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Co-evolution of oceans, climate, and the biosphere during the 'Ordovician Revolution': A review

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1. Introduction

The Ordovician Period (~485–444 Ma) was an interval of major, causally interconnected changes in the Earth's biotic, climatic, and environmental systems. The diversity of marine life increased sharply during the Great Ordovician Biodiversification Event (GOBE; Webby et al., 2004; Fig. 1). The GOBE was terminated by the end-Ordovician mass extinction, the first of the 'Big Five' Phanerozoic mass extinctions (Sepkoski, 1996), which coincided with the Hirnantian glaciation, the first ice age since the late Neoproterozoic. This event was the culmination of a cooling trend that had begun in the Early or Middle Ordovician (Trotter et al., 2008; Vandenbroucke et al., 2010), and that was linked to some combination of reduced volcanic arc outgassing (McKenzie et al., 2016), enhanced silicate weathering (Young et al., 2009; Lefebvre et al., 2010; Nardin et al., 2011), and increased organic carbon burial (Brenchley et al., 1994; Yan et al., 2009; Zhang et al., 2010; Hammarlund et al., 2012). Also important were contemporaneous bioevolutionary events, i.e., the appearance of various zooplankton clades (Servais et al., 2016–in this volume) and the earliest land plants (Lenton et al., 2012), oceanographic changes, e.g., intensified ocean circulation related to climatic cooling (Kidder and Tomescu, 2016–in this volume), and geotectonic processes, e.g., a possible mid-Ordovician superplume (Algeo, 1996; Barnes, 2004a). The relationships among these many co-occurring developments are complex, which makes the Ordovician a classic example of co-evolution of Earth systems and a fascinating geologic period for study.

This special issue of *Palaeogeography, Palaeoclimatology, Palaeoecology* is thematically dedicated to the 'Ordovician Revolution'. It builds on earlier

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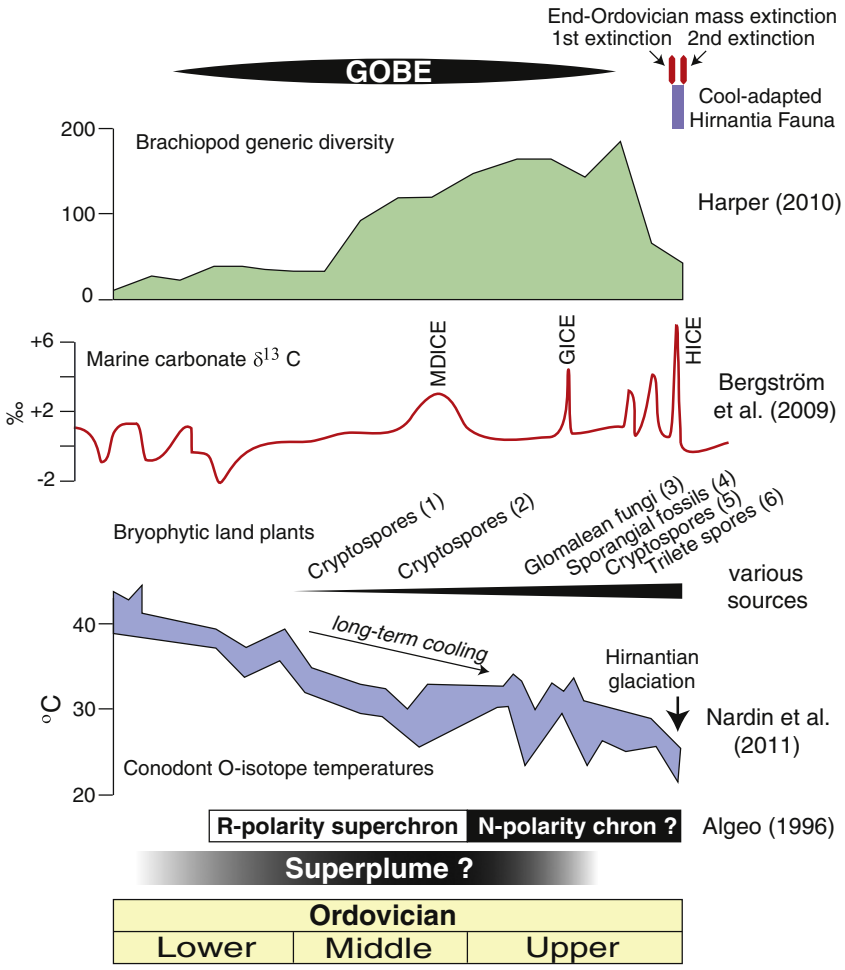

Fig. 1. Major Ordovician events. GOBE = Great Ordovician Biodiversification Event; HICE = Hirnantian carbon isotope excursion; GICE = Guttenberg carbon isotope excursion; MDICE = mid-Darriwilian carbon isotope excursion. Paleobotanic data: 1 — Volkheimer, (1980), Wellman and Gray (2000), Rubinstein et al. (2010); 2 — Vavrdová (1984, 1990), Strother et al. (1996), Steemans et al. (2009); 3 — Redecker et al. (2000); 4 — Wellman et al. (2003); Steemans et al. (2009); 5 — Badawy et al. (2014); 6 — Steemans et al. (2009).

organized research efforts, in particular those of International Geoscience Programme (IGCP) projects 410 (2000–2004), 503 (2005–2010), and 591 (2011–2016), which have yielded many advances in our understanding of the Ordovician Revolution. The 13 contributions in this volume cover many aspects of the major changes that characterize the Ordovician Period. In addition to this introductory review paper, various contributions investigate the relationship of surface-ocean circulation patterns to atmospheric CO_2 levels (Pohl et al., 2016–in this volume), major changes in marine phytoplankton communities (Servais et al., 2016–in this volume), changes in the marine silica cycle possibly linked to increased radiolarian productivity (Kidder and Tomescu, 2016–in this volume), marine carbonate and/or organic carbon isotope records (Pruss et al., 2016; Quinton et al.,

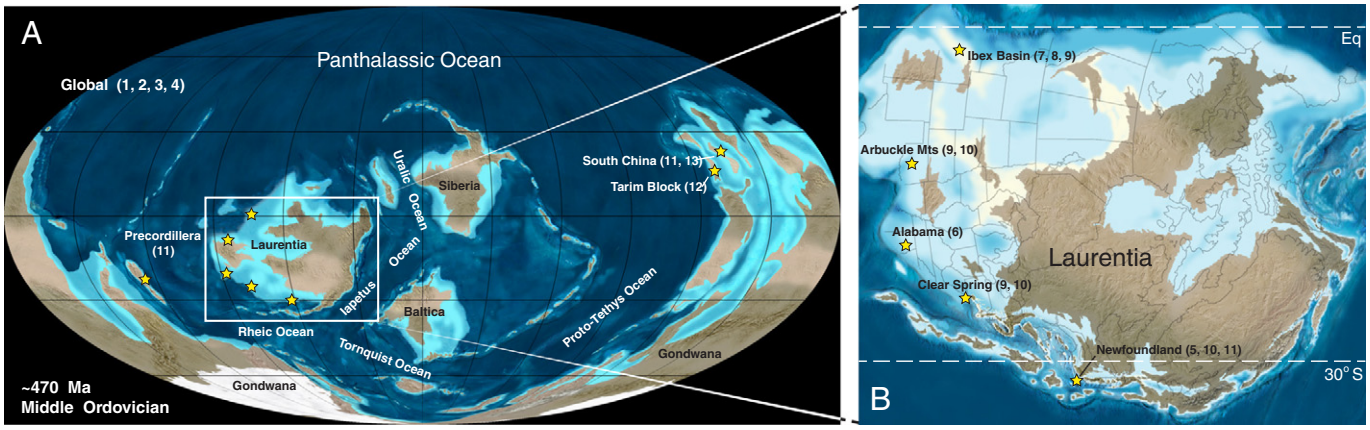

Fig. 2. Paleogeographic distribution of studies in this volume globally (A) and in North America (B). Middle Ordovician paleogeographic base maps courtesy of Ron Blakey (www2.nau.edu/rcb7). Numbered sections are keyed to the papers in this volume: (1) Algeo et al. (this paper), (2) Servais et al. (2016), (3) Kidder and Tomescu (2016), (4) Pohl et al. (2016), (5) Pruss et al. (2016), (6) Quinton et al. (2016), (7) Marenco et al. (2016), (8) Jones et al. (2016), (9) Edwards and Saltzman (2016), (10) Young et al. (2016), (11) Kah et al. (2016), (12) Zhang and Munnecke (2016), and (13) Zhang et al. (2016).