THE GLOBAL DEVONIAN, CARBONIFEROUS AND PERMIAN CORRELATION PROJECT: A REVIEW OF THE CONTRIBUTION FROM GREAT BRITAIN

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A contribution on the lithostratigraphy and palaeoenvironments of Devonian, Carboniferous and Permian successions onshore in Great Britain, prepared for an international project, is summarised with particular reference to south-west England. Devonian and Carboniferous successions present in that region occur in the Rhenohercynian Tectonic Zone, to the south of the Variscan Front (VF), and their complexity reflects formation in six composite basins. They differ substantially from contemporaneous successions north of the VF. Whereas Devonian successions south of the VF are largely marine, those to the north are continental. Carboniferous successions south of the VF are predominantly marine, but shallow-water and deltaic facies occur in the highest formations. North of the VF, marine conditions were superseded by paralic and continental sedimentation. Erosion, following Variscan tectonism, resulted in the Permian successions generally resting unconformably upon older Palaeozoic rocks. In south-west England a continental succession may extend, with depositional hiatuses, from the latest Carboniferous to the Late Permian and is the most complete Permian succession in Great Britain. However, the position of the Permian–Triassic boundary in the south-west, and elsewhere in the country, is not yet resolved.

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INTRODUCTION

The Global Devonian-Carboniferous-Permian (DCP) Correlation project arose from international collaboration on the *Stratigraphische Tabelle von Deutschland 2002* (Deutsche Stratigraphische Kommission, 2002). It was organised by Manfred Menning (Potsdam) and Jörg Schneider (Freiberg) in support of Deutsche Forschungsgemeinschaft (DFG) programme SPP 1054 (Evolution of the system Earth during the Late Palaeozoic in the light of sediment geochemistry). The objective was the creation of *DCP 2003*, a global correlation chart of Devonian, Carboniferous and Permian sequences, utilising all available means of dating and correlation.

Menning approached the first author in May 2003 regarding a contribution on British Permian successions, and suggested that others in the British Geological Survey (BGS) might also contribute to a version of *DCP 2003* to be presented at Utrecht in August 2003. Meaningful representation of British onshore successions was dependent upon revisions of lithostratigraphical nomenclature and dating which were not completed before that meeting and a project workshop in Potsdam in October 2003, or in time for inclusion in a version of *DCP 2003* displayed at the International Geological Congress (IGC) in Florence in 2004. The complexity of the British successions necessitated a doubling of the space originally allocated on the DCP chart, but space limitations still precluded representation of all sequences, notably the Carboniferous of South Wales. The resulting contribution was submitted in 2008 and, with minor amendments made in April 2012, was incorporated in an updated chart exhibited at the IGC in Brisbane in August 2012. It is anticipated that the full results of the project will be published in 2013.

In the DCP chart successions will be depicted in relation to a timescale, and colour used to indicate palaeoenvironments. In this review the lithostratigraphy is depicted schematically in relation to chronostratigraphical units (Figures 1-3), and palaeoenvironments are noted in the text. Detailed information on the successions, including such aspects as their biostratigraphy, is given, together with further bibliographical sources, in the references cited at the beginning of each section.

DEVONIAN SUCCESSIONS

Successions to the south and north of the VF (Figure 1) have been compiled by B.E. Leveridge and W.J. Barclay, respectively (see: Barclay *et al.*, 2005, in prep.; Leveridge, 2011; Leveridge and Shail, 2011a, b; Whittaker and Leveridge, 2011).

Successions south of the VF are complex, reflecting their formation in six composite basins; from south to north, the Gramscatho, Looe, South Devon, Tavy, Culm and North Devon basins. Successions in the Gramscatho Basin occur in four northward- directed nappes, and in the underlying parautochthon. The Lizard Nappe includes oceanic lithosphere and pre-rift basement that was obducted onto the northern continental margin of the oceanised basin during latest

Devonian–early Carboniferous collision. Deep-water flysch sequences occur in the other nappes, with allochthonous Gramscatho Group deposits present in the Dodman, Veryan and Carrick nappes, and generally more distal Gramscatho Group deposits forming the parautochthon of the northern margin.

The Looe, South Devon, Tavy and Culm basins, and their sub-basins, developed sequentially northwards by rifting of the extending passive margin of the Gramscatho Basin. Each basin is characterized by its own succession, but there is some overlap between basins. In the Looe Basin the terrestrial Dartmouth Group is succeeded by shallow-water marine and paralic deposits of the Meadfoot Group, and part of the deeper-water marine Saltash Formation that is developed mainly in the South Devon and Tavy basins. The South Devon and Tavy basins are constrained by the elevated edges of half-graben blocks or residual horsts; both contain deep-water marine mudstones of the Saltash Formation, and shallow-water marine successions, such as reefal carbonates and condensed cephalopodic limestones, deposited on 'highs'. The Culm Basin is a graben complex that was closed by northward-prograding deformation; only latest Famennian sediments are present, represented by deep-water marine and mixed deep- and shallow-water marine deposits at the base of the largely Early Carboniferous Boscastle and Hyner Mudstone formations, respectively. In the North Devon Basin major transgressive–regressive cycles formed on the non-rifted passive margin. Here, the shallow marine Lynton Formation is succeeded by the coarse-grained, terrestrial Hangman Sandstone Formation. This is, in turn, overlain by a predominantly shallow marine sequence, comprising the Ilfracombe and Morte Mudstone formations. The latter is succeeded by the Pickwell Down Sandstone Formation which passes upwards into paralic deposits in the Upcott Mudstone and Baggy Sandstone formations. The overlying mixed, shallow- to deep-water marine Pilton Mudstone Formation is largely Early Carboniferous in age (Figure 2).

Conodonts provide biostratigraphical control in limestone successions and, together with palynomorphs, ammonoids and ostracods, give sporadic biostratigraphical control in basinal deposits.

North of the VF, Devonian successions in the Anglo-Welsh Basin comprise red-bed terrestrial deposits of the Daugleddau Group, of Late Silurian (Ludfordian) to Emsian age, and the Late Devonian Brecon Beacons Group; strata of Eifelian to Frasnian age are missing. A similar situation occurs in the Midland Valley, Scotland, where the Lochkovian to Emsian succession consists of coarse- and some fine-grained terrestrial deposits of the Arbuthnott-Garvock and Strathmore groups (Figure 1). The former includes the Ochil Volcanic Formation and overlies the partly pre-Devonian Dunnottar-Crawton Group. Farther north, in the Orcadian Basin, only an incomplete Pragian to Emsian sequence, and one spanning Eifelian to Frasnian time, are present (Figure 1). The Pragian to Emsian succession is represented by predominantly coarse-grained terrestrial formations that constitute the Sarclet Group. The Eifelian to Frasnian succession comprises the predominantly fine-grained terrestrial deposits of the Lower Caithness Flagstone Group, which includes the Achannaras Limestone, and the Upper Caithness Flagstone Group. The succeeding coarse-grained

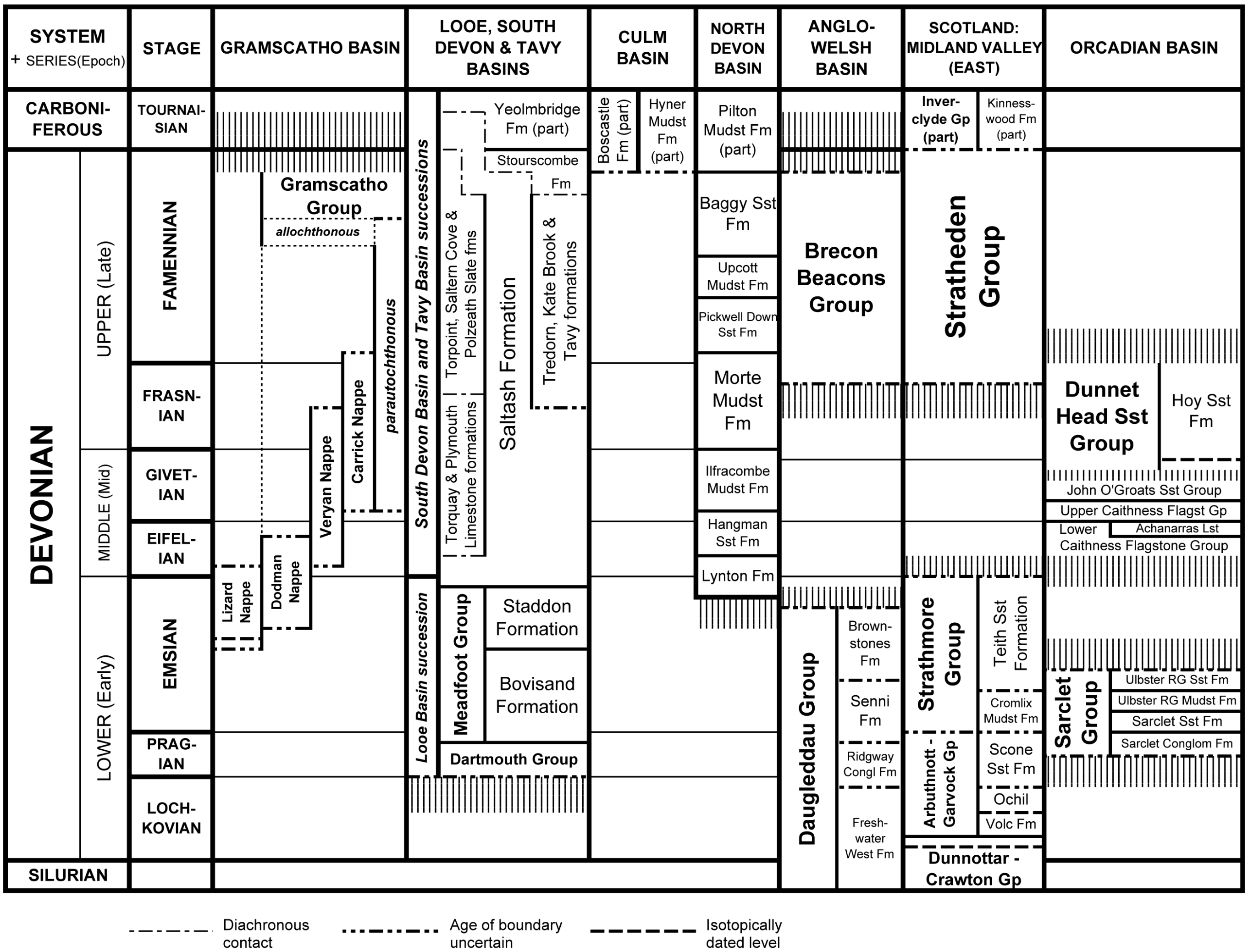

Figure 1. *Outline lithostratigraphy and correlation of Devonian successions. (Ulbster RG - Ulbster Riera Geo [Mudst/Sst Fm]).*

John O'Groats Sandstone Group is separated by a minor intra-Givetian unconformity from coarse-grained terrestrial deposits of the overlying Dunnet Head Sandstone Group, which includes the Hoy Lavas.

Miospores and microinvertebrates provide biostratigraphical control, and there is a low-resolution fish biozonation in the Orcadian Basin. Age control is provided by isotopic dates from volcanics in the Dunnottar-Crawton Group and the Ochil Volcanic and Hoy Sandstone formations.

Carboniferous successions

Successions to the south and north of the VF (Figure 2) have been compiled by B.E. Leveridge and C.N. Waters, respectively (see: Leveridge and Hartley, 2006; Waters *et al.*, 2009, 2011; Dean *et al.*, 2011; Waters and Condon, 2012).

South of the VF deep-water marine facies predominate. The succession in the South Devon and Tavy basins spans the Tournaisian, Visean and Serpukhovian stages. Shallow-water marine deposits (Yeolmbridge Formation) of the lower Tournaisian are followed by the deep-water marine Winstow Chert Formation, which is succeeded by proximal turbidites of the Ugbrooke Sandstone Formation. In the Culm and North Devon basins the successions extend higher, into the Moscovian in the former and the Bashkirian in the latter. Mixed deep- and shallow-water marine facies occur in the lower Tournaisian Hyner and Trusham Mudstone formations in the Culm Basin, and in the lower part of the Pilton Mudstone Formation in the North Devon Basin (Figure 2). The remainder of the succession in the North Devon Basin is of deep-water marine origin, but paralic facies developed in the highest units in the Culm Basin, the Bideford and Bude formations, as it inverted during ongoing closure. Palynomorphs, ammonoids, ostracods and conodonts give sporadic biostratigraphical control on these successions.

North of the VF, in the Pennine Basin, shallow marine carbonates of the late Tournaisian Bowland High Group formed on tilt-block highs, and deep marine suspension deposits of the largely Visean Craven Group infilled half-grabens. In Serpukhovian to Moscovian times evolution of a thermally-subsiding basin, on which glacio-eustatic changes were superimposed, coincided with a transition to paralic

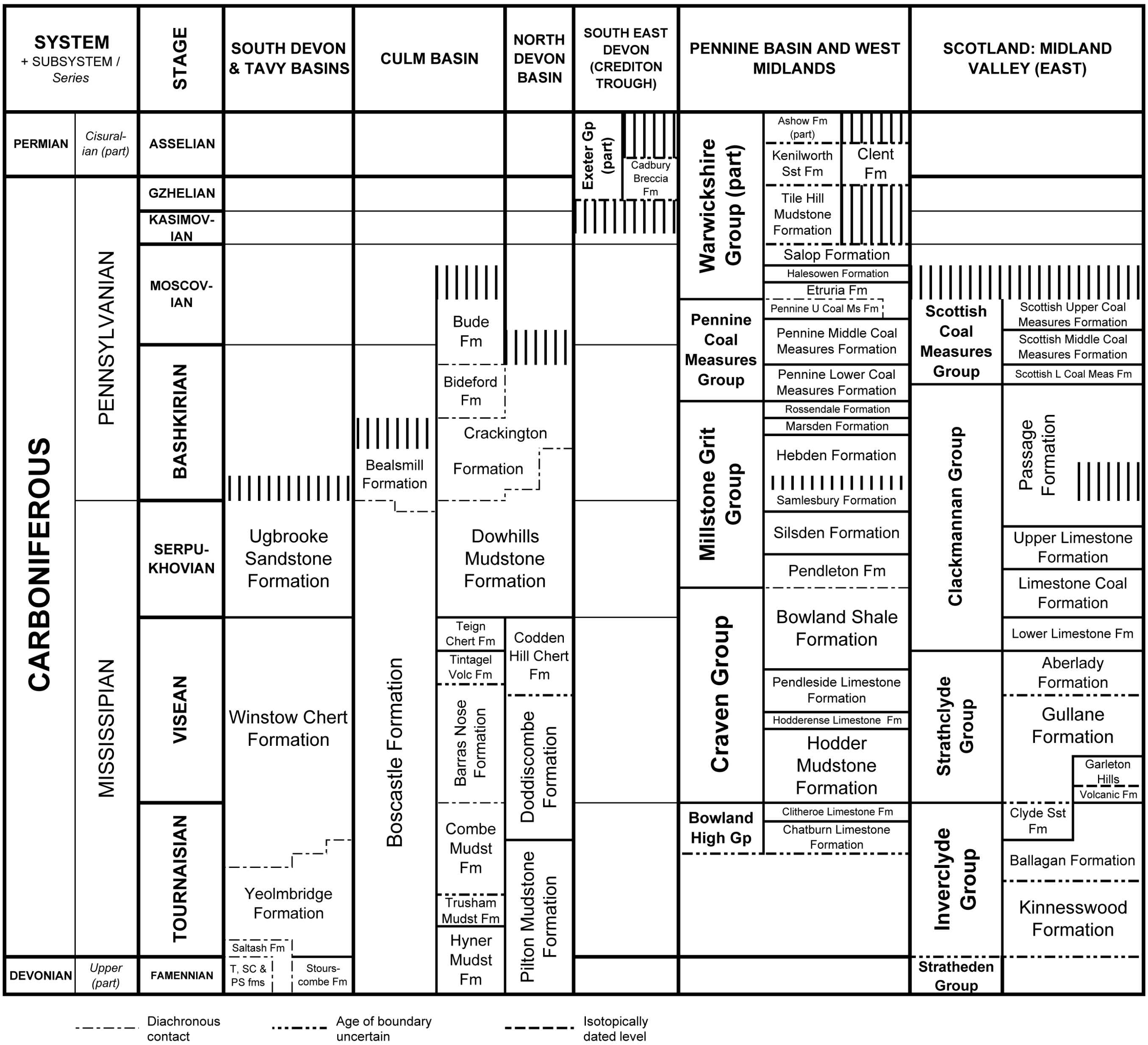

Figure 2. *Outline lithostratigraphy and correlation of Carboniferous successions. (T, SC & PS fms - Torpoint, Saltern Cove & Polzeath Slate formations).*

sedimentation, producing the Millstone Grit and Pennine Coal Measures groups. Later, a change to humid, tropical, and subsequently to semi-arid conditions in late Moscovian to Kasimovian–Gzhelian times resulted in a transition to terrestrial red-beds of the Warwickshire Group which extends up into the Permian (Figure 3).

In the Midland Valley in Scotland, the Tournaisian Inverclyde Group includes the alluvial Kinnesswood Formation, followed by mixed marine and terrestrial deposits (Ballagan Formation). The remainder of the succession is dominated by paralic (Strathclyde and Scottish Coal Measures groups) and mixed marine and terrestrial facies (Clackmannan Group) that reflect glacio-eustatic changes imposed on variable basin subsidence caused by displacement across Caledonoid faults. Ammonoid-bearing marine bands provide biostratigraphical control in Visean to early Westphalian successions in the Pennine Basin, but miospores are more important in the Midland Valley. The Silsden and Pennine Middle Coal Measures formations in the former area, and volcanics in the latter, have been dated isotopically.

Permian successions

Permian successions (Figure 3) have been compiled by the first author (see: Smith, 1995; Benton *et al.*, 2002; Glennie, 2002; Warrington, 2005, 2008; Hunt and Lucas, 2006; Bachmann *et al.*, 2010; Peryt *et al.*, 2010; Barton *et al.*, 2011).

In south-west England the Variscan orogenic episode was followed by erosion and north-south extension accompanied by plutonic and associated igneous activity that was contemporaneous with the deposition of continental sediments on an eroded surface of folded pre-Permian rocks, the youngest of which is early Moscovian (Bolsovian) in age. The continental succession includes the Exeter and succeeding Aylesbeare Mudstone groups. The former consists largely of coarse-grained, proximal fluvial deposits that grade laterally into finer-grained distal facies, but includes a largely aeolian unit, the Dawlish Sandstone, near the top. The Aylesbeare Mudstone Group formed under alternating lacustrine and desiccated mudflat conditions in an arid to semi-arid, sabkha-playa environment.

The Cadbury Breccia, the lowest unit in the Exeter Group, may be partly latest Carboniferous in age, but the lower part of the remainder of the group is, from isotopically dated volcanics,

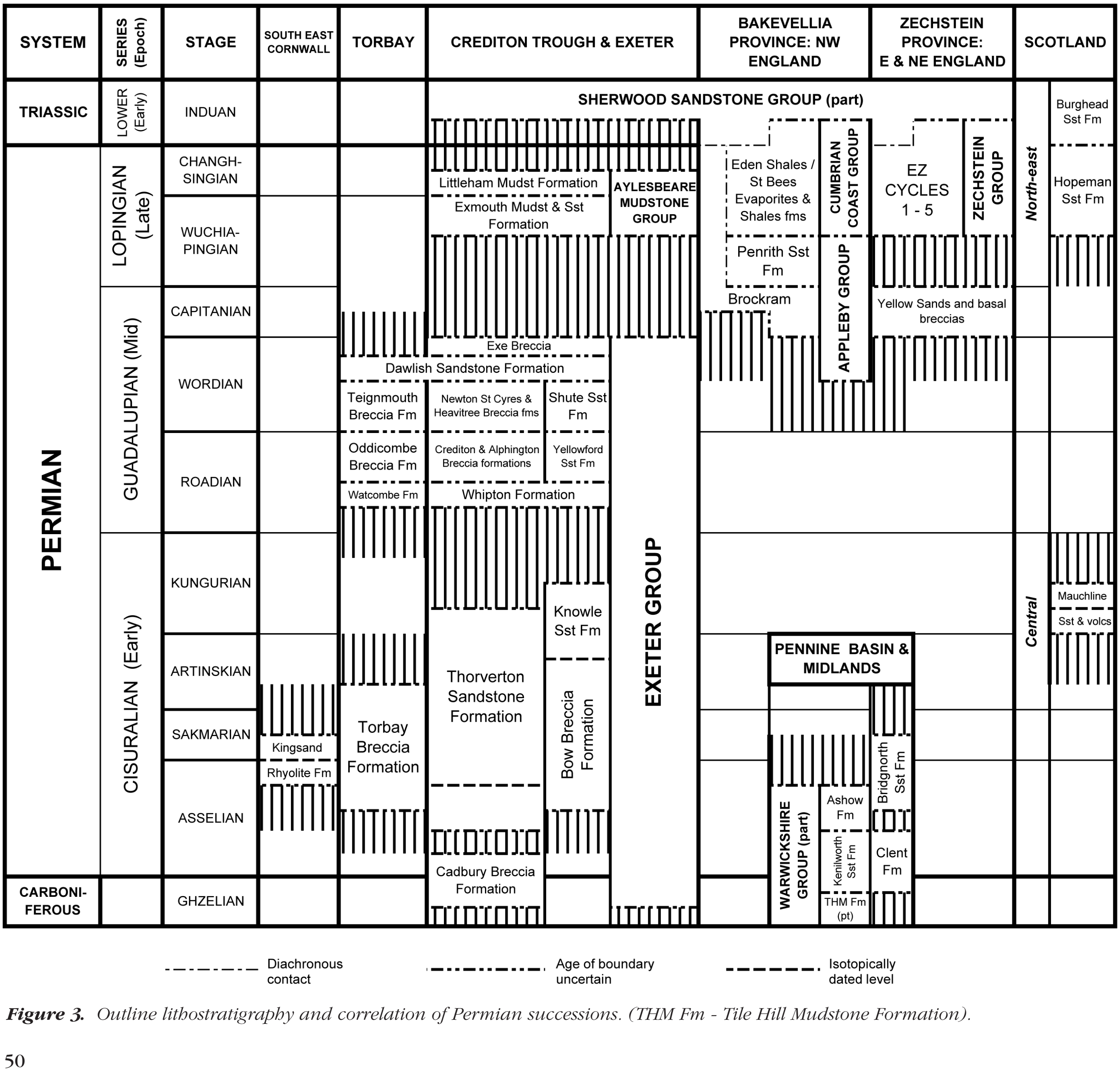

Figure 3. *Outline lithostratigraphy and correlation of Permian successions. (THM Fm - Tile Hill Mudstone Formation).*

Early Permian. This is succeeded unconformably by a sequence that, on palynological and magnetostratigraphical evidence, is Mid-Permian. Deposition of the Early Permian succession was contemporaneous with two phases of acid igneous intrusion that resulted in the Cornubian Granite Batholith. The earlier intrusions were rapidly exposed and contributed debris to the Early Permian part of the group; those of the later phase contributed to the Mid-Permian part.

The Aylesbeare Mudstone Group is separated from the underlying Exeter and overlying Sherwood Sandstone groups by unconformities and is interpreted, on magnetostratigraphical evidence, as Late Permian (Figure 3). The position of the Permian-Triassic boundary is unresolved, there being no evidence for the age of units in the Sherwood Sandstone Group below the Mid-Triassic Otter Sandstone Formation.

In Central England, limited palaeontological evidence indicates that the terrestrial red-beds of the Warwickshire Group extend up into the Early Permian but such evidence is lacking from other units in this region, such as the Bridgnorth Sandstone Formation, that are commonly regarded as Permian.

In north-east England the Zechstein Group comprises a succession of carbonate and evaporite cycles deposited on the western margin of a marine and evaporite province that extended eastwards as far as Poland. These deposits are, on conodont evidence, Late Permian in age. They rest unconformably on the predominantly aeolian Yellow Sands, which lack evidence of age and which, in turn, rest on basal breccias that are unconformable on older rocks. The highest Zechstein cycle is succeeded by the Sherwood Sandstone Group; the boundary is diachronous, becoming younger to the east. There is no evidence for the position of the base of the Triassic within this succession. A comparable situation occurs in north-west England where the Cumbrian Coast Group includes cyclic deposits with carbonates and evaporites that have correlatives in the Zechstein Group. This sequence overlies the Penrith Sandstone Formation and a coarse marginal facies (Brockram) that together constitute the Appleby Group, which rests unconformably on older rocks.

In Scotland the Permian is represented by scattered occurrences of fluvial and aeolian deposits in southern, central, and north-eastern parts of the country; direct evidence of age is, however, scarce. Isotopically-dated volcanics at Mauchline in the Midland Valley, central Scotland, are of late Early Permian age. In the Elgin area, north-east Scotland, the aeolian Hopeman Sandstone Formation has yielded reptilian material indicative of a latest Permian age, and vertebrate tracks of the *Chelichnus* ichnofacies occur there and in aeolian deposits at Locharbriggs in southern Scotland.

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