REVIEW OF THE STRATIGRAPHY OF THE WENLOCK SERIES IN THE WELSH BORDERLAND AND SOUTH WALES

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ABSTRACT. The stratigraphy and correlation of the Wenlock Series (Silurian) in its type area of the Welsh Borderland and also in South Wales are reviewed in the light of new faunal information. Two correlation charts are presented to relate the various lithostratigraphical sequences to one another and to the standard graptolite zones. The Wenlock Limestone is shown to be diachronous from the *lundgreni* to the *ludensis* Zone between Dudley and Ludlow. Palaeogeographical maps are constructed for early and late Wenlock times.

THE recent Special Report of the Geological Society of London on Silurian correlation in the British Isles (Cocks *et al.* 1971) outlined both the present state of our knowledge and the unresolved problems. The authors pointed out (1971, p. 104) that 'since the Second World War, the Wenlock Series has received less attention than the Llandovery and Ludlow' and that 'the time is not yet ripe for the formal erection of stages within the Wenlock Series'. These comments are especially relevant to the strata of the shelly facies, in which correlation is still based largely on the lithological divisions erected by Murchison (1833, 1834, 1835, 1839).

As a result of the Special Report, the Stratigraphy Committee of the Geological Society set up a Working Group to investigate the problems of erecting stages within the Wenlock Series; this Group now consists of Professor C. H. Holland, Dr. L. R. M. Cocks, Dr. R. B. Rickards, Dr. P. T. Warren, and the present author. Immediate agreement was reached that the main problem lay in correlating the shelly sequence of the type area of Wenlock Edge in Shropshire with the succession of graptolite zones in the basin facies (Elles 1900), which have been revised recently by Rickards (1967, 1969), working in the north of England, and Warren (1971), working in North Wales. The Working Group thus decided to carry out extensive fieldwork along Wenlock Edge in an attempt to establish graptolite control prior to the erection of formal stages; this work is now completed and the results in press elsewhere.

This review is intended to provide a background to the stratigraphy of the Wenlock Series throughout the Welsh Borderland and South Wales (text-fig. 1) in order to set the type Wenlock area in its regional context.

The term Wenlock was first used by Murchison (1833, 1834, 1835) for the shales and limestones in Shropshire between the top of his Caradoc Sandstone (i.e. top of the Llandovery Series of modern nomenclature) and the Ludlow rocks; he later (1839, p. 409) grouped the Wenlock rocks as a formation, and following modern stratigraphical practice the beds are now regarded as being of Series rank (see Evans *in* Whittard 1961, p. 253). In 1880 Lapworth (p. 48) introduced the term Salopian for strata of Wenlock and lower Ludlow age, and the name has subsequently been used by numerous authors, especially for rocks in graptolitic facies. Jones (*in* Evans and Stubblefield 1929, p. 89) suggested that if Salopian is to be retained it should embrace

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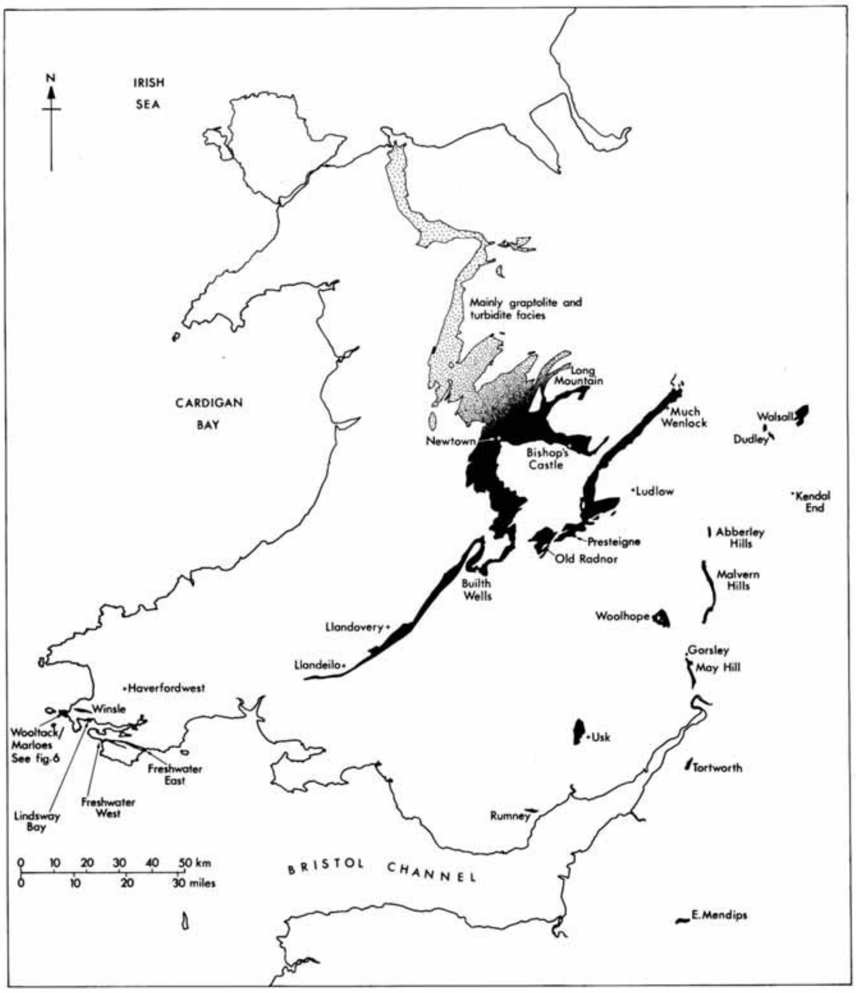


TEXT-FIG. 1. Outcrop and location map of the Wenlock rocks of Wales and the Welsh Borderland. The areas discussed in this paper are shaded in solid black.

the whole of the Wenlock and Ludlow, but I agree with Cocks *et al.* (1971, p. 104) that the term has no place in modern stratigraphical classification and should not be used.

In Shropshire the Wenlock Series comprises two broad lithological divisions, the Wenlock Shale and the Wenlock Limestone, while in parts of the southern half of the Welsh Borderland a third unit, the Woolhope Limestone, is present at the base of the Series as a lateral equivalent of part of the Wenlock Shale of Shropshire. The Woolhope Limestone was initially included by Murchison (1839, p. 429) in the top of his 'Caradoc Sandstone' but, following De la Beche (1846, pp. 38–39) and Phillips (1848, pp. 75, 167), was later placed by him (1854, p. 106) at the base of the Wenlock, an interpretation which is now accepted in the light of subsequent correlation. In South Wales the limestone and shale facies of the Welsh Borderland are replaced by clastic sequences consisting mainly of calcareous and arenaceous mudstones and siltstones. Variations in the thickness of the Wenlock Series and the correlation of its constituent lithostratigraphical units are illustrated in text-figs. 2 and 4.

Following the outline of the graptolite succession given immediately below, the nature and age of the contacts of the Wenlock with Llandovery and older rocks, and with Ludlow and younger rocks, are then discussed in order to define the limits of the Series throughout the shelf area, and to stress the pulsatory pattern of Lower Palaeozoic earth movements which partially controlled Wenlock sedimentation and palaeogeography (see George 1963; Ziegler 1970). The stratigraphy of individual areas shown in text-fig. 1 is then described, followed by a synthesis of Wenlock palaeogeography.

THE WENLOCK GRAPTOLITE SUCCESSION

Although graptolites have been recorded comparatively rarely from the Wenlock shelf facies, some valuable specimens have been mentioned by authors from different areas. Since some of the following discussion on stratigraphy is based on graptolite evidence, the zonal scheme recognized in the basin facies is given below (see also text-figs. 2 and 3). This is the succession established at Builth (Elles 1900; Elles and Wood 1918), with modifications in nomenclature based on Rickards (1965, p. 248, text-fig. 1; 1969), Warren *et al.* (1966, p. 466), Holland *et al.* (1969, p. 676, text-fig. 4), Warren (1971), and Cocks *et al.* (1971, text-fig. 2).

Monograptus ludensis	(= *vulgaris* auct.)
Cyrtograptus lundgreni	
Cyrtograptus ellesae	(= *rigidus* auct.)
Cyrtograptus linnarssoni	
Cyrtograptus rigidus	(= *symmetricus* auct.)
Monograptus riccartonensis	
Cyrtograptus murchisoni	
Cyrtograptus centrifugus	

It should be emphasized that this range of zones is Wenlock by correlation as opposed to being Wenlock by definition, since the limits of the type Wenlock Edge succession are not yet known with certainty in graptolite terms. Subdivisions of these zones, and regional variations in nomenclature in the basin successions in different parts of Britain, are given by Rickards (1965, text-fig. 1; 1967, text-fig. 8; 1969, text-fig. 2) and Warren (1971, text-figs. 1 and 2).

WENLOCK/PRE-WENLOCK CONTACTS

In the southern half of the Welsh Borderland the junction between the uppermost Llandovery and lowest Wenlock rocks is exposed only in the Tortworth, May Hill, and Woolhope Inliers and to the west of the Malvern Hills, and in all cases the relationship is one of conformity. Thus at Woolhope, May Hill, and in the Malverns the Woolhope Limestone succeeds deposits of latest Upper Llandovery (C_6) age (Upper Haugh Wood Beds, Yartleton Beds, and Wych Beds respectively) with no apparent break, and in the Tortworth Inlier an unnamed limestone unit at the base of the Wenlock Brinkmarsh Beds similarly rests on uppermost Tortworth Beds of C_6 age. In the western English Midlands, around Walsall and Dudley, the Llandovery/Wenlock contact is not exposed at the surface, but a borehole at Walsall (Butler 1937, p. 249) shows a conformable transition between the two Series.

In parts of the northern half of the Welsh Borderland and in south Central Wales there are stratigraphical breaks of varying magnitude between Llandovery and Wenlock strata, although previous descriptions of breaks within some parts of this area require further comment. At the north-east end of Wenlock Edge the base of the Wenlock is taken at the base of the Buildwas Beds (Wenlock Shale) at their contact with the Purple Shales. This horizon has generally been accepted as the base of the Series since its definition by Salter and Aveline (1854, p. 63), following the original description of the area by Murchison; however, the correlation of this horizon with the graptolite sequence has been the subject of some discussion. Whittard (1952, p. 169) suggested that graptolites recorded by earlier authors, notably Whittard (1928), Das Gupta (1932), and Pocock *et al.* (1938), from low Wenlock Shale horizons, 'do not warrant correlation with any zone older than *linnarssoni*', implying that the *centrifugus*, *murchisoni*, *riccartonensis*, and *rigidus* zones are absent. In addition, Whittard found no evidence from his own earlier work (1928, 1932) for the Upper Llandovery *griestoniensis* and *crenulata* zones, and he suggested that there is a considerable stratigraphical break below the Buildwas Beds. More recently Cocks and Rickards (1969, pp. 224–227) reassessed all previous records of graptolites from the uppermost Llandovery and lowest Wenlock of Shropshire and concluded (pp. 228–229) that within the type area there is no large sedimentary break at the Purple Shales/Buildwas Beds junction which 'approximately coincides with . . . the base of the *centrifugus* Zone'. Two of the zones (*griestoniensis* and *rigidus*) thought by Whittard to be missing were shown by Cocks and Rickards to be present, thus reducing the previously postulated break, and although the *crenulata*, *centrifugus*, *murchisoni*, and *riccartonensis* zones remained unproven by graptolites, some 60 m of rock without diagnostic graptolite species could accommodate some or all of them. From this evidence the correlation of the base of the Buildwas Beds with that of the *centrifugus* Zone is a reasonable approximation; the current work of the Geological Society Working Group is aimed at producing positive evidence to resolve the problem.

At the south-west extremity of Wenlock Edge the Buildwas Beds are overlapped by higher horizons of the Wenlock Shale (Coalbrookdale Beds) which eventually overstep on to the Purple Shales. West of the Church Stretton fault the extent of the overstep is known in some detail from the faunal evidence in boreholes (Cocks and Rickards 1969) where the *centrifugus*, *murchisoni*, and all or part of the *riccartonensis* zones are cut out; to the south of Church Stretton the Wenlock Shale finally oversteps on to the Ordovician (Dean 1964). At Bishop's Castle, some 15 miles to the south-west of Wenlock Edge (see text-fig. 1) the same infra-Wenlock unconformity is detected, with the local basal Wenlock beds, belonging to the *lundgreni* Zone (Allender *in* Allender *et al.* 1960, p. 223), resting directly on the Upper Llandovery. At Nash Scar, near Presteigne in Radnorshire, the base of the Wenlock succession is represented by the Nash Scar Limestone, which rests on the Folly Sandstone of early Upper Llandovery (C_{1-2}) age (Ziegler *et al.* 1968, p. 750); there is thus a possibility that part of the Nash Scar Limestone is as old as C_3, but the total fauna collected by the present author (p. 759) is more suggestive of a Wenlock age, and this, together with the evidence of a disconformable relationship with the Folly Sandstone on the north side of the Presteigne Inlier (Ziegler *et al.* 1968), strongly points to an unconformable Folly Sandstone/Nash Scar Limestone contact throughout the area. At Dolyhir, near Old Radnor, some 7 km south-west of Nash Scar, the local basal Wenlock correlative of the Nash Scar Limestone is the Dolyhir Limestone, which rests with gross unconformity on Pre-Cambrian rocks. In the Long Mountain syncline of Montgomeryshire and north Shropshire Das Gupta (1932, pp. 326–327) suggested that there was also an unconformity at the base of the Wenlock throughout the area, with *riccartonensis* Zone or younger strata resting directly on the Upper Llandovery Buttington [Purple] Shales (see also Wade 1911, p. 436; Elles 1900, pp. 386–397). However, a preliminary revision of the stratigraphy by Palmer (1970), with revised nomenclature, indicates conformity between the Llandovery (Buttington Mudstone Formation) and the Wenlock (Trewern Brook Mudstone Formation), and this is supported by faunal evidence from Buttington brickworks in the north of the syncline (SJ 3266 3100) where a basal Wenlock graptolite sequence through the *centrifugus*, *murchisoni*, and *riccartonensis* zones is present (Ziegler *et al.* 1968, p. 766; Cocks and Rickards 1969, pp. 226–227; Cocks *et al.* 1971, p. 109).

Throughout the Builth district of Radnorshire, where Elles (1900) first demonstrated the succession of Wenlock graptolite zones, basal Wenlock Beds are largely obscured by overlap by the higher zones (Jones 1947). In the sections north and east of Builth this overlap is most marked and increases in intensity to overstep on to Llandovery and then Ordovician rocks of the Carneddau range. The Llandovery Trecoed Beds (Ziegler *et al.* 1968, p. 769; Cocks *et al.* 1971, p. 108, text-fig. 2 column D) of this area crop out in a thin, discontinuous strip from Park Wells to near Maesgwynne (Jones 1947, pl. 1) and contain a mid Upper Llandovery (C_{3-4}) fauna. Highest Upper Llandovery Beds are not known below the Wenlock but the detailed extent of the sub-Wenlock unconformity is uncertain since the graptolite faunas of the lowest Wenlock Beds need revision. The lowest (*murchisoni*) Zone as recognized by Elles (1900) is now generally subdivided into a *centrifugus* Zone below and a *murchisoni* Zone above (e.g. see Rickards 1967, 1969), and the *centrifugus* Zone has not yet been proved at Builth. Elles's faunal lists (1900, table 1, p. 378) are of little help, but her record of *Retiolites geinitzianus* Barrande from Pencerig may indicate that the *centrifugus* Zone is represented at that locality, since the species is rare or absent in many areas at higher horizons; it has, however, been recorded from the *murchisoni* Zone of North Wales (Warren 1971) and Poland (Teller 1969).

West of Builth, and south-westwards towards the Garth area (Breconshire), basal Wenlock Beds are again cut out both by overlap and overstep on to Llandovery horizons, but around Garth itself the two Series reappear for a short distance in conformable sequence (Andrew 1925, p. 399; Andrew and Jones 1925, p. 412); as at Builth there is no modern record of the *centrifugus* Zone, but since mudstones of the highest Llandovery *crenulata* Zone pass transitionally into sediments containing *C. murchisoni*, the *centrifugus* Zone is probably represented. Within a mile to the south-west of Garth overlap within the Wenlock again takes place, followed by very rapid overstep across the Llandovery strata and on to the Ordovician, a relationship which is continued for some 16 km in the same direction towards the town of Llandovery (Carmarthenshire).

Around Llandovery itself, and south-westwards to Maes-y-fallen, some 3·2 km south-east of Llandeilo, Llandovery rocks reappear between the Wenlock and the Ordovician. In the northern part of the Llandovery district, the uppermost Llandovery (Pale Mudstone Group) is either faulted against or followed conformably by basal Wenlock rocks (Jones 1949, p. 58, pl. 3), but in the southern district a south-westerly overstepping relationship between the two Series takes place once more (Jones 1925, p. 376, pl. 21). The increasing intensity of this overstep south-westwards to Maes-y-fallen has been well documented by Williams (1953, pp. 198–200, pl. 9) and beyond this point Wenlock beds again transgress on to the Ordovician. Some modification in the geographical extent of the overstep described by Williams is suggested by a re-examination of the section in the Sawdde gorge south of Llangadog; here Williams recorded (1953, p. 199) Llandovery strata of C_{4-5} age overlain by Wenlock beds provisionally assigned to the *riccartonensis* Zone, but recent collecting close to the boundary, both by the author and independently by Mr. N. J. Hancock, has revealed brachiopod faunas of probable C_6 age, with an apparently conformable transition upwards into the Wenlock, although firm graptolite control is still lacking (see p. 766); however, Williams's reconstruction south-westwards from the Sawdde is confirmed by his faunal evidence and rapid thinning of both the Llandovery and lower Wenlock sediments.

Between Maes-y-fallen and Llanarthney, beds of late Wenlock age rest directly on Llandeilo and Llanvirn rocks, and to the west of Llanarthney the Wenlock is itself finally overstepped by the Old Red Sandstone (Strahan *et al.* 1907).

Westwards through the remainder of Carmarthenshire and across central and north Pembrokeshire there are no outcrops of Wenlock rocks, but along the south coast of Pembrokeshire deposits of this age are present in tectonically isolated sections (text-figs. 1 and 6). The base of the Series is exposed only at Marloes Sands and at Renney Slip, although its exact level has not yet been determined; in both sections beds low in the Coralliferous 'Series' contain distinctive highest Llandovery (C_6) faunas which grade upwards into the Wenlock (Cantrill *et al.* 1916; Ziegler *et al.* 1969, pp. 429–435; Bassett 1971, pp. 207–216). South of Milford Haven, at Freshwater East and Freshwater West, beds of probable Wenlock age (see p. 769) rest directly on Llanvirn graptolitic shales.

WENLOCK/POST-WENLOCK CONTACTS

In all but six of the areas included in this account conformable contacts are exposed between highest Wenlock beds and the overlying Ludlow Series. The exceptions are: (1) the Eastern Mendips Inlier, where the Wenlock is followed unconformably by Old Red Sandstone sediments (Reynolds 1907); (2) the Tortworth Inlier where the uppermost Brinkmarsh Beds, of late Wenlock age, are succeeded with gross unconformity by Upper Old Red Sandstone and Mesozoic strata (Curtis and Cave 1964, p. 438; Curtis 1972, p. 3, fig. 3); (3) Gorsley where beds of Lower Leintwardinian (mid-Ludlow) age rest on an eroded surface of the local equivalent of the Wenlock Limestone (Lawson 1954, p. 231, text-fig. 2); (4) around Walsall where late Carboniferous strata transgress across the Wenlock (e.g. Cantrill 1919; Whitehead and Eastwood 1927); (5) at Kendal End where the Wenlock is now seen faulted against Pre-Cambrian and late Carboniferous; and (6) at Winsle in Pembrokeshire where some marine Silurian beds appear to be cut out beneath overstepping Old Red Sandstone (Cantrill *et al.* 1916, p. 86, see also p. 769). Throughout the Welsh Borderland the Wenlock/Ludlow boundary is drawn at the base of the Lower Elton Beds, at their contact with the Wenlock Limestone. This is the horizon established originally by Murchison (1839, p. 209) and defined by Holland *et al.* (1963, pp. 139–141, text-fig. 11) at a standard section at Pitch Coppice, Ludlow.

The base of the Ludlow Series in the graptolite sequence has, until recently, been generally accepted as at the base of Wood's (1900, p. 422) zone of *Monograptus vulgaris* (= *ludensis*: see Warren *et al.* 1966). In the Ludlow anticline, however, there is now evidence for the *ludensis* Zone both below and within the Wenlock Limestone (Warren *et al.* 1966, p. 466; Holland *et al.* 1969) and most or all of this Zone belongs in the Wenlock; this is supported by the probable presence of the same Zone below the Wenlock Limestone of Wenlock Edge (Cantrill 1927, p. 43; Pocock *et al.* 1938, pp. 101, 113). From the reassessment of the level of the *ludensis* Zone, Warren *et al.* and Holland *et al.* indicated that the base of the Ludlow in the shelf facies (i.e. the base of the Lower Elton Beds) correlates most closely with the base of the *nilssoni* Zone, the latter authors pointing out at the same time (1969, p. 261) that the correlation is still not precise, since diagnostic graptolites are absent in the Lower Elton Beds and highest Wenlock Limestone. Bassett and Shergold (1967, p. 395) and Shergold and Bassett (1970, p. 135) also commented on the degree of uncertainty in the correlation and suggested that along Wenlock Edge the *ludensis* Zone extends into the Lower Elton Beds, based on Das Gupta's records (1932, pp. 351–352; 1933, p. 113 and map, p. 111) of *ludensis* (*sic vulgaris*) from that horizon, together with the identification of lower *nilssoni* Zone faunas by Shergold and Shirley (1968, text-fig. 1) from the basal Middle Elton Beds. Holland *et al.* (1969, pp. 673–674) also recorded *M. ludensis* from within the lower *nilssoni* Zone and so this species in itself does not prove the *ludensis* Zone. Das Gupta's evidence is thus not necessarily at variance with that of Holland *et al.*, though final clarification must await further graptolites from the Lower Elton Beds at Ludlow and Wenlock Edge.

The stratigraphical consequences of slightly different interpretations of the position of the base of the Lower Elton Beds in the graptolite sequence have been outlined by Holland *et al.* (1969, p. 681) and discussed by Lawson (1971, pp. 304–306, fig. 1).

One consideration, not mentioned by these authors, is that the base of the Lower Elton Beds may be diachronous, being at or close to the *ludensis/nilssoni* boundary at Ludlow but becoming progressively older in a general easterly direction. This suggestion is supported by the evidence of graptolites from the Wenlock Limestone of Wren's Nest, Dudley; collections in Birmingham University Museum contain a number of specimens of *Monograptus flemingii* (Salter) from Dudley, and although not all of them are accurately localized within the Wenlock Limestone, the lithology of the matrix is undoubtedly from that horizon, and one specimen (BU511 and counterpart 511A) is known to be from 2·4 m above the base of the Limestone on the east side of Wren's Nest hill. *M. flemingii* is not known above the *lundgreni* Zone, providing a firm upper age limit for at least the lower part, and probably all, of the Wenlock Limestone at Dudley (see p. 757). Since the lower part of the Wenlock Limestone at Ludlow is known to be in the *ludensis* Zone (see above), the base of the formation must be diachronous between the two areas, and thus possibly also from Ludlow north-eastwards along Wenlock Edge. A corollary to this is that the base of the overlying lithological unit (Lower Elton Beds at Ludlow/Lower Ludlow Shales at Dudley) is probably also diachronous. This picture is in keeping with the general palaeogeographical reconstruction of continuity of deposition across the shelf area during late Wenlock/early Ludlow times, when limestone deposition would have commenced earlier in the shallower water to the east than along the shelf/basin margins to the west, followed by shallowing and seaward spreading of limestone deposition with time (Scoffin 1971, p. 212 and fig. 27).

In the north and west of the Welsh Borderland and through central and south Wales the Wenlock Limestone is not developed, but, apart from at Rumney (Cardiff) and in Pembrokeshire, the Wenlock/Ludlow boundary can be correlated satisfactorily by means of graptolites. Around Builth and in the Long Mountain, the argillaceous sequence of this level is well documented (Jones 1947; Elles 1900; Wood 1900; Das Gupta 1932; and Palmer 1970). South-westwards from Builth towards Llandovery and Llandeilo the Wenlock/Ludlow succession passes laterally into a conformable sequence of calcareous mudstones and sandstones with a mixed shelly and graptolite fauna. The sequence was formerly mapped as a single unit (Murchison 1839; Strahan *et al.* 1907) but recently Potter and Price (1965) subdivided the Ludlow through much of the area and correlated the base of the Series with the base of the Tresglen Beds, mainly on shelly faunal criteria; this correlation is supported by Price's earlier (*in* Lawson *et al.* 1956, p. 568) correlation of the lower Tresglen Beds with the *nilssoni* shales of Builth, that is immediately above the *ludensis* Zone.

At Rumney (Cardiff) there is apparent conformity between beds of Wenlock and Ludlow age, through a very poorly fossiliferous succession of coarse sandstones, sandy mudstones, and sandy limestones (Sollas 1879, p. 488, fig. 4), but although Sollas correlated part of the sequence with the Wenlock Limestone the sections are now partly obscured and the base of the Wenlock cannot now be fixed accurately; the writer is remapping the inlier and also excavating temporary sections. There are also difficulties in recognizing Wenlock/Ludlow contacts in south Pembrokeshire; north of Milford Haven, where the Coralliferous 'Series' passes conformably upwards into the Sandstone 'Series' at Pittingales Point on the south-east side of Deadman's Bay, along Marloes Sands, and in the Lindsway Bay sections near St. Ishmaels, a number of authors have suggested that the limited faunal evidence indicates a Wenlock/Ludlow transition low in the Sandstone Series, but this evidence is still far from conclusive (Cantrill *et al.* 1916, p. 55; Bassett 1971, p. 207; Sanzen-Baker 1972, p. 144); south of Milford Haven Dixon (1921, pp. 12–13) described an unconformable Wenlock/Ludlow contact at Freshwater East, but other accounts suggest conformable relationships throughout the sections, though it is not yet clear if the beds are of Wenlock or Ludlow age (Bassett 1971, p. 220; Walmsley *in* Owen *et al.* 1971, pp. 46–47; Sanzen-Baker 1972, p. 147). The problems of the age of the Pembrokeshire sections are discussed further below (p. 767).

LOCAL STRATIGRAPHY

WENLOCK EDGE

Text-fig. 2, col. 1

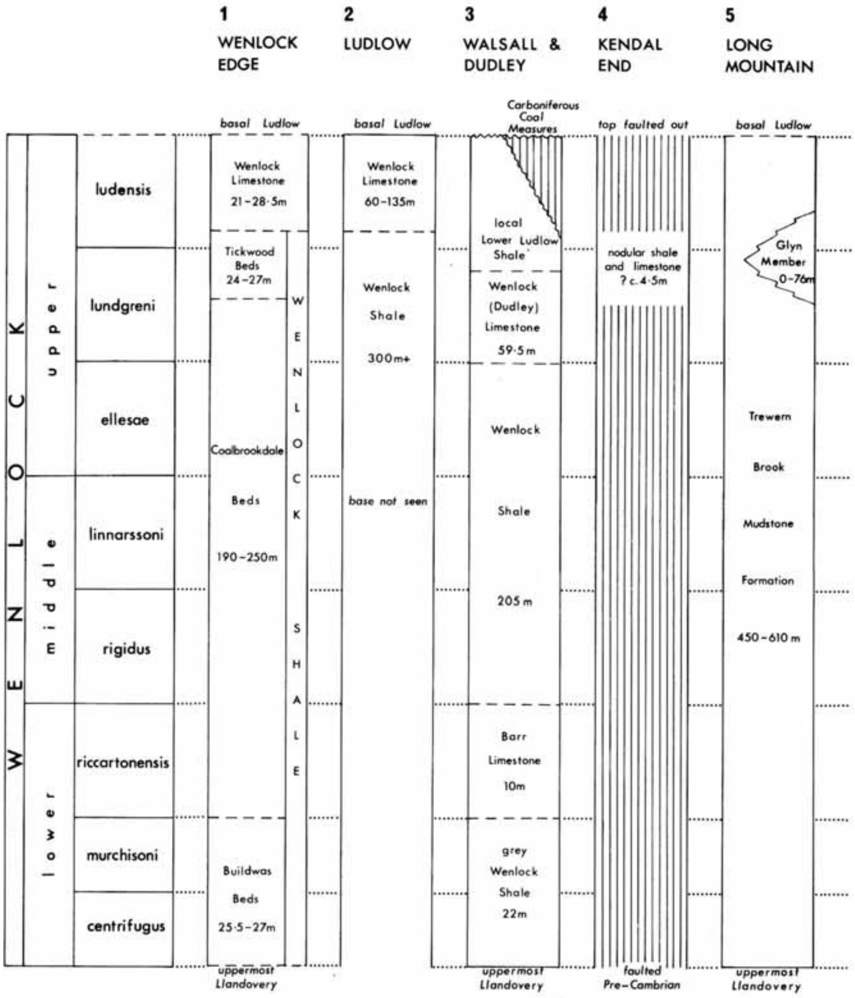
Murchison (1833, p. 475) first divided the Wenlock sequence of Wenlock Edge into an uppermost Wenlock Limestone division, underlain by 'Lower Ludlow Rock or Die Earth', but later (1834, p. 14 and table opposite p. 13) referred the latter to the Wenlock Shale and consistently employed this terminology in subsequent accounts (1835, 1839, 1854–1872). Salter and Aveline (1854, pp. 63, 71) clarified the separation of the Wenlock Shale from the remainder of Murchison's 'Caradoc Sandstone' and confined the Shale to the unit overlying the Purple Shales. Davidson and Maw (1881, pp. 102–104; *in* Davidson 1882, pp. 67–70) further subdivided the Wenlock Shale into Basement Beds, Buildwas Beds, Coalbrookdale Beds, and Tickwood Beds, and also included shales above the Wenlock Limestone within the Wenlock; this classification was followed in full by Lapworth and Watts (1894, p. 325) and in part by Watts (1925, p. 346), but Whittard (1928, p. 752) subsequently pointed out that the Basement Beds belong to the Llandovery Purple Shales, while most authors have followed Murchison's original definition (1839) in including the shales above the Wenlock Limestone within the Ludlow.

The lithological divisions now recognized in the type area are:

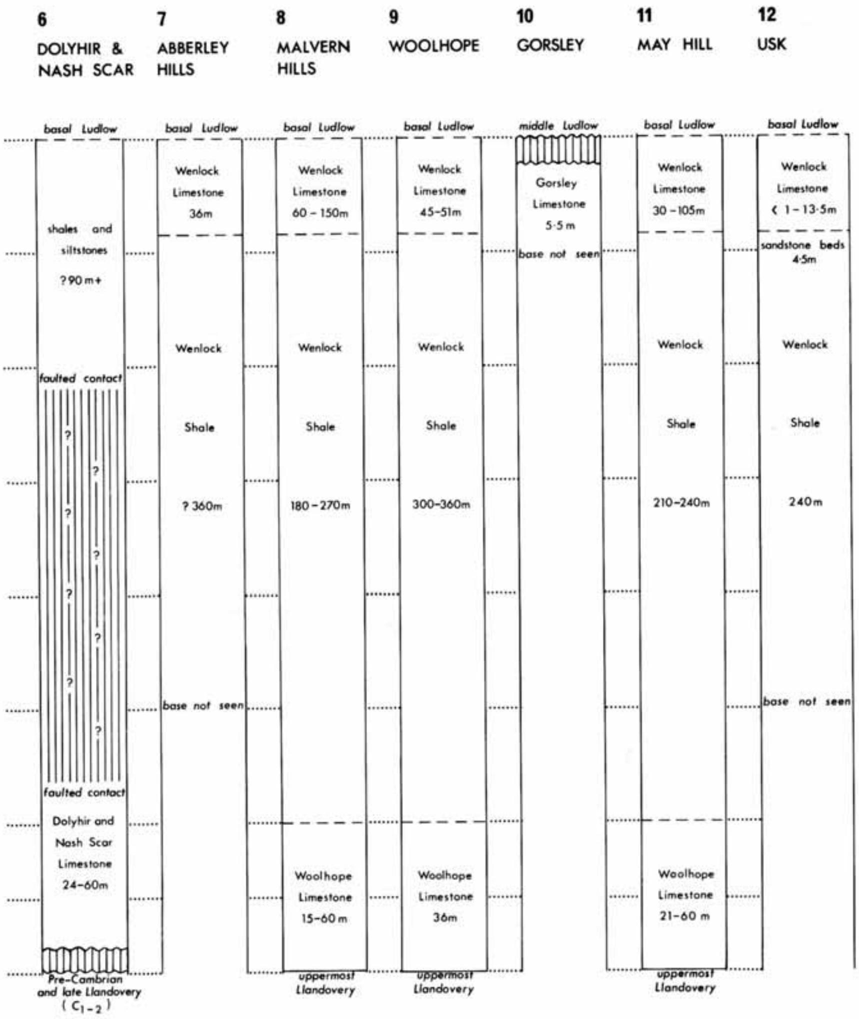
Wenlock Limestone		21–28·5 m
Wenlock Shale	Tickwood Beds	24–27 m
	Coalbrookdale Beds	190–250 m
	Buildwas Beds	25·5–27 m

In the south-west half of Wenlock Edge the Wenlock Shale has been described recently by Greig *et al.* (1968) as a single lithological unit.

The Buildwas Beds are well exposed only in the north-east of the area, being covered largely by drift south-westwards from Ticklerton and overlapped by the Coalbrookdale Beds close to the Onny River; they have been described by Davidson and Maw (1881) and Pocock *et al.* (1938). As discussed earlier (p. 748) Whittard considered that the Buildwas Beds belong either to the *rigidus* or *linnarssoni* Zone, but Cocks and Rickards have suggested that their base may approximate to the base of the *centrifugus* Zone. Aldridge (1972, p. 141) has recently recorded an *amorphognathoides* Zone conodont fauna from the Buildwas Beds near Ticklerton (SO 481 901); correlatives of this zone elsewhere are known to span the Llandovery/Wenlock boundary (in graptolite terms), lending support to a *centrifugus* Zone age for at least part of the Buildwas Beds. Graptolites recorded by Pocock *et al.* (1938) from the lower part of the overlying Coalbrookdale Beds suggest a correlation with the *linnarssoni* Zone, and the higher faunas from this unit suggest the *ellesae*, *lundgreni*, and possibly part of the *ludensis* zones. The record of abundant specimens of *Gothograptus nassa* in the Tickwood Beds indicates that they fall within either the upper part of the *lundgreni* Zone or the *ludensis* Zone (Pocock *et al.* 1938, p. 101; Das Gupta 1935, p. 110), and the overlying Wenlock Limestone is probably wholly within the latter zone. The nature and variation in lithology of the Wenlock Limestone have been described by Crosfield and Johnson (1914), Hill *et al.* (1936), Pocock *et al.* (1938), Greig *et al.* (1968), Shergold and Bassett (1970), and Scoffin (1971).



TEXT-FIG. 2. Correlation chart of Wenlock sequences in south-central Wales and the Welsh Borderland north of the Bristol Channel.


6
DOLYHIR & NASH SCAR
7
ABBERLEY HILLS
8
MALVERN HILLS
9
WOOLHOPE
10
GORSLEY
11
MAY HILL
12
USK
basal Ludlow
basal Ludlow
basal Ludlow
basal Ludlow
middle Ludlow
basal Ludlow
basal Ludlow
shales and siltstones ?90m+
faulted contact
faulted contact
Dolyhir and Nash Scar Limestone 24–60m
Pre-Cambrian and late Llandovery (C1-2)
Wenlock Limestone 36m
Wenlock Shale ?360m
base not seen
Wenlock Limestone 60 – 150m
Wenlock Shale 180 – 270m
Woolhope Limestone 15–60 m
uppermost Llandovery
Wenlock Limestone 45–51m
Wenlock Shale 300–360m
Woolhope Limestone 36m
uppermost Llandovery
Gorsley Limestone 5·5 m
base not seen
Wenlock Limestone 30 – 105m
Wenlock Shale 210–240m
Woolhope Limestone 21–60 m
uppermost Llandovery
Wenlock Limestone < 1 – 13·5m
sandstone beds 4·5m
Wenlock Shale 240m
base not seen

THE LUDLOW ANTICLINE

Text-fig. 2, col. 2

The base of the Wenlock is not exposed in the Ludlow district, where the core of the anticline is occupied by at least 300 m of Wenlock Shale (Holland *et al.* 1963). Although this thickness is approximately equal to the full Wenlock sequence at Wenlock Edge, the beds at Ludlow fall wholly within the upper Wenlock, since graptolites from the lower half of the succession suggest a *lundgreni* Zone age (Holland *et al.* 1969, p. 676). At the top of this zone a thin horizon with a restricted graptolite fauna of *Gothograptus nassa* and *Pristiograptus dubius* correlates with the '*nassa*/*dubius* Interregnum' of Jaeger (1959). Immediately succeeding beds, some 100 m below the base of the Wenlock Limestone, contain *Monograptus ludensis*, marking the base of that zone, which is now known to extend through the upper half of the Wenlock Shale and at least the lower part of the Wenlock Limestone (Holland *et al.* 1969, pp. 676–678). The Wenlock Shale at Ludlow has not been subdivided lithologically as at Wenlock Edge, and Lawson (1971, p. 306 and fig. 1, col. E) has pointed out that the lower, graptolite-bearing part of the Wenlock Limestone as mapped by Holland *et al.* (1963) is lithologically similar to, and may correlate with, the Tickwood Beds.

Thus in graptolite terms the age of the highest Wenlock Limestone at Ludlow remains equivocal, but it probably falls within the upper part of the *ludensis* Zone, since the base of the overlying Elton Beds is at or close to the *ludensis*/*nilssoni* boundary (Holland *et al.* 1969, text-fig. 4, pp. 679–681). The Wenlock Limestone thins from west to east across the Ludlow anticline from 135 m to 60 m; the lower, graptolitic beds consist of alternations of hard ribs of flaggy, silty limestone and grey silty mudstones and shales, while the highest 15 m are hard grey to buff nodular limestones. The base of the Ludlow Series, Eltonian Stage, and Lower Elton Beds is defined at a standard section in the old quarry in Pitch Coppice (SO 4726 7301), where some 4·5 m of uppermost Wenlock Limestone is overlain by Lower Elton siltstones (Holland *et al.* 1963, pp. 139–141 and fig. 11).

WALSALL AND DUDLEY

Text-fig. 2, col. 3

The Walsall borehole section (Butler 1937*a*) and neighbouring surface exposures indicate that there is a full Wenlock succession within the English Midlands. I agree with Ziegler *et al.* (1968, p. 763) that in the borehole the Llandovery/Wenlock boundary is best correlated with the base of Butler's division M at a depth of 261 m where there is a lithological change from grey mudstones to purple and grey-green shales, corresponding to that at the Buildwas Beds/Purple Shales junction in Shropshire. Above this Butler's divisions M to F inclusive correspond with the Wenlock Shale and comprise 237 m of grey and grey-green mudstones and shales, with thin limestones and bands of calcareous nodules, and twenty-four bentonitic clays. *Cyrtograptus murchisoni* and *Monograptus priodon* are recorded from division M of the borehole at a depth of 279·5 m (Butler 1937*a*, p. 246), indicating the presence of the *murchisoni* Zone, and although not recorded as such the basal Wenlock *centrifugus* Zone is probably represented in the underlying grey sediments of the same division, since these pass downwards without a sedimentary break into the purple shales which contain an uppermost Llandovery *crenulata* Zone fauna.

A prominent 10-m thick calcareous horizon known as the Barr Limestone occurs 22 m above the base of the Wenlock in the Walsall borehole. Some previous accounts (Cantrill 1919; Whitehead and Eastwood 1927) have equated this unit with the Woolhope Limestone at the base of the Wenlock in the southern part of the Welsh Borderland, but the presence of *murchisoni* Zone faunas below the Barr Limestone indicates that it is younger than the Woolhope Limestone (see text-fig. 2), and that it probably correlates with all or part of the *riccartonensis* Zone. The Barr Limestone is poorly exposed but can be examined in its type area between Hay Head and Great Barr, some 2 km east of Walsall, where it crops out in the line of old quarries between Cuckoo's Nook (SP 0530 9900) and Daisy Bank (SP 0410 9765). Only the top 4–5 m remain exposed here, consisting of grey and olive, calcareous, blocky and flaggy-bedded shales and siltstones, with lines of limestone nodules. There are also three bentonites within these sections, the lower two of which are 25 mm thick, while the upper one is 152 mm. It is not possible to correlate these bentonites with any of the four recorded by Butler (1937*a*, p. 254) from within the Barr Limestone of the Walsall borehole, since none of the thicknesses of bentonites or intervening sediments are comparable.

From a limestone sample from the stream bed at a small waterfall near the north end of the old quarries (SP 0484 9879) within the top 3 m of the Barr Limestone, Dr. R. J. Aldridge has identified the following conodont form species: *Drepanodus aduncus* Nicoll and Rexroad, *Hindeodella equidentata* Rhodes, *Ligonodina* sp., *Lonchodina* sp., *Neoprioniodus excavatus* (Branson and Mehl), *Ozarkodina media* Walliser, *Ozarkodina* sp., *Paltodus costalatus* Rexroad, *Panderodus simplex* (Branson and Mehl), *P. unicostatus* (Branson and Mehl), *Plectospathodus extensus* Rhodes, *Spathognathodus inclinatus* (Rhodes), *Spathognathodus* n. sp. Walliser 1964, and *Trichonodella excavata* (Branson and Mehl). Dr. Aldridge comments that the only specimens of possible stratigraphical value are the two identified as *Spathognathodus* n. sp. Walliser, recorded by Walliser (1964) only from the *sagitta* conodont Zone, but this is a tenuous correlation with the conodont sequence. Limestones and siltstones associated with the conodont-bearing sample yielded fragments of the trilobite *Bumastus barriensis* Murchison and the brachiopods *Dicoelosia biloba* (Linnaeus) and *Leangella segmentum* (Lindström). The beds immediately above the Barr Limestone are not exposed, but at least 63 m of the upper part of the Wenlock Shale crop out below the Wenlock Limestone in the railway cutting at Daw End, Walsall (SK 0360 0030). Comparison with the Walsall borehole suggests that the lowest beds in the railway cutting are within Butler's division H. The topmost few metres of the Wenlock Shale are also exposed at Wren's Nest, Dudley.

Butler (1939) divided the Wenlock Limestone of Dudley into five units, totalling 66 m.

Passage Beds	2·66 m
Upper Quarried Limestone	7·49 m
Nodular Beds	37·41 m
Lower Quarried Limestone	9·78 m
Basement Beds	2·94 m

These were formerly accessible in the en-echelon periclines of Dudley Castle Hill, Hurst Hill, and Wren's Nest Hill, but in the first two they are now obscured by buildings. At Wren's Nest, however, the full sequence can be seen, although the Lower and Upper Quarried Limestones have been almost removed by quarrying. Reef structures are well developed at Wren's Nest (Butler 1939). As mentioned earlier, the Wenlock Limestone of Dudley has yielded specimens of *M. flemingii*. Butler (1939, p. 55) also recorded *flemingii* from both immediately below and above the Limestone, indicating that the whole sequence, including the local 'Lower Ludlow Shale', is no younger than the *lundgreni* Zone.

The Basement Beds and the Lower Quarried Limestone also crop out in the Daw End cutting at Walsall (Butler 1939, pp. 54–55), and were penetrated by the Walsall borehole (Butler 1937*a*), but higher beds have been removed by erosion. Wenlock strata are known to occur at depth below Upper Carboniferous and younger rocks over a wide area of the west Midlands. Details of these sub-surface sequences, and of numerous surface outcrops which are no longer accessible are well documented in the relevant memoirs of the Geological Survey (Jukes 1853, 1859; Cantrill 1919; Eastwood *et al.* 1925; Whitehead and Eastwood 1927; Whitehead and Pocock 1947; Whitehead *et al.* 1928; Pocock *et al.* 1938).

KENDAL END

Text-fig. 2, col. 4

Hardie (1954) has described the small area of Wenlock rocks at Kendal End Farm (SP 004 745) near Barnt Green, Worcestershire, at the southern end of the Cambrian ridge of the Lickey Hills. The outcrop was first recorded by Murchison (1839, p. 493), but by 1898 Lapworth (p. 350) reported that there were no visible exposures and today the section remains overgrown. However, by trenching and augering Hardie was able to map a wedge-shaped outcrop some 225 m long with a maximum width of about 70 m, faulted on all sides against Pre-Cambrian, together with minor outcrops of limestone some 135 m to the west, faulted between Pre-Cambrian and Carboniferous. The total thickness is not known, but from the descriptions by Murchison and Hardie it appears that at least 4·5 m of steeply dipping nodular shales and limestones, with a bed of massive limestone about 1 m thick, were once exposed in the old quarry near the northern end of the outcrop.

On lithological grounds both Murchison and Lapworth correlated the Kendal End rocks with the Woolhope Limestone, supported by Hardie from the evidence of faunas collected from the old quarry waste, with particular emphasis on varieties of *Atrypa reticularis* as described by Alexander (1949). Through the courtesy of Dr. I. Strachan I have examined the material collected by Hardie, now in the Geological Museum of Birmingham University, and identified the following brachiopods: *Atrypa reticularis* (Linnaeus), *Antirhynchonella linguifera* (J. de C. Sowerby), *Dicoelosia biloba* (Linnaeus), *Dolerorthis rustica* (J. de C. Sowerby), *Leptaena depressa* (J. de C. Sowerby), *Orbiculoidea forbesi* (Davidson), *Resserella canalis*

(J. de C. Sowerby), *Dalejina hybrida* (J. de C. Sowerby), *Eoplectodonta duvalii* (Davidson), *Streptis grayii* (Davidson), ?*Whitfieldella* sp., *Meristina obtusa* (J. Sowerby), and *Isorthis amplificata* Walmsley. This list is a revision of the species listed by Hardie (1954, p. 14), with the addition of *M. obtusa* and *I. amplificata*. The assemblage is clearly of upper Wenlock age, precluding correlation with the Woolhope Limestone. In particular, *D. rustica*, *M. obtusa*, and *I. amplificata* occur only in the upper half of the Wenlock elsewhere throughout the Welsh Borderland. The lithologies described from Kendal End compare most closely with the uppermost, nodular Wenlock Shale, or Wenlock Limestone of the Walsall and Dudley sequence. Hardie's specimens of *A. reticularis* are too poorly preserved and limited in number to allow confident comparisons with Alexander's (1949) varieties, but my own studies throughout the British Wenlock suggest that her varieties do not show consistent variation of stratigraphical value. The remainder of the fauna listed by Hardie is consistent with the late Wenlock age indicated by the brachiopods, although the stratigraphical range of them all is not yet known. I have, however, confirmed the identification of the coral *Ketophyllum duplex* (Butler), which has been recorded elsewhere only from an horizon high in the Wenlock Shale at Dudley (Butler 1937*b*, p. 82).

On the northern margin of the Lickey Hills at Rubery, some 3 km NNW. of Kendal End, Murchison (1839, p. 493), Lapworth (1898, p. 358), Eastwood *et al.* (1925, pp. 14–15), and Wills *et al.* (1925, p. 67), recorded the presence of grey shales, thin sandstones, and limestones considered to be of early Wenlock (Woolhope Limestone) age, conformably succeeding the Llandovery. I have not examined these beds (Rubery Shale 'Series') which are reported to crop out in Callow Brook in the grounds of Rubery Hill Asylum (SO 992 778), but as noted by Wills (1938, p. 177) and Ziegler *et al.* (1968, p. 764) both the graptolites and brachiopods recorded indicate that the sequence is entirely of late Upper Llandovery age, possibly no younger than C_5.

THE LONG MOUNTAIN

Text-fig. 2, col. 5

Palmer's (1970) revised stratigraphy of the Long Mountain syncline includes a complete Wenlock sequence within the Trewern Brook Mudstone Formation. This unit comprises 450–610 m of grey mudstones with occasional interbedded nodular horizons and calcareous shelly mudstones. Earlier accounts (Elles 1900; Das Gupta 1932) of the sequence of graptolite zones in the area suggested that some of the lower Wenlock horizons are cut out by overlap. Palmer does not comment on this problem, but as noted earlier (see p. 749) a conformable faunal succession from the Llandovery can be demonstrated around Buttington. In the upper part of the Trewern Brook Mudstone Formation a persistent, lenticular development of shelly mudstones, within the laminated graptolitic mudstones, is referred by Palmer to the Glyn Member, varying in thickness from 0 to 76 m. Dr. Palmer has previously informed the author (see Bassett 1972, p. 57) that the Glyn Member includes horizons which correlate with the late *lundgreni* Zone and '*nassa-dubius* Interregnum'. The uppermost beds of the Trewern Brook Mudstone Formation grade upwards into the Long Mountain Siltstone Formation of Ludlow age.

BUILTH

Elles (1900, p. 371) regarded the Builth district as the type area for the Wenlock graptolite zones, a sequence later confirmed by Jones (1947, p. 3). Only six zones from *murchisoni* to *lundgreni* were included initially in the scheme, but at the top of the sequence, the *ludensis* Zone, now known to be of Wenlock age, was shown by Wood (1900, pp. 432–438, as *vulgaris*) to be present in the area. A separate *centrifugus* Zone has not yet been confirmed at the base of the sequence, but as at Pencerig (see p. 749), it may be represented in the River Ithon where Jones (1947, p. 9) described a gradation from the uppermost Llandovery (*crenulata* Zone) to the *murchisoni* Zone. Jones (1947, p. 4) divided the Wenlock at Builth into two lithological divisions, from *murchisoni* to *rigidus* (of current nomenclature) and *linnarssoni* to *lundgreni* zones respectively; with the addition of a thickness of 30 m for the *ludensis* Zone (Wood 1900, pp. 433, 435) the total thickness varies from 630 m in undisturbed bedded sediments, to 900 m in areas where slumped beds are developed. The lower division, some 155 m thick, consists of dark blue-grey, flaggy-bedded, silty mudstones, thin striped shales, and thin horizons of shelly siltstones, with an irregular calcareous horizon ('*Acidaspis* limestone'), less than 1 m thick, developed locally at the base. In the upper division the bedded sediments are again dark, striped silty mudstones and shales, but this part of the sequence contains three major slump sheets, one within each of the *linnarssoni*, *ellesae*, and *lundgreni* zones. The slumped beds consist of hard, massive, dark siltstones with pockets of shelly fossils, and form prominent positive topographical features; they vary in thickness across the area, the lower sheet from 0 to 75 m, the middle from 0 to 105 m, and the upper from 10 to 150 m. The Builth sections need revision to provide modern faunal lists for the type sequence of graptolite zones, and for correlation with the type Wenlock of Shropshire; the Builth area is in any case important in its intermediate position between the shelf and basin successions and in having thin shelly horizons within the graptolite beds.

DOLYHIR AND NASH SCAR

Text-fig. 2, col. 6

In east Radnorshire, around Dolyhir near Old Radnor and Nash Scar near Presteigne, the lower part of the Wenlock succession comprises a thick development of massive, dark grey to white, crystalline algal and bryozoan limestone. The minimum average thickness of the limestone is about 24 m, while at Nash Scar Quarry (SO 3025 6225) up to 60 m may be present, although this may be an over-estimate due to repetition by faulting. Algal colonies make up a high proportion of the limestone, with *Solenopora gracilis* Garwood and Goodyear, *Rothpletzella gotlandica* (Rothpletz), *Girvanella pusilla* Johnson, and *G. problematica* Nicolson and Etheridge dominant. Garwood and Goodyear (1919) have described the limestone, together with the structural complexity of this area, close to the Church Stretton fault belt.

The basal metre or so of the Dolyhir Limestone consists of conglomerates and breccias which rest directly on shattered Pre-Cambrian (Longmyndian) grits, sandstones, mudstones, and dolerites. The Nash Scar Limestone sits disconformably on the Folly Sandstone of early Upper Llandovery (C_{1-2}) age (Ziegler *et al.* 1968, p. 750). Although Garwood and Goodyear (1919, pp. 17, 19) recorded large faunas from around Dolyhir, well-preserved fossils are not common, but the specimens collected by the author indicate that the limestone is of the same age in both areas. However, both the lower and upper age limits are difficult to assess in detail. The brachiopod fauna includes *Antirhynchonella linguifera* (J. de C. Sowerby), *Streptis grayii* (Davidson), *Atrypa* sp., *Leptaena* sp., *Megastrophia* (*Protomegastrophia*) sp., ?*Ancillotoechia* sp., *Whitfieldella* sp., and *Plectatrypa* sp., and Dr. R. M. Owens has kindly identified the following trilobites from Dolyhir: *Cornuproetus peraticus* Owens, *Bumastus* sp., ?*Prantlia* sp., a lichid, a scutellid, and an odontopleurid. As pointed out by Ziegler *et al.* (1968, p. 750), the evidence of the Folly Sandstone indicates that the Nash Scar Limestone could possibly be as old as C_3 on stratigraphical grounds, but the fauna listed above contains no diagnostic Llandovery elements, and both *Cornuproetus* and *Bumastus* are known only from post-Llandovery strata. A Wenlock age is supported by the record of *Rhipidium* in the Garwood Collection at the Institute of Geological Sciences (Ziegler *et al.* 1968), but I have not been able to trace the specimens. The specimens of *Whitfieldella* and *Plectatrypa* are close to, and possibly conspecific with, material collected by the author from the Woolhope Limestone in the Welsh Borderland, suggesting an early Wenlock age for at least part of the Dolyhir and Nash Scar Limestones, and supporting a general correlation with the Woolhope Limestone as assumed by Garwood and Goodyear (1919) and earlier authors. Kirk (1951*a*, p. 56) regarded the Dolyhir Limestone and shelly mudstones of Hanter Hill as contemporaneous with the *murchisoni* and *riccartonensis* zones. From both the Nash Scar and Dolyhir Limestones Dr. R. J. Aldridge (pers. comm.) has recovered conodont faunas of the *sagitta* Zone (Walliser 1964), with *Spathognathodus sagitta rhenanus* Walliser dominant. The earliest known *sagitta* Zone faunas are in the Högklint Beds of Gotland (Fåhreus 1969, p. 9), which contain *riccartonensis* Zone graptolites (Bassett and Cocks 1974, p. 5); thus the Dolyhir and Nash Scar Limestones appear to extend upwards into the *riccartonensis* Zone or younger horizons.

Both at Dolyhir and Nash Scar the overlying shales and siltstones are faulted against the limestones, precluding a firm stratigraphical assessment of the original age relationships. Kirk (1951*a*, p. 56) briefly stated that 'the limestone is overlain by mudstones with *Cyrtograptus symmetricus*' (*sic rigidus*). Within the main limestone mass at Dolyhir Quarries (SO 2412 5808), the small, faulted patch of shale referred to by Garwood and Goodyear (1919, p. 19 and pl. 7), has yielded *Monograptus flemingii* (Salter), indicating an age within the *rigidus* to *lundgreni* zones. The shales immediately above the Nash Scar Limestone at the north-east end of Nash Scar Quarry (SO 3045 6245), have yielded to Mr. N. J. Hancock and the author a fauna definitely referable to the *lundgreni* Zone. The thickness of Wenlock beds above the limestones is probably at least 90 m, and includes part of the shelly olive mudstones which Kirk (1951*b*, p. 72) reported to span the *lundgreni*, *ludensis*, and *nilssoni* zones.

THE ABBERLEY HILLS

Text-fig. 2, col. 7

The complex structural setting of the Silurian of the Abberley Hills (Herefordshire and Worcestershire) has long been known (Murchison 1839; Phillips 1848; Groom e.g. 1900), and the stratigraphy has been revised by Mitchell *et al.* (1962) and Phipps and Reeve (1967). Lowest Wenlock rocks are nowhere exposed, being cut out by thrusting or overlain unconformably by Triassic strata, and younger Wenlock Shale is exposed only in a few small, isolated patches (for details see Mitchell *et al.* 1962, pp. 26–27). In the largest of these outcrops, between Hillside (SO 754612) and Kingswood Common (SO 747601) to the north-west of Martley, up to 360 m of grey calcareous shales and siltstones with thin nodular limestones may be present, but part of the succession may be repeated by faulting. The Wenlock Limestone, 36 m thick, is well exposed in the southern half of the area, where steeply dipping and overturned beds crop out in a line of quarries for about 3 km northwards from the large quarry at Penny Hill (SO 7515 6145). The blue-grey bedded and nodular limestones contain numerous thin partings of grey shale, and a number of cream-coloured bentonitic clays up to about 200 mm thick.

THE MALVERN HILLS

Text-fig. 2, col. 8

The thrusting which affects the Silurian of the Abberley Hills is not developed to the same extent along the southerly continuation of the structural line into the Malvern Hills (Herefordshire), and so in the latter area a full Wenlock succession is present along most of the outcrop. Phipps and Reeve (1967) have revised the stratigraphy and given an outline of previous work, and Penn and French (1971) have also commented on the succession. The basal lithological unit of the Wenlock is the Woolhope Limestone, which is present here in its most northerly development within the inliers of the Welsh Borderland. It has an average thickness of 15–21 m, but may thicken to a maximum of 60 m near North Malvern (Phipps and Reeve 1967, p. 343). It mainly consists of olive-grey, rubbly, calcareous siltstones and argillaceous limestones, which separate an upper and lower development of flaggy bedded, silty limestones; southwards through the area the calcareous beds become more dominant at the expense of the siltstones. *Eocoelia* cf. *sulcata* (Prouty) occurs in this unit, indicating faunal continuity from the underlying Wych Beds, which are of latest Upper Llandovery (C_6) age in their upper part (Ziegler *et al.* 1968, p. 757). Olive-grey siltstones and shales with lines of calcareous nodules comprise the bulk of the Wenlock Shale, which varies from 180 to 270 m thick; the nodule horizons become more common in the top 10 m of the sequence, immediately below the transition into the Wenlock Limestone. Within the latter division Phipps and Reeve (1967, p. 345) described five principal lithofacies types: calcareous mudstones, nodular limestones, bioclastic (coquinal) limestones, pisolitic limestones, and bioherms. These may occur in any order or association within the succession, which varies in thickness from 60 to 150 m; however, the pisolitic limestones are often developed close to the base of the Wenlock Limestone and usually close to bioherms. Penn (1971) has described the development of bioherms in the Malvern area.

THE WOOLHOPE INLIER

Text-fig. 2, col. 9

The Woolhope Limestone of the type area is 36 m thick (Squirrell and Tucker 1960); apart from a development of thickly bedded shelly limestone in the middle of the sequence, it consists largely of rubbly calcareous siltstones and nodular argillaceous limestones similar to the Malvern Hills. *Costistricklandia lirata lirata* (J. de C. Sowerby) and *Eocoelia* cf. *sulcata* (Prouty) occur rarely in this unit, confirming the evidence from the Malverns of faunal continuity from the Upper Llandovery. There is no graptolite evidence to confirm the basal Wenlock age of the Woolhope Limestone, which on the evidence of *C. lirata lirata* could, in part, be as old as latest Upper Llandovery (C_6), but the base of the Woolhope Limestone is some metres stratigraphically above typical late C_6 associations of *Costistricklandia* and *Palaeocyclus porpita* (Linnaeus), while its total shelly fauna and lithologies compare closely with those of the Buildwas Beds of Shropshire and contain brachiopod elements such as *Eoplectodonta duvalii* (Davidson) and *Anastrophia deflexa* (J. de C. Sowerby), which are very rare or absent in the British Upper Llandovery. Dr. P. D. Lane informs me that the Woolhope Limestone also contains the trilobite genus *Bumastus* which is not known outside the Wenlock elsewhere in Britain. I have argued previously (in discussion of Cocks and Rickards 1969, p. 236) that the Woolhope Limestone is slightly younger than the Buildwas Beds, but in the light of subsequent studies I now consider that minor differences in the two faunas are more likely to be environmentally, rather than stratigraphically, controlled.

The uppermost Woolhope Limestone grades into the siltstones and thin argillaceous limestones of the overlying Wenlock Shale, which varies in thickness from 300 to 360 m and which in turn is overlain by 45–51 m of Wenlock Limestone. Shales with limestone nodules, similar to the Tickwood Beds of Wenlock Edge, are developed at the top of the Wenlock Shale, and nodular limestones occur both at the base and top of the irregularly bedded Wenlock Limestone.

GORSLEY

Text-fig. 2, col. 10

Between the Woolhope and May Hill Inliers, Silurian rocks are exposed around the village of Gorsley, Herefordshire, where the succession has been described by Lawson (1954). The oldest Silurian beds belong to the Gorsley Limestone, whose base is not seen but which is exposed to a thickness of 3·6 m in Linton Quarry (SO 6770 2574) and 5·5 m in Hartley's Quarry (SO 6770 2616) (Lawson 1954, pp. 229–231). Through the courtesy of Dr. I. Strachan I have examined some of Lawson's specimens from the Gorsley Limestone, now deposited in Birmingham University; these faunas confirm Lawson's assignment of the Gorsley Limestone to the Wenlock rather than the Ludlow (Aymestry Limestone) as previously supposed (Lawson 1954, p. 227). In particular, the common occurrence of *Meristina obtusa* (J. Sowerby) is a clear indicator of an age within the upper half of the Wenlock, and combined with the distinctive blue-grey massive limestone lithology there can be no doubt that the Gorsley Limestone is a correlative of the Wenlock Limestone. The top of the Gorsley Limestone is an irregular erosion surface on which early Leintwardian (Ludlow) siltstones rest unconformably.

THE MAY HILL INLIER

Text-fig. 2, col. 11

In the May Hill Inlier the Woolhope Limestone, similar to the same horizon at Woolhope and the Malverns, appears to thicken southwards from 21 m at May Hill itself to over 60 m at Little London (Lawson 1955); as at Woolhope these beds contain *C. lirata lirata*. The Wenlock Shale is 210–240 m thick and the succeeding Wenlock Limestone reaches a maximum thickness of 105 m. Lawson (1955, pp. 89–90) described three units within the Wenlock Limestone. The lowest division is some 18 m of thinly bedded grey limestone in which reef structures are developed, with bands of pisolitic limestone similar to those low in the Wenlock Limestone of the Malverns; these are succeeded by thinly bedded nodular limestones and shales, in turn overlain by thinly bedded nodular limestones passing laterally southwards into ferruginous and oolitic beds. In the extreme south of the inlier the Wenlock Limestone thins to 30 m and the upper unit cannot be recognized separately.

THE USK INLIER

Text-fig. 2, col. 12

The Wenlock Shale, with a minimum thickness of 240 m (Walmsley 1959), occupies the core of the Usk inlier. At a trackside section (SO 3435 0395) above the right bank of the River Usk 100 m south-east of the pumping station on Craig y Pandy, beds close to the axis of the anticline, and hence close to the oldest exposed, have yielded a number of *Monograptus flemingii flemingii* (Salter). These are the first graptolites recorded from the Wenlock of Usk, and since *flemingii* first occurs with certainty in the *rigidus* Zone, the whole of the exposed Usk Silurian succession can be dated as post-*riccartonensis* Zone in age. The bulk of the Wenlock Shale consists of grey-green and buff shales and calcareous siltstones with occasional bands of nodular limestone, but the top 4·5 m comprise rust brown calcareous and micaceous sandstones indicative of a period of shallowing. The overlying Wenlock Limestone has a maximum thickness of 13·5 m in the west of the area, where a lower, massive division and an upper, nodular division may be recognized, but it thins rapidly eastwards to less than 1 m (Walmsley 1959, p. 487). In most exposures the highest limestones are succeeded by 1–2 m of buff-coloured calcareous siltstones with a typically Wenlock fauna and grouped by Walmsley (p. 487) within the Wenlock Limestone; more recently Squirrell and Downing (1969, pp. 11–12) mapped these beds as basal Elton Beds within the Ludlow. In the northern half of the inlier limestone beds are rarely exposed, but at Weir Wood, Trostrey (SO 3602 0420) about 6 m of nodular beds are seen to overlie some 12 m of green and buff siltstones (Walmsley 1959, pp. 487–488, fig. 2). A thin bed of crinoidal limestone within the siltstones has yielded a conodont fauna (Austin and Bassett 1967) referable to the *sagitta* Zone.

In 1964 a large trench was excavated across the central area of the Usk anticline, in a roughly east–west direction, in connection with a drainage scheme from the Llandegveth reservoir. The trench, which was about 4 km long, 3 m wide, and 2–4 m deep, provided some excellent exposures in the Wenlock Shale at its western end (text-fig. 3), but unfortunately over 3 km of the section to the east passed through glacial and alluvial drift. The oldest beds in the trench, at Grid Reference SO 3435 0245, were some 247 m stratigraphically below the base of the Wenlock Limestone, which must be close to the oldest beds brought to the surface in the inlier. The beds there consist of fossiliferous grey-green silty shales with occasional muddy grey calcareous nodules. In the debris of material excavated from these oldest beds, one nodule yielded a single graptolite identified as *Monograptus flemingii flemingii*, confirming the post-*riccartonensis* Zone age of the sequence indicated by the fauna from Craig y Pandy (see above).

Between the above-mentioned exposure and the railway line (see text-fig. 3) at Grid Ref. SO 3371 0215 the trench was cut through deep drift deposits, but the remaining 562 m of the section to a point near Cwm (SO 3335 0173) revealed continuous exposure through a thickness of some 135 m of Wenlock Shale. The beds consist mostly of a series of monotonous grey and green blocky mudstones with subordinate bands of pale olive laminated shales. Fossils were found to be rare throughout the bulk of the succession although good collections of typical late Wenlock brachiopods were made from the horizons indicated in text-fig. 3. Of especial interest was the presence of two thin (100 mm) beds of coarse-grained, buff, calcareous, ripple-marked sandstone 45 m below the base of the Wenlock Limestone, containing many brachiopods and bivalves and lithologically similar to the topmost 4·5 m of the Wenlock Shale of the inlier. Another thin sandstone band 37·5 m below the base of the Wenlock Limestone includes a number of grey mudstone pellets of Wenlock Shale sediment. The youngest beds exposed in the trench were 4·5 m below the base of the Wenlock Limestone and immediately below the topmost sandy beds of the Wenlock Shale which outcrop in the adjacent laneside section at Grid Ref. 3480 9990 (Walmsley 1959, p. 487, loc. 3).

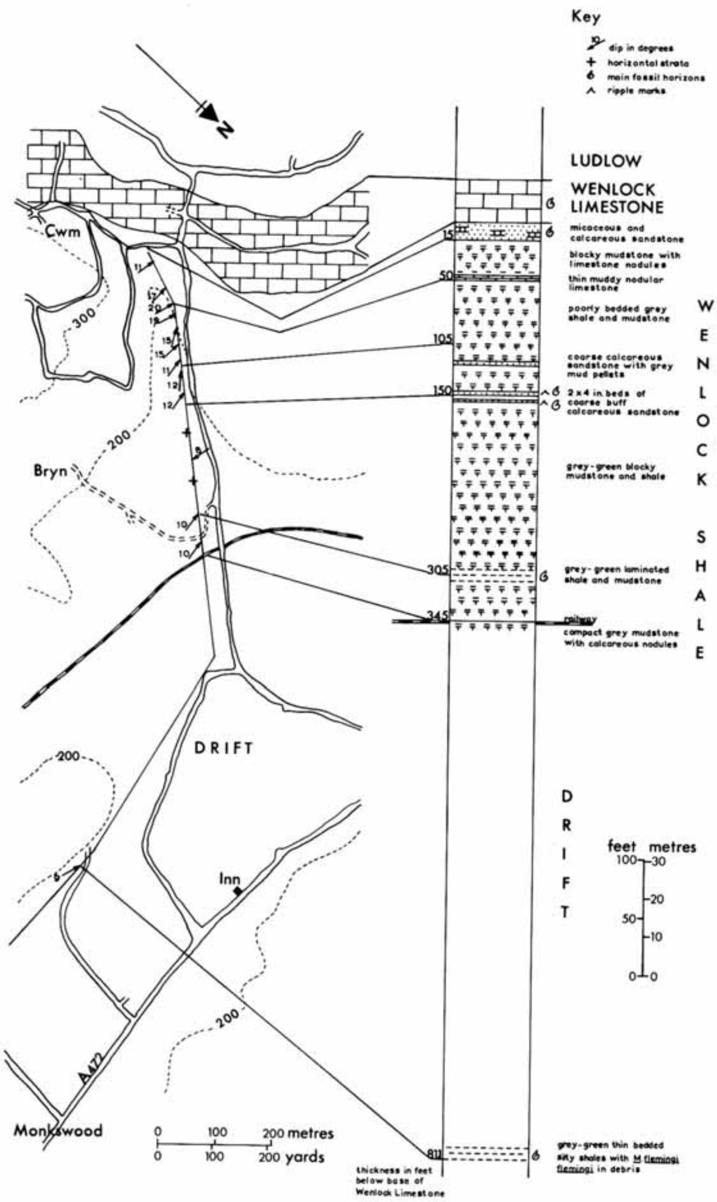
THE TORTWORTH INLIER

Text-fig. 4, col. 1

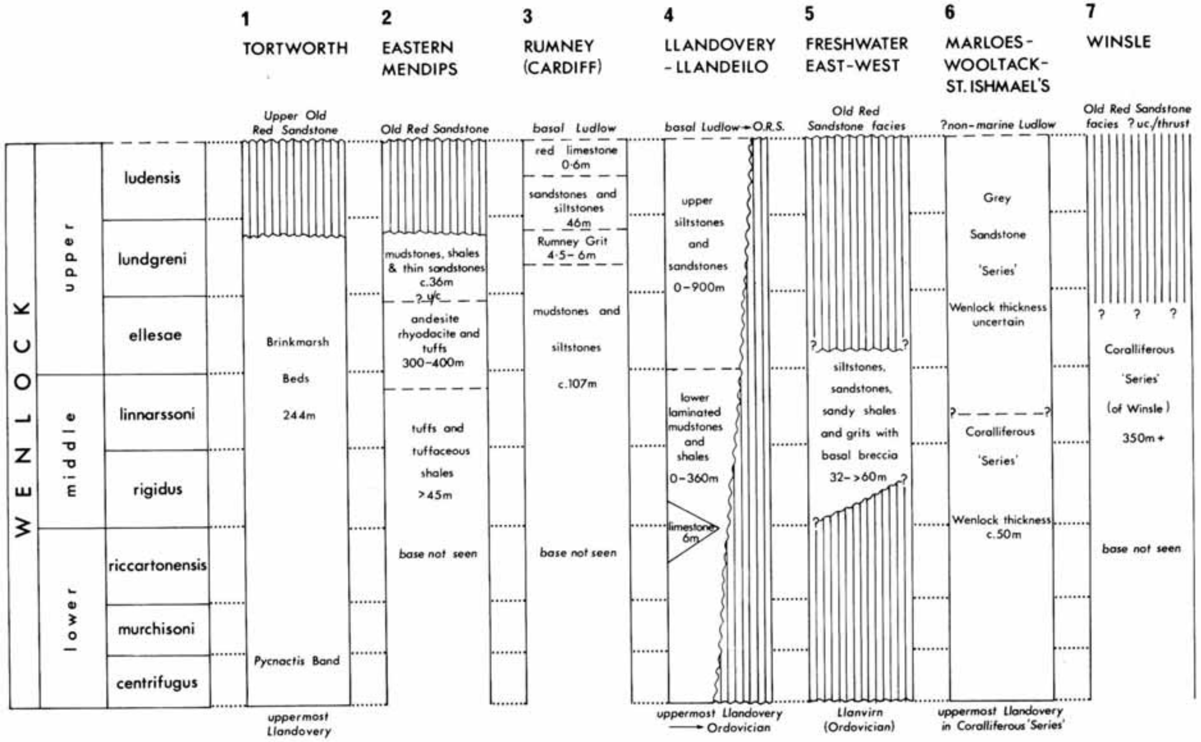
The Wenlock rocks in the Tortworth Inlier, Gloucestershire, have been assigned by Curtis (1972) to a single stratigraphical unit, the Brinkmarsh Beds, which comprise some 244 m of shales, mudstones, siltstones, and calcareous sandstones, with a number of impersistent limestones. The sequence is best exposed in the southwest of the inlier, to the south of Whitfield, where three prominent limestones occur, at the base and near the middle and top of the succession respectively (Curtis 1972, pp. 20–21 and fig. 3). The basal limestone, which passes laterally into calcareous sandstones, is a correlative of the lower part of the Woolhope Limestone, and as at May Hill, Woolhope, and in the Malverns it contains rare remnant Llandovery brachiopod species such as *Leptostrophia compressa* (J. de C. Sowerby). Immediately above the limestone there is a distinctive horizon, the *Pycnactis* Band, consisting of about 3 m of maroon-red shales and siltstones with a rich coral/brachiopod fauna, of which *Pycnactis mitratus* (Schlotheim), *Phaulactis glevensis* (Ryder), *Resserella whitfieldensis* Bassett, and *Whitfieldella* sp. are the most common species.

The middle part of the sequence is poorly exposed, but the uppermost 30 m, immediately below the unconformable base of the Upper Old Red Sandstone, are very well exposed in the A38 road near Buckover (SO 6668 9071–SO 6677 9078). The late Wenlock age suggested by Curtis (1972, p. 26) and Curtis and Cave (1964, p. 431) for these uppermost beds is confirmed by abundant specimens of *Meristina obtusa* (J. Sowerby), together with species such as *Trigonirhynchia stricklandi* (J. de C. Sowerby), *Cordatomyonia edgelliana* (Davidson), *Leptaena depressa* (J. de C. Sowerby), *Amphistrophia funiculata* (McCoy), and *Protochonetes minimus* (J. de C. Sowerby), which together indicate a correlation with an horizon high in the Wenlock Shale or the Wenlock Limestone. Curtis (1972, pp. 25–26) has commented on the similarity of the arenaceous deposits at Tortworth with parts of the succession in the Usk and Rumney (Cardiff) Inliers. Early work in both the Tortworth and Eastern Mendips Inliers (see below) has been summarized by Curtis (1955).

Wenlock rocks also crop out in three very small inliers in the bed of the Little Avon river near Wickwar,



TEXT-FIG. 3. Map and vertical section of temporary (1964) exposure in the Wenlock Shale of the Usk Inlier between Cwm and Monkswood.



TEXT-FIG. 4. Correlation chart of Wenlock sequences in South Wales and south of the Bristol Channel.

some 2 km to the south of the eastern margins of the main Tortworth Inlier. Whittard and Smith (1944), who were the first to describe the outcrops, recorded at least 8·5 m of fossiliferous, dolomitic limestones and siltstones, which they correlated with the Wenlock Limestone (see also Curtis 1972, p. 24). The Wenlock beds at Wickwar are overlain by strata of Downtonian age.

THE EASTERN MENDIPS INLIER

Text-fig. 4, col. 2

Between Downhead (ST 692459) and Beacon Hill (ST 639459) in east Somerset, Silurian rocks occupy a narrow core within the Upper Palaeozoic of the Mendip Hills. Tuffs and tuffaceous shales which appear to be at the base of the sequence have been considered to be of Upper Llandovery age (Reynolds 1907, 1912; Green 1962; Green and Welch 1965) but more recently Ziegler *et al.* (1968, p. 765) considered them to be Wenlock. Collections from the tuffs exposed in Walltyning Plantation (ST 674458) and from debris in a ditch in a neighbouring field (ST 6752 4583) contain *Salopina conservatrix* (McLearn), *Sphaerirhynchia* sp., and *Acaste downingiae* (Murchison), confirming a Wenlock age. The extensive faunas listed by Reynolds (1907, 1912) are clearly in need of revision.

The fossiliferous tuffs, which appear to be at least 45 m thick, are overlain by 300–400 m of andesitic lavas, agglomerates, and tuffs, including a 166-m thick Main Andesite Group in the middle. Apart from bentonites, these are the only volcanic rocks developed in the Wenlock of Great Britain. Kamp (1970) recently made a chemical and petrographic study of the Mendips volcanics, many of which he classified as rhyodacites; additional comments on their composition have been made by Green and Welch (1965, p. 8) and Ponsford (1970, p. 561). Between the lavas and the unconformable base of the Old Red Sandstone are some 36 m of olive shales, siltstones, and micaceous sandstones, which yielded a Wenlock fauna to Reynolds (1912) from a temporary trench. From the old railway track (ST 6650 4580) south-east of Moon's Hill Quarry, Dr. R. M. Owens has collected a trilobite fauna including *Dalmanites myops* (König), *Proetus latifrons* (McCoy), and *Encrinurus* cf. *tuberculatus* (Buckland), again indicative of the Wenlock. Reynolds's fauna (1912, p. 78) has not been checked, but his record of the distinctive trilobite *Dudleyaspis* [*Acidaspis*] *quinquespinosa* (Lake) suggests a correlation with a late Wenlock horizon of the Welsh Borderland. The contact between these shales and the underlying lavas was interpreted by Green (1962) and Green and Welch (1965) as one of angular unconformity, although good exposures are lacking.

THE RUMNEY (CARDIFF) INLIER

Text-fig. 4, col. 3

Since Sollas (1879) described the small Silurian Inlier near the centre of Cardiff, much of the area has been concealed by urban development, but from his account (see also Strahan and Cantrill 1902, 1912) and from the mapping of temporary exposures by the author, it is possible to recognize a Wenlock succession some 159 m thick, passing conformably upwards into Ludlow beds. From the site of the former Penylan Quarry (ST 1980 7877), beds close to the core of the anticline have yielded *Monograptus flemingii* (Salter), proving a post-*riccartonensis* Zone age for the complete sequence (Bassett 1969). Large collections of shelly fossils from the same locality include numerous specimens of *Meristina obtusa* (J. Sowerby) and other elements indicative of a late Wenlock age (see also Ziegler *et al.* 1968, pp. 765–766).

The oldest unit comprises about 107 m of olive and yellow-green mudstones and siltstones, with thin sandstones, calcareous lenses, and a number of bentonites. These beds are succeeded by 4·5–6 m of coarse, shallow-water, ripple-marked and cross-bedded grits and sandstones known as the Rumney Grit, which crops out in one of the few permanent exposures in the inlier at Rumney Quarry (ST 2153 7880). Within a metre or so of the top of the Grit there is a distinctive horizon of yellow friable sandstone referred to by Sollas (1879, p. 482) as the '*Ctendonta-bed*'; in addition to the casts of bivalves this horizon contains specimens of *Orbiculoidea*, and plants belonging to *Prototaxites storriei* (Barber) and *Pachytheca* sp. The succeeding 46 m of sandstones and siltstones are poorly fossiliferous, but the overlying bed of red crinoidal limestone, 0·6 m thick, contains a rich brachiopod fauna dominated by *Gypidula galeata* (Dalman), *Strophonella euglypha* (Dalman), and *Spaerirhynchia wilsoni* (J. Sowerby); this bed is probably a correlative of part of the Wenlock Limestone as suggested by Sollas (1879, pp. 485, 488, fig. 4). The Llandovery brachiopod elements *Pentamerus* and *Stricklandia* recorded by Sollas from the upper part of the Cardiff Wenlock have been shown by Bassett (1969) to be misidentifications of common Wenlock species.

THE LLANDOVERY–LLANDEILO DISTRICT

Text-fig. 4, col. 4

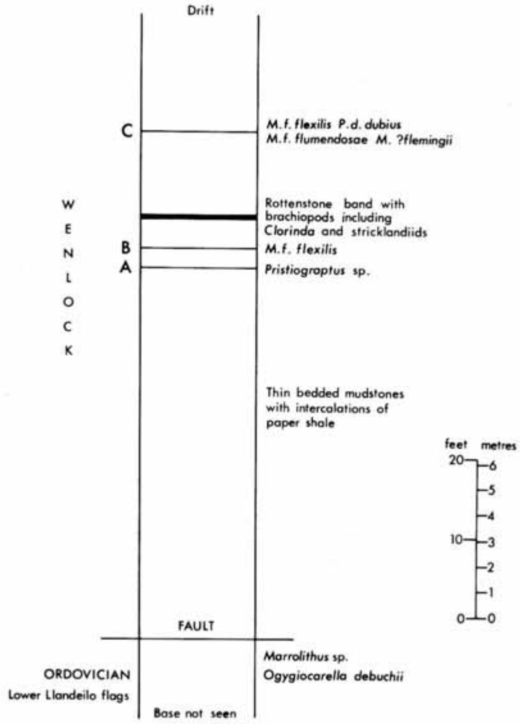
The only attempt to sub-divide the Wenlock of this area was made by Williams (1953, pp. 198–200) who recognized a 'Lower Wenlock' group resting unconformably on the Llandovery and in turn overlain unconformably by an 'Upper Wenlock' group. He suggested (p. 198) that the unconformity within the Wenlock might 'represent a considerable time interval . . . equivalent to the zones of *Cyrtograptus symmetricus* (*sic rigidus*), *C. linnarssoni* and *C. rigidus* [*sic ellesae*]'. Reinvestigation of a number of sections has clearly revealed that two broad lithological divisions, corresponding to those described by Williams, are present throughout most of the area, but the faunal and structural evidence suggests to the writer that there is no break between them, except in the extreme south-west where rapid overlap takes place.

The lower division is well exposed in the Sawdde Gorge section south-east of Llangadog, where it consists of some 240 m of blue-grey laminated mudstones with a 6-m thick band of impure limestone about 135 m above the base. Near the base Groom (in discussion of Jones 1925, p. 414) recorded the occurrence of *Monograptus riccartonensis* Lapworth, suggesting the presence of that zone; coupled with his lack of evidence for latest Upper Llandovery (C_6) beds throughout the area, this led Williams to map an unconformable junction below the Wenlock. However, in the Sawdde section both Mr. N. J. Hancock and the author have recognized beds of C_5 and C_6 age (dated by species of *Eocoelia* and *Costistricklandia*) passing conformably upwards into the Wenlock.

One of the key sections within the lower group is the outlier near Bethlehem (SN 6899 2580) which was first described by Williams (1953, p. 199). The beds there are faulted to the east against the Lower Llandeilo (Ordovician) flags and are obscured to the west by alluvium, but within the section some 24 m of beds are now exposed, consisting of thinly bedded, dark grey silty mudstones, which weather to an olive-grey colour, with intercalations of buff-coloured paper shales (text-fig. 5). From this section Williams recorded *Monograptus dubius* Suess, *M. priodon* (Bronn), *M. riccartonensis*, and *M. vomerinus* Nicholson, which together suggest a *riccartonensis* Zone age. However, graptolites collected by the writer from three of the paper shale bands indicate that the beds are considerably younger. These three horizons are indicated in text-fig. 5. A thin bed at A, 14·6 m above the fault contact with the Ordovician, yielded poorly preserved specimens identified as *Pristiograptus* sp. The second horizon at B, 15·2 m above the fault contact, yielded *Monograptus flexilis flexilis* Elles, and the third horizon at C, 19·8 m above the fault, yielded *M. flexilis*, *M. ?flemingii*, *Monoclimacis flumendosae flumendosae* (Gortani), and *Pristiograptus dubius dubius* (Suess). The presence of *M. f. flexilis* in the upper bands is extremely useful since this species has never been recorded outside the *linnarssoni* Zone. *M. flumendosae* and *P. dubius* are also common in this zone. This evidence indicates that the 'Lower Wenlock' beds of the area extend well up into the middle of the Wenlock graptolite sequence and include at least the middle one of the three graptolite zones which Williams suggested might be absent. The Bethlehem locality is also of interest in that it has yielded specimens of stricklandiid brachiopods, probably referable to *Costistricklandia lirata lirata*, from between levels B and C and thus undoubtedly from the *linnarssoni* Zone; this is the youngest documented record of stricklandiids in Britain. (Cocks 1971, p. 224 referred in error to these specimens as being from the *riccartonensis* Zone.)

South-westwards from the Sawdde this lower group thins beneath higher overlapping beds, eventually disappearing near Maes-y-fallen. In Cwm Dwr, to the east of Llandovery, the division is expanded to reach an estimated thickness of 360 m.

The 'Upper Wenlock' group of Williams comprises a comparatively thick sequence of olive, buff, and grey rubbly and sandy siltstones. In the Sawdde Gorge, where there is continuous exposure throughout the Wenlock, this upper division has a thickness of about 480 m and grades conformably up from the lower division. There is no evidence of the discordance of dip between the groups which was recorded by Williams (1953, p. 198) near Bryn-glas only 2·4 km to the east of the Sawdde. The overlap across the lower division mentioned above probably begins therefore to the south-west of the Sawdde, and within a short distance oversteps on to the Ordovician. Near Golden Grove Park the upper beds are reduced to less than 300 m and near Llanarthney they are themselves overstepped by the Old Red Sandstone. This south-western end of the outcrop has been described by Strahan *et al.* (1907, pp. 41–52). A thin horizon of dark crystalline limestone which crops out between Ty-Newydd and Pistyll-Dewi Farms is probably close to the base of the group; its age has been discussed by Bassett (1972, p. 31). North-eastwards from the Sawdde Gorge the upper Wenlock division thickens to a maximum of 900 m at Cwm Dwr, just east of Llandovery. In the Sawdde the beds have yielded *Monograptus flemingii flemingii* about 45 m below the conformable base of the Ludlow



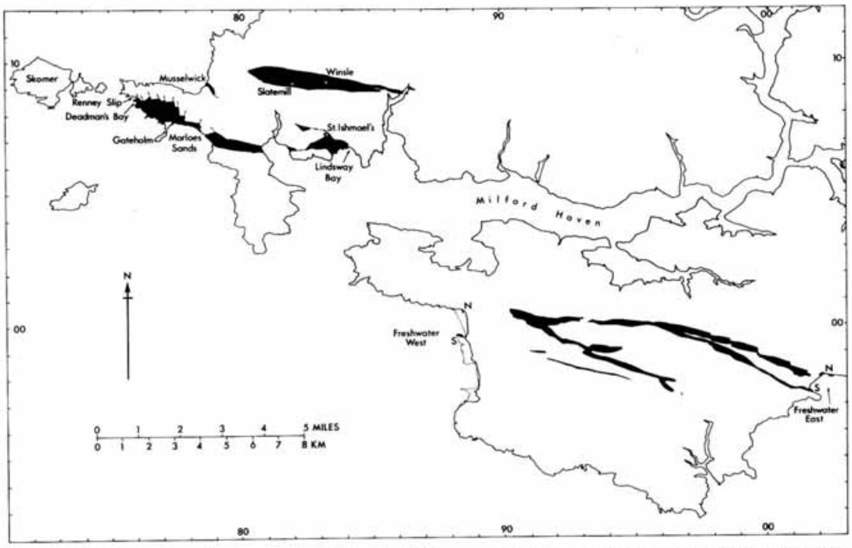
TEXT-FIG. 5. Vertical section of the Wenlock Outlier at Bethlehem, Carmarthenshire SN 6899 2580.

Tresglen Beds. Typical assemblages of Wenlock shelly fossils occur throughout the lower and upper successions within the area.

PEMBROKESHIRE

Text-fig. 4, cols. 5, 6, 7

Stratigraphical relationships and correlation of much of the Silurian of Pembrokeshire remain uncertain in detail, although in the coastal sections from Skomer eastwards to Marloes Sands, recent work by Ziegler *et al.* (1969) has allowed precise dating of a number of horizons within the Llandovery. Following the initial accounts by Murchison (1839, pp. 389–393) and De la Beche (1846, pp. 25–29, 54) rocks of Wenlock age have been described from both north and south of Milford Haven (text-fig. 6), and in all the outcrops the post-Llandovery stratigraphy is dependent almost entirely on the detailed mapping by the Geological Survey (Cantrill *et al.* 1916; Dixon 1921). However, the recent analysis of sedimentary environments and facies relationships by Sanzen-Baker (1972) now makes it clear that the dating of rocks previously assigned to the Wenlock and/or Ludlow is in need of major revision, and to this end Dr. V. G. Walmsley and the present author are reassessing the biostratigraphical evidence both from new collections and from the extensive material in the Survey. The differences in facies and faunas between Pembrokeshire and the Welsh Borderland have been emphasized elsewhere (Walmsley 1962, p. 293; Bassett 1971, p. 206), and since these



TEXT-FIG. 6. Outcrop and location map of the Coralliferous and Grey Sandstone 'Series' of Pembrokeshire.

differences also lead to problems of correlation between the Silurian outcrops of Pembrokeshire themselves, the areas indicated on text-fig. 6 are discussed separately below.

Marloes Sands. The Coralliferous 'Series' of De la Beche (1846, p. 26) is exposed in three tectonically separated sections along Marloes Sands (see Cantrill *et al.* 1916, fig. 11 and Bassett 1971, fig. 2) where it reaches a thickness of about 100 m. Although the lowest beds are of latest Upper Llandovery (Telychian) age, with typical C_6 associations of the coral *Palaeocyclus porpita* (Linnaeus) and the brachiopods *Eocoelia sulcata* (Prouty) and *Costistricklandia lirata lirata* (J. de C. Sowerby), the level of a transition into the Wenlock is not known exactly. *C. lirata lirata* continues to occur for about 50 m above the base and then dies out, suggesting a broad correlation with the Woolhope Limestone of the Welsh Borderland at about this horizon (Bassett 1971, p. 216); the upper half of the Coralliferous 'Series', of blue-grey cleaved silty mudstones, with thin sandstones, calcareous lenses, tuffaceous bands, and bentonitic clays, is thus probably of Wenlock age. The succeeding Grey Sandstone 'Series' has generally been correlated in the past with the Ludlow (e.g. see Cantrill *et al.* 1916, pp. 60-62), but the limited faunas present low in the succession are similar to those from high in the Coralliferous 'Series' and may also indicate a Wenlock age. The Grey Sandstone succession consists of at least 300 m of sandstones, grits, sandy mudstones, and quartzites; the extent of any beds of possible Ludlow age is not known, since fossils are extremely rare or absent from the upper horizons, where deltaic sediments are interbedded with very shallow marine deposits (Walmsley 1962, pp. 291-292; Sanzen-Baker 1972, pp. 145-146).

Wooltack Park. The succession at Marloes Sands is repeated along the south coast of the Wooltack peninsula from the eastern side of Renney Slip, through Deadman's Bay south-eastwards to just north of Gateholm (text-fig. 6). The Coralliferous 'Series' attains a thickness of up to 135 m, with the highest 100-110 m occupying the whole of Deadman's Bay; the faunas mirror those at Marloes, with *C. lirata lirata* ranging up to the middle of the succession in the centre of the bay. The base of the Grey Sandstone 'Series' is exposed along the south-east side of Deadman's Bay below Pittingale Point, from where up to 600 m of beds may be present before passing into Old Red Sandstone facies north of Gateholm, but it is probable that part of the succession is repeated by strike faulting which is undetected in the steep cliffs; the lithologies and limited faunas of the lower beds again indicate a general correlation with the Marloes sequence. At Musselwick

Sands, on the north side of the Wooltack peninsula, a narrow wedge of sandstones, faulted between Llandeilo beds on the south and Old Red Sandstone on the north, appears to belong to a low horizon in the Grey Sandstone 'Series', and is thus probably of Wenlock age.

St. Ishmael's-Lindsway Bay. The Lindsway Bay outcrop on the north coast of Milford Haven (text-fig. 6), including the smaller Wenall and Watch House Bays, exposes some 66 m of upper Coralliferous 'Series' and 300 m of Grey Sandstone 'Series' in a series of fault blocks (see Cantrill *et al.* 1916, figs. 16 and 17); all the beds are probably of post-Llandovery age since none of the diagnostic C_6 elements found at Marloes and Wooltack appear to be present. Inland, towards the village of St. Ishmael's, the succession is again repeated to the north of a major fault, and although the exposures are poor there appears to be a conformable downward transition through the Wenlock, from Grey Sandstone 'Series' to low beds in the Coralliferous 'Series' containing *Palaeocyclus* and *Costristricklandia* indicative of the Upper Llandovery.

The Winsle Inlier. The narrow Silurian outcrop extending from Sandyhaven Pill (SM 862 088) via Upper Winsle (SM 085 093) to Orlandon (SM 811 094) consists of 350 m or more of steeply dipping green and buff shaly siltstones with thin sandstones and calcareous lenses, bounded on all sides by Old Red Sandstone. The beds appear to be wholly of Wenlock age, with well-preserved faunas from around Upper Winsle and Slatemill (SM 8215 0917) containing associations such as *Meristina* sp. and *Calymene* cf. *blumenbachii* Brongniart suggestive of the middle to late Wenlock; the record of middle Wenlock graptolites from Upper Winsle (Cocks *et al.* 1971, pp. 107–108) supports this correlation. The relationships with the Old Red Sandstone are unclear. Cantrill *et al.* (1916, pp. 85–87) described faulted and unconformable relationships, but Sanzen-Baker (1972, p. 149) implied a sedimentary transition upwards from the marine Silurian, which would suggest a Wenlock age for at least part of the red beds; the undoubted structural complexity of the area suggests that this latter view may be an over-simplification which requires further examination.

Freshwater East and Freshwater West. The Silurian sequences south of Milford Haven are restricted in their development compared with those to the north. The thickest exposed succession is in the foreshore and cliffs along the south side of Freshwater East Bay, where it consists of a minimum of 60 m of unnamed, fossiliferous siltstones, sandstones, sandy shales, grits, and decalcified 'rottenstones', followed unconformably by (and locally faulted against) Old Red Sandstone conglomerates and marls. Dixon (1921, pp. 12–15) reported the presence of both Wenlock and Ludlow rocks, with a possible unconformity between them, but although the sediments show minor channelling and scouring structures there is no evidence of a major physical break, and the essential homogeneity of faunas throughout the section suggests that there is no great age difference between the oldest and youngest marine beds. In the absence of Wenlock faunas comparable with those of the Welsh Borderland, both Bassett (1971, p. 220) and Walmsley (*in* Owen *et al.* 1971, p. 46) tentatively suggested a Ludlow age for the whole sequence, an interpretation which appeared to be supported by Dixon's (1921) records of common specimens of *Salopina* cf. *lunata* (J. de C. Sowerby) and *Homalonotus* sp. since these fossils characteristically occur together in late Ludlow beds elsewhere in Britain. However, it is now also clear that other elements of the fauna have little in common with those from the British Ludlow, whereas a re-examination of *Salopina* (by the author and Dr. V. G. Walmsley) and homalonotid specimens (by Dr. R. M. Owens) from Freshwater East allows them to be re-identified as *S.* cf. *conservatrix* (McLearn) and *Trimerus* sp. respectively, both of which are more indicative of a Wenlock age. On balance, therefore, a Wenlock age for the whole sequence now seems most likely, a correlation supported by the faunal and lithological similarity to beds low in the Sandstone 'Series' north of Milford Haven.

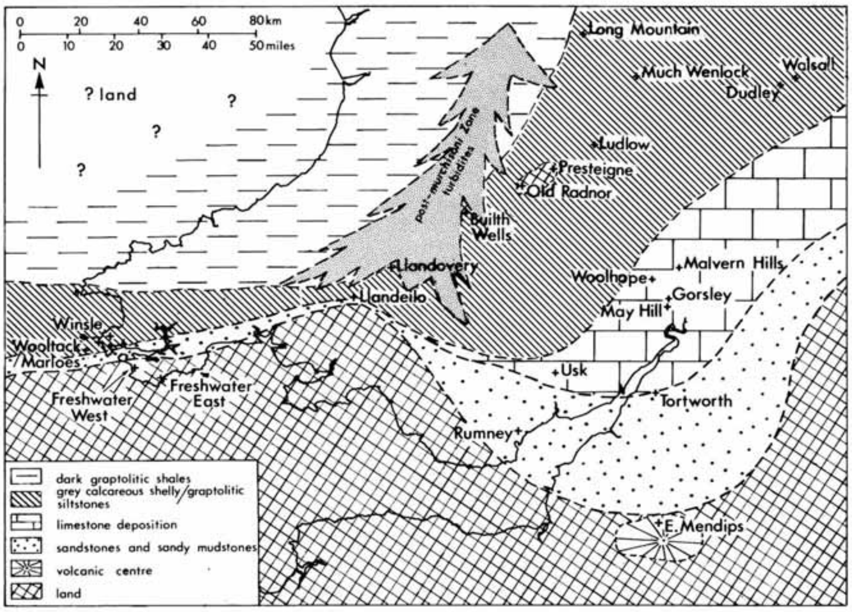
On the north side of Freshwater East similar beds to those on the south side of the bay crop out below the Old Red Sandstone in two narrow strips on the foreshore, separated by faults; a maximum thickness of 22 m is exposed, with a sparse fauna similar to that of the southern outcrop and suggestive of the same age. From the westernmost strip (SS 0220 9812), which is faulted against Old Red Sandstone marls, Richardson and Lister (1969, p. 211) recorded spores which they regarded as being questionably of Ludlow age, while from the overlying Red Marl Group they recorded a Downtonian assemblage. Between Freshwater East and Freshwater West the narrow belt of inland exposures mapped and described briefly by Dixon (1921) is now obscured. On the foreshore at the south side of Freshwater West (SR 8830 9960) the base of the Silurian comprises 2·1 m of breccia resting unconformably on black Llanvirn (*bifidus* Zone) shales; the succeeding 9 m of beds up to the base of the Old Red Sandstone conglomerate are similar to those of Freshwater East, and thus, although previously regarded as being of Ludlow age (Dixon 1921, pp. 16–19), they may belong to the Wenlock. The same age can probably be assigned to the section on the north side of Freshwater West (SM 8800 0055) where similar faunas are again present through at least 51 m of strata (Dixon 1921, p. 16); much of this section is covered from time to time with beach sand, and the base and top are not exposed.

WENLOCK PALAEOGEOGRAPHY

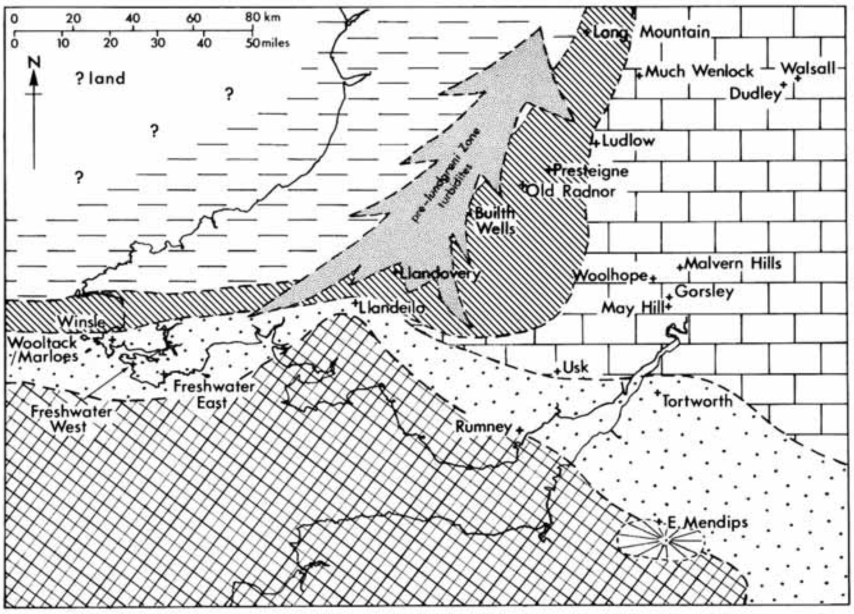
The easterly and southerly transgression of the Llandovery sea from Central Wales across the Welsh Borderland (Ziegler *et al.* 1968) established the geographical framework within which Wenlock rocks were deposited. The setting of this framework within an evolving Lower Palaeozoic geosyncline, including the differentiation of shelf and basin facies, has long been recognized; Ziegler (1970) has recently synthesized its evolution during Silurian times, updating the well-known palaeogeographical maps of Wills (1951). Further analysis of the stratigraphical relationships allows refinements to be made to Wenlock reconstructions. These revisions are illustrated in text-figs. 7 and 8; ideally, as Ziegler (1970, p. 451) has commented, it would be desirable to draw such reconstructions on palinspastic base maps, but it is not possible to eliminate the effects of orogenic distortion and crustal shortening, while it remains useful to illustrate the distribution of ancient land, sea, and facies patterns in relation to present-day geography.

Early Wenlock. By late Upper Llandovery times the north-west margin of the Midland Block, forming the eastern and southern shoreline of the shelf sea, ran close to the northern coast of the present Bristol Channel and in a south-west to north-east direction through the English Midlands (Ziegler 1970, fig. 5). From early Wenlock through to the early Ludlow Ziegler (1970, figs. 6 and 7) envisaged this shoreline as a permanent feature through the Midlands, and consistently to the south of the Welsh coast. However, for the early Wenlock (text-fig. 7) this line can be modified to run through Pembrokeshire south of Milford Haven but north of Freshwater East and West, where the lowest Wenlock is absent (text-fig. 4, col. 5), and in a broad salient through Carmarthenshire towards Llandeilo, where shallow-water facies indicate the proximity of land. This positive salient appears to have been a permanent feature throughout much of the Silurian, acting as a source of deltaic sediments at least from the Upper Llandovery (Smith and Long 1969, pp. 243, 250) to the late Ludlow (Potter and Price 1965, p. 396) (cf. Ziegler 1970, figs. 4–7).

Immediately to the north of the shoreline lay a belt of shallow-water arenaceous sediments which, in the southern Welsh Borderland, passed laterally into limestones represented by the Woolhope Limestone; lateral interdigitation of limestones and calcareous sandstones at the base of the Tortworth sequence indicates that this area lay close to the boundary between these facies. The calcareous lenses within the Wenlock of the Llandeilo district suggest that tongues of the limestone facies periodically reached that far to the west. Beyond the limestone belt lay a broad area in which grey calcareous shales and siltstones were deposited, with a mixed shelly-graptolitic fauna; this area is narrower to the west and south-west, where it is represented in Pembrokeshire by the middle Coralliferous 'Series'. Faunas from this horizon, and contemporaneous deposits in the Welsh Borderland such as the Buildwas Beds, suggest that this facies occupied depths comparable to those of the *Stricklandia* and



TEXT-FIG. 7. Generalized reconstruction of early Wenlock palaeogeography and patterns of sedimentation in the Welsh Borderland and South Wales.



TEXT-FIG. 8. Generalized reconstruction of late Wenlock palaeogeography and patterns of sedimentation in the Welsh Borderland and South Wales. Key as in text-fig. 7.

Clorinda communities of the Llandovery (Ziegler 1965), deepening to the north-west, along the Builth–Long Mountain line, into marginal *Clorinda* (Cocks and Rickards 1969) and graptolite communities. The whole of this belt can be interpreted as a deepening slope between the shelf and basin, and the narrowing of the facies across Pembrokeshire is consistent with the closer spacing of the fossil communities from Upper Llandovery times onwards (Ziegler 1970, figs. 4–7). Together these features suggest a steeper palaeoslope across south-west Wales than in the Welsh Borderland, which probably accounts for the absence of shelf limestones west of Llandeilo.

The shallow-water Dolyhir and Nash Scar algal limestones suggest that the Presteigne–Old Radnor area remained largely emergent until some time during the early Wenlock, probably as an up-faulted island of Pre-Cambrian on the submarine slope. At the foot of this slope turbidity currents flowed north-eastwards along the bathymetric axis of the basin to deposit greywackes and grits from *riccartonensis* Zone times onwards (Cummins 1957). Stratigraphical breaks between Builth and Llandeilo, once believed to indicate the proximity of land areas, can now be explained partly as a reflection of penecontemporaneous submarine erosion (see Ziegler 1970, p. 453), which provided slumped material for turbidity flows. Close to Llandeilo itself, however, the persistent south-westerly overlap and overstep of all divisions of the Silurian are still best explained in terms of progressive on-lap against a shoreline.

Over much of mid-Wales there are no Wenlock outcrops, but the presence of black graptolitic shales of Ordovician to Upper Llandovery age indicates that this was a basin area of prolonged deep-water deposition, and there is no reason to suppose that similar conditions did not exist throughout the Wenlock. To the west of the present Welsh coastline, there is evidence that the basin was bounded by an Irish Sea land mass (Jones 1938, p. lxxxvii; George 1963, pp. 14–18; Ziegler 1970, p. 456), although by Wenlock times this may have existed as a submarine rise rather than a positive land area (George 1963, p. 18).

Late Wenlock. During middle Wenlock times the shelf sea deepened gradually across the Welsh Borderland, depositing Wenlock Shale sediments further to the east and south-east; this deepening, which can be regarded as an extended phase of the Upper Llandovery transgression, resulted in further accretion of the Midland Block. Marine and inter-tidal deposits in the Grey Sandstone 'Series' indicate that by middle Wenlock times the shoreline had retreated just to the south of Pembrokeshire, and by the late Wenlock (text-fig. 8) there is no evidence that the Midland Block remained as a positive feature over central England (cf. Ziegler 1970, fig. 7). The exact dating of its final submergence is uncertain, but it appears to have taken place by *lundgreni–ludensis* Zone times when the Wenlock Limestone was deposited as a final Wenlock shallowing phase, since there is no indication in the Limestone facies of the proximity of land to the east or south-east (Scoffin 1971, p. 215). It is probable that the former Midland Block was by now reduced to an island occupying much of the Bristol Channel area.

Around the remaining land area the late Wenlock facies belts were similar to those of the early Wenlock, but the Wenlock Limestone platform occupied an increasingly large area, both extending eastwards and building out westwards across the slope (text-fig. 8). This appears to have resulted in the narrowing and probable steepening of the slope in the Welsh Borderland, reflected in the increased slumping in areas such as Builth. Turbidite deposition continued along the foot of the slope until the end of *ellesae* Zone times (Cummins 1957).

The southern margin of the Wenlock Limestone platform lay close to Usk and Tortworth, where arenaceous sediments interdigitate with calcareous horizons. The east and south-east limits of the platform are uncertain, but at Ware in Hertfordshire (Whitaker and Jukes-Brown 1894, p. 506) and Cliffe in Kent (Bullard *et al.* 1940, p. 89) faunas and lithologies similar to those of the Wenlock Shale are known from boreholes; the similarity of these facies to those of the Welsh Borderland suggest continuity of deposition across the Midlands, but in the absence of Wenlock Limestone facies in the boreholes it is not clear whether the argillaceous sediments are co-eval with the Wenlock Shale and indicative of fairly early breaching of the Midland Block, or whether they are a lateral, deeper-water facies to the south-east of the limestone shelf. Additional borehole evidence at Stutton in Suffolk, with possible early Wenlock sediments, may indicate slightly further off-shore environments (Bullard *et al.* 1940, p. 87; Cocks *et al.* 1971, p. 125). Certainly by late Wenlock times the Wenlock sea appears to have spread from the Welsh Borderland south-eastwards across England, probably deepening continuously into the Central European geosyncline, and also extending north-eastwards across a shallow shelf to the Baltic area.

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