Palaeogeography, Palaeoclimatology, Palaeoecology 294 (2010) 232–241

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Paleobiogeography, high-resolution stratigraphy, and the future of Paleozoic biostratigraphy: Fine-scale diachroneity of the Wenlock (Silurian) conodont *Kockelella walliseri*

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ARTICLE INFO

Article history:
Received 20 April 2009
Received in revised form 30 December 2009
Accepted 2 January 2010
Available online 7 January 2010

Keywords:
Wenlock
Silurian
Conodont zonation
Carbon isotope
Sequence stratigraphy
Chronostratigraphy
Ireviken Event
Paleobiogeography

ABSTRACT

The Wenlock Epoch of the Silurian Period has become one of the chronostratigraphically best-constrained intervals of the Paleozoic. The integration of multiple chronostratigraphic tools, such as conodont and graptolite biostratigraphy, sequence stratigraphy, and $\delta^{13}C_{carb}$ chemostratigraphy, has greatly improved global chronostratigraphic correlation and portions of the Wenlock can now be correlated with precision better than ±100 kyr. Additionally, such detailed and integrated chronostratigraphy provides an opportunity to evaluate the fidelity of individual chronostratigraphic tools. Here, we use conodont biostratigraphy, sequence stratigraphy and carbon isotope ($\delta^{13}C_{carb}$) chemostratigraphy to demonstrate that the conodont *Kockelella walliseri*, an important guide fossil for middle and upper Sheinwoodian strata (lower stage of the Wenlock Series), first appears at least one full stratigraphic sequence lower in Laurentia than in Baltica. Rather than serving as a demonstration of the unreliability of conodont biostratigraphy, this example serves to demonstrate the promise of high-resolution Paleozoic stratigraphy. The temporal difference between the two first occurrences was likely less than 1 million years, and although it is conceptually understood that speciation and colonization must have been non-instantaneous events, Paleozoic paleobiogeographic variability on such short timescales (tens to hundreds of kyr) traditionally has been ignored or considered to be of little practical importance. The expansion of high-resolution Paleozoic stratigraphy in the future will require robust biostratigraphic zonations that embrace the integration of multiple chronostratigraphic tools as well as the paleobiogeographic variability in ranges that they will inevitably demonstrate. In addition, a better understanding of the paleobiogeographic migration histories of marine organisms will provide a unique tool for future Paleozoic paleoceanography and paleobiology research.

1. Introduction

Paleozoic paleobiogeography provides both an invaluable tool for paleogeographic reconstruction (Lees et al., 2002; Cocks and Torsvik, 2002), and at the same time, tremendous challenges for high-resolution global biostratigraphy. In some intervals of the Paleozoic, endemic marine populations preclude meaningful global zonations (e.g. Geyer and Shergold, 2000; Mei and Henderson, 2001), and even during intervals of comparatively cosmopolitan marine faunas, diachronous biostratigraphic first appearances can complicate global chronostratigraphic correlation (cf. Ma and Day, 2003). Typical Paleozoic biostratigraphic zones average roughly 1 million years (Myr) in duration (Ogg et al., 2008), whereas speciation and distribution of marine faunas were likely to have taken place on the scale of global ocean mixing times (measured in thousands of years). As a result, paleobiogeographic variability between regional first appearances of marine faunas typically has been considered an issue of finer resolution than the biostratigraphically-based Paleozoic timescale could evaluate.

The recent growth of high-resolution Paleozoic chronostratigraphy, which has been made possible largely as a result of improved

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doi:10.1016/j.palaeo.2010.01.002

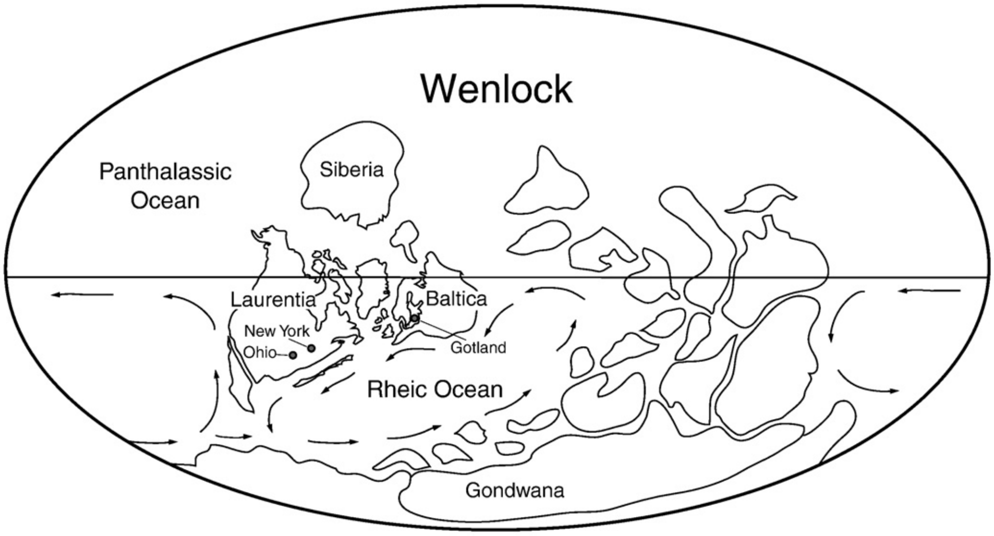

Fig. 1. Wenlock paleogeographic map after Woodcock (2000), Cocks (2001), Johnson et al. (2001) and Cocks and Torsvik (2002) showing sample localities of Gotland, New York and Ohio. Generalized southern hemisphere ocean circulation (after Parrish, 1982; Parrish et al., 1983; Moore et al., 1993) shows two major oceanic gyres: the Rheic Ocean gyre, and the southern hemisphere Panthalassic Ocean gyre.

biostratigraphy, has begun to demonstrate the need to carefully consider the global chronostratigraphic implications of paleobiogeographic speciation and distribution. As more Paleozoic stratigraphic research is conducted at high-resolution (significantly finer than the Myr-scale), temporal paleobiogeographic variability becomes a major practical concern. Global variations in first and last appearances are difficult to identify, however, because the Paleozoic timescale, against which such variability must be measured, is calibrated using biostratigraphy. Furthermore, when multiple faunal groups are available for chronostratigraphic correlation (e.g. conodonts and graptolites), they often are not found together in abundance. When they do co-occur, their first and last appearances may vary with respect to each other from locality to locality and it is frequently unclear which faunal group was displaying the variability (the conodonts, the graptolites, or both; e.g. Loydell et al., 2007). The integration of biostratigraphy with other chronostratigraphic tools, such as sequence stratigraphy and carbon isotope ($\delta^{13}C_{carb}$) chemostratigraphy, therefore is critical to the future of high-resolution Paleozoic stratigraphy.

The conodont *Kockelella walliseri* is an important guide fossil for middle and upper Sheinwoodian strata (Jeppsson, 1997). Here, we demonstrate that *K. walliseri* had a slightly earlier first Sheinwoodian appearance in Laurentia than in Baltica by directly integrating high-resolution conodont biostratigraphy, sequence stratigraphy, and carbonate carbon isotope ($\delta^{13}C_{carb}$) chemostratigraphy from three

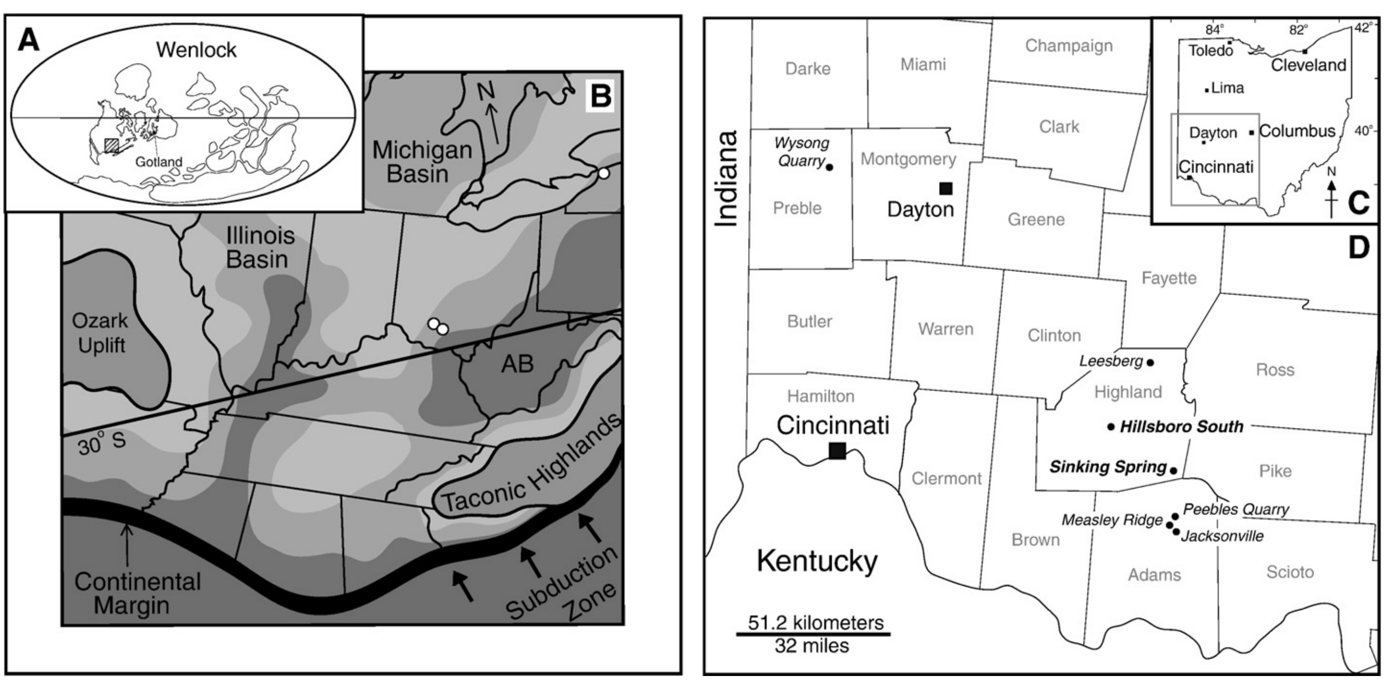

Fig. 2. Paleogeographic and paleobathymetric reconstructions of southern Laurentia (A and B) and locality map for southern Ohio (C and D), modified from Cramer and Saltzman (2005) and McLaughlin et al. (2008). Hatched box in panel A indicates area shown in panel B. The New York locality in panel B is the northeastern most of the two white dots, and NY locality information is given in Cramer et al. (2006a). Close up map of the state of Ohio (C) with grey outline indicating the area shown in panel D. Panel D shows southern Ohio localities discussed in the text. The Hillsboro South and Sinking Spring sections are illustrated in Fig. 7.