The Geology of the Forest of Dean: a Bibliographical Review

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Abstract: A concise account of the structure and stratigraphy of the Forest of Dean, Gloucestershire, is presented in a sectionalized bibliographical review which assesses the current state of knowledge and highlights the principal issues of debate relating to this classic district of British geology.

1. Introduction

The Forest of Dean is a compact and distinctive district of west Gloucestershire, situated between the lower courses of the rivers Severn and Wye. Its form is that of a dissected plateau-like upland, which despite a complex erosional history reflects the lithological components and structural lineaments of the fractured, asymmetrical structural basin of Upper Palaeozoic rocks. Embodying a discrete geological framework which is deceptively simple in essentials but intriguing in its more complex aspects, the Forest of Dean has attracted the interest of geologists since the early days; this reputation, together with its recognized value for teaching purposes and a continuing importance in research terms, has made it classic ground. It is also of considerable significance in the wider regional context. The long and varied history of investigation has been further enriched by the remarkable mining and quarrying traditions of the Forest and the strikingly individual landscapes which have been created. One of the consequences is that the geological literature is not only extensive but also rather scattered; the present article attempts to assemble, order and integrate the principal sources, reviewing them with respect to the themes and issues which continue to draw research geologists, student classes and field excursions.

The strata encountered in the Forest of Dean region are Silurian, Devonian and Carboniferous in age, the three principal lithostratigraphical components being the Old Red Sandstone (ORS), Carboniferous Limestone and Coal Measures (Fig. 1). The small

			Thickness (metres)
CARBONIFEROUS	UPPER COAL MEASURES	Supra-Pennant Formation	max. 360
		Pennant Formation	180 - 260
		Trenchard Formation	15- 120
		unconformity	
	LOWER COAL MEASURES (Sullivan,1964a) CARB. LST. (Cleal,1986b)	Edgehills Sandstone	min. 5
		? unconformity ? (Sullivan, 1964a)	
	CARBONIFEROUS LIMESTONE	Drybrook Sandstone Formation	max. 230
		Whitehead Limestone	15 - 60
		minor unconformity	
		Crease Limestone	10- 30
		Lower Dolomite	65- 130
		Lower Limestone Shale	55 - 70
SILURIAN - DEVONIAN	UPPER OLD RED SANDSTONE	Tintern Sandstone Formation	75- 150
		Quartz Conglomerate	3 - 35
		unconformity	
	LOWER OLD RED SANDSTONE	Brownstones Formation	0 - 1220 max ?
		St Maughan's Formation	380 - 610
		Raglan Mudstone Formation	305 - 610
		Downton Castle Sandstone	15 - 25

Fig. 1. The stratigraphical column in the Forest of Dean. The age of the Edgehills Sandstone and its relationship to adjacent strata are uncertain.

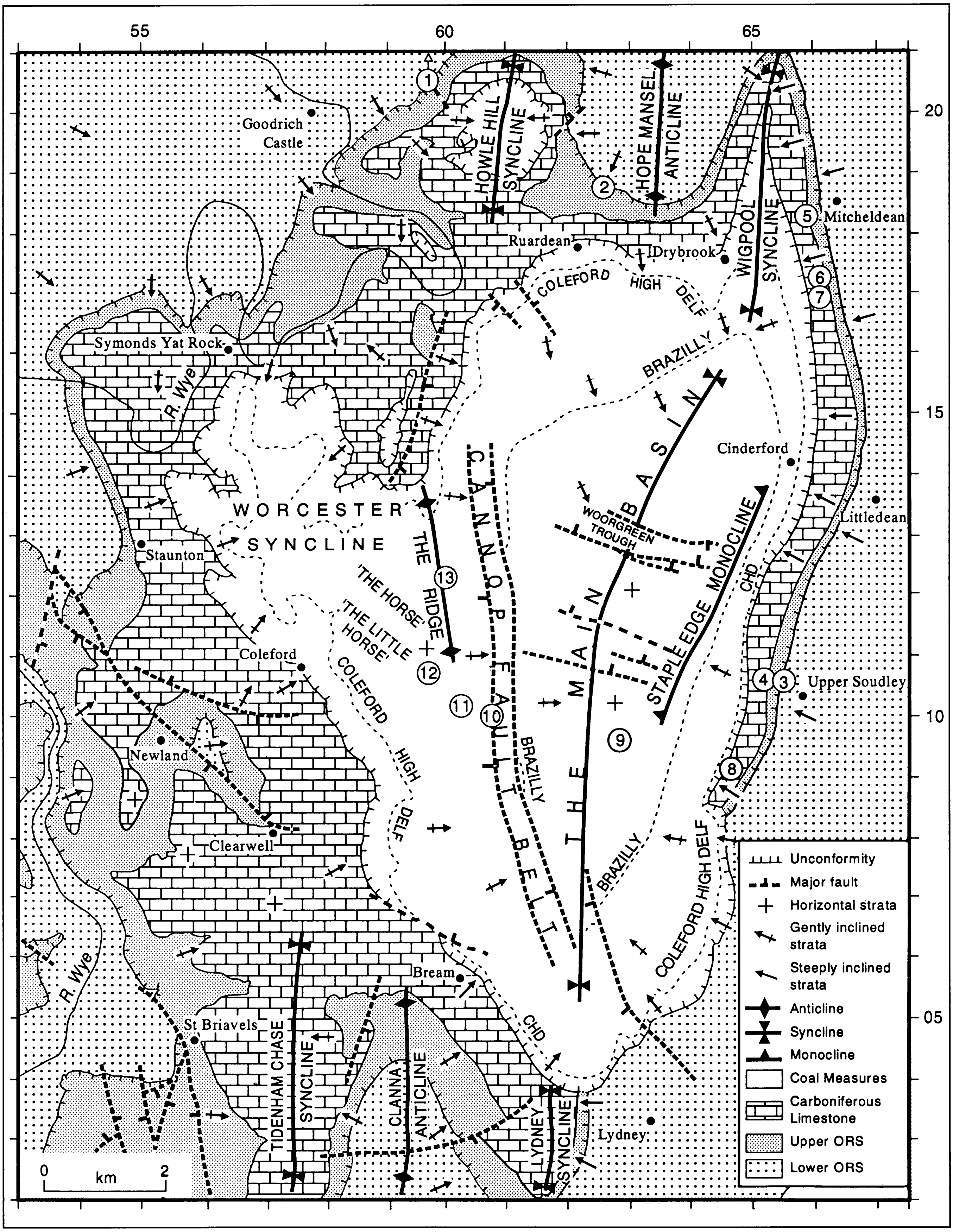

Fig. 2. Simplified geological map of the Forest of Dean (based partly on BGS 1:50 000 sheets 233 and 234*). The numbers refer to the localities described in the field excursion itinerary. Within the Coal Measures, the dividing line between the Trenchard Formation and the Pennant Formation is drawn at the floor of the Coleford High Delf and that between the Pennant and Supra-Pennant formations at the floor of the Brazilly Seam. * by permission of the Director, British Geological Survey; NERC copyright reserved.

coalfield constitutes the heart of the district, the basin of Upper Coal Measures being underlain and surrounded by older rocks which were subjected to earth movements before the Upper Carboniferous (Silesian) strata were laid down. Following the deposition of the Silesian rocks, a second major tectonic phase took place and the Coal Measures were gently folded to produce the coalfield basin. At the same time, the previously folded ORS and Carboniferous Limestone were reaffected; these strata exhibit their own structures, particularly to the north and south of the Main Basin, where they emerge from beneath the Coal Measures cover in sets of asymmetrical folds exhibiting high westerly dips (Fig. 2). In these folds the strata are generally much more steeply inclined, especially on the eastern side of the Forest close to the line of the Malvern Axis, where they are near-vertical (Fig. 3), vertical or even overturned locally. The angular intra-Carboniferous unconformity is characterized by overlap and overstep, the latter being demonstrated most dramatically on the south-eastern side of the Main Basin, where the Coal Measures conceal the whole of the Carboniferous Limestone and Upper ORS and come to rest directly on the Lower ORS.

The following bibliographical review is confined to published works and theses. It begins with early research and general references, then deals with structure; the account of the strata that follows is based upon lithostratigraphical units. If a reference is relevant to more than one section, it is given in full on the first occasion and thereafter in an abbreviated form of author and date, followed by a number in brackets indicating the section in which the full citation may be found. The general references, pertinent throughout, are not repeated.

2. Early research (to 1850)

Several of the most prominent figures of nineteenth-century geology referred in their writings to the Forest of Dean, notably Buckland, Conybeare, Phillips, Murchison and De la Beche, but the earliest contribution of all was (and in many ways remains) the most remarkable. The detailed and accurate vertical section of the strata of the Forest produced by David Mushet (1772-1847), the eminent Scottish metallurgist, was communicated to the Geological Society in 1812 and reproduced in Buckland and Conybeare's paper of 1824. The year 1812 also saw the publication of a paper by Mushet, the first general description of the geology of the Forest to appear in print. His representation of the Coal Measures is especially impressive; indeed, the particulars given of the strata in the upper division of the Supra-Pennant Measures have not been substantially bettered to this day. Geological information was collected during the progress of the Ordnance Survey in 1830 (Maclauchlan, 1840), and by the time that the first Geological Survey one-inch maps and sections were published in 1845-46, the general outlines of the geology were broadly known. In 1837 Thomas Sopwith, having compiled a notable plan of the coal-mines and iron-mines, produced his cleverly constructed 1:12 672 geological model of the Forest; this was followed by one at a scale of 1:6 336. Buckland and De la Beche paid tribute to their usefulness, and they became the objects of much admiration and discussion (Anon, 1840; Turner and Dearman, 1982).

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Fig. 3. Shakemantle Quarry, Ruspidge (SO 653 113): Lower Dolomite dipping 65° to the west.

4. Regional tectonic setting

The Forest of Dean is situated immediately to the west of the deep-seated line of disturbance associated with the Malvern Fault Zone. The nature and recurrent influence of this, the most important structure in the region, have been much debated (Butcher, 1962). Especial regard has been given to the dominance of N-S Variscan folds (anomalous in orientation and asymmetrical in form) and the possible relevance of strike-slip faults in the basement for patterns of deformation, notably in the neighbouring Silurian periclinal inliers of Woolhope and May Hill and that at Usk, which complements the Dean basin on the west (Kellaway and Hancock, 1983; Williams and Chapman, 1986; Wilson *et al.*, 1988). The timing of the various tectonic events assumes particular significance in the context of the Forest of Dean, where the absence of Namurian strata makes it difficult to determine whether the main intra-Carboniferous movements were Sudetic (pre-Namurian) or Malvernian (pre-Morganian, i.e. pre-Upper Coal Measures). If the Edgehills Sandstone, apparently positioned below the angular unconformity (Fig. 1), is concluded not to be the conformable member of the Dinantian succession that it appears (Jones, 1984; Cleal, 1986b), but rather, on the basis of controversial miospore evidence, Lower Westphalian A in age (Sullivan, 1964a; Spinner, 1984b), then the Malvernian phase could be identified as being the more important. However, the regional role of Sudetic movements can be demonstrated; of particular interest is the sub-Namurian unconformity in the South Wales Coalfield, which increases eastwards (towards the Usk Anticline) and is accompanied by overstep and overlap (George, 1962, 1970; Barclay and Jones, 1978). The eastward attenuation which characterizes the Ammanian (Lower and Middle Coal Measures) suggests that uplift of the Usk Axis persisted during the Westphalian; Cleal (1986a) proposed that the Forest was part of an area of non-deposition (which included Usk) from late Viséan (?Asbian) times to mid-Westphalian D (Owen, 1970; Kelling, 1974), when sedimentation commenced in association with the Leonian (late Variscan) phase of uplift (Dvořák *et al.*, 1977).

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5. Structure

The main structural features of the Forest of Dean are depicted and labelled in Figure 2; speculation continues as to their mutual relations. The principal questions are the causes of the asymmetry, *en échelon* arrangement and alignment of the folds, the relationship between the pre- and post-Westphalian structures, and the roles played by the Malvern Axis, the Severn Estuary Fault Zone, and the faults in the basement complex (Wilson *et al.*, 1988). Of specific interest is the nature and origin of the Staple Edge Monocline, which provides an exception to the otherwise gentle structures characterizing the coalfield (Morgan, 1916); Kellaway and Hancock (1983) proposed that it is parasitic on the Main Basin, its formation being connected with the creation of the one notable fault complex, the Cannop Fault Belt, which consists of a set of normal faults arranged *en échelon*. They discussed other examples nearby of localized steepening on west-facing folds, most pronounced in the Flaxley and Newnham overfolds, which Lawson (1955) saw as being clearly related to the Staple Edge Monocline. Butcher (1962) envisaged a regional set of N-S monoclinal folds and related their formation to the pattern of the intra-Carboniferous unconformity with easterly overstep. Moore and Blundell (1952) drew a comparison between the coalfields of the Forest of Dean and South Wales in this respect, where the easterly overstep and overlap reflect the proximity of the Malvern and Usk axes respectively.

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6. Lower Old Red Sandstone

The ORS in the Forest of Dean comprises two major cycles of clastic red-bed sequences of predominantly fluvial origin. These sediments were deposited as post-orogenic molasse in the Anglo-Welsh external basin, which was situated between the developing continent in the north and an expanding ocean to the south. The Lower ORS is a progressively upward-coarsening offlap succession characterized by rhythmic sedimentation and a range of sedimentary structures produced by meandering river channels migrating laterally across the broad plains of alluviation. The seminal works of J. R. L. Allen (1960 ff.), incorporating detailed sedimentological studies, have greatly advanced the state of knowledge. Attention concentrates on the problems of lithostratigraphical classification, biostratigraphical correlation, chronostratigraphical definition (the Downtonian is now assigned to the Silurian Přídolí Series), the appropriateness of modern environmental analogues, the mechanisms responsible for the fining-upwards cyclothems, the origin of the red beds with their subsidiary green or grey zones and patches, and the mode of formation and palaeoenvironmental significance of the horizons of calcareous concretions (Fig. 4). These have been interpreted as being the ancient equivalents of the nodular or indurated calcareous materials known as calcrete, developed in the soils and sediments of certain present-day semi-arid regions.

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Fig. 4. Multistorey calcrete profile ('*Psammosteus*' limestones) developed in thick red mudstones at the junction of the Raglan Mudstone Formation and the St Maughan's Formation, Lower ORS; cliff near the salmon putcheons, Lydney (SO 655 022). The lowermost calcrete shown here, which forms the lower portion of the cliff, is particularly strongly developed; it displays pseudo-anticlines and fan-like arrangements of glaebules, with a horizon of crudely prismatic, coalesced nodules in the upper part which has been taken to mark the top of the Raglan Mudstone Formation (Allen, 1974b, 1986).

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7. Upper Old Red Sandstone

The Farlovian Upper ORS, comprising the Quartz Conglomerate (Mushet's 'Great plum-pudding stone') and the overlying soft arenaceous rocks of the Tintern Sandstone Formation, rests unconformably upon folded and eroded Lower ORS (Fig. 5). Sandstones (channel sediments) and siltstones (floodplain deposits) are arranged cyclically (Allen, 1965b, 1971, 1974a). Recent research has concentrated on contemporary palaeogeography, the source-regions of the sediments, the significance of the various conglomerate formations in the ORS of the Anglo-Welsh basin including the Quartz Conglomerate, and the nature of the earth movements responsible for the apparent absence of the Middle ORS and part of the Upper ORS.

Fig. 5. The intra-ORS unconformity, Upper Soudley railway cutting, looking S along the strike; the Quartz Conglomerate (to the right of the hammer) rests upon the Brownstones (left).

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8. Carboniferous Limestone

The early Dinantian (Courceyan) marine transgression was pulsed (Ramsbottom, 1973, 1980; Wright, 1987; Davies *et al.*, 1991), so that although the junction between the Tintern Sandstone Formation and the diachronous Lower Limestone Shale (Burchette, 1977) is apparently comformable, the interdigitating beds of fluvial sandstone and marine shale make it difficult to determine the dividing line or identify the Devonian-Carboniferous boundary. The base of the Carboniferous is currently placed, on palaeontological evidence (Stubblefield, 1937), within the highest beds of the Tintern Sandstone Formation. In the nineteenth century, the 'Transition Beds' were both well exposed (in the Deep Cutting at Euroclydon) and much discussed, notably by De la Beche (1846), Jones and Lucy (1867), and in a series of papers by Wethered.

The general debates concerning the respective importance of eustatic sea-level oscillations (the mesothemic cycles of Ramsbottom (1980)) and contemporary tectonism (George, 1978; Johnson, 1982), and their relationship with George *et al*'s (1976) chronostratigraphical regional stages (Leeder, 1988), have provided the background to the modern study of the complex lithostratigraphy of the Dinantian of the South-West Province. In the Forest of Dean, the succession (predominantly one of carbonates) has prompted continuing research. The correlation of the traditional formations and coral-brachiopod zones with the new chronostratigraphical divisions has received considerable attention (George *et al.*, 1976; Lowe, 1989a, 1989b; Riley, 1993). Other inquiries have been directed towards identification of non-sequences and diachronous horizons, the pattern of lithofacies produced by the development of the carbonate ramp and subsequent evolution of a typical shelf configuration (Burchette, 1977, 1987; Wright, 1987), palaeoclimatic reconstruction (Wright, 1990), the processes responsible for the dolomitization, and the interpretation of the siliciclastic sediments (Drybrook Sandstone Formation) at the top of the sequence. These sediments were formerly mapped as Millstone Grit and are now famous for the Asbian flora collected at Puddlebrook Quarry (Hazel Hill) (Lele and Walton, 1962; Rowe, 1986ff.). The proposed Asbian age, derived from new miospore data, accords with that suggested by Cleal (1986b), on macrofloral evidence, for the problematic Edgehills Sandstone, which the Puddlebrook bed resembles in several of its characteristics.

The origin of iron ores in the Forest of Dean, disposed irregularly in the Dinantian rocks as the presumed product of downward-percolating solutions, is probably related to lithological variation, dolomitization, tectonism, solution processes and palaeokarst, the brecciation observed at the 'mid-Avonian break' (the pre-C_2S_1 Zone 'Nassauic parorogeny' of Simpson (1962)), and the form of the intra-Carboniferous unconformity.

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9. Coal Measures

The long history of coal mining (by crop workings, shafts and opencast) in the exposed basin of the Forest of Dean coalfield has bequeathed much detailed information concerning the Coal Measures. This knowledge is, however, selective. The older literature concentrates on the coal seams of the 'productive' divisions (Insole and Bunning, 1881; Joynes, 1889; Hoskold, 1892), the structure of the basin as regards its implications for the drainage of shafts sunk in the central part (Anon, 1878a; [Binks], 1902; Brown and Brain, 1905), and upon such features as washouts (Buddle, 1842) and the Staple Edge Monocline (Morgan, 1916) which presented problems with respect to mining operations. The concealment of the Carboniferous Limestone by the overstepping Coal Measures on the south-east side of the basin was long attributed to its being cut out by a fault, until Sibly (1912) demonstrated the unconformity.

The modern study of the Coal Measures rests on Trotter's (1942) memoir and his tripartite scheme of Trenchard, Pennant and Supra-Pennant groups, the status of which was revised by Ramsbottom *et al.* (1978) to that of formation. The principal outstanding questions concern palaeogeography, facies patterns and sediment provenance (Gayer and Stead, 1971; Jones, 1972; Kelling, 1974; Stead, 1974; Cleal, 1987), relationship with the other 'Variscan Foredeep' coalfields (Wagner and Spinner, 1972), significance of the subgreywacke Pennant Sandstones (Kelling, 1974; Thomas, 1974; Hartley and Warr, 1990), and the age of the strata. Cleal (1986a, 1991), reviewing all the evidence, argued cogently that the base of the succession is of late Westphalian D age and that the previous assignment of the Trenchard Formation to the Bolsovian (Westphalian C) Stage is without foundation.

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10. Post-Carboniferous events

Little has been written on the Mesozoic and Cenozoic history of the Forest; given the absence of post-Silesian rocks, conclusions remain speculative. This is especially so with regard to the existence or otherwise of former Triassic, Jurassic and Cretaceous covers, inferred from the present disposition of strata belonging to these systems that crop out successively with increasing distance to the east and south-east. The matter is closely related to the broader issues of regional palaeogeography (Wills, 1948; Cope *et al.*, 1992), regional geological evolution (Jones, 1956; Owen (Ed.), 1974; Cope, 1984), the history of denudation, planation and possibly exhumation, the role of Tertiary earth movements, and the origins of the present river system (Strahan, 1902; Jones, 1951). Geologists have been joined in these investigations by geomorphologists, especially those of the denudation chronology school (Brown, 1957, 1960), some of whom have worked specifically on the Forest of Dean and the Wye Valley (Clarke, 1934; Miller, 1935; Caton, 1964). Welch and Trotter (1961), noting the absence of Permian and Bunter deposits in the neighbouring 'New Red Sandstone', maintained that by early Triassic times the Forest was part of a wide upland ridge connected to the Welsh massif. Miller (1935) and Trotter (1942), citing the character and arrangement of the Keuper Marl outcrops to the south-east and south of the Forest, were sceptical of the former existence of a thick Trias mantle. In connection with the origin of the iron ores, Trotter joined Jones (1931) in postulating the destruction, on a Triassic land surface and in an oxidizing environment, of Coal Measures containing ironstones and pyrites; Wethered (1882b, 1888) and Sibly (1919), on the other hand, had attributed the iron to a Keuper cover.

It is concluded that the Forest of Dean lay beyond, but at times very close to, the limits of the Pleistocene glaciations (Lewis, 1970; Bowen, 1973). However, evidence of (?Devensian) periglacial activity is found in the scatters of angular blocks on slopes below the outcrop of the Quartz Conglomerate, in the tilting of rock fragments in regolith disturbed by frost heaving (well displayed at the tops of quarry faces and in sections beside forest tracks), and in the presence of locally thick solifluxion and related deposits (mapped as 'Head'), especially on the coalfield.

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