COMMENT

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Calner (2005) perceptively recognizes an episode of increase in “anachronistic” facies, including flat-pebble conglomerates, normal-marine stromatolites, oncoids, and subtidal wrinkle structures, in the Late Silurian of Gotland, Sweden. He suggests that this is evidence for reduced grazing and infaunal activity, causally related to an extinction event—the late Ludlow Lau Event—420 Ma.

It has long been suggested that secular variation in the abundance of stromatolites and other microbial carbonates could reflect biotic competition in its broadest sense (Fischer, 1965). The classic example is where metazoan origin and diversification may have caused Late Proterozoic stromatolite decline (Awramik, 1971). Once metazoans became established in the Phanerozoic, a reverse effect could have applied with metazoan reduction at mass extinction events, permitting recovery of stromatolites as “disaster biotas” (Schubert and Bottjer, 1992). By this reasoning, even a relatively minor extinction, such as the Lau Event, might give rise to detectable stromatolite resurgence, as Calner (2005) suggests.

However, in addition to biotic competition, environmental factors also are likely to have influenced the secular abundance of microbial carbonates. Seawater chemistry is particularly important in this respect through its effect on the synsedimentary lithification that is essential for the accretion and preservation of microbial carbonates (Riding and Liang, 2005a). Fischer (1965) suggested that microbial calcification was limited by reduction in pCO₂ from the Ordovician onward. Microbial calcification is mediated by saturation ratio (Ω) with respect to CaCO₂ minerals (Riding and Liang, 2005b). Seawater Ωaragonite and Ωcalcite can be calculated for the Phanerozoic from estimates of past seawater ionic composition and atmospheric CO₂ levels (Riding and Liang, 2005b) (Fig. 1). Microbial carbonate abundance shows broad positive correspondence with calculated seawater saturation state throughout much of the Phanerozoic, especially prior to the Cretaceous, indicating that seawater chemistry has indeed influenced the formation and preservation of microbial carbonates (Riding and Liang, 2005a). The calculated saturation ratio trend shows generally high values 540–340 Ma, with maxima at ~520 and ~350 Ma. In between these maxima, the highest Ω values were reached ~420 Ma. This relatively brief episode coincided with a short-lived increase in microbial carbonates (Arp et al., 2001, Fig. 3D; Riding and Liang, 2005b, Fig. 1B) (Fig. 1), of which the anachronistic deposits of the Eke Formation described by Calner (2005) are an example.

It is therefore possible that, in addition to a decrease in metazoan competition and disturbance induced by the Lau Event, the Eke-Burgsvik deposits of Gotland also were influenced by a contemporaneous increase in seawater saturation state. Reduction in biotic competition caused by the Lau Event was relatively short-lived (~0.5 m.y.) (Calner, 2005, Fig. 2), whereas an elevated saturation state during the Late Silurian may have persisted for 10 m.y. or more (Riding and Liang, 2005b) (Fig. 1). An increase in saturation state could account not only for Eke-Burgsvik facies but also for increased abundance in microbial carbonates during the mid-Late Silurian generally (Arp et al., 2001, Fig. 3d), and conceivably for their continuation into the earliest Devonian too (Kissling, 2002, Fig. 16). Furthermore, in addition to stimulating microbial carbonate formation, elevated saturation state is arguably a more significant factor than biotic competition in determining the formation of Eke Formation flat-pebble conglomerates, which Calner (2005) includes as anachronistic facies, and could also account for the marine pisoids of the overlying Burgsvik Formation (Groves and Calner, 2004). It can thus be argued that the effect of the Lau Event on the increase in microbial carbonates and anachronistic facies was relatively minor in comparison with a contemporaneous but longer-lived rise in seawater saturation state.

Such attempts to gauge the relative importance of fluctuations in competition and in seawater saturation state are central to understanding disaster biotas and anachronistic facies following mass extinction events (Riding and Liang, 2005a). Microbial carbonates do not always show resurgence in mass extinction aftermaths (Schubert and Bottjer, 1992). Comparing Phanerozoic changes in metazoan diversity, seawater saturation state, and microbial carbonate abundance, Riding (2005) concluded that microbial carbonates were most abundant when elevated saturation state coincided with low metazoan diversity, and least abundant when reduced saturation state coincided with high metazoan diversity. It seems likely that microbial carbonate development during the Late Silurian, including the Lau Event, reflects elevated saturation state as well as low biotic diversity.

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Figure 1. Calculated saturation ratio (Ω) for calcite and aragonite, for past ~550 m.y. Periods of abundance of nonskeletal and/or microbial carbonates (stippled) broadly coincide with saturation state maxima. Gray arrow indicates brief episode of microbial carbonate increase ~420 Ma that coincides with Late Silurian Lau Event. Adapted from Riding and Liang (2005b, Fig. 1B).

Ωcalcite
Ωaragonite

Million years before present
550 500 450 400 350 300 250 200 150 100 50 0
5 4 3 2 1 0
REPLY

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In my paper (Calner, 2005a), I presented stratigraphic and sedimentary data from the Late Silurian of Gotland, Sweden, that supported a substantial increase of microbially mediated carbonate facies and sedimentary structures during the time interval corresponding to the Lau Event. I noted that the sudden appearance of normal-marine stromatolites, wrinkle structures, and a mass occurrence of oncoids during the event suggested that minor extinction events also resulted in anachronistic periods that were less devastating but fully comparable to those reported from the aftermath of the end-Ordovician and end-Permain mass extinctions.

In his comment, Riding also addresses the seawater saturation state of CaCO₃ minerals as an important control on the secular variation and preservation of microbial carbonate deposits in the Phanerozoic. It indeed has been adequately shown that the combined efforts of metazoan evolution and changing seawater saturation state likely have determined the general long-term pattern of microbial carbonate abundance (Riding and Liang, 2005a). As Riding notes, attempts to go further and gauge the relative importance of biotic competition and seawater carbonate saturation state are important to understanding the significance of disaster biotas, and this can certainly be discussed in more detail. There seems to be little doubt that the Lau Event occurred during an extended period of elevated seawater saturation state, and I agree that this, at least partly, has contributed to the relative increase in microbial carbonate facies noted in the middle and Late Silurian (Arp et al., 2001). I do not agree, however, that seawater saturation state would be the overriding control on the increase of microbial facies during the Lau Event, as indicated by Riding. A point that should be addressed in better detail is that of temporal stratigraphic resolution. The seawater saturation curve presented by Riding and Liang (2005b), and herein, shows a period of increasing seawater saturation state through the Silurian, peaking at ~420 Ma. Thereafter, the curve shows a distinct decline that does not end until approximately the Frasnian-Famennian boundary (at ~375 Ma), which is close to the start of an extended period of elevated seawater saturation state. As is always and inevitably the case with long-term curves, this curve does not provide the necessary resolution for separating short-term anomalies from the long-term trend; in this case, short-term biotic anomalies superimposed on the general seawater saturation curve. The most striking and intriguing points with the microbial resurgence during the Lau Event are its well-defined stratigraphic range and its contemporaneous occurrence in various environments over that same period. A similar—but on Gotland, less well-developed—rise of microbial facies is associated with the middle Silurian Mulde Event only a few m.y. earlier (at ~425 Ma; Calner 2005b; Fig. 1). Microbial carbonate facies such as micro- and macro-oncoids notably increase in abundance also at this stratigraphic level, and the reef composition also changes (Calner, 2005b). In fact, this stratigraphic level conforms very well to the maximum abundance of marine calcified cyanobacteria reported by Arp et al. (2001, supplementary Table 4). Importantly, the several-million-year time interval between the Mulde and Lau Events does not show any significant increase in microbial facies or oolites, although the succession on Gotland was formed in very shallow tropical waters and under a successively increasing seawater saturation state, according to the curve of Riding and Liang (2005b). Instead, this interval is associated with carbonate platforms with major, often stromatoporoid-dominated reef complexes (Fig. 1). Hence, although the biodiversity and paleoecological trends of Silurian extinctions still need to be monitored quantitatively, it can be argued that these short-term biotic events repeatedly are associated with increases in microbial carbonates and nonskeletal carbonates such as oolites. As noted by Riding, the long-term changes in seawater saturation state, on the other hand, occur over millions of years and the elevated saturation state of the Late Silurian oceans persisted for at least 10 m.y. Thus, it appears as the biotic perturbations of the Silurian events overprint the long-term seawater saturation changes. This agrees well with the observations of Riding (2005) that Phanerozoic microbial carbonate abundance peaks during periods when an elevated saturation state coincided with low metazoan diversity.

The increase of oolitic strata in association with the Mulde and Lau Events (Groves and Calner, 2004; Calner, 2005b) may also have been partly promoted by the Silurian elevated seawater saturation state. But again, oolites of any significant thickness (several meters) on Gotland occur only in association with the Mulde and Lau Events, although there is a long-term increase in seawater saturation state through the middle and Late Silurian. Hence, the overriding control on oolite formation, is better explained by short-term anomalies related to the biotic events (Groves and Calner, 2004).

REFERENCES CITED


Figure 1. The middle and Late Silurian stratigraphy of Gotland includes two distinct levels of increased microbial abundance. Both levels are associated with biotic events. Light gray shading denotes stratigraphic range of two events, and darker shading denotes stratigraphic range of anomalous carbonate facies for each event. For references to this figure, see Calner (2005).

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