanding of the spatial variation in the earth's structures and processes and their interaction with human systems. this route attracts those students who wish to study a route similar to the more traditional Geography degree routes. Employment potential for such graduates would arise in such areas as Education, Leisure and Tourism industries, Local authorities, and Information management industries.

It is anticipated that the emphasis on practical skills offered by the presence of Earth Science in these combinations, together with an ethos of Applied Science, will result in the production of more marketable graduates.

4. Teaching Methods in Earth Science

The Course Team, having had many years experience of active involvement in teaching education, are particularly concerned with providing the students in Earth Science with interesting, rewarding and enriching learning experiences. A wide range of teaching methods are employed appropriate to the particular intellectual and practical skills. Teaching methods include lectures, seminars, tutorials, laboratory practicals and field experience. At all times an emphasis is laid upon student-centred learning.

Lectures

Large first year groups are taught by traditional lecturing techniques, using illustrated material from a wide range of British and foreign locations, including extensive use of visual and audio-visual material. Lectures to smaller groups in later years do not merely convey information in this traditional manner, but also use more informal techniques. Interactive teaching methods and problem solving are introduced within the context of the lectures. At all times efforts are made to draw upon the students' own experiences.

In the second and third years, seminars are used to develop student-centred learning. Students are encouraged to become familiar with the wide range of Earth Science literature sources. In the initial stages they are expected to comprehend and synthesise carefully selected papers. Open ended literature searches become necessary at a later stage. The development of communication skills is a priority. Seminars also serve to relate theoretical and empirical methodologies.

Tutorials

Tutorials are an integral part of the Earth Science Named Route from the outset. In the First Year, they provide a framework for equalising students' previous educational experiences, as well as offering opportunities to identify particular learning problems. Subsequently they are used to reinforce lecture and practical sessions and to identify student-centred learning problems.

Laboratory Practicals

Earth Science is a practical subject, and therefore a significant amount of the students' time is spent in the laboratory. They are expected to work either in small groups or individually on student-centred, guided projects. Learning packages include course booklets, tape-slide programmes, videos and instructional and interactive computer programmes. It is necessary to utilise open laboratory learning in addition to formal practical sessions. Staff are available for consultation to deal with specific problems, and to monitor student progress. This ensures that theoretical and practical learning are synchronous.

Fieldwork

Fieldwork is an integral and essential component of Earth Science. Each 6 credit module requires students to spend at least six days in the field. In addition, the Final Year Project is normally field based. These demands are based upon the need to develop an appreciation of in situ relationships, and to deepen the student's understanding of specific Earth Science phenomena, processes and materials.

In the First Year, small groups and individuals are assigned to specific tasks, covering a wide range of Earth Science techniques. In Part II, the more specific nature of the course modules demand more individual or paired studies, helping students to assume responsibility for their own learning strategies. Staff monitor student progress both in the field and in the office.

At all stages, the field experience is supported by formal and informal discussions, to examine and interpret observations and measurements.

Information Technology

Information Technology is introduced in the first year, in the Natural Science Methods module, when students are introduced to both mainframe and micro-computer technology, involving the use of commercial software to solve specific Earth Science problems. Statistical packages, work processing, spreadsheets and databases are introduced.

In Part II, these techniques are developed in all courses, but receive particular emphasis in Earth Science Methods when students are encouraged to use computer aided design for data handling, and graphical and cartographic reproduction.

There is particular emphasis upon information technology applied to land surveying and remote sensing. Commoner remote sensing techniques are studied, with an emphasis upon their application to specific problems.

The Project

The aim of the Project is to enable the student to demonstrate a level of understanding of current Earth Science debate and the ability to conceive, investigate and synthesise a problem competently. Students choose a topic by Easter in the second year, in consultation with tutors. The specific topic must involve fieldwork and must be original. The range of topics suitable for investigation at Honours level is very considerable.

Discussion with staff will include an introduction to previous work, field and laboratory techniques, and the location of possible field sites/areas. A member of academic staff will normally visit each student in the field at an appropriate time.

Coursework

The emphasis placed upon coursework in Earth Science reflects the importance that the Course Team place upon the acquisition and application of skills and techniques in the laboratory and in the field. Coursework will include formal essays, seminar presentation, laboratory practicals, fieldwork assignments and the presentation of projects based upon a combination of all these methods. The balance between these components will vary from module to module.

5. Entry Requirements

Applicants must normally have GCSE/GCE O level qualifications in an approved mathematical subject and in an approved science subject, as well as two A levels; AS level qualifications are equally acceptable. Mature students will be considered individually. For further information please contact:-

The Admissions Tutor, Mr. Neil Bowden 051-231 2088,
Earth Science, Liverpool John Moores University,
Byrom Street, Liverpool L3 3AF

Joe Crossley
(Course Leader)

Table 1 . Modules in Earth Science (Levels 1, 2 and 3)

The student programme for each Level consists of modules totalling 30 credits - a credit being 30 hours of student learning. Progression from Level 1 to Level 2 and Level 3 is dependent upon the student successfully gaining 30 credits at Level 1 and Level 2 respectively.

		Credits	Single Hons.	Joint Hons	Major	Minor	Cert.	Dip. HE
Level 1								
NATES100	Hazards and Environment	2	√√	√√			√	√
NATES101	Earth Materials	2	√√	√√			√	√
NATES102	Earth Surface Processes	2	√√	√√			√	√
NATES103	Environments in Time and Space	2	√√	√√			√	√
NATES104	Applied Earth Systems	2	√√	√√			√	√
NATES105	Structural Geology	2	√√	√√			√	√
NATES106	Geochemical Systems	2	√	√				
NATES109	Earth, Origin and Structure	2	√√	√				
NATES110	Invertebrate Palaeontology and Evolution	2	√√	√				
NATES111	The Making of the British Isles	2	√√	√				
NATES112	Methods of Fieldwork	4	√√					
NATGN109	Methods in Natural Science	6	√√	√			√	√
(may be shared with Countryside Management - 3 credits each)			28-30	12-18			<12	
Level 2								
NATES200	Fluvial Systems	3	√√	√	√	√		√
NATES201	Soil Science	3	√	√	√	√		√
NATES202	Landscape Processes	6	√√	√	√	√		√

NATES203	Sediments in Time and Space (NATES103)	6	√√	√	√	√	√
NATES204	Crystalline Rocks and Processes	6	√√	√	√	√	√
NATES205	Earth Science Methods	6	√√	√	√	√	√
NATES206	Solid Earth Geophysics	3	√	√	√	√	√
			27-30	12-15	12-24	6-12	<24
Level 3							
NATES300	Quaternary Studies (NATES 202, NATES200)	6	√	√	√	√	
NATES301	Applied Soil Science (NATES201)	6	√	√	√	√	
NATES302	Applied Geomorphology (NATES202)	6	√	√	√	√	
NATES303	Geological Evolution and Resources (NATES203)	6	√	√	√	√	
NATES304	Plutonic Studies (NATES204)	6	√	√	√	√	
NATES305	Engineering Geology (Any 12 credits from Level 2)	6	√	√	√	√	
NATES306	Exploration Geology (Any 12 credits from Level 2)	6	√	√	√	√	
NATES307	Project (Any Level 2 module)	6	√√	√	√	√	
			30	12-15	12-24	6-12	
			(1)	(2)	(3)	(4)	

√√ Core Module
√ Optional Module

Prerequisites are listed in brackets where appropriate.

Degree students are required to gain 45 credits at Levels 2 and 3 including a Project (3 credits).

(1) BSc Hons Earth Science; (2) BSc Joint Hons (Earth Science and another Subject); (3) BSc Combined Hons (Earth Science with another subject); (4) BSc Combined Hons (Another subject with Earth Science).

FIELD EXCURSIONS

Manchester Geological Association visit to the Clitheroe Limestones

led by
Adam Czarnecki (Senior Geologist, Robinson Fletcher) and
Peter del Strother (Works Manager, Castle Cement)
Sunday, May 10th 1992

Introduction

The object of the excursion was to examine the succession and structure of the Lower Carboniferous (Dinantian) in the immediate vicinity of Clitheroe.

In the morning the group examined the Chatburn Limestone Group, a thick sequence of argillaceous limestones and minor shales well exposed in Castle Cement's Lane Head Quarry. In the afternoon the Waulsortian mudmound at Coplow was visited to demonstrate its regional context and rich echinoderm fauna. Both of these localities are private property, and thanks are due to Castle Cement for permission to visit them. Some of the group also took part in a guided tour of the Cement Works in the late afternoon.

Other good local exposures such as those in the Salthill SSSI, in the road cutting on the bypass, and under Clitheroe Castle were omitted. These are always accessible. A guide to the Salthill SSSI is available from the Tourist Information Office in Clitheroe (Grayson 1981).

Regional Context

The rocks outcropping the area are predominantly of Dinantian age and consist of a varied sequence of limestones and shales with subordinate sandstones. Certain facies are highly fossiliferous.

These deposits were formed in the relatively deep waters of the developing Craven Basin. The basin was of half-graben nature modified by contemporaneous faulting. There is evidence of evolution from ramp to slope deposition (Gawthorpe 1986 and 1987).

A number of Waulsortian carbonate mudmounds formed during the early Dinantian. The origin of the Waulsortian mudmounds is still contentious, but it seems increasingly accepted that they accumulated under biological control, possibly algal.

A number of stratigraphic schemes have been established for the Dinantian in the Clitheroe district; see particularly Miller and Grayson 1972, Fewtrell and Smith 1980, and Riley 1990. Miller and Grayson is used here (Table 1).

GROUP	FORMATION		Thickness (m)
WORSTON SHALE GROUP	*Bollandoceras hodderense* Beds		5.5 - 16
	Cephalopod Shales		up to 580
	CLITHEROE LIMESTONE COMPLEX	Salthill Cap Beds unconformity	0 - 45
		Salthill Bank Beds	10 - 365
		Peach Quarry Limestone	61-92
		Upper Coplow Shales	80+
		Coplow Bank Beds	C. 100
		Lower Coplow Shales	100
CHATBURN LIMESTONE GROUP	Bold Venture Beds		127
	Bankfield East Beds		143
	Horrocksford Beds		23
	Undivided Chatburn Beds (base not seen)		--

Table 1

The Craven Basin Waulsortian mudmounds are of Chadian age; deposition of mudmounds at Waulsort in Belgium and in the Derbyshire/North Staffordshire area also took place in the Chadian. For a guide to the echinoid fauna, see S. K. Donovan, 1992. For a detailed synthesis of research on carbonate sediments and rocks, see Tucker and Wright, 1990.

Locality 1

Locality 1 provided an overview of the quarry with the Clitheroe Anticline striking approximately east/west with its fold hinge horizontal. On the north side of the anticline the beds were seen to dip highly variably to the north, whilst to the south the dips were a uniform 30 to 40 degrees.

Locality 2 (Fig. 1)

At an old mineral loading point on the north side of the anticline, the Horrocksford Hall Thrust was located. The Chatburn Limestone beds were observed turning in the space of a few metres from horizontal to more than 90

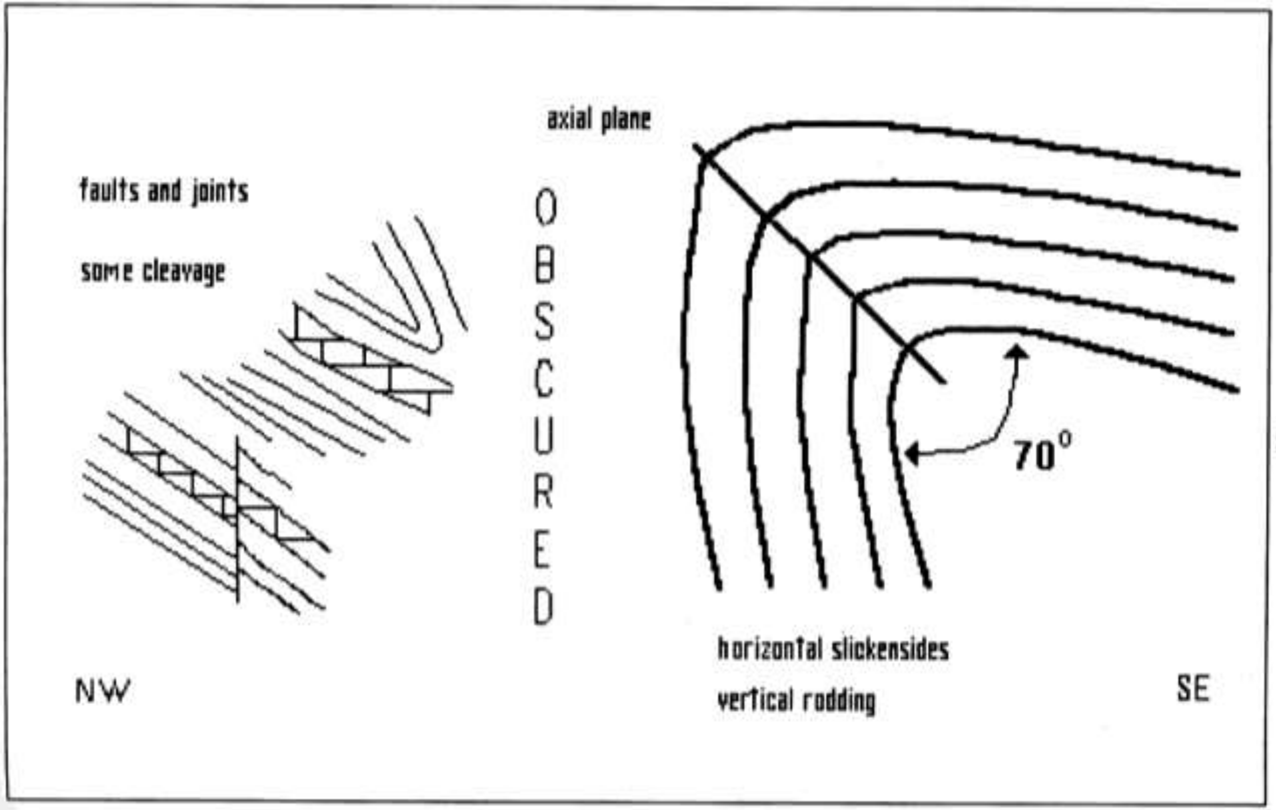

faults and joints
some cleavage
NW
axial plane
OBSCURED
70°
horizontal slickensides
vertical rodding
SE

Figure 1.

degrees. The competent beds showed horizontal slickensiding on some surfaces, and vertical rodding on others.

The contact was not exposed, but less than ten metres away the underlying (presumed) Worston Shales were exposed. The estimated minimum throw on the thrust was therefore circa 600 metres. The shales are described in the Clitheroe Memoir as isoclinally folded turbidites. The folding was not obvious, but cleavage/bedding relationships, disrupted limestone beds and at least one tight fold were consistent with that interpretation. That they were turbidites was not confirmed, although there was limited evidence of sharp, fine to coarse contacts and a few (transported?) crinoid fragments in the occasional limestone beds.

The disruption to these relatively soft shales caused by the overthrusting of the Chatburn Limestone extends at least as far as the Ribble, some 100 metres to the north. There (but not visited on this occasion) a series of monoclines is exposed in the bed of the river. These are best seen 10 to 50 metres downstream of West Bradford Bridge on the south bank, where perhaps six fold hinges can be discerned.

Locality 3

A short stop was made where a cutting had been made through part of the Chatburn Limestone and overlying boulder clay. The boulder clay contained well-rounded fragments of limestone - probably from further up the Ribble Valley, as some contained *lithostrotion* type fossils in a very pale limestone matrix.

Near this cutting, which was very close to the Horrocksford Hall Thrust, the limestone was seen to be very fractured and shot through with calcite veining. Certain of these infilled fractures were en-echelon and sigmoidal.

There was also evidence of mineralisation. Although some sphalerite is found in dolomitised limestones associated with faults in the Clitheroe area, none was found here. What was interesting was pyrite which here was found to be concentrated in certain thin (10 to 30 mm) beds, but not apparently associated with the fault. No convincing explanation was agreed upon.

A well weathered surface of one of the shales was examined. A number of the fossils were identified, including abundant bryozoa, *syringopora*, brachiopods, and zaphrentid corals.

Locality 4

The party then moved on to the Waulsortian mudmound at Coplow where an exposure of the Lower Coplow Shales was examined. Bedding planes were covered with a profusion of crinoid columns and occasional echinoid plates.

Certain bedding planes were 'wavy' due to bottom current action, or to later deformation. Geopetal infillings suggested originally horizontal deposition.

Within the mudbank facies were found a number of vugs, often infilled with dolomite.

Further into the quarry, screes from the Lower Coplow Shales yielded many crinoid cups and two complete echinoids.

Acknowledgements

Thanks are due to Adam Czarnecki for preparing and leading this excursion. Any errors in this account are mine.

Peter del Strother

References

Donovan, S. K. 1992. A field Guide to the fossil echinoderms of Coplow, Bellman and the Salthill Quarries, Clitheroe, Lancs. North West Geologist, No. 2.

Earp, J. R. et al. 1971. Geology of the Country around Clitheroe and Nelson, Mem. Geol. Surv. G.B. London, HMSO.

Gawthorpe, R. L. 1986. Sedimentation during carbonate ramp-to-slope evolution in a tectonically active area; Bowland Basin (Dinantian), Northern England. Sedimentology. Vol. 33.

Gawthorpe, R. L. 1987. Tectono-sedimentary evolution of the Bowland Basin, Northern England during the Dinantian. J. Geol. Soc. Lo. Vol. 144.

Grayson, R. F. 1981. Salthill Quarry Geological Trail. Nature Conservancy Council.

Miller, J. and Grayson, R. F. 1972. Origin and Structure of the Lower Visean "reef" limestones near Clitheroe, Lancs. Proc. Yorks Geol Soc. Vol. 26.

Riley, N. J. 1990. Stratigraphy of the Worston Shale Group (Dinantian), Craven Basin, North West England. Proc. Yorks Geol Soc. Vol. 48.

Tucker, M. E. and Wright, V. P. 1990. Carbonate Sedimentology. Blackwell Scientific Publications.

MANCHESTER GEOLOGICAL ASSOCIATION FIELD EXCURSION TO ROOLEY MOOR, LANCS.

led by JOHN STOPFORTH
Saturday, September 3rd, 1992

The object of this excursion was to examine the upper Namurian and lower Westphalian rocks on Rooley Moor. This is an area of high moorland, lying to the north of Rochdale, which at the present time appear to be rarely visited by geologists (although it has been the scene of intense activity in the past).

The party assembled at 10.30am on a dull day in almost continuous drizzle on the edge of the Moor some 100 metres to the north of Catley Lane Head on the old road - itself a relic of the Industrial and pre-Industrial Revolution communication routes. Before that time, many of the Pennine valleys were virtually impassable, being blocked by woodland and scrub so that the roads and pack-horse trails ran over the relatively clear hill-tops.

On a good day the view from this point allows distant sightings of Mow Cop and the hills of North Wales. But not, regrettably, on this occasion! Eastwards could be seen Brown Wardle and the line of hills alongside the Whitworth Valley over which ran the second of the two old routes north from Rochdale. It was called "Limers Gate" since along it, supposedly, limestone was brought by pack-horse. The most obvious source of the limestone would be the Ribblesdale quarries. But an alternative explanation is that the limestone was collected as erratics from the glacial till left by the Ribblesdale Ice in the Burnley district. It is known that limestone was extracted by "hushing" [1] in this area.

Locality 1 (see Fig. 1)

At this stage the road is still in a good state of repair with the sets in excellent condition. A small north-east to south-west fault passes through this point contrary to the more usual direction. It cannot be seen but to the south of it the Helpet Edge Rock is exposed and to the north, the Darwen Flags (Fig. 2). These have been quarried quite extensively on both sides of the road though many of the workings have been filled with tipped material.

Some time was spent in comparing the features shown on the geological map with the features visible in the surrounding countryside. It was immediately obvious that there were considerably fewer faults drawn on the area of the moor, in marked contrast to the very large numbers in the lower ground surrounding the area. This would seem to lend support to the current view that the "Rossendale Anticline" is not so much an anticline, but more a fault controlled feature over a rigid block. However, the point was made that the strata in the

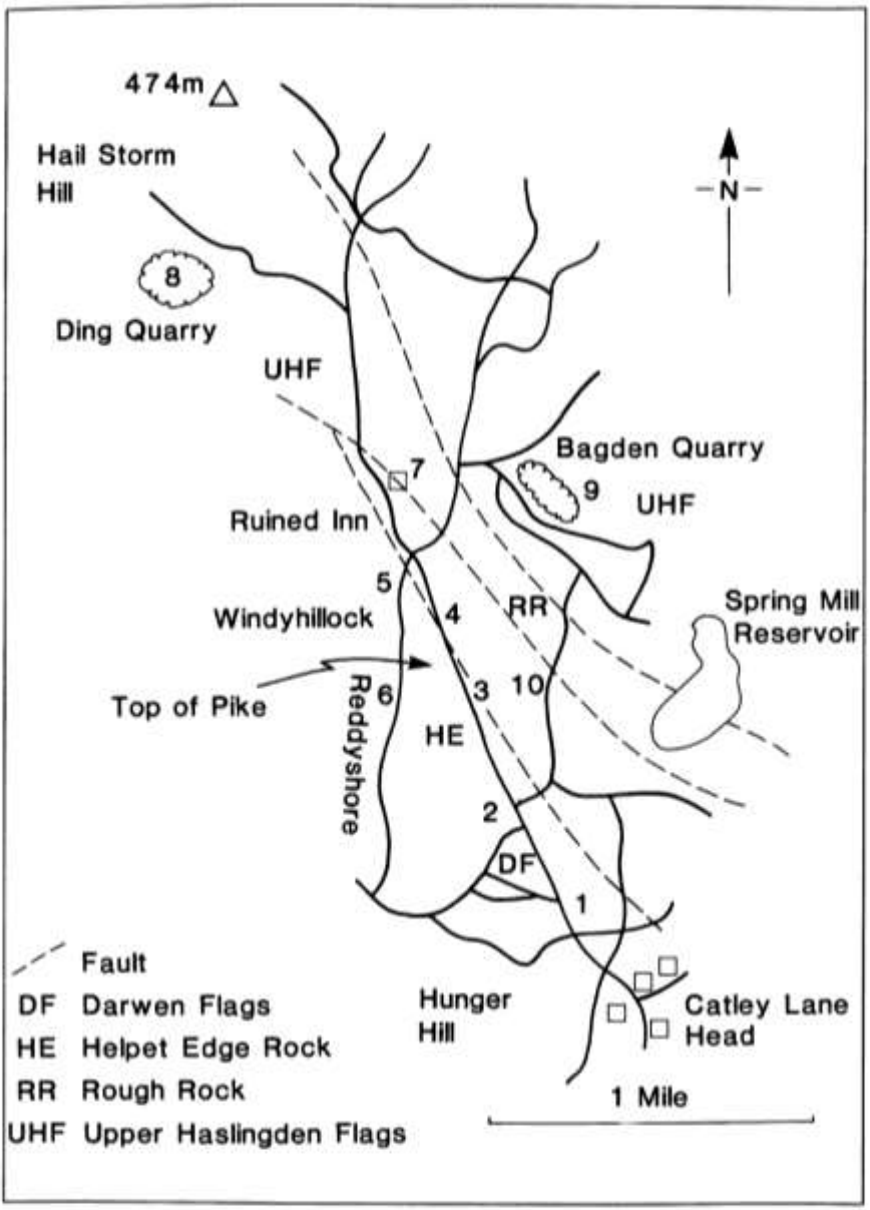


Figure 1. Sketch map of the Rooley Moor area.

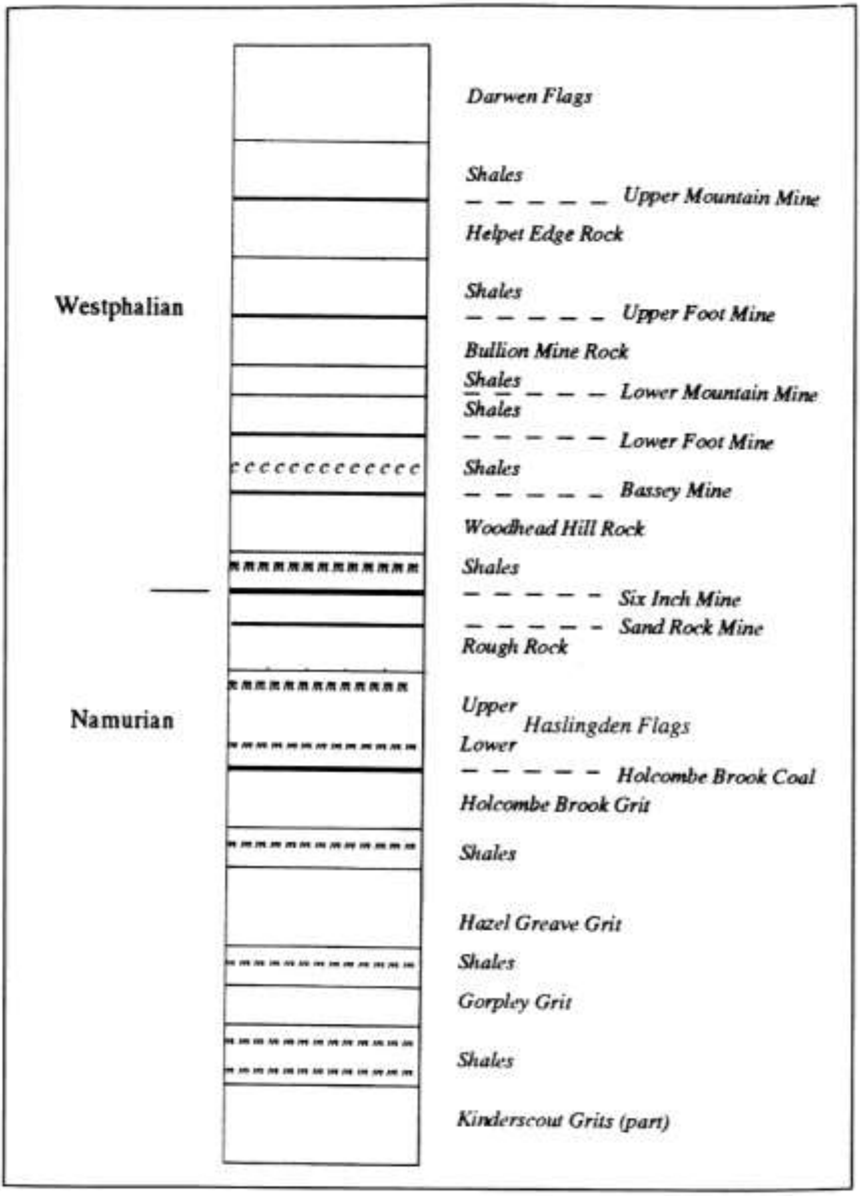


Figure 2. A simplified Geological Column for the area around Rooley Moor.

lower ground are obscured by till and glacial sands; the faults were found and mapped during the mining activities which have been much more frequently carried out there than on the higher ground. So the difference in the numbers of faults may be more apparent than real.

To the west could be seen evidence of spoil heaps and a pond which marks the site of Rooley Moor Colliery where the Upper Foot or Bullion Mine coal was worked. The coal seam had a fairly uniform thickness of about one foot (hence the name) but its high sulphur content meant that it was not mined as frequently as other seams. The Upper Mountain Mine coal was notable by its absence in this colliery. The gap in which the colliery is situated, between Hunger Hill and Whimsey Hill, stands at 300 metres and is the second highest glacial meltwater channel for waters draining from a westerly direction.

Some distance to the east was a small spoil heap and a capped shaft.

Locality 2 was an old overgrown quarry in the Darwen Flags and although long since abandoned, it still has several interesting features. The stone is not uniform throughout its thickness. The lower part is quite blocky and very hard and as such the stone was valuable for building and for road sets. The upper part is more flaggy, much of it with flakes of mica and with ripple marks, and dipping approximately 5° to the south east. Above the quarry the glacial till is exposed with pebbles - some local but others indicative of an origin via Irish Sea Ice.

The party walked up the road towards the brow of the hill (**Locality 3**) where the Helpet Edge Rock is exposed and examined a small quarry to the east of the road in which Helpet Edge Rock is exposed with interesting slickensliding effects. Along the road itself, it was quite easily possible to trace the outcrops of the harder rocks since the builders had not laid sets at these points. On a clear day the view from the Top of Pike is extensive, - but not on this occasion! Beyond the brow of the hill and into the dip beyond, the road passes over both the Upper and Lower Foot Mines and on to the Woodhead Hill Rock.

At **Locality 4**, the bottom of the dip, there is the highest of the glacial meltwater channels at 400m where the water has taken advantage of a fault to erode the softer shales and coals below the Helpet Edge Rock. From this point could be seen in the east the Lower Coal Measures of the hills above the Whitworth valley, Brown Wardle and Rushy Hill; whilst to the west is Knowle Hill where Lower Coal Measures are exposed on the dip slope of the Rough Rock (approximately 5° SE).

At the bottom of the dip where a path crosses the road there is a small exposure of the Woodhead Hill Rock. **Locality 5** is a few yards to the south-east. At this point there are signs of adits having been driven into the hillside, apparently to extract the Lower Mountain Mine which was of considerable economic importance in the district. The Lower Foot Mine did not have the same value and has therefore been left. It is exposed near the top of the face and on the mounds in front. There is about a foot of coal still to be seen, with its seat earth. Below this are about 2 metres of sandy shale; this band containing *carbonicola*. The Bassey Mine should lie somewhere below at the foot of the slope. But only an iron-rich seepage can be seen although this is characteristic of the Bassey Mine. It was known in the district as the Dirty Yard Mine and is said by Wright [2] not to have been worked. But looking at the ground, there are all the signs of its having been extracted here and a little further round the hillside on Windy Hillock.

Locality 6 was Reddyshore where the Upper Foot Mine or Bullion Mine is exposed half way up a steep cliff. The shales above this are highly fossiliferous with a rich fauna including *gastrioceras listeri*. Unfortunately, however, these shales are highly weathered and only fragments were found, with one specimen of an orthocone nautiloid. The general appearance of the cliff, and the debris at its foot, gave us the impression that it had perhaps been formed by a landslip.

From here it was intended to visit **Locality 7** where there is another fault which allows the Rough Rock to outcrop, and **Locality 8** (Ding Quarry) where the Haslingden Flags were both quarried and mined. But in view of the weather it was decided not to venture across the open moorlands.

Instead the party walked directly to Bagden Quarry, **Locality 9**. This quarry is also in the Haslingden Flags but has all the appearance of having been abandoned in a hurry. There are flagstones all stacked up as though ready for use. It is possible to trace the different beds of rock and see how their lithology has made them suitable for the different applications.

Locality 10 was visited on the return journey and just under the Top of Pike. At this point coal-bearing spoil heaps have set on fire and left large lumps of shale, turned red and glued together by the burning of the tars.

References

1 Thornber, J. T. The Mystery of the Sheddon Valley. Proc. North East Lancashire Group of the Geologists' Association. 3.24. pp 428-440.

2 Wright et al. 1927. The Geology of the Rossendale Anticline. Mem. Geol. Surv. GB. London HMSO.

John Stopforth

BOOK REVIEW

GEOLOGY OF ENGLAND AND WALES

Edited by P. McL. Duff and A. J. Smith
The Geological Society of London 1992. 651pp. £34 Softback.

This book has been written by no fewer than twenty two authors, all well known geologists of stature with varying academic and industrial backgrounds. The text covers the stratigraphy of England and Wales from the Precambrian to the Quaternary, the igneous rocks, geological structure, deep geology and economic geology. It also covers the offshore geology of England and Wales, an important feature omitted from the book's title. This is surprising in view of the vital economic role these offshore areas have played and still play for the United Kingdom as a whole.

The book claims to present the geology of England and Wales "particularly in a stratigraphical context". This statement I took as a health warning and indeed in various places in the book (especially in the earlier chapters) there are tracts of text heavily loaded with rock formation names and fortified with long lists of fossils. Such texts reminded me of papers I was obliged to read some forty years ago as an undergraduate student. However, elsewhere in the book the text comes to life with discussions of depositional environments, radiometric dating, plate tectonic settings, structure, mineralisation, and other aspects of geology which have come to the fore in recent years. Of course, with so many authors, the approach taken is bound to be varied. This, combined with the broad range of readership targetted (practically anyone with a geological interest, to judge from the blurb on the book's cover) will ensure that reactions to the book will be mixed.

A feature of this book that needs to be emphasised is its value as a guide to recent literature on the geology of England and Wales (and adjacent offshore areas). Whatever the approach taken by individual authors, all have made reference to recent work in their chosen areas. This is the book to look up the answers to those geological questions to which you know there is an answer but cannot recollect where the answer was published.

The layout of the book is generally attractive. In the copy I have seen the text on some pages was uneven to the extent that some lines, even paragraphs, appear to have been set in bold type. The diagrams and photographs are numerous and generally excellent. Figure 19.1 appears to have been lost. There is an index.

For a book of this scope and size (651 pages) the price of £34 is more than reasonable. The book is a 'good buy' if you can afford it. If not, then every effort should be made to persuade all friends, colleagues and libraries to buy the book and then hope that you can borrow it in the future.

Fred Broadhurst

FOR YOUR LIBRARY LIST OR BOOKSHELF

G. Y. Craig ed. 1991. Geology of Scotland. Third edition. Geological Society of London. pp608. £29. Softback.

A new edition of this classic work. Several new authors and rewritten chapters in a volume one-third larger than the second edition. May seem pricy but still excellent value.

Staffordshire Wildlife Trust. 1992. Brown End Quarry Geological Nature Reserve.

The official guide to this new SSSI produced with the help and guidance of the North Staffs Group of the Geologists' Association. Available from the Trust, Freepost, Stafford ST18 0BR. £1 post free.

R. M. C. Eagar and F. W. Dunning. 1992. The Geological Column. 7th edition (revised). Available from Printguide Ltd, Southmoor Road, Wythenshawe, Manchester M23 9NR. 95p plus 18p postage.

A new edition of this invaluable little publication with six panels - chief divisions of geological time; plate tectonic processes; major mountain-making movements; palaeoclimates; stages in plant evolution; evolution of animal life.

The Geologists' Association Guides

Guides still available include the Lake District, the Yorkshire Coast, The Manchester area. Look out in 1993 for - the Isle of Man (Trevor Ford), the Dorset Coast (revised 2nd edition by M. R. House). Also, we are told, 'Iceland' and 'Cyprus' are on the horizon.

P. McL. Duff ed. 1993. Holmes' Principles of Physical Geology. Fourth edition. Chapman and Hall. pp791. Softback £24.95.

Still surely the best introduction to the Earth Sciences for the Thinking Person. Sticks pretty closely to the chapter layout of the earlier editions but extensively revised and brought up to date by a team of contributors (mostly from Edinburgh University). 'Suspect terranes' and 'mantle plumes' find a place, and 'Further Reading' includes 1992 references. Many new illustrations, some in colour. Weighs over 6lbs and so is not suitable for reading in your bath!

PROCEEDINGS OF THE LIVERPOOL GEOLOGICAL SOCIETY

1991/92 - 133RD SESSION

1991

Oct. 15 - The Presidential Address by Dr. Rodney Wright. "Tertiary Volcanoes of the Hebrides'. Hon. Treasurer's and Hon. Secretary's Reports.

Oct. 27 - Llangollen with Philip Phillips.

Oct. 29 - The Distinguished Visitor's Address - 'Sediment Calibre: the link between Clastic Depositional Systems. Are there Macrosystems?' by Harold G. Reading.

Nov. 12 - 'The Naivasha Volcanic Complex, Kenya Rift Valley: hot, flushed and ready to go!' by Ray MacDonald.

Nov. 19 - Practical Session at Liverpool Polytechnic on Geological Maps with Joe Crossley and Hazel Clark.

Dec. 3 - 'The Devensian Stage - an Update' by Professor Peter Worsley.

Dec. 10 - 'The Geology of French Wine' with Geoff Tresise.

1992

Jan. 21 - 'Mersey Barrage Geology' by Brian O'Connor', a Joint Meeting with the N. W. Regional group of The Geological Society.

Feb. 4 - 'Belemnites' by Simon Mitchell.

Feb. 7 - The Society Dinner at the Bluecoat Cafe Bar.

Feb. 18 - 'Storm Deposits' by Joe Crossley

Feb. 22 - Practical Session at Liverpool Museum on Multimedia Geology with Philip Phillips.

Mar. 8 - Alderley Edge with Tony Browne.

Mar. 10 - 'Mount Etna' by Mick Wright.

Mar. 13-16- North Yorkshire with Joe Crossley, Hazel Clark and Richard Pepper.

Mar. 24 - 'Microseismic Monitoring - a Tool for Predicting Catastrophic Failures in Geological Context' by Peter Styles.

May 17 - Mapping in North Staffordshire with Chris Hunt and Hazel Clark.

Jun. 23 - Thurstaston Country Park and the Dungeon with Philip Phillips.

Jul. 5 - The Torrs, New Mills with Derek Brumhead.

Jul. 25 - Ravenhead (Steetley) Brickworks, Upholland with Hazel Clark.

Sep. 27 - Loggerheads with Chris Paul.

Officers and Members of Council - 133rd Session

President - Dr. R. C. Wright, M.A., D.Phil.
Ex-President - Prof. A. L. Harris, B.Sc., Ph.D., M.I. Geol., F.G.S.
Vice President - Mrs. H. Davies, M.A.
Hon. Secretary - J. D. Crossley, B.Sc., Cert.Ed., M.I. Geol., F.G.S.
Hon Asst. Secretary - Mrs. J. V. White
Hon. Treasurer - G. W. Rowland, M.I.M.B.M.
Hon. Asst. Treasurer - Miss E. M. Bailey
Hon. Editor (Geol Journal) - Dr. P. J. Brenchley, M.A., Ph.D.
Hon. Editors (N.W. Geologist) - N. C. Hunt, B.Ed. & T. Metcalfe, B.A.
Hon. Librarian - Mrs. L. Rimmer, A.R.I.C.
Hon. Excursion Secretary - Miss H. E. Clark, B.Sc., M.Sc., A.M.I. Geol.
Hon. Treasurer Special Issues Fund - G. G. Harden, L.D.S.
Hon. Archivist - P. W. Phillips, B.Sc., A.M.A.

COUNCIL

L. J. Baxter, B.A.
Mrs. D. Bowcock
N. Harrison
Miss B. Jones
A. Clark
Mrs. A. Ellis.
Mrs. M. E. Williams, B.Sc., Cert.Ed.
C. R. C. Paul, M.A., Ph.D.
C. Rigby
D. L. Williams, B.Sc.

Membership on 30th September 1992:-

212 Ordinary Members, 43 Student Members, 5 Honorary Members and 3 Life Members - Total = 263

The Liverpool Geological Society Prizes for General Excellence in the University of Liverpool, Geology, Physical Geology and Geomorphology and Geophysics Honours Degree Finals were awarded to:-
A. Lind, D. Sherwin and M. J. Oppenheim respectively; in the Liverpool Polytechnic Miss C. J. Whitmore for General Excellence in the C.N.A.A. Earth Science Honours Degree Finals.

J. D. Crossley
(Honorary Secretary)

PROCEEDINGS OF THE MANCHESTER GEOLOGICAL ASSOCIATION

1991-1992 - Session

1991

Apr. 24 - 'Conversazione' with an exhibition of minerals by Jim Francis.

Apr. 27 - Field excursion to examine Namurian and Westphalian strata north of Bolton - Kevin Riley.

May 12 - Field excursion to examine the Lower Coal Measures succession in Lyme Park, Disley - Elaine Walker.

Jun. 9 - Field excursion with OUGS (NW Branch) to the National Stone Centre at Wirksworth.

Jul. 13 - Field excursion to examine the New Red Sandstone of the Wirral at Mill Road cutting - Dr. Tim Robinson.

Sep. 11 - Indoor meeting on 'Minerals' by Jim Francis.

Sep. 14 - Annual Dinner of the Association at Hulme Hall.
Guest of Honour: Professor Charles Curtis.

Sep. 29 - Field excursion to examine the Pleistocene deposits of Cheshire - Dr. Elizabeth Oldfield.

Oct. 6 - Field excursion to examine the quarries and building stones in and around Macclesfield - Dr. Fred Broadhurst.

Oct. 9 - 'Changing climates of the geological past. Do they shed light on our present concerns?' - Dr. Fred Broadhurst. (A joint lecture with the Manchester Branch of the Geographical Association).

Nov. 13 - 'Dynamic Iceland: geology and geomorphology' - A. C. Benfield of University of Hull.

Dec. 11 - 'Upper Carboniferous marine transgressions and their deposits' - Dr. J. Maynard of University of Leeds.

1992

Jan. 15 - 'Tin mining in Cornwall and Thailand: contrasting cultures tackle similar geology' - Dr. D. Manning, University of Manchester.

Feb. 12 - Annual General Meeting and Presidential Address by Dr. Paul Selden - 'Fossil Spiders'.

Mar. 11 - 'The tectonics of mountain belts in central Asia' - Dr. M. Allen of University of Leicester.

Officers and Members of Council

President - P. A. Selden, B.Sc., Ph.D.
Vice-Presidents - A. E. Adams, B.A., Ph.D.
- D. C. Arnott, M.B.A.
Hon. Secretary - D. D. Brumhead, M.A., M.Ed.
Hon. Treasurer - G. M. Henderson
Hon. Excursion Secretary - Norma Rothwell, B.A.
Hon. Editors (Geol. Journal) - R. M. C. Eagar, M.A., Ph.D., D.Sc.
- A. E. Adams, B.A., Ph.D.
Hon. Editors (The North West Geologist) - G. D. Miller, B.A.
- Sheila Owen, B.A.
Hon. Librarian - M. T. Elsworth
Hon. Auditor - E. Foster M.A.

R. Clarkson
J. Nudds, B.Sc., Ph.D.
J. E. Siddelly, B.Sc.
J. Spencer, B.Sc.
D. Wilde, B.Sc. (Eng.)

W. A. Kennett, B.Sc.
J. A. McCurdy, M.Eng.
J. Stopforth, M.Ed.
Betty Whitehead, B.Sc.
President of University of Manchester Geological Society (Ex Officio)

Membership Spring 1993

181 Ordinary Members, 19 Student Members and 4 Honorary Members - Total = 204.