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Gauging the impact of glacioeustasy on a mid-latitude early Silurian basin margin, mid Wales, UK

Jeremy R. Davies [a,*], Richard A. Waters [b], Stewart G. Molyneux [c], Mark Williams [d], Jan A. Zalasiewicz [d], Thijs R.A. Vandenbroucke [e]

[a] Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth SY23 3DB, UK
[b] Department of Geology, National Museum of Wales, Cathays Park, Cardiff CF10 3NP, UK
[c] British Geological Survey, Keyworth, Nottingham NG12 5GG, UK
[d] Department of Geology, University of Leicester, University Road, Leicester LE1 7RH, UK
[e] Department of Geology (WE13), Ghent University, Krijgslaan 281 S8, BE-9000 Ghent, Belgium

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ABSTRACT

The early Silurian (Llandovery) Gondwanan South Polar ice sheet experienced episodes of ice retreat and re-advance. Marine base level curves constructed for the interval are widely assumed to provide a record of the associated glacioeustasy. In revealing a series of progradational sequences (progrades) bounded by flooding surfaces, recent work on the Type Llandovery succession in mid Wales (UK) has provided an opportunity to test this hypothesis. The grouping of these progrades into three composite sequences underpins the construction of both low order (small amplitude, high frequency) and high order (large amplitude, low frequency) base level movement curves. Revised biostratigraphical datasets for the type succession permit the accurate dating of base level events. The composite sequences record progradational acmes in the *acinaces*, lower *convolutus* and upper *sedgwickii-halli* graptolite biozones. A series of transgressions that postdate the Hirnantian glacial maximum culminated in an upper *persculptus* Biozone high-stand. Maximum flooding events also occurred during the *revolutus* and lower *sedgwickii* biozones, and the base of the early Telychian *guerichi* Biozone also marked the onset of a pronounced deepening. A review of 62 published datasets, including global and other regional base level curves, records of glacial activity, isotope data, patterns of facies and faunal flux and putative climate models, permits an evaluation of the origins of these local base level events. The concept of a Eustasy Index is introduced and shows that the impacts of global sea level movements can only be demonstrated within narrow 'eustatic windows' coincident with times of ice sheet collapse. At other times, the geometry of Llandovery area progrades reflects their accumulation across a faulted basin margin where, during periods of slow ice sheet advance, epeirogenic processes outstripped sea level movements as the dominant forcing factors. Increased levels of Telychian subsidence at first enhanced and then overwhelmed the influence of glacioeustasy as part of the region's response to the north European Scandian deformation.

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* Corresponding author.
E-mail address: jrdav@bgs.ac.uk (J.R. Davies).

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1. Introduction

Recent studies have shown that, following its maximum in the Late Ordovician (Hirnantian), the early Silurian retreat of the Gondwana-based South Polar ice sheet was punctuated by separate episodes of ice re-advance (e.g. Grahn and Caputo, 1992; Caputo, 1998; Dias-Martinez and Grahn, 2007). Glacioeustasy has been widely cited as significant in shaping Llandovery age successions around the world, including the Type Llandovery succession in mid Wales, UK (e.g. McKerrow, 1979; Johnson et al., 1991b), and in influencing the form of Silurian sea level curves (e.g. Haq and Schutter, 2008; Johnson, 2010; Munnecke et al., 2010). Remapping and extensive biostratigraphical resampling in the Llandovery area have allowed a new sedimentary architecture to be erected and the positions of key biozonal boundaries to be revised (Figs. 2–5) (Davies et al., 2013). Graptolite discoveries coupled to new microfossil analyses underpin major changes to the biozonal cross-correlations put forward by Cocks et al. (1984) that have informed global Llandovery analysis for over a generation. In allowing more precise comparisons with other regional datasets, these revisions have permitted a critical evaluation of the influence of glacioeustasy on the type succession.

Deposition of the Type Llandovery succession took place in a ramp-like setting located along the SE margin of the ensialic Lower Palaeozoic Welsh Basin, in mid-southern palaeolatitudes (Cherns et al., 2006; Woodcock and Strachan, 2012). Though traditionally recognised as forming part of the Eastern Avalonia microcraton, Waldron et al. (2011) suggested that the Welsh Basin has more complex crustal foundations. However, the term 'Avalonian' remains relevant in the biopalaeogeographical sense of Cocks and Fortey (1990) and as a label for a group of loosely associated crustal terranes, the 'Anglo-Acadian belt' of Cocks and Fortey (1982), that lay to the south of the contemporary Iapetus Ocean (Fig. 1). Docking of these 'Avalonian' terranes with the more easterly craton of Baltica took place along the northern European Tornquist Zone, and is recorded in Wales by the late Katian (mid Ashgill) 'Shelvian' deformation (Toghill, 1992). By Llandovery times, these once separate crustal elements formed part of a unified tectonic plate and faunal province (e.g. Cocks and Fortey, 1990). Early Llandovery closure of the northern sector of the Iapetus Ocean initiated the Scandian Orogeny in Baltica (e.g. Ladenberger et al., 2012) at the same time as the late stages of the Taconic and Salinic tectonic episodes were being felt in North America (e.g. Ettensohn and Brett, 1998). Hence, tectonism was ongoing during the Llandovery throughout the circum-Iapetus realm where, within migrating foreland basins and faulted-bounded depocentres, evolving patterns of subsidence competed with eustasy in the shaping of sedimentary successions (e.g. Baarli et al., 2003).

Nowhere is this more evident than in the Type Llandovery area, where active basin-bounding faults accommodated the subsidence of the basin to the west and uplift of source areas to the east (Davies et al., 2013). Notwithstanding this tectonic backdrop, early Hirnantian facies at Llandovery and throughout the Welsh Basin, as elsewhere, record the impact of Late Ordovician glacioeustasy (e.g. Brenchley and Cullen, 1984; Davies et al., 2009). Preserved in distal settings are strata that were deposited during the maximum drawdown in sea level, whereas an unconformity records the coincident emergence and deep erosion of proximal regions. Late Hirnantian units record the pulsed transgression that post-dated the glacial maximum, and the resulting re-ventilation and faunal re-stocking of the Welsh Basin and its marginal shelf. The current study seeks to evaluate the role that eustasy, specifically glacioeustasy, went on to play in the shaping of the succeeding Type Llandovery succession.

Telychian and lower Wenlock rocks at Llandovery provide a record of deep and distal shelfal sedimentation and of increased subsidence and disruption by synsedimentary slides. Coincidental increases in the volume and grade of sediment supplied to the Welsh Basin, sourced from new quadrants and accommodated by active faulting, confirm that the late Llandovery to early Wenlock was a time when regional tectonism was resurgent throughout Wales (e.g. Woodcock et al., 1996; Davies et al., 1997). However, preceding Rhuddanian and Aeronian rocks comprise a cyclical succession of variably bioturbated and fossiliferous sandstones, sandy mudstones and mudstones that has proved better suited for eustatic analysis. It is these strata, viewed in the context of a clinoform facies model (see Davies et al., 2013), on which this study principally focuses (Figs. 3, 6).

The parameters used to establish the base level history of the Llandovery area (Sections 3 and 4) allow comparison with global syntheses of Silurian sea level change and other regional base level datasets (Fig. 1) that sample tectonic settings ranging from cratonic interiors and passive margins to deep oceans and orogenic belts (Sections 5 and 6). They also enable comparison with datasets that, by charting the distribution of glacial facies, changing isotope ratios and faunal flux, purport to chronicle sea level-linked climatic events (Section 7). A novel method of assessing the levels of correspondence between these varied datasets and the record of base level movements in the Type Llandovery area is developed (Section 8).

2. Implications of revised biostratigraphical correlations

The revised cross-correlation of the various macro- and microfossil biozonal schemes applicable to the Type Llandovery area is presented in Fig. 5. This forms the basis for the nomenclature and calibration applied throughout the paper. The graptolite biozonal scheme is that