The chronology of the Permian succession in Devon – an updated review

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Warrington, G. 2018. The chronology of the Permian succession in Devon – an updated review. *Geoscience in South-West England*, **14**, 207–210.

In Devon, continental deposits that rest unconformably on Carboniferous rocks affected by the Variscan orogeny have been assigned to the Permian on the basis of isotopic dating of interbedded volcanics and scarce biostratigraphic evidence from the Exeter Group. Limited magnetostratigraphic information from that and the succeeding Aylesbeare Mudstone Group supported that interpretation. This has now been augmented by new evidence which has allowed refinement of the dating of the succession following recognition, in the uppermost Exeter Group, of the end of the Kiaman Superchron, an important Wordian (Mid-Permian) event. Younger Mid-Permian deposits and an incomplete Late Permian succession have been identified following the recognition of divisions of the Illawara Superchron in the Aylesbeare Mudstone. A substantial hiatus separates the latest Permian and youngest Triassic deposits and the system boundary is not present in the rock succession.

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Keywords: Devon (SW England), Permian, timescale, isotopic dating, biostratigraphy, magnetostratigraphy.

Introduction

The post-Variscan succession in Devon commences with the Exeter and overlying Aylesbeare Mudstone groups. Warrington (2005) reviewed the limited isotopic, biostratigraphic and magnetostratigraphic evidence of the Permian age of formations that constitute these groups. Isotopic ($^{40}Ar/^{39}Ar$) analyses indicated Early Permian (Sakmarian to Artinskian) ages for Exeter Volcanic Rocks (EVR) in the lower part of the Exeter Group. The upper part of that group was interpreted as no older than Roadian (early Mid-Permian), on biostratigraphic (palynological) evidence. There was no isotopic or biostratigraphic evidence for the age of the Aylebeare Mudstone. Reversed palaeomagnetic signatures had been obtained from the EVR and some sediments in the Exeter Group, and reversed and normal signatures from the Aylebeare Mudstone. The Aylesbeare Mudstone is succeeded unconformably by the Chester Formation (formerly the Budleigh Salterton Pebble Beds; Ambrose *et al.*, 2014) for which a late Olenekian to early Anisian (late Early to early Mid-Triassic) age had been proposed on the basis of magnetostratigraphy.

Warrington (2005) suggested, from the then published magnetostratigraphic evidence, that the Permian–Triassic boundary was above the Aylesbeare Mudstone and not represented in the rock succession; this was illustrated in a subsequent contribution (Warrington *et al.*, 2012). However, Gallois (2014) proposed correlation of the base of the Aylesbeare Mudstone with that of 'TR1', the lowest of four tectonic-stratigraphic successions recognised in the southern North Sea (Hounslow and Ruffell, 2006), and that the group was of Induan to early Olenekian (Early Triassic) age.

There has been little change to the isotopic evidence and none to that noted by Warrington (2005) in the biostratigraphy from the Exeter Group. Advances in the magnetostratigraphy have been made with the publication of additional information from that group and the full results of the study of the Aylesbeare Mudstone (Hounslow *et al.*, 2017). The position of the 'Illawara Reversal', at the end of the Kiaman Superchron in the Wordian (mid Mid-Permian) has been identified, and dates for levels in the uppermost Exeter Group and the Aylesbeare Mudstone succession inferred by reference to a Geomagnetic Polarity Timescale. The Permian–Triassic boundary is confirmed as being above the Aylesbeare Mudstone, as suggested by Warrington (2005).

The Permian timescale and the isotopic, biostratigraphic and magnetostratigraphic information now available from the succession in Devon are reviewed in the following sections.

The Permian timescale

The timescale adopted for the Permian is from the International Commission for Stratigraphy (ICS) *International Chronostratigraphic Chart* (Version 2017-2), except for the base Sakmarian age which is that advocated by Ramezani and Bowring (2018, fig. 1) and used by the Subcommission on Permian Stratigraphy (SPS) in the latest issue of its newsletter (*Permophiles* **65**, 53; December 2017). The other stage boundary ages used by those authors correspond with, or are very similar to, those adopted by the ICS and SPS which are retained here (Figure 1).

The isotopic dating record

Two occurrences of the EVR in the lower part of the Exeter Group have yielded $^{40}Ar/^{39}Ar$ dates; other dates from the EVR are from K/Ar analyses and have wide error ranges (Warrington, 2005). A $^{40}Ar/^{39}Ar$ plateau age from the Killerton lamprophyre (290.8±0.8 Ma) places that around the Sakmarian-Artinskian

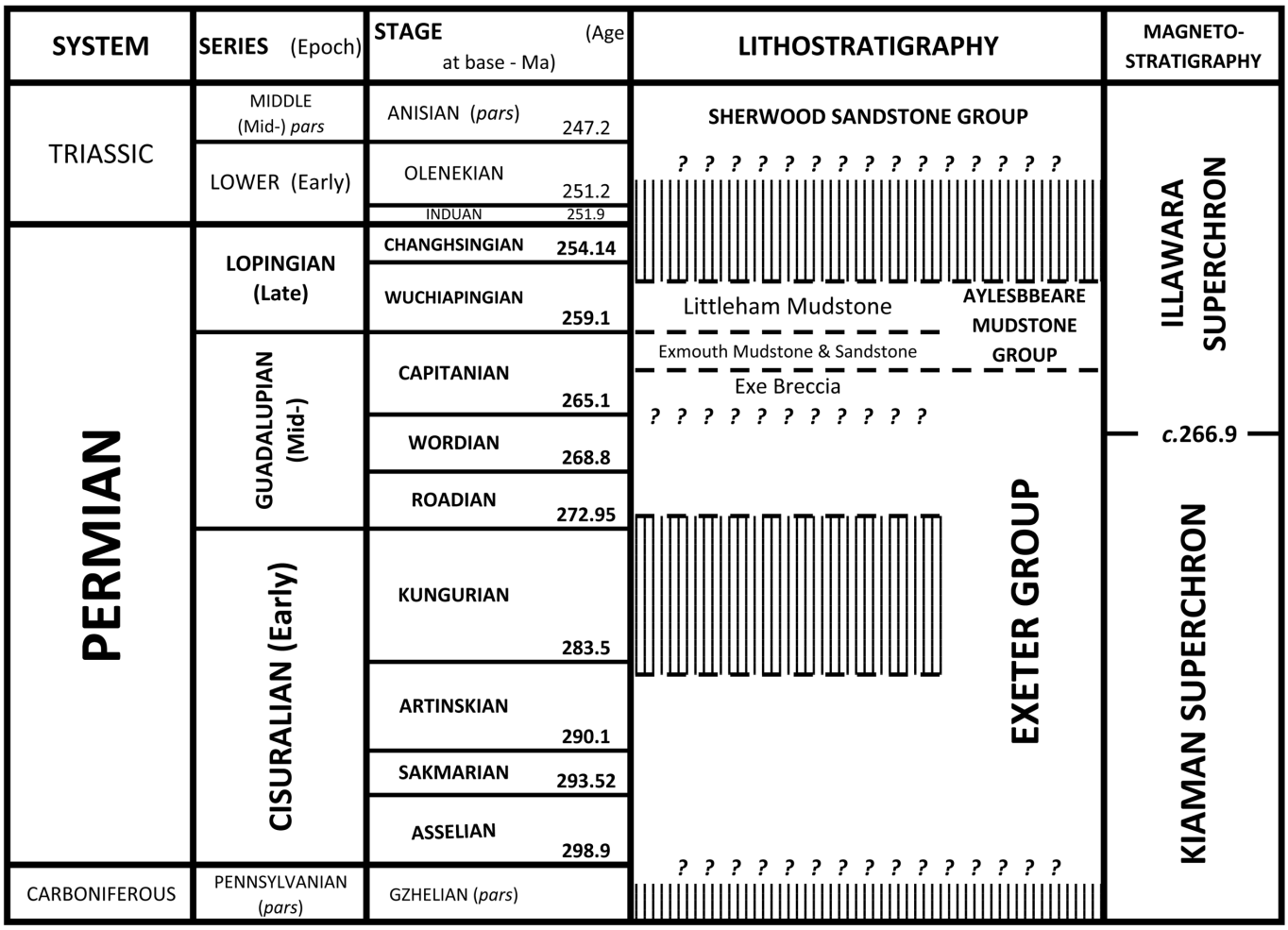

Figure 1. *The chronology of the Permian and contiguous units in Devon.*
(Timescale after the ICS International Chronostratigraphic Chart *(Version 2017-2) and Ramezani and Bowring (2018). Outline magnetostratigraphy after Hounslow* et al. *(2017). Interpretation of the relationship of lithostratigraphic units to the timescale is based on isotopic, biostratigraphic and magnetostratigraphic information in the sources reviewed in the text.*
Major unconformities indicated by vertical ruling; minor unconformities omitted. Approximate boundary positions are indicated by broken lines and uncertain positions or relationships by question marks).

boundary. A lava at Knowle Hill exhibits secondary alteration and a $^{40}Ar/^{39}Ar$ date of 281.8±0.8 Ma may reflect argon loss; this occurrence may therefore be late Artinskian rather than early Kungurian.

Biotite from a volcaniclastic bed in the Corbyn's Head Member in the Torbay Breccia Formation near Torquay is reported to have yielded an 'earliest Permian' $^{40}Ar/^{39}Ar$ age (Scrivener *et al.*, 2015). However, the age for this potentially important addition to the chronology of the Exeter Group in that area has not been published.

The biostratigraphic record

The only biostratigraphically significant fossils known from the Permian succession in SW England remain the miospores from the upper part of the Exeter Group (Warrington and Scrivener, 1990; Warrington, 2005). These occur below the level of the 'Illawara Reversal' and were assessed as Roadian(?) to mid-Wordian (early(?) to mid Mid-Permian), on the basis of the presence of *Lueckisporites virkkiae* which first appears in beds of that age in the Euramerican palaeobotanical province (Warrington, 1996). However, Hounslow *et al.* (2017) stated that, in the northern hemisphere, this taxon first appears in deposits of latest Kungurian (latest Early Permian) to early Roadian (earliest Mid-Permian) age. The sources cited contain no unambiguous evidence of a first appearance in the Kungurian. However, a first appearance in the Roadian, taken from Utting (1996), is supported by the work of others (e.g. Utting *et al.*, 1997; Götz and Silantiev, 2015; Stephenson, 2015, 2018) and is retained here.

Tetrapod tracks from the Dawlish Sandstone Formation near the top of the Exeter Group (Clayden, 1908a, b; Warrington and Scrivener, 1990) are referable to the ichnogenus *Chelichnus* and may be of pelycosaurian origin (Lucas and Hunt, 2006). They comprise a *Chelichnus* ichnocoenosis, or trace fossil assemblage, which is indicative only of a general Permian age and characterizes the *Chelichnus* ichnofacies which is associated with aeolian dune deposits (Hunt and Lucas, 2006, 2007).

The magnetostratigraphic record

The publication (Hounslow *et al.*, 2017) of magnetostratigraphic results from the upper part of the Exeter Group and from the Aylesbeare Mudstone augments those previously available from those groups (Cornwell, 1967; Hounslow *et al.*, 1998). The Kiaman Superchron, a period of predominantly reversed polarity that extends from the Carboniferous into the Permian is succeeded, at the 'Illawara Reversal', by the Illawara Superchron, a period with mixed reverse and normal polarities that extends above the Permian. The end of the Kiaman Superchron is in the uppermost Exeter Group where the Exe Breccia is the lowest unit with the mixed polarity signature of the Illawara Superchron. The end of the Kiaman Superchron is

in the Wordian at *c*. 266.9 Ma, based on dates of 266.66±0.76 Ma and 267.1±0.8 Ma proposed by Hounslow and Balabanov (2018) and Hounslow *et al*. (2017) respectively. Ramezani and Bowring (2018) proposed a younger date (*c*. 265.3 Ma) for this event.

In addition to this valuable addition to the otherwise poorly constrained chronology for the Permian succession in Devon dates have been proposed for the bases of divisions (chrons) in the magnetostratigraphy of the Exe Breccia and the Aylesbeare Mudstone (Hounslow and Balabanov, 2018, fig. 7, table 3). Guadalupian (Mid-Permian) chrons are identified as GU1 to 3 and those from the Lopingian (Late Permian) as LP0 to 3; subdivisions of these indicate normal (n) and reverse (r) polarity intervals.

The record from the Exe Breccia commences in GU2n.1n, above an unsampled section separating it from the Dawlish Sandstone and lower formations with the reverse polarities of the Kiaman Superchron, and continues up into the lowest part of GU2r (Hounslow and Balabanov, 2018, fig. 7). The record from the lower (Exmouth Mudstone and Sandstone) formation in the Aylesbeare Mudstone commences in GU2r and continues up into LP0r; that from the overlying Littleham Mudstone Formation extends from that level up into LP2n. The Littleham Mudstone is overlain unconformably by the Chester Formation, and the higher part of LP2 and all of LP3 are missing.

In the Exe Breccia the base of GU2n.1n, the lowest chron recorded above the unsampled section, is placed at 264.375 Ma and the top of the formation slightly above that of GU2r at 262.74 Ma (Hounslow and Balabanov, 2018, table 3). The Exmouth Mudstone and Sandstone ranges up from that level to above the base of LP0r at 259.832 Ma. The Littleham Mudstone ranges up from that level to above the base of LP2n at 255.922 Ma. On the basis of these dates the Exe Breccia represents at least 1.6.my, the Exmouth Mudstone and Sandstone at least 2.9 my, and the Littleham Mudstone *c*. 3.9 my. The age for the base of the lowest Triassic chron (LT1: 252.242 Ma) is close to that adopted by the ICS for the base of the Triassic (251.9 Ma) and therefore the last *c*. 3.7 to 4.0 my of the Permian may be unrepresented in Devon. In relation to the timescale for the Permian (Figure 1) the Exe Breccia is early Capitanian, the Exmouth Mudstone and Sandstone later Capitanian and the Littleham Mudstone latest Capitanian to mid-Wuchiapingan. The later Wuchiapingan and the Changhsingian are not represented. Hounslow and McIntosh (2003) proposed a maximum age of late Olenekian (late Early Triassic) for the Chester Formation, with the Induan and early Olenekian, from 251.9 Ma to between 251.2 Ma and 247.2 Ma (the base of the Mid-Triassic), not represented. The duration of the hiatus between Permian and Triassic deposition is therefore between *c*. 4.7 and *c*. 8 my.

The end of the Kiaman Superchron, in the Wordian at *c*. 266.9 Ma, places an upper age limit on the Dawlish Sandstone and other formations below the Exe Breccia in the Exeter Group. That part of the succession therefore spans *c*. 32 my, though with a number of gaps, the most significant being that between the lower part of the group with dated (Sakmarian to Artinskian) volcanics and the upper part which commences in beds with biostratigraphic evidence of a maximum age of Roadian (*c*. 272.9 Ma). The Kungurian (*c*. 10.5 my) may be unrepresented.

Summary

The chronology of part of the Permian succession in Devon has been refined by the recognition of the end of the Kiaman Superchron, in the uppermost part of the Exeter Group, and of divisions (chrons) of the Illawara Superchron in the Aylesbeare Mudstone Group. Dates have been proposed for this otherwise poorly constrained part of the succession. The Permian-Triassic boundary is not represented in the rock succession; an hiatus occurs between the Littleham Mudstone (early Late Permian) and the Chester Formation (late Early Triassic).

Acknowledgements

An anonymous reviewer is thanked for constructive comments, and Dr R.C. Scrivener for advice on EVR isotopic dates.

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