Late Devonian Extinction: Cause and Effect on Reef-Building Corals

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November 16, 2010

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Abstract

In the early Devonian, coral reefs thrived during a period of global climatic warming, which caused flooding of the interior of Euramerica and provided an abundant area in which reefs could live. However, by the beginning of the Frasnian, the seas began to change from calcite to aragonite and the water temperatures began to cool. This icehouse effect caused a drop in sea level, exposing the reefs. This event was devastating to the reef building corals. Throughout the rest of the Devonian the corals gradually became extinct, dropping from 200 genera to 10. The tabulate corals were most affected, while the rugose corals maintained a better survival rate. It is most commonly believed the solitary forms of the rugose corals allowed more rugose than tabulate corals to survive. In the Carboniferous, the rugose corals rebuilt most of their diversity, while the tabulate corals only revived a third of the original diversity. This gradual extinction of reef-building corals in the Devonian is comparable to what is happening to modern corals today. While global climatic cooling destroyed the Devonian corals, today global climatic warming is destroying modern corals. Global ocean temperature rise is forcing corals' zooxanthellae to leave causing coral bleaching, which is gradually killing modern corals. From this research, it is clear global climatic changes, whether warming or cooling, can destroy reef-building corals.

Table of Contents

Introduction……………………………………………………………………………1

Reef Population Explosion of the Early-Middle Devonian………………………...1

The Frasnian Stage: The Beginning of the
End of Reef Building Corals in the Devonian……………………………………...3

Extinction and Recovery of Reef-Building
Corals in the Famennian and Carboniferous ………………………………………5

Reefs and the Late Devonian Mass Extinction……………………………………..8

Conclusion……………………………………………………………………………8

References Cited……………………………………………………………………10

Introduction

During the early-mid Devonian, there was a population explosion of reefs. At no other time known in Earth's history have reefs been more complex and extensive as in the early Devonian (Copper, 2002). This explosion was the primary result of calcite seas and of the flooding of continental interiors in tropical climates (Copper, 1994, 2002). During this time reefs flourished with more than 200 genera of tabulate and rugose corals. However, a regression in the early Frasnian brought about the beginning of the demise of the extreme reef diversity, specifically in the corals (Copper, 2002).

By the Famennian, reefs only consisted of a small diversity of tabulate and rugosan corals (Copper, 2002). Although the extinction wiped out over 100 genera of rugose corals, they recovered almost their entire diversity of the Devonian during the Carboniferous (McGhee, 1996). Tabulate corals, however, struggled during the Carboniferous and recovered only a third of their diversity (McGhee, 1996).

Reef Population Explosion of the Early-Middle Devonian

The most extensive reef development known to have existed on Earth occurred during the Emsian and Givetian stages of the Devonian (Copper, 1994). During this time, there was extensive global warming, which led to the flooding of vast continental interiors (Copper, 2002). Specifically, Laurentia, which was fused to Baltica, forming Euramerica, was covered by approximately "15 million square kilometers of seaboard, most of it carbonate platform, and probably 30% of that would have provided some 5 million square kilometers of reef tracts" (Figure 1; Copper, 1994, p. 7). According to Copper (2002, p. 28) the flooding created the perfect tropical shallow water environment to house "'skeleton framework reef factories' and coral-stromatoporoid sponge carpets and meadows."

Additionally, much higher CO_2 levels and high rates of weathering of terrestrial Ca/Mg silicates caused a long-term transfer of atmospheric CO_2 to oceanic-stored $CaCO_3$, meaning oceans were undergoing a calcite sea period, further promoting reef development (Copper, 2002). Reefs during this time primarily consisted of a diverse range of tabulate and rugose corals, cyanobacterian calcimicrobes with calcite skeletons, and aragonitic stromatoporoid sponges.

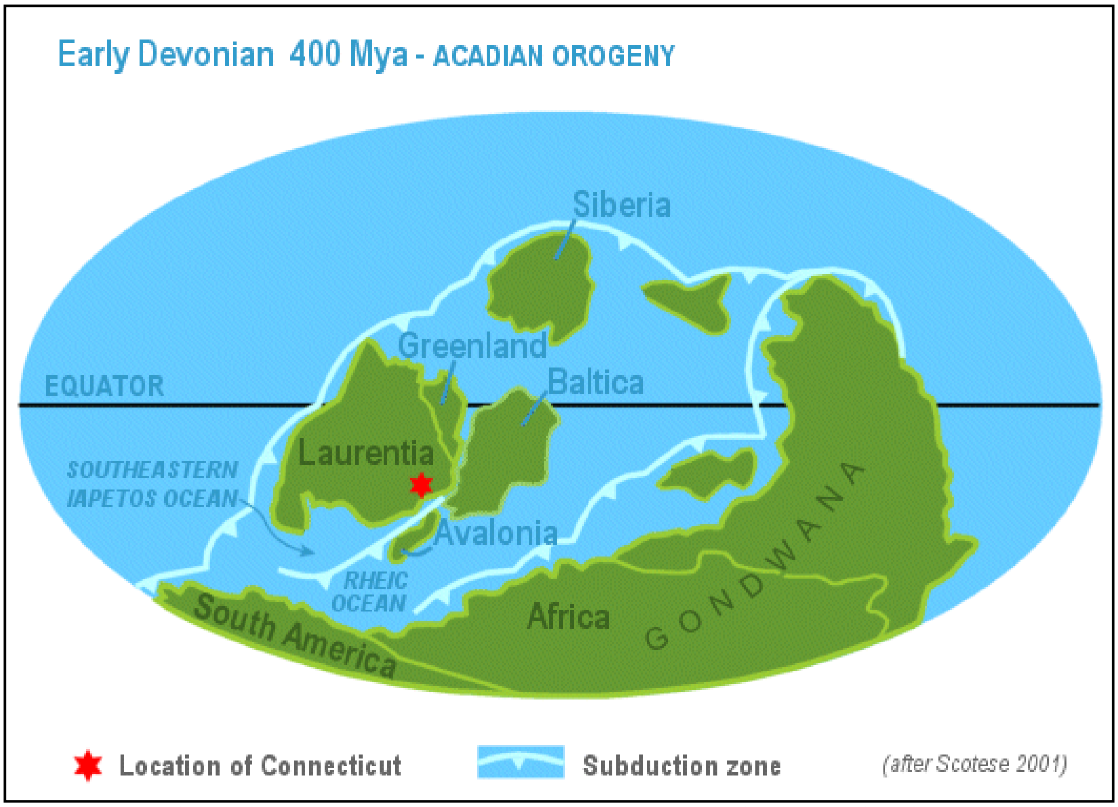

Figure 1. The early Devonian during the time of extremely high reef development (from http://www.lisrc.uconn.edu/lisrc/geology.asp?p2=History&p3=glhct).

The Frasnian Stage:
The Beginning of the End of Reef Building Corals in the Devonian

By the beginning of the Frasnian, however, reef ecosystems had lost more than 50% of their tabulate and rugose coral diversity (Copper, 2002). During the early Devonian, reefs contained over 200 different genera of tabulate and rugose corals; however, the Frasnian reefs were mainly comprised of only a small diversity of alveolitid and thamnoporid tabulates and giant phaceloid to aphroid rugosan corals (Figures 2 and 3; Copper, 2002).

During the early Frasnian, regression began to occur exposing the shallow water, tropical reefs of the Givetian (Copper, 2002). Additionally, there was a change from calcite to aragonite seas triggered by rising O_2 and cooler temperatures (Copper, 2002). As a result, there was an overall reduction in reef building activity and many reefs vanished entirely, leaving a small diversity of corals in the early Frasnian. During the mid-Frasnian, however, reef development began to turn around again, and although diversity was low, the reefs had recovered to a considerable extent in size (Copper, 2002). Nevertheless, this odd turn around was short-lived and in the late-Frasnian reefs were again diminished in abundance and distribution (Copper, 2002). This time period during the Frasnian caused a slow but progressive decrease in the diversity of reef taxa and marked the beginning of the extinction of reef-building corals (Fagerstrom, 1994).

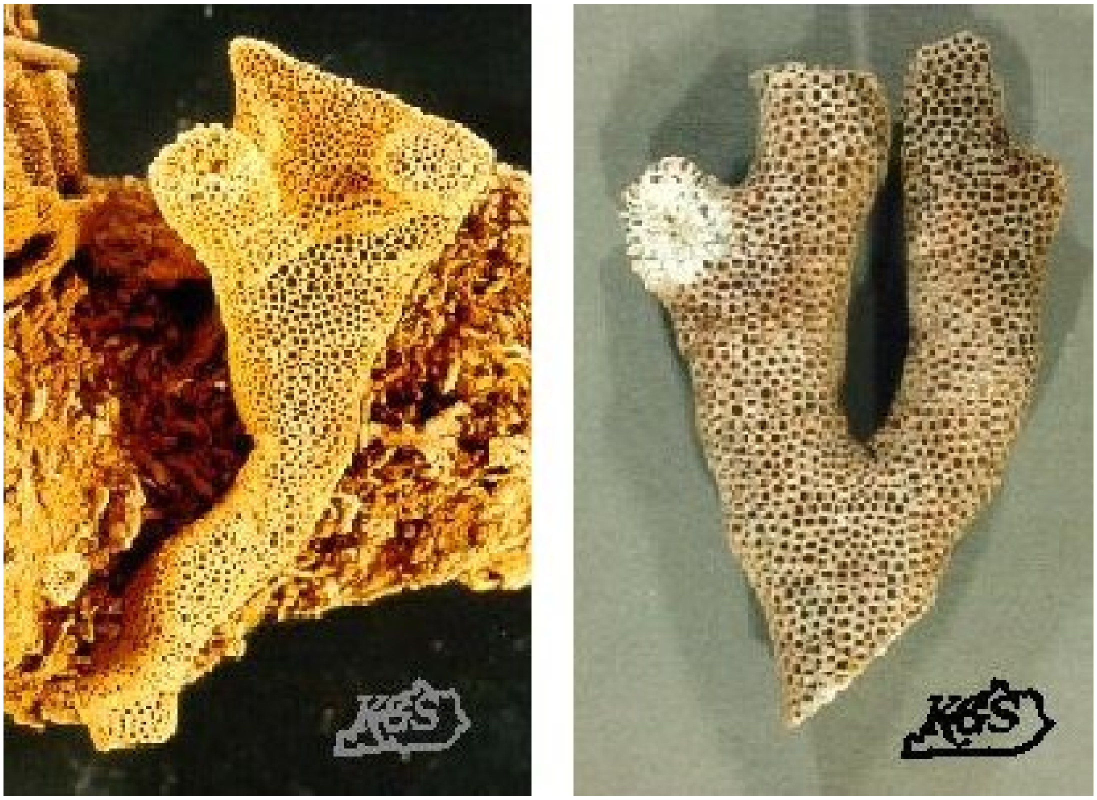

Figure 2. Thamnoporid tabulate corals from the Jeffersonville Limestone, Devonian in age (from http://www.uky.edu/KGS/fossils/tabulatebranching3.htm).

Figure 3. Modern corals with phaceloid growth patterns. They are defined by their uncommon growth form in which the colony shape is determined by the presence of elongate corallites joined only at their base (from http://data.aims.gov.au/coralpages/html/States/Growthform/GFphaceloid.htm#).

Extinction and Recovery of Reef-Building Corals in the Famennian and Carboniferous

Diversity of rugose and tabulate reef-building corals had gradually been diminishing due to the global sea level drawdown in the late Devonian. By the Famennian stage at the end of the Devonian, less than 10 genera survived the final phases of the mass extinction (Copper, 2002 and McGhee, 1996). Interestingly though, the rugose corals had a better recovery than the tabulate corals (McGhee, 1996).

One major contributor to the survival of the rugose corals over the tabulate corals is believed to be the solitary form of the rugose corals (McGhee, 1996 and Scrutton, 1988). The tabulate corals, which were exclusively colonial, lose 80 to 92% of all genera by the end of the final extinction event (McGhee, 1996). On the contrary, the rugose corals, of both solitary and colonial form, lose only 60% of all genera (McGhee, 1996). The solitary, nondissepiment rugose corals appear to be almost entirely unaffected by the extinction, leading to a smaller loss and better recovery of the rugose corals (McGhee, 1996 and Scrutton, 1988). Although most scientists seem to agree on this theory that solitary forms survived the extinction better than colonial forms, Copper (2002), as stated in the previous section, interestingly believed phaceloid (colonial) rugose corals to be one of the few that survived to the Frasnian. Though it seems most evident that solitary forms survived the best there may be some argument to that statement.

Although there is limited information, another possible contributor to the recovery failure of the tabulate corals is the extinction of 46% of stromatoporoid genera (McGhee, 1996 and Scrutton, 1988). During the Paleozoic, stromatoporoids had created reefal niches that strongly contributed to tabulate coral success and with the extinction of many of the stromatoporoid genera went the tabulate corals (Scrutton, 1988).

Overall, the tabulate corals never fully recover in diversity from the Devonian mass extinction due to their colonial forms and the extinction of half the stromatoporoid diversity. At most, they recover a third of their early Devonian diversity (McGhee, 1996). However, during the Carboniferous the rugose corals recover almost all of their diversity from the early Devonian because of their high survival rate of nondissepiment solitary forms (Figure 4; McGhee, 1996).

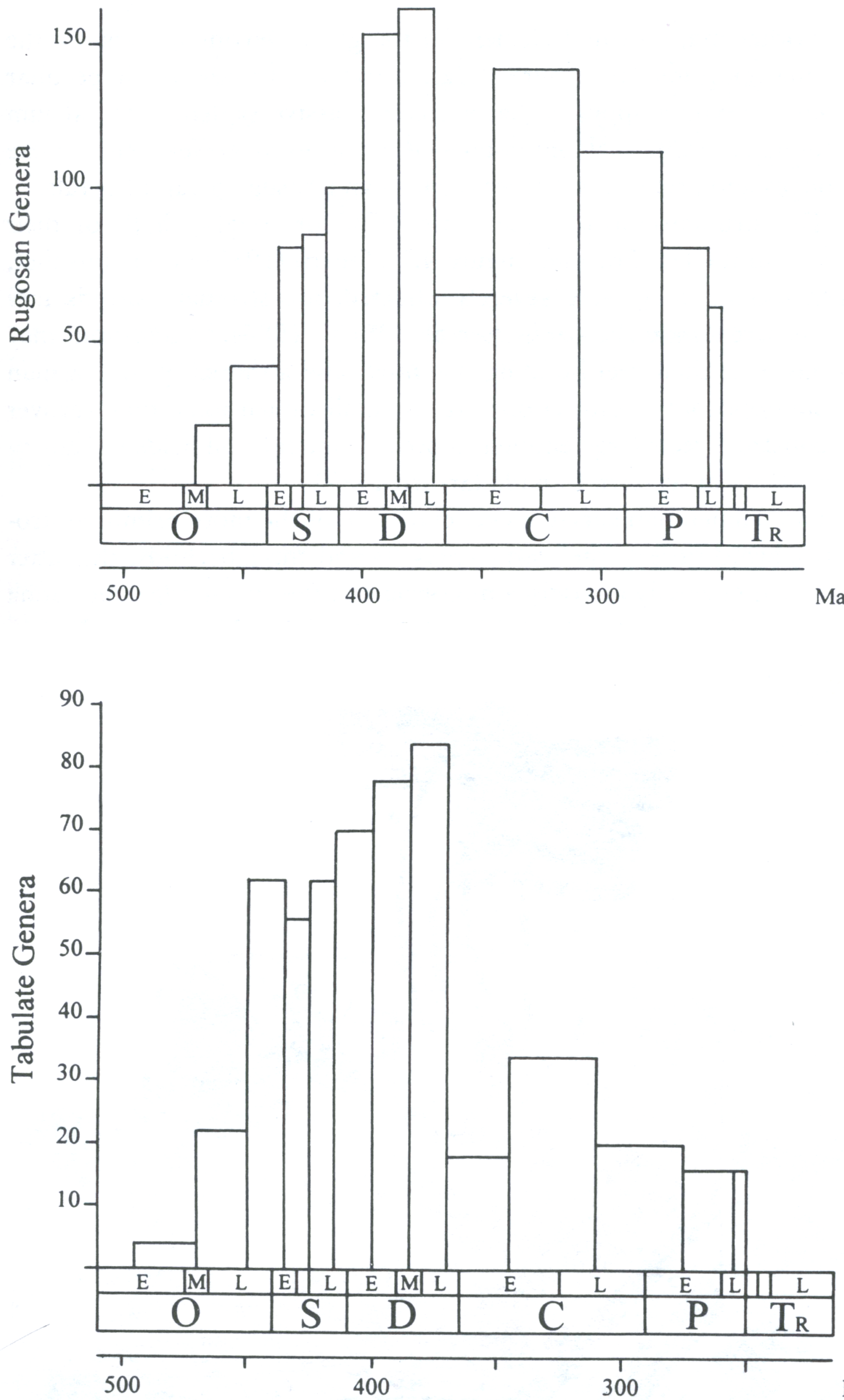

Figure 4. Charts of the diversity of rugose and tabulate corals over time (from McGhee, 1996, figs. 4.5 and 4.6).

Reefs and the Late Devonian Mass Extinction

Fischer, 1981 initially proposed the idea that reef expansion and collapse seem to reflect global greenhouse and icehouse climatic oscillations. Copper (1994) expanded upon this idea explaining that generally speaking, due to climatic changes reefs usually disappear well before final extinction events. Therefore, while many people assume the extinction of most reef-building corals was a result of the late Devonian mass extinction, reefs actually died out before the mass extinction and denote a global climatic cooling prior to whatever may have caused the mass extinction event (Copper, 1994).

As explained previously, in the Devonian reefs are generally absent from the uppermost part of the Frasnian stage (Copper, 1994). There are very few genera of reef-building corals that survive up to the Frasnian-Famennian extinction boundary. Beginning at the end of the Givetian and up to the Famennian, nearly all of the tabulate corals and a significant number of rugose corals go extinct (McGhee, 1996). That being the case, the Devonian extinction of reefs appears to be a gradual process, and did not occur abruptly at the mass extinction event at the Frasnian/Famennian boundary.

Modern Reefs and Climate Change

As stated previously, there was a change from calcite to aragonite seas triggered by rising O_2 and cooler temperatures, indicating a change from greenhouse to icehouse in the early Frasnian (Copper, 2002). This climatic change in the Devonian led to the demise of reef-building corals due to the sea level drop that coincided with greenhouse effects. Today, climate change is also affecting modern reefs, like the Great Barrier Reef. Although global climatic warming allowed reefs to thrive in the early Devonian, it is negatively affecting modern reefs. Today, the primary adverse affect of global climatic warming is a rise in sea-level temperature, which is causing the gradual demise of corals and reefs similar to what happened in the Devonian.

Modern corals have a symbiotic relationship with algae, known as zooxanthellae, which live inside of them. The corals provide a safe place for the zooxanthellae to reside, while the zooxanthellae photosynthesize and provide the corals with energy. The rise in sea-level temperature places the corals in stressful environmental conditions, which in turn causes the zooxanthellae to leave the corals' tissue (AIMS, 2007). This process is known as coral bleaching since the zooxanthellae, which normally make coral reefs vibrant colors leave, and the corals are left with only their white calcium carbonate skeleton. Color bleaching is detrimental to coral reefs since they no longer receive energy from the zooxanthellae.

Since the 1980's, coral reefs have been closely monitored for coral bleaching since they provide protection for many species of fish, help control carbon dioxide levels in the oceans, and act as a barrier by slowing down strong currents and waves as they reach the coast (Ocean World, 2010). In 1998, one of the most significant rises in ocean temperature caused up to 70% of corals to die from coral bleaching in particular reef areas (AIMS, 2007). Similarly, in 2006 another mass bleaching event occurred and caused a 40% mortality of coral reefs. If the effects temperature rise has on reefs continue, global climatic warming could cause another mass extinct of reef-building corals as global climatic cooling did in the Devonian. Rumor has it, that if sea-level temperatures continue to rise, reefs could lose 95% of living coral by 2050 (Hoegh-Guldberg et al., 2007)

Conclusion

Due to interior continental flooding and rich calcite seas, the Devonian began with an enormous area of Earth covered by the most diverse reefs known. However, as sea level began to fall and calcite seas became aragonitic at the beginning of the Frasnian, reef diversity and size began to fall dramatically. By the end of the Frasnian and beginning of the Famennian, nearly all of the rugose and tabulate corals were extinct. The extinction of stromatoporoid reefal niches and the colonial forms of tabulate corals weakened tabulate corals' chance of recovery. In the Carboniferous, tabulate corals only recovered one third of their Devonian diversity. Rugose corals, on the other hand, were more fortunate and because of their nondissepiment solitary forms they were able to recover almost all of their genera from the Devonian. Today global climatic warming could cause similar devastating effects to modern corals. Global climatic warming is causing a global rise in sea-level temperature, which in turn causes coral bleaching and the death of large areas of coral reeds. From this information, it is clear climatic changes, whether global warming or cooling, have devastating impacts on reef-building corals.

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