Paleozoic stromatactis and zebra carbonate mud-mounds: Global abundance and paleogeographic distribution

Federico F. Krause Department of Geology and Geophysics, University of Calgary, Calgary, Alberta T2N 1N4, Canada
Christopher R. Scotese Department of Geology, University of Texas at Arlington, Arlington, Texas 76019-0049, USA
Carlos Nieto Department of Geology and Geophysics, University of Calgary, Calgary, Alberta T2N 1N4, Canada
Selim G. Sayegh Energy Branch, Saskatchewan Research Council, Regina, Saskatchewan S4S 7J7, Canada
John C. Hopkins Department of Geology and Geophysics, University of Calgary, Calgary, Alberta T2N 1N4, Canada
Rudolf O. Meyer Department of Earth Sciences, Memorial University Newfoundland, St. John's, Newfoundland A1B 3X5, Canada

ABSTRACT

Carbonate mud-mounds with zebra and stromatactis structures are present in every Paleozoic system and series, but are more common in Devonian and Carboniferous deposits, reaching their acme in Mississippian System (lower Carboniferous) rocks. Global distributions illustrate that mud-mounds spanned the planet ranging from tropical to polar circles. Such a wide latitudinal span signifies that they not only grew in and occupied warm depositional environments, but also in settings where oceanic waters were cold and seasonally light limited. Moreover, their proliferation during the Devonian and Carboniferous was at a time when planet-wide climatic ice-house conditions are thought to have prevailed. Mud-mounds, therefore, may also be products of cool and cold-water carbonate sedimentation.

Keywords: mud-mound, zebra structures, stromatactis structures, gas hydrates, Paleozoic paleogeography, Paleozoic paleolatitude.

INTRODUCTION

Although carbonate mud-mounds have a geologic record that spans at least 1 b.y., from the Proterozoic to the present, it is the Paleozoic mud-mound record that currently is best known (Wilson, 1975; Pratt, 1995; Kiessling et al., 1999). Also, it is in Paleozoic mud-mounds that stromatactis structures were first identified and described (Dupont, 1881; Bathurst, 1982; Wilson, 1975). Zebra structures, in contrast, while abundant in Paleozoic mud-mounds, were first identified in Triassic rocks (Fischer, 1964). The origin and development of stromatactis and zebra structures are enigmatic and have been the topic of extensive consideration, as noted by many, including Bathurst (1982), Pratt (1995), and Krause (2001). Further, they have been correlated to conditions associated with the consolidation and dissociation of submarine gas–charged ice (Krause, 2001). Gas clathrate hydrates have only been recognized in submarine environments during the past three decades as a result of extensive sampling of the seafloor during the Deep Sea Drilling Project and Ocean Drilling Program (DSDP and ODP) (Sloan, 1998). Gas clathrate hydrates consolidate below the sediment-water interface, and are known to persist to depths as great as 225 m below the seafloor before their temperature- and pressure-defined stability field is exceeded (Spence et al., 2000). Thus, carbonate mud-mounds with zebra and stromatactis structures may prove to be useful indicators of cool, cold, and deep waters in ancient submarine settings. In this article, we explore these ideas with the aid of paleogeographic distribution maps, because they provide global positions that locate Paleozoic carbonate mud-mounds in time and space.

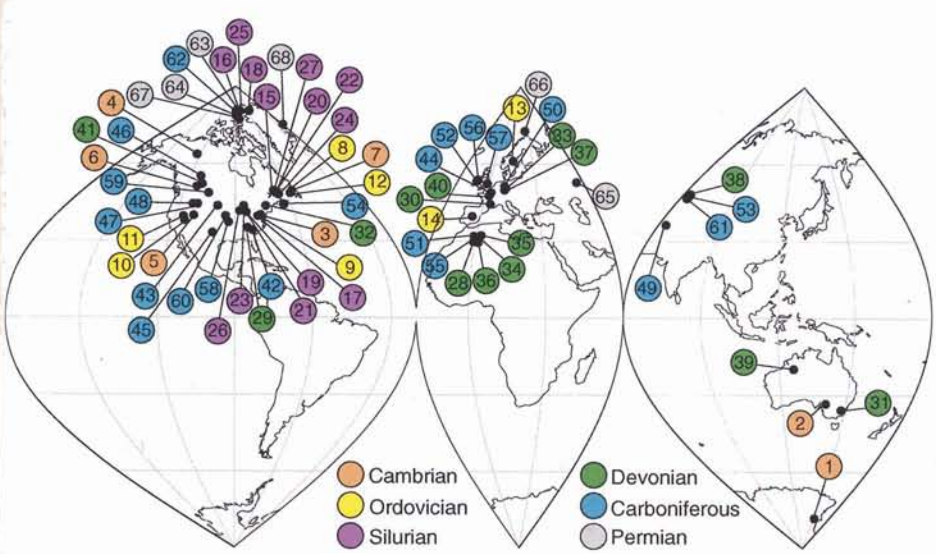

Figure 1. Mud-mound index map with localities color coded for stratigraphic age.

DISTRIBUTION IN TIME AND SPACE

Carbonate mud-mounds with zebra and stromatactis structures have been identified in all present-day continents with the exception of South America (Fig. 1). They are known from 68 localities[1] worldwide, but these localities are distributed unequally about the planet (Fig. 1). The Northern Hemisphere contains 95% of currently known mounds; of these, close to 60% are in North America, 20% in Europe, and the remainder are found in Africa and Asia. In the Southern Hemisphere, Oceania and Antarctica account for 5% of known mounds (Fig. 1). Although it is obvious that carbonate mud-mounds are common, they have been identified and described with great regularity by North American and European geologists. This, in part, is the result of the economic importance that carbonate reefs and mud-mounds have gained as petroleum and mineral exploration targets (Wilson, 1975; Watts et al., 1994; Kiessling et al., 1999). Nonetheless, the inherent cultural bias that could be attributed to these data is reduced when the chronological sequence and paleogeographic distribution of mud-mounds are studied.

Carbonate mud-mounds are not distributed evenly in the Paleozoic (Fig. 2). The total

[1]GSA Data Repository item 2004031, localities where carbonate mud-mounds with zebra and stromatactis structures have been identified and related references, is available online at www.geosociety.org/pubs/ft2004.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

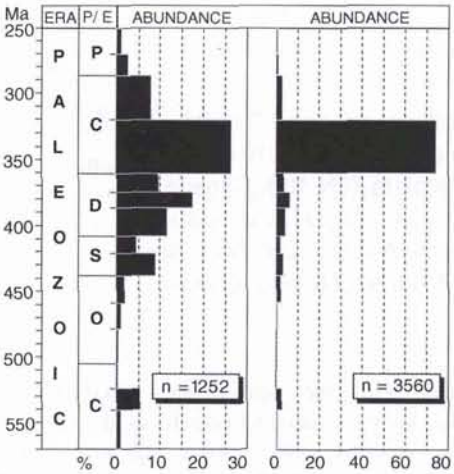

Figure 2. Paleozoic mud-mound abundance through time. Left histogram excludes Mississippian (lower Carboniferous) mounds of Ireland, which strongly skew overall distribution, as depicted in histogram on right. P—Permian; C—Carboniferous; D—Devonian; S—Silurian; O—Ordovician; C(bottom)—Cambrian.

number of mounds identified to date is 1252, the largest number of which is found between the Early Devonian and the Mississippian (early Carboniferous) (Fig. 2). On balance, it is likely that the total number of Paleozoic occurrences is much more than 1252 mounds, as can be inferred if the occurrence of Irish Waulsortian mounds is included in this tally. Mounds in the Carboniferous Shannon and Midland-Dublin Basins of Ireland, an area covering ~51,600 km^2, are known to be abundant. Although a definitive number has not been established, they are thought to number in the thousands (Lees and Miller, 1995; A. Lees, 2002, personal commun.). This observation indicates that the Mississippian, because of the sheer number of Irish deposits, would outrank all other intervals in terms of the total number of known mud-mounds. To test this hypothesis and establish a systematic count of mounds, we discretized the map of Lees (1964, his Fig. 17) for the Lough Ree area of Ireland, a Waulsortian mound locale of the Midland-Dublin Basin. To characterize this map we chose a 1.0 km^2 grid, even though mud-mounds in the geologic record often are recognized to be smaller. It is well known that mounds are often aggregated into complexes hundreds of meters square and that they evolve from smaller tabular and knoll-shaped masses that may be meters to tens of meters square in size (Lees, 1964; Lees and Miller, 1995). Mud-mounds encompassing areas larger than 1.0 km^2 have been identified from the Canadian Arctic and the subsurface of Alberta, but most mounds described are smaller and have areas of <0.3 km^2 (Davies et al., 1989; Watts et al., 1994; de Freitas and Dixon, 1995; Wendt et al., 2001). The 1.0 km^2 filter that we applied in the discretization of Lees's 1964 map provides a conservative estimate for the possible number of mounds in the Shannon and Dublin-Midland Basins (Table 1). Our lowest estimate is 2308 Waulsortian mounds. This estimate indicates that the Tournaisian and Visean Series of the Mississippian may contain at least 74% of known Paleozoic mud-mounds worldwide (Fig. 2). As can be appreciated from Table 1, the number of mounds would be greater by an order of magnitude if those having an estimated area of 0.3 km^2 were included. In this instance, the Mississippian would include 96% of known Paleozoic mounds.

TABLE 1. ESTIMATED NUMBER OF MUD-MOUNDS

Location and basins	Area (km^2)	No. of mounds (1 km^2 size)	No. of mounds (0.33 km^2 size)
Lough Ree	715	55	495
Shannon/Dublin-Midland	~30,000	2308	20,769

Global paleogeographic maps (Scotese, 2003) illustrate that Paleozoic mud-mounds spanned the globe and occupied submarine environments between the Arctic and Antarctic Circles (Fig. 3). We propose that their skewed distribution may reflect an overall cool and cold planetary climate that accompanied worldwide icehouse and low global sea-level conditions during the middle and late Paleozoic (Fig. 4) (Fischer, 1981; Given and Wilkinson, 1987). It is likely that oceanic waters exposed to an icehouse climatic regime enhanced the consolidation of gas clathrate hydrates below the seafloor and their incorporation into mud-mounds. It is also apparent that mud-mounds were not restricted to middle and upper Paleozoic rocks, because they also occur in rocks deposited when greenhouse conditions are thought to have prevailed and when the planetary climate was milder (Figs. 2, 3, and 4). This broader pattern is examined here because it reflects a wider range of geologic variables than currently recognized. These include not only planetary icehouse conditions, but depositional settings and relative sea level.

AUTOMICRITES AND RELATIVE SEA LEVEL

Several researchers have highlighted the concept that mud-mounds represent point sources of carbonate materials, i.e., the bulk of micrite, spar, and organic constituents in such mounds are derived from within or near their immediate environs (Lees and Miller, 1995; Monty, 1995; Reitner and Neuweiler, 1995). Muds that originate in this way are identified as automicrites (Lees and Miller, 1995; Monty, 1995; Reitner and Neuweiler, 1995). A number of authors studying mounds have also recognized multiple generations of automicrites, termed polymuds (Lees, 1964; Ross et al., 1975; Lees and Miller, 1995), supporting the hypothesis that mudstones in mud-mounds may form in place. The other dominant constituent of a mound is spar, a carbonate material that precipitates in place and may constitute greater than half the volume of the mound (Ross et al., 1975; Bathurst, 1982).

Identification of carbonate mud-mound production processes at or near the site of accumulation reinforces observations made by earlier workers that many Paleozoic mud-mounds are common to deep-marine environments in slope and toe-of-slope settings, at platform edges drowned during relative sea-level rise, or at downfaulted platform margins and interior embayments and troughs (Wilson, 1975; de Freitas and Dixon, 1995; Bridges et al., 1995; Pratt, 1995). The growth of mud-mounds during transgressions is important because the seafloor in the region of a mud-mound lithifies progressively. Exposed surfaces provide hardened foundations that may be colonized by reef-forming organisms. Colonization by phototrophic organisms may occur either during relative sea-level fall or as growing mud-mounds project into shallower and warmer water (de Freitas and Dixon, 1995; Bridges et al., 1995). Mud-mound growth during transgressions and subsequent colonization by shallow-water dwellers have been recognized repeatedly, as described in the Silurian of the Michigan Basin and the Canadian Arctic (Wilson, 1975; de Freitas and Dixon, 1995). Significantly, the Silurian mounds identified in these studies grew in tropical and temperate latitudes. Likewise, the submerged fronts of platforms that deepen abruptly in response to faulting, or by margin collapse, are also common sites for mud-mound development. Examples are the faulted escarpments of the Middle Cambrian of the Rocky Mountains and the Carboniferous troughs in the Peace River embayment of Alberta and the Central Montana trough (Fig. 3) (Bridges et al., 1995; Elrick and Snider, 2002; Motz et al., 2001).

CONCLUSIONS

Mud-mounds with zebra and stromatactis structures have been identified in every Paleozoic system and series. They were most common during the middle and late Paleozoic, a time during which global icehouse climate conditions prevailed. Paleogeographic plots of

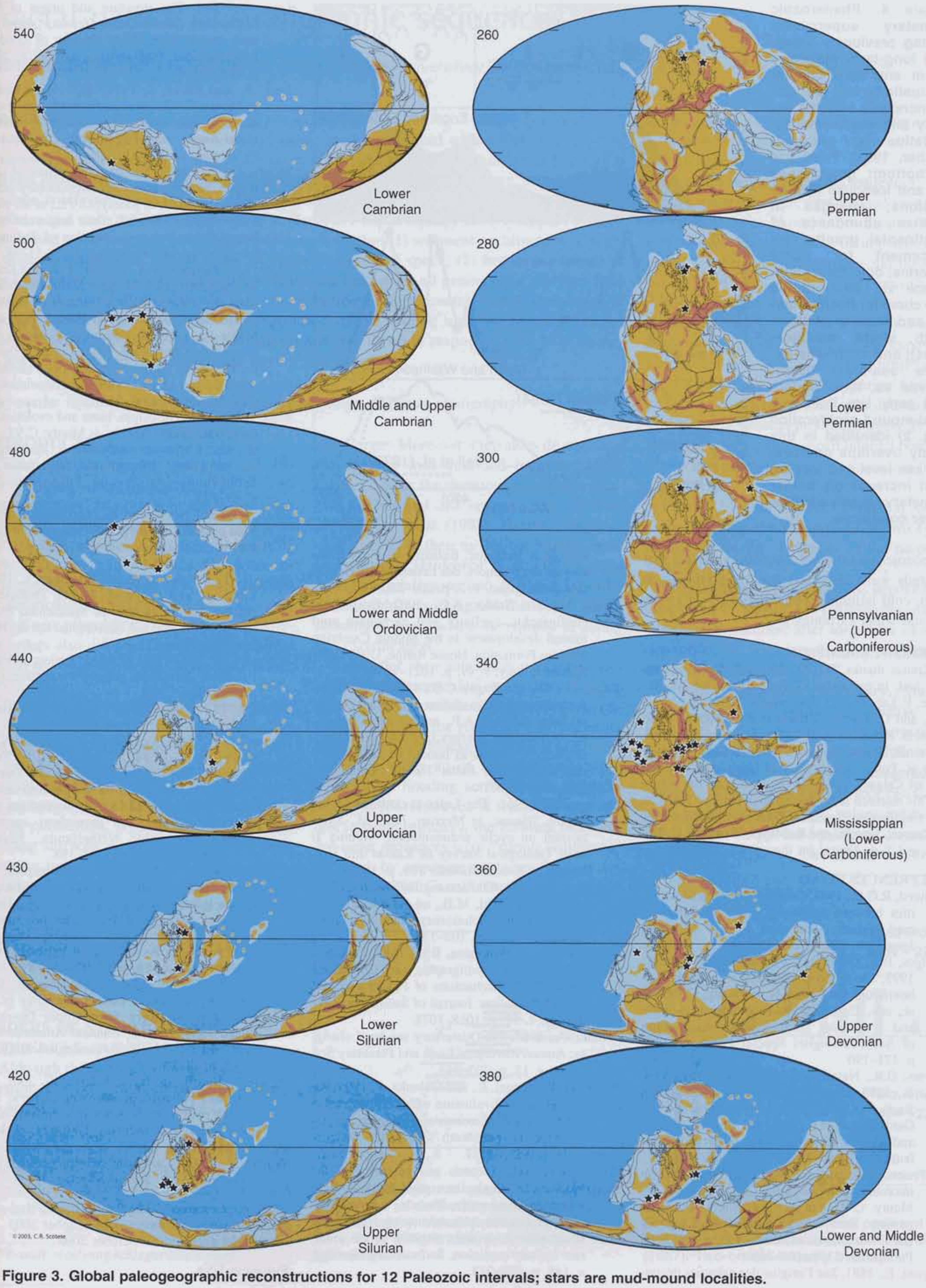

Figure 3. Global paleogeographic reconstructions for 12 Paleozoic intervals; stars are mud-mound localities.

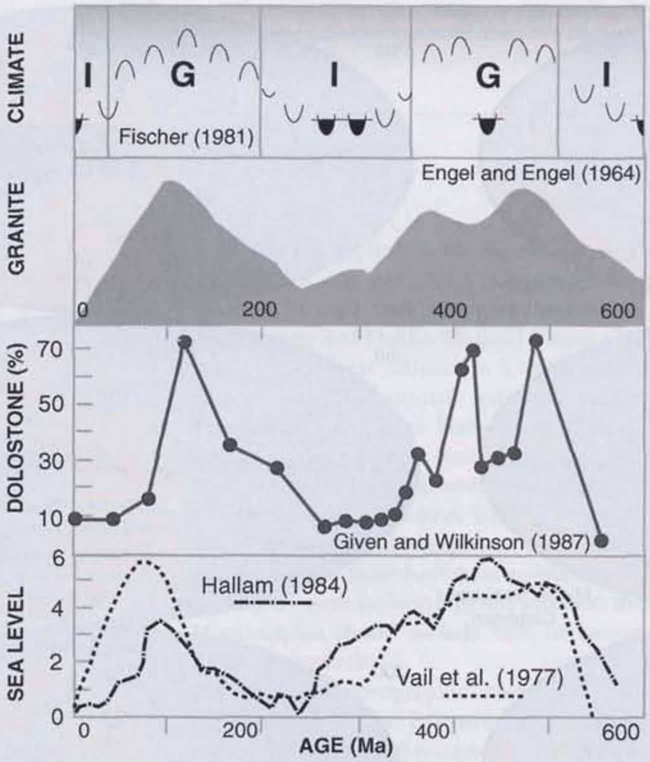

Figure 4. Phanerozoic planetary supercycles linking previously identified long-term planetary warm and cold climate fluctuations with periods of increased tectonic activity and continental inundation by seawater (Fisher, 1981). From top to bottom: greenhouse (G) and icehouse (I) fluctuations; changes in relative abundance of continental granite emplacement for North America; dolostone abundance vs. stratigraphic age curve for North America and Russian platform (with slight modifications); and worldwide relative sea-level height curves vs. time. Middle and early late Paleozoic mud-mound proliferation (Fig. 2) identified in this study overlaps decreasing sea level and may reflect increasingly colder planetary climate and seawater conditions.

Paleozoic mud-mound distribution reveal that mounds were dispersed widely, extending to high, cold latitudes. Thus, they may originate as cold-water carbonates.

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