The position of the Permo-Triassic boundary in Devon, UK

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An almost complete Permo-Triassic succession over 3 km thick is exposed on the south Devon coast between Torbay and Lyme Regis. With the exception of the youngest (Rhaetian) part, the succession is in red-bed facies that includes breccias that were deposited in wadis and on fans, aeolian and fluviatile sandstones, and playa-lake and sabkha mudstones. Few of the formations can be dated with any certainty. Radiometric dates from contemporaneous igneous rocks in the older parts of the succession indicate Early Permian ages; a miospore from the middle part of the succession indicates an Early or Mid Permian age. A reptile track from younger strata also indicates an Early or Mid Permian age. This is overlain by up to >1,000 m of sediments, almost all of which are exposed in the coastal cliffs, for which there is no age-related evidence. A well documented vertebrate assemblage in the higher part of the succession indicates a Middle Triassic age which has been confirmed by magnetostratigraphy. In the absence of reliable age data for much of the succession it has been assumed that it contains unconformities that lasted for up to 10 million years. Re-examination of the field evidence has shown that there are few, if any, geologically important time breaks in the succession and that it is best interpreted as relatively continuous sedimentation punctuated by numerous hiatuses, many of which resulted from climatic changes and a few from tectonic events.

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Introduction

A 3,000+ m thick Permo-Triassic succession of terrestrial sedimentary rocks, one of the most complete of its kind in Europe, is exposed on the Devon coast between Torbay and Lyme Regis (Figure 1). There have also, from time to time, been extensive inland exposures in quarries, road cuttings and marl pits. Notwithstanding the wealth of readily accessible exposures, the positions of the Permian-Triassic system boundary and most of the chronostratigraphical stage boundaries cannot be identified with any degree of certainty. This is principally because the sediments, which range from coarse breccias to mudstones, were almost all deposited in oxidising environments that left little palaeontological evidence other than trace fossils that are not age diagnostic. In addition, it is difficult in terrestrial sediments to differentiate local events such as flash floods, river avulsion or a change from a wetter to a drier climate which give rise to erosive lithological boundaries, from unconformities that represent significant time gaps in the sedimentary record.

The internationally agreed Global Boundary Stratotype Section and Point (GSSP) for the base of the Triassic is a section in marine sediments in Zhejiang Province in China where the boundary is taken at the incoming of the conodont *Hindeodus parvus*. Similarly, GSSPs have been agreed for six of the nine Permian stage boundaries, all based on the first appearance of a particular species of conodont, and three of the seven stage boundaries have been agreed for the Triassic, one based on the first appearance of a conodont species and two based on ammonite species. It should be noted, however, that the practicality and advisability of using conodont-based definitions has been questioned by Lucas (2013).

Vertebrate faunas, palynomorphs (spores and pollen), conchostracans (brine shrimps) and trace fossils have been used to correlate parts of non-marine Permo-Triassic successions with the standard marine successions in some areas in Europe. To date, this has not been possible at any levels in Devon. The most promising method of chronostratigraphical correlation described to date for unfossilferous sediments such as these is magnetostratigraphy. Polarity chrons, intervals between reversals of the earth's magnetic field, have been recorded from marine and terrestrial Permian and Triassic successions world wide, and some of these have been correlated with the successions at the GSSPs (Hounslow and Muttoni, 2010). However, in the absence of independent corroborative evidence of the age of the sediments such as that obtained from fossils or radiometric dates, the magnetic signatures still have limited potential.

In a review of the chronostratigraphy of the Devonian to Permian rocks of Great Britain, Warrington *et al.* (2012) concluded that the Permo-Triassic succession adjacent to the system boundary in South-West England includes three unconformities that represent breaks of several million years and that, although the position of the boundary was unresolved, there was sufficient evidence to place it at the base of the Budleigh Salterton Pebble Beds Formation (Figure 2). There is no reliable evidence for the positions of the Permian stage boundaries except for a few radiometric dates from close above the Carboniferous-Permian boundary. Re-examination of the field evidence has shown that one of the three unconformities is a conformable boundary, one may be a lesser sedimentary break and the third may not have lasted as long as