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# Paleogeographic trends in Late Triassic reef ecology from northeastern Panthalassa

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ABSTRACT

The Late Triassic was a pivotal period in reef evolution, but the majority of information about reef ecology during this time comes from buildups in the Alps (e.g., the Tethys Ocean). Recent studies of reefs in western North America have recognized unique ecologies along the eastern margin of the Panthalassa Ocean. Although there are numerous (twenty-five) localities with putative reef builders, only four buildups had syndepositional relief and a rigid framework (i.e. true reefs). The most paleo-northern true reefs were microbial patch reefs with only a few large skeletal bioconstructors; hypercalcified sponges and spongiomorphs built the mid-latitude reefs, with secondary microbial encrustation and branching, phaceloid *Retiophyllia* corals. Corals are the primary bioconstructors in Panthalassa's most paleo-equatorial reefs and calcareous microbes are sparse. When all reefal deposits are analyzed, the N–S gradient is also present, with microbial and bivalve deposits in the north, sponge-coral deposits in the mid latitudes, and coral deposits near the equator. This ecological gradient is not apparent in the Tethys Ocean. Tethyan reefs thrived in oligotrophic, tropical waters without strong latitudinal gradients; by contrast, paleoceanographic considerations suggest that cool, nutrient-rich waters swept south along the western North American borderlands in the Late Triassic. The eastern boundary current is interpreted to have created a strong north–south differentiation of environments in northeastern (NE) Panthalassa that was manifested in both the biotic and abiotic characteristics of eastern Panthalassic reefs. Reefs from equatorial Panthalassa are similar to Tethyan reefs (warm-water, photozoan, coral reef structures), whereas higher paleo-latitude reefs from Panthalassa are interpreted as cool-water (heterozoan) buildups, with abundant calcareous microbes, diminutive biocalcifiers, and few large, framework-building corals.



**Contents**



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## 1. Introduction

### 1.1. Triassic reefs

The Triassic period marks a major revolution in reef ecosystems, and the appearance of the first "modern" reefs built by scleractinian corals (Flügel, 2002; Stanley, 2003). Scleractinians are thought to have acquired photosymbionts (zooxanthellae) as early as the Middle Triassic (Stanley and Swart, 1995; Muscatine et al., 2005; Kiessling, 2010; Stanley and Helmle, 2010), which may have induced a reef bloom in the Late Triassic, 235 to 201.3 Ma (Stanley, 1988; Flügel, 2002). Throughout the Late Triassic, large metazoan reefs, typically built by sponges and corals, proliferated globally between >30°N and 35°S paleolatitude (Fig. 1) (Flügel, 1981; Flügel and Senowbari-Daryan, 2001; Flügel, 2002). The best-known examples of Late Triassic reefs are from central Europe; Alpine reefs have been studied in great detail and account for the majority of the quantitative data about Triassic reef ecosystems (e.g., Supplemental Fig. 1) (Flügel, 1981, 1982, 2002).

Panthalassic reefs are comparably rare, but there are several occurrences of reef material from North America (Fig. 1, Table 1). Additionally, most Panthalassic reefs have not been studied as extensively or as quantitatively as their European counterparts (e.g., no quantitative data on organism abundance or dominance, and/or no assessment of the degree of skeletal intergrowth, i.e. framework). Although excellent taxonomic data have been published for the conspicuous macrofauna (corals and sponges), most reef sites lack thorough microfacies description and quantitative estimates of reef ecology. Many sites, particularly the biostromes, are only briefly mentioned, and in some cases there is little to no data published at all (e.g., Merritt and Manson River, Table 1).

The aim of this paper is to provide a summary of the Late Triassic reef ecosystems from northeastern (NE) Panthalassa and to evaluate the environmental and oceanographic factors that controlled their ecology. The reefs from NE Panthalassa are also compared to those from the Tethys Ocean in order to address the differences between reef ecosystems in these two regions during the Late Triassic.

### 1.2. Microbialites and microbial carbonates in reefs

Microbial communities that result in carbonate microbialites are key reef constructors in Paleozoic and Precambrian reefs and featured as significant components in many Mesozoic reefs (Kiessling, 2009). Although these carbonates are easy to identify as "microbial in origin", the geobiology of the communities that precipitated the structures is not certain. Traditionally, microbial fabrics were assumed to have been produced by some form of schizophycean blue-green algae (cyanobacteria that produce extracellular polysaccharides); fabrics have been classified as either spongiostromate crusts (well defined growth forms that lack organic microstructures) or porostromate crusts (microbialites with tubular growth structures) (Flügel, 2004). However, by modern geomicrobiological standards, these are very coarse and unsubstantiated assumptions. Other microbial communities such as sulfate-reducing and heterotrophic bacteria were likely involved in reef microbialites and would have had distinct metabolic requirements and byproducts. These communities would have also had different ecological preferences, thus allowing microbialites to be successful in many environments (e.g. shallow, tropical marine systems vs. dark, cryptic reef habitats). Few geobiological studies of Mesozoic microbialites have been done, but recent work on Triassic material from Italy has

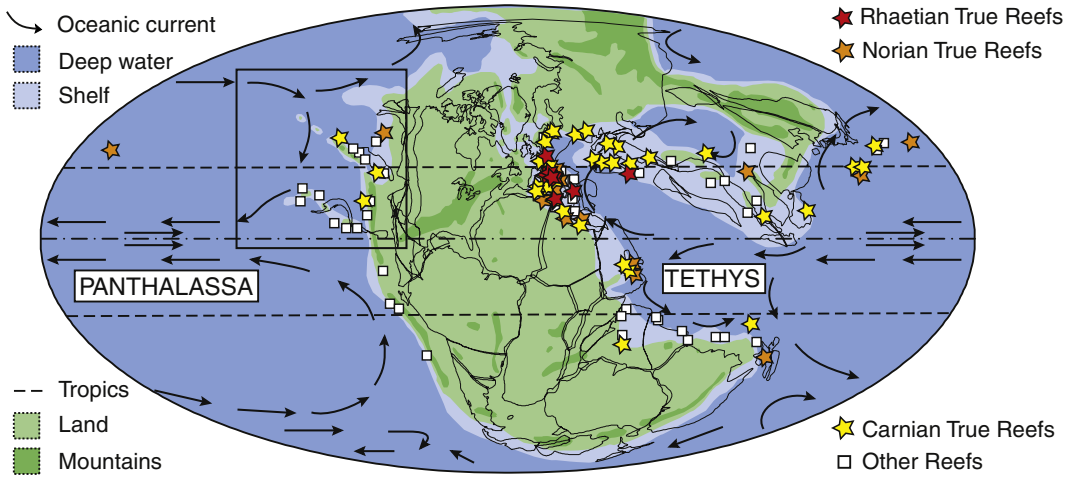


**Fig. 1.** The Late Triassic globe and location of Late Triassic reefs from the PaleoReefs Database (box indicates northeastern Panthalassa; Fig. 2). Paleogeographic reconstruction modified from Golonka (2002, 2007) and Flügel (2002) with updated NE Panthalassic paleogeography from Zonneveld et al. (2007); this reconstruction is herein referred to as a "moderate displacement" paleogeography. Known locations of reefs from the PaleoReefs Database (Kiessling et al., 2003; Kiessling pers. comm. 2012) with updates from Martindale et al. (2010, 2012a,b). True reefs are buildups (bioherms) where reef organisms form a rigid framework (ecological reefs). Undifferentiated reefs (white boxes) are Late Triassic reef mounds, mud mounds, or biostromes (sensu Kiessling and Flügel, 2002).