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Research Report RR/14/02

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Lithostratigraphy of the Old Red Sandstone successions of the Anglo-Welsh Basin

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Keywords

Old Red Sandstone, lithostratigraphy, Devonian.

Front cover

Sandstones and mudrocks of the Freshwater West Formation, Daugleddau Group. Cobbler's Hole, St Anne's head, Pembrokeshire. P006692.

Bibliographical reference

BARCLAY, W J, DAVIES, J R, HILLIER, R D, AND WATERS, R A. 2015. Lithostratigraphy of the Old Red Sandstone successions of the Anglo-Welsh Basin. *British Geological Survey Research Report*, RR/14/02. 96pp.

ISBN 978 0 85272 773 7

Keyworth, Nottingham British Geological Survey 2015

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Foreword

This report presents a revised lithostratigraphy of the Old Red Sandstone of the Anglo-Welsh Basin, prepared under the auspices of the British Geological Survey (BGS) Stratigraphical Framework Committee (SFC). The report provides a correlation of the successions in different parts of the basin and rationalises group and formation nomenclature for the outcrops of Old Red Sandstone in England and Wales. It is based on a previous discussion document (Barclay, unpublished MS, 2007) which presented options in a three-step approach towards rationalisation to a proposed single, standard scheme that can be applied to most of the Pridoli–Lochkovian succession (lower part of the Lower Old Red Sandstone) of the Anglo-Welsh Basin.

The earlier discussion document was circulated among geologists with expertise in the Old Red Sandstone of the Anglo-Welsh Basin in and outside the British Geological Survey. This version takes account of the suggestions for improvement and comments made during the consultation process. One significant change from previous classifications concerns the base of the Old Red Sandstone. There is a consensus that this should be placed at the base of the first major incoming of red- or green-bed ('Old Red Sandstone') terrestrial facies, thereby excluding the shallow marine Downton Castle Sandstone and Tilestones formations that have traditionally been included in the Old Red Sandstone. The report proposes the introduction of two new names and group status for the successions traditionally referred to as the Lower Old Red Sandstone and Upper Old Red Sandstone. The two successions are separated by the major, regional, cleavage-forming Acadian unconformity, and because of this, the authors have made a case for giving them supergroup status. However, they are here accorded group status in accordance with practice in the other Old Red Sandstone basins of the United Kingdom, both onshore and offshore. In nationwide standardisation, all the groups are informally referred to the as-yet undefined parent 'Old Red Sandstone Supergroup', although the authors propose that the term 'Old Red Sandstone' is best retained as a facies (or magnafacies) term. The Lower Old Red Sandstone is termed the Daugleddau Group and the Upper Old Red Sandstone is termed the Brecon Beacons Group.

Acknowledgements

The authors are grateful to D Lowe, A Smith and C N Waters and the other members of the BGS Stratigraphy Committee for their work on the initial draft of this report and to J B Richardson (Natural History Museum, London) and B P J Williams (University of Aberdeen) for their criticisms and comments on an early version of the report. We are also grateful to members of the BGS Stratigraphy Committee (J Powell, C N Waters, A Smith, I Wilkinson, P Hopson, G Kirby, R Bowie, M Gillespie, H Johnson and J Merritt) for their valuable comments on a more recent version of the report. We also acknowledge the work of a large number of Geological Survey officers whose mapping of the Old Red Sandstone of the Anglo-Welsh Basin in south central, south-east and south Wales and the Welsh Borderland and West Midlands has contributed to our understanding of its lithostratigraphy. In areas of south-west Wales not recently mapped in detail by the British Geological Survey, the work of academic geologists, particularly that of J R L Allen and B P J Williams, requires special mention.

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Summary

The Stratigraphy Committee of the British Geological Survey (BGS) undertook a review of stratigraphical classification for all parts of Great Britain. Several Stratigraphical Framework Committees (SFCs) have been established to review problematical issues for various parts of the stratigraphical column. Each SFC had the following terms of reference:

- To review the lithostratigraphical nomenclature of designated stratigraphical intervals for a given region, identifying problems in classification and correlation.
- To propose a lithostratigraphical framework down to formation level.
- To organise peer review of the scheme.
- To present the results in a document suitable for publication.
- To ensure that BGS Lexicon entries are completed for the areas of responsibility covered by the SFC.

This report summarises the SFC lithostratigraphical scheme for onshore nonmarine Devonian ('Old Red Sandstone') successions of the Anglo-Welsh Basin.

The Old Red Sandstone, comprising continental strata of late Silurian to early Carboniferous (but mainly Devonian) age has been studied since the early days of geological research, the early interest being focussed on its fossil fish remains. Most of the research predated the establishment of formal stratigraphical procedures, resulting in a haphazard approach to the naming and hierarchical arrangement of units. From an early, relatively simple framework, subsequent work, including that of the Geological Survey, has introduced increased stratigraphical resolution and refinement at a local scale, but has led to a profusion of local names.

As the British Geological Survey extended its map coverage of the Old Red Sandstone outcrop westwards from south-east Wales and part of the Welsh Borderland, a uniform, rationalised scheme was adopted for the Lower Old Red Sandstone. This report extends that rationalisation to the remainder of the Old Red Sandstone outcrop, except for Anglesey. A rationalisation of the two Pembroke peninsula nomenclature schemes erected for each side of the Ritec Fault (Allen and Williams, 1978; Williams et al., 1982) is proposed, with that south of the Ritec Fault being selected as the standard. Further rationalisation of this scheme with the BGS scheme in the remainder of the basin is proposed. The widespread presence of two marker horizons allows correlation between the Pembroke peninsula and the main outcrop. These horizons are the Chapel Point Limestone and the Townsend Tuff Bed. The position of the base of the Old Red Sandstone is formally redefined, in a departure from its previously defined position at the base of the shallow marine Downton Castle and Tilestones formations. It is here defined at the major incursion of red- or green-bed terrestrial sedimentation.

In Anglesey, there are similarities with the succession of the main outcrop and correlations have been suggested (e.g. Allen, 1974a). However, there are also differences, such as a basal proximal conglomerate facies and higher lacustrine facies not present elsewhere. For this reason, the Anglesey nomenclature erected by Allen (1965a) is retained, with the addition of the name Dulas Bay Subgroup. Red-bed facies of Early Devonian age on the Isle of Man (the Peel Sandstone Group) were deposited in a wholly separate basin (Crowley et al., 2009). These and the deposits of other small separate basins such as those in and around the Lake District are not included in

this review. Also excluded are the red-bed incursions into the Cornubian North Devon Basin (parts of the Middle Devonian Hangman Sandstone Formation and the Upper Devonian Pickwell Down Sandstone Formation).

1 Introduction

The Anglo-Welsh Basin is one of several basins bordering the North Atlantic that have a sedimentary fill of terrestrial red-bed ('Old Red Sandstone') deposits of late Silurian to early Carboniferous age (Friend and Williams 2000; Williams et al. 2000; Kaufman, 2006). In addition to the Anglo-Welsh Basin, the other principal occurrences of these deposits in the United Kingdom are in the Orcadian Basin of northern Scotland and the Midland Valley of central Scotland. A lithostratigraphical scheme for the latter has been published (Browne et al., 2002) and work on a scheme for the former is in progress. Smaller basins include the Scottish Border Basin in southern Scotland and Northumberland, the Mell Fell Trough in the Lake District and the Peel Sandstone Basin in the Isle of Man.

The Anglo-Welsh Basin formed on the southern margin of the newly amalgamated Laurussian (Old Red Sandstone) continent and the northern margins of the evolving Rheic Ocean (Figure 1). The basin has been interpreted variously as a load-generated flexural subsidence foreland basin, formed as a result of the continuing crustal compression of the Caledonian Orogeny (James, 1987; King, 1994; Friend et al., 2000), and as a tectonic basin formed in response to orogen-wide, sinistral strike-slip megashearing (Dewey and Strachan, 2003; Soper and Woodcock, 2003; Woodcock and Strachan, 2012). The basin lay in a distal ('external') setting relative to the Caledonian Orogen in the Early Devonian (Allen, 1979). Anglesey, the Isle of Man and localities in and around the margins of the Lake District were the sites of small isolated internal basins within the orogen for at least some of the Early Devonian, although Soper and Woodcock (2003) surmise that an Old Red Sandstone overburden at least 3.5km thick may have been deposited in the southern Lake District, north Wales and East Anglia and subsequently eroded. Local variations on the regional subsidence pattern were generated by synsedimentary extensional and transtensional faults. The former were particularly active in Pembrokeshire in the late Silurian–Early Devonian. The latter may have caused the intermittent emergence of a landmass in the Bristol Channel area in the Early and Mid Devonian.

The Anglo-Welsh Basin is now represented by extensive outcrops in south and south-central Wales, Anglesey, the Forest of Dean, Welsh Borderland, West Midlands, Mendips and the Bristol area (Figure 2). There is also a small inlier of Upper Devonian strata comprising an interbedded succession of marine and Old Red Sandstone facies deposits at Merevale in the West Midlands (Taylor and Rushton, 1971). Concealed successions are present onshore in southern England and offshore in the southern North Sea. The concealed Old Red Sandstone onshore proven in southern England (Chaloner and Richardson, 1977; Allen, 1979; Belka et al., 2010), known only from boreholes, has not generally been assigned lithostratigraphical names and is not discussed further in this report. An exception is the Upper Devonian succession proved in the Steeple Aston Borehole, in which Poole (1977) named the marine Famennian beds the Holt Farm Group and the Frasnian Old Red Sandstone facies beds the Hopcroft Halt Group. Offshore, the Upper Devonian succession of the southern North Sea is named the Buchan Formation (Cameron, 1993).

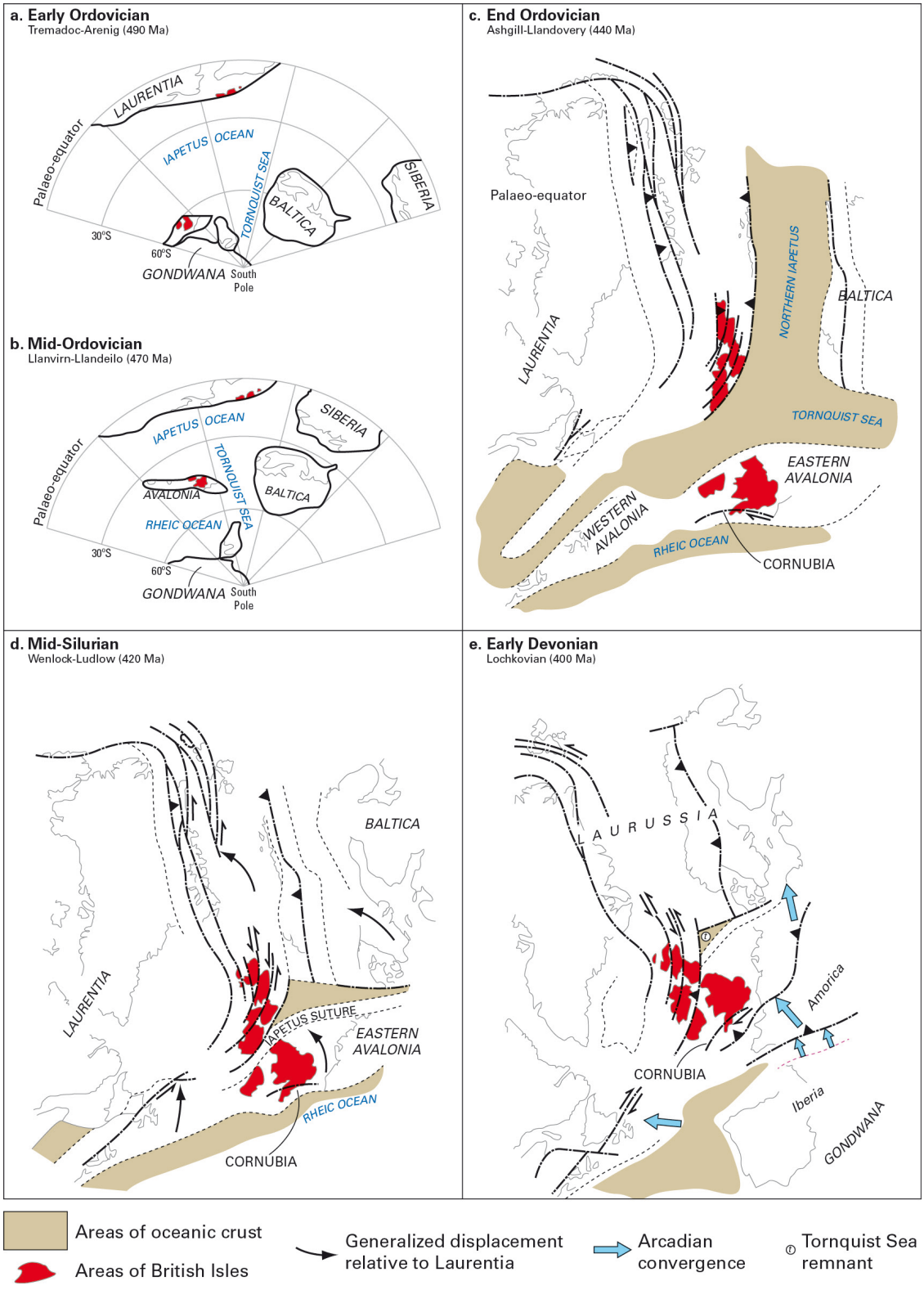

Figure 1 Sketch maps showing the movements of the early Palaeozoic continents and the amalgamation of the Old Red Sandstone (Laurussian) continent. (a) and (b) illustrate the fragmentation of Avalonia from Gondwana and its drift northwards as the Iapetus Ocean closed (adapted from Torsvik et al. (1992) by Trench and Torsvik (1992). (c), (d) and (e) show the later stages of the Caledonian Orogeny. Sinistral strike-slip movements along the Laurentian margin culminated in the Acadian Orogeny in Emsian times (after Barclay et al. (2005) and Stephenson et al. (1999), adapted from Soper et al. (1992)).

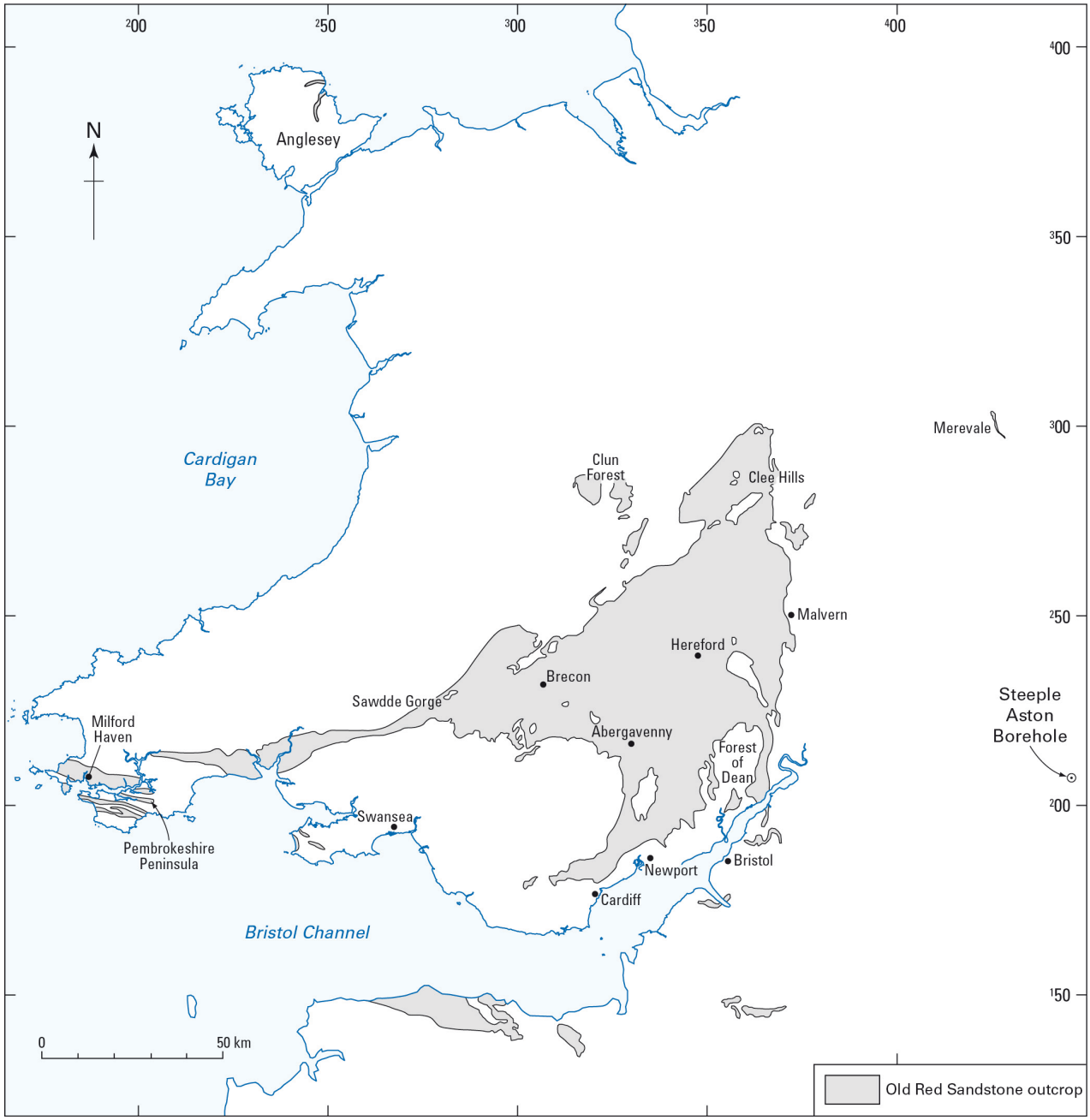

Figure 2 Old Red Sandstone outcrops in England and Wales.

Old Red Sandstone facies red-bed sedimentation commenced locally in south-west Pembrokeshire and Carmarthenshire in the Ludlow, but generally began in the Pridoli, following the rapid late Ludlow shallowing of the Lower Palaeozoic marine Welsh Basin (Figure 3). The Old Red Sandstone extends throughout the Devonian, with the Mid Devonian largely unrepresented in the rock record, except for the northerly derived Hangman Sandstone Formation of north Devon (not discussed in this study). For the most part, the late Early to Mid Devonian Acadian Orogeny (Woodcock et al., 2007) resulted in uplift and erosion of the Anglo-Welsh Basin, now represented by a regional unconformity below strata of Late Devonian age. The main basin extended south-eastwards into south-east England where the Old Red Sandstone

is concealed by younger strata. Pridoli and Lochkovian–Pragian strata are widespread in south-central Wales and the Welsh Borderland, but younger (Emsian, Frasnian and Famennian) strata occur mainly as narrow outcrops around the South Wales and Forest of Dean coalfields and as outliers, as for example in the Clee Hills of Shropshire.

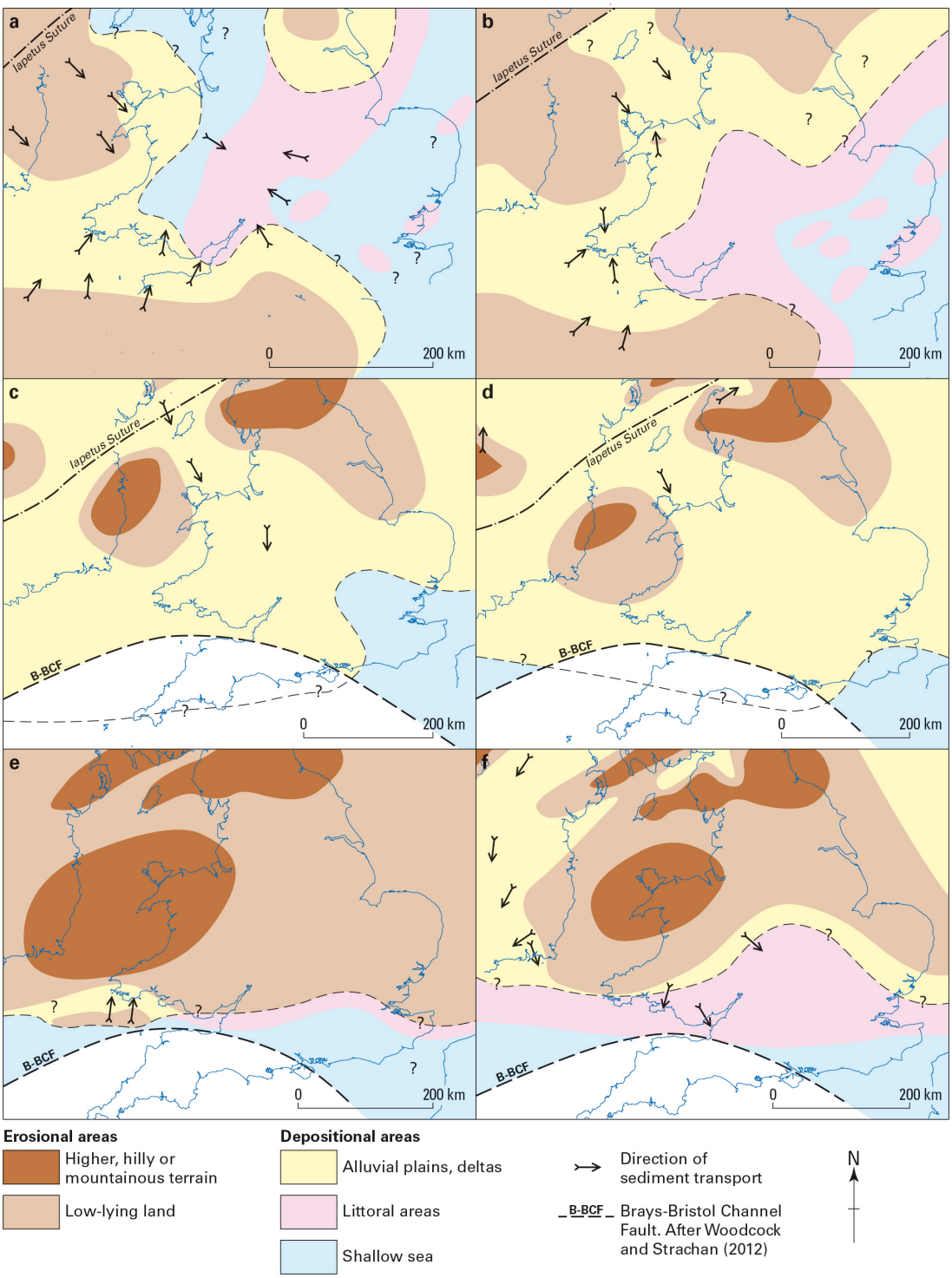

Figure 3 Palaeogeographical evolution of the Anglo-Welsh Basin. (a) earliest Pridoli; (b) mid-Pridoli; (c) Lochkovian; (d) late Pragian – early Emsian; (e) Givetian; (f) Frasnian – early Famennian. Adapted from Barclay et al. (2005); (a) and (b) after Bassett et al. (1992); (c)-(f) after Bluck et al. (1992).

Summaries of the Old Red Sandstone succession of the Anglo-Welsh Basin were given by Allen (1974a; 1977), Barclay (2005a) and Hillier and Williams (2006). Bluck et al. (1992), Barclay (2005a) and Woodcock and Strachan (2012) presented regional overviews. A maximum thickness of about 4.3 km of strata is present north of the Ritec Fault in Pembrokeshire, with up to about 2 km elsewhere. Two major Old Red Sandstone megasequences are recognised, traditionally referred to the Lower Old Red Sandstone and the Upper Old Red Sandstone. The earlier Lower Old Red Sandstone succession represents the last depositional phase of the Caledonian orogenic cycle that was ended by the Acadian Orogeny. The later Upper Old Red Sandstone succession represents the first depositional phase of the Variscan cycle. Thus, it is appropriate to apply different names to the upper and lower successions. The lower is here named the Daugleddau Group and the higher is here named the Brecon Beacons Group (Table 1). Table 2 shows the new classification and an earlier one applied to the Lower Old Red Sandstone in the south Wales and the Welsh Borderland. The Lower Old Red Sandstone succession is mainly of late Silurian (Ludlow to Pridoli) to Early Devonian (Emsian) age (Table 3). The Upper Old Red Sandstone is of Late Devonian (Frasnian–Famennian) age. The Mid Devonian is not represented in the Anglo-Welsh Basin, Upper Old Red Sandstone rocks resting unconformably on Lower Old Red Sandstone or older strata as a result of late Emsian Acadian uplift and erosion.

			Pembrokeshire	**Wales, Welsh Borderland, Bristol etc**	**Anglesey**
Old Red Sandstone	Upper ORS	Brecon Beacons Group	Skrinkle Sandstones Subgroup	Portishead Subgroup	
	UNCONFORMITY				
	Lower ORS	Daugleddau Group	Cosheston Subgroup Milford Haven Subgroup		Dulas Bay Group

Table 1 Stratigraphical framework for the Old Red Sandstone of the Anglo-Welsh Basin.

<table>
<tr><th colspan="2">Earlier classification
(e.g. Waters et al., 2007a)</th><th>Revised classification
(this account)</th></tr>
<tr><td rowspan="3">Lower Old Red Sandstone Group</td><td>Brecon Subgroup</td><td>Cosheston Subgroup</td></tr>
<tr><td>Ditton Subgroup</td><td rowspan="2">Milford Haven Subgroup</td></tr>
<tr><td>Downton Subgroup</td></tr>
</table>

Table 2 Earlier and revised classifications of the Lower Old Red Sandstone of south Wales, the Welsh Borderland and Bristol district.

The position of the Silurian–Devonian (Pridoli Series–Lochkovian Stage) boundary within the Lower Old Red Sandstone remains imprecise. Spore evidence suggests that it lies below the Chapel Point Calcrete of the Pembroke peninsula and its correlatives in south-east Wales and the Welsh Borderland (the Bishop's Frome Limestone; Edwards and Richardson, 2004). The Chapel Point Limestone lies at the top of the Moor Cliffs Formation and its correlatives to the east (Raglan Mudstone Formation). Devonian spores occur at the base of the overlying Freshwater West Formation (formerly St Maughans Formation; Wellman et al., 2000), but there is no spore evidence for the location of the Silurian–Devonian boundary at that point (cf. Williams et al., 2004, Figure 2). Allen and Williams (1981) proposed that the Townsend Tuff Bed, which lies about 100 m lower, could be regarded as the 'local Silurian–Devonian boundary'. However, the presence of the thelodont *Turinia pagei* and *pre-micrornatus–newportensis* (MN) Biozone spores of the *Apiculiretusispora* sp. E Biozone (Barclay et al., 1994) at least 33 m below the base of the Freshwater West Formation indicates that the boundary is about 70 m higher (Edwards and Richardson, 2004). High-precision radiometric zircon U-Pb dating of the tuff is currently being carried out by BGS.

Most Old Red Sandstone workers regard the ORS as a facies, or magnafacies. Today the facies is exposed around the North Atlantic margin and is characterised by continental red beds (Friend et al., 2000). In southern Ireland, the Anglo Welsh Basin, the Lake District, the Scottish Borders and the Midland Valley of Scotland, the Middle Devonian is absent, Upper Devonian strata resting unconformably on Upper Silurian to Lower Devonian strata as a result of the Acadian Orogeny. The name Old Red Sandstone (ORS) has been used as a facies name (the Old Red Sandstone magnafacies of Allen, 1979), as a long-established traditional, informal lithostratigraphical name and as a more formal, but undefined lithostratigraphical name (the Old Red Sandstone Supergroup; e.g. Cameron, 1993) for the red-bed facies of Silurian to Carboniferous age deposited on the south-eastern margin of the Caledonian Orogen after the amalgamation of Laurentia, Baltica and Avalonia. Collapse of the orogen and its erosion

produced the ORS, deposited in accommodation space created by transtensional movement on regional strike-slip faults (Woodcock and Strachan, 2012). Although originally introduced as a lithological term, the looser stratigraphical principles of bygone days also resulted in use of ORS as a pseudochronostratigraphical term for the red beds of Devonian age. However, the international agreement at the Montreal Devonian Symposium in 1972 to define the base of the Devonian in the fully marine, graptolite-bearing succession exposed at Klonk in the Czech Republic, at the base of the Monograptus ultimus Biozone (e.g. House, 1977) places the basal part of the ORS in the Silurian. The strata from the Ludlow Bone Bed up to the base of the Devonian, as yet poorly defined in the Old Red Sandstone, have generally been regarded as belonging to the Pridoli Series, the uppermost series of the Silurian. However, Loydell and Fryda (2011) have suggested that the base of the Pridoli is considerably higher on the basis of isotope excursion data.

<table>
<tr><th></th><th></th><th>Period/System</th><th>Epoch</th><th>Series</th><th>Stage</th><th>Age (Ma)</th></tr>
<tr><td>Carboniferous Limestone Supergroup</td><td></td><td>Carboniferous</td><td>Early</td><td>Lower Mississippian</td><td>Tournaisian</td><td></td></tr>
<tr><td rowspan="7">Old Red Sandstone</td><td rowspan="2">Brecon Beacons Group</td><td rowspan="5">Devonian</td><td rowspan="2">Late</td><td rowspan="2">Upper</td><td>Famennian</td><td>358.9</td></tr>
<tr><td>Frasnian</td><td>372.2</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Mid</td><td rowspan="2">Middle</td><td>Givetian</td><td>382.7</td></tr>
<tr><td>Eifelian</td><td>387.7</td></tr>
<tr><td rowspan="3">Daugleddau Group</td><td rowspan="3">Early</td><td rowspan="3">Lower</td><td>Emsian</td><td>393.3</td></tr>
<tr><td>Pragian</td><td>407.6</td></tr>
<tr><td>Lochkovian</td><td>410.8</td></tr>
<tr><td rowspan="2">Silurian</td><td rowspan="2">Late</td><td>Pridoli</td><td></td><td>419.2</td></tr>
<tr><td>Ludlow</td><td>Ludfordian</td><td>423.0</td></tr>
</table>

Table 3 Major subdivisions of the Old Red Sandstone and its chronostratigraphy. Ages from Gradstein et al. (2012).

The plethora of local names, inconsistent application of lithostratigraphical hierarchies, and mixing of lithostratigraphical and chronostratigraphical nomenclature has hindered a regional understanding and detailed correlation of the Old Red Sandstone successions of the Anglo-Welsh Basin. From an early, relatively simple framework, subsequent surveys and publications have added to the complexity of the nomenclature, much of it due to work being carried out before modern rules and procedures for naming litholostratigraphical units were established. Table 4 shows a correlation of the successions in different areas of the basin.

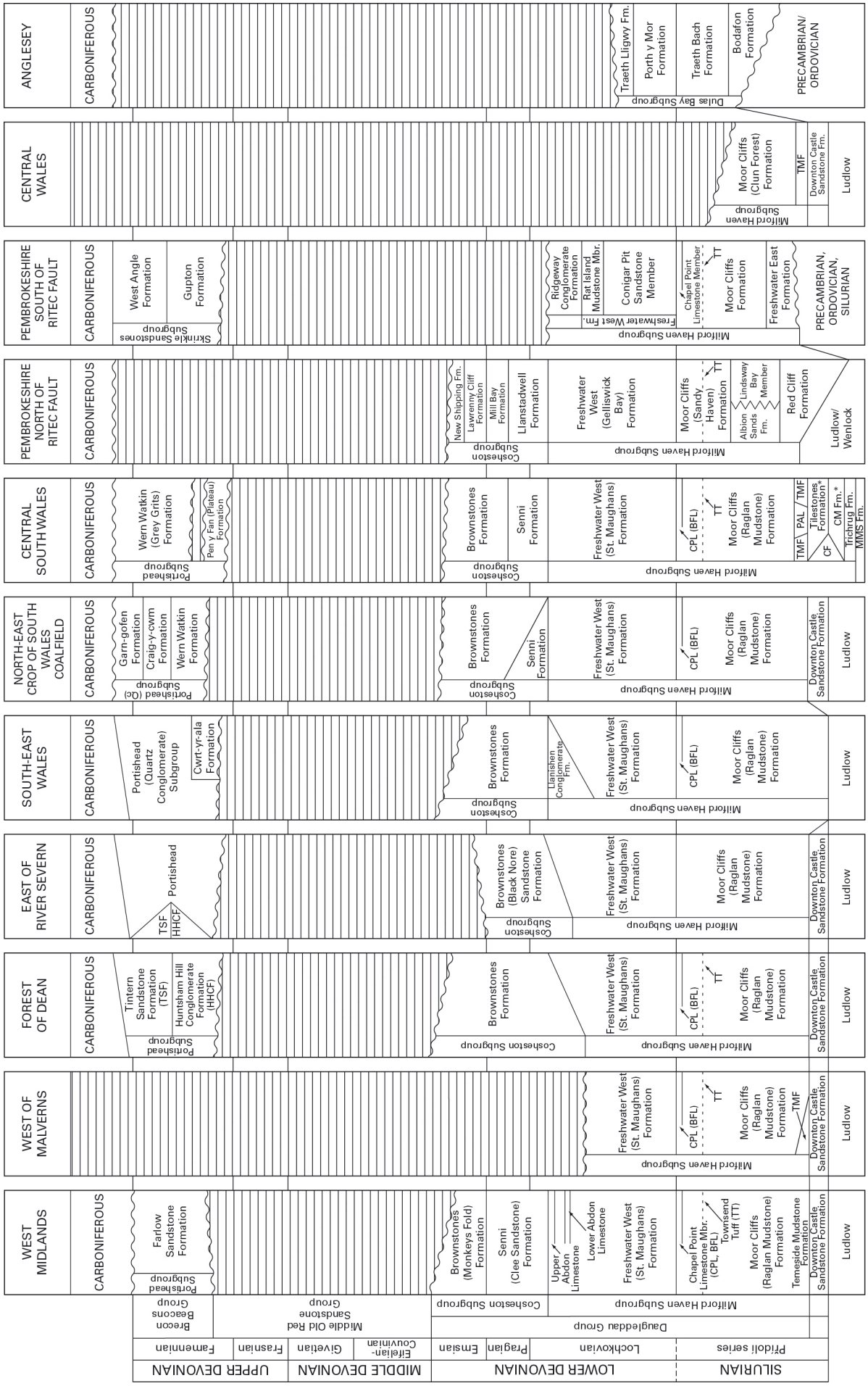

Table 4 Old Red Sandstone successions in the Anglo-Welsh Basin.

This review mainly follows the guidance of the North American Stratigraphic Code (NACSN, 1983) and of the Geological Society, London (Whittaker et al., 1991). The Geological Society Special Report for the Devonian (House et al., 1977) provided correlations between areas of the Anglo-Welsh Basin. It made no attempt to rationalise nomenclature, but provides an invaluable basis for the rationalisation proposed in this report. The abandonment of the terms Lower and Upper Old Red Sandstone departs from offshore North Sea terminology (Cameron, 1993; Marshall and Hewitt, 2000), in which the names are retained, but the word 'Sandstone' is omitted (e.g. Lower Old Red Group). It also departs from the BGS Framework report for the Old Red Sandstone in Scotland south of a line from Fort William to Aberdeen (Browne et al., 2002) which replaces the terms Lower and Upper Old Red Sandstone with Lower and Upper Old Red Sandstone Lithofacies. Work on a revised lithostratigraphy of the Old Red Sandstone of the Orcadian Basin in northern Scotland is in progress (J E A Marshall, personal communication 2011). Here, Middle Devonian strata, absent elsewhere in the UK, form a large part of the Old Red Sandstone succession, with conformable boundaries between the Lower, Middle and Upper Old Red Sandstone locally. This is the best area for the formal definition and naming of an 'Old Red Sandstone Supergroup' and it is therefore best left until the lithostratigraphical review of the Orcadian Basin is completed. However, it is geologically illogical to have a major cleavage-forming deformation event (the Acadian Orogeny), as represented by a major regional unconformity, within a supergroup. For this reason, the authors initially proposed a scheme comprising two supergroups to represent the Lower and Upper ORS successions. However, in the interests of rationalisation of the ORS successions throughout the United Kingdom, and in accordance with the scheme already published for the Midland Valley of Scotland they are here accorded Group status. We thus favour retention of the term 'Old Red Sandstone' as an informal descriptive term for all the red bed facies of late Silurian to early Carboniferous age. A formal lithostratigraphical entity is not strictly needed and if promulgated, would not be used by the majority of workers, who will continue to use 'Old Red Sandstone' as a facies term.

The proposed scheme for the Anglo-Welsh Basin in this report supersedes the broad sequence-stratigraphical scheme of Woodcock (1990), in which the entire Lower Old Red Sandstone succession was included in Woodcock's Powys Group. It also supersedes a BGS interim scheme (Barclay, 2007; Waters et al., 2007a), utilised most recently by Woodcock and Strachan (2012). Table 1 presents a summary of the proposed lithostratigraphical framework down to group level.

2 The base of the Old Red Sandstone

Murchison (1839) first placed the base of the Old Red Sandstone at the top of the Downton Castle Sandstone and Tilestones in the Anglo-Welsh Basin (although he had previously included the latter in the ORS). Following a proposal by French workers, Stamp (1920, 1923) placed it at the base of the Downton Castle Sandstone Formation (and at the base of its basal component, the Ludlow Bone Bed) in the Welsh Borderland and at the base of the Tilestones Formation (the Long Quarry Formation of Potter and Price, 1965) in south-central Wales (see White (1950) and Potter and Price (1965) for comprehensive reviews of the ups and downs of the Silurian–ORS boundary). The position of the base of the ORS (Figure 4) has essentially remained as defined by Stamp, albeit with some local variations, mainly by the Geological Survey, until a recent suggestion (Davies et al., 2008) that, in the Llandovery–Llandeilo area, it should be placed at the base of the Upper Ludlow alluvial fan/fluvial deposits of the Trichrug Formation (sensu Schofield et al., 2008; Hillier et al., 2011a). This resurrects a very early classification by Phillips (1848), who placed the Trichrug Formation in the ORS (Siveter, 2000).

This study provides the opportunity to re-examine and reassess the base of the ORS in terms of modern lithostratigraphical procedures and in the light of recent sedimentological studies. Some authors (e.g. Allen and Tarlo, 1963) have interpreted the Ludlow Bone Bed as marking the start of a transgression and thus the natural position of the base of the ORS. West of the 'Brecon Anticlinal', in the absence of the Ludlow Bone Bed, the base is placed either at the base of the Platyschisma Shale Member of the Downton Castle Sandstone Formation, or at the base of the Tilestones Formation. The base of the Tilestones Formation has been interpreted as transgressive, overstepping onto increasingly older strata south-westwards from the 'Brecon Anticlinal' (Potter and Price, 1965; Squirrell and White, 1978). The base of the Tilestones is conformable except possibly in the westernmost 2 km of the Carmarthenshire crop (pers.comm. Hillier, R D and Waters, R A). Therefore in the absence of convincing sedimentological and sequence stratigraphical analysis supporting the thesis of a basal Pridoli transgression involving the Tilestones Formation in the west and the Ludlow Bone Bed in the east, there is no strong case, other than tradition, for placing the base of the ORS at this horizon. Furthermore, there is no logical reason to define the base of a largely terrestrial succession by a marine transgression.

The traditional positioning of the base of the terrestrial red-bed ORS at the base of the Ludlow Bone Bed (Figure 4) in the Welsh Borderland clearly presents sedimentological difficulties, in the inclusion of a shallow marine sandbody (the Downton Castle Sandstone Formation) in the ORS; similarly, in south-central Wales, where the shallow marine sands of the Tilestones Formation are included in the ORS (e.g. Schofield et al., 2004; Barclay et al., 2005). Also included is the Pont ar Llechau Formation of the Sawdde Gorge (Almond et al., 1993; Wilby, 2005a; Schofield et al., 2008), which overlies the Tilestones Formation. Sedimentologically the base of the ORS should be placed at the incursion of terrestrial red beds. This is at the base of the Raglan Mudstone Formation (now Moor Cliffs Formation) in much of south-east Wales and the Welsh Borderland. Green beds intervene locally between the underlying marine sandbodies and the red beds. These are the marine-influenced alluvial coastal plain, calcrete-bearing sediments of the Temeside Mudstone Formation of the Welsh Borderland and the Green Beds of the Cennen Valley (Squirrell and White, 1978). The Green Beds were named the Capel Berach Beds by Potter and Price (1965) and are included in the Temeside Mudstone

Formation in this report (p.41), apart from their more sandy lower part which is differentiated as the Cwmffrwd Formation (p.38). The Basement Beds of Pembrokeshire, traditionally regarded as the equivalent of the Green Beds. These beds north of the Benton Fault comprise stacked multistorey pebbly sandstones with much soft sediment deformation interbedded with calcretised green mudrocks which become progressively red upsection.

Whereas the Temeside Mudstone Formation shows evidence of marine influence and sporadic marine incursion, its predominantly terrestrial nature, with evidence of subaerial exposure and calcretisation, favour its inclusion in the ORS. For similar reasons, the heterolithic Pont ar Llechau Formation of the Sawdde Gorge is included in the Old Red Sandstone. Schofield et al. (2008) describe it as lacustrine, whereas Almond et al. (1993) interpret the basal 5 m as the infill of a shallow lagoon by washover sheet sands, the overlying 15 m as nearshore, shallow marine and tidal channel heterolithics, and the uppermost 6 m as subtidal to supratidal muds, the latter with incipient calcretisation. The formation comprises three upward-coarsening cycles separated by sequence boundaries, consisting of grey-green shallow-marine open bay and red coastal sand flat facies, that developed marginal to an alluvial fan (pers.comm. Hillier, R D and Waters, R A). The late Gorstian ORS facies Trichrug Formation of the Sawdde Gorge and Cennen Valley (Davies et al., 2008; Hillier et al., 2011a) is included in the Old Red Sandstone, as a tongue of the Milford Haven Subgroup. At Wernbongam on the Ammanford Sheet the Trichrug Formation sits unconformably on strata of Wenlock age and is overlain by the Green Beds (the Cwmffrwd and Temeside Mudstone formations of this report).

In the Marloes Peninsula of south-west Pembrokeshire, the base of the ORS is placed at the late Ludfordian appearance of red beds (Hillier and Williams, 2004). It lies at the conformable junction of the underlying tidal delta deposits of the Grey Sandstone Formation and the overlying red alluvial facies of the Red Cliff Formation (Hillier, 2000; Hillier and Morrissey, 2010). Although white mica in the formation indicates a Laurentian (northerly 'ORS') source (Sherlock et al., 2002), palaeocurrents indicate a southerly and westerly ('Avalonian') source, the Laurentian micas perhaps being windblown (Hillier and Williams, 2004). Elsewhere in Pembrokeshire, the base of the ORS is placed at the base of the Freshwater East Formation (p.22), a thin basal heterolithic conglomerate and sandstone unit underlying the red mudrock-dominated Moor Cliffs Formation. This rests unconformably on the Wenlockian marine Grey Sandstone Formation (Hillier and Morrissey, 2010).

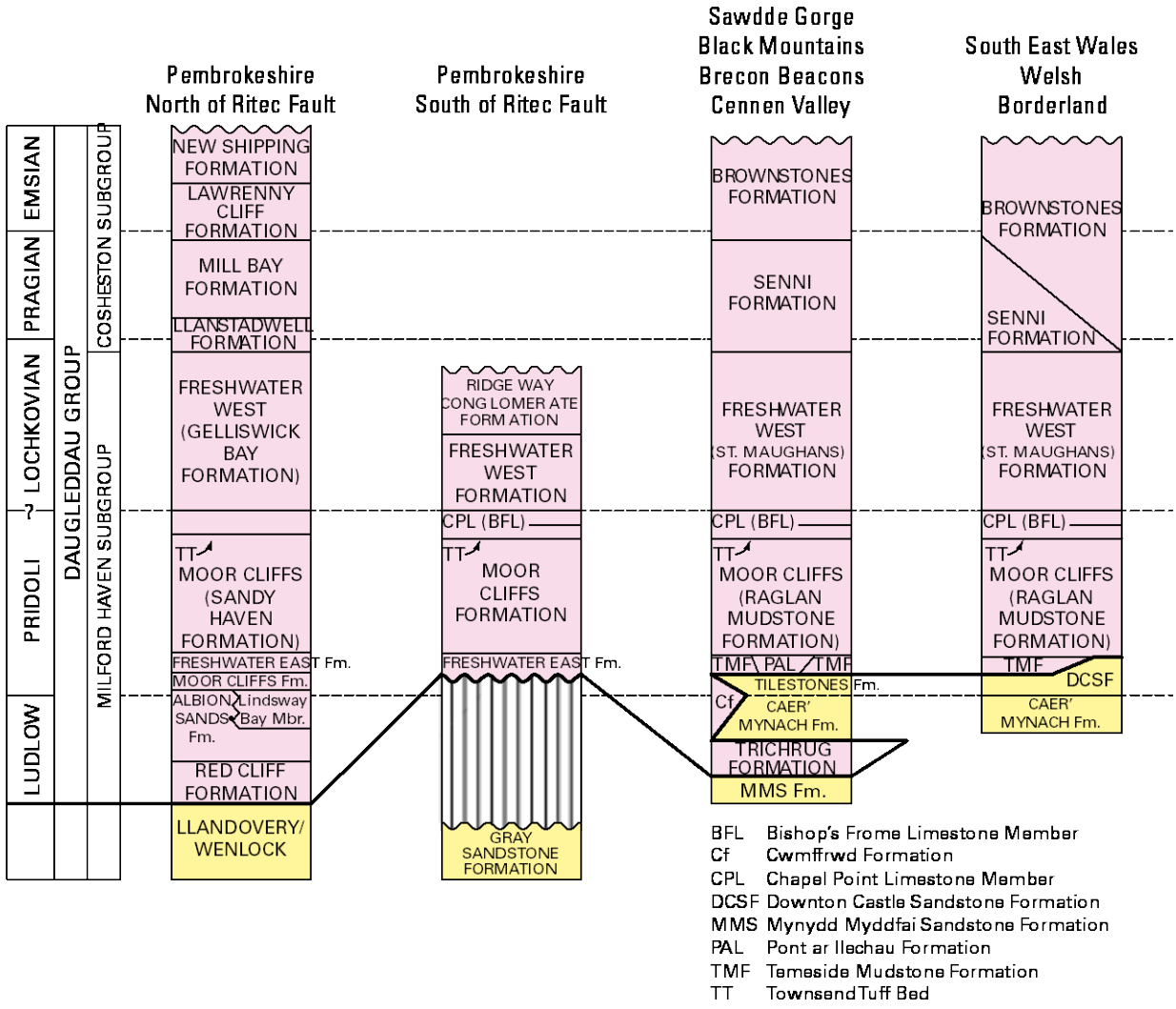

Figure 4 Comparative sections of the Lower Old Red Sandstone of the Anglo-Welsh Basin to illustrate the proposed new base of the Old Red Sandstone (bold line). Standard names are given first, former/pre-existing names are given in brackets.

3 The top of the Old Red Sandstone

The upper boundary of the Old Red Sandstone (and of the Upper Old Red Sandstone) is placed generally at the top of the highest red bed of terrestrial facies, and at the base of limestones and mudstones of the Avon Group of the Carboniferous Limestone Supergroup, which mark the marine transgression in the early Carboniferous and the inception of shallow marine carbonate sedimentation. In northern outcrops, as on the North Crop of the South Wales Coalfield and in outliers in the Clee Hills, the boundary is sharp and disconformable, with a basal Carboniferous conglomerate commonly overlying the topmost Upper Old Red Sandstone strata. In southern, more distal outcrops, as in Pembrokeshire, on the South Crop of the South Wales Coalfield and in the Bristol area, the early Carboniferous transgression was pulsed, resulting in a heterolithic interdigitation of red Old Red Sandstone terrestrial facies and grey, shallow marine and lagoonal facies. This, in turn, has resulted in differing interpretations and positioning of the Old Red Sandstone–Carboniferous Limestone boundary. These are based essentially on whether the junction is placed at the first (lowest) limestone marking the first transgressive marine pulse or at the top of the last (highest) red bed, marking the final phase of terrestrial sedimentation. Further complexity arises where marine waters influenced red bed coastal plain sedimentation or where pedogenic and other subaerial processes affected shallow marine sediments. The interdigitation of the facies has resulted in the topmost beds of the Old Red Sandstone being assigned an early Carboniferous (Tournaisian) age on the basis of spores and macrofossils present in the limestones (e.g. Gayer et al., 1973). The following section reviews the previous work in the areas of interdigitation and attempts to provide a rationalisation of the positioning of the top of the Old Red Sandstone, although areas such as the Bristol district and the Mendips require detailed modern investigation.

Pembrokeshire

In the Pembroke Peninsula, there is an interdigitation of red, green and grey lithologies in a gradational passage between the Skrinkle Sandstones and the Avon (formerly Lower Limestone Shale) Group (e.g. Marshall, 1978, 2000a). Marshall (1977, 1978, 2000a, b) informally subdivided the Skrinkle Sandstones into a lower Gupton Formation and an overlying West Angle Formation. He further divided the West Angle Formation into a lower Conglomerate Member and an overlying Red-Grey Member (the Heterolithic Member of Marshall, 1978). The latter comprises a heterolithic package of red and grey beds (Figure 5).

At West Angle Bay, Marshall (2000a) followed Dixon (1921) in placing the top of the Skrinkle Sandstones (and of the Red-Grey Member) at the top of a reddish grey, well-sorted, 4.7 m-thick calcareous sandstone with well-rounded quartz pebbles and a sparse fauna of brachiopods, bryozoa and ooliths. It has northerly directed palaeocurrents and is interpreted by Marshall (2000a) as a shallow marine barrier sand that transgressed over a coastal lagoon. It, and about 20 m of the underlying part of the Red-Grey Member should arguably be included in the overlying Avon Group, but here the boundary is in need of re-examination.

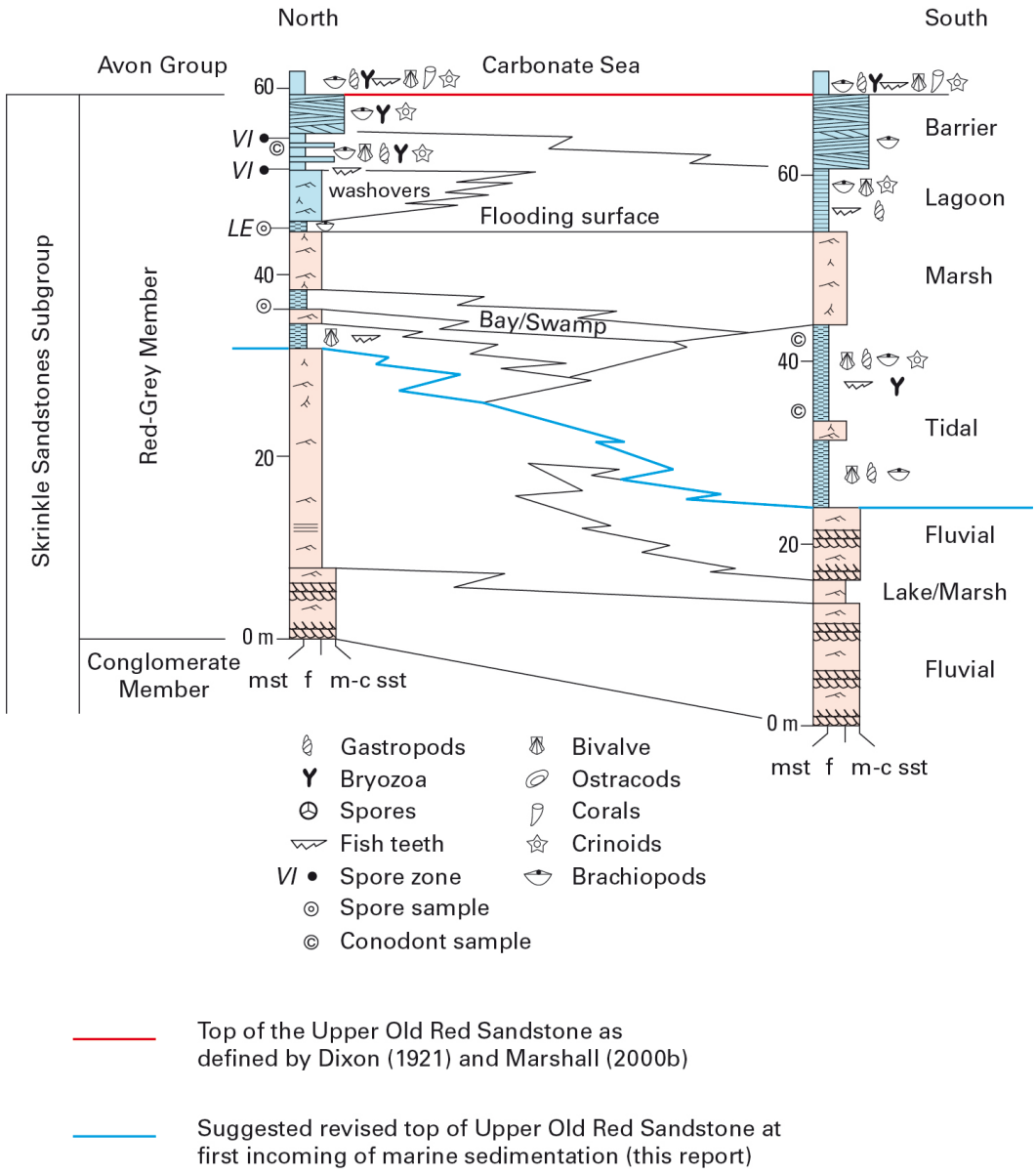

Figure 5 The Red-Grey Member of the West Angle Formation: schematic sections and interpretation of depositional environments across West Angle Bay, Pembrokeshire (Marshall, 2000a).

At West Angle Bay (north), the boundary could be placed about 32 m lower on the north side of the bay, where shallow marine, fossiliferous tidal deposits overlie lake/marsh deposits, as interpreted by Marshall (2000a). On the south side of the bay, this lies about 24 m above the base and about 44 m below the top of the member. A compromise, intermediate position would be at a flooding surface 45 m up from the base of the Red-Grey Member, which caps the highest terrestrial red beds. This has the advantage of being close below the Devonian–Carboniferous boundary. In terms of stratigraphical age, spore data by Dolby (1971) and Bassett and Jenkins (1977) show the Devonian–Carboniferous boundary to lie within the Red-Grey Member. Devonian (LE Zone) spores were recovered from just above the flooding surface at 45 m up from the base (and about 15 m below the top) of the member on the north side of West Angle Bay. Tournaisian (VI) spores were recovered from beds about 6 to 8 m higher. Thus, if the

lower, revised position of the top of the Red-Grey Member were accepted, it would be entirely Devonian in age, and the basal part of the Avon Group would be similarly of Devonian age (see Figure 5).

South crop: Cardiff–Newport area

On the South Crop of the South Wales Coalfield, the boundary is conformable and placed at the sharp to gradational incoming of grey limestones and mudstones of the basal Avon Group. Where the boundary is gradational, as in Pembrokeshire, differences in interpretation of the exact position of the boundary have led to different positioning of the Devonian–Carboniferous boundary and of the top of the Upper Old Red Sandstone.

In the Newport area, Squirrell and Downing (1969) erroneously placed the boundary between the Upper Old Red Sandstone and the Avon Group at the base of a thick limestone (the Castell Coch Limestone of Waters and Lawrence, 1987), in and above which the rocks are fully marine, although they noted a strong case for drawing the boundary at the lowest horizon above which marine fossils occur. Gayer et al. (1973) placed the boundary at a lower horizon in a section exposed in a pipe trench in Greenmeadow Wood [ST 1354 8227]. These authors provided details of this section and another exposed in road cuttings at Tongwynlais (ST 1302 8245] in the Taff Gorge (Adams et al., 2004). Waters and Lawrence (1987) re-examined the Tongwynlais road cutting and noted a sharp, but conformable junction at the change from the sandstone-dominated sequence of the Quartz Conglomerate Group (now Portishead Subgroup) below, to the sequence of sandy limestone and grey mudstone of the Tongwynlais Formation of the Avon Group above. This lies 2.6 m below the horizon chosen by Gayer et al. and 5 m below the base of the Avon Group as proposed by Burchette (1987).

The BGS Cwrt-yr-ala Borehole ST 17SW/47 [ST 1403 7339] and BGS Ewenny Borehole SS 97NW/157 [SS 9010 7697] provided detailed records of the boundary (Waters and Lawrence, 1987; Davies et al., 1991). A heterolithic 3.6 m-thick unit of red, sparsely shelly, calcareous sandstones, sandy limestones, and mudstones with calcrete nodules overlies the red fluvial sandstones and forms the top of the Portishead Subgroup. These strata comprise a shoaling-upwards cycle (Cycle A of Davies et al., 1991), interpreted as the deposits of a pedogenically and marine-influenced alluvial plain (Figure 6). The sharp base of Cycle A records a rise in sea level that converted the pre-existing fluvial braid plain into a low-lying alluvial coastal plain affected by temporary storm-driven shallow marine inundation, as well as perhaps longer periods of marine conditions (Davies et al., 1991). Marine microplankton-bearing mudstone provides the first evidence of marine influence, perhaps with the marine waters backing up river channels and the muds being deposited as localised overbank sediments. Davies et al. (1991) placed the top of the Old Red Sandstone (and base of the overlying Tongwynlais Formation) at the top of Cycle A, at the incoming of restricted marine or peritidal, green or grey mudstones, micrites, calcisiltites and skeletal packstones/grainstones. In terms of biostratigraphy, the Devonian–Carboniferous (LN–VI) boundary lies at, or up to 8 m below the Upper Old Red Sandstone–Avon Group boundary.

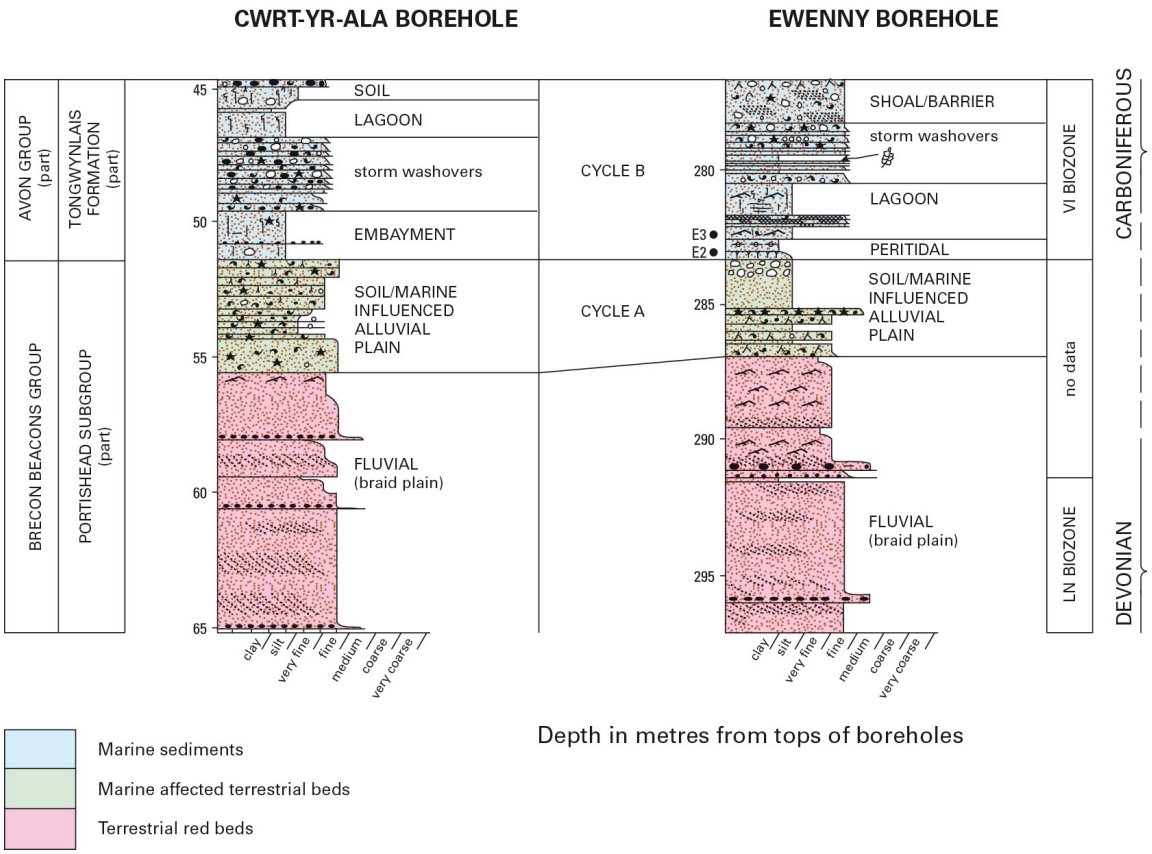

Figure 6 Sections of part of the Cwrt-yr-ala and Ewenny boreholes showing the position of the top of the Old Red Sandstone (Davies et al., 1991).

Bristol–Mendips

North of Bristol, the Upper Old Red Sandstone succession, comprising the Huntsham Hill Conglomerate (formerly the Quartz Conglomerate) and Tintern Sandstone formations, can be correlated with that of the Forest of Dean (Green, 1992; Kellaway and Welch, 1955, 1993). West of Bristol and southwards to the Mendips, these formations cannot be recognised and the succession is named the Portishead Subgroup. The top of the Old Red Sandstone is conformable and placed at the transitional incoming of grey limestones and mudstones. The transitional sequence of beds is termed the Shirehampton Formation (Barton et al., 2002) and forms the base of the Avon Group (Waters et al., 2009). However, there are differences in correlation and the positioning of the boundary (see Kellaway and Welch, 1993: Figure 6). For example, the Shirehampton Formation of the Bristol area is included in the Portishead Subgroup (formerly Portishead Beds/Formation) of the Mendips (Green and Welch, 1965; Kellaway and Welch, 1955, 1993). A fish-bearing conglomerate or pebbly sandstone, the Sneyd Park Fish Bed, is taken, for practical mapping purposes, as the top of the Upper Old Red Sandstone in the Bristol area, but is correlated with a horizon within the Portishead Formation in the Mendips (Kellaway and Welsh, 1993). Palynological evidence suggests that the Devonian–Carboniferous boundary lies within the Upper Old Red Sandstone in the Bristol area (Dolby and Neves, 1970; Utting and Neves, 1970). The Sneyd Park Fish Bed contains Holoptychius, which is absent above the Devonian–Carboniferous boundary. A modern examination of the boundary is clearly required.

4 Daugleddau Group (*new name*)

The Daugleddau Group (new name) is applied to the strata formerly referred to the Lower Old Red Sandstone. It includes the Milford Haven Subgroup (formerly Group) and the Cosheston Subgroup (formerly Group). The Milford Haven Group was erected by Allen and Williams (1978) for the sedimentary, siliciclastic rocks of terrestrial, red-bed facies of Ludlow to Lochkovian age in south Pembrokeshire, previously named the Red Marls by the Geological Survey. The upper part of the Daugleddau Group is the sandstone-dominated Cosheston Subgroup, representing increasingly proximal alluvial deposition, culminating in coarse conglomeratic fan deposition locally. In Anglesey, strata of Old Red Sandstone facies traditionally ascribed to the Lower Old Red Sandstone are included in the Daugleddau Group and named the Dulas Bay Subgroup (new name).

Name
Derived from the Daugleddau Estuary near Milford Haven, Pembrokeshire [SM 899 061].

Type area
The Daugleddau Estuary near Milford Haven, Pembrokeshire.

Lithology
Mainly comprises a coarsening-upwards offlap dryland succession of, successively, coastal plain, alluvial floodplain and alluvial fan deposits.

Lower and upper boundaries
The position of the base of the Old Red Sandstone (and of the Daugleddau Group and Milford Haven Subgroup) is discussed in Section 2. It is placed at the first appearance of red (or green) continental/terrestrial beds (Figure 4). In the Marloes Peninsula of south-west Pembrokeshire this is dated as late Ludlow (Hillier, 2000; Hillier and Williams, 2004) and placed at the conformable junction of the tidal/estuarine deposits of the Wenlockian Grey Sandstone Formation and the overlying red alluvial facies of the Red Cliff Formation. Locally, there is an unconformable base, as in Pembrokeshire south of the Ritec Fault, where red and green beds of the Freshwater East Formation overlie the Wenlockian Gray Sandstone Formation (formerly Gray Sandstone Group; Hillier and Morrissey, 2010). Elsewhere in south Wales and the Welsh Borderland, the base of the Old Red Sandstone has been traditionally placed at the base of the Ludlow Bone Bed Member of the Downton Castle Sandstone Formation. It is here placed at the base of the Temeside Mudstone Formation, or in its absence, at the base of the Raglan Mudstone Formation. In the Sawdde Gorge near Llandovery in south-central Wales, the base of the Trichrug Formation (Davies et al., 2008) is taken as the local base of the Daugleddau Group. The upper boundary of the group is placed at the top of the highest beds below the Acadian unconformity (Section 3).

Thickness
Up to about 4400 m

Distribution
Widely throughout south and central Wales, the Forest of Dean, the Bristol district, Mendips, Welsh Borderland, West Midlands and Anglesey.

Depositional environment
The lower part of the group (Milford Haven Subgroup) records mainly successively coastal plain, alluvial floodplain and alluvial fan dryland deposition in a semi-arid climate. Earlier wetland shallow lake and debris-flow-dominated alluvial fans are represented by the Trichrug Formation. Most of the deposits were derived from the north, but the Ridgeway Conglomerate Formation was derived from the south. The Cosheston Subgroup represents fluvial deposition in sand- and gravel-bed, high-energy braided and meandering streams, as well as by sheet flooding and floodplain mud and silt deposition.

Age
Late Gorstian to Emsian

4.1 MILFORD HAVEN SUBGROUP

Name
The Milford Haven Subgroup was formerly named the Milford Haven Group by Allen and Williams (1978). The strata were historically termed the Red Marls of Pembrokeshire by the Geological Survey. The name is derived from the Milford Haven, area, Pembrokeshire.

Type area
Milford Haven area, Pembrokeshire [SM 899 061].

Lithology
Red mudrocks, with common calcrete predominate in the lower part. Its sandstones range from high-sinuosity channelised deposits to low-sinuosity, braided stream deposits, the latter including sheet flood sandstones and laterally accreted sandbodies. In addition to the siliciclastic red beds, fossil soil carbonate horizons are ubiquitous in the floodplain facies, and range from small calcrete glaebules to massive, rubbly and nodular well developed hardpan calcretes. Of these, the Chapel Point calcretes of Pembrokeshire and equivalent Bishop's Frome (Psammosteus) Limestone of south-east Wales and the Welsh Borderland form a basin-wide marker. Others such as the Ruperra Limestone of south-east Wales, the Ffynnon limestones of the Black Mountains and the Abdon limestones of the Clee Hills are less extensive, but may be broadly correlative. Volcaniclastic sediments include the Rook's Cave Tuff, Townsend Tuff and Pickard Bay Tuff. The Townsend Tuff occurs basin-wide, but the others, as well as thinner tuffs of the same age (late Pridoli to early Lochkovian), are less widespread and mainly found only in the Pembroke Peninsula. Subordinate sandstones and conglomerates include the southerly derived petromict conglomerates of the Ridgeway Conglomerate Formation.

The subgroup is subdivided into a number of formations. Two different sets of names were erected for the successions north and south of the Ritec Fault (Allen and Williams, 1978, 1979; Allen et al., 1981a, 1982), but rationalisation of these two sets of names into a standard nomenclature is proposed here. Similarly, rationalising of the formation names used in the other parts of the Anglo-Welsh Basin into the standard nomenclature is proposed. The selection of

standardised names and type localities is based on where the constituent formations are thickest and best exposed, and where formation boundaries can be accurately pinpointed and described. The magnificent coastal sections of south Pembrokeshire satisfy these criteria and the names used south of the Ritec Fault are selected as the standard on account of the recent detailed work that has been carried out on the succession there.

Lower and upper boundaries

The position of the base of the Milford Haven Subgroup is discussed in Section 2. It is placed at the first appearance of red (or green) continental/terrestrial beds (Figure 2). In the Marloes Peninsula of south-west Pembrokeshire this is dated as late Ludlow (Hillier, 2000; Hillier and Williams, 2004) and placed at the conformable junction of the tidal deposits of the Wenlockian Grey Sandstone Formation and the overlying red alluvial facies of the Red Cliff Formation. Locally, there is an unconformable base, as in Pembrokeshire south of the Ritec Fault, where red beds of the Freshwater East Formation overlie the Wenlockian Gray Sandstone Formation (Hillier and Morrissey, 2010). Elsewhere in south Wales and the Welsh Borderland, the base of the Old Red Sandstone has been traditionally placed at the base of the Ludlow Bone Bed Member of the Downton Castle Sandstone Formation. It is here placed at the base of the Temeside Mudstone Formation, or in its absence, at the base of the Raglan Mudstone Formation. In the Sawdde Gorge near Llandovery in south-central Wales, the base of the Trichrug Formation is taken as the local base of the Milford Haven Group (Davies et al., 2008). Farther west in Carmarthenshire and east Pembrokeshire, the Cwmffrwd Formation is taken as the local base.

The upper boundary is a gradational passage into green sandstones of the Cosheston Subgroup north of the Ritec Fault (Allen et al., 1981a). South of the Ritec Fault, the upper boundary of the subgroup (i.e. the top of the Ridgeway Conglomerate Formation) is an unconformity overlain by the Skrinkle Sandstones Subgroup of the Brecon Beacons Group.

Thickness

The subgroup is about 1850 to 2637 m thick in the type area of Milford Haven, north of the Ritec Fault. The thicknesses of the subgroup and its constituent formations were overestimated by Allen and Williams (1978) at Lindsway Bay, where these authors measured across both limbs of the Rooks Nest Anticline, thereby duplicating the section (Hillier and Williams, 2004). To the south of the Ritec Fault the subgroup is 443 to 1382 m thick.

Distribution

Widely distributed throughout south and central Wales, and in the Forest of Dean, the Bristol district, Mendips, Welsh Borderland, West Midlands, Clee Hills and Anglesey.

Depositional environment

The subgroup records successively coastal plain, alluvial floodplain and alluvial fan deposition in a semi-arid climate. Most of the deposits were derived from the north, but the Ridgeway Conglomerate Formation was derived from the south.

Biostratigraphical characterisation
Palynological data indicate a range from the *libycus–poecilomorphus* Zone (Red Cliff Formation) to the *micrornatus–newportensis* Zone (Freshwater West Formation), (Edwards and Richardson, 2004).

Age
The group ranges in age from Gorstian (Trichrug Formation) to late Ludfordian (Red Cliff Formation of Pembrokeshire) to Early Devonian (Lochkovian).

4.1.1 Red Cliff Formation

Name
This name was erected by Allen and Williams (1978). It is derived from Red Cliff [SM 789 068] at the south-east end of Marloes Sands. Hillier and Williams (2004) provided a more recent detailed description.

Type section
Albion Sands [SM 771 077], to the north of Gateholm Island west-south-west of Marloes

Reference sections
There are reference sections on the northern side of the embayment of Red Cliff [SM 789 068] 2 km south-east of Albion Sands and at Lindsway Bay [SM 8425 0665–8445 0640].

Lithology
Mainly red mudstones and sandstones exposed on the cliffs and rocky foreshore at the northern end of Albion Sands [SM 771 077]. The formation comprises red to purple mudstones/siltstones and red, purple and greyish pink, typically fine-grained sandstones.

Lower and upper boundaries
At the type section, the lower boundary is conformable, where the basal red mudstones of the Red Cliff Formation rest on grey deltaic deposits of the Gray Sandstone Formation (Hillier, 2000; Hillier and Williams, 2004). At Red Cliff, calcretised red mudstones interdigitate with grey sandstones with inclined heterolithic stratification of the Gray Sandstone Formation (Hillier, 2000). The upper boundary is placed at the top of red mudstones, where they are overlain by pale quartz-rich sandstones of the Albion Sands Formation.

Thickness
Thicknesses range from 17 m at Lindsway Bay and 50 m at Albion Sands to 55 m at the type section of Red Cliff (Hillier and Williams, 2004).

Distribution
Pembrokeshire, north of the Ritec Fault.

Depositional environment
Dryland alluvial environments with deposition in low-sinuosity ephemeral sand-bed channels, point bar lateral accretion and unconfined sheetfloods. The mudstones represent floodplain deposits subjected to pedogenic vertisol development as well as fluvial deposition of mud aggregates (Hillier and Williams, 2004).

Age
Hillier and Williams (2004) reported a late Ludfordian age based on a trilete spore assemblages.

4.1.2 Albion Sands Formation

Name
The name is derived from Albion Sands [SM 771 077], near Marloes, Pembrokeshire (Allen and Williams, 1978).

Type section
Cliffs at Albion Sands [SM 771 077], north of Gateholm Island, west-south-west of Marloes

Lithology
Westerly derived pale yellow to buff, quartz-rich sandstones and pebbly sandstones with subordinate red mudstones and conglomerates, and thin air-fall dust and crystal-lithic tuffs. Hillier and Williams (2004) provided a recent description.

Lower and upper boundaries
The lower boundary of the formation is placed at the base of the pale quartz-rich sandstones, where they overlie red mudstones of the Red Cliff Formation. The upper boundary is placed at the top of metre-thick, massive coarse-grained mud-matrix quartz-rich sandstones of the Albion Sands Formation, where they are succeeded conformably by red mudstones of the overlying Moor Cliffs (formerly Sandy Haven) Formation exposed at the base of Gateholm Stack [SM 773 075].

Thickness
Up to 95 m

Distribution
Confined to the area between the Ritec Fault in the south and the Musselwick Fault to the north.

Depositional environment
Shallow fluvial sand deposition in low- to moderate-sinuosity braided channels and some mud deposition on floodplains and in channels as bedload pelleted mud aggregates (Hillier and Williams, 2004).

Age
?lLatest Ludlow to ?Pridoli

4.1.2.1 LINDSWAY BAY MEMBER

Name
The name Lindsway Bay Formation was erected by Allen and Williams (1978) for a unit of exotic conglomerates that interfingers with and overlies the Albion Sands Formation. This unit has not yet been mapped inland and it would be very difficult to do so. Its status is therefore downgraded to a member of the Albion Sands Formation. The name is derived from Lindsway Bay [SM 844 066], Pembrokeshire.

Type section
Coast exposures in Lindsway Bay from near Sprat's Point [SM 8425 0665] south-eastwards to Rook's Nest Point [SM 8445 0640] (Hillier and Williams, 2004).

Lithology
The member comprises exotic conglomerates with subordinate red, commonly gritty mudstones and calcretes.

Lower and upper boundaries
The base of the member is placed at the base of the lowest exotic conglomerate, the member interfingering with the Albion Sands Formation. The upper boundary is placed at the top of the highest exotic conglomerate, the highest beds interfingering with the Albion Sands Formation and the overlying Moor Cliffs Formation.

Thickness
Up to 21 m; structural complexity involving backthrusts off the Wenall Fault result in a number of steeply dipping horst blocks. This led Allen and Williams (1978) to overestimate thickness (Hillier and Williams, 2004).

Distribution
Mainly confined between the Musselwick and Ritec faults, but also extends beyond them.

Depositional environment
Debris-flow-dominated subaerial fan deposition of gravel and sand in broad, shallow channels with some mudflow deposition (Hillier and Williams, 2004).

Age
?Latest Ludlow to ?Pridoli

4.1.3 Freshwater East Formation

Name
The formation was named by Williams et al. (1982) and comprises the basal conglomeratic beds of the Old Red Sandstone south of the Ritec Fault. It was previously named the Basement Group (Dixon, 1921). The name is derived from Freshwater East Bay [SS 021 981], Pembrokeshire.

Type section
The type section is at the northern side of Freshwater East Bay [SS 021 981], where the formation is 50.25 m thick and lies disconformably on fossiliferous sandstones and mudstones of the Gray Sandstone Formation of Wenlock age (Dixon, 1921; Bassett, 1982).

Reference sections
Foreshore exposures at the southern end of Freshwater West [SR 884 996] provide a reference section 23 m thick. Here a scoured, channelled surface cuts into the underlying Wenlock sequence and is unconformably overlain by a 5 m thick basal conglomerate of the formation (Dixon, 1921; Bassett, 1974; Allen et al., 1982; Barclay and Williams, 2005). Lingulid faunas are observed 10.8 m above the formation base in a heterolithic, grey mudstone-dominated unit

that is most likely the correlative of one of the four grey-green heterolithic units at Freshwater East (pers.comm. Hillier, R D). The latter study has also recognised the presence of the formation north of the Ritec Fault for the first time. It crops out on the eastern cliffs of Gateholm Island 34.5 m above the base of the Moor Cliffs Formation (SM 7714 0737). Here the formation attains a thickness of 36.4 m. This interval was previously included in the Sandy Haven Formation by Allen and Williams (1978). An additional reference section occurs at Gravel Bay [SM 880 005].

Lithology

The formation comprises green to dark grey granule- to pebble-grade exotic clast conglomerates interbedded with fine- to medium-grained sandstones and green-grey mudstones and finer-grained red sandstones and mudstones the latter of which contain well-developed calcrete palaeosol profiles, commonly with tubular morphology. Mottled red-green 'redoximorphic' pheneomena are common in both mudstone and sandstone lithologies. At Freshwater East the formation comprises four discrete green-grey heterolithic units that contain lingulid faunas, vertebrate (fish) spines, and a diverse ichnotaxa including *Diplichnites, Palmichnium, Rusophycus, Isopodichnus, Striatichnium, Arenicolites* and *Helminthopsis* (Morrissey et al., 2012). Coalified plant fragments are locally abundant (Edwards, 1979). Lingulid and fish faunas are also recorded at Gateholm Island.

Lower and upper boundaries

At Freshwater East the lower boundary is placed at the base of a 1.8 m thick heterolithic unit that is conglomerate dominated and locally scours into the underlying Wenlock Gray Sandstone Formation. The basal conglomerate is of pebble to cobble grade, and is overlain by buff coloured, cross-stratified pebbly sandstone. The upper boundary is placed at the top of the fourth grey-green heterolithic unit and marked by a gradual change into red calcretised mudstone with wedge-shaped peds of the Moor Cliffs Formation. The upper boundary at Freshwater West is placed at the top of a green calcretised mudrock unit, at the conformable junction with thick, red, calcretised mudstones of the overlying Moor Cliffs Formation. At Gateholm Island, the formation conformably overlies red pedified mudrocks of the Moor Cliffs Formation, its base being defined by a 0.6 m thick green-grey heterolithic unit comprising discontinuous, decimetre-thick lens-like exotic clast, granule-grade conglomerates which contain lingulids, Pachytheca, fish spines and fish fragments. These are interbedded with green-grey pinstripe-laminated mudstones and fine-grained sandstones. The top of the formation is defined by a gradual change to red pedified mudstones and thin fine- to medium- grained sandstones of the Moor Cliffs Formation.

Thickness

18 to 50 m; 50.25 m at the type section and 18.45 m at Freshwater West.

Distribution

Freshwater East, Gravel Bay, Freshwater West, Gateholm Island, Pembrokeshire.

Regional correlation

The identification of the formation at Gateholm Island allows correlation across different fault blocks in southern Pembrokeshire for the first time. The formation occurs as a tongue close to

the base of the Moor Cliffs Formation at Gateholm Island. Its presence at the base of the Moor Cliffs Formation elsewhere, and the distinctive exotic clast conglomerate beds indicate the likelihood of significant topography at the time of deposition, most likely being tectonically generated (pers.comm. Hillier, R D).

Depositional environment
Interbedded red sandstone sheets and calcretised mudrocks are similar to those in other alluvial Lower ORS dryland examples such as the Moor Cliffs Formation. The heterolithic units suggest periodic shallow-marine/brackish water influence, most likely the deposits of a coastal lagoon and associated wetlands (pers.comm. Hillier, R D). Redoximorphic indicators reflect periodic wetting and drying of the wetland environment.

Age
Pridoli, as indicated by the coalified plant fragments (Edwards 1979). Sporomorphs recovered from the formation at Freshwater East appear to confirm an early Pridoli age (pers.comm. Higgs, K).

4.1.4 Moor Cliffs Formation

Name
Formerly termed the Lower Marl Group (Williams, 1971) of the Red Marls (Dixon, 1921), this unit was renamed the Moor Cliffs Formation by Williams et al. (1982). The name is derived from West Moor Cliff [SS 036 978] and East Moor Cliff [SS 047 976], Pembrokeshire.

The formation has been hitherto widely referred to as the Raglan Mudstone Formation in the Welsh Borderland, West Midlands, south and south-central Wales by BGS. It was formerly named the Raglan Marl Group (e.g. Welch and Trotter, 1961). Brandon (1989) provided a comprehensive description of the formation in the Hereford district. It was named the Ledbury Formation, as the proposed standard name for the red beds of the Downton Group, by White and Lawson (1989). East of the Severn, the name Thornbury Beds (or Formation) was formerly applied to beds at the same stratigraphical level and of the same facies (e.g. Green, 1992; Kellaway and Welch, 1993). The name Clun Forest Formation (Cave and Hains, 2001) was applied in the Montgomery district of central Wales to a grouping of these beds together with the Platyschisma Beds, Downton Castle Sandstone and Temeside Mudstone formations, but there is little reason to retain this name and it was abandoned in the adjacent Welshpool district (Cave, 2008).

Type sections
Cliff sections of West Moor Cliff and East Moor Cliff (Marriott and Wright, 2004).

Reference section
M50 Motorway cutting section [SO 6685 2636] near Ross-on-Wye. The section is now poorly exposed, but the log by Allen and Dineley (1976) provides a good reference section for the formation in the Welsh Borderland.

Lithology
Red (mainly) and green mudstones and siltstones rich in calcrete nodules, subordinate very fine- to fine-grained sandstones, rare exotic extraformational and intraformational conglomerate and

air fall tuffs, and thick well-developed calcretes at the top (Chapel Point Limestone Member). The airfall tuffs include the Pickard Bay, Rooks Cave and Townsend tuffs. Marriott and Wright (2004) and Williams and Hillier (2004) provide more recent sedimentological descriptions. There are two named units: the informally named Holdgate Sandstone of the Cleobury Mortimer–Abberley district (Mitchell et al., 1962) and the widely distributed Chapel Point Limestone Member.

Lower and upper boundaries
The formation lies conformably on grey/green fossiliferous sandstones and mudstones of the Freshwater East Formation at Freshwater East in Pembrokeshire (Dixon, 1921; Williams et al., 1982). In the Welsh Borderland the lower boundary is placed at the top of the Downton Castle Sandstone Formation, or at the top of the Temeside Mudstone Formation where it is present, the boundary being marked in both cases by the incoming of red mudrock facies.

The upper boundary is placed at the sharp junction of the basal pebbly sandstone of the Conigar Pit Sandstone Member of the Freshwater West Formation, where it overlies the topmost calcrete of the Chapel Point Limestone Member at West Moor Cliff [SS 032 980] and at Manorbier [SS 046 978]. Outside south Pembrokeshire, the upper boundary is placed at the top of the Chapel Point Limestone Member (formerly Bishop's Frome Limestone Member), where the topmost mature calcrete of the member is overlain by more sandstone-dominated strata of the Freshwater West (formerly St Maughans) Formation.

Thickness
From 120 to 371 m in the type area (Williams and Hillier, 2004); up to 800 to 1100 m in the Welsh Borderland.

Distribution
Widely distributed throughout Wales, the Welsh Borderland and the West Midlands.

Regional correlation
The formation was formerly named the Red Downtonian in central Wales (e.g. Holland, 1959) and later included in the Clun Forest Formation (Lynas, 1987; Cave and Hains, 2001). It was named the Gwynfe Formation by Almond (1983) in the Sawdde Gorge, the Ledbury Formation in the Welsh Borderland (e.g. White and Lawson, 1989), although this excluded the equivalent of the Chapel Point Limestone Member) and the Raglan Mudstone Formation throughout south Wales, the Welsh Borderland and West Midlands by the BGS.

Depositional environment
Tropical dryland alluvial and coastal plain environments subject to repeated and prolonged emergence and carbonate soil formation. Shallow braided channel systems and sheet floods reworked aeolian silts and calcretes. Distant plenian volcanic ash eruptions deposited thin tuffs.

Age
Pridoli to earliest Lochkovian

4.1.4.1 CHAPEL POINT LIMESTONE MEMBER

Name

The name Chapel Point Calcretes was erected by Allen and Williams (unpublished manuscript, 1979) and first published by Williams et al. (1982) for the thick development of stacked, well-developed palaeosol carbonate (calcrete) profiles at the top of the Moor Cliffs Formation. It equates with the Psammosteus Limestone(s) of the older literature (e.g. White, 1946). The name is revised to Chapel Point Limestone and the unit given member status. The name is derived from Chapel Point [SS 1435 9576] on Caldey Island, Pembrokeshire. It was formerly named the Bishop's Frome Limestone Member by BGS (Brandon, 1989) in south Wales and the Welsh Borderland.

Type section

Sea cliffs on Caldey Island, Pembrokeshire, where over 30 m of calcretes are magnificently exposed.

Reference sections

Reference sections in Pembrokeshire are provided by foreshore exposures and a gully wall of Little Furzenip headland [SR 8851 9939] at Freshwater West, where the member is 5.7 m thick (Allen et al., 1981a; Williams et al., 1982), and cliff exposures at King's Quoit [SS 0596 9733], Manorbier, where it is 10 to 15 m thick (Barclay, 2005b). A coastal section at Llansteffan, Carmarthenshire [SN 353 101–350 099] provides a magnificent development of six stacked, well developed calcretes totalling about 15 m (Allen, 1978a, Allen et al., 1981b, Barclay, 2005c). The M50 motorway provides a reference section in the Welsh Borderland (Allen and Dineley, 1976). Here, a 12 m-thick well developed rubbly calcrete caps a succession of mudstone/calcrete about 27 m thick.

Lithology

Mudstone with an abundance of calcrete development in the form of massive limestones, tubules and large concretions, and interbedded intraformational calcrete-clast conglomerates at the type locality (Williams et al., 1982); elsewhere, it comprises similarly white, rubbly limestone, or a group of limestones, generally culminating in one or more thick, massive limestone(s) at or near the top of the member.

Lower and upper boundaries

The lower boundary is gradational, and placed where red mudstones become increasingly calcretised and pass into the lowermost of a thick sequence of stacked calcrete horizons. In south Pembrokeshire, the upper boundary is placed at the sharp, conformable junction of the basal sandstone of the Conigar Pit Sandstone Member of the Freshwater West Formation, where it overlies the topmost calcrete of the Chapel Point Limestone Member. Elsewhere, the upper boundary is placed at the sharp, conformable junction between the topmost, well developed calcrete of the member and the overlying sandstone at the base of the Freshwater West Formation.

Thickness

Thickness is variable, ranging from 5.7 m to over 30 m on Caldey Island. Elsewhere, it is up to about 12 m.

Distribution
Restricted to south of the Ritec Fault in Pembrokeshire, but widespread elsewhere throughout south Wales, the Welsh Borderland and West Midlands.

Regional correlation
Correlated with the horizon formerly named the Psammosteus Limestone throughout south Wales, the Welsh Borderland and West Midlands, and more recently named the Bishop's Frome Limestone Member by BGS.

Depositional environment
Carbonate soils formed in a semi-arid tropical climate, representing basin-wide shut-down caused either by large-scale tectonic movement, a regressive event or a period of extended aridity.

Age
Not yet known precisely, being either late Pridoli or early Lochkovian.

4.1.4.2 TOWNSEND TUFF BED

The Townsend Tuff Bed (Allen and Williams, 1978, 1981; Allen et al., 1981b) is an extensive airfall tuff. It was first described by the Geological Survey (Dixon, 1921), and its regional extent was recognised by Allen and Williams (1981). Although one of a number of tuffs in the Moor Cliffs Formation, it is the only one so far recognised throughout the Anglo-Welsh Basin.

Name
Derived from the hamlet of Townsend [SM 8126 0610], Pembrokeshire.

Type section
Sea cliff exposures near Townsend, on the west side of Dale Roads, west of Milford Haven, Dyfed [SM 8126 0610] (Allen and Williams, 1978).

Reference section(s)
Little Castle Head [SM 855 065], on the north shore of Milford Haven (e.g. Barclay, 2005d) and Old Castle Head [SS 0741 9664] (Allen and Williams, 1981; Barclay, 2005b).

Lithology
Composite purple and green tuff comprising 3 to 4 m-thick unit of three graded airfall crystal-lithic tuff beds (falls A, B, C) and intervening dust tuffs (porcellanites).

Lower and upper boundaries
The lower boundary is a sharp junction where the base of Fall A rests on underlying bright red mudstone. The upper boundary is a sharp junction where the dust tuff (porcellanite) above Fall C is overlain by red mudstones.

Thickness
3 to 4 m

Distribution
Widely distributed throughout Pembrokeshire, south-central Wales, the Welsh Borderland and West Midlands.

Depositional environment
Volcanic ash deposits

Age
Pridoli; Allen and Williams (1981) suggested that it be used as the local Silurian–Devonian boundary in the Anglo-Welsh Basin. Current U-Pb age dating by BGS will provide an absolute age and perhaps ascertain its position in relation to the Silurian–Devonian boundary at its type section in the Czech Republic.

4.1.5 Freshwater West Formation

Formerly part of the Red Marls of Dixon (1921), this unit comprises the Sandstone and Marl and Upper Marl Subgroups of Williams (1971). Named by Williams (1978), it comprises two members in south Pembrokeshire, the Conigar Pit Sandstone Member and the overlying Rat Island Mudstone Member (Allen et al., 1981a, b; Williams, 1978; Williams et al., 1982). It was named the Gelliswick Bay Formation north of the Ritec Fault (Allen and Williams, 1978).

The formation was formerly named the St Maughan's Group in the Forest of Dean (e.g. Pocock, 1940; Welch and Trotter, 1961) and Welsh Borderland (Allen and Dineley, 1976). More recently, the name St Maughans Formation has been widely used on BGS maps of the Welsh Borderland, West Midlands and south and south-central Wales. In the West Midlands and Clee Hills, the formation was formerly named the Ditton Group (e.g. Allen, 1961, 1977; Greig et al., 1968), although this unit included the Psammosteus Limestone (now Chapel Point Limestone Member) at its base. In Allen's (1961) classification, the Ditton Group excluded beds between and including the Abdon limestones, which were referred to the Abdon Group (Table 5). These beds are here included in the Freshwater West Formation. The Abdon limestones, named by W W King (Ball and Dineley, 1952, 1961) are two mature calcretes, and were named the Lower Abdon Limestone and Upper Abdon Limestone by Greig et al. (1968). Allen (1961, 1974b, 1977) named the lower calcrete the Hillside Dolomitic Formation, the main (intervening) part of the Abdon Group the Nordybank Formation and the higher calcrete the Abdon Limestone Formation (Table 5). There seems little need to perpetuate these names.

Name
From Freshwater West [SR 885 994], Pembrokeshire.

Type section
Foreshore exposures at Freshwater West [SR 885 994], Pembrokeshire (Allen et al., 1981b; Barclay and Williams, 2005; Williams, 1978; Williams et al., 1982).

Reference sections

1. Low cliffs east and west of Gelliswick Bay [SM 88 5053], 2 km west of Milford Haven.
2. The log of the M50 Motorway cutting section [SO 663260] near Ross-on-Wye (Allen and Dineley, 1976) provides a good reference section, although the section itself is now sporadically exposed.

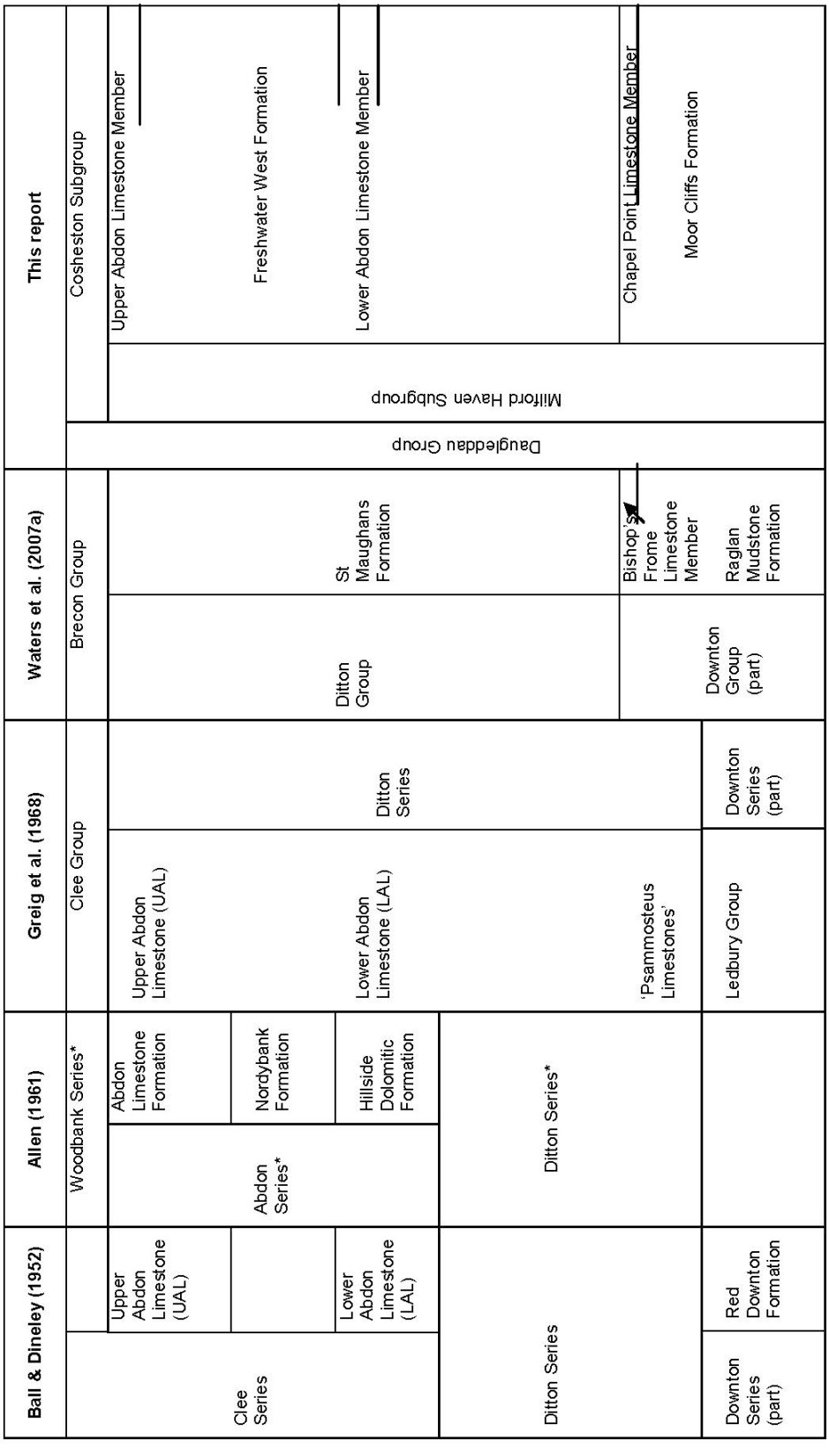

Table 5 Proposed and previous lithostratigraphical classifications of the Lower Old Red Sandstone of the Clee Hills, West Midlands.

Lithology
Very fine- to medium-grained sandstones with subordinate calcrete-bearing mudstones and intraformational conglomerates (Conigar Pit Sandstone Member) and thick, red mudstones–siltstones that are commonly blue-mottled, laminated, and calcretised (Rat Island Mudstone Member); at Gelliswick Bay it consists of fining-upwards alluvial cycles of sandstone–siltstone–red mudstone. The sandstones are dark red to brown and intraformational conglomerate lenses occur locally at the bases of cycles. In the Welsh Borderland the formation comprises interbedded red mudstones (about 60 to 70 per cent) and red-brown, purple and green sandstones, commonly arranged in fining-upwards fluvial cycles, subsidiary intraformational conglomerates, common calcrete glaebules in the mudstones; mature calcretes are sporadically preserved, the Lower and Upper Abdon Limestones being more widespread.

Lower and upper boundaries
In Pembrokeshire, the lower boundary is placed at the sharp junction where the basal sandstone of the formation (and of the Conigar Pit Sandstone Member) rests conformably on the top of the topmost calcrete of the Chapel Point Limestone Member. The upper boundary, previously interpreted as a disconformity or unconformity at the type locality, is now re-interpreted as a conformable boundary (Hillier and Williams, 2007). It is placed where the topmost red-brown mudstones of the formation (and of the Rat Island Mudstone Member) are overlain by interbedded intraformational conglomerates and bright red mudstones of the Ridgeway Conglomerate Formation, the junction being placed at the first appearance of conglomerate. North of the Ritec Fault, the upper boundary is a conformable junction where green sandstones and mudstones of the Llanstadwell Formation of the Cosheston Subgroup succeed red mudstones and sandstones of the Freshwater West Formation. In continuous exposure, the top is placed ‘at the base of lowest mudstone with a recognisably grey-green colouration’ (Allen and Williams, 1978).

In the Welsh Borderland, the base of the formation in the M50 section rests on a particularly thick (about 15 m) calcrete (the Chapel Point Limestone Member), above which fluvial sandstones appear in large quantity in the succession. The top is transitional here, and placed at the top of the highest substantial calcrete, which may correlate with a similar horizon in the Black Mountains and the Clee Hills. The upper boundary is placed at the base of the Brownstones Formation and (locally) Senni Formation, where sandstone-dominated sequences begin. Locally, the top of the formation is placed at the top of the higher of two well-developed calcretes. These are the Abdon Limestones in the Clee Hills (the Hillside Dolomitic Formation and Abdon Limestone Formation of Allen, 1961). These are correlated with the Ffynnon Limestones of the Black Mountains (Barclay and Wilby, 2003) and the Ruperra Limestone of Pontypool (Squirrell and Downing, 1969).

Thickness
The formation is 305 to 580 m thick south of the Ritec Fault and 1000 to 1500 m thick to the north of the fault in Gelliswick Bay. In the Welsh Borderland, about 630 m of beds are present in the M50 section assuming that no strata are cut out or repeated by faulting in the intervals that were unexposed when the motorway was made (Allen and Dineley, 1976).

Distribution
Widespread throughout south Wales, the Welsh Borderland and West Midlands.

Regional correlation
The formation was named the St Maughans Formation (formerly St Maughans Group) by the BGS south Wales, the Welsh Borderland and West Midlands. In the West Midlands, it was formerly named the Ditton Series (or Group), this including the equivalent of the Chapel Point Limestone Member.

Depositional environment
Tropical dryland alluvial deposition in a range of floodplain and perennial and ephemeral meandering river channel environments.

Age
Lochkovian; Higgs (2004) reported MN Spore Zone assemblages from the Conigar Pit Sandstone at Freshwater West.

4.1.5.1 CONIGAR PIT SANDSTONE MEMBER

Name
From Conigar Pit [SS 0724 9696], near Manorbier, Pembrokeshire.

Type section
Conigar Pit [SS 0724 9696], near Manorbier, Pembrokeshire; the east cliff exposes a magnificent, complete type section in beds dipping steeply northwards (e.g. Williams et al., 1982).

Lithology
Very fine- to medium-grained sandstones, intraformational conglomerates and calcrete-bearing mudstones, commonly arranged in fining-upwards cycles (Williams, 1978). Hillier et al. (2007) provided a recent description of the facies.

Lower and upper boundaries
The lower boundary is placed at the sharp, conformable junction where the basal sandstone of the member rests on top of the topmost calcrete of the Chapel Point Limestone Member. The upper boundary is placed at the top of the highest green sandstone complex of the member, where it is conformably overlain by thick red mudstones of the Rat Island Mudstone Member.

Thickness
265 m at the type section

Distribution
The member has been mapped and recognised only in the Pembroke Peninsula south of the Ritec Fault.

Depositional environment
Tropical dryland alluvial deposits of alternating perennial and ephemeral rivers.

Age
Lochkovian (Higgs, 2004).

4.1.5.2 RAT ISLAND MUDSTONE MEMBER

Name
From Rat Island, off the western tip of the Angle Peninsula [SM 841 027], Pembrokeshire.

Type section
The type section is at Freshwater West [SR 885 994], Pembrokeshire, where the member is completely exposed on a wave-cut platform.

Lithology
Red mudstones–siltstones that are commonly blue mottled, laminated, and calcretised (Williams, 1978).

Lower and upper boundaries
The lower boundary is placed at the base of thick red mudstones, where they rest conformably on a green sandstone body which forms the topmost bed of the Conigar Pit Sandstone Member. Formerly considered to be a disconformity or unconformity, the upper boundary is now considered to be conformable, where the topmost red-brown mudstones of the Rat Island Mudstone Member are overlain by intraformational conglomerate and bright red mudstone at the base of the Ridgeway Conglomerate Formation (Hillier and Williams, 2007).

Thickness
81 m at the type section

Distribution
Recognised only in Pembrokeshire, south of the Ritec Fault.

Depositional environment
Tropical dryland alluvial deposits of ephemeral rivers.

Age
Lochkovian

4.1.5.3 HACKLEY LIMESTONE MEMBER

Name
From Hackley Farm [SO 636 534], Herefordshire.

Type area
Around Hackley Farm, Herefordshire.

Reference sections
Disused lime pits near Hackley Farm [SO 636 534] where 0.4 to 0.5 m of rubbly limestone are exposed. A stream [SO 6332 5336] exposes the basal 0.4 m of the member overlying mudstone.

Lithology
Rubbly, feature-forming limestone with concretions up to 0.3 m. Locally, as in the type area south-east of Hackley Farm, the member comprises two limestones separated by several metres of mudstone.

Lower and upper boundaries
Not formally defined, but sharp and conformable, and placed at the base and top respectively of the well developed limestone, where it overlies red mudstones at its base and is overlain by red mudstones above its top.

Thickness
Up to 5 m

Distribution
In Herefordshire, about 4 km on the eastern limb of the Bredenbury Anticline south-west and north-west of Bromyard from near The Wells [SO 6265 5400] to The Greeve [SO 6625 5175] and near Peacock's Heath [SO 6400 5640 to 6505 5595] respectively. It is probably also on the eastern limb of the fold at Crowels Ash [SO 622 525]. It is probably absent over parts of the area due to fluvial channelling.

Depositional environment
Calcic vertisol (calcrete) formed during a prolonged period of exposure on an alluvial plain in a hot, semi-arid tropical climate with seasonal rainfall.

Regional correlation
It has been suggested (Brandon, 1989) that the member, along with less well-developed calcretes in close proximity, may correlate with the similar beds near the top of the formation around Ross-on-Wye and Monmouth (Allen and Dineley, 1976; Welch and Trotter, 1961), with the Ruperra Limestone of the Newport district, Monmouthshire (Squirrell and Downing, 1969) and possibly with the Abdon Limestone of the Clee Hills (Allen, 1974b). However, in these areas the calcretes occur at the top of the formation whereas here the formation continues above for several hundreds of metres. A more likely correlation may be with the Coldra Limestone of the Newport district.

Age
Lochkovian

Name
From Hackley Farm [SO 636 534], Herefordshire.

Type area
Around Hackley Farm, Herefordshire.

Reference sections
Disused lime pits near Hackley Farm [SO 636 534] where 0.4 to 0.5 m of rubbly limestone are exposed. A stream [SO 6332 5336] exposes the basal 0.4 m of the member overlying mudstone.

Lithology
Rubbly, feature-forming limestone with concretions up to 0.3 m. Locally, as in the type area south-east of Hackley Farm, the member comprises two limestones separated by several metres of mudstone.

Lower and upper boundaries
Not formally defined, but sharp and conformable, and placed at the base and top respectively of the well developed limestone, where it overlies red mudstones at its base and is overlain by red mudstones above its top.

Thickness
Up to 5 m

Distribution
In Herefordshire, about 4 km on the eastern limb of the Bredenbury Anticline south-west and north-west of Bromyard from near The Wells [SO 6265 5400] to The Greeve [SO 6625 5175] and near Peacock's Heath [SO 6400 5640 to 6505 5595] respectively. It is probably also on the eastern limb of the fold at Crowels Ash [SO 622 525]. It is probably absent over parts of the area due to fluvial channelling.

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Calcic vertisol (calcrete) formed during a prolonged period of exposure on an alluvial plain in a hot, semi-arid tropical climate with seasonal rainfall.

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Age
Lochkovian

4.1.6 Ridgeway Conglomerate Formation

The Ridgeway Conglomerate Formation was, until recently, considered to be of Mid Devonian age. Work by Hillier and Williams (2007) has shown it to be Early Devonian, confirming early Geological Survey mapping by Dixon (1921). It is one of the few formations in the Anglo-Welsh Basin to be sourced from a southerly province.

Name
From The Ridgeway, south Pembrokeshire, which is formed by the outcrop of the formation; The Ridgeway extends from east of Pembroke [SS 060 095] to Penally [SS 110 995].

Reference sections

1. Cliff section in West Angle Bay, south side [SM 852 034], where the formation is 183 m thick (Hillier and Williams, 2007, fig. 10).
2. Foreshore section at Freshwater West [SR 885 986], where the formation is 115 m thick and includes eleven major conglomerates, which form 30 m of the formation (Hillier and Williams, 2007, fig. 7a).
3. East Pennar Point [SM 9446 0308], where about 378 m are present and both top and base are exposed (Hillier and Williams, 2007, fig. 11).
4. Skrinkle Haven [SS 0807 9712], where the formation is 42 m thick (Hillier and Williams, 2007, fig. 7b).

Lithology

Heterolithic mix of polymictic conglomerates, sandstones and gritty bright red mudrocks with calcrete (Williams, 1964, 1971; Hillier and Williams, 2007).

Lower and upper boundaries

The lower boundary is either placed at the base of the lowest extraformational conglomerate, or, as at West Angle Bay (south side), at the base of a heterolithic channel fill comprising medium- to coarse-grained sandstones rich in exotic clasts. Initially interpreted by the Geological Survey as a conformable transition (Dixon, 1921), the junction was later interpreted as disconformable, with the conglomerates overlying a surface that cuts deeply into the underlying red mudstone of the Freshwater West Formation (Williams et al., 1982). However, locally, the facies interdigitate (Dixon, 1921; Hillier and Williams, 2007) and the lower boundary of the formation is now again regarded as conformable and mainly transitional. At Freshwater West, the junction is not significantly erosive, but more of a disconformable nature. The upper boundary is placed at an unconformity that truncates the formation and is overlain by sandstones of the Upper Devonian Skrinkle Sandstones Subgroup.

Thickness

Up to a maximum of 387 m at Sawdern Point; the formation thickens markedly northwards towards the Ritec Fault from its zero edge in a line running eastwards through Caldey Island.

Distribution

Confined to south Pembrokeshire, south of the Ritec Fault.

Depositional environment

Alluvial fan and high-sinuosity river deposition (Hillier and Williams, 2007); initial deposition was in a hangingwall alluvial fan that was sourced from a Lower Palaeozoic/Precambrian source in the area of the present Bristol Channel. Conglomerates were deposited primarily by laterally extensive sheetfloods and as bars in low-relief laterally accreted channels. Sandstones were also predominantly of sheetflood origin. Gritty mudrocks were deposited by cohesive debris flows. Northward progradation of the fan produced interdigitation with a low-gradient, high-sinuosity fluvial channel. Thinly laminated mudstones and sandstones formed in fan-toe and axial-valley lakes, possibly during subhumid climatic episodes. Fan gravels prograded into the axial valley during periods of increased sediment flux. Calcretes throughout the formation in fan and axial

valley facies indicate semi-arid conditions, although Hillier et al. (2011b) raised the possibility that some of the calcretes of groundwater origin and not formed as a result of pedogenic processes.

Age
Latest Lochkovian to possibly earliest Pragian (Hillier and Williams, 2007).

WEST MIDLANDS, WELSH BORDERLAND, SOUTH-EAST AND SOUTH-CENTRAL WALES, BRISTOL

The Milford Haven Subgroup in these areas comprises the Trichrug Formation, a lowermost tongue of Old Red Sandstone facies in the late early Ludlow (Gorstian) succession of Carmarthenshire, the Pont ar llechau Formation and Cwmffrwd Formation of Carmarthenshire, the Temeside Mudstone Formation and the widespread Moor Cliffs and Freshwater West formations. The succession, except for the Trichrug Formation, was hitherto ascribed to the Downton Group (e.g. Allen, 1974a; Bassett et al., 1982; White and Lawson, 1989) and the Ditton Group. The Downton Group comprises the Downton Castle Sandstone, Temeside Mudstone and Ledbury/Raglan Mudstone formations. The redefinition of the base of the Old Red Sandstone, the base of the Daugleddau Group and the base of the Milford Haven Subgroup at the inception of red-bed or green-bed, alluvial or lacustrine facies (Section 2) excludes the shallow marine Downton Castle Sandstone Formation and the Tilestones Formation, its correlative in Powys and Carmarthenshire. The name Downton Group is therefore superfluous and is abandoned. Hitherto named the Raglan Mudstone Formation by BGS in much of this region, and formerly the Ledbury Group in the West Midlands (Greig et al., 1968) and Ledbury Formation in the Ludlow area (White and Lawson, 1989), the Moor Cliffs Formation (p.24) includes one named informal unit (the Holdgate Sandstone of the Clee Hills and West Midlands) and one named member (the Chapel Point Limestone Member). The latter was named the Bishop's Frome Limestone Member by BGS in this region (Brandon, 1989).

The Holdgate Sandstone lies about 120 m above the base of the formation and is named from the village of Holdgate, Shropshire [SO 562 896]. King (1925) named the horizon the Holdgate coarse sandstone and later (King, 1934) the Holdgate Sandstone. Dineley and Gossage (1959) referred to a group of sandstones on the southern limb of the Cleobury Mortimer Syncline, as the 'Holdgate Sandstones'. Allen and Tarlo (1963) referred to a group of sandstones, of which King's Holdgate Sandstone is one, to the Holdgate Sandstones Group. Dineley (1999a, fig. 4.3) termed these the Holdgate Sandstones Formation. The unit is a subgreywacke in the type area of Holdgate, typically medium grained, limonite and iron stained, relatively well sorted and consisting of subangular grains of quartz, feldspar, lithic fragments and detrital heavy minerals (Greig et al., 1968). In the Neen Solars and Abberley areas, it is a coarse-grained, gritty, commonly pebbly, ridge-forming, red-brown sandstone, locally containing fish fragments (Mitchell et al., 1962). With no formally defined boundaries, and King's (1934) criterion for identifying the sandstone on the grounds of its coarse nature questioned by Greig et al. (1968), an informal status for the unit is retained. The identification of a group of similar sandstones by Allen and Tarlo (1963) supports this view. As envisaged by King, the unit is 5 to 10 m thick at Holdgate, but the Holdgate Sandstones Group/Formation of Allen and Tarlo (1963) extends to about 120 m.

The unit occurs in the area west of the Clee Hills around Broncroft and in the Neen Sollars to Abberley area of Shropshire. The north-east-trending Broncroft outcrops include the type area of Holdgate. The Neen Sollars outcrops lie on both sides of the Neen Sollars Thrust. On the west (footwall) side the member crops out around a pericline, the western north–south limb of which lies 240 m west of Neen Sollars church. On the east (hangingwall) side, it crops out in the Shakenhurst area south-eastwards to March Common, to the south-east of where it is unconformably overlain by the Carboniferous Salop Formation. Near Abberley, it crops out from 400 m east of Newhouse Farm [SO 7730 6925] south-westwards to 0.5 km south of Abberley church [SO 7555 6730], the outcrop displaced by several NNW-trending faults.

The Freshwater West Formation (p.28), formerly ascribed to the Ditton Series (or Ditton Group) and named the St Maughans Formation by BGS, includes one named member in this region – the Hackley Limestone Member near Bromyard, Herefordshire (Brandon, 1989), which lies 350 to 400 m above the base of the formation (p.32). It also includes the Coldra Limestone, an informally named calcrete in the Newport district, south-east Wales (Squirrell and Downing, 1969).

4.1.7 Trichrug Formation

The Trichrug Formation was first named by Cantrill (in Strahan et al., 1907) as the Trichrug Beds. Early workers (Strahan et al., 1907; Potter and Price, 1965; Squirrell and White, 1978) included a distinctive 50 m-thick unit of grey and greyish purple conglomeratic quartzites and quartzitic sandstones in the lowest part of the formation, but as it represents marine shoreface deposits, it has been differentiated as the Mynydd Myddfai Sandstone Formation, with the Trichrug Formation redefined (Schofield et al., 2008).

Name
Derived from the mountain of Trichrug [SN 7023], Carmarthenshire, the formation forming its central ridge.

Type section
The gorge of the Afon Sawdde [SN 7280 2460] (Hillier et al., 2011a).

Reference section
Road section on the A476 [SN 610 191] in the Cennen Valley (Squirrell and White, 1978). Here, alluvial fan deposits more proximal than those in the Afon Sawdde are preserved. They include pebble-grade exotic clast debrites and interbedded pebbly sandstones with redoximorphic features (pers.comm. Hillier, R D and Waters, R A).

Lithology
Red-brown, gritty, argillaceous sandstones and very subordinate siltstones and mudstones with scattered thin to medium tabular beds of medium- to coarse-grained greyish purple quartzite. Calcretes, ferricretes and desiccation cracks occur sporadically. Breccias are also present, deposited in proximal settings.

Lower and upper boundaries
The basal boundary of the formation is sharp but conformable with the underlying Mynydd Myddfai Sandstone Formation in the Afon Sawdde. The upper boundary of the formation is

conformable with the basal quartzites and conglomerates of the overlying Cribyn Du Member of the Cae'r Mynach Formation, representing a major transgression in the late Ludlow that re-introduced marine shelf facies.

Thickness
Up to a maximum of 170 m 2 km west of the Afon Sawdde, feathering out to the north-east and south-west.

Distribution
A narrow north-east-trending outcrop of steeply dipping beds in the Myddfai Steep Belt extends for about 18 km from near Treiorwg [SN 653 203] in the south-west to Mynydd Myddfai [SN 805 298] in the north-east.

Depositional environment
Wetland alluvial fan deposition; bioturbation, including *Skolithos* 'pipes', is abundant, suggesting deposition in very shallow lakes fed by debris flow-dominated alluvial fans in a wetland environment (Davies et al., 2008; Hillier et al., 2011a). The formation has common redoximorphic iron oxide mottles generated by repeated wetting and drying within soil profiles marginal to the wetland. Marine inundation of the wetland is represented by three thin units of grey and grey-green mudstone and sandstone that contain *Lingula* and *Orbiculoidea*.

Age
Thought to be late Gorstian, being overlain by marine sediments of early Ludfordian age.

4.1.8 Cwmffrwd Formation *(new name)*

The Cwmffrwd Formation is the new name for beds formerly comprising the lower part of the Green Beds of Strahan et al. (1907). It interfingers with and is overlain by green calcretised mudstones that are here considered to be the Temeside Mudstone Formation. The Green Beds were recognised in the Ammanford district by Cantrill and Thomas (in Strahan et al., 1907) and described in detail by Squirrell and White (1978), who reported them as overstepping the Tilestones Formation to rest on Lower Ordovician strata before failing in a westwards direction. Potter and Price (1965) named them the Capel Berach Beds. Squirrell and White (1978) included the beds in the Raglan Marl Group and assigned them a Pridoli age. Hurst et al. (1978) suggested that they were the lateral equivalent of the upper Wenlock Ffinnant Sandstone. New work (RDH and RAW) suggests that the Cwmffrwd Formation is in part the fluvial lateral equivalent of the predominantly shallow marine Tilestones Formation and is restricted to the area west of the Cennen Valley.

In the Haverfordwest district, Strahan et al. (1914) described similar strata as Basal Green Beds. These are up to 244 m thick and crop out north and south of the Pembrokeshire Coalfield in the Templeton and Llangwm areas respectively, north of the Benton Fault. Originally placed in the Silurian, these beds in the Templeton area, like those in the Ammanford district, pass laterally westwards into red beds and are absent west of Narberth. They were included in the Red Marls of the Old Red Sandstone by Cantrill et al. (1916) and comprise green mudstones with calcretes and subordinate sandstones. A widespread basal conglomerate up to about 1 m thick rests unconformably on the underlying Llandovery strata and consists of angular and rounded pebbles

mainly of quartz, quartzite and felsite. However, in the Llangwm area, these beds comprise stacked multistorey pebbly sandstones with much soft sediment deformation interbedded with calcretised green mudrocks which become progressively red upsection. These are similar to the Mill Bay Formation south of the Benton Fault, rather than the Basal Green Beds, and thus may be part of the Cosheston Subgroup (p.35). At the base they are juxtaposed against sandstones of the Mill Bay Formation across the Benton Fault.

Name
Derived from Cwmffrwd, Carmarthenshire [SN 4231 1738].

Type section
Nant Cwmfffrwd [SN 423 173] provides a well exposed type section, where the base is unconformable on strata of Arenig age.

Lithology
Mainly calcretised green siltstones, green and pale grey sandstones, some of which are conglomeratic and pebbly, and calcrete-clast intraformational conglomerates.

Lower and upper boundaries
The lower boundary is an unconformity overstepping progressively on to lower rocks westwards from the Cennen Valley to rest on Ordovician strata. The upper boundary is conformable with green calcretised mudstones that were formerly considered to comprise the same lithostratigraphical unit (the Green Beds), but are here recognised as typical Temeside Mudstone Formation lithologies, as for example in Nant Cwmffrwd [SN 423 173].

Thickness
Up to 65 m.

Distribution
West of the Cennen Valley, Carmarthenshire.

Depositional environment
Fluvial sheetflood and channelised sands with floodplain silts subjected to subaerial exposure and carbonate soil formation.

Age
Probably late Ludlow to Pridoli.

4.1.9 Pont ar llechau Formation

Recognised by Strahan et al. (1907) and defined by Almond (1983) as a member of the Gwynfe Formation (the Raglan Mudstone Formation of BGS), this has been given formation status by Schofield et al. (2008). It represents a transitional facies between the underlying shallow marine Tilestones Formation and the overlying terrestrial Moor Cliffs Formation. On the basis of a predominantly terrestrial origin, the formation is included in the Milford Haven Subgroup of the Daugleddau Group.

Name
Derived from Pont-ar-llechau [SN 7282 2452] in the Sawdde Gorge, Carmarthenshire (Almond, 1983).

Type area/section
The Sawdde Gorge, Carmarthenshire, upstream (south) of Pont-ar-Lechau [SN 7282 2452–7286 2449].

Lithology
The formation consists of red-brown, bioturbated, gritty, argillaceous sandstones and thin heterolithic units that comprise dull green and yellowish green, lenticular siltstones and mudstones interbedded with grey-green sandstones. The heterolithic units display a diverse shallow marine ichnofauna comprising *Skolithos*, *Palaeophycus*, *Thalassanoides*, *Teichichnus*, *Planolites*, *Arenicolites* and *Schaubcylindrichnus* burrows (pers.comm. Hillier, R D and Waters, R A). Some of the sandstones within these units are amalgamated and many rest on erosion surfaces, their bases containing scattered quartz granules, intraformational mudstone clasts and/or shell fragments; one shows excellent soft-sediment deformation structures. The three heterolithic units present in the Sawdde section are confined to the lower 18 m of the formation, the lowest, a 5 m-thick unit present at the base of the formation, comprising an upwards-coarsening sequence of stacked, grey and green-grey, micaceous sandstones, which preserve horizontal to low-angle cross-lamination where not homogenised by bioturbation (Almond et al., 1993). These heterolithic deposits are interpreted as forming between storm and fair-weather wave base in an open bay environment.

Interdigitated with the green heterolithic facies are red, micaceous, predominantly massive fine- to medium-grained argillaceous sandstones, homogeneous siltstones and laminated mudstones, some containing desiccation cracks. Redoximorphic iron oxide mottling is observed, as are discrete ferricrete nodules. Bioturbation includes *Skolithos*, *Planolites* and probable *Beaconites*. The beds have yielded a poor, low-diversity, nearshore, shallow marine fauna including *Lingula*, gastropods and modiolopsids. The topmost 11m are dull red, massive sandstones with incipient calcrete and ferricrete nodules. Some of the sandstones are gritty and pebbly and all the lithologies are commonly intensely bioturbated. These red bed lithologies are envisaged as coastal sandflat deposits developed at the toe of an alluvial fan that periodically advanced across the shallow open bay heterolithic deposits in response to episodes of tectonic uplift on adjacent fault blocks.

Lower and upper boundaries
The lower boundary of the formation is placed at the conformable junction with the Tilestones Formation (Figure 4; Almond et al., 1993; Wilby, 2005a). Grey-green, highly micaceous sandstones of the topmost Tilestones Formation (Long Quarry Member of Almond et al.1993) are overlain by coarser sandstones arranged in a stacked upward-coarsening sequence of erosively based beds at the base of the Pont ar llechau Formation The upper boundary is placed where massive red sandstones at the top of the formation are overlain conformably by red and green mudstones with well developed calcrete nodules and wedge-shaped peds of the Moor Cliffs Formation (Almond et al., 1993; Wilby, 2005a).

Thickness
Up to 43 m

Distribution
Only present south-west of Rhiwe Farm [SN 737 250], in the south of the Llandovery district.

Depositional environment
A predominantly terrestrial origin is inferred (cf. Almond, 1983; Almond et al. 1993). Almond suggested a lagoonal/peritidal environment, with the lowermost 18 m containing evidence of periodic marine incursion. Sedimentological research is ongoing by two of us (RDH and RAW). The formation's temporal and spatial relationships with the Temeside Mudstone Formation are uncertain. One possibility is that it was deposited within the confines of a valley that incised into the Temeside Mudstone Formation. Alternatively, the Temeside Mudstone may have been excluded from the Pont ar llechau tract by the relief of the alluvial fan that supplied its sandflat facies, in which case the Pont ar llechau Formation must be viewed as contemporaneous with at least part of the Temeside Mudstone Formation.

Age
Late Ludlow to Pridoli

4.1.10 Temeside Mudstone Formation

This is the Temeside Beds of Ball (1951) and Temeside Shale(s) (Formation) of later authors. White and Lawson (1989) gave details. It also includes the Green Downtonian of Holland (1959) and the upper part of the Green Beds of Strahan et al. (1907).

Name
From the River Teme, Herefordshire and Shropshire.

Type sections

1. On the south bank of the River Teme, near the footbridge, east of Ludford Bridge, Ludlow, Shropshire [SO 5190 7423]. This is Locality 5 of White and Lawson (1989);
2. A disused quarry in Tin-Mill Wood, on the south bank of the River Teme near Bringewood Forge Bridge, Downton, Herefordshire [SO 4548 7500]. This is Locality 4 of White and Lawson (1989).

Lithology
Green to olive mudstones and siltstones with calcrete nodules and subsidiary green to brown, micaceous sandstones; locally, the latter contain scattered vertebrate bone fragments and lingulids (the Temeside Bone Bed).

Lower and upper boundaries
The lower boundary of the formation is placed at the sharp, locally disconformable junction of green mudstones of the Temeside Mudstone Formation and the underlying buff sandstone of the Downton Castle Sandstone Formation or of the Tilestones Formation. Locally, the junction is clearly an erosion surface, as, for example, at Werngwilym [SO 0760 3925], where at least 0.5 m of erosion is observed into underlying Tilestones Formation. In the stream section in Blaen

Duhonw [SN 9890 4694], south-west of Builth Wells, the base of the formation is marked by a discontinuous lag up to 0.45 m thick of intraformational conglomerate of reworked calcrete nodules. In western Carmarthenshire the base is gradational with the underlying Cwmffrwd Formation. The upper boundary is placed at the conformable junction of the topmost green mudstones of the formation and the basal red mudstones of the overlying Moor Cliffs Formation.

Thickness
The formation is 12 to 27 m in the type area, 10 to 13 m in south Staffordshire, up to 50 m in the Brecon district (Barclay et al., 2005) and 40 to 80 m in the Builth Wells district (Schofield et al., 2004).

Distribution
Extends throughout the West Midlands, Welsh Borderland and south-central Wales.

Depositional environment
Coastal plain mudflats subjected to subaerial exposure and pedogenic carbonate nodule development, along with sporadic marine inundation.

Age
Pridoli

4.1.11 Llanishen Conglomerate Formation

The Llanishen Conglomerate Formation is a distinctive unit in the Cardiff area of south Wales that contains conglomerate beds of exotic pebbles derived from a southerly direction (Heard and Davies, 1924; Dixon (in discussion, Heard and Davies, 1924); Allen, 1975; Squirrell and Downing, 1969; Waters and Lawrence, 1987; Wilson et al., 1990). Squirrell and Downing (1969) included the unit within the St Maughans Formation (St Maughan's Group), Waters and Lawrence gave it separate formation status.

Name
Derived from the village of Llanishen [ST 175 818] near Cardiff.

Type section
Railway cutting [ST 1812 8229] at Llanishen Station (Squirrell and Downing, 1969 and references therein).

Lithology
Red sandstones, siltstones and mudstones with beds of pebbly sandstone and conglomerate containing exotic pebbles sourced from the south; common calcrete profiles. The lithologies are commonly arranged in fining-upwards cycles which overlie erosion surfaces.

Lower and upper boundaries
The base of the formation is conformable and placed at the base of the lowest conglomerate with exotic pebbles (extraformational conglomerate) which overlies mudstones, siltstones and sandstones and intraformational conglomerates of the Freshwater West Formation. The upper boundary is conformable and placed at the appearance of drab brown sandstones of the Brownstones Formation. In the M4 Motorway Pantmawr cutting [ST 1487 8219] the top of the

formation lies 5.6 m from the top of the highest bed of extraformational conglomerate, where the junction is sharply defined by the appearance of the first drab brown sandstone of the Brownstones Formation.

Thickness
About 137 to 150 m

Distribution
The formation crops out south and south-west of Machen, Monmouthshire, in the Cardiff district in the core of the Cardiff–Cowbridge Anticline, on the north-west limb of the Rogerstone Anticline and in two fault-bounded inliers at Michaelston-super-Ely and Drope.

Depositional environment
Proximal alluvial deposits derived from the south (Allen, 1979); the conglomerates and sandstones were the deposits of channelised, low-sinuosity stream systems that interfingered laterally and downslope with flood flats. Calcretes formed on these flats and in abandoned channels (Waters and Lawrence, 1987).

Age
Lochkovian–Pragian

4.2 COSHESTON SUBGROUP

The Cosheston Group was erected by Strahan et al. (1914) for the thick succession of green sandstones and conglomerates that occur between the Benton and Ritec faults in south-central Pembrokeshire. Thomas (1978) retained the term, subdividing the group into five formations (Llanstadwell, Burton Cliff, Mill Bay, Lawrenny Cliff and New Shipping)(Allen et al., 1981a; Wellman et al., 1998). Thomas et al. (2006) revised this scheme, incorporating the Burton Cliff Formation into the Llanstadwell Formation. Coeval strata previously referred to the Brecon Group of central south Wales are included in the subgroup. The lower part of the unit (Llanstadwell and Mill Bay formations) is of green sandstones correlatable with the Senni Formation of central south Wales. The upper part (Lawrenny Cliff and New Shipping formations) consists of red-brown coarse-grained sandstones and conglomerates, and invites comparison with the Brownstones Formation of south Wales, the Forest of Dean and the Welsh Borderland.

Name
Derived from the village of Cosheston [SM 998 050], Milford Haven, Pembrokeshire. Hitherto termed the Cosheston Group, the unit is here downgraded to subgroup status.

Reference sections

1. Muscle Bridge Quarry [SM 9565 0558], which exposes the basal 60 m of the subgroup
2. Section in Mill Bay West, Cosheston [SM 998 050], which exposes 470 m of beds comprising 425 m of the Mill Bay Formation and 45 m of the overlying Lawrenny Cliff Formation (Thomas et al., 2006).

Lithology
The lower part (Llanstadwell and Mill Bay formations) consists of green sandstones with subordinate red sandstones, red and green siltstones and green intraformational conglomerates, all arranged in fining-upwards cycles. The higher part (Lawrenny Cliff and New Shipping formations) consists mainly of red-brown sandstones, siltstones and conglomerates. The sandstones are commonly coarse-grained, and the conglomerates contain a wide range of exotic igneous, sedimentary and metamorphic clasts (Allen et al., 1981a; Thomas et al., 2006).

Lower and upper boundaries
The lower boundary is a conformable junction where green sandstones of the Cosheston Subgroup succeed red mudstones and sandstones of the Freshwater West Formation (Milford Haven Subgroup). In continuous exposure, the base is placed 'at the base of lowest mudstone with a recognisably grey-green colouration' (Allen and Williams, 1978). The upper boundary is an unconformity, the subgroup being overlain by limestones of the Avon Group in Pembrokeshire and by conglomerates and sandstones of the Portishead Subgroup elsewhere in Wales, the Welsh Borderland, Forest of Dean, the Bristol district and Mendips.

Thickness
1500 to 1800 m

Distribution
In its type area of Pembrokeshire, the subgroup is restricted to the the Burton Anticline in Milford Haven [SN 00 05] between the Benton Fault to the north and the Ritec Fault to the south (the Winsle Block of Sanzen-Baker, 1972). Elsewhere, it is widespread throughout south Wales, south central Wales, the Welsh Borderland, Clee Hills, Forest of Dean and east of the Severn Estuary.

Depositional environment
Fluvial deposition in braided and meandering streams as well as sheet flood and floodplain deposition.

Age
Latest Lochkovian to Emsian (Wellman et al., 1998).

PEMBROKESHIRE

4.2.1 Llanstadwell Formation

The Llanstadwell Formation was formerly split into the Llanstadwell and overlying Burton Cliff formations (Thomas, 1978); these are now known as the Hobbs Point and Burton Cliff palynological associations of the Llanstadwell Formation (Thomas et al., 2006).

Name
Derived from the village of Llanstadwell [SM 954 050], Milford Haven, Pembrokeshire.

Type sections (partial)

1. Partial type section in the railway cutting in the naval depot at Newton Noyes, Pembrokeshire [SM 9150 0530], where the lowermost 96.35 m are exposed (see Thomas et al., 2006, fig.7 for a detailed log of section)
2. Partial type section in shore exposures east of Hobbs Point, Milford Haven, Pembrokeshire [SM 9722 0438–9692 0416], where 235.39 m of beds are exposed (see Thomas et al., 2006, fig. 8 for a detailed log of the section).

Lithology

Predominantly grey-green very fine-to medium-grained, plant-bearing sandstones, with some intraformational conglomerates with red-brown and purple-brown siltstone interbeds; the facies are mainly arranged in fining-upwards cyclothems and up to 20 per cent of the formation is affected by soft-sediment deformation.

Lower and upper boundaries

The base of the formation is placed at the base of the lowest green siltstone at the western end of the railway cutting in the naval depot at Newton Noyes, Pembrokeshire [SM 9150 0530]. This is a 0.32 m-thick greenish grey, coarse-grained, parallel-laminated siltstone 21.07 m above the base the section logged by Thomas et al. (2006), which lies conformably on red mudstones of the underlying Gelliswick Bay Formation (formerly Red Marl Group). The upper boundary of the formation is placed at the base of an 11.8 m-thick multistorey complex of interbedded grey-green intraformational conglomerates and sandstones with a few siltstones at the base of the overlying Mill Bay Formation. The boundary at Burton Cliff [SM 9897 0526] is placed north-east of Burton Hawn at a low-relief scour surface overlain by the lowermost intraformational conglomerate of the Mill Bay Formation (see Thomas et al., 2006, fig. 9 for a detailed log of the beds above and below the boundary).

Thickness

435 to 550 m

Distribution

Geographically, it is confined to the northern side of the Daugleddau estuary, Milford Haven, except for a small area east of Hobbs Point [SM 971 043] on the south side of the estuary from Llanion [SM 97 04] to Waterloo [SM 98 04]. On the north side, an outcrop extends from west of Newton Noyes [SM 92 05] to the east of Weir Point [SM 940 043]; the main outcrop extends from Llanstadwell [SM 950 050] eastwards to near Burton [SM 990 052], and from there north-north-westwards around the axis of the Burton Anticline to the Benton Fault east of Rosemarket [about SM 960 080] (see Thomas et al., 2006, fig. 1).

Depositional environment

Fluvial deposits of perennial meandering channels that were internally braided, with pedogenic carbonate nodules forming on interfluves. Sheetflooding triggered by rainstorms reworked floodplain sediments and palaeosols (Thomas et al., 2006).

Age

Latest Lochkovian to Pragian

4.2.2 Mill Bay Formation

Name
Derived from Mill Bay [SM 9964 0506 to SN 0026 0491] on the southern shore of the Daugleddau Estuary 3.5 km north-east of Pembroke Dock, Milford Haven.

Type section
Mill Bay; the bay is split into western and eastern sectors by a 50 m-wide central inlet. The section in the western sector (Mill Bay West [SM 998050] begins near the low water mark [about SM 9964 0506]; see Thomas et al. (2006, fig. 14b) for a representative part of the succession. It exposes 470 m of beds comprising 425 m of the Mill Bay Formation and 45 m of the overlying Lawrenny Cliff Formation (Allen et al., 1982). The eastern sector (Mill Bay East) starts a few metres below high water mark on the north-east side of the central inlet [SN 0026 0491] at the base of a 1.59 m-thick fine-grained, horizontally and low-angle parallel-laminated sandstone. It exposes the uppermost 23 m of the formation and the junction with the overlying Lawrenny Cliff Formation (Thomas et al., 2006, fig. 14b).

Lithology
Coarse- to very fine-grained green-grey sandstones (68 per cent), interlaminated/thinly interbedded medium- to very fine-grained sandstones and red-brown siltstones (15 per cent), intraformational conglomerates (10 per cent) and red-brown siltstones (7 per cent). All three sandstone categories in the Cosheston Subgroup (i.e. litharenite, sublitharenite and subarkose) are present, but the last is restricted to this formation. About 30 per cent of the formation is affected by synsedimentary deformation structures.

Lower and upper boundaries
The base of the formation is conformable on the underlying Llanstadwell Formation. It is defined at Burton Cliff north-east of Burton Hawn [SM 98967 05258], at the base of an 11.8 m-thick, multistorey complex of grey-green, interbedded intraformational conglomerates, horizontally or low-angle parallel-laminated fine/medium- to very fine-grained sandstones and a few thin siltstones (Thomas et al., 2006, figs. 9 and 10). The base (at 110.34 m above the base of the section measured by Thomas et al., 2006) is a low-relief (≤ 0.02 m) scour surface in red-brown siltstone overlain by a 0.05 m-thick intraformational conglomerate.

The upper boundary is a conformable, transitional one with the overlying Lawrenny Cliff Formation. The Mill Bay (east) section is the only one that exposes the boundary, 60 m south-west of the quay [SN 0057 0526]. It lies 139.91 m above the base of the section measured by Thomas et al. (2006, fig 14b). The boundary is placed at an erosion surface with up to 0.97 m relief cut in red siltstone and overlain by a 0.09 m-thick extraformational conglomerate that forms part of a 0.48 m-thick unit of interbedded sandstones and extraformational conglomerates forming the base of the Lawrenny Cliff Formation.

Thickness
540 to 600 m

Distribution
On and adjacent to the shores of the the Daugleddau estuary, Milford Haven, Pembrokeshire around the axial trace of the Burton Anticline. This encompasses an area around Cosheston

village [SN 00 04] from Cosheston Pill [SM 995 035] northwards to Mill Bay [SN 00 05], and on the west side of the Daugleddau from east of Burton [SN 000 055] north-west to Benton Fault in the Houghton [SM 983 073] to Williamson [SM 990 070] area (Thomas et al., 2006, fig 1).

Depositional environment
Fluvial deposits of meandering and braided rivers deposited under pluvial conditions with high water-table levels.

Age
Pragian

4.2.3 Lawrenny Cliff Formation

Name
Derived from Lawrenny Cliff [SN 00 04], which forms the western margin of the Lawrenny peninsula, Milford Haven, Pembrokeshire.

Type sections
The eastern sector of Mill Bay ('Mill Bay East') [SN 0026 0491] provides a stratotype for the base of the formation and the lowermost beds (Thomas et al., 2006, fig. 14b). Lawrenny Cliff, south of the Benton Fault [SN 0093 0669 to 0946 0650] provides a partial type section. Lawrenny Cliff is divided into northern, central and southern sections. The central section provides a partial type section for the formation (Thomas et al., 2006, fig. 17), exposing all but the basal 20 m.

Lithology
Very fine- to coarse-grained, grey-green sandstones (46 per cent), extraformational conglomerates (19 per cent), interlaminated fine-medium-grained to very fine-grained sandstones and red-brown siltstones (23 per cent), red-brown siltstones (10 per cent) and intraformational conglomerates (2 per cent). The rocks are arranged predominantly in 0.4 to 11.10 m-thick, fining-upward rhythms. Abundant exotic detritus in extraformational conglomerates characterise the formation and differentiate it from the underlying Mill Bay Formation. The formation is predominantly grey-green (68 per cent), the remainder (mainly siltstones) are red-brown or red-purple; reddish colouration increases upwards in the formation.

Lower and upper boundaries
The base of the formation is a conformable, transitional junction with the Mill Bay Formation. It lies 139.91 m above the base of the section in the eastern section of Mill Bay (Mill Bay East) measured by Thomas et al. (2006), at the base of the first extraformational conglomerate which is 0.09 m thick and contains over 10 per cent of exotic clasts of the total clast population. It lies above an irregular erosion surface with up to 0.07 m relief, and forms part of a 0.48 m-thick unit of interbedded sandstones and extraformational conglomerates (Thomas et al., 2006, fig. 14b). The upper boundary is a conformable transition from the grey-green sandstones and conglomerates at the top of the formation into red-brown, coarser extraformational conglomerates of the overlying New Shipping Formation.

Thickness
210 to 250 m

Distribution
The formation occupies most of the southern half of the Lawrenny Peninsula [about SN 015 065] south of the Benton Fault. It also crops out on the west side of the Daugleddau Estuary in a small area north of Williamston Pill [SM 995 065] to the Benton Fault [SM 995 075] north-west of Benton Castle in the core of the Lawrenny Syncline. It is also present in a small, fault-bounded outlier at the southern end of Williamston Cliff [SN 002 054]. The main outcrop lies south of the Lawrenny Peninsula, south of the Carew River and east of Cosheston [SN 00 04] from near Paskeston [SN 025 035] north to the Carew River near Mount Pleasant [SN 016 059].

Depositional environment
Fluvial deposits of meandering and braided, high energy, mixed-load perennial river systems with relatively high but flashy discharge.

Age
Late Pragian to Emsian

4.2.4 New Shipping Formation

Name
Derived from New Shipping Point [SN 0335 0463] on the Carew River, Pembrokeshire.

Type section
The type section at New Shipping exposes about 380 m of the formation, in discontinuous low cliffs and rock platforms on the northern shore of the Carew River between New Shipping Point [SN 0335 0463] and 200 m SSW of New Shipping Farm [SN 0388 0410]. The section is mostly a dip or oblique-dip section, the beds dipping 15 to 55º south or south-east and is cut by two faults of unknown sense and throw. See Thomas et al., 2006, fig. 19a for a representative 32 m portion of the section.

Lithology
Red-purple extraformational conglomerates (41 per cent) with a wide range of exotic pebbles, red-purple very fine- to very coarse-grained sandstones (35 per cent), and sandy, coarse-grained siltstones (24 per cent), principally arranged in 1 to10 m-thick, fining-upward units, with a few coarsening-upward sequences up to 7 m thick.

Lower and upper boundaries
The lower boundary is conformable and transitional with the underlying Lawrenny Cliff Formation and placed where red-brown beds of the formation succeed the green beds of the Lawrenny Cliff Formation. The actual junction is nowhere exposed. The upper boundary is not seen, the formation being unconformably overlain by strata of the Avon Group (formerly ‘Lower Limestone Shales’) of early Carboniferous age. This junction is seen on the shore on the east side of the Carew River [SN 03852 04105] south-south-east of New Shipping Point. It is a scour surface with up to 2 cm relief cut in medium- to coarse-grained purple sandstone overlain by a bed of quartz grit up to 4 cm thick with shell fragments.

Thickness
320 to 440 m

Distribution
The formation occupies a small area around New Shipping [SN 035 043] in the upper reaches of the Carew River east of Milford Haven, Pembrokeshire. It is also present in a small outcrop east of Ford Point [SN 0346 0404]. On the west side of the Carew River, it crops out west of Ford Pill from near Paskeston [SN 028 035] north to Hakin Point [SN 033 043]. It is also present in a small area in the north-east of the Lawrenny Peninsula 500 m south of Lawrenny [SN 019 066]; in a faulted block on the western shore of Cosheston Pill [SM 982 040] near Waterloo; and in a partially faulted block on the northern shore of Cosheston Pill [SM 996 035] 500 m south-west of Cosheston.

Depositional environment
Fluvial, perennial, high-energy, bedload-dominated, braided rivers characterised by flashy discharge.

Age
Emsian

SOUTH AND SOUTH CENTRAL WALES, FOREST OF DEAN, WELSH BORDERLAND, SEVERN ESTUARY

The Cosheston Subgroup in this area was formerly ascribed to the local Breconian Stage (Croft, 1953) and termed the Brecon Series (Squirrell and White, 1978) and the Brecon Group (e.g. Waters et al., 2007a). It comprises the Senni and Brownstones formations of south and south-central Wales and the Welsh Borderland. It equates with the Woodbank Group of Allen (1961, 1977), which comprises the Clee Sandstone Formation and the Monkeys Fold Formation (see below). These strata were referred to the Clee Group by Greig et al. (1968). The Clee Sandstone Formation comprises mainly green sandstones and the Monkeys Fold Formation consists of pink and white, commonly pebbly and conglomeratic sandstones. All of the Woodbank Group has been correlated with the Senni Formation of south Wales by Allen (1961), although Ball and Dineley (1952) suggested that the topmost beds might correlate with the Brownstones Formation. There seems little reason to perpetuate the terms Woodbank Group and Brecon Group and the strata are here referred to the Cosheston Subgroup.

The subgroup consists of green-grey and red-brown sandstones with subordinate green-grey and pale grey mudstones; minor intraformational conglomerates with calcrete clasts. In this area, the lower boundary is placed, as for the base of the Senni Formation, at the transitional, conformable junction of green-grey sandstones of the Cosheston Subgroup with cyclic red-brown sandstones and mudstones of the underlying Freshwater West (formerly St Maughans) Formation. Where mature calcretes at the top of the Freshwater West Formation are present (the Upper Abdon Limestone of the Clee Hills, the Ffynnon Limestones in the Black Mountains and the Ruperra Limestone of Pontypool, south Wales), the base of the subgroup is placed at the top of the uppermost calcrete. The upper boundary is an unconformity, as for the upper boundary of the Brownstones Formation.

4.2.5 Senni Formation

Name
Derived from the Senni Valley (Glyn Senni), Powys, south-central Wales. The name Senni Formation supersedes the traditional Geological Survey name Senni Beds (Cantrill in Strahan et al., 1904). In the Clee Hills, the formation was previously named the Clee Sandstone Formation.

Type area
Senni Valley [SN 930 209]

Partial type section
Waterfall exposures [SN 930 209] in a tributary of the Afon Senni (Nant Ystwyth) above Tyleglas.

Reference sections

1. Heol Senni Quarry [SN 9154 2210], Powys provides a well documented reference section. It exposes about 40 m of grey-green sandstones, with minor siltstones, mudstones and intraformational conglomerates at the top of the formation (e.g. Edwards et al., 1978; Loeffler and Thomas, 1980; Dineley, 1999b; Barclay, 2005e).
2. Cliffs at Craig Ddu on the western side of the Llansteffan peninsula, Carmarthenshire [SN 32441015](Owen, 1995). These reach a height of 20 m and have continuous exposure for 400 m of beds near the top of the formation.
3. The stream draining north-westwards across Clee Liberty [SO 583 848–587 844] in the Clee Hills exposes about 140m of the formation (Allen, 1961) and provides a reference section for this area.

Lithology
Mainly of green and green-grey (locally red-brown and purplish green), very fine to medium-grained, micaceous sandstones, mainly channelised, cross-bedded and parallel-laminated, with green and red-brown siltstone and mudstone interbeds, some calcretes and intraformational conglomerates; the formation is characterised by the presence of vascular fossil plant remains and some soft sediment deformation is also present. In the Clee Hills, pale green sandstones are mainly arranged in fining-upwards conglomerate–sandstone–siltstone cycles, with subordinate red or green, sporadically calcretised mudstone/siltstone interbeds (Ball and Dineley, 1952, 1961; Allen, 1961; Greig et al., 1968).

Lower and upper boundaries
The lower boundary is placed at the base of green sandstones, which overlie red-brown sandstones and mudstones of the underlying Freshwater West (formerly St Maughans) Formation. Where mature calcretes at the top of the Freshwater West Formation are present (the Ffynnon/Abdon Limestones), the base of the formation is placed at the top of the uppermost calcrete. The upper boundary is placed where red-brown sandstones of the Brownstones Formation overlie the green sandstones of the Senni Formation, the junction being gradational. In the Clee Hills, Here, the lower boundary of the formation is placed at an erosion surface cut in the uppermost calcrete of the Upper Abdon Limestone, where it is sharply overlain by the basal green sandstones. The upper boundary is a gradational passage into generally coarser-grained

strata lacking in argillaceous beds and in which the sandstones are more variably coloured, these being assigned to the Brownstones (previously Monkeys Fold) Formation.

Thickness
300 to 450 m in the Brecon Beacons and Black Mountain, 150 to 200 m in the Black Mountains and 152 to 167 m in the Clee Hills.

Distribution
From Carmarthen Bay eastwards to the Black Mountain, Brecon Beacons and Black Mountains, and from there southwards to Abergavenny, wedging out north of Pontypool.

Depositional environment
High-discharge, mixed-bedload, sand-dominated, braided stream systems with relatively high sedimentation rates and water-table levels; although the formation is dominated by in-channel deposits, overbank floodplain silt and mud deposition also occurred.

Age
Latest Lochkovian to latest Pragian or Emsian in age.

4.2.6 Brownstones Formation

The Brownstones Formation is widely present throughout south Wales, south-central Wales, the Welsh Borderland, Forest of Dean, Clee Hills and east of the Severn estuary. At the last, it is named the Black Nore Sandstone Formation (e.g. Pick, 1964), but there seems little point in perpetuating both names, and it is proposed here that the term Brownstones Formation be applied to the strata east of the Severn also, with the term Black Nore Sandstone Formation being discontinued. In the Clee Hills, Allen (1961) named the succession the Monkeys Fold Formation, but, in rationalisation of the nomenclature, this name is also abandoned.

Name
A long-established traditional name (Symonds, 1872) adopted by the Geological Survey, the formation being named because of its predominantly brown colour.

Type areas
The Black Mountains [about SO 22 29] and the Brecon Beacons [about SO 02 21].

Partial type section
The north face of Pen y Fan [SO 013 216], Brecon Beacons (Tunbridge, 1981).

Reference sections
Wilderness Quarry [SO 6720 1850], Forest of Dean (Allen et al., 1968; Barclay, 2005f, Hillier et al., 2008) provides a reference section. Cliffs [ST 461 770] to the south of Portishead (Avon) between Woodhill Bay and Black Nore Point provide a reference section on the south side of the Severn estuary (Pick, 1964; Wilby, 2005b.) In the Clee Hills, the formation comprises green, red and white, calcareous fine- to very coarse-grained, flaggy, cross-bedded sandstones with rare siltstone-limestone intraformational conglomerate lenses. Crags [SO 593 858] on the hillside east of Abdon expose the lowest 15 m of the formation and provide a reference section for this area.

Lithology
Red-brown and purple sandstones with red mudstone interbeds, and locally, pebbly sandstones and conglomerates (Allen, 1974a, b).

Lower and upper boundaries
The lower boundary is placed where sandstones become dominant over mudstones and there is a gradational passage from the underlying Freshwater West (formerly St Maughans) Formation, or at the colour change from predominantly green sandstones of the Senni Formation below to red sandstones of the Brownstones Formation above. In the Clee Hills, the lower boundary is a gradational passage into generally coarser-grained sandstones lacking in argillaceous beds and in which the sandstones are more variably coloured, compared to the green sandstones with argillaceous interbeds of the underlying Senni (formerly Clee Sandstone) Formation. In the westernmost Brecon Beacons, the topmost 70 m of the Brownstones Formation is fine-grained, as in sporadic exposures above Llyn y Fan [SN 7975 2203 to 7972 2160], comprising red mudstones with drab haloes and incipient calcretes (85 per cent of the exposed section) with thin flat-bedded, parallel-laminated, fine-grained sandstone sheets up to 1 m thick.

The upper boundary is an unconformity, where Upper Devonian or lower Carboniferous beds rest sharply on the topmost beds of the formation.

Thickness
The formation is up to 1200 m, this maximum thickness occurring in the Forest of Dean. Only 67 m are present in the Clee Hills.

Distribution
Widespread throughout south Wales, south-central Wales, the Welsh Borderland, Forest of Dean, Clee Hills and east of the Severn estuary.

Depositional environment
Mainly high-energy channel-fill deposition of sand-bed low-sinuosity braided streams in a proximal fan setting, along with lesser distal flood basin deposition of muds, silts and sands.

Age
Emsian

4.3 DULAS BAY SUBGROUP (*NEW NAME*)

Name
The Dulas Bay Subgroup is a new name for the Lower Old Red Sandstone of Anglesey. The name is derived from Dulas Bay on the north-east coast of Anglesey, north Wales [SH 49 90].

Type area
Dulas Bay, Anglesey [SH 49 90].

Lithology
The subgroup comprises four units, named by Allen (1965a, 1977) the Bodafon Beds, Traeth Bach Beds, Porth-y-Mor Beds and Traeth Lligwy Beds. These names are now given formation status (Davies, 2005).

Lower and upper boundaries
The lower boundary is of the group is an unconformity, where the lowest conglomerate of the Bodafon Formation rests on underlying lower Palaeozoic or Precambrian rocks. The upper boundary (i.e. the upper boundary of the Traeth Lligwy Formation) is not seen.

Thickness
About 546 m

Distribution
The group occupies a narrow coastal strip on the east coast of Anglesey, and from Traith Dulas southwards to the flanks of Mynydd Bodafon and from there south to 0.8 km north of Llangefni.

Regional correlation
Whilst there are gross similarities between the red-bed succession here and that in the main outcrops of the Milford Haven Subgroup (Daugleddau Group) to the south, there are also differences. The Traeth Bach Formation is similar to the Moor Cliffs Formation, with a 1.5 m-thick well developed calcrete at its top inviting correlation with the Chapel Point Limestone Member. The overlying Porth-y-Mor Formation is similar to the Freshwater West Formation. However, the Bodafon Formation has no correlative and the Traeth Lligwy Formation is a lacustrine unit absent to the south.

Depositional environment
As detailed by Allen (1965a) and summarised by Davies (2005), initial alluvial-fan gravels (Bodafon Formation) accumulated along a basin margin sourced from Precambrian and older Lower Palaeozoic outcrops to the south-west. Subsequent deposition in ephemeral non-saline playa lakes (Traeth Bach Formation) was succeeded by fluvial deposition in a broad south-east-trending meandering river belt (Porth-y-Mor Formation). This was followed by deposition in more permanent flood basin lakes (Traeth Lligwy Formation).

Age
There is no diagnostic proof of the age of the group, but it is likely to be late Silurian to Lochkovian. On the basis of the presence of *Beaconites antarcticus* and the absence of *B. barretti* (the latter being indicative of a Devonian age), Morrissey (2006) suggested a pre-Lochkovian age.

4.3.1 Bodafon Formation

Name
Derived from crags on the north-east slopes of Mynydd Bodafon, Anglesey [SH 474 866–477 863]. This is the Bodafon Beds of Allen (1965a).

Partial type section
Crags on the north-east slopes of Mynydd Bodafon [SH 474 866–477 863].

Reference section
Coast exposures at Trwyn Cwmrwd [SH 492 902].

Lithology
Conglomerates and pebbly sandstones with abundant clasts of the adjacent Precambrian and Ordovician rocks.

Lower and upper boundaries
The lower boundary of the formation is an unconformity, where the lowest conglomerate of the Bodafon Formation rests on the underlying lower Palaeozoic or Precambrian rocks. The upper boundary is placed at the top of the main conglomerate development, where fine-grained calcareous strata of the Traeth Bach Formation overlie the conglomerates. The boundary is gradational, the conglomerates interfingering with both the Traeth Bach and Porth-y-Mor formations.

Thickness
Up to 45 m

Distribution
Confined to a narrow outcrop extending north–south on the east coast of Anglesey from Traeth Dulas southwards to the flanks of Mynydd Bodafon and from there south to 0.8 km north of Llangefni.

Depositional environment
Basin-margin alluvial fan deposition of gravels sourced from Precambrian and older lower Palaeozoic rocks to the south-west.

Age
Not known, but probably late Silurian to Early Devonian.

4.3.2 Traeth Bach Formation

Name
Derived from the cove of Traeth Bach [SH 4890 8896], Anglesey. This is the Traeth Bach Beds of Allen (1965a).

Type section
Low cliffs [SH 487 888 to 489 887], which include the cove of Traeth Bach, north and east of the knoll on the south side of Traeth Dulas.

Lithology
Red, calcretised siltstones with grey to brown massive limestone or dolomite calcretes, sporadic thin sandstones and extraformational and intraformational conglomerates.

Lower and upper boundaries
The lower boundary is transitional, and placed where the conglomerates of the underlying Bodafon Formation are overlain by red siltstones. The upper boundary is placed at an erosion surface cut in a thick, massive calcrete at the top of the formation on the south side of Traeth yr Ora, where extraformational conglomerate at the base of the Porth-y-Mor Formation is overlain by the calcrete. Note that this is higher than the position cited by Allen (1965a) (Davies, 2005).

To the south, the formation is cut out by an unconformity at the base of the Porth-y-Mor Formation.

Thickness
About 165 m

Distribution
Restricted to a narrow outcrop on the south side of Traeth Dulas and a small outcrop on the north side of Traeth Dulas.

Regional correlation
Similar to and possible correlative of the Moor Cliffs Formation of south Wales.

Depositional environment
Ephemeral nonsaline playa lakes (Allen, 1965a).

Age
Not known, but likely to be late Silurian to Early Devonian.

4.3.3 Porth-y-Mor Formation

Name
Derived from the cove of Porth-y-Mor [SH 4928 8815]. This is the Porth-y-Mor Beds of Allen (1965a).

Type section
Cliffs north and south of Porth-y-Mor [SH 490 885 to 494 878].

Lithology
Conglomerates, sandstones and red siltstones, typically arranged in fining-upwards alluvial cycles; the siltstones commonly contain calcrete glaebules and grade up into well developed, massive limestone or dolostone calcretes.

Lower and upper boundaries
The lower boundary is placed at an erosion surface that truncates 1.5 m of massive calcrete at the top of the underlying Traeth Bach Formation and is overlain by a 1.5 m-thick extraformational conglomerate on the south side of Traeth yr Ora at the base of the Porth-y-Mor Formation. Note that this is slightly above the boundary proposed by Allen (1965a) (Davies, 2005). The upper boundary is placed at 477 m (1565 feet) from the base of the section measured by Allen (1965a), at the base of a thinner bedded sandstone/mudstone succession lacking intraformational conglomerates and thick cyclic units (the Traeth Lligwy Formation).

Thickness
311.5 m at the coast, perhaps thinning inland as a result of internal overlap.

Distribution
Extends from Traeth yr Ora to south of Porth-y-Mor [SH 490 885 to 494 878] and inland to Llangefni.

Regional correlation
Similar to and possible correlative of the Freshwater West Formation of south Wales.

Depositional environment
Fluvial deposition in a broad south-east-trending meandering river belt.

Age
Probably Lochkovian, but no diagnostic fossil evidence has yet been found.

4.3.4 Traeth Lligwy Formation

Name
Derived from Traeth Lligwy [SH 4933 8748]. This is the Traeth Lligwy Beds of Allen (1965a).

Partial type section
Cliffs on the north side of Traeth Lligwy [SH 494 878–493 875].

Lithology
Thinly interbedded red, fine-grained, commonly bioturbated sandstones and siltstones.

Lower and upper boundaries
The lower boundary is placed 477 m (1565 feet) from the base of the section measured by Allen (1965a), where the basal sandstone of a thinly bedded sandstone/red siltstone succession of this formation overlies the thicker bedded succession of the underlying Porth-y-Mor Formation. The upper boundary is not seen.

Thickness
25 m+

Distribution
Confined to a small area in the core of a syncline on the north side of Traeth Lligwy.

Depositional environment
Perennial flood basin lakes; reduced amounts of calcrete and an abundance of burrowing structures suggest a high water table and less prolonged periods of subaerial exposure.

Age
Probably Lochkovian, but no diagnostic fauna has yet been found.

5 Brecon Beacons Group (*new name*)

The name Brecon Beacons Group is applied to all the strata previously referred to the Upper Old Red Sandstone (Group). Table 6 shows the main subdivisions of the group. It comprises two subgroups – the Skrinkle Sandstones Subgroup of the Pembroke Peninsula and the Portishead Subgroup. Table 6 also shows the constituent formations of these subgroups. The Skrinkle Sandstones Subgroup comprises the Gupton Formation and overlying West Angle Formation (Marshall, 2000a, b). The Portishead Subgroup encompasses all the other successions of Late Devonian age in the Anglo-Welsh Basin. These include the Pen y Fan, Wern Watkin, Craig-y-cwm and Garn-gofen formations of the North Crop of the South Wales Coalfield, the Pennard Conglomerate Formation of Gower, the Huntsham Hill Conglomerate and Tintern Sandstone formations in the Forest of Dean, the beds formerly ascribed to the Portishead Beds east of the Severn Estuary, the Farlow Sandstone Formation in the Clee Hills and the Oldbury Farm Sandstone Formation in the Merevale district in the West Midlands. Concealed Upper Devonian strata in Oxfordshire are named the Hopcroft Halt and Holt Farm formations (Poole, 1977).

Name
Derived from the Brecon Beacons in Powys, south central Wales [SO 042 215], the strata capping these mountains.

Type area
Brecon Beacons, Powys [SO 042 215]

Lithology
The group in south-east Wales and the Forest of Dean consists mainly of grey-green and buff sandstones with characteristic quartz pebble conglomerate bodies (the Portishead Subgroup (formerly Quartz Conglomerate Group). Red-brown quartz-rich sandstones occur in the Cardiff–Bridgend area (the Cwrt-yr-ala Formation; Waters and Lawrence, 1987; Wilson et al., 1990). Present locally in Powys are red to purple sandstones, some possibly of aeolian origin, and a heterolithic sequence of red sandstones and mudstones which contain a shallow marine brachiopod fauna (the Pen y Fan Formation; Lovell, 1978a, b). The Gupton Formation comprises two coarsening-upwards sequences of mature, clean, fluvial sandstones. The West Angle Formation is characterised by red sandstones, calcretes and conglomerates rich in igneous, sandstone and phyllitic slate clasts. In the Forest of Dean, the Portishead Subgroup comprises quartz conglomerates (the Huntsham Hill Conglomerate Formation) overlain by buff sandstones (the Tintern Sandstone Formation). East of the Severn, the succession thickens southwards into the Bristol district, the distinction between lower conglomerates and upper sandstones is lost and the Portishead Subgroup is undivided.

	Pembrokeshire			Gower	North Crop	South-east Crop	Forest of Dean/north Bristol	South Bristol/Mendips	Clee Hills	Merevale	Oxfordshire
Brecon Beacons Group	Skrinkle Sandstones Subgroup	West Angle Formation	Portishead Subgroup	Pennard Conglomerate Formation	Garn-gofen Formation Craig-y-cwm Formation Wern Watkin Formation Pen y Fan Formation	Portishead Subgroup (undivided) Cwrt-yr-ala Formation	Tintern Sandstone Formation Huntsham Hill Formation	Portishead Subgroup (undivided)	Farlow Sandstone Formation	Oldbury Farm Sandstone Formation	Hopcroft's Holt Formation
		Gupton Formation									

Table 6 Stratigraphical framework for the Brecon Beacons Group of the Anglo-Welsh Basin.

Lower and upper boundaries

The lower boundary of the group is placed at the base of the lowest bed that overlies the regional Acadian unconformity. A change of colour from red sandstones below the unconformity to pale green or buff sandstones above is common. Note, however, that the topmost beds of the underlying formation are locally leached to pale green. Where red beds also overlie the unconformity, as in the case of the Pen y Fan Formation (p.67), a distinctive bed of red mudstone with quartz granules, interpreted as a mudflow, forms the basal bed (Lovell, 1978a, b). An angular discordance between the beds above and below the unconformity is visible in places on the North Crop of the South Wales Coalfield. In the Forest of Dean, the lower boundary is a marked unconformity, the group (represented by the Portishead Subgroup) resting on progressively lower levels of the Brownstones Formation (Cosheston Subgroup). In the Bristol district, the lower boundary is placed where the basal beds of the formation rest unconformably on drab red-brown sandstones of the underlying Brownstones (formerly Black Nore Sandstone) Formation, or on Silurian volcanic rocks. At Woodhill Bay, south of Portishead, the lower boundary is placed at the base of the Woodhill Bay Conglomerate, at a sharp, irregular surface scoured to a depth of 1 m and with a locally well developed calcrete [ST 4579 7681; 4585 7686].

The upper boundary is described in Section 3. In the North Crop of the South Wales Coalfield and in the Clee Hills, the upper boundary is marked by a sharp, disconformable break, where the lowermost limestone beds of the Avon Group of the Carboniferous Limestone Supergroup overlie the topmost sandstones of the Wern Watkin (formerly Grey Grits) Formation and a phosphatic, pebbly conglomerate forms the basal bed of the limestones. On the South Crop of the South Wales Coalfield and in south Pembrokeshire and the Bristol–Mendips area, the boundary is conformable and placed at the sharp to gradational incoming of grey limestones and mudstones of the basal Avon Group. Where the boundary is gradational, with interdigitation of terrestrial red-bed Old Red Sandstone facies and grey, shallow marine and lagoonal facies, its exact position has been the subject of discussion and differing interpretations. In south Pembrokeshire, much of the Red-Grey Member of the West Angle Formation (Marshall, 2000a, b; see below) should arguably be included in the overlying Avon Group, but here the boundary is in need of re-examination. It is suggested that the boundary be taken at the incoming of grey strata with a restricted marine fauna. At West Angle Bay (south), the boundary is 23 m above the base of the Red-Grey Member and at West Angle Bay (north) 33 m above the base, where shallow marine, fossiliferous tidal deposits overlie lake/marsh deposits, as interpreted by Marshall (2000a).

In northern outcrops, as on the North Crop of the South Wales Coalfield and the Clee Hills, the upper boundary is disconformable and placed at the top of the highest red bed, where there is a sharp junction with the overlying limestones of the Avon Group. In southern outcrops, as in the Pembroke Peninsula, south-east Wales the Bristol district and the Mendips, there is an interdigitation of red, green and grey lithologies in a gradational passage between the Skrinkle Sandstones Subgroup and the Avon Group in Pembrokeshire (e.g. Marshall, 2000a, b) and between the Portishead Subgroup and Avon Group in south-east Wales and in the Bristol district and Mendips.

Thickness
In Wales, the thickness of the group ranges from 45 m on the south-east crop of the South Wales Coalfield to 350 m in the Pembroke peninsula. A maximum thickness of 490 m occurs east of the Severn Estuary.

Distribution
Widely distributed in the Pembroke Peninsula, the periphery of the South Wales Coalfield, Forest of Dean, Bristol district and the Mendips, along with an outlier in the Clee Hills and an inlier at Merevale, Warwickshire; also present at depth in southern and eastern England south of Cambridge.

Depositional environment
Predominantly fluvial environments in a southerly flowing drainage regime; these include low-sinuosity high-energy gravel- and sand-bed river channels, as well as high-sinuosity sand-bed channels and associated point bar, crevasse splay and levee deposition. The alluvial floodplains were subject to pedogenic processes and calcrete formation. Localised lacustrine environments are represented by part of the Skrinkle Sandstones Subgroup in the Pembroke Peninsula and the Hopcroft's Holt Formation in the Steeple Aston Borehole, Oxfordshire. Shallow marine environments, including tidal channels and intertidal mudflats, are represented by part of the Pen y Fan Formation on the North Crop of the South Wales Coalfield and the Oldbury Farm Sandstone Formation at Merevale, with a more distal marine environment represented by the Holt Farm Formation in the Steeple Aston Borehole. The yellow, large-scale cross-bedded sandstones of the Farlow Sandstone Formation in the Clee Hills suggest aeolian deposition.

Age
Previously referred to the local Farlovian stage of the Anglo-Welsh Basin (e.g. Allen, 1977), fish fragments including *Holoptychius* and *Bothriolepis* and brachiopods including *Cyrtospirifer verneuili*, *Leptodesma lichas* and *Ptychomaletoechia omaliusi* indicate a Late Devonian (late Frasnian? to Famennian) age. Beds formerly ascribed to the topmost Upper Old Red Sandstone in the Cardiff–Newport area contain early Tournaisian (VIa) miospores (e.g. Squirrell and Downing, 1969; Gayer et al., 1973) and are now re-interpreted as belonging to the Avon Group (Davies et al., 1991; Waters and Lawrence, 1987; Waters et al., 2007b). In south Pembrokeshire, the Skrinkle Sandstones Subgroup spans the Devonian–Carboniferous boundary (Dolby, 1971; Bassett and Jenkins, 1977; Marshall 2000a). Spores recovered from the Red-Grey Member (Marshall, 2000a) 45 m above its base belong to the LE zone (Devonian), and spores recovered 5 m higher belong to the VI Zone (Tournaisian). However, if the upper boundary of the Skrinkle Sandstones (and Brecon Beacons Group) were to be repositioned, the Brecon Beacons Group would be entirely of Late Devonian age. A similar situation is reported in the Bristol–Mendips area (Barton et al., 2002), where there is an upward-fining sequence with marine passage beds at the top of the group of Carboniferous age, transitional into the overlying Shirehampton Formation of the Avon Group (Waters et al., 2009).

5.1 SKRINKLE SANDSTONES SUBGROUP

Dixon (1921) defined the Skrinkle Sandstones to encompass the red-bed succession of the Pembroke Peninsula (Marshall, 1977, 1978, 2000a, b). They are here assigned subgroup status.

Name
Derived from Skrinkle Haven [SS 082 974], south Pembrokeshire. Marshall (1977, 2000a, b) subdivided the subgroup into the Gupton Formation and overlying West Angle Formation. These formations are formalised here. Further subdivision of the formations by Marshall into informal members comprises the Lower Sandstone and Stackpole Sandstone members of the Gupton Formation and the Conglomerate and Red-Grey (or Heterolithic) members of the West Angle Formation. Of these, only the Stackpole Sandstone is an acceptable term according to the lithostratigraphical code for naming procedures, and all are here retained as informal members.

Type section
Sea cliff exposures in Skrinkle Haven [SS 082 974].

Reference section
Sea cliff exposures on the north side of West Angle Bay [SM 852 034], Pembrokeshire (Marshall, 1978, 2000a, b; Wilby, 2005c) provide a reference section. The subgroup here is 128 m thick and comprises 6 m of quartzose sandstones (the Stackpole Sandstone Member of the Gupton Formation of Marshall), 63 m of conglomerates and sandstones (the Conglomerate Member of the West Angle Formation of Marshall) and 59 m of heterolithic beds (the Red-Grey (or Heterolithic) Member of the West Angle Formation of Marshall.

Lithology
Interbedded grey, quartzose and red lithic sandstones, conglomerates, red mudstones and siltstones; the subgroup includes a lower quartz arenite unit 15.5 m thick and an upper conglomerate unit 54 m thick (Williams, 1971). The upper unit contains a 0.35 m-thick, grey and red mottled siltstone containing *Lingula* sp. and bivalves including *Modiola* sp.

Lower and upper boundaries
The lower boundary is placed at a sharp, unconformable junction where the basal sandstones of the subgroup rest on the topmost conglomerate of the underlying Ridgeway Conglomerate Formation. The upper boundary is described as a sharp junction at the type section in Skrinkle Haven, where green sandstones are overlain by grey shales at the base of the Avon Group (formerly Lower Limestone Shale; Williams, 1971). However, marine or marginal marine beds underlie the green sandstone, which itself may be marine, and here, as elsewhere, there is a gradational passage in which red and green beds of terrestrial Old Red Sandstone facies beds interdigitate with grey marine or lacustrine beds in a transitional boundary. The position of the upper boundary of the Skrinkle Sandstone Subgroup here (and of the Brecon Beacons Group) thus remains a matter of debate. Marshall (2000a, fig. 17) places grey lagoonal mudstones and yellow offshore barrier sandstones in the Skrinkle Sandstones Subgroup. These should arguably be placed in the Avon Group, in accordance with a similar situation in south-east Wales, where lagoonal and barrier sediments were placed in the base of the Avon Group by Davies et al. (1991). In West Angle Bay, the characteristic red-grey interbedding of the Red-Grey Member of Marshall (2000a) is replaced about 7 m beneath the top of the member by the abrupt appearance of interbedded grey shales and thin (generally less than 15 cm), yellow-weathering, dolomitic sandstones. Dixon (1921) recorded fish fragments, bivalves (*Modiola lata*), crinoid ossicles and brachiopods (*Lingula* sp.) from these beds and an orthocone nautiloid (*Orthoceras* sp.) from the red siltstone immediately beneath. These beds are succeeded by about 3 m of cross-bedded

sandstone containing bryozoa and ooliths, which Marshall placed as the topmost bed of the Skrinkle Sandstones (but see Section 3).

Thickness
From 75 m to 400 m; it is 91 m at the type section and 128 m at the reference section.

Distribution
Confined to south Pembrokeshire.

Depositional environment
Fluvial and lacustrine deposition in successive coarsening- and thickening-up sequences (Marshall, 2000a, b). In the Gupton Formation, initial sheetflood systems within lacustrine or floodplain environments are succeeded by meandering channel fluvial deposition (Lower Sandstone Member). This was followed by lacustrine deposition and then by high-energy braidplain deposition (Stackpole Sandstone Member). In the West Angle Formation, initial channelised gravel deposition was followed by meandering channel deposition on a semi-arid floodplain that prograded southwards from the Ritec Fault or Benton Fault. The upper part of the West Angle Formation (Red-Grey Member) records the pulsed onset of the Carboniferous transgression, with initial fluvial meandering channel deposition, but with a higher water table. Grey beds record local lake development and sporadic marine fossils record shallow marine input.

Age
Late Devonian (?Frasnian–Famennian) to Courceyan (as the subgroup is currently defined); Dolby (1971) placed the Devonian–Carboniferous boundary 8 to 15 m below the top of the Skrinkle Sandstones Subgroup as then defined. Redefining the top of the subgroup (and base of the succeeding Avon Group) as the first incursion of grey, marine sediment at a flooding surface 15 m below would place the Skrinkle Sandstones Subgroup entirely in the Devonian.

5.1.1 Gupton Formation

Name
From Gupton Burrows [SR 887994], just east of the headland of Little Furzenip at Freshwater West (Marshall, 1977).

Type section
Stackpole Quay [SR 994 958].

Reference sections
West Angle Bay [SR 850 032], Freshwater West [SR 886 987] and Skrinkle Haven [SS 083 974].

Lithology
The formation comprises two coarsening-upwards sequences of red mudstones passing up into clean, well-sorted sandstones. The lower sequence (the Lower Sandstone Member) consists of thick, lenticular and tabular sandstones and pebbly sandstones which coarsen and thicken upwards. It shows an upward change from thin multistorey sandstones in a background of red

mudstones and siltstones to thicker single-storey sandstones and eventually into stacked, pebbly sandstone-based fining-upwards units. It is only present in the southernmost outcrops at Freshwater West, where it is 55 m thick and crops out in the cliffs and foreshore [SR 8876 9885]. The upper sequence (the Stackpole Sandstone Member) comprises a lower mudstone-rich heterolithic facies association and an upper trough cross-bedded and parallel-laminated sandstone association. It ranges from 6 m in thickness in the north near the Ritec Fault to 68 m in the south.

Lower and upper boundaries
The lower boundary overlies the regional Acadian unconformity. The formation rests unconformably on the underlying Lower Devonian Ridgeway Conglomerate Formation, overstepping it eastwards to lie on the Milford Haven Subgroup. The Lower Sandstone Member is unconformably overlain by the Stackpole Sandstone Member. The latter oversteps both the Lower Sandstone Member and the Ridgeway Conglomerate Formation to extend eastwards across the entire Pembroke Peninsula, resting directly on the Freshwater West Formation in the east, as for example on Caldey Island.

The upper boundary is disconformable in northern exposures, where an erosion surface at the top of the formation is cut in texturally mature trough-cross-bedded and parallel laminated sublitharenites and is overlain by immature pebbly red lithic sandstones and conglomerates rich in volcanic debris and calcrete-rich mudstones that form the base of the West Angle Formation. In the south, there is a transitional upper boundary, with interdigitation of the mature and immature facies.

Thickness
From 61 m to 123 m

Distribution
Extends across the Pembroke Peninula from West Angle Bay to Caldey Island.

Depositional environment

Two episodes of alluvial basin fill are proposed by Marshall (2000a, b). The earlier represented by by the Lower Sandstone Member is interpreted as a possible terminal fan prograding into the deeper part of the Tenby–Angle Basin. The later (Stackpole Sandstone Member) records initial lacustrine deposition of a heterolithic facies association followed by sandy braidplain deposition.

Age
Late Devonian (Famennian) on the basis of the presence of *Holoptychius* sp. recovered from the base of the Lower Sandstone Member.

5.1.2 West Angle Formation

Name
Derived from West Angle Bay, Pembrokeshire [SM 8503] (Marshall, 1977).

Type and reference sections
West Angle Bay provides type and reference sections on its north [SM 852 034] and south sides respectively.

Lithology
Marshall (1977, 1978, 2000a) described the formation. It consists of a lower conglomeratic facies (the Conglomerate Member) and an upper heterolithic unit (the Red-Grey (or Heterolithic) Member. The Conglomerate Member consists of red sandstones, conglomerates and mudstones, and is markedly different in texture and composition from the underlying beds. The sandstones and conglomerates are rich in lithic debris and there is an abundance of calcrete in the mudstones, the facies being arranged in fining-upwards couplets. Thin sheets of intraformational conglomerate and overlying rippled sandstone occur within the mudstones. The upper part of the formation (Red-Grey Member) is predominantly red, but is characterised by the incoming of sporadic grey-green sandstones and pebbly sandstones with well preserved plant fragments. The sandstones occur at the bases of fining-upwards sequences capped by calcretised red mudstones. Grey mudstones with spores, coalified plant debris and lingulids appear higher in the member, along with a few sheets of phosphatised pebble conglomerate. The topmost beds of the formation are red and grey sandstones with mudstone interbeds capped by a mature, calcareous sandstone with well-rounded quartz pebbles and sparse marine brachiopods and bryozoa.

Lower and upper boundaries
The base of the formation is disconformable in northern exposures, resting on an erosion surface of the Gupton Formation (see above), and transitional over an interval of 2 to 5 m in the south. The upper boundary of the formation with the Avon Group is as described for the top of the Skrinkle Sandstones Subgroup (p.60).

Thickness
About 60 m at the typr locality of West Angle Bay, comprising 43 m beds of the Conglomerate Member and 17 m of the Red-Grey Member.

Distribution
Pembroke Peninsula

Depositional environment
Initial channelised gravel deposition was followed by meandering channel deposition on a semi-arid floodplain that prograded southwards from the Ritec Fault or Benton Fault. The upper part of the formation (Red-Grey Member) records initial fluvial meandering channel deposition, but with a higher water table. Succeeding grey beds record local lake development, sporadic marine fossils record shallow marine influence at the start of the pulsed Carboniferous marine transgression.

Age
Late Famennian (LE Zone of Higgs et al., 1988), to early Tournaisian (VI) (Dolby, 1971, Bassett and Jenkins, 1977), as currently defined (but see above).

5.2 PORTISHEAD SUBGROUP

The name Portishead Beds or Portishead Formation has traditionally been applied to the Upper Devonian (Upper Old Red Sandstone) strata south of Bristol on the eastern side of the Severn estuary. It is here upgraded to subgroup status and applied to the entire outcrop of these strata on both sides of the Severn estuary. Northwards from the Bristol–Mendip area, the subgroup is

differentiated into the Huntsham Hill Conglomerate Formation and the overlying Tintern Sandstone Formation of the Forest of Dean. The subgroup also encompasses the beds hitherto referred to the Quartz Conglomerate Group in south Wales, as well as the underlying Cwrt-yr-ala Formation in the Cardiff area and the Pen y Fan (formerly Plateau) Formation of the North Crop of the South Wales Coalfield.

On the North Crop of the South Wales Coalfield, Lovell (1978a) recognised three formations – lowermost quartz arenites (the Wern Watkin Formation), middle quartz conglomerates (the Craig-y-cwm Formation) and uppermost richly micaceous sandstones (Garn-gofen Formation). The Wern Watkin Formation is the lateral equivalent of the Grey Grits Formation of the central part of the north crop of the coalfield and the latter name is here discarded in favour of the former. This formation overlies the Pen y Fan Formation of the Brecon Beacons and Carmarthen Fans. In south-east Wales, these beds were traditionally named the Quartz Conglomerate Group (e.g. Heard and Davies, 1924; Robertson, 1927). In the Cardiff area, Waters and Lawrence (1987) subdivided this into the Cwrt-yr-ala Formation and an overlying redefined Quartz Conglomerate Group. In Gower, quartz arenites and quartz conglomerates exposed on Cefn Bryn are named the Pennard Conglomerate Formation (Barclay, 2011). Also included in this subgroup are the Farlow Sandstone Formation of the Clee Hills. The Oldbury Farm Sandstone of the Merevale district and the concealed Hopcroft's Holt Formation of Oxfordshire.

Name
From Portishead, Avon [ST 460 770]

Partial type section

The coast section at Woodhill Bay [ST 4579 7681] south of Portishead (e.g. Wilby, 2005b) provides a type section in which the lowermost 40 m of the formation and its junction with the underlying Brownstones (formerly Black Nore Sandstone) Formation are exposed.

Reference sections
Exposures on the left bank of the River Avon, Abbot's Leigh, Bristol (Avon Gorge) [ST 5525 7480] provide a section more complete than the type section, although it is less accessible (Kellaway and Welch, 1993). A reference section is provided by the BGS Cwrt-yr-ala Borehole (ST 17SW/47 [ST 1403 7339]), Cardiff, from 51.36 to 99 m depth (Davies et al., 1991), Also, the basal about 13 m of the BGS Ewenny Borehole (SS 97NW/157 [SS 9010 7697]) proved the topmost part of the subgroup.

Lithology
In the type area of the subgroup comprises red and green mudstones and calcareous mudstones, red siltstones, red to yellow, hard, fine-grained, quartz-rich sandstones and minor conglomerates. In the Cardiff area, the upper part of the subgroup comprises sandstones with interbedded mudstones, the lower part consists of lenticular quartz-conglomerates with sandstones, grits and quartz-arenites.

Lower and upper boundaries
The lower boundary subgroup is placed where the basal beds rest unconformably on drab red-brown sandstones of the underlying Brownstones Formation, or on Silurian volcanic rocks. At the partial type section, the lower boundary is placed at the base of the Woodhill Bay

Conglomerate, at a sharp, irregular surface scoured to a depth of 1 m and with a locally well developed calcrete [ST 4579 7681; 4585 7686]. The Woodhill Bay Conglomerate is a thin (4 to 4.5 m), laterally extensive conglomerate of pebbles and cobbles predominantly of vein quartz and dark red-brown quartzite. In the Cardiff area, the lower boundary is placed at the sharp base of lenticular quartz-conglomerate beds with sandstones, grits and quartz-arenites, where they rest unconformably on drab red-brown sandstones of the Brownstones Formation.

The upper boundary is placed at the conformable upward passage from sandstones and mudstones of the subgroup into limestones and calcareous mudstones of the Avon (formerly Lower Limestone Shale) Group. Locally, a basal conglomerate to the Avon Group indicates a disconformable upper junction. In the Cardiff area, the upper boundary is placed at the base of the lowermost grey mudstone or limestone of the Avon (formerly Lower Limestone Shale) Group (Courceyan), where there is a conformable, transitional passage from the red beds of the Portishead Subgroup into the lowermost Carboniferous grey beds (Section 3).

Thickness
300 m in the type area

Distribution
South Wales, Forest of Dean, Clee Hills, Bristol area and Mendips.

Depositional environment
Predominantly fluvial environments, including low-sinuosity high-energy gravel- and sand-bed river channels, as well as high-sinuosity sand-bed channels and associated point bar, crevasse splay and levee deposition. Alluvial floodplains were subject to pedogenic processes and calcrete formation. Marginal, shallow marine environments are represented in the Pen y Fan Formation, in which some possible aeolian deposition has been suggested.

Age
Famennian

GOWER

5.2.1 Pennard Conglomerate Formation (new name)

The Pennard Conglomerate Formation (Barclay, 2011) was previously referred to as the Quartz Conglomerate (Strahan, 1907a; IGS, 1973) or Upper Old Red Sandstone undivided (BGS, 2002).

Name
From Pennard Pill [SS 5392 8837] near Pennard Castle.

Partial type section
Pennard Pill [SS 5392 8837] provides the best section of the formation, where 23.88 m of quartz conglomerates, quartz arenites and red mudstone are exposed.

Lithology
Quartz conglomerates and quartz-arenites.

Lower and upper boundaries
The lower boundary is an unconformity where the basal conglomerate of the formation overlies red sandstones and mudstones of the Brownstones Formation (Owen and Rhodes, 1969). The upper boundary is a conformable junction with the overlying mudstones of the Avon Group (formerly Cefn Bryn Shale Formation), as seen near Fairyhill [SS 471 914] (Strahan, 1907a).

Thickness
About 100 m

Distribution
Limited to the core of the Cefn Bryn Anticline, on Cefn Bryn [SS 51 89], Gower (Strahan, 1907a, b).

Depositional environment
High-energy, low-sinuosity, gravel- and sand-bed fluvial channel deposition.

Age
Presumed to be Famennian, although no fauna has yet been found.

NORTH, EAST AND SOUTH-EAST CROPS OF THE SOUTH WALES COALFIELD

5.2.2 Pen y Fan Formation (*new name*)

Name
Traditionally termed the Plateau Beds by the Geological Survey (e.g. Strahan et al., 1904), these beds were given formation status by Lovell (1978a) and termed the Plateau Beds Formation. This is unacceptable according to the lithostratigraphical code for naming procedures and the formation is here named the Pen y Fan Formation from the mountain of Pen y Fan [SO 012 216] in the Brecon Beacons, Powys. It caps the mountain, as well as others in the vicinity, the previous name being derived from the plateau-like features that cap both the Brecon Beacons and Carmarthen Fans [about SN 82 22].

Type area
Brecon Beacons, Powys

Reference section
Cliffs at the head of the Duffryn Crawnon Valley [SO 0945 1500], Powys, south Wales (Lovell, 1978a, b; Barclay, 2005g).

Lithology
Red-brown and purple quartz-rich sandstones, locally pebbly and conglomeratic with interbeds of red-brown mudstone (Taylor, 1972; Hall et al., 1973; Taylor and Thomas, 1974, 1975; Lovell, 1978a, b); some sandstones contain fish fragments and some beds yield brachiopods. A fish-bearing horizon, the Afon y Waen Fish Bed was thought by Hall et al. (1973) to be a laterally continuous horizon and was used by them to divide the Plateau Beds into lower and upper units. Lovell (1978a) considered that the horizon was not continuous, but that fish-bearing

conglomerates occur as lenses at different levels. He recognised three subdivisions (Divisions A, B and C) on sedimentological grounds.

Lower and upper boundaries
The lower boundary of the formation is placed at a sharp junction where the basal hard purple sandstones of the formation unconformably overlie the softer drab red sandstones of the Brownstones Formation. A quartz granule debrite bed marks the base of the formation locally. A slight angular discordance between the formations is visible locally, as on the Carmarthen Fans of Bannau Sir Gaer and Fan Brycheiniog. The upper boundary is placed at a sharp junction where the topmost red sandstones of the formation are overlain by grey and grey-green sandstones of the overlying Wern Watkin (formerly Grey Grits) Formation.

Thickness
36 m at outcrop, with up to 58 m proved in boreholes at depth (Taylor and Thomas, 1975).

Distribution

From Pont Clydach [SO 740 194] to Blaen Onneu [SO 167 169] on the North Crop of the South Wales Coalfield.

Depositional environment
Mainly fluvial, but with some shallow marine environments; some possible aeolian deposition has also been suggested (Lovell, 1978a, b), but a tidal channel environment may be more likely. A mudflow debrite lies at the base of the formation.

Age
Frasnian to Famennian

5.2.3 Cwrt-yr-ala Formation

Name
This name was erected by Waters and Lawrence (1987) for the succession between the Brownstones Formation and an unnamed part of the Portishead Subgroup (formerly Quartz Conglomerate Group) proved in the BGS Cwrt-yr-ala Borehole (ST 17SW/47; Davies et al., 1991). The name is derived from the hamlet of Cwrt-yr-ala [ST 1447 7320] near Cardiff.

Type section
Beds in the BGS Cwrt-yr-ala Borehole (ST 17SW/47) [ST 1408 7339] from 99 m to 182.72 m depth provide the type section.

Lithology
Thinly interbedded quartz-rich sandstones, siltstones and mudstones with subordinate thick commonly pebbly sandstone units and nodular calcretes; the lithologies are arranged in fining-upwards cycles.

Lower and upper boundaries
The lower boundary is placed at the unconformable junction with the drab brown to purple sandstones of the underlying Brownstones Formation, at 182.72 m depth in the Cwrt-yr-ala

Borehole. The upper boundary is placed at a sharp conformable junction at 99 m depth in the Cwrt-yr-ala Borehole, above which multistorey sandstones with beds of quartz conglomerate (Portishead Subgroup) appear.

Thickness
From 15 m in the north of the outcrop to 83.72 m in the Cwrt-yr-ala Borehole.

Distribution
The formation occurs on both limbs of the Cardiff–Cowbridge Anticline and in small inliers to the south at Cyntwell and Cwrt-yr-ala.

Depositional environment
Fluvial, channel and laterally accreted deposition in high sinuosity channel systems, as well as floodplain crevasse splay and levee deposition. The mudstones represent more distal floodplain environments.

Age
Famennian

5.2.4 Wern Watkin Formation

Name
The name Wern Watkin Formation was erected by Lovell (1978a). It is derived from Wern Watkin Farm [SO 2107 1530] near the small village of Pant y Rhiw, Llangynidr, Powys, south Wales.

Partial type section
Disused quarry [SO 2107 1530] near Wern Watkin Farm.

Reference sections
Abercriban Quarries [SO 0635 1225; 0635 1272], north-north-east of Ponsticill, Powys, south Wales provide reference sections. The more northerly of two quarries provides a complete section (Barclay, 2005h; Lovell, 1978a, b).

Lithology
Pale greenish grey and buff, fine-grained, parallel-bedded quartz rich sandstones (quartz arenites) in mainly tabular beds with sharp, erosional contacts; there are minor green mudstone and siltstone interbeds and some pebbly horizons (Lovell, 1978a, Barclay, 1989).

Lower and upper boundaries
Locally a thin, fish-bearing intraformational conglomerate lies at the base. Also locally, the lower boundary appears to be gradational with the underlying Lower Devonian Brownstones Formation, but an unconformity is assumed from regional considerations. The upper boundary is placed at the top of a persistent rubbly or massive calcretised sandstone, sharply overlain by conglomerates at the base of the Craig-y-cwm Formation. In the west, the upper boundary is placed at a sharp erosion surface overlain by a thin conglomerate at the base of the overlying Castell Coch Limestone Formation (Avon Group).

Thickness
Up to 19 m in the Merthyr Tydfil area, about 8 m in the Llangynidr area, Powys and up to about 16 m in the Pontypool area, Gwent.

Distribution
The formation extends from near the River Heptse [SN 9835 1419 to SN 9845 1353] on the North Crop of the South Wales Coalfield in the west to Pontypool on the East Crop.

Regional correlation
The formation was formerly referred to the Grey Grits Formation in the Merthyr Tydfil district (e.g. Barclay et al., 1988; Barclay, 2005h).

Depositional environment
Taylor and Thomas (1975) envisaged a marginal marine environment. However, Allen (1965b) and Lovell (1978a, b) favoured a fluvial environment, with deposition in shallow, possibly ephemeral, sand-bed braided streams flowing in a broadly southwards direction. An extensive, well developed calcrete at the top of the formation represents abandonment of this alluvial complex (Barclay, 1989).

Age
Famennian

5.2.5 Craig-y-cwm Formation

Name
Derived from Craig-y-cwm [SO 283 088], near Blaenavon, south Wales (Lovell, 1978a).

Partial type section
Exposures on the steep, north-east-facing slope of Craig-y-cwm [SO 2825 0885], about 3 km south-east of Blaenavon provide a partial type section.

Lithology
Mainly quartz pebble conglomerates, with fine-grained, quartz-rich grey-green sandstones, pebbly sandstones and red-brown mudstones (Lovell, 1978a; Barclay, 1989).

Lower and upper boundaries
The lower boundary of the formation is placed at the base of 2.25 m of faintly trough cross-bedded conglomeratic sandstone which overlies a persistent calcrete at the top of the Wern Watkin Formation (Lovell, 1978a). The upper boundary is placed at a surface cut in quartz pebble conglomerates, overlain by pale yellow to white micaceous sandstone of the Garn-gofen Formation (Lovell, 1978a).

Thickness
5 m to 12 m

Distribution
From the Blaen Onneu area [about SO 1835 1655] near Crickhowell on the North-east Crop of the South Wales Coalfield eastwards and southwards to Pontypool [about SO 292 013] on the East Crop.

Regional correlation
Formal subdivision of the Portishead Subgroup to the south of Pontypool has not yet been attempted (Squirrell and Downing, 1969), but it is likely that the Craig-y-cwm Formation correlates at least in part with quartz conglomerates and sandstones which occupy the basal 40 m of the Upper Old Red Sandstone sporadically between Pontypool and Machen. Squirrell and Downing (*op. cit.*) equate the basal conglomerates with the Quartz Conglomerate (now Huntsham Hill Conglomerate Formation) of the Chepstow and Monmouth districts.

Depositional environment
Gravelly braided stream bed-load deposition in low-sinuosity channels flowing south-eastwards with calcrete-prone floodplain mud deposition (Lovell, 1978a).

Age
Famennian

5.2.6 Garn-gofen Formation

Name
Derived from the house named Garn-gofen [SO 2856 0868] near Craig-y-cwm [SO 2825 0885] (Lovell, 1978a).

Partial type section
Exposures on the steep, north-east-facing slope of Craig-y-cwm [SO 2825 0885], about 3 km south-east of Blaenavon provide a partial type section.

Lithology
Interbedded sandstones and red-brown mudstones; the sandstones in the basal part are pale grey-green quartz-arenites, those in the upper part are grey-green, soft, friable, richly micaceous and feldspathic (Lovell, 1978a; Barclay, 1989).

Lower and upper boundaries
The lower boundary of the formation is an erosion surface cut in conglomerates of the Craig-y-cwm Formation, overlain by pale yellow to white micaceous sandstone at the base of the Garn-gofen Formation (Lovell, 1978a). The upper boundary is placed at the sharp top of a thick-bedded, micaceous, trough cross-bedded sandstone, where it is disconformably overlain by limestone of the Castell Coch Limestone Formation of the Avon (formerly Lower Limestone Shale) Group. A thin but persistent granule and fine pebble conglomerate marks the base of the Castell Coch Limestone Formation.

Thickness
Up to 20 m

Distribution
From the Blaen Onneu–Daren Cilau area near Crickhowell on the North-East Crop of the South Wales Coalfield eastwards and southwards to Pontypool on the East Crop.

Regional correlation
Recognition of the formation to the south of Pontypool towards Risca and Machen is unclear within the Upper Old Red Sandstone (now Portishead Subgroup) of Squirrell and Downing (1969), but it is likely to equate at least in part with the succession of up to about 120 m of mainly soft, poorly cemented, grey, green and yellow sandstones which Squirrell and Downing (*op. cit.*) correlate with the Tintern Sandstone Formation of the Chepstow district.

Depositional environment
High sinuosity meandering streams flowing from the north or north-east. The abundance of clastic mica, garnet and feldspar suggests sourcing from a nearby metamorphic rock outcrops (Lovell, 1978a).

Age
Famennian

FOREST OF DEAN, BRISTOL DISTRICT AND MENDIPS

5.2.7 Huntsham Hill Conglomerate Formation (new name)

Name
This name is proposed for the former Quartz Conglomerate of the Forest of Dean (Eastwood, 1935; Trotter, 1942). It is derived from Huntsham Hill [SO 562 167], Herefordshire.

Partial type section
Road cutting [SO 562 167] on Huntsham Hill (Welch and Trotter, 1961).

Reference section
Road cutting at Euroclydon [SO 644 187] (Allen, 1971). The section in this cutting is now obscured by gabions. Crag exposures at the north end of the north-nort-west-trending ridge between Huntsham Hill and Symonds Yat East provide an exposed reference section [SO 5620 1652] (T. Richards, personal communication, 2013).

Lithology
Well sorted, red-brown, medium- to coarse-grained pebbly sandstones and quartz pebble conglomerates with some mudstone interbeds. The pebbles are predominantly of vein quartz, with rare quartzite, jasper and silicified igneous rocks. Bedding traces are rare, but conglomerate units can be locally seen to be cross-bedded and to fill shallow channels (Allen, 1971).

Lower and upper boundaries
The lower boundary is placed at the base of lowest quartz pebble conglomerate, at the sharp, disconformable or unconformable) junction with underlying red-brown sandstones of the Brownstones Formation. The upper boundary is placed at the top of the highest quartz pebble conglomerate bed, where it is overlain by pale yellow and green sandstones of the Tintern Sandstone Formation.

Thickness
Up to 30 m

Distribution
The Forest of Dean and north of Bristol east of the Severn Estuary.

Depositional environment
Fluvial deposition in high-energy gravel-bed, braided, low-sinuosity streams, with some muddy floodplain deposits preserved.

Age
Famennian

5.2.8 Tintern Sandstone Formation

Name
This name was erected by Trotter (1942) for the topmost unit of the Upper Old Red Sandstone in the Forest of Dean (Kellaway and Welch, 1955; Welch and Trotter, 1961). It is derived from the village of Tintern [SO 536 006] in the Wye Valley, Monmouthshire.

Type area
The area around Tintern, the deeply incised Wye Valley affording good exposures.

Reference sections

1. Road cutting at Euroclydon [SO 644 187], where the formation is 80 m thick (Allen, 1971). This section is now obscured by gabions (T. Richards, personal communication, 2013).
2. St Anne's Well Borehole (SO 50SE/2[SO 577 028]), north-east of Hewelsfield, in which the topmost 73.4 m were proved (Welch and Trotter, 1961).
3. Crag exposures on ridge between Huntsham Hill and Symonds Yat East [SO 5621 1649–5623 1646].

Lithology
Buff-yellow, tan and green sandstones with lenses of conglomerate and thin subordinate red and purple siltstone/mudstone beds; the facies are arranged in fining-upwards cycles, each resting on a laterally extensive erosion surface cut in the underlying siltstone or very fine grained sandstone. Pebbly sandstones at the base of the cycles contain vein quartz and intraformational fragments, as well as sporadic fish remains. The overlying sandstones are typically cross-bedded in thick sets and parallel-laminated, but deep weathering obscures sedimentary structures in many of them. The siltstones are coarse grained, generally sandy and micaceous and locally contain nodular calcrete beds (Allen, 1971).

Lower and upper boundaries
The lower boundary is placed at the base of the lowest buff sandstone, where it rests on quartz pebble conglomerate of the underlying Huntsham Hill Conglomerate Formation. The upper boundary is placed at the conformable upward passage from buff yellow sandstones to

limestones of the Avon (formerly Lower Limestone Shale) Group. The junction is placed at the base of the lowest limestone or blue-grey shale of the Avon Group.

Thickness
Up to about 80 m

Distribution
Forest of Dean and north of Bristol to the east of the Severn Estuary.

Depositional environment
Fluvial deposition in meandering sand-bed streams, their channels being less steep and more sinuous than those of the underlying Huntsham Hill Conglomerate Formation; floodplain deposition is represented by the siltstones.

Age
Famennian

CLEE HILLS AND WEST MIDLANDS

5.2.9 Farlow Sandstone Formation

Name

Outliers of buff and grey sandstone of Late Devonian age in the Clee Hills are assigned to the Farlow Sandstone Formation. The name is derived from the village of Farlow [SO 6403 8064], Shropshire. The local Old Red Sandstone stage name Farlovian was also derived from the village of Farlow (e.g. Allen, 1965b). Formerly referred to variously as the Farlow Group or Farlow Series (King, 1925; Ball and Dineley, 1961; Greig et al., 1968), Allen (1974a, c, 1977) named the unit the Farlow Sandstone Group, with a lower Yellow Farlow Formation and upper Grey Farlow Formation. It is here named the Farlow Sandstone Formation, with Allen's formations downgraded to informal member status.

Partial type section
Exposures at the base of Farlow Bank, where a 1.2 m-thick basal quartz conglomerate is overlain by 4.9 m of yellow pebbly sandstone [SO 639 807], provide a partial type section.

Reference section
Roadside exposures at Prescott, Shropshire [SO 663 812] (Dineley, 1999c) provide a good, accessible reference section.

Lithology
Large-scale, planar cross-bedded, yellow sandstones and pebbly sandstones overlain by grey pebbly calcareous sandstones.

Lower and upper boundaries
The lower boundary of the formation is placed at an unconformity where the basal conglomerate sharply overlies red-brown mudstones of the Freshwater West (formerly St Maughans) Formation (at the type section) or red sandstones of the Brownstones (formerly Clee Sandstone)

Formation. The upper boundary is placed at an unconformity where the topmost grey sandstones of the formation are sharply overlain by the basal conglomerate of the Carboniferous-age Oreton Limestone Formation (Pembroke Limestone Group; Waters et al., 2009), the latter being overstepped completely in parts of the Clee Hills area.

Thickness
70 to 154 m

Distribution
Around Farlow and in small outcrops south and east of Titterstone Clee Hill.

Depositional environment
The distinctive yellow, large-scale planar cross-bedded sandstones suggest aeolian deposition, although no detailed sedimentological work has yet been done on them. The pebbly sandstones were the deposits of gravel-bed fluvial channels.

Age
Famennian

5.2.10 Oldbury Farm Sandstone Formation

Name
An outcrop of Upper Devonian strata in the Merevale area on the east side of the Warwickshire Coalfield was referred to the Upper Old Red Sandstone by Taylor and Rushton (1971). The beds were formally named the Oldbury Farm Sandstone Formation by Bridge et al. (1998).

Type section
From 53.9 m to 213.4 m in the Merevale No. 2 Borehole (SP39NW/6)[SP 3001 9509] (Taylor and Rushton, 1971).

Reference sections
Exposures (now much overgrown) in a small cutting [SP 3013 9572] 500 m NNW of Oldbury Farm serve as a reference section for the marine part of the formation (Taylor and Rushton, 1971; Bridge et al., 1998). Partial sections in the lower beds were proved in the Merevale Nos. 1 and 1A boreholes (Taylor and Rushton, 1971).

Lithology
23 cyclic fining-upwards sequences of conglomerate or coarse-grained sandstone passing upwards through fine- or medium-grained sandstone into mudstone or siltstone (Taylor and Rushton, 1971; Bridge et al., 1998).

Lower and upper boundaries
The lower boundary is placed at the sharp unconformable junction at 213.4 m in the Merevale No. 2 Borehole where a conglomerate with subordinate sandstone layers rests on an erosion surface cut in reddish purple shaly mudstone of the Merevale Shale Formation of Ordovician age. The upper boundary is placed where greyish green siltstones with large rhizomes at the top of the formation are unconformably overlain by Namurian pale grey sandstone with mudstone clasts and carbonised wood fragments.

Thickness
152 m true thickness in the Merevale No. 2 Borehole.

Distribution
From just south of Outwoods [SP 2975 9614] southeastward to just south-east of Moor Wood Farm [SP 3133 9417] for 2.5 km along the western margin of the Nuneaton Ordovician inlier; the outcrop attains a maximum width of 450 m to the north of Oldbury Farm [SP 303 953] before terminating against the Arley Fault System.

Depositional environment
Fluvial high sinuosity channelised and floodplain deposition and shallow marine sand and intertidal mudflat deposition.

Age
Mid Frasnian to early Famennian; Bridge et al. (1998) gave details of the faunas recovered from the formation. Marine invertebrates from exposures point to a Late Devonian age. A particularly diverse marine fauna in an interval in the Merevale No. 2 Borehole occurs elsewhere in middle and/or upper Frasnian strata, suggesting that that these beds span the mid Frasnian to early Famennian period (Butler, 1981). Fish remains in the same borehole reported by Miles and Toombs (in Taylor and Rushton, 1971) are typical of Late Devonian Upper Old Red Sandstone assemblages. The absence of *Phyllolepis* suggests a late Frasnian age, although this may be due to environmental factors.

CONCEALED STRATA

Concealed onshore Lower and Upper Devonian strata proved in boreholes in southern and eastern England have generally not been assigned lithostratigraphical names (e.g. Chaloner and Richardson, 1977; Allen, 1979). An exception to this is the Upper Devonian strata proved in the IGS Steeple Aston Borehole (see below). The topmost beds, named the Holt Farm Formation by Poole (1977), are marine and excluded from this review of terrestrial Old Red Sandstone facies.

5.2.11 Hopcroft's Holt Formation (HPH)

Name
Strata in the IGS Steeple Aston Borehole, Oxfordshire were named by Poole (1977) the Hopcroft Halt Group, presumably from the nearby Hopcroft's Holt; the name is here revised to Hopcroft's Holt and the unit downgraded to formation status.

Type section
From 938.89 m to 966.90 to 967.00 m in the IGS Steeple Aston Borehole [SP 42NE/12; 4687 2586].

Lithology
Reddish purple, green and grey calcareous, silty mudstones with calcareous nodules and a few thin fine-grained sandstones.

Lower and upper boundaries
The lower boundary is placed at the base of thermally metamorphosed mudstones of the Hopcroft Halt Formation. The basal about 7 m of the formation are thermally metamorphosed, becoming increasingly hard downwards and eventually converted below 961.27 m to dark purplish grey marble with serpentinite, calcite and hematite in veins and patches. This marble extends to 966.70 m, where it rests on a very hard, dark purple hornfels with a contact dipping at 45^{o} with an underlying basaltic intrusion. The upper boundary is placed at the conformable upward passage of mudstones with desiccation cracks of the Hopcroft Halt Formation into the calcareous sandstone-shale facies of the overlying Holt Farm Formation.

Thickness
28 m drilled thickness. Dip measurements of 5˚ recorded in the lower beds of the overlying Holt Farm Formation suggest a true thickness slightly less.

Depositional environment
Poole (1977) regarded the formation as the deposits of a shallow water lagoon subject to periodic drying and oxidation. Only fish fragments are recorded, suggesting a freshwater lacustrine environment.

Age
Frasnian

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Appendix 1 List of Old Red Sandstone lithostratigraphical units

The areas listed are Anglesey (A), Bristol (B), Forest of Dean (FD), south Wales (SW) south-east Wales (SEW), south-central Wales (SCW), Welsh Borderland (WB), Pembrokeshire (P), Pembrokeshire north of the Ritec Fault (PNR), Pembrokeshire south of the Ritec Fault (PSR), West Midlands (WM), throughout Anglo-Welsh Basin (AWB) and concealed strata (C). * indicates that the unit is not shown on a BGS map.

Name	**Area**	**Current status**	**Proposed new status (if different from current)**	**BGS Lex code**	**BGS map code**	**Notes**
Albion Sands Formation*	PNR	Formation				
Bodafon Formation*	A	Beds	Formation			Change of status
Brecon Beacons Group*	SCW, SEW, WB, WM					Proposed new name
Brownstones Formation	SW, SEW, SCW, WB	Formation		BRS	BrS	
Chapel Point Limestone Member*	PSR	Member				Proposed change from Chapel Point Calcrete(s)
Conglomerate Member*	PSR	Informal unit of West Angle Formation				Erected by Marshall (2000a)
Conigar Pit Sandstone Member*	PSR	Member				
Cosheston Subgroup	AWB	Subgroup				
Craig-y-cwm Formation*	SEW	Formation			cg	
Cwmffrwd Formation*	SCW	New name				New name for lower part of Green Beds of Strahan et al. (1907)
Cwrt-yr-ala Formation	SEW	Formation		CWA	Cwa	

Daugleddau Group*	AWB	Proposed new name for Lower Old Red Sandstone				
Dulas Bay Subgroup*	A	New name				
Farlow Sandstone Formation	WM	Group	Formation	FRL	Frl	Change of status
Ffynnon Limestones*	SCW		Informal units			Proposed informal members of Freshwater West (formerly St Maughans) Formation
Freshwater East Formation*	PSR	Formation				
Freshwater West Formation*	AWB	Formation				Supersedes St Maughans Formation of BGS
Garn-gofen Formation*	SEW	Formation				
Gupton Formation*	PSR	Formation				Formation of Skrinkle Sandstones Subgroup (Marshall, 2000a,b)
Hackley Limestone Member	WB	Member		HL	HL	Named member of Freshwater West (St Maughans) Formation (Brandon, 1989)
Holdgate Sandstone	WM	Informal unit				Mitchell et al. (1962)
Hopcroft's Holt Formation*	C	Formation		HPH		Amended from Poole (1977)
Huntsham Hill Conglomerate Formation*	FD	Formation				Proposed new name for Quartz Conglomerate (Forest of Dean)
Lawrenny Cliff Formation*		Formation				
Llanstadwell Formation*	PNR	Formation				
Lindsway Bay Member*	P	Formation	Member			Proposed downgrade to member of Albion Sands Formation
Llanishen Conglomerate Formation	SEW	Formation		LLC	LlC	
Lower Abdon Limestone*	WM		Informal unit			Informal unit (of Freshwater West Formation)

Lower Sandstone Member*	PSR	Informal member of Gupton Formation	Informal unit			Erected by Marshall (2000b)
Milford Haven Subgroup*	AWB, A	Group	Subgroup			Change of status
Mill Bay Formation*	PNR	Formation				
Moor Cliffs Formation*	PSR	Formation				
New Shipping Formation*		Formation				
Oldbury Farm Sandstone Formation	WM	Formation		OFS	OFS	
Pennard Conglomerate Formation*	SW		Formation	PEC	PeC	New name for Quartz Conglomerate of Gower (Barclay, 2011)
Pen y Fan Formation	SCW	Formation		PLB	PlB	Proposed change from Plateau (Beds) Formation
Pont ar llechau Formation	SCW	Formation		POL	Pol	
Porth-y-Mor Formation*	A	Beds	Formation			Change of status
Portishead Subgroup	B, SEW, WB, WM	Beds/ Formation	Subgroup			Proposed status upgrade
Rat Island Mudstone Member*	PSR		Member			
Red Cliff Formation*	PNR	Formation				
Red-Grey Member*	PSR	Informal unit of West Angle Formation				Erected by Marshall (2000a)
Ridgeway Conglomerate Formation	PSR	Formation				
Ruperra Limestone	SEW	Informal unit	Informal unit			Informal unit of Freshwater West (formerly St Maughans) Formation
Senni Formation	SCW	Formation		SEN	Sen	Formerly Senni Beds
Skrinkle Sandstones Subgroup*	PSR	Group	Subgroup			Proposed new status downgraded from Group

Stackpole Sandstone Member*	PSR	Informal unit of Gupton Formation				Erected by Marshall (2000b)
Temeside Mudstone Formation	SCW, SEW, WB	Formation		TSH	TSh	Formerly Temeside Shales/Beds; includes Green Beds
Tintern Sandstone Formation	FD	Formation		TSG	TSG	
Townsend Tuff Bed	AWB	Bed		TWT	TwT	
Traeth Bach Formation*	A	Beds	Formation			Change of status
Traeth Lligwy Formation*	A	Beds	Formation			Change of status
Trichrug Formation	SCW	Formation		TUG	Tug	
Upper Abdon Limestone*	WM	None	Informal unit			Proposed informal member status of Freshwater West Formation
Wern Watkin Formation*	SEW	Formation				
West Angle Formation*	PSR	Informal formation	Formation			
Woodhill Bay Conglomerate	B	Informal unit	Informal unit	WBCO	cg	

Appendix 2 List of redundant Old Red Sandstone lithostratigraphical names

Name	Reason for discarding	Replacement	Comment/key reference
Abdon Group/Series	Unnecessary; topmost part of Freshwater West (St Maughans) Formation		Erected by Allen (1961, 1977)
Abdon Limestone Formation	Upper Abdon Limestone Member preferred to avoid confusion with Lower Abdon Limestone	Upper Abdon Limestone Member	Erected by Allen (1961, 1977)
Bishop's Frome Limestone Member	Replaced by standard name	Chapel Point Limestone Member	
Black Nore Sandstone Formation	Rationalisation with south Wales name	Brownstones Formation	
Burton Cliff Formation	Now included in Llanstadwell Formation (Burton Cliff Association)	Llanstadwell Formation	Thomas et al., 2006
Clee Sandstone Formation	Replaced by Senni Formation	Senni Formation	
Clun Forest Formation	Local name used as an expedient in poorly exposed ground on the Montgomery district.	Subdivided, as previously, into Platyschisma Beds, Downton Castle Sandstone Formation and Raglan Mudstone Formation	Erected by Hains (in Lynas, 1987); Cave and Hains (2001)
Downton Group/Subgroup	Lower part removed from the ORS	Milford Haven Subgroup (part)	
Ditton Subgroup	Replaced by standard name	Freshwater West Formation	
Gelliswick Bay Formation*	Replaced by standard name	Freshwater West Formation	
Green Beds	Replaced	Temeside Mudstone Formation /Cwmffrwd Formation	
Grey Farlow Formation	Proposed informal name for upper part of Farlow Sandstone Formation	Grey Farlow Sandstone	Erected by Allen (1977)
Gwynfe Formation	Replaced by standard name	Moor Cliffs Formation	Erected by Almond (1983)

Hillside Dolomitic Formation	Former name Lower Abdon Limestone preferred	Lower Abdon Limestone	Erected by Allen (1961) as lower formation of Abdon Subgroup
Llandeusant Formation	Replaced by standard name	Freshwater West Formation	Erected by Almond (1983)
Lower Old Red Sandstone Group	Replaced	Daugleddau Group	
Ledbury Formation	Replaced by standard name	Moor Cliffs Formation	Proposed as standard by White and Lawson (1989)
Monkeys Fold Formation	Replaced	Clee Hills local name; replaced by Brownstones Formation	
Nordybank Formation	Unnecessary name	Freshwater West Formation (part)	Sandstone-rich top of Freshwater West (St Maughans) Formation between Abdon limestones; erected by Allen (1961, 1977) as middle part of Abdon Group
Plateau Formation	Unnacceptable name	Pen y Fan Formation (this report)	
Quartz Conglomerate Group	Replaced	Portishead Subgroup	
Quartz Conglomerate (Forest of Dean)	Proposed replacement name	Huntsham Hill Conglomerate Formation	Proposed new name (this report)
Quartz Conglomerate (Gower)	Proposed replacement name	Pennard Conglomerate Formation	New name (Barclay, 2011)
Raglan Mudstone Formation	Replaced	Moor Cliffs Formation	
Red Marls	Superseded by constituent formations		Traditional Geological Survey name
Sandy Haven Formation	Replaced	Moor Cliffs Formation	Erected by Allen and Williams (1978)
St Maughans Formation	Replaced	Freshwater West Formation	
Thornbury Beds	Replaced	Moor Cliffs Formation	Traditional Geological Survey name east of Severn
Upper Old Red Sandstone Group	Replaced	Brecon Beacons Group	
Woodbank Group	Replaced	Cosheston Subgroup	Erected by Allen (1961, 1977)
Yellow Farlow Formation	Proposed informal unit of Farlow Sandstone Formation	Yellow Farlow Sandstone	Erected by Allen (1977)