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A multi-proxy approach to identifying short-lived marine incursions in the Early Carboniferous

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This study is a contribution to the TW:eed Project (Tetrapod World: early evolution and diversification), which examines the rebuilding of Carboniferous ecosystems following a mass extinction at the end of the Devonian. The project focuses on the Tournaisian Ballagan Formation of Scotland and the Borders, which contains rare fish and tetrapod material. The Ballagan Formation is characterised by sandstones, dolomitic cementstones, paleosols, siltstones and gypsum deposits. The depositional environment ranges from fluvial, alluvial-plain to marginal-marine environments, with fluvial, floodplain and lacustrine deposition dominant.

A multi-proxy approach combining sedimentology, palaeontology, micropalaeontology, palynology and geochemistry is used to identify short-lived marine transgressions onto the floodplain environment. Rare marginal marine fossils are: *Chondrites-Phycosiphon, Spirorbis, Serpula*, certain ostracod species, rare orthocones, brachiopods and putative marine sharks. More common non-marine fauna include Leiocopida and Podocopida ostracods, Mytilida and Myalinida bivalves, plants, eurypterids, gastropods and fish. Thin carbonate-bearing dolomitic cementstones and siltstone contain are the sedimentary deposits of marine incursions and occur throughout the formation.

Over 600 bulk carbon isotope samples were taken from the 500 metre thick Norham Core (located near Berwick-Upon-Tweed), encompassing a time interval of around 13 million years. The results range from –26‰ to –19‰, $\delta^{13}C_{org}$, with an average of –19‰ much lighter than the average value for Early Carboniferous marine bulk organic matter (δ^{13}C of –28 to –30‰). The isotope results correspond to broad-scale changes in the depositional setting, with more positive δ^{13}C in pedogenic sediments and more negative δ^{13}C in un-altered grey siltstones. They may also relate to cryptic (short-lived) marine incursions. A comparison of δ^{13}C values from specific plant/wood fragments, palynology and bulk sedimentary organic matter from the core is used to identify further changes in environment and vegetation.

From the base to the top of the formation, there is a gradual increase in relatively drier conditions, with more developed palaeosols and deep desiccation cracks. However, the main character of the formation is that of rapidly changing deposition between silts, sands and carbonates with many periods of pedogenesis and/or desiccation suggesting frequent switching from alluvial-plain to coastal environments. Marine incursions were short-lived, but important and caused a significant increase in the macro and microfaunal diversity. This temporal variability in the environments may have been an important factor in the evolution of tetrapods in the Early Carboniferous.