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Ichnology and depositional environment of the Middle Devonian Valentia Island tetrapod trackways, south-west Ireland

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ABSTRACT

Nine tetrapod trackways are described from the Middle Devonian continental Valentia Slate Formation on the north-eastern coast of Valentia Island in County Kerry, Ireland. The trackways occur at three sites – Dohilla, Coosadillisk and Culoo Head – the latter two being recorded for the first time. Morphological and taphonomic analyses of the trackways suggest they were made by populations of similar tetrapods, but of varying size (body length = 0.5 to 1 m; width = 0.15 to 0.30 m), that moved in some cases by terrestrial locomotion and in others possibly by a slow "paddling gait" while the substrate was submerged by very shallow floodwater. Sedimentological facies analysis of the trackway-bearing sequences has been carried out for the first time and shows that the preserved trackways are associated with the late stages of (1) a principal river channel margin (Coosadillisk), (2) a minor floodplain drainage channel (Culoo Head) and (3) a sand-rich crevasse splay/medial alluvial-ridge environment (Dohilla). The Valentia Island tetrapods inhabited marginal environments of proximal river channels <20 km from the northern margin of the Munster Basin, where hinterland drainage basins probably provided reliable sources of water in an overall semi-arid climate. It is proposed that the more perennial river channel belts crossing the basin would have provided conducive route ways that allowed ancestral tetrapods to migrate (>170 km) northwards into the continent from postulated shallow marine habitats as they evolved this capability over a potential 4–5 million year period during the Middle Devonian.

1. Introduction

Over the last 30 years, research on the fish-tetrapod transition has established a widely accepted model for earliest tetrapod evolution. The prevailing view, based on skeletal fossil material, is that the fish-tetrapod transition took place exclusively in the Late Devonian period and within a continental setting. However, the stratigraphic record of reliably identified tetrapod trace fossils (mainly trackways) also has significant implications for the timing and environment of tetrapod evolution. Unfortunately, the number of Devonian tetrapod trackways considered securely interpreted as such in reviews of the topic (Clack, 1997, 2012; Lucas, 2015) is relatively small (i.e., Warren and Wakefield, 1972; Rogers, 1990; Stössel, 1995, 2000) within a larger group discussed in the literature, amongst which there is significant imprecision in terms of age and environment of formation.

The most controversial evidence concerns the diverse suite of prints and tracks discovered at Zachełmie (Holy Cross Mountains, Poland) from early Middle Devonian marine dolomicritic laminites. These traces were interpreted to be of tetrapod origin by Niedzwiedzki et al. (2010), but this has been recently questioned by Lucas (2015), who regards them as fish feeding traces/nests (*Piscichnus*). If correct however, the interpretation of Niedzwiedzki et al. (2010) has radical implications for both the timing and the environment of early tetrapod evolution: (1) the well-constrained Eifelian age is significantly older than any of the known tetrapod body fossils and their tetrapodomorph fish ancestors; (2) The strata at Zachełmie indicate that the fish-tetrapod transition may have arisen in either shallow marine tidal-flats (Niedzwiedzki et al., 2010; Janvier and Clément, 2010) or marine non-tidal shallow lagoons in an otherwise open marine carbonate platform to shelf setting (Narkiewicz and Retallack, 2014; Narkiewicz et al., 2015), rather than the traditionally favoured continental freshwater environment (*e.g.*, Barrell, 1916; Romer, 1958; Long and Gordon, 2004; but see also George and Blieck, 2011; Schultze, 2013).

It is clear from the above controversy that the study of ichnofossils is critical in documenting the early evolution of tetrapods (Friedman and Brazeau, 2011). In this regard, the late Middle Devonian tetrapod trackways on Valentia Island in south-west Ireland have been re-

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investigated. We present new information from the original tetrapod trackway of Stössel (1995), and describe five additional trackways at the same site (herein called the Dohilla trackway locality). Furthermore, we report two new trackway sites at Coosadillisk and Culoo Head (Fig. 1). The new information permits a better interpretation of the morphological diversity and size of the tetrapods that lived in the Valentia Island region. Detailed sedimentological analyses of the three trackway-bearing sequences at Dohilla, Coosadillisk and Culoo Head provide a clearer understanding of the depositional setting and environment of the Valentia Island trackways. Combining the new ichnological and sedimentological data we discuss the wider implications for understanding the palaeoenvironmental setting of the earliest tetrapods.

2. Geological setting

The Devonian rocks in the western part of the Iveragh Peninsula of County Kerry are composed of a thick succession of continental Old Red Sandstone facies. The succession has been subdivided into three formations (Fig. 2A), in ascending order these are: the Valentia Slate Formation, St. Finan's Sandstone and the Ballinskelligs Sandstone Formations (Capewell, 1975; Pracht, 1996). These continental Old Red Sandstone sediments were deposited in a major Mid to Late Devonian extensional basin (Fig. 2B) the Munster Basin (Capewell, 1965, 1975; Williams, 2000), in south-west Ireland. A minimum thickness of 5.5 km of sediment accumulated in the basin depocentre (Williams et al., 1989). The minimum palinspastic (pre-Variscan) width of the basin was *ca*. 170 km (Williams, 2000) and sediment was supplied from the north, transversely across the extensional margin (Graham, 1983; Russell, 1984; Williams, 2000). The Valentia Island region occupied a highly proximal position within the basin, being located only 16–20 km (now tectonically reduced to 5–10 km) south-southeast of the basin margin fault zone (Fig. 2B).

The Valentia Slate Formation (≥1560 m) is predominantly composed of fine-grade purple and green sandstones and purple siltstones. The proximity of the Valentia Island region to the basin margin is demonstrated by the occurrence of several discrete conglomerate- and pebbly sandstone-rich member scale units within the dominantly fine-grained succession (Capewell, 1975; Russell, 1984; Graham et al., 1992; Pracht, 1996). These are interpreted as the distal spreads of gravel from small-radius alluvial fans that were sourced from the immediate footwall pre-rift basement to the NNW (*e.g.,* the Coosagauna, Doulus and Reacaslagh Conglomerates of Capewell, 1975). Further south, at St. Finan's Bay, these coarse grained units are absent and fine grade purple sandstone and siltstones form the bulk of the formation (Russell, 1984). The Valentia Slate Formation also contains a variety of dolerite intrusions and volcaniclastic deposits (Graham et al., 1995). The latter include, the mafic Bealtra Volcanic Breccia (an agglomerate composed of dominantly basic to intermediate, sand- to boulder-grade volcanic phenoclasts) and two prominent felsic tuff beds: the Enagh Tuff Bed in the Valentia Harbour area and the Keel Tuff Bed in St. Finan's Bay to the south. These volcaniclastic horizons are important marker beds both for stratigraphical correlation and for geochronological dating. However, due to lateral facies changes and tectonic complications, stratigraphical correlation of the Valentia Slate Formation sequences between Valentia Island and the Valentia Harbour area is not straightforward. However, using geochemical and petrological evidence Williams et al. (2000) correlated the Bealtra Volcanic Breccia Bed of Valentia Harbour with the thinner and finer grained basic Reenadrolaun Tuff on Valentia Island (Fig. 3). The geological age of the Valentia Slate Formation has been determined by radiometric dating of the Enagh Tuff Bed and the Keel Tuff Bed. Chronometric data, based on high-precision U-Pb isotope dating of magmatic zircons, yield a $^{207}Pb/^{206}Pb$ weighted mean age of 384.9 ± 0.7 Ma for the Enagh Tuff Bed (Williams et al., 1997), and 385.0 ± 2.9 Ma for the Keel Tuff Bed (Williams et al., 2000). In terms

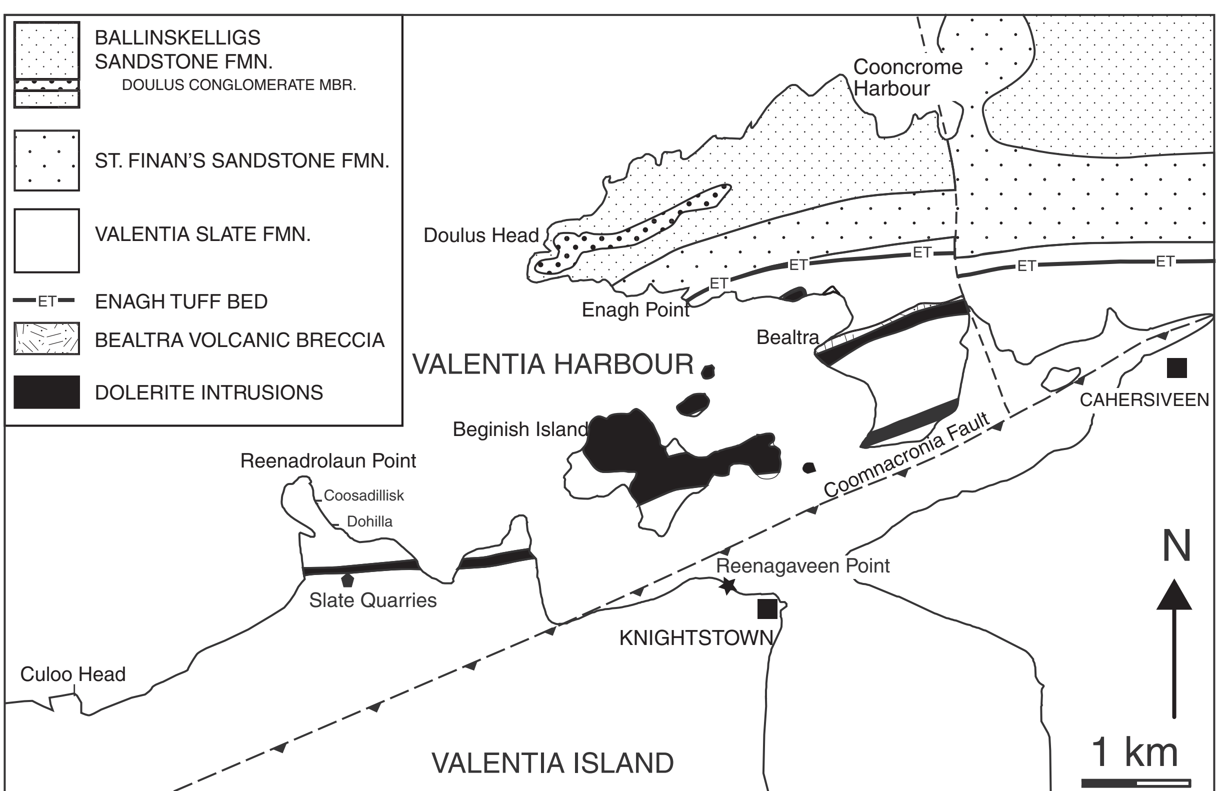

Fig. 1. Geological map of the northern part of Valentia Island and Valentia Harbour area. Mapping of the mainland and Beginish Island after Stössel (1993); Coomnacronia Fault after Capewell (1975).