Available online at www.sciencedirect.com

SCIENCE DIRECT®

Palaeogeography, Palaeoclimatology, Palaeoecology 219 (2005) 333–349

PALAEO

www.elsevier.com/locate/palaeo

Sequestration of ^{12}C in the deep ocean during the early Wenlock (Silurian) positive carbon isotope excursion

Bradley D. Cramer*, Matthew R. Saltzman

Department of Geological Sciences, The Ohio State University, Columbus, Ohio 43210, USA

Received 23 June 2004; received in revised form 3 December 2004; accepted 12 January 2005

Abstract

Marine carbonates from three biostratigraphically well-dated Silurian sections from the mid-continent of North America were analyzed for carbon isotopic ($\delta^{13}C_{carb}$) study. The early Wenlock positive carbon isotope excursion (Ireviken Excursion) is recorded in three sections from Tennessee, Iowa, and Ohio, with values of >+4.5‰. This global shift in the carbon isotopic ratio of marine waters began during a protracted extinction event (Ireviken Event) that spanned the Llandovery–Wenlock boundary. Although several oceanographic models have been developed to account for the coincident changes in lithology, biology, and carbon isotope stratigraphy during this interval of the Silurian, their proposed causal connections among glaciation, oceanography, primary productivity, and the global carbon cycle remain a matter of debate. This investigation provides carbon isotopic and lithologic evidence that the Ireviken Excursion occurred during a time of relatively oligotrophic conditions, a third order transgressive–regressive cycle, and increased carbonate production throughout the mid-continent of North America. The Ireviken Excursion is recorded in relatively pure carbonate sequences and is immediately preceded by a significant unconformity in each of the measured sections. It is proposed that the Ireviken Excursion was the product of sequestration and burial of ^{12}C in deep water as a result of altered deep ocean circulation.

Keywords: Ireviken; Carbon isotope; North America; Glaciation; Oceanography

1. Introduction

Historically, the Silurian System has been considered an interval of relative climatic stability within a greenhouse period (Fischer, 1983; Scotese and McKerrow, 1990; Bassett and Edwards, 1991). However, recent investigations of Silurian carbon isotope stratigraphy suggest a more volatile ocean–atmosphere system. The presence of four major positive carbon isotope ($\delta^{13}C_{carb}$) excursions during the Silurian indicates that fundamental changes in the global carbon cycle were more frequent during the Silurian (4 excursions of >+4‰ in 30 million years) than any other System of the Phanerozoic (Odin et al., 1986; Harland et al., 1990; Samtleben et al., 1996;

* Corresponding author.
E-mail address: cramer.70@osu.edu (B.D. Cramer).

0031-0182/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.palaeo.2005.01.009

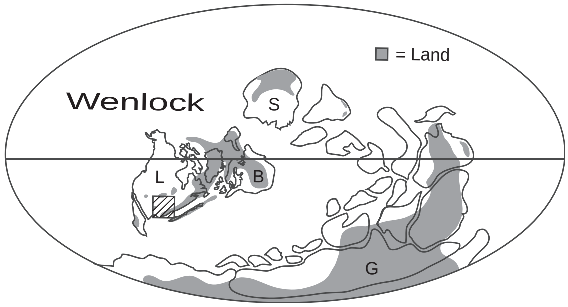

Fig. 1. Wenlock paleogeography (primarily after Woodcock, 2000; Cocks, 2001; Johnson et al., 2001). Grey areas denote land. Capital letters refer to major emergent landmasses: (L) Laurentia; (B) Baltica; (S) Siberia; (G) Gondwana. Diagonally hatched box indicates area shown in Fig. 2.

Bickert et al., 1997; Azmy et al., 1998; Saltzman, 2001, 2002a; Calner et al., 2004).

The positive carbon isotope excursions of the Silurian are all closely associated with major biotic crises and changes in the health of the shallow water carbonate factory (Jeppsson, 1990, 1998; Jeppsson et al., 1995; Quinby-Hunt and Berry, 1991; Berry, 1998; Mikulic and Kluessendorf, 1999; Saltzman, 2001, 2002a; Munnecke et al., 2003; Calner et al., 2004). In an effort to explain the apparent cyclicity of extinction events and lithologic changes in Silurian strata of Gotland, an oceanographic model was developed based on changes in climate (i.e., icehouse–greenhouse transitions) and the hydrologic cycle (Jeppsson, 1990). However, the location and timing of increased organic matter production and burial (^{12}C sequestration) in shelf or deep sea sediments during the Silurian remain a matter of debate (e.g., Wenzel and Joachimski, 1996; Bickert et al., 1997; Azmy et al., 1998).

A unique feature of Silurian $\delta^{13}C_{carb}$ excursions is that they generally occurred during periods of widespread carbonate deposition in shelf environments (Azmy et al., 1998; Brunton et al., 1998; Saltzman, 2001). For example, the early Wenlock is characterized by high $\delta^{13}C_{carb}$ values and has also been identified as a global episode of prolific reef development by Brunton et al. (1998). This contrasts with other Paleozoic positive carbon isotope excursions such as the Frasnian–Famennian boundary excursion, which shows peak $\delta^{13}C_{carb}$ values during periods of organic rich deposition in shelf environments (e.g., Joachimski and Buggisch, 1993). As modeling for $\delta^{13}C$ excursions shows (Kump and Arthur, 1999), we expect the positive excursions in the Silurian to be the result of increased organic carbon burial relative to carbonate carbon which would leave the ocean enriched in ^{13}C. However, a high burial fraction of organic carbon in shallow settings is seemingly inconsistent with the widespread reef building episodes that coincide with Silurian $\delta^{13}C$ excursions, but can be resolved if organic carbon burial is taking place in deeper water away from the shelf.

The Llandovery–Wenlock boundary interval was chosen as the focus of this investigation because it is a particularly well-studied, representative transition between climate states in the Silurian that has provided the basis for many aspects of climatologic and oceanographic models (e.g., Jeppsson, 1990). We have examined three sections that span a wide region of the mid-continent of North America in an effort to extend the geographic coverage of Silurian carbon isotope data between the well studied sections of the Baltic region (e.g., Samtleben et al., 1996; Kaljo et al.,

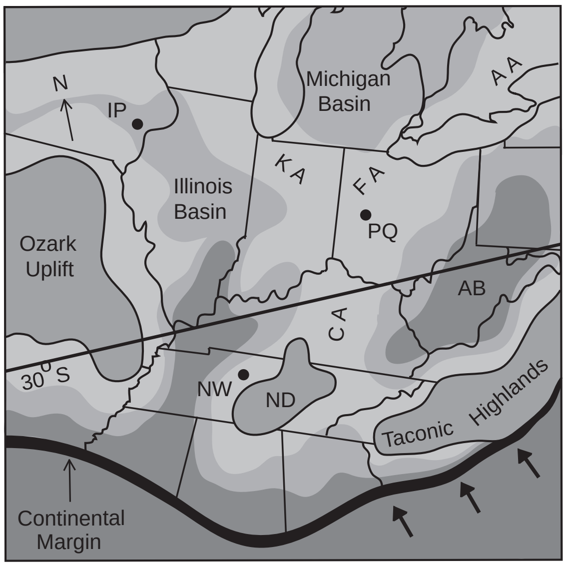

Fig. 2. Paleogeographic and paleobathymetric reconstruction of the mid-continent of North America (compiled mainly from Horvath, 1969; Berry and Boucot, 1970; Shaver, 1996). Darker shaded areas of basins represent deeper water. Relative size and emergence of the Ozark uplift are speculative. Abbreviations: (KA) Kankakee Arch; (FA) Findlay Arch; (AA) Algonquin Arch; (CA) Cincinnati Arch; (AB) Appalachian Basin; (ND) Nashville Dome. Black dots indicate location of the three measured sections: (NW) Newsom Roadcut, Tennessee; (IP) IPSCO core OW-5, Iowa; (PQ) Piqua Quarry, Ohio.