Palaeogeography, Palaeoclimatology, Palaeoecology 445 (2016) 50–59

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Orbital-scale glacio-eustasy in the Middle Devonian detected using oxygen isotopes of conodont apatite: Implications for long-term greenhouse–icehouse climatic transitions

Maya Elrick [a,*], Brian Witzke [b]

[a] Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, United States
[b] Iowa Geological and Water Survey, Iowa Dept. of Natural Resources, Iowa City, IA 52242-1319, United States

ARTICLE INFO

Article history:
Received 15 December 2015
Accepted 15 December 2015
Available online 6 January 2016

Keywords:
Conodont oxygen isotopes
Orbital scale glacio-eustasy
Middle Devonian
Cycles
Greenhouse–icehouse

ABSTRACT

Results from previous paleoclimate studies indicate Gondwanan glaciation, marking the onset of middle Paleozoic icehouse climate conditions, began by the Latest Devonian (Famennian). More recently, $\delta^{18}O$ trends from conodont apatite suggest cooling Middle Devonian subtropical seasurface temperatures >20 My prior to Famennian glaciation and high-latitude temperatures cool enough to permit the growth of continental glaciers which controlled longer term (My-scale) glacio-eustasy. This study evaluates the details and patterns of Middle Devonian high-frequency (<100 ky) climate variability that are superimposed upon these longer term cooling trends and evaluates the origins of common and globally widespread carbonate cycles (or parasequences).

Thirteen complete Middle Devonian (Givetian) subtidal cycles (0.5–3 m thick) in the Little Cedar Formation of southeastern Iowa are characterized by oxygenated offshore facies (transgression), poorly oxygenated offshore facies (maximum flooding), a return to oxygenated facies, and are capped by bioturbated lower shoreface facies (regression/lowstand) which lack evidence of subaerial exposure. Across-shelf cyclostratigraphic facies relationships suggest relatively subdued water-depth changes were responsible for cycle development. Measured $\delta^{18}O$ values from conodont apatite range from 15.9‰ to 18.4‰ and repeated, systematic intracycle trends are dominated by lower isotopic values in offshore facies and higher isotopic values in cycle-capping lower shoreface facies, which is consistent with glacio-eustasy driving the water-depth changes. The average ~0.6‰ magnitude of intracycle isotopic shift (0.2‰ to 1.0‰ = total range) suggests ~15–23 m glacio-eustatic oscillations were responsible for observed water-depth changes. The higher range of intracycle isotopic magnitudes may be the result of increased subtropical evaporation rates during glacial stages which locally enriched surface seawater $\delta^{18}O$ values.

Orbital-scale (<100 ky) glacio-eustasy superimposed on Middle Devonian cooling trends ~20 My prior to Late Devonian glaciation highlights the difficulties in attempting to pinpoint the specific timing of the middle Paleozoic greenhouse-to-icehouse climate transition and calls in to question the traditional delineations of greenhouse versus icehouse conditions.

1. Introduction

Long-term Phanerozoic climate changes are characterized by alternating greenhouse (warmer) and icehouse (cooler) intervals, each of which lasted up to many tens of millions of years (Fischer, 1982; Frakes et al., 2005). Traditionally, greenhouse versus icehouse climates were interpreted from the paleolatitudinal distribution and abundance of climate-sensitive rock types and biota. Using these data, greenhouse intervals were characterized by the lack of large permanent continental glaciers, gentle pole-to-equator temperature gradients, warm mean ocean temperatures, globally high sea levels, and sluggish ocean circulation with a tendency towards anoxia; icehouse climates were typified by the opposite trends. More recently, a range of geochemical paleoclimate proxies (i.e., stable isotopes, Ca/Mg, Sr/Ca ratios, carbonate clumped isotopes) have been utilized to more quantitatively constrain the magnitude of these climate conditions and when combined with higher resolution sampling regimes, is refining our understanding of the patterns and timing of deep-time (pre-Cenozoic) climates and how modern climate shifts compared to those of the past.

This study focuses on the middle Paleozoic greenhouse-to-icehouse climatic transition. Previous studies document the occurrence of Late Devonian (Famennian) glaciation in South America and Africa (Isaacson et al., 2008; Caputo et al., 2008) indicating that the middle Paleozoic greenhouse–icehouse transition occurred many tens of millions of years earlier than the traditional Early to Late Mississippian glacial onset (e.g. Frakes et al., 2005). Since then, oxygen isotope trends from Devonian conodont apatite document that Middle Devonian subtropical surface seawater temperatures (SSTs) were cooler than the modern

* Corresponding author.
E-mail address: dolomite@unm.edu (M. Elrick).

http://dx.doi.org/10.1016/j.palaeo.2015.12.019
0031-0182/

(≤25 °C; Joachimski et al., 2009) and high-latitude climates during the late Early Devonian to Middle Devonian were cool enough to permit continental glacier growth and melting driving 3rd order (1–5 My scale) sea-level changes (Elrick et al., 2009). These cool Middle Devonian climate results suggest that the greenhouse-to-icehouse transition began at least 20 My earlier than the Famennian glaciation, thus significantly shifting the onset timing of icehouse conditions.

This study builds on these previous oxygen isotope studies to evaluate the details and patterns of Middle Devonian high-frequency (<100 ky) climate variability that are superimposed upon longer term climatic trends and to evaluate the origin(s) of common and globally widespread carbonate cycles (or parasequences). Samples for this study were collected at the 10–100 cm-scale to evaluate orbital-scale and finer climatic variability. Specific questions that we address include: are orbital-scale (<100 ky) climate changes superimposed on longer term Middle Devonian cooling trends? If so, what are the magnitudes of those climatic oscillations? With increasingly higher resolution paleoclimate studies, what is the definition of an icehouse or greenhouse climate? In other words, how much glacial ice or how permanent must the ice be to define a so-called icehouse climate? The specific objectives of this study include: 1) describe cyclic facies and oxygen isotope trends within stacked subtidal cycles of the Middle Devonian (Givetian) Little Cedar Formation, Iowa, and 2) interpret magnitudes of water-depth and climate changes and discuss the implications of these changes on the timing and patterns of the middle Paleozoic greenhouse-to-icehouse climatic transition.

2. Geologic background

Middle Devonian global paleogeography is dominated by Laurentia and Gondwanan continents distributed mainly within the southern hemisphere and the impending closure of the Rheic ocean during the formation of Pangea (Fig. 1a). Globally high sea levels related to the Middle Devonian Taghanic onlap (Johnson, 1970) resulted in the flooding of much of the continents and the formation of a vast epicontinental sea on Laurentia (Fig. 1b). Iowa lay within the seaway interior and during the Middle Devonian was connected to the Rheic and Panthalassa oceans by deeper marine seaways and breaching of the Transcontinetal arch.

Three late Middle Devonian (Givetian) transgressive–regressive sequences (termed T–R 'cycles' If, IIa-1, and IIa-2) are recognized (Johnson and Klapper, 1992; Johnson et al., 1985), each spanning ~1–1.5 My. These T–R sequences in Iowa are called Iowa T–R 'cycles' 2, 3, 4 (Fig. 1c; Day, 2006). For clarification, this study focuses on

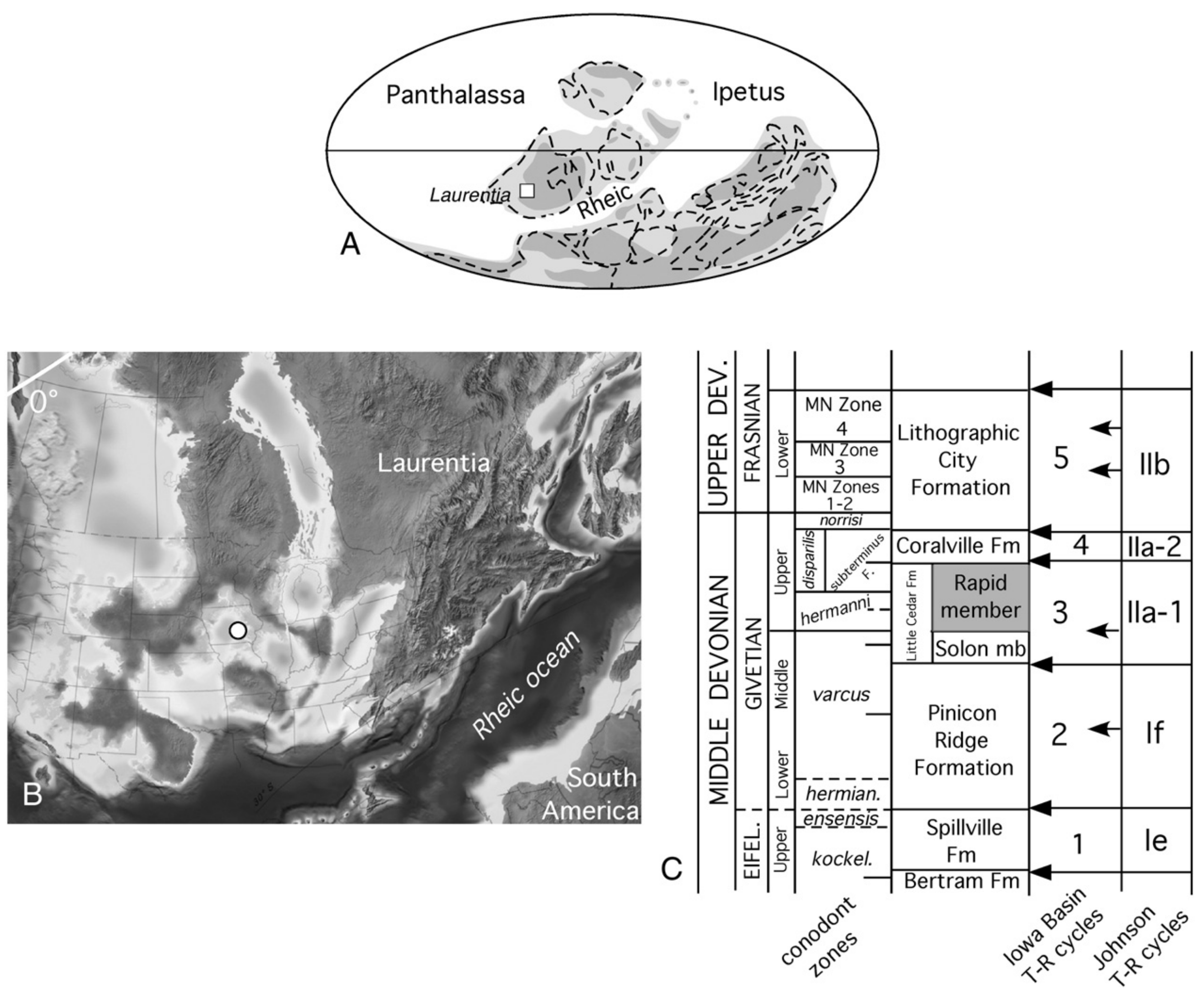

Fig. 1. A) Middle Devonian global paleogeography modified from Scotese (2014; http://www.scotese.com/newpage3.htm). White box = study area, light gray = shallow marine, dark gray = approximate paleocontinent outline, dashed line = approximate modern continent outline. B) North America paleogeography, white circle = approximate location of two study areas in southeastern Iowa. White line labeled 0° = approximate paleoequator; modified from Blakey (2013; http://cpgeosystems.com/images/NAM_key-375Ma_LDev-sm.jpg). C) Chronostratigraphy of a portion of the Middle Devonian in southeastern Iowa (modified from Day, 2006). Gray shading outlines Rapid Member study interval, black arrowhead lines indicate transgressions at base of individual T–R cycles recognized by Johnson et al. (1985) and Johnson and Klapper (1992) and Iowa T–R cycles from Day (2006).