OLD RED SANDSTONE OF THE BLACK MOUNTAINS

Duncan Hawley and Geraint Owen

View E over the Rhiangoll valley from near locality 8, the Allt Mawr ridge and the S flanks of the Black Mountains,

PLEASE NOTE: This itinerary is an extract from a book partly compiled during the 1990s. The text and photographs reflect the geological knowledge of that time as well as the accessibility of the locations.

Please ensure that you ask permission from landowners to visit any of the locations mentioned in this text, which are on private property and that you are suitably equipped for rough terrain and fickle local weather.

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OLD RED SANDSTONE OF THE BLACK MOUNTAINS

Duncan Hawley[1] and Geraint Owen[2]

1 Swansea School of Education, Swansea Metropolitan University, Townhill Campus, Swansea SA2 0UT (duncan.hawley@smu.ac.uk)

2 Department of Geography, Swansea University, Singleton Park, Swansea SA2 8PP (g.owen@swansea.ac.uk)

Maps *Topographical:* 1:50 000 Landranger 161 (Abergavenny and the Black Mountains)
1:25 000 Explorer OL13 (Brecon Beacons National Park - Eastern area)

Geological: 1:250 000 Mid Wales and the Welsh Marches (Solid, 1990) and Geological Map of Wales (1994)
1: 50 000 Sheets 214 (Talgarth), 215 (Hay-on-Wye) and 232 (Abergavenny)

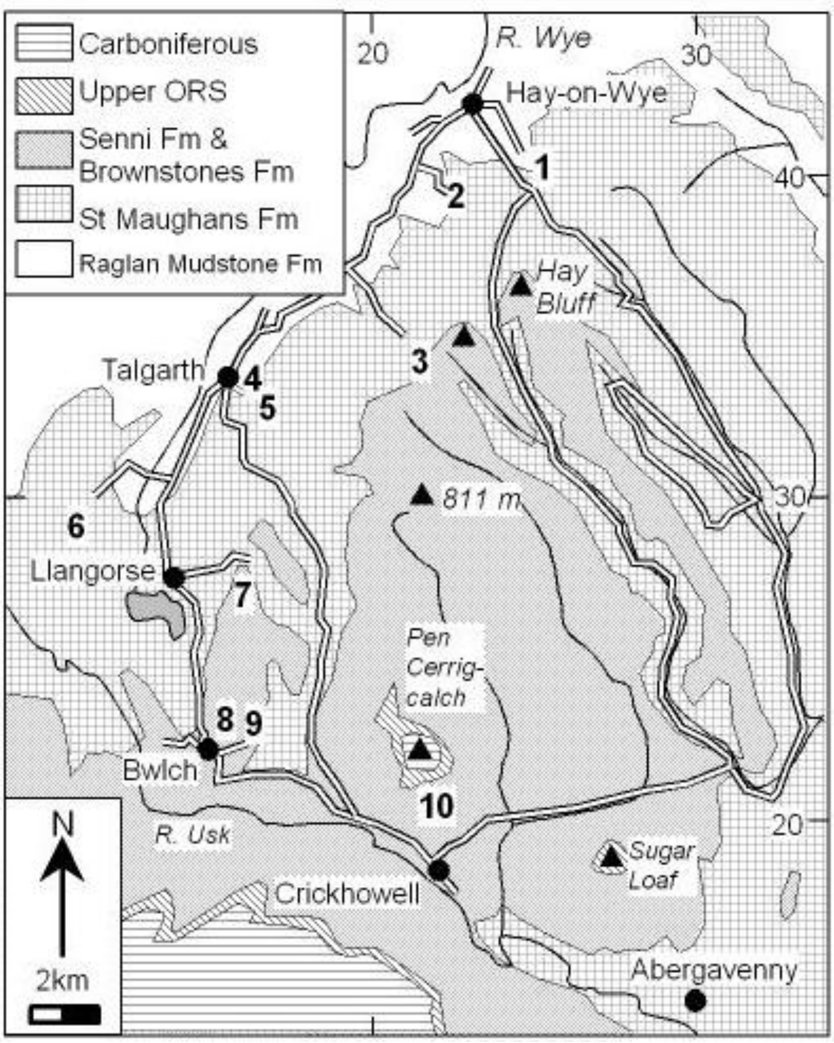

Figure 1. Location map for the itinerary. Geology simplified from 1:250,000 Geological Map of Wales.

The Black Mountains are a dissected upland plateau of Old Red Sandstone extending from SE Powys into Herefordshire, England, reaching 811 m elevation on Waun Fach (SO 216 300), drained to the SE by deep, sub-parallel valleys, and separated from the prominent outlier of the Sugar Loaf in the S by the Grwyne Fawr valley (Fig. 1). The geology was first explored by Murchison as part of his quest to define the Silurian system (Murchison 1839), and was systematically mapped by the Geological Survey between 1845 and 1857. McCaw (1936) published a rudimentary description and map based on work by King (1934). From the 1930s to the 1950s, palaeontologists from the British Museum (Natural History) collected early vertebrate remains from the area and recorded brief lithological descriptions (e.g., White 1946, 1950). Allen (1974) provided a general description, and three localities were described in the field guide to Powys by Davies *et al.* (1978). Hassan (1982) included the area in a palynological study of the Lower Old Red Sandstone and provided generalised sedimentary logs. Hawley (1989, 1991) developed a geological trail at Pwll-y-wrach, where the micro-vertebrate fauna was described by Turner *et al.* (1995). Revised editions of the Talgarth sheet explanation (Barclay & Wilby 2003) and map (2004) have been compiled, largely from photographic information. Significant discoveries have been made by local amateur geologists (notably R.B. Williams and P.W. Bennett) and research on the sedimentology, palaeoecology and palaeontology is in progress at several sites.

The formal Old Red Sandstone lithostratigraphy in South Wales is still in a state of flux. Internationally defined Devonian stages are not easily applied and the use of local names persists (Woodcock & Bassett 1993). Traditionally, the Lower Old Red Sandstone of central South Wales has been allocated to three poorly-defined ‘stages’ - Downtonian, Dittonian, Breconian - and the Upper Old Red Sandstone to the Farlovian (House *et al.* 1977, Barclay 1989). More recently, standardised formations or groups have been applied across the region (Fig. 2), based on lithostratigraphical affinities, lithological changes, and correlation with standard stratigraphical units (Přídolí to Famennian) using micro-vertebrates (Turner 1973, Turner *et al.* 1995) and spores (Hassan 1982, Richardson *et al.* 1982).

The early Devonian palaeolatitude of the area was about 17º S (Channell *et al.* 1992) and it formed part of the Anglo-Welsh Basin, an external foreland basin exposed from Pembrokeshire to Shropshire and in the subsurface across SE England, that developed in response to flexural subsidence on the Midlands microcraton of Eastern Avalonia (King 1994, Friend *et al.* 2000). The Přídolí to Emsian basin fill (Lower Old Red Sandstone) is a coarsening-upward sequence about 1,000 m thick in the Black Mountains. The Přídolí Raglan Mudstone Formation represents a regressive mudflat environment crossed by rivers supplied from a metamorphic source. A widespread hiatus indicated by a thick pedogenic limestone (Bishop’s Frome Limestone Member) marks a fundamental reorganisation of the source area, and the St Maughans, Senni and Brownstones Formations were sourced from Lower Palaeozoic sedimentary and reworked Lower Old Red Sandstone sources NW of the Welsh Borderland fault system (Allen 1983, 1985a). In Dittonian times (St Maughans Formation), mixed-load, S-flowing, meandering rivers shifted across a broad floodplain. After a further hiatus represented by the Ffynnon Limestones (and equivalents), sand-bed braided rivers dominated (Senni and Brownstones Formations). Rapid progradation and basin fill culminated in the late Emsian to mid-Devonian climax of the Acadian (late Caledonian) orogeny, with uplift and erosion of the Midland Platform. Deposition resumed in the

Famennian (Upper Devonian) with the unconformable Upper Old Red Sandstone Quartz Conglomerate Group (Woodcock & Bassett 1993, Friend *et al.* 2000).

Much of the detail of the Old Red Sandstone of the area is recorded here for the first time, and this excursion complements the guide to the central and western Brecon Beacons by Almond *et al.* (1993). Together, these excursions provide a comprehensive field guide to the Old Red Sandstone of the Brecon Beacons National Park area.

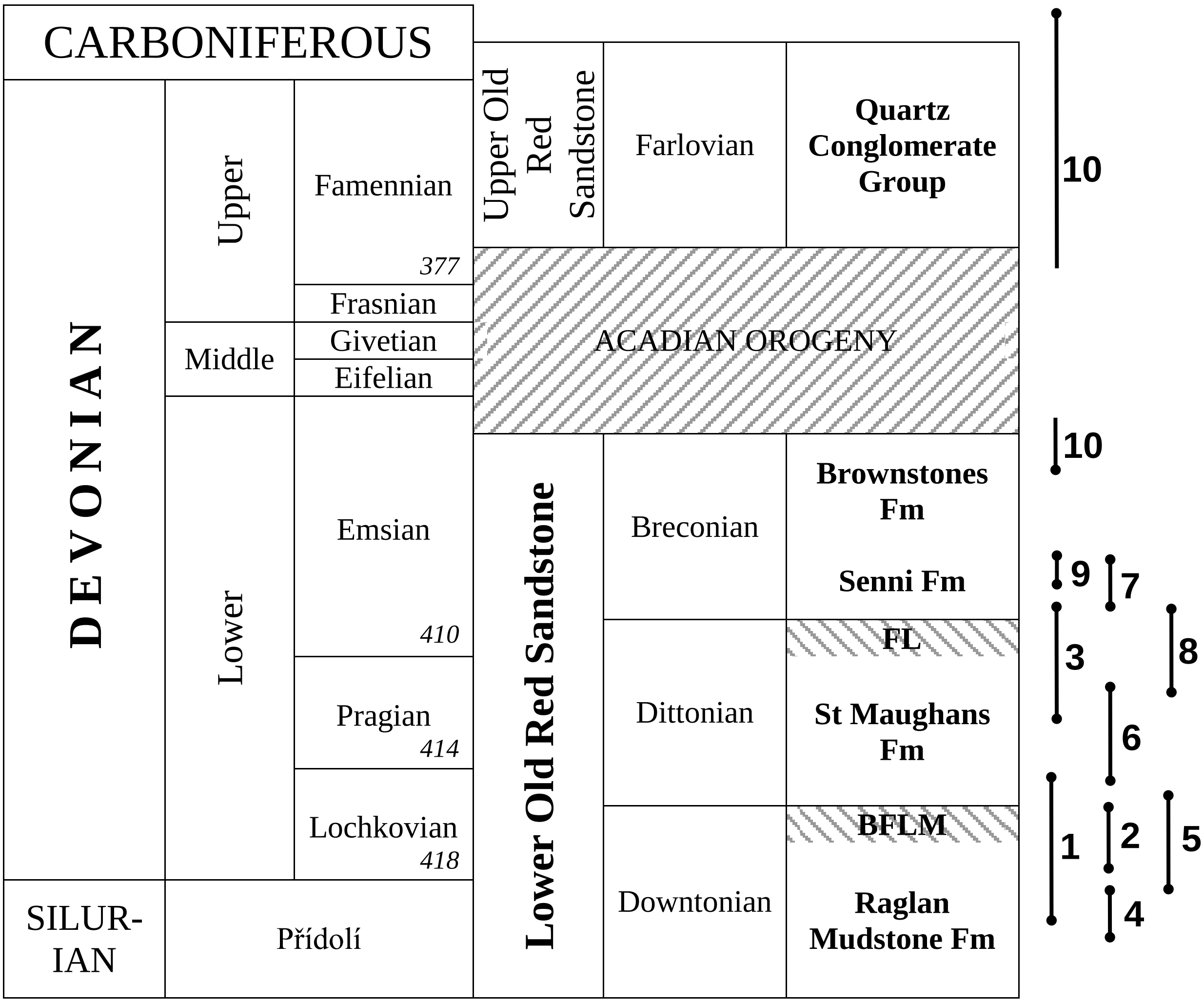

Fig. 2. Old Red Sandstone stratigraphy in the area. BFLM, Bishop's Frome Limestone Member; FL, Ffynnon Limestones. Ages in millions of years from Friend et al. (2000).

ITINERARY

The excursion circumnavigates the Black Mountains from the Wye valley near Hay-on-Wye on the Wales-England border, skirting the W flanks to the Usk Valley in the S and returning via the E edges (Fig. 1). Localities 1-6 on the N slopes examine the Raglan Mudstone and St Maughans Formations, including two important marker horizons; 7-9 examine the Senni Formation in the W and SW; and 10 examines the Brownstones Formation and Upper Old Red Sandstone on the S slopes above Crickhowell.

1. Cusop Dingle

(This locality has limited parking and is not suitable for coaches)

From Hay-on-Wye take the B4348 E towards Bredwardine. At the edge of Hay-on-Wye cross a bridge over the Dulas Brook into England and turn immediately right up a road signposted as a dead end to Cusop Dingle. Follow this for 2 km to a small parking area on the right just beyond Paper Mill Cottage, opposite the gateway to Ty Coch farm.

Cusop Dingle, a deep valley cut in the footslopes of the Black Mountains, forms the England-Wales border for much of its length. Stream sections in the Dulas Brook and its tributaries, the Crigiau Stream and Esgryn Brook, expose 215 m of the late Přídolí - early Devonian Lower Old Red Sandstone succession, one of the two most continuously exposed inland sections of this interval in the Welsh Borderland - central South Wales area (the Sawdde Gorge is the other - Almond *et al.* 1993). Much of the section lies on private land and is not easily accessible, but exposures in the banks of the Dulas Brook give a good overview of the upper Raglan Mudstone Formation (late Downtonian / Přídolí) and lowest St Maughans Formation (Dittonian) (Fig. 3).

1A. Paper Mill Cottage Falls (SO 243 407). Walk back down the lane for 20 m to a point overlooking the Dulas Brook and a small waterfall behind Paper Mill Cottage. The Brook here is typical of streams in the N valleys of the Black Mountains, where more resistant beds form small waterfalls. The waterfall is formed by 0.8 m of coarse, green, cross-bedded sandstone, underlain by 8 m of friable red siltstone, typical of finer-grained intervals in the Raglan Mudstone Formation. The friability is caused by remnant pedogenic structure breaking the siltstone into blocky peds.

Return to the parking area and, by the bench, cross over the bank down to the stream bed, which follows the upper surface of the coarse sandstone bed. The right (English) bank exposes the overlying beds, two thin sandstones separated by red siltstone. The lower sandstone is red, fine-grained and parallel laminated, with large desiccation cracks on its upper surface. The upper sandstone is green and medium-grained, with an undulating lower bounding surface and low-angle cross-bedding. These three sandstone beds characterise one of the sandstone facies in this succession, although they are thinner here than is typical, deposited as broad bar forms and low-relief dunes in a high-sinuosity, laterally migrating river channel subject to variable discharge, which occasionally dried out completely (Hawley 2005).

Return to the road and walk upstream to a bridge leading to Llangwathan Farm. Exposed beneath it are 3 m of brick-red siltstone with a blocky structure, abundant blue veining and crude parallel bedding, typical of this section. Upstream from the bridge, scattered small calcrete nodules can be seen towards the top of a slot cut into the siltstones. Curved surfaces in the stream bed represent weakly developed ‘pseudo-anticlines'. At the top of the slot a small waterfall marks the position of a sandstone unit comprising three thin (0.15-0.40 m) beds of fine-medium sandstone with low-angle cross-bedding and small, circular burrows and branching trails on their upper surfaces. Such thin, sheet sandstones punctuate the red siltstones of the Raglan Mudstone Formation, forming a second sandstone facies, interpreted as shallow outbreak channels and poorly channelised or unconfined flood flows spilling onto interfluvial areas from a larger, confined river channel. The moisture allowed brief colonisation of the sediments by an invertebrate fauna (Hawley 2005). A similar sequence of beds is exposed in the opposite (Welsh) stream bank at the next bend up the road, where another thin sheet sandstone forms a small waterfall and chute.

1B. Townsed Tuff Bed (SO 250 400). Continue up the road for 250 m. At the end of the metalled road follow the public footpath past Brickyard Cottage, where bricks were produced for the local building trade in the late 19th - early 20th centuries using weathered red siltstone dug from the steep bank opposite the cottage. Cross the stile by the gate to the far side of the field and follow the track with the stream on your right. Cross another stile and gate, noting more siltstone in the brook, and in 50 m a path forks left up the valley side; do not take this yet, but follow the indefinite path ahead to meet the Dulas Brook at an old ford. A fine-grained, green, splintery tuff about 1.5 m thick with a distinctive fracture pattern is exposed in the stream bed immediately downstream of a wire fence across the Dulas Brook and in the right (English) bank just above the waterfall downstream. It is overlain by two poorly exposed, thinner beds of hard, pale purple tuff with green mottling, separated by a thin, red, coarse sandstone. The lower purple bed is very fine-grained; the upper is coarser-grained and contains glassy fragments. These beds, and correlatives in the Digedi Brook and River Ennig to the W and Scotland Dingle and Merbach Brook to the E, are equated with the Townsend Tuff Bed of Allen & Williams (1981), which is a valuable stratigraphical marker horizon across the Anglo-Welsh Basin from Pembrokeshire to the Welsh Borderland, and provides evidence of a Plinian-type eruption that deposited volcanic ash across the floodplain. Its source is not known, although Allen & Williams (1981) suggested it might have been dispersed by winds from a source to the W or E along the trend of the developing Rheic Ocean.

1C. Lime Kiln Quarry and Crigiau Stream (SO 253 398). Return to the fork in the path and turn right up the slope for 300 m to where the ground opens out at a quarry on the left, opposite the remains of a lime kiln. This quarry exposes the Bishop's Frome Limestone Member; another, better exposure is accessible at a waterfall in the Crigiau Stream, 100 m W of the quarry (2540 3975), reached by a narrow path that forks off to the right 20 m past the quarry; **care must be taken on this path, especially in wet conditions.** The limestone is 4 m thick, its thickest development in the area. Large, rubbly, grey-white pedogenic calcium carbonate nodules in host sediment at the base coalesce upwards to form massive limestone in the top metre. Calcrete palaeosols and pedogenic features throughout the Lower Old Red Sandstone vary in maturity, indicating intervals of non-deposition of at least 500 years (Retallack 1990). The Bishop's Frome Limestone represents the longest hiatus, probably of the order of 100,000 years. Above is a facies change, and the top of the Bishop's Frome Limestone marks the top of the Raglan Mudstone Formation. This horizon represents a very mature calcrete palaeosol profile and forms a resistant, easily mapped horizon that is a regional marker throughout the Lower Old Red Sandstone of South Wales and the Welsh Borderland (Barclay & Wilby 2003). Classically, it has been referred to as the main 'Psammosteus' Limestone, a term introduced by King (1925) for an interval comprising several limestones in the uppermost Raglan Mudstone (Downtonian) and lowermost St Maughans Formation (Dittonian). Brandon (1989) renamed the horizon the Bishop's Frome Limestone, arguing that the term 'Psammosteus' is misleading and inappropriate, referring to an ostracoderm fish, 'Psammosteus anglicus', found not in the limestone but in associated sandstones and siltstones, and which has, furthermore, been recognised as two distinct species of *Traquairaspis (Phialaspis)* (White 1946) and so has been super-ceded in the nomenclature.

A short distance upstream, scattered exposures in the banks are the lowermost beds of the St Maughans Formation, comprising two upward-fining channel-fill cycles of grey-green sandstone. At the base, lenses of poorly sorted conglomerate contain a mixture of pebble types, including calcrete, sandstone and quartz, and yield fragments of the fish *Phialaspis symondsi*, *Corvaspis kingi* and *Anlaspis maculloghi*, a vertebrate assemblage typical of the succession above the Bishop's Frome Limestone. These gravel lag lenses are overlain by sandstones that fine upwards from planar and trough cross-bedding through low-angle cross-bedding and horizontal lamination with parting lineation to ripple cross-lamination. Some coarser sandstones contain scattered plant fragments. A small waterfall and cliff in the left bank expose the second cycle, marked by an erosive base cutting into grey silty sandstones and a basal lag with abundant large plant fragments. The main cliff shows trough cross-bedded coarse sandstones.

Carefully retrace your steps. On re-joining the main path turn right, up the hill. Immediately on the left, a small quarry affords a better view of the junction between the two sandstone cycles. Fine sandstone and siltstone dominate the lower part of the exposure, and careful examination of bedding surfaces reveals arthropod trackways. Towards the top of the section a conglomerate lens indicates the base of the next cycle. The coarse sandstone above has a rippled upper surface, with plugged shafts of shallow burrows in the ripple troughs.

Return the way you came. Loose blocks of landslip material in the field (SO 248 403), originating from a sandstone quarry high up the steep bank, have yielded vertebrate fragments including ischnacanthid spines and large toothwhorls of *Didymaspis sp.* and *Hemicyclaspis sp.*, a different assemblage from that above the Bishop's Frome Limestone.

2. Penyrwrlodd (SO 221 398)

Return to Hay-on-Wye and take the B4530 towards Brecon. On the outskirts of Hay-on-Wye fork left onto the minor road towards Llanigon. On reaching Llanigon turn left immediately after the garage, just before the bend into the main part of the village. Follow the lane uphill for just over 1 km to where it passes through the farmyard of Penyrwrlodd. Vehicles should be parked in the open space at the far end of the farmyard beyond the narrow corner. Cuttings on the left, beyond the stable buildings and opposite the stone barns, expose the uppermost Raglan Mudstone Formation and the base of the Bishop's Frome Limestone.

The Raglan Mudstone Formation comprises typical red fine sandstone and laminated siltstone. Some coarser beds show low-angle cross-bedding and ripple cross-lamination, but most have wavy or parallel laminae. Mica is concentrated along parting surfaces, many of which reveal wrinkle structures, surface undulations with wavelengths of a few millimetres (Fig. 4). Allen (1985b) interpreted wrinkle structures as aseismic load structures formed by the action of estuarine waves as the tide retreats. Loading of a recently deposited couplet of clay or silt (lower) and silty sand (upper), separates the upper layer into elongate pods, giving the surface a wrinkled appearance. Hagadorn and Bottjer (1997) offered an alternative interpretation related to microbial mats forming in a stressed marine environment. The mats facilitate the trapping of clay on the crests and troughs of uneven, wrinkled surfaces, leading to preferential cleaving along mica-rich horizons caused by diagenetic growth of mica from clays. Both interpretations imply pulses of sedimentation associated with changes in water level, that may have resulted from a tidal influence or, more probably in the context of the Raglan Mudstone Formation, from repeated inundation of a floodplain with sediment-charged floodwater. Each flood brought conditions analogous to tidal conditions, with coarser sediment deposited by the incoming flood waters and finer laminae settling from suspension during the waning phase. The structures at Penyrwrlodd accord with criteria proposed by Allen (1985b) for an aseismic loading origin, including alternating coarser and finer laminae and small-scale flame structures (Fig. 4). They are best viewed in small weathered faces near the corner, which should not be hammered. Convolute lamination near the right corner of the 'main' face provides further evidence of soft-sediment deformation and rapid sedimentation rates.

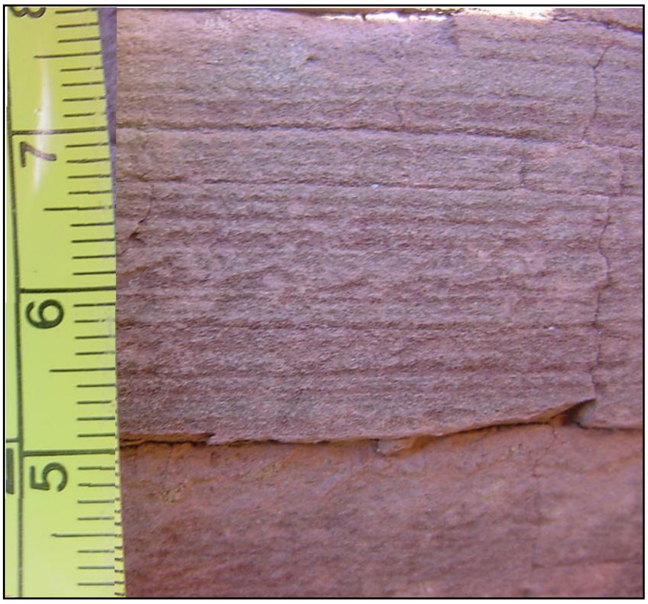

Fig. 4. Small load casts interpreted as wrinkle marks in laminated sandstones of the Raglan Mudstone Formation at Penyrwrlodd (locality 2). The most prominent horizon is marked by an arrow. Scale in mm.

Some parting surfaces reveal indistinct, intermittent arthropod trackways. Medium to low density infaunal burrowing affected some beds, and slightly sinuous vertical shafts up to 15 cm long are best observed in the beds on extreme left of the 'main' face. The bedding becomes more disturbed upwards, where blue-veined silstsones pass up into rubbly calcrete which coalesces to form a limestone about 1 m thick, the Bishop's Frome Limestone, best seen in the bank by the narrow corner at the far end of the section, where it meets the road.

3. Rhiw y Fan Gully (SO 215 346)

Return to Llanigon and turn left through the village towards Velindre. Proceeed for about 4 km, and about 750 m past Tregoyd (at SO 191 372) turn SE up the lane signposted Newcourt Farm. Follow this for about 3 km, where a cattle grid leads onto open grazing land, and park on the bend (SO 210 351). Follow the track SE alongside the fence and cross the stream to ascend the lower slopes of the escarpment for about 1 km to a track junction (SO 215 347). Turn right and walk W to meet a stream. Follow this up to the bottom of the gully and the first exposures on its W side. Allow at least 2.5 hours for this locality (30 minutes to the gully, 1.5 hours to ascend the gully and 30 minutes return). The ascent climbs the Black Mountains escarpment and is **a serious outing that should be avoided in bad weather or wet conditions.** A poorly defined, block-strewn path follows the bed of the gully, so sensible footwear must be worn. The gully follows a fault and its walls are very steep and **should not be climbed**; the dip allows detailed examination along the gully floor. Extensive views of the exposure can be gained from the gully floor and binoculars are recommended.

The W wall of Rhiw y Fan gully provides continuous exposure through 165 m of the upper St Maughans Formation (Fig. 5). Five successive facies associations can be interpreted as changes in fluvial style.

3A. The lowest facies association (65 m thick) comprises units 0.2-2.0 m thick of basal cross-bedded scour-and-fill channel-lag conglomerate with poorly sorted calcrete and siltstone clasts that fine up through trough cross-bedded medium sandstone to thin, finer-grained tabular and rippled sandstone. They occur as single beds or amalgamated units of two to four beds, separated by red siltstone units up to 6.6 m thick, with calcrete nodules at the top of thicker units. The proportion of sandstone to siltstone is about equal, although siltstone beds are thicker lower in the succession. This facies association is typical of small meandering channel deposits.

3B. The succeeding facies association (31 m thick) is characterised by an increase in the ratio of siltstone to sandstone to approx. 9:1. Sandstones occur in the middle of the interval as solitary beds tens of cm thick, and the uppermost sandstone is an amalgamated unit 1.6 m thick. Typical beds comprise sharp-based, green, medium sandstone with low-angle cross-bedding or cross-lamination. Parting surfaces show tracks, trails and shallow desiccation cracks. They fine upwards through mottled and laminated sandstone to siltstone with incipient calcrete development. This facies association represents flood-basin deposits, with distal crevasse-splay sands resulting from occasional inundation of subaerially exposed inter-channel areas by overspill from the main channel belt.

3C. The next facies association (21 m thick) is composed of 19 cyclic units (0.5-2.7 m thick) of tabular fine-medium sandstone passing up into siltstone. The sandstone bases, many of which comprise a single layer of intraformational pebbles, overlie siltstone with sharp or low-relief erosive contacts. Grain size fines upwards from planar or trough cross-bedding with occasional burrows through low-angle cross-bedding and parallel lamination to red siltstone with incipient calcrete development. The cyclic sandstones represent point-bar deposits from successive meanders of a shallow, sinuous channel migrating over its floodplain. The siltstones are floodplain fines that were subaerially exposed for a long period before further channel deposition.

3D. The next facies association (25 m thick) comprises three sandstone bodies 1.9-3.25 m thick, bounded by siltstone units 8-10 m thick which contain isolated thin, green sandstone beds and frequent calcrete horizons. Sandstone bodies are erosively based, with a basal conglomerate 0.2-1.5 m thick overlain by cross-cutting, trough cross-bedded channels and medium-grained sandstone lenses, fining upwards into red, rippled and planar-bedded medium sandstone. The topmost sandstone forms a feature at the top of the gully and across the upper slopes of the W wall. This facies association represents higher-energy deposits of low-sinuosity channels transitional in style between meandering and braided.

3E. The succeeding unit is a rubbly, siltstone-hosted calcrete, 10.5 m thick. Nodule density increases upwards to massive limestone. This is the lowest bed of the Ffynnon Limestone (Croft 1953). Above this, the cliffs of the W gully wall comprise red channel sandstone bodies, 2.8-10.5 m thick, with upper flow-regime structures, interbedded with thinner, heavily calcretised red siltstone. This bedding style is similar to 3D, but at the top the sandstones are stacked to form a multi-storey body. The unit is topped by a massive calcrete limestone - the upper Ffynnon Limestone - which marks the top of the St Maughans Formation (Barclay & Wilby 2003). Sandstones above this belong to the Senni Formation.

Carefully ascend the grassy slopes at the top of the gully to meet the path along the escarpment. Turn left (N) and almost immediately follow a small grassy path over the edge of the escarpment, leading to a well-defined path downslope. Exposures adjacent to the path are dominantly green sandstones at the base of the Senni Formation. In about 500 m, at a spring seepage, the path crosses a broad band of nodular calcrete marking the outcrop of the Ffynnon Limestones. These are at a lower altitude than in the W gully wall, indicating that this is the downthrown side of a fault aligned with the gully. After a further 500 m the track turns back on itself, continuing downslope to the road.

4. Talgarth

Return to the Llanigon-Velindre road. Turn left and continue through Velindre to join the A4078. Turn left and in a further 1.5 km left again on the A479 to reach Talgarth. Take the B4560 towards Llangorse and in 100 m turn left into the car park (SO 153 337). Walk left along High Street and right at the end into Bell Street. After 75 m, by 'The Strand' bookshop, bear left. Turn left down the public footpath immediately after two brick cottages to reach a bridge over the River Ennig near its the confluence with the River Ellywe (SO 156 337).

Raglan Mudstones are exposed in the river bed. Downstream from the bridge, on a small promontory between the rivers, red siltstones display blue veining and curved fracture planes, common products of vertisol development in the Raglan Mudstones. In contrast to locality 1A, it is possible here to see their three-dimensional, bowl-shaped form. Vertisols are soils developed on fine-grained substrates with a high percentage of swelling clays where marked differences in soil moisture occur through the year in response to wet and dry seasons or periods of flooding. The clay-rich soils swell and shrink during the wet and dry phases respectively. Shear stresses at depths of 0.3-1.0 m lead to lenticular, bowl-shaped, slickensided fracture surfaces with dips up to 60°, commonly described as 'pseudo-anticlines' (Marriott & Wright 1993, Wright & Marriott 1996).

Upstream from the bridge is a platform of siltstone with embedded calcrete nodules. The bank above this platform exposes a green air-fall tuff with faecal pellets on its upper surface, that forms the prominent ledge below the recess in the face of the waterfall upstream. This tuff lies approx. 15 m below the Townsend Tuff Bed, which crops out 700 m upstream in the River Ennig, and may be the equivalent of a thin tuff recorded in a similar stratigraphical position in the 'Middle division' of the Gwynfe Formation in the Sawdde Gorge by Almond *et al.* (1993). Below the main tuff, three thin, laterally impersistent, green and red mottled dust tuffs mixed with red siltstone can be viewed on the upper surface of the siltstone platform and in the promontory area adjacent to the concrete retaining wall. These tuffs seem restricted to roughly circular areas 1-2 m in diameter, and may represent remnants of ash in gilgai depressions on the floodplain surface. Subsequent floods swept ash away from elevated areas, but in depressions it mixed with silt to be preserved as thin, impersistent tuffaceous deposits. The origin of the tuffs was probably the same source of Plinian-type eruptions that gave rise to the Townsend Tuff Bed.

5. Pwll-y-wrach falls and quarry

From the car park drive towards locality 4, but continue past the cottages and up the lane. After 500 m pass the entrance to the former Mid-Wales Hospital on the left, and in a further 250 m park on the right at the entrance to Pwll-y-wrach (SO 162 328), a Brecknock Wildlife Trust reserve. Follow the path along the wooded valley side for 600 m to an information board. Continue upstream alongside the River Ennig for 300 m to reach Pwll-y-wrach waterfall.

The waterfall is formed by the Bishop's Frome Limestone. Its face displays 10 m of red siltstone with horizontal bedding planes, 'pseudo-anticlines', and vertical burrows (*cf. Skolithos sp.*), some of which can be traced for over a metre across bedding surfaces, indicating very rapid deposition. Close examination is best in the cliff on the left (far) bank of the pool; the river can be crossed at times of low water level.

Go up the steps on the bank. Just before the stile a short path leads left to an exposure of the Bishop's Frome Limestone. Red siltstone at the base is overlain by rippled fine sandstone and a darker, flaggy sandstone with limestone nodules that become more numerous and coalesce upwards into the Bishop's Frome Limestone. This succession represents a mature calcrete palaeosol profile, indicating a long period of non-deposition on the floodplain.

Return to the stile and cross it to view the Bishop's Frome Limestone in the stream bed at the top of the waterfall. A few metres upstream, a conglomerate lens in the right bank has yielded fish microfossils dominated by thelodont scales (*Turinia pagei*), together with acanthodians, heterostracans and cephalaspids (Turner *et al.* 1995), placing the beds immediately above the Bishop's Frome Limestone within the lowest Lochkhovian.

Take the path up the valley side, which zig-zags close to a wire fence. After the fifth bend, cross the stile and follow the path into a disused quarry. This exposes a typical sandstone unit of the lowermost St Maughans Formation (Fig. 6). **Do not stand directly under the quarry face;** all key features can be viewed from the quarry floor. A prominent basal erosion surface scours into a blocky purple siltstone and is overlain by a lag of calcrete clasts, quartz pebbles and large mudstone clasts, which can be examined on a large block on the quarry floor. The erosion surface and gravel lag represent the base of a river channel. The overlying red, medium-coarse sandstone is about 2.5 m thick and fines up into thinner sets of cross-bedding draped with red siltstone, typical of bar-top deposits. A prominent surface cutting these beds is overlain by sandstone with cross-strata dipping at about 10° that are internally cross-laminated. Mean palaeoflow was to the SE (left to right) but bedform migration was to the SW, indicating that these features represent 'epsilon cross-stratification' (Allen 1963), formed by lateral accretion on the point bar of a meander. The base of the quarry face exposes the upper part of a similar sandstone unit, showing the cyclic nature of such deposits.

Fig. 6. Basal erosion surface and lateral accretion surfaces in sandstone channel fill in the basal St Maughans Formation at Pwll-y-wrach (locality 5).

A path exits the far (W) end of the quarry along the line of an old tramway that carried stone for the construction of the former Mid-Wales Hospital, opened in 1903. Follow this along the valley side, passing exposures of sandstone and a small quarry of 'cornstone' conglomerate that has yielded fossil fish fragments. Where the path meets the road, turn left down the lane. Alternatively, return to the stile and ascend the steps to exit onto the lane through a gate on the left.

6. Tredomen Quarry (SO 116 304)

Return to Talgarth and take the B4560 towards Llangorse. After 3.5 km turn right along a lane signposted Tredomen and Llanfilo (SO 135 305). Follow this for about 1 km and at the end of a straight section, before reaching Tredomen, turn left onto an unmetalled track. Follow this across a stream, through a gate up the hillside, and park at a small cleared area with some old machinery. Continue on foot to the top of the hill, where the quarry entrance is screened by trees. Permission to enter should be obtained from the owner, Mr. Jones, at the quarry office (tel. 07971-783836). **This is a working quarry so extreme care should be taken and standard safety practices followed.**

The quarry has two working areas - the West and East pits. Excellent exposures of the lower St Maughans Formation allow the reconstruction of changing fluvial architecture and environments (Fig. 7). Bedding dips gently SE, with the lowest strata exposed in the West pit. A small fault cuts the N part of the East pit. The quarry has yielded important arthropod trackways, fish trails (Morrissey *et al.* 2004) and a single, rare example of an arachnid, *Trigonotarbid* (Dunlop and Selden 2004). Research is continuing and all finds must be reported to the Department of Geology at the National Museum of Wales or to Duncan Hawley.

6A. West pit. The lowest strata exposed are 3 m of parallel bedded, green, medium to coarse-grained, micaceous sandstone. Some beds have large grey mudstone clasts at the base, giving a shaley appearance from a distance, and straight-crested, slightly asymmetrical ripples at the top, indicating flow to the SE. Parting lineation is common, with dominantly NE-SW orientation. Some shallow scours oriented NW-SE are overlain by trough cross-bedding passing up into planar cross-bedding and ripples. Towards the top some wavy surfaces resemble hummocky cross-stratification, suggesting upper flow-regime conditions (cf. Rust & Gibling 1990). Many parting surfaces show black, carbonaceous plant fragments and spherules (?*Pacytheca sp.*) with long axes aligned NW-SE. This facies represents broad, shallow, perennially-charged channels of a river flowing S or SE, which regularly overtopped its banks, ripping up finer-grained deposits and plants from the banks.

Above this is 0.25 m of medium sandstone with flaser bedding, in which alternating green and red laminae become more red and finer-grained upwards, culminating in a metre-thick, parallel-laminated, fine sandstone with arthropod trackways and wrinkle-marked surfaces. The interval is capped by 2.5 m of siltstone with weakly developed slickensided surfaces indicating pedogenic development, and lenses of coarse sandstone, leading to a calcrete with desiccation cracks and blue veining. A prominent, thin, very fine-grained, pale green bed is probably a tuff. This interval records a transition through fluctuating flows to drier conditions, probably due to channel avulsion leading to a change from active floodplain sedimentation to pedogenesis.

The next interval comprises 3 m of laminated fine-medium sandstone with flaser bedding, desiccation cracks and incipient calcrete nodules. Load structures and large siltstone clasts in one bed indicate very rapid deposition. This facies represents intermittent spilling of the active channel onto the floodplain through crevasse splays.

The upper bench in the NW of the pit comprises 2.25 m of brick-red floodplain siltstone with four very thin (approx. 1 cm), green, fine-grained sandstones. A channel trending NE-SW is filled with about 1 m of fine sandstone, overlain by siltstone with a thin groundwater calcrete and desiccation cracks. Above this, a thin conglomerate bed is overlain by 2.5 m of compound cross-bedded channel facies comprising basal conglomerate, green and grey medium and coarse-grained, planar and trough cross-bedded sandstone with siltstone clasts, and erosional scours filled with calcrete or mudstone clasts. These grade up into thin plane-bedded sandstone with vertical burrows (*Skolithos sp.*) up to 40 cm long, which can be examined in the faces of the bays in the upper bench, and correlated with strata in the East pit (see below).

6B. East Pit. The S face in the East pit displays a complex of four stacked channel units trending NNE-SSW (Fig. 7), overlying at least 2 m of red siltstone with desiccation cracks, groundwater calcrete and *Beaconites barretti* burrows, confirming a position in the St Maughans Group (Morrissey *et al.* 2004).

In channel unit A an erosional base and thin intraformational lag conglomerate overlain by 2 m of red, trough cross-bedded, medium sandstone grade up into 1 m of coarse red siltstone. The unit thickens to the W where it terminates laterally against the underlying red siltstone.

Channel unit B comprises up to 1 m of green, medium-coarse sandstone and can be traced across the entire 150 m of the S quarry face. A gently undulating, erosive base cuts out the siltstone at the top of unit A near the centre of the face, and the basal conglomerate can be correlated with that on the upper bench in the West pit (see above) where the channel fill is more complete. The sandstone displays planar cross-bedding dipping ESE in the basal metre, and the overlying compound cross-bedded channel facies can be correlated with similar beds in the faces of the bays on the upper bench in the West pit.

Channel unit C forms a striking feature cutting across unit B in the centre of the face. It is up to 2.7 m thick, filled with rotted, decalcified, sandy intraformational conglomerate. It can also be seen on the N face of the East pit, where cross-bedding indicates deposition on gravel bars accreting downstream to the SW. Some bar faces are draped with sandstone, indicating discharge fluctuations. Channel margins are exposed at the E end of the N face and W end of the S face, where planar and cross-laminated, green micaceous sandstones interfinger with scours filled by laterally accreting gravel bars, indicating frequent spilling and scouring at the channel edges. Some beds yield abundant plant material, suggesting that thick stands of vegetation grew in the moist, sand-filled hollows of the marginal scours of the channel.

The base of Channel unit D cuts across units B and C to the E. The infill can be examined in small faces on the N margin of the quarry, by the entrance, and comprises green-grey, medium-grained, planar laminated, micaceous sandstone with parting lineation indicating a NE-SW current trend. Sheet geometries represent shallow channels and broad, flat bars; this facies was desposited by broad, unconfined, perennial, fast-flowing rivers, under similar conditions to the green sandstones of the West pit, in contrast to the more channelised facies of units A-C.

This sequence is similar to approximately equivalent deposits further W described by Owen & Hawley (2000), who interpreted the fluvial style as a local response to displacements along the Caledonoid Carreg Cennen Disturbance. Similar tectonic processes may have affected the Tredomen area, which lies a few km S of the Swansea Valley Disturbance (Weaver 1975).

7. Cockit Hill (SO 160 278)

Return to the B4560 and proceed to Llangorse. Go through the village, past the church and two pubs, turning left at the next junction (SO 136 277). Follow this lane for about 1.5 km, bear left at the top and continue uphill. In 1 km cross a cattle grid onto open land and park at the summit, taking care not to block the road. Follow the well-marked path up the ridge to the S to the crags on the upper slopes. Towards the top the path zig-zags, then broadens onto a gently ascending shoulder with magnificent views over Llangorse Lake and basin towards the Brecon Beacons. Exposures of the lower Senni

Formation (Breconian) can be examined in crags on the left and over the crest of the ridge along the hillside to the SE.

The crags comprise medium-coarse sandstone in upward-fining channel units up to 2 m thick. Erosive bases are overlain by thin intraclast lag conglomerates that pass up through compound and trough cross-bedding to wavy lamination, planar bedding and some rippled surfaces. Finer-grained lithologies are preserved only as drapes at the top of some units and as intraclasts. Palaeoflow was to the SE and S, although cross-bedding exhibits considerable variation. Some flows to the E or NE may indicate reverse flow into abandoned channel segments (cf. Owen 1995). The Senni Formation was deposited by high-energy, sand-dominated braided rivers, contrasting with the meandering channel and floodplain facies of the underlying St Maughans Formation.

Fig. 8. Burrow traces in cross-bedded sandstones of the Senni Formation at Cockit Hill (locality 7): Diplocraterion-type burrows (left) and Beaconites (right). Scale in mm.

Several types of burrow traces (ichno-structures) occur here (Fig. 8).

1. Vertical, *Skolithos*-type burrows with shafts a few mm in diameter are up to 1.5 m long, commonly crossing bedding surfaces or penetrating more than one channel unit, and terminating upwards at an erosion surface. Some have curved, J-shaped terminations at the base (L. Morrissey, pers. comm.) and some are deflected downstream at the top of cross-sets, indicating that upward burrowing kept pace with sedimentation. These burrows are abundant in coarser-grained, trough cross-bedded bar sandstones.
2. U-shaped *Diplocraterion*-type burrows are less numerous but occur in similar facies to the *Skolithos* type.
3. *Scoyenia*-type shallow burrows, 2-3 mm in diameter, with short shafts, curved bases and cross-cutting horizontal or sub-horizontal tunnels occur rarely in coarser sandstones.
4. *Beaconites*-type burrows are large (up to 2 cm diameter, 15 cm long), slightly curved at the base and back-filled with upward-arching meniscae, similar to *Beaconites antarcticus*. They are common in cross-bedded sandstones.

5. Reticulated bioturbated patches of unknown affinity (the 'pepperpot structures' of W.H. Ball, quoted in Barclay & Wilby 2003) comprise dense networks of connected meniscae with weathered areas between, producing a pitted appearance. They are abundant, typically forming a margin around other ichno-structures, although they also occur as isolated patches 5-30 cm across. They may indicate re-burrowing and bio-exploitation of sediment already loosened or inhabited by other burrowers.

Croft (1953) referred to these ichno-structures as 'distinctive problematical structures' and considered them confined to the Senni Formation. *Skolithos*-type vertical burrows do occur in the uppermost St Maughans Formation, but the density and variety of burrow traces can be used as an indicator of the lower Senni Formation.

8. Bwlch Cutting (SO 148 222)

Return to Llangorse and turn left on the B4560 to Bwlch. There turn left on the A40 and after 150 m, just over the rise, turn right into Buckland Hill at the end of the cutting. A few vehicles can park by the gate around the bend; there is more parking back through the cutting in the residential cul-de-sac, Buckland Drive.

The Ffynnon Limestone Member dips 5° SE and is accessible from the pavement at the W part of the cutting on the N side of the road, and comprises three units (Fig. 9). The lowest, a red-purple, laminated, medium sandstone with low-angle cross-bedding and calcrete nodules towards the top, is overlain by a metre-thick, mature calcrete with an uneven, eroded upper surface, that thickens to the SE (the Ffynnon Limestone). It is capped by up to 1 m of rubbly calcrete in a siltstone host, that thins to the SE, where it abuts the massive calcrete. These relationships indicate at least two phases of prolonged calcrete development. Above the Ffynnon Limestone Member are a thin red siltstone, a laminated sandstone, and an erosively based, green-purple, medium sandstone with several internal erosion surfaces, which passes up through thinly interbedded siltstone and sandstone to a thicker purple siltstone, exposed in the top of the bank next to the stone wall.

Before the wall was built in 1993, two NE-SW oriented channels were exposed above the purple siltstone. The lower was filled with purple-grey sandstone, passing up through coarse sandstone with calcrete intraclasts to red and purple siltstone. The upper channel was filled with at least 2.5 m of grey, cross-bedded conglomerate with clasts of red and green sandstone, red siltstone and calcrete in a coarse sandstone matrix. Clast orientation and cross-bedding indicated palaeoflow to the SW. This was overlain by a thin lag conglomerate and 2 m of planar bedded medium sandstone. The facies below and above the Ffynnon Limestone record a palaeoenvironmental change from shallow meandering channels to more flashy rivers with periodic high-energy flows in confined channels and unconfined, rapidly-waning sheet flows (cf. Allen & Williams 1979).

9. Tremynfa Quarry (SO 159 224)

Take the A40 towards Crickhowell. 75 m past the Star bunkhouse turn left at Well Cottage up Tremynfa Road (SO 151 221). Follow this for about 1 km, crossing a cattle grid onto open land with Tremynfa house on the right. Park on the grass verge opposite the signposted footpath.

There is a fine view E over the Rhiangoll valley, the Allt Mawr ridge and the S flanks of the Black Mountains, formed mainly of beds of the Breconian series. The Senni Formation underlies the lower slopes and Brownstones cap much of the high ground.

The boundary is a transition from green to purple or red sandstones (Barclay 1989), and approximates to the upper limit of cultivated ground, the well featured upper slopes with small terraces and scarps being characteristic of the Brownstones (Barclay & Wilby 2003). The smooth profile of the middle horizon, descending S to the Usk Valley, is sharply interrupted by a steep break in slope formed by a major landslip, The Darren (locality 10).

Walk back to the cattle grid and take the grassy track up the bank to the N leading around the gate to the quarry. Tremynfa Quarry exposes conglomerates and channel sandstones in the Senni Formation, about 100 m stratigraphically above the Ffynnon Limestones. The quarry faces are about 10 m high. Three bays give 100 m of continuous exposure and promontory faces show perpendicular sections. The entrance track leads to the main bay, with two others to the NE. Two major bounding surfaces (A, B) can be traced throughout the quarry, defining three sandstone units (S1-S3) with internal bounding surfaces (Fig. 10). The sandstones are predominantly purple-grey, which contrasts with the typical characterisation of Senni Beds as green.

Conglomerate forms the quarry floor in the main bay, overlain by sandstone S1. This comprises up to 6 m of tabular medium-coarse sandstone with large, disc-shaped clasts of red siltstone and planar and low-angle cross bedding, representing flows over a mobile sand bed in a broad channel. Bounding surface A, with up to 4 m of relief, defines channel forms approx. 45 m wide. Above it, the base of sandstone S2 comprises erosional remnants of poorly sorted conglomerate dominated by reworked red siltstone pebbles and cobbles, with some worn calcrete pebbles, overlain by cross-sets of poorly sorted, re-worked siltstone mixed with coarse sandstone. This facies represents channels filled by downstream-accreting bars in response to fluctuating flows to the SSW, and is well exposed on the promontory at the E end of the main bay. In the main face, S2 comprises planar and compound cross-bedded, medium-coarse sandstone with conglomerate lenses. In the NE, stacked, symmetrical channels are filled with coarse sandstone or conglomerate. Bounding surface B has little relief, although it cuts down 2 m in the SE. It is overlain by lenses of conglomerate similar to those above bounding surface A. At the N end of the main face, about 5 m above the quarry floor, a ribbon sandstone with very steep channel margins cuts through the conglomerate. S3 comprises tabular medium sandstone with planar and low-angle cross-bedding indicating a SW palaeoflow. Flute casts on the base indicate erosional scour by powerful S-flowing currents.

The sequence at Tremynfa Quarry records two distinct fluvial styles. S1 and S3 represent channels wider than the available exposure, with a mobile sand bed and a high width:depth ratio. S2 represents mixed-load deposition on downstream-accreting bars in channels with a lower width:depth ratio. Accretion occurred in response to the stripping of floodplain sediments by flashy floods, building a network of small, sand-dominated, braided channels and bars.

10. The Darren (SO 213 212) and Table Mountain (SO 225 207), Crickhowell

The Darren and Table Mountain afford some of the few readily accessible exposures where the contrast between the uppermost Brownstones and the lowest Upper Old Red Sandstone (Quartz Conglomerate Group) can be examined. Murchison visited this locality in 1835 while developing his stratigraphy of the Silurian system. The Darren is an excellent example of a landslip, and provides views over the middle Usk Valley to the Llangattock escarpment in the S and the Brecon Beacons to the W. The visit can be extended to examine the Carboniferous outlier at the summit of Pen Cerrig-calch. The Darren is at an altitude of 500 m, so prepare for upland terrain and conditions. Allow at least 3.5 hours (1 hour to The Darren, 1.5 hours there and 1 hour return via Table Mountain) and a further 1.5 hours to visit Pen Cerrig-calch. Binoculars are recommended.

Return to Bwlch and turn left on the A40. At Crickhowell, turn left shortly after the start of a high stone wall on the right (before the garage), and follow Llanbedr Road out of the village. Bear left at the top and in 200 m park by an electricity sub-station on the right (SO 223 193). Walk along the unmetalled stony lane opposite for about 500 m to the W, to where a narrow path leads uphill (SO 219 193). Take this, following signs for Table Mountain, to join another path up through a wooded valley. Cross a stream and follow the path through a field leading to a stone sheep pen (SO 218 209) where the backscar cliffs of The Darren come into view (Fig. 11). Ascend the path on the left to a stone wall and from the shoulder strike N uphill over bouldery landslipped ground to the foot of the cliffs.

Fig. 11. Landslip and backscar cliffs of Upper Old Red Sandstone, with Brownstones Formation at the base, The Darren, Crickhowell (locality 10).

The cliff base exposes the uppermost 4 m of the Brownstones Formation, comprising red-brown, fine-medium sandstone with planar bedding and some low-angle cross-bedding. This facies is comparable with the medial facies association in the Brownstones of the Brecon Beacons (Tunbridge 1981), deposited by flood events in wide, shallow, low-sinuosity channels. The Brownstones Formation in the Black Mountains is about 200 m thick, compared with 450 m in the Brecon Beacons (Barclay & Wilby 2003), and the uppermost beds (proximal facies) may have been truncated by the overlying unconformity, which records mid-Devonian uplift and erosion during the

Acadian orogeny (Woodcock & Bassett 1993). The unconformity is not angular, and is usually obscured by scree and vegetation.

The remainder of the cliff belongs to the Quartz Conglomerate Group, which is Farlovian (Famennian) in age and correlates with the Grey Grits Formation of the Brecon Beacons (Barclay 1989). Above the unconformity, 3 m of gravelly, buff and green sandstone yields fragments of the fish *Holoptychius* (recorded by Murchison) and *Bothriolepis sp.*, and may be a remnant of the Plateau Beds (Barclay & Wilby 2003). This is overlain by 2 m of siltstone and 20 m of buff, grey or grey-green sandstone in tabular, cross-bedded units, fining up to parallel laminated beds, with a few impersistent red-brown siltstone interbeds. The Quartz Conglomerate Group represents S-flowing, shallow, possibly ephemeral, sandy braided streams of an alluvial fan complex (Barclay & Wilby 2003).

From the E end of The Darren, contour E around Cwm Cwmbeth, heading for the corner of a stone wall at SO 223 211. Follow this to Table Mountain (SO 225 207). Alternatively, to reach Pen Cerrig-calch, skirt the cliffs on the E side of The Darren and head up to the NE. After about 1 km join the main path from Crickhowell to the summit. This Carboniferous outlier comprises 45 m of Dinantian limestone capped by 20 m of Namurian quartzitic sandstones. Details are given by George (1928) and Barclay & Wilby (2003). Descend via the well marked path to Table Mountain.

Ramparts and ditches of an Iron Age fort surround the summit of Table Mountain, the 'original' Crug Hywel (Crickhowell). It is composed of grey-green, locally pebbly, quartzitic sandstones, whose stratigraphical position has been much debated. They dip 15° SE, in contrast to the general local dip of 6° SW, and have been attributed to the Millstone Grit (Murchison 1839) and to the Quartz Conglomerate Group, with an origin due to faulting (Robertson 1927) or synclinal folding. The current consensus is that Table Mountain is a landslipped mass of the Quartz Conglomerate Group, displaced under periglacial conditions (Barclay 1989).

Descend the well-marked path on the W side of Table Mountain to a stile at SO 225 203, and join a shaded track. After passing Dol-y-gaer farmhouse, turn left over the stile and follow the path downhill to The Wern (SO 223 196). Go through the farmyard and follow the lane back to the parking area.

11. Return to Hay-on-Wye

The shortest return route is via the A40 and A479 over the Pengenffordd pass to Talgarth and the Wye valley. For alternative routes on the E side of the Black Mountains, continue along the lane N to Llanbedr. Turn right by the church in the village, then left towards Fforest Coal Pit. This lane follows the Grwyne Fawr valley along the Coedycerrig Fault, part of the Neath Disturbance (Barclay 1989). Upper Old Red Sandstone capping the Sugar Loaf, S of the valley, has been uplifted by 200 m relative to Pen Cerrig-calch (Owen 1953). Continue ENE along the dry valley of Cwm Coedycerrig to meet the B4423 in the Vale of Ewyas (SO 301 217). From here, either turn left and proceed N up the Vale of Ewyas, past Llanthony Priory and over the Gospel Pass to Hay-on-Wye, or, to examine more of the Senni Formation, turn right towards Llanvihangel Crucorney. After going under the railway bridge, before entering the village, turn left and head N towards Longtown. Proceed through Longtown past the castle towards Craswall. A left fork at SO 317 300 enters the Olchon Valley, where the spectacular Red Daren landslip (parking at SO 298 299) and the arête-like ridge leading to Black Hill (parking at SO 288 328) expose substantial sections of the Senni Formation. To return to Hay-on-Wye, take the minor road from Longtown up the Monnow valley through Craswall to cross the Monnow-Wye watershed.

ACKNOWLEDGEMENTS

The following are thanked for helpful discussions on the geology of the area: Bill Barclay, Keith Jones, Lance Morrissey and R B Williams.

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