

The Old Red Sandstone of Britain and Ireland – a review

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Abstract

The Old Red Sandstone (ORS) is an informal term which is given to continental, predominantly siliclastic, strata of late Silurian to early Carboniferous age which were deposited across the continent of Laurussia at sub-tropic to tropical latitudes. The coincidental development of land plants had a major impact on the atmosphere and global climate by lowering atmospheric carbon dioxide levels, which profoundly affected the style of alluvial sedimentation during this interval, by stabilising flood plains and facilitating the development of soils. The ORS also provides examples of syn- to post- orogenic deposition related to the Caledonian Orogeny, which was affected by synchronous tectonism and volcanism. The influence of Variscan tectonics on basin deformation and tectonism are also evident in the ORS sequence.

In October 2014, a symposium was held, organised by the South Wales Geologists' Association, entitled *The Old Red Sandstone: is it Old, is it Red and is it all Sandstone?* The event consisted of talks and posters on topics associated with the Old Red Sandstone deposits, principally of Wales and the Welsh Borders and the Scottish Borders in the UK, and included a series of field trips. Seven of the speakers have contributed manuscripts which are presented in this volume. These include papers discussing fossil fish and plant assemblages, the Fforest Fawr Geopark, Old Red Sandstone building stones, and soft sediment deformation. A brief report on the event and acknowledgements is also included.

Introduction

The deposition of the Old Red Sandstone (ORS) occurred during a critical period of Earth history both globally and regionally, with profound innovations in terrestrial ecosystems, and concomitant changes in sedimentological regimes. During this time, complex, terrestrial ecosystems were established (Jeram *et al.*, 1990; Edwards and Selden, 1993; Gray, 1993; Edwards and Wellman, 2001; Shear and Selden, 2001), including the proliferation of land plants which had a major impact on both earth surface processes and atmospheric composition (Retallack, 1997; Berner, 1998; Elick *et al.*, 1998; Algeo *et al.*, 2001; Driese and Mora, 2001). The establishment of surface vegetation impacted the style of alluvial sedimentation, by stabilising flood plains and facilitating the development of soils (Davies and Gibling, 2010b). By the late Silurian, vascular plants were well established on land, but were restricted to small forms, typified by *Cooksonia* which grew up to 2cm tall and possessed networks of shallow, horizontal, primitive roots (Edwards and Wellman, 2001; Edwards and Richardson, 2004). By the late Silurian (Přídolí) and Lower Devonian, plants had become larger and possessed more complex root systems, and had greater diversity in terms of their morphology and geographic distribution (Davies *et al.*, 2011). Their deeper rooting systems consolidated the soil and

contributed organic content, thereby decreasing surface run-off (Davies and Gibling, 2010 and b) and creating new habitats and nutrient sources for terrestrial faunas (Selden and Edwards, 1989; Shear and Selden, 2001). The expanded vegetation cover has also been linked to enhanced rates of pedogenesis (Allan, 1974; Algeo *et al.*, 2001; Brasier, 2011), as plant growth and the incorporation of organic matter raised the concentration of CO₂ in soils. Plant respiration and microbial decay facilitated the production of carbonic acid, which in turn dissolved limestone producing bicarbonate ions, which ultimately contributed to calcrete precipitation which is a characteristic of the ORS (Brasier *et al.*, 2014).

Vascular plants spread to upland areas during the Devonian, where their deep root systems contributed to enhanced chemical and physical weathering of silicate rocks (Algeo *et al.*, 2001; Brasier, 2011), enhancing the production and delivery of finer-grained sediments into the sedimentary systems (Davies and Gibling, 2010a, 2010b). The transported sediment included the breakdown products of bacterial and fungal activity on plant detritus, which facilitated algal blooms and the development of anoxic conditions in closed water basins. A mass extinction event in the oceans at this time extinguished approximately 70 to 80 percent of shallow marine organisms (Algeo *et al.*, 1998 and 2001).

The proliferation of land plants is thought to have had a major impact on global atmospheric carbon dioxide (CO₂) and oxygen (O₂) concentrations (Retallack, 1997; Berner, 1998; Elick *et al.*, 1998; Algeo *et al.*, 2001; Driese and Mora, 2001). High levels of atmospheric CO₂ during the earlier Palaeozoic was followed by a significant drop at the Silurian - Devonian boundary. This is attributed to the rise of vascular land plants, which caused increases in the rates of chemical weathering of silicates and burial of organic matter which caused a rise of O₂ and drop in atmospheric CO₂ concentrations (Berner and Kothavala, 2001, Berner, 1991, 1998 and 2006). As atmospheric concentrations of CO₂ are thought to be a primary control of global temperatures (Royer *et al.*, 2003 inc Mann *et al.*, 1998; Crowley, 2001) this would have contributed to global cooling (Algeo and Scheckler, 1998).

Rocks of the ORS preserve a diverse assemblage of animal trace fossils, consistent with the diversification of terrestrial faunas/enhanced complexity of terrestrial ecosystems. Examples from the Anglo-Welsh Basin are mainly preserved in fine-grained, alluvial facies. The most common trackways are those generated by arthropods, including arachnids, eurypterids, myriapods and *Diplopodichnus*. Other traces include worm burrows and faecal/feeding pellets (Morrissey *et al.*, 2012, Davies *et al.*, 2011, Davies and Gibling, 2010a, 2010b).

The appearance of land plants had a dramatic and lasting effect on alluvial geomorphology and sedimentology (Davies *et al.*, 2014). Prior to the Devonian, alluvial networks were predominantly coarse-grained and braided, with laterally-accreted channel sediments and floodplain muds and silts which subsequently developed soils to become the calcrete palaeosols. By the Early Devonian, the river networks diversified to include discrete channel lenses and the establishment of coastal plains (Morrissey *et al.*, 2012).

The sediments of the ORS also provide opportunity to investigate syn- to post- orogenic deposition associated with a major orogeny - the Caledonian Orogeny. These sediments are modified by synchronous tectonism and volcanism. The influence of Variscan tectonics on basin formation and deformation is also recorded within its sediments (Hillier and Williams, 2006).

The ORS is known to be of late Silurian to early Carboniferous age (Friend and Williams, 2000, Becker *et al.*, 2012), but the precise ages of its upper and lower boundaries within Britain and Ireland remains contentious. This is primarily because it is dominated by continental facies which have poor

fossil preservation potential. Palynomorphs, vascular plant fossils and fish are useful, but problems remain with their correlation with schemes used in coeval marine facies (Becker and Kirchgasser, 2007). There are a number of schemes which utilise palynomorphs. These include Streele *et al.* (1987), Richardson and McGregor (1986), Richardson *et al.*, (2000) and Steemans (1989). Vascular plant based biozonal schemes have been provided by Banks (1980) and subsequent work by Edwards *et al.* (2000). Biozonal schemes based on fossil fish (the principal macro-fossils) and other microvertebrate remains, are summarised by Blicek and Janvier (1989), Blicek and Turner (2000) and Vergoossen, 2000 (Becker *et al.*, 2012).

This special issue of the *Proceedings of the Geologists' Association* has been compiled following a symposium, held in Brecon, south Wales in October 2014, entitled *The Old Red Sandstone: is it Old, is it Red and is it all Sandstone?* The symposium was held at the Elim Church Centre in Brecon and was convened jointly by the South Wales Geologists' Association and the Fforest Fawr Geopark, supported by the Palaeontological Association and the Geologists' Association. The aim was to bring together researchers with diverse interests in the Old Red Sandstone (ORS) in order to share ideas. Discussion covered many aspects, but mainly focused on the Midland Valley of Scotland and the Anglo-Welsh Basin. The present paper presents a summary of the Old Red Sandstone in these regions, and is intended to provide context to the themed collection of papers, summaries of which are provided at the end. See Appendix 1 at the end of this paper, for an acknowledgement to all those involved in making the meeting such a success.

Present day ORS distribution

ORS deposits are known from almost every continent of the world, including Arctic Canada, western Europe, Russia, the Altai-Sayan region of Central Asia, east Asia, Australia, Antarctica, the Falkland Islands and countries bordering the north Atlantic (Friend, 1968 and Dinley, 1984). Britain and Ireland, which are the focus of this paper, fall into the north Atlantic region, which stretches from the Appalachians of North America and Canada, Arctic Canada, Spitsbergen, the Baltic and Greenland (Friend *et al.*, 2000) (Figure 1).

Suggested position for Figure 1

Within Britain and Ireland, there are five principal areas of outcrop. These are: Orkney, Shetland and North East Scotland, the Midland Valley of Scotland, the Scottish Borders and Northumberland, southern Lake District and south Wales and the Welsh borders. There are also a number of other smaller basins in Wales and Ireland (Figure 2) (Barclay *et al.*, 2005, Leveridge and Shail, 2011).

Suggested position for figure 2

Palaeogeographical setting

For much of the early Palaeozoic, the southern part of Britain and Ireland formed the eastern part of a continental fragment, known as Avalonia, which lay within the Iapetus Ocean. The continent of Laurentia, which included parts of modern day Scotland, lay to the north of Avalonia, and the continent of Gondwana lay to the south. Avalonia rifted away from Gondwana during the

Ordovician and it moved northwards towards Laurentia as the Iapetus Ocean gradually closed throughout the Ordovician and Silurian. To the east, another continental fragment, known as Baltica, drifted north-east as the Tornquist Sea (an eastern arm of the Iapetus Ocean) closed (Woodcock, 2012b).

The timing and manner in which Avalonia, Baltica and Laurentia converged to form the resulting continent of Laurussia is a matter of debate (Barclay et al., 2005). Cocks and Torsvik (2002) suggest that Avalonia and Baltica collided at about 440 Ma, and from 425 to 420 Ma these combined landmasses collided with Laurentia to produce the Scandian Orogeny. Dewey and Strachan (2003) propose an alternative idea that the Scandian orogeny was the result of collision by sinistral transtension of Laurentia and Baltica from about 435 Ma to 425 Ma, and that around 425 Ma Avalonia then collided with Laurentia/Baltica with highly oblique sinistral transpression (Figure 3).

Suggested position for figure 3

By late Llandovery times, the oblique collision had caused major, orogen-parallel, sinistral strike-slip displacements along major NE-SW trending transcurrent faults (Dewey and Strachan 2003 and Hillier and Williams 2006). By the late Silurian (Ludlow), the continents of Avalonia, Baltica and Laurentia had fully docked, the Iapetus Ocean was closed, and the new Old Red Sandstone (Laurussia) continent had formed (Barclay et al., 2005). Basins along the northern edge of Eastern Avalonia deepened in response to crustal flexures to the south of the suture, and over-supply of sediment from the new mountains caused the basins to fill rapidly, replacing marine conditions with terrestrial (Hillier and Williams 2006).

The Rheic Ocean lay to the south of newly formed Laurussia, and separated it from the continent of Gondwana, which was drifting northward, progressively closing the ocean (Figure 3). Ahead of the main collision between Laurussia and Gondwana, other continental fragments moved towards, and eventually collided with, Laurussia. The collision of one such continental fragment, named Armorica, is thought to be responsible for the Acadian Orogeny during the late Early to Middle Devonian (Woodcock and Strachan, 2000, Woodcock, 2012a and 2012b). The resulting phase of uplift and erosion is now represented by a regional unconformity below strata of Late Devonian age (Barclay et al., 2015).

During the Devonian, Laurussia lay in tropical to sub-tropical latitudes, with Britain lying at approximately 5 to 15° S (Scotese, 2001). Palaeomagnetic data from South Wales supports this, suggesting a latitude of 17 +/- 5° S (Channel et al., 1992 and Barclay et al., 2005).

ORS basins of Britain and Ireland

The closure of the Iapetus Ocean produced new mountainous areas of land from which large volumes of clastic sediments were derived and deposited under mainly continental conditions (Allan, 1979). The ORS sediments are preserved in several basins, each recording local variations in subsidence, uplift, sediment sources and marine influences (Allen, 1977 and Hillier and Williams, 2006). The ORS basins in Britain and Ireland are broadly classified with respect to their positions relative to the Caledonian Mountains (Figure 4a and b) (Woodcock and Strachan 2000).

Basins formed to the north west of, and along the line of, the Iapetus Suture (Figure 2) and the Caledonian Mountains are known as Internal or Intramontain basins. These had little or no access to the ocean, and formed above the remnant of the north-west-dipping slab of Iapetus oceanic lithosphere. There was also local subsidence triggered by regional-transension and local-transension around strike slip faults (Woodcock, 2012a). Examples of such internal basins include the Orkney, Shetland and North East Scotland and the Midland Valley Basins (Figure 2).

External ORS basins are located to the south of the Caledonian Mountains and underwent transtensional or flexural subsidence during the Silurian. These basins had river networks which drained to coastlines at the south and east. Examples include the Anglo-Welsh Basin and the Dingle-Shannon Basin of southern Ireland (Figure 6). Both basins have successions with no major breaks in deposition from the Silurian to the Early Devonian, suggesting continued subsidence during this interval (Woodcock, 2012b).

Suggestion position for figure 4 (3 parts – a, b and c)

In much of Britain and Ireland, Lower ORS deposits terminate at an unconformity of late early to Middle Devonian age. This unconformity marks the deformation and uplift associated with the Acadian Orogeny. This unconformity does not occur in north-east Scotland (Orcadian Basin), where mid-Devonian rocks are preserved (Woodcock, 2012b).

The main focus of the ORS symposium, for which this special volume has been created, was the Anglo-Welsh Basin and the Midland Valley Basin of Scotland. These are discussed in more detail:

Midland Valley Basin

The ORS of the Midland Valley of Scotland was deposited in a series of basins within a northeast-southwest oriented rift, bounded to the north by the Highland Boundary Fault and to the south by the Southern Uplands Fault (Figure 5). The rift extends into the North Sea and into the Irish Sea and Ireland (Browne and Barclay, 2005). The Midland Valley contains a number of separate Lower ORS basins, divided by an east-west volcanic ridge (the Ayr-Ochil-Sidlaw volcanic axis) lying above an Ordovician arc. To the north of the arc are the Strathmore, Stonehaven and Crawton basins, and to the south, the Lanark Basin (Browne *et al.*, 2002 and 2005; Woodcock, 2012b) (Figure 5).

The Devonian of the Midland Valley records a history of transtensional faulting, which opened pull-apart basins, and transpressive movements, which inverted them. The faulting created new areas of high ground which provided a source of sediments. There was also intermittent volcanism along faults (Bluck, 2000). The basins contain successions organised into two major cycles, separated by a Middle Devonian unconformity. The cycles each begin with conglomerates and fine upwards into sandstones, recording fault initiation and declining sediment supply due to progressive erosion of the source areas (Bluck, 2000) leading to the reduction of relief and hence stream power.

During Lower ORS times, both the Strathmore and Lanark basins had a south-west trunk drainage (Figure 5) and carried sediments derived from the Scandian mountains between Baltica and Laurentia (Woodcock, 2012a). The Stonehaven Basin contains the oldest ORS aged sediments, being Wenlock in age, and records a distinct episode of basin fill (Woodcock, 2012b), sourced from the

south-west. The Stonehaven Basin was succeeded by the larger Crawton Basin which extended south-westwards. The Crawton Basin was filled with conglomerates and sandstones predominantly derived from the north, although some conglomerates have a southerly derivation (Barclay *et al.*, 2005). The separate Lower ORS basins were succeeded by a single Upper ORS basin known as the Midland Valley Basin (Figure 5), whose rivers principally drained north-eastwards (Woodcock, 2012b).

Suggested position for figure 5

Anglo-Welsh Basin

The ORS of the Anglo-Welsh Basin outcrops in south-west Pembrokeshire and continues eastwards through the Carmarthen Fans, Black Mountains, Brecon Beacons, the coalfields of south Wales and the Forest of Dean, into the Welsh Borders (Figure 2).

The Anglo-Welsh basin is thought to have been created by transtensional faulting along the southern margin of the Laurussian continent, on the northern margin of the Rheic Ocean (Barclay *et al.*, 2005, Woodcock, 1990; Friend *et al.*, 2000; Dewey and Strachan, 2003; Soper and Woodcock, 2003).

Deposition of ORS sediments began in the Late Silurian (Přídolí) times as the marine Lower Palaeozoic Welsh Basin was inverted by the Acadian Orogeny. As the collision continued, the Welsh Basin received large volumes of siliclastic sediment, deposited within a continental environment (Williams and Hillier, 2004).

The sediments of the Lower ORS comprise an overall upward-coarsening succession. They begin with marginal marine, coastal floodplain, river channel and floodplain deposits which, with increased proximity to the Acadian front, progress upwards to alluvial fan deposits. These facies belts prograde southwards with the advancing orogenic front (Barclay *et al.*, 2005) and were supplied by the Laurentian hinterland, although it is also possible that there was a continuous long-distance network of rivers draining the Scottish Highlands (Simon and Bluck, 1982 and Allen and Crowley, 1983). During Ludlow to Přídolí times, there were periods of widespread and prolonged soil development, representing phases of tectonic quiescence and sediment starvation and the ultimate development of paleosols. The most well developed soil calcrete is known as the Chapel Point Limestone Member (formerly the Psammosteus Limestone), which constitutes an important regional marker horizon (Allen, 1974 and Williams and Hillier, 2004).

The oldest ORS deposits occur in southeast Pembrokeshire, where they are Wenlock to early Ludlow in age (Barclay *et al.*, 2015). In the Llandovery area, they are Gorstian in age. ORS sediments extend through the Devonian into the Early Carboniferous. However in this region, the Middle Devonian was a time of pronounced uplift and erosion associated with the Caledonian Orogeny, and is marked by an unconformity in the Anglo-Welsh Basin. An emergent landmass along the Bristol Channel during this time provided detritus for isolated alluvial fans in south-west Wales, but deposition only resumed across the rest of the Anglo-Welsh Basin during the late Devonian. The latter record the final stages of the Caledonian Orogeny and a transition to the active extensional subsidence of the Early Carboniferous. Global sea-level rise eventually flooded much of the alluvial plains and the ORS deposits pass conformably up into marine sediments of Carboniferous age. (Woodcock, 2000).

Suggested position for figure 6 a and b

Edwards and Richardson (2004) present spore evidence that the Silurian-Devonian boundary lies below the Chapel Point Limestone Member and its equivalents, highlighting the importance of this regional marker horizon in the Anglo-Welsh Basin. Allen and Williams (1981) propose the Townsend Tuff Bed, which is approximately 100 m stratigraphically lower than the Chapel Point Limestone Member, as a local approximate marker for the Silurian-Devonian boundary.

ORS Stratigraphy

The term 'Old Red Sandstone' has been in use for more than 200 years. It was introduced by Jameson in 1808, but he incorrectly applied it in the UK, believing the rocks to be equivalent to the Permian-aged Rothe Tode Liegende (Red Dead Foundation) of Germany (Jameson, 1808). Phillips (1818) was one of the earliest to correctly use the term, describing rocks of the Old Red Sandstone as underlying the Mountain Limestone Formation (Carboniferous Limestone Group) (Phillips, 1818).

Murchison was the first major supporter of the Old Red Sandstone as a geological unit. In his book, *The Silurian System*, he defines the Old Red Sandstone as "consisting of various strata of conglomerate, sandstone, marl, limestone and tilestone, the youngest beds of which dip conformably beneath the carboniferous deposits, whilst the oldest repose upon and pass into certain grey-coloured rocks.... upper part of the Silurian" Murchison (1839). Murchison recognised three major subdivisions of the Old Red Sandstone - Lower, Middle and Upper - which are retained as informal stratigraphic terms (Barclay, 2005).

Sedgwick and Murchison, based on the work of Lonsdale (Lonsdale, 1840), recognised that the marine rocks of south-west England were equivalent of the Old Red Sandstone deposits over the rest of the UK (Leveridge and Shail, 2011) and also established the term Devonian System (Sedgwick and Murchison, 1839; Becker *et al.*, 2012).

The symposium, from which these papers were derived focused on the Anglo-Welsh Basin and the Midland Valley of Scotland. The stratigraphic subdivision of these basin are summarised below.

Stratigraphic nomenclature for the Midland Valley of Scotland

The stratigraphy of the ORS of the Midland Valley of Scotland was revised in 2002 by Browne *et al.* including the addition of a new term, the Lanark Group, to include all the late Silurian to early Devonian formations in the Lanark Basin which occupy the southern Midland Valley (Figure 7). Group terminology was also revised for the northern Midland Valley to incorporate research which indicated that the Lower ORS was deposited in three sedimentary basins: Stonehaven, Crawton and Strathmore. The Upper ORS is all included in the Stratheden Group (Table 2).

Suggested position for figure 7

Suggested position for table 1

Stratigraphic nomenclature for the Anglo-Welsh Basin.

In 2015, Barclay *et al.* summarised a lithostratigraphic scheme for the non-marine Old Red Sandstone succession of the Anglo Welsh Basin, rationalising terms introduced by previous workers. Correlation between the Pembroke peninsular in the west and the main outcrop is made using two widespread marker horizons: the Chapel Point Limestone Member and the Townsend Tuff Bed. Barclay *et al.* (2015) also redefine the base of the Old Red Sandstone. Previously, this was placed at the base of the shallow marine Downton Castle and Tilestones formations, but Barclay *et al.* locally position it lower at the incoming of red- or green-bed terrestrial sediments. Table 1 (Barclay *et al.*, 2015) summarises the Old Red Sandstone succession in the Anglo-Welsh Basin, with old terms given in brackets.

Suggested position for Table 2

Contents of special issue

The contributions to this special issue review the state of current knowledge and present new information on a range of topics relating to the Old Red Sandstone in Wales and Scotland. The manuscripts are broadly arranged into sections - sedimentology, human interaction, and palaeontology.

Geraint Owen's contribution, entitled **Origin and significance of soft-sediment deformation in the Old Red Sandstone of central South Wales, UK (Owen, 2017)**, concerns the origin of vertically-orientated water-escape structures. These are the most common type of soft sediment deformation structure within sandstone-rich Brownstones and Senni formations of the Lower ORS of south Wales. The paper discusses a range of structures, some of which indicate deformation due to flood events and others which suggest widespread liquefaction in response to earthquakes.

Christian Baars' **Review of plant evolution and its effect on climate during the time of the Old Red Sandstone** (Baars, 2017) discusses the evolution of plants during the ORS and considers the impact that they likely had on atmospheric carbon-dioxide concentrations and the climate at that time.

Alain R. M. Blicek and David K Elliott present a paper entitled **Pteraspitomorphs (Vertebrata), the Old Red Sandstone, and the special case of the Brecon Beacons National Park, Wales, U.K.** (Blicek and Elliott, 2017) in which they provide an overview of the armoured, jawless fossil vertebrates – the Pteraspitomorphs - in terms of their palaeogeographic- and stratigraphic distributions. The paper describes the variations in plate anatomy between different species and describes many convergences in adaptive morphologies with ostracoderms. Palaeoecological and sedimentological analyses are presented that discuss the likely environments in which these fish lived, including their usefulness in indicating the margins of palaeocontinents.

Michael James Newman, Carole J Burrow, Robert G Davidson, Jan L den Blaauwen and Roger Jones present a paper entitled **Comparison of the vertebrate faunas of the Lower Old Red Sandstone of the Anglo-Welsh Basin with contemporary faunas in Scotland (Newman et al., 2017)**. This paper provides a comprehensive review and reappraisal of the correlation between the vertebrate faunas of the Lower Old Red Sandstone of Scotland and the Anglo Welsh Basin, with a focus on faunal similarities between the two basins.

Susan Turner, Carole J Burrow, Rod B Williams and Peter Tarrant present **Welsh Borderland bouillabaisse: Lower Old Red Sandstone fish microfossils and their significance (Turner et al., 2017)**. This contribution presents a detailed discussion of the utility of fish microfossil species as biostratigraphic markers within the Anglo-Welsh Basin. Many of the species discussed are considered to be indicative of waters of particular salinity (fresh-, brackish- or saline) and the authors discuss their environmental significance in the Anglo-Welsh succession.

Next there are two papers which illustrate the relationship between local communities and the ORS rocks and landscapes on which they live and work. Elliot Carter, Elizabeth Andrews and Katherine Andrew present a paper entitled: **The provenance, petrology and sedimentology of building stone in 2 Bromyard, Herefordshire, UK** (Carter et al., 2017) which describes a multi-disciplinary approach to tracing the original quarries that provided building stones for Bromyard, Bromyard Downs and Bringsty Common, an area of west Midland England and the English/ Welsh borderland. They also discuss how variation in local facies adds a level of complexity to the correlation of building stones and quarries. Tony Ramsay presents a paper entitled: **Fforest Fawr Geopark - a UNESCO Global Geopark distinguished by its geological, industrial and cultural heritage (Ramsey, 2017)**. Fforest Fawr Geopark is predominantly underlain by rocks of the ORS and the landscape is dominated by the effects of glacial activity acting on these sediments. This paper describes the importance of geoparks and the impact that they have on their local businesses and communities.

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Appendix 1.

A) In addition to the papers presented in this volume the following presentations were given (abstracts available on the SWGA website) and thanks is given to them: -

Brian Williams, The Lower Old Red Sandstone Continent: Wales and Beyond

Anthony Brook, Murchison and Miller: Contrasting founders of the Devonian or Old Red Sandstone

Toby Driver, Old Red Sandstone landscapes in Wales: the view from the air

Jennifer Morris, Colonisation of the Old Red Sandstone Continent: recent advances in early land plant research from the Welsh Borderland

Duncan Hawley, the Old Red Sandstone of the Black Mountains of Powys & Herefordshire: Filling the 'Black Hole'

John Davies, the identification of mappable, litho-stratigraphical sub-divisions of the Brownstones across its outcrop

Allan Cuthbertson, The ORS from the air.

Kester & Elizabeth Webb, The hidden edge of Exmoor, north Devon – low level aerial photographs and topographical drawings

B) Field trips were led by the following who are also thanked: -

Duncan Hawley, The Old Red Sandstone of the Black Mountains Tredomen Quarry, Cockit Hill and Tremynfa Quarry

John Davies, Fan Fawr and Blaen Llia

Jana Horak and John Davies, The Building Stones of Brecon Town

C) Groups and individuals who put on displays are thanked: -

South Wales Geologist's Association

Geologists Association National Body

National Museum of Wales

Teme Valley Geological Society

Woolhope Naturalists' field club

British Geological Survey Welsh Office

Forest Fawr Geopark

OUGS Severnside Branch

SE Wales RIGS group

Geoworld Travel

Natural Resources Wales

Mid Wales geology Club

Hereford and Worcester Earth Heritage Trust

Welsh Borders Early Vertebrate Research Group

Kester and Elizabeth Webb

Colin Humphrey

Mike Featherstone

Peter Tarrant & Maggie Rowlands

D) The organizers would like especially thank the following people for their direct work on the event:

-

Stephen Howe, Alan Bowring, Geraint Owen, Hazel Trenbirth, Janet Hiscott, Rhian Kendall, Cindy Howells, Lynfa Lewis, Brian Drew. Marnix Roels, Toby Small, Clive Williams, Judith Harvey, Ron Layton.

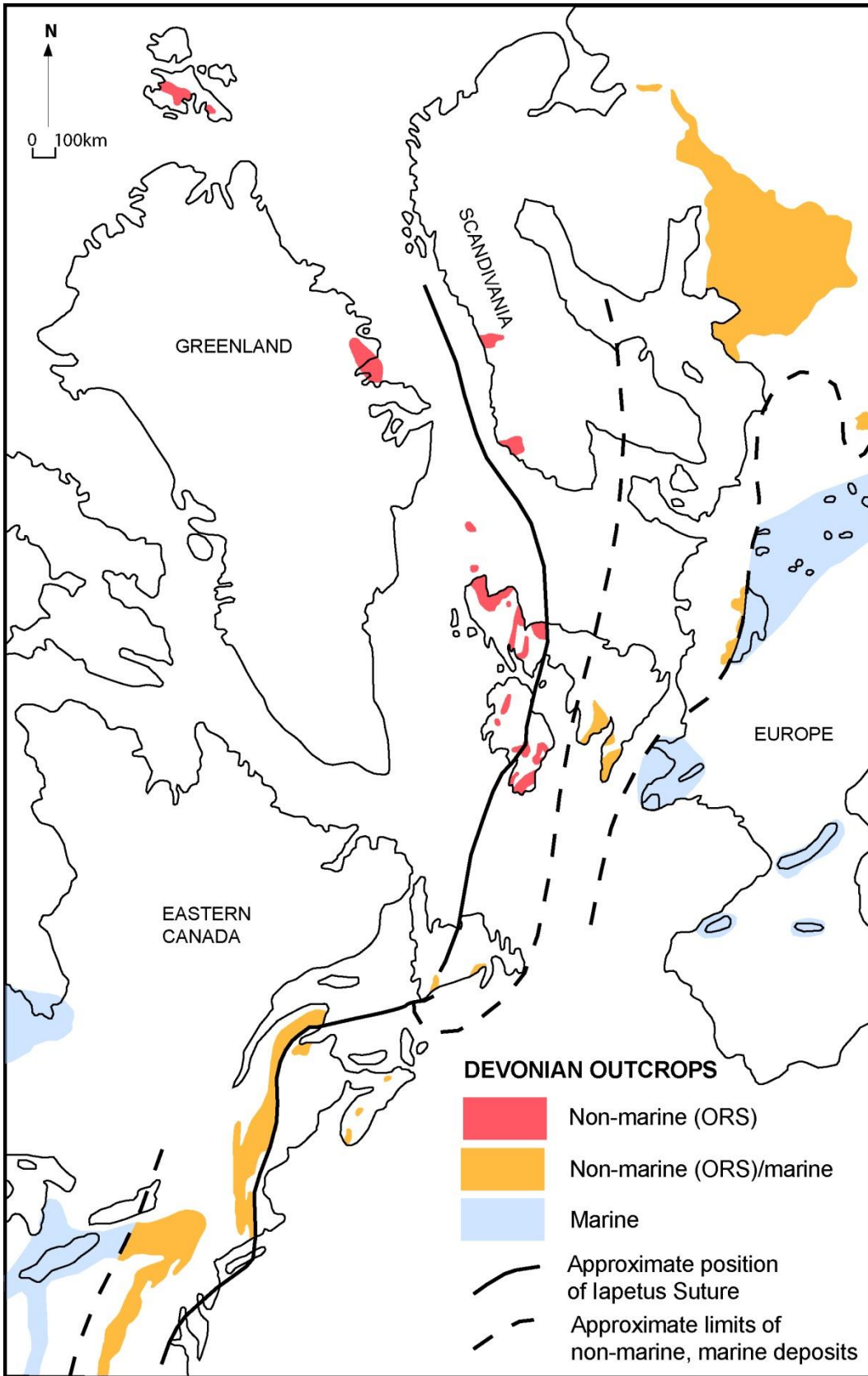


Figure 1 North Atlantic Devonian Basins (after Friend 1969, Dinley 1984 and Miall 2000)

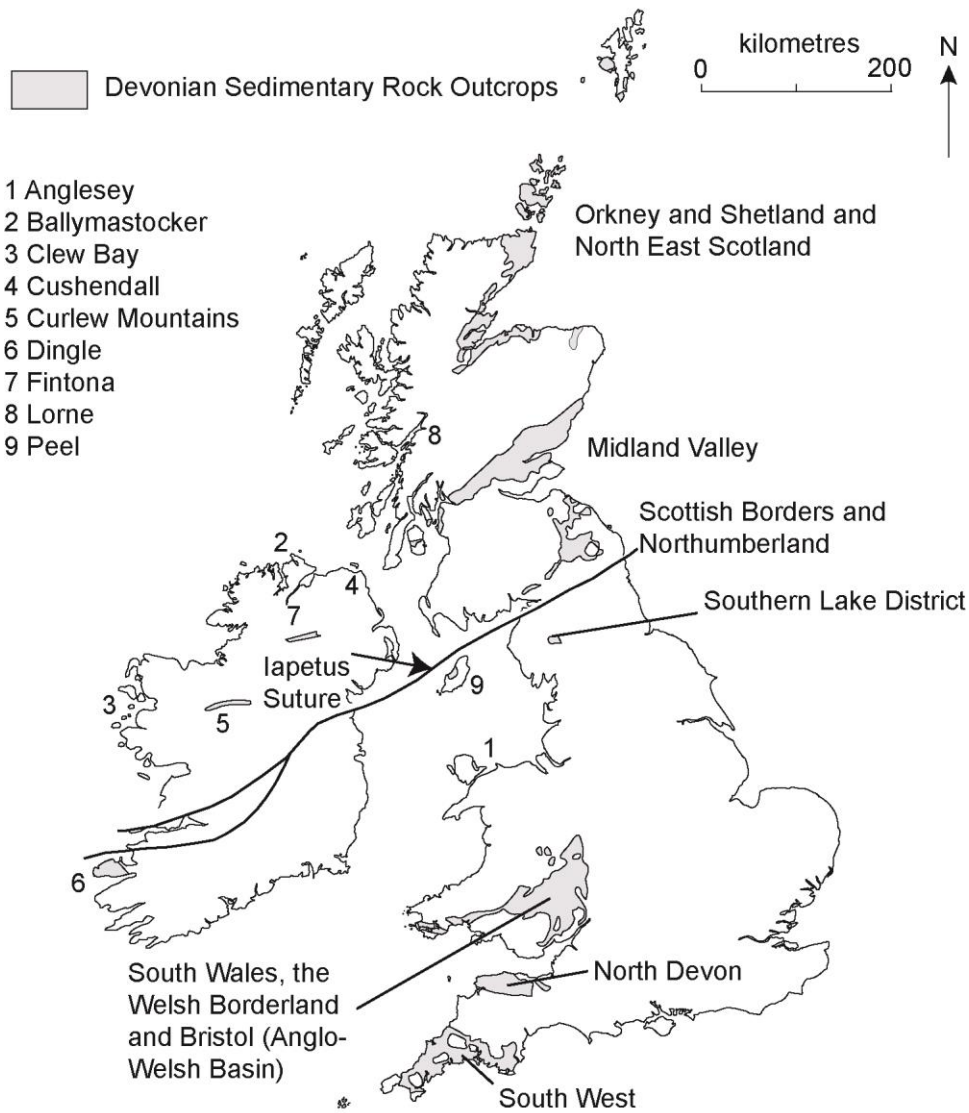


Figure 2 Distribution of Devonian sedimentary rocks in Britain and Ireland (After Barclay *et al.*, 2005 and Woodcock, 2012a)

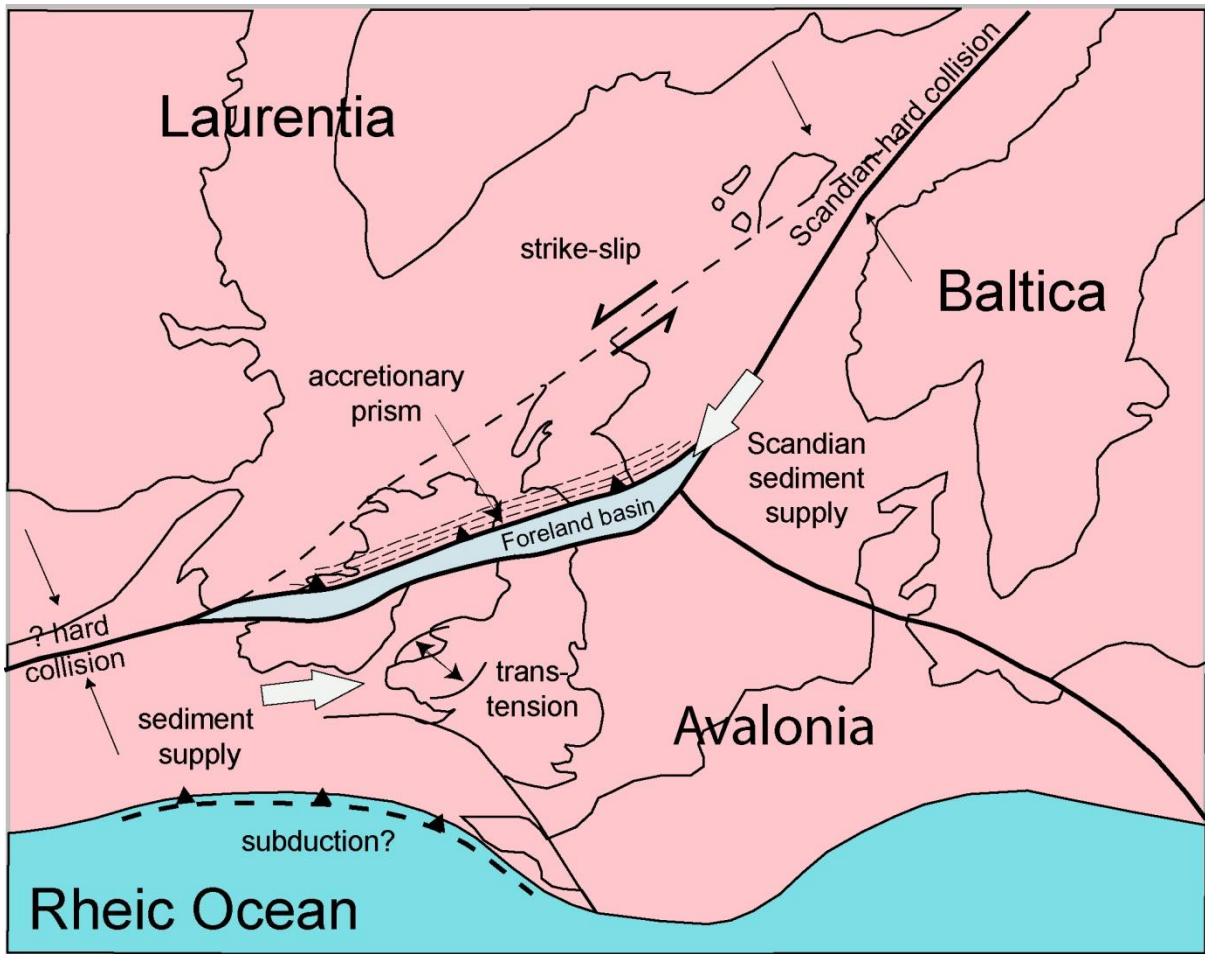


Figure 3 Palaeogeography of the closure of the Iapetus Ocean in early to mid-Silurian time. After Woodcock (2012b)

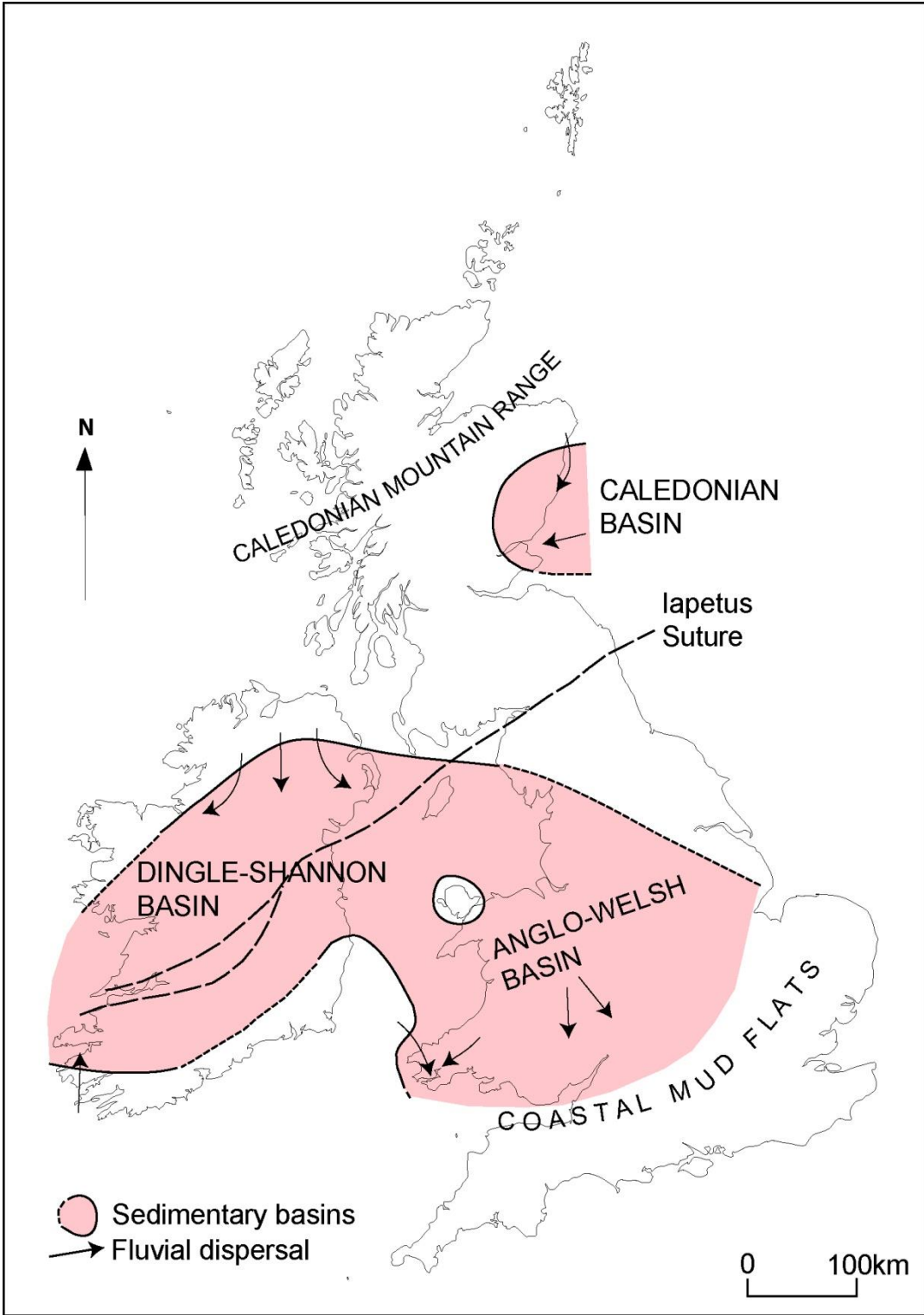


Figure 4a

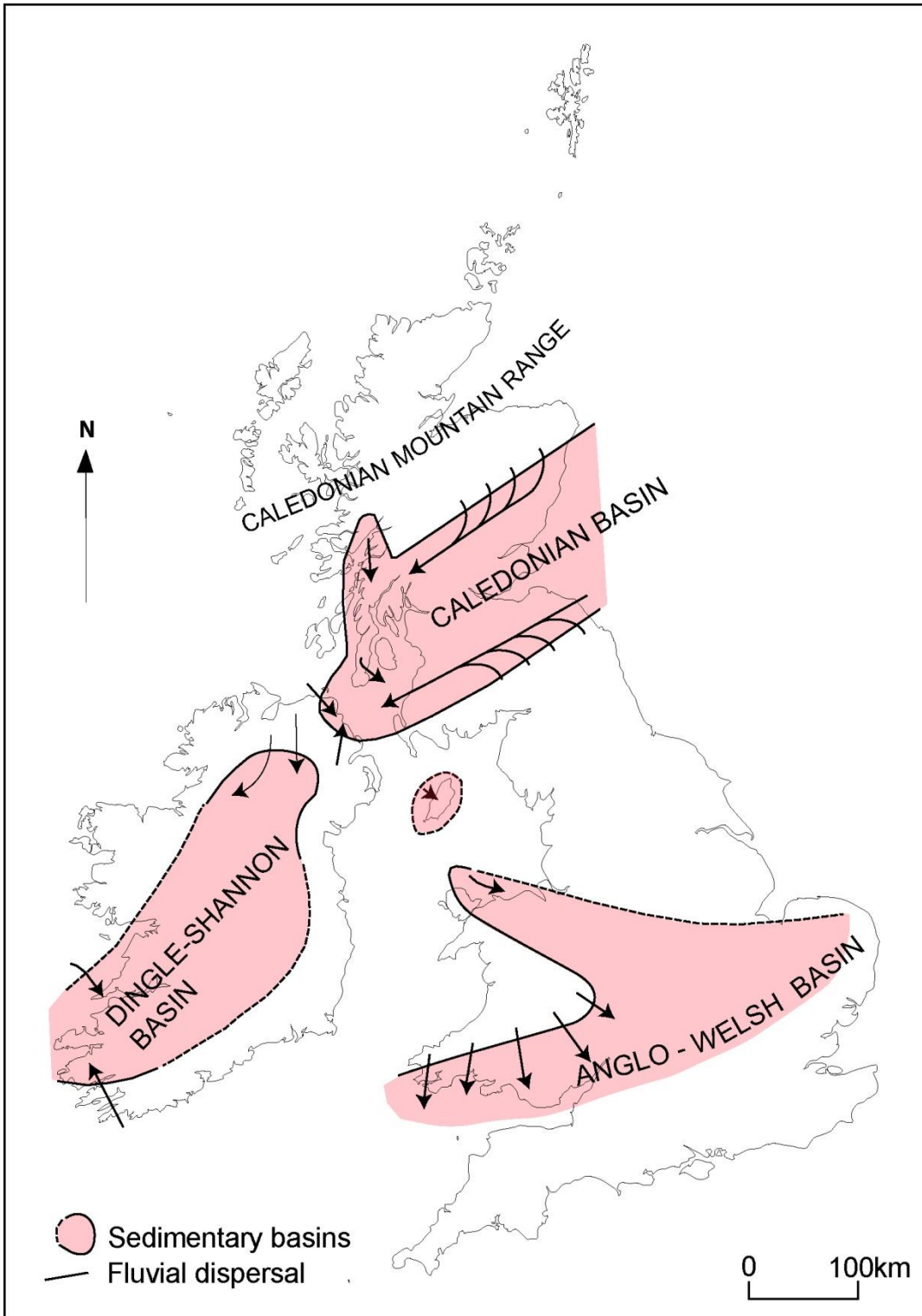


Figure 4b

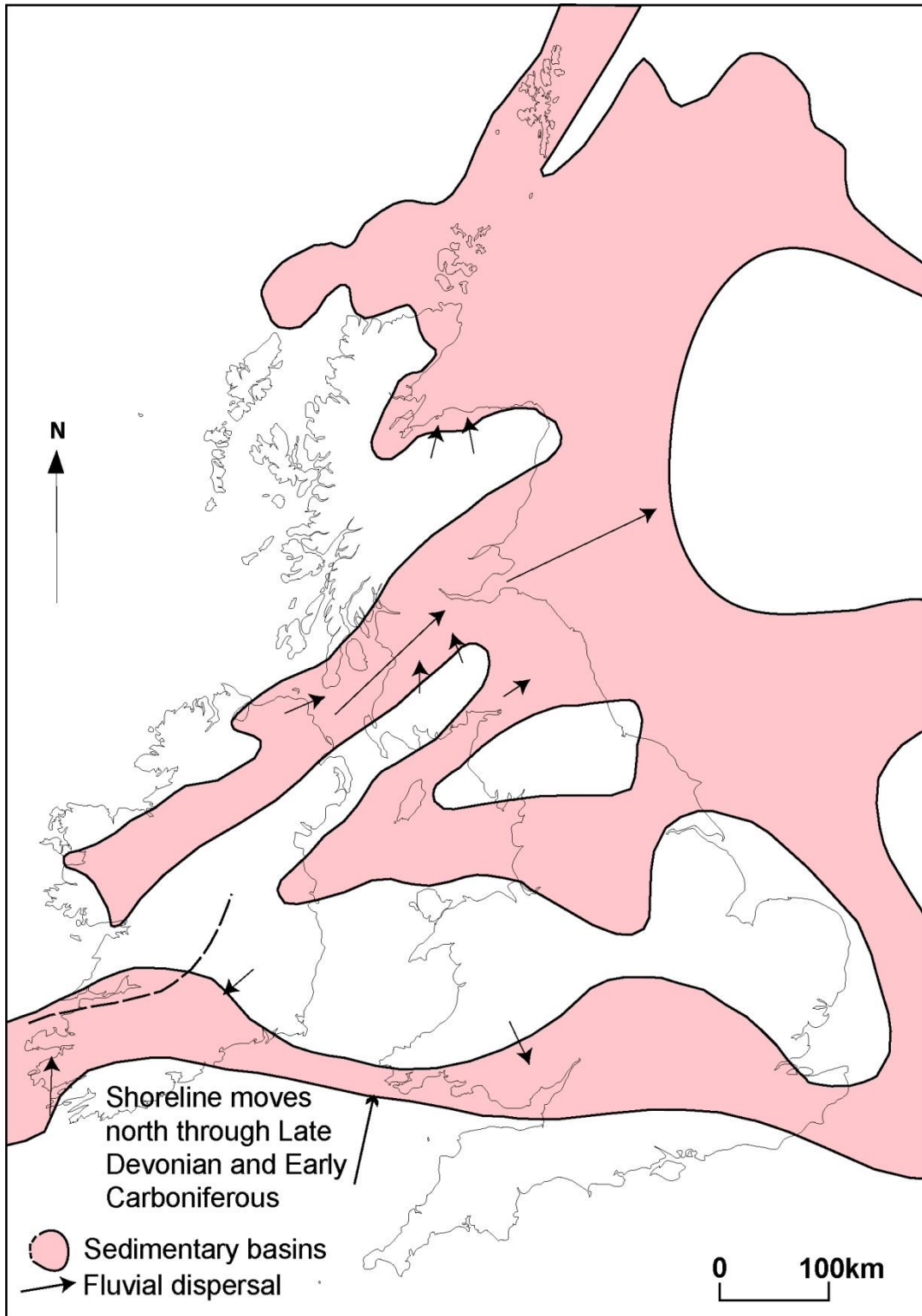


Figure 4c

Figure 4 Likely position of sedimentary basins and direction of fluvial dispersal (a) Mid Přídolí, (b) Mid to Late Lochkovian (after Allen and Crawley, 1983 and Marriot and Hiller, 2014), (c) Late Devonian (after Ziegler, 1990)

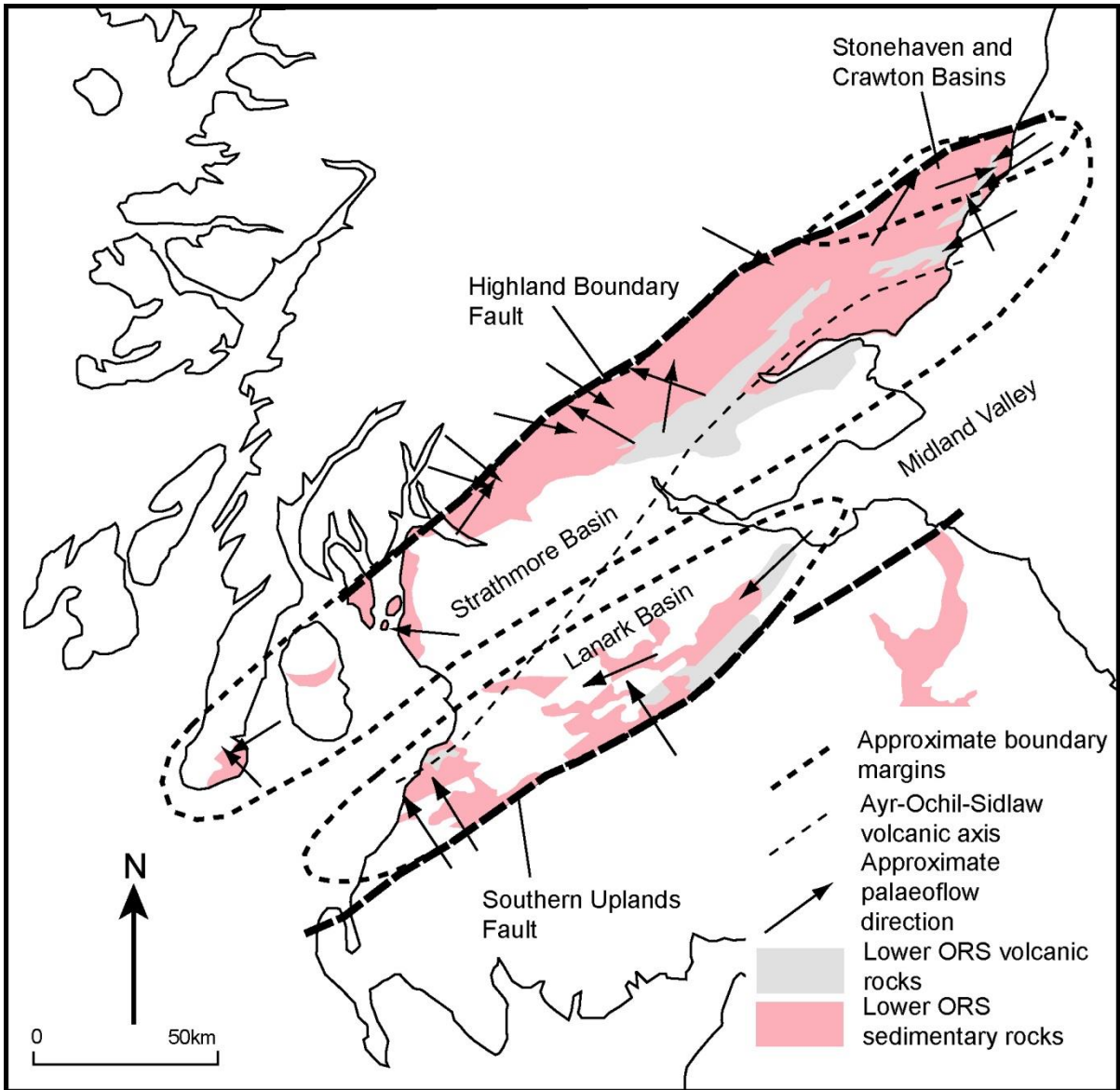


Figure 5 Lower ORS of the Midland Valley of Scotland (after Woodcock 2012a, Bluck, 2000).

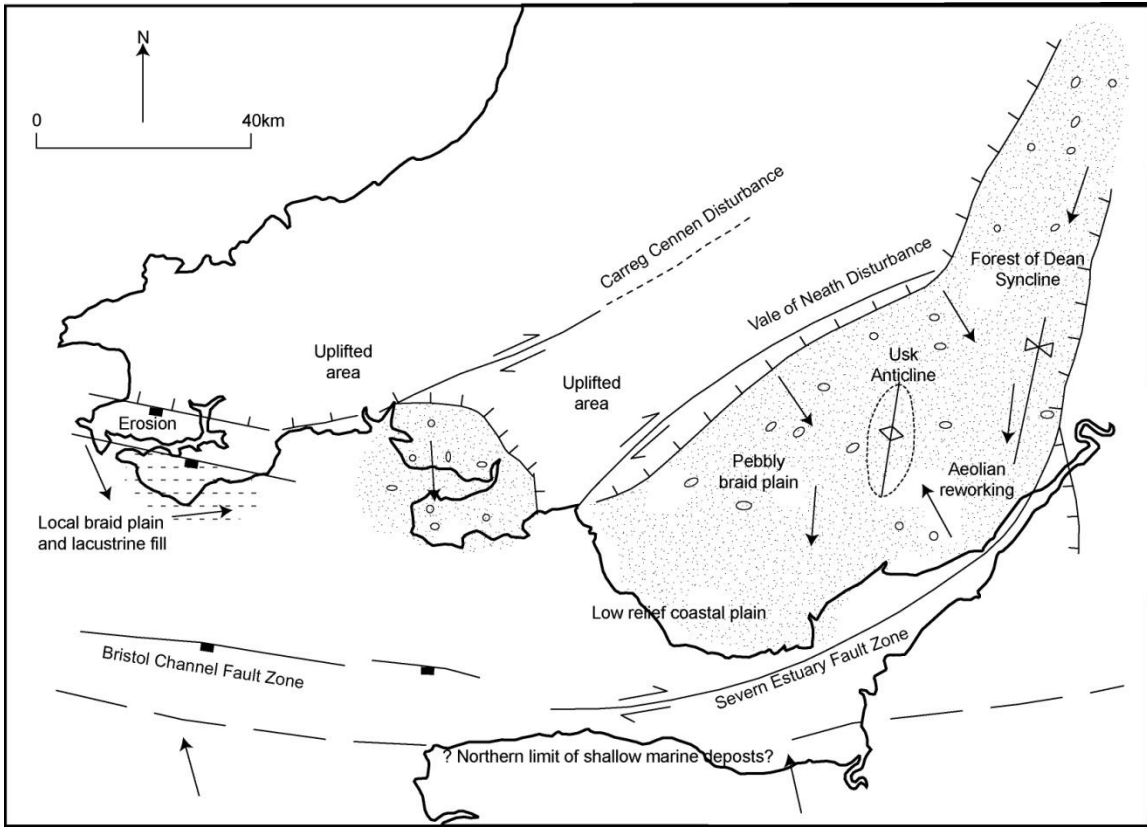


Figure 6a

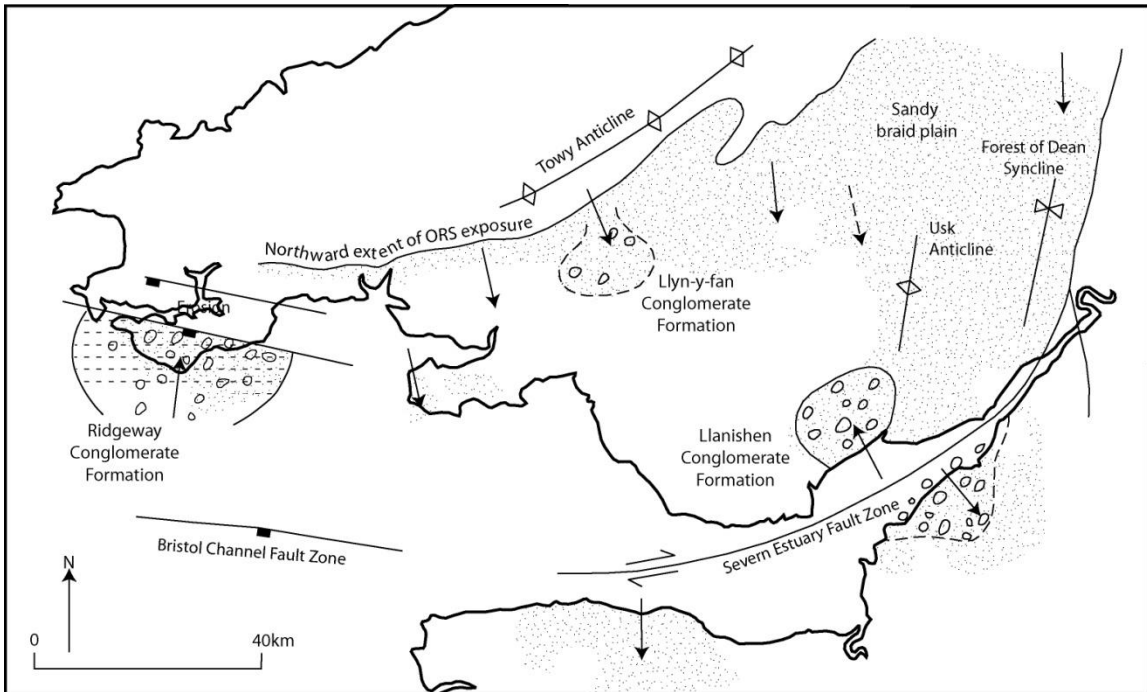


Figure 6b

Figure 1. a Latest Lower ORS palaeogeography of south Wales, indicating presumes tectonic controls and sediment sources After Hillier and Williams 2006, Tunbridge (1981 and 1986) and Wilson *et al.* (1988). b Upper ORS palaeogeography of South Wales and intra-basinal tectonism (after Lovell 1978, Wilson *et al.*, 1988, Marshall 2000a and b and Hiller and Williams 2006)

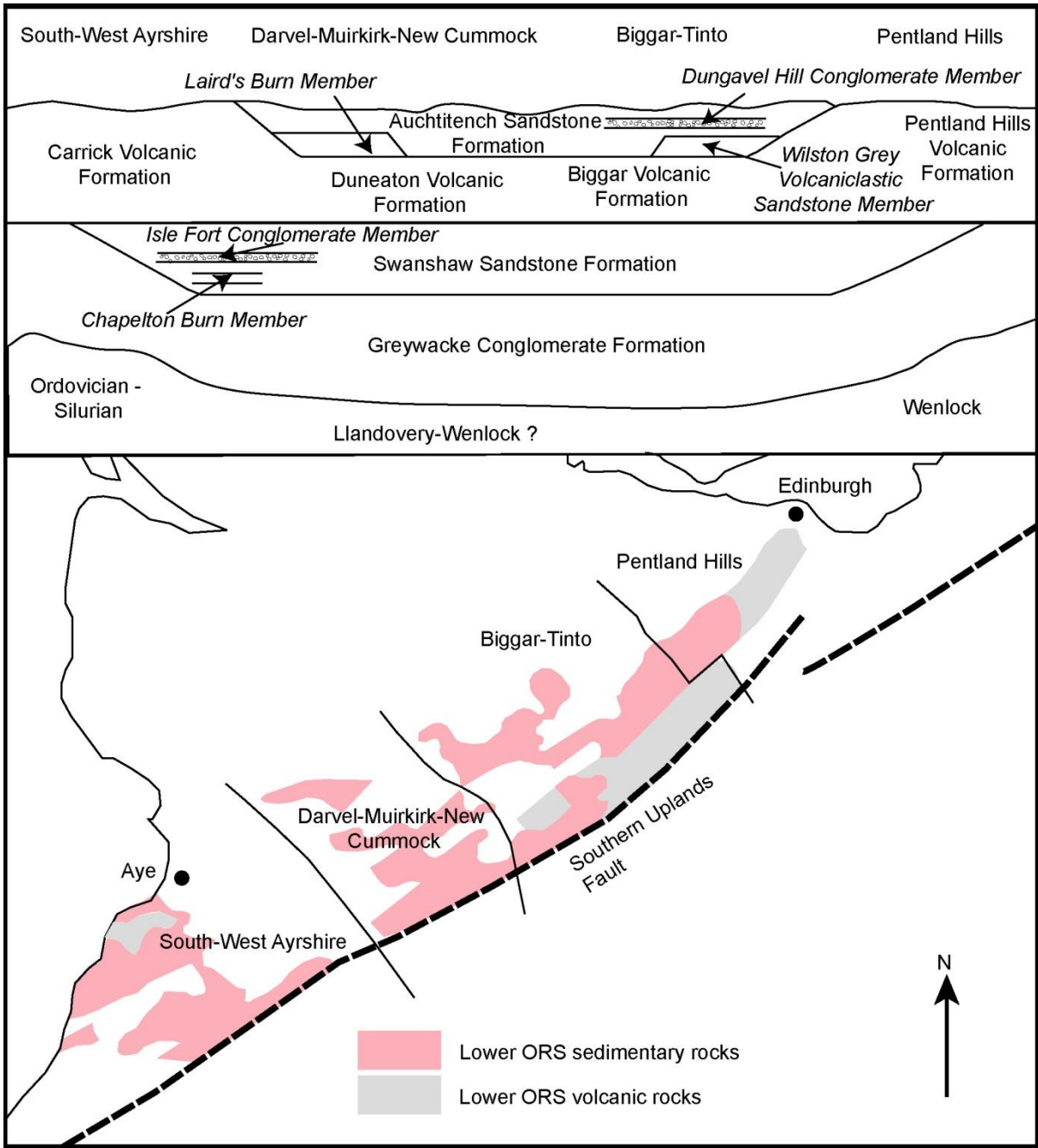


Figure 7 Lanark Group of the Southern Midland Valley of Scotland (Browne *et al.*, 2005)

	Callander- Aberfoyle	Stirling- Perth- Dundee	Blairgowrie- Edzell	Stonehaven- fettercairn	
Lower Devonian	Teith Sandstone Formation	Teith Sandstone Formation	Teith Sandstone Formation	Teith Sandstone Formation	Strathmore Group
			Gannochy Conglomerate Formation		
	Cromlix Mudstone Formation	Cromlix Mudstone Formation	Cromlix Sandstone Formation	Cromlix Sandstone Formation	
	Ruchill Flagstone Formation	Scone Sandstone Formation	Scone Sandstone Formation	Deep Conglomerate Formation	Arbuthnott- Garvock Group
	Craig of Monievreckie Conglomerate Formation	Dundee Flagstone Formation	Craighall Conglomerate Formation	Montrose Volcanic Formation	
Ochil Volcanic Formation		Catterline Conglomerate Formation			
Silurian			Lintrathen Tuff Member	Crawton Volcanic Formation	Dunnottar- Crawton Group
				Whitehouse Conglomerate Formation	
				Gourdon Sandstone Formation	
				Tremuda Bay Volcanic Formation	
				Dunnottar Castle Conglomerate Formation	
			Carron Sandstone Formation	Stonehaven Group	
			Cowie Sandstone Formation		

Table 1 Late Silurian to Early Devonian stratigraphy of the northern Midland Valley of Scotland (Browne *et al.*, 2005).

Geological Period	UPPER DEVONIAN				MIDDLE DEVONIAN				LOWER DEVONIAN				SILURIAN			
	Famennian	Frasnian	Givetian	Middle Old Red Sandstone Group	Bracon Subgroup	Beacon Subgroup	Bracon Subgroup	Bracon Subgroup	Emsian	Fragian	Lochkovian	Lochkovian	Lochkovian	Pridoli series	Pridoli series	Pridoli series
WEST MIDLANDS	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Farrow Sandstone Formation				Tintern Sandstone Formation (TSP) Huntham Hill Conglomerate Formation (HHCF)				Brownstones Formation				Freshwater West (St. Maughans) Formation			
WEST OF MALVERNS	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
FOREST OF DEAN	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				TSP HHCF				Brownstones Formation				Freshwater West (St. Maughans) Formation			
EAST OF RIVER SEVERN	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
SOUTH-EAST WALES	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
NORTH-EAST CROP OF SOUTH WALES COALFIELD	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
CENTRAL SOUTH WALES	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
PEMBROKESHIRE NORTH OF RITEC FAULT	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
PEMBROKESHIRE SOUTH OF RITEC FAULT	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
CENTRAL WALES	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			
ANGLESEY	CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS				CARBONIFEROUS			
	Beacon Subgroup				Portlathhead Subgroup				Brownstones Formation				Freshwater West (St. Maughans) Formation			

Table 2 Old Red Sandstone succession in the Anglo-Welsh Basin (Barclay *et al.*, 2015)