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Microbes into atolls – Triassic carbonate production and accumulation in the Dolomites

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The vast majority of carbonate sedimentary rocks are marine in origin, precipitated from the dissolved load of the sea. The platforms in the Dolomites are no exception to this rule. Precipitation in the sea occurs either if evaporation is able to increase the salinity (and ion concentration) to levels where inorganic precipitation begins. For instance, at about 3 times normal salinity gypsum starts to precipitate, at 10 times normal salinity halite forms. An alternative pathway to precipitation opens up where organisms extract ions from seawater and precipitate minerals in their cells. An example are radiolarians and diatoms that form skeletons of opal (amorphous SiO_2) even though the entire ocean is thermodynamically undersaturated with respect to this substance.

Marine carbonate precipitation follows either the abiotic or the biotic pathway. The biotic pathway is split into biotically induced and biotically controlled precipitation: Some organisms induce precipitation outside the cells without controlling the exact location, composition or shape of the precipitate; others operate like the radiolarians and diatoms, totally controlling the precipitation process in their cells. The biotically controlled precipitates are divided into products of autotrophic and heterotrophic organisms. Autotrophs use sunlight as energy source for growth, heterotrophs obtain energy from feeding on other organisms. Fig. 1 depicts the cascade of options realized in the marine carbonate world.

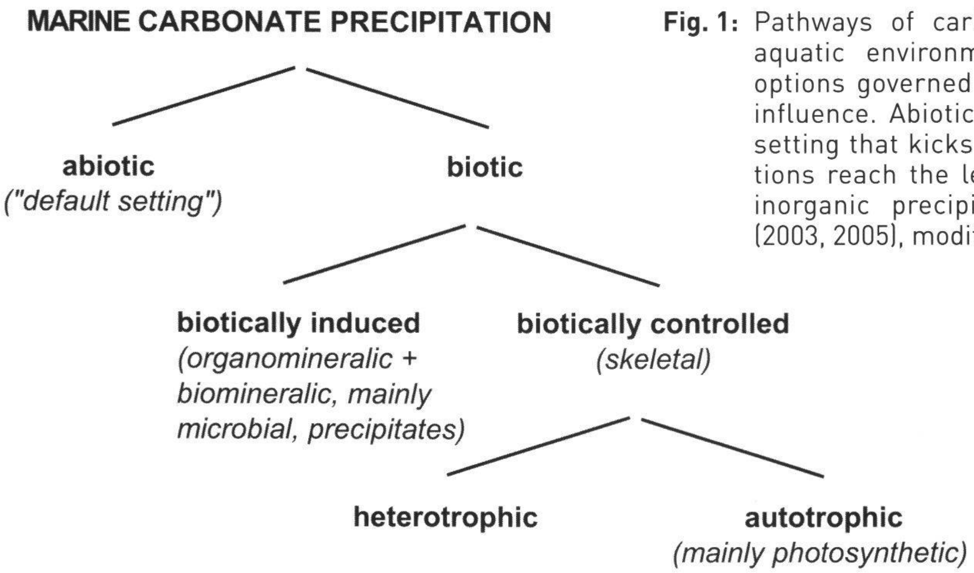

Fig. 1: Pathways of carbonate precipitation in aquatic environments – a cascade of options governed by the degree of biotic influence. Abiotic pathway is the default setting that kicks in when ion concentrations reach the level required for purely inorganic precipitation. After Schlager (2003, 2005), modified.

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Summary of a talk and contributions to the field trips given at the VSP/ASP annual convention, Ortisei, Italy, June 2007.

In carbonate depositional environments, usually several modes of precipitation operate side by side. However, at the scale of geological formation the precipitation pathways combine in characteristic ways to form three common production systems, or «factories», as shown in Fig. 2 (Schlager 2003, 2005). The factories differ with regard to the composition of the sediment produced (Fig. 3), the depth window of production and the growth potential (Fig. 4), as well as the characteristic geometry of their accumulations (Fig. 5).

The platforms of the Dolomites have been likened to modern coral reefs and their associated sediments for 150 years (Mojsisovics 1879, Leonardi 1967). This comparison would label them products of the T factory. The interpretation was supported by the occasional findings of corals and sponges and was further strengthened by the morphology of many platforms. They were round, isolated structures bounded by steep slopes and deep water on all sides – seemingly perfect analogues of modern coral atolls. This view has changed drastically in the past decade. Detailed studies revealed that skeletal carbonate, i. e. biotically con-

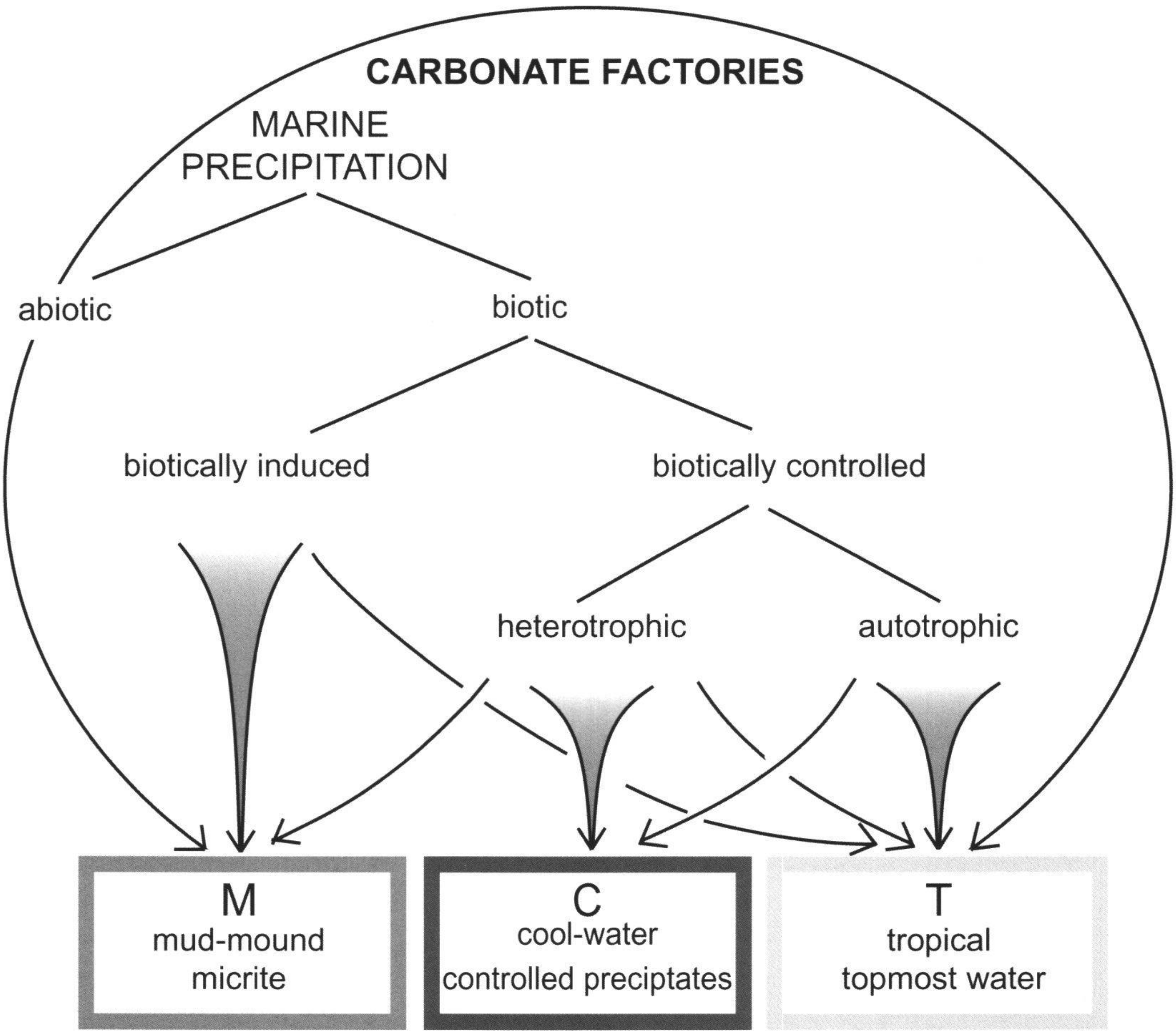

Fig. 2: Carbonate factories. At the scale of geological formations, the pathways of precipitation of Fig. 1 combine in characteristic ways to form carbonate factories. The characteristic material of the T factory are biotically controlled precipitates from autotrophic organisms (or heterotrophic organisms with autotrophic symbionts); the C factory is dominated by heterotrophic organisms and the M factory by biotically induced precipitates, mostly micrite. After Schlager (2003, 2005), modified.

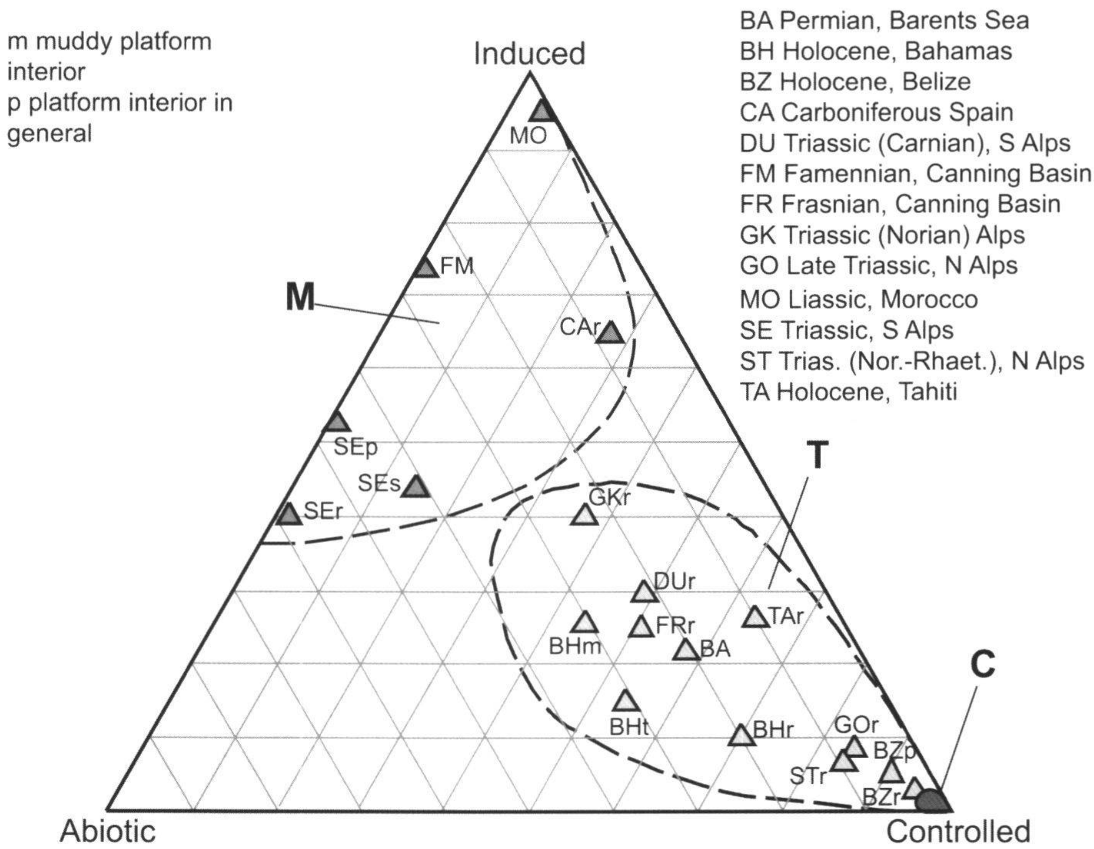

Fig. 3: Proportions of abiotic, biotically induced and biotically controlled material in factory output estimated from the composition of some well-known Phanerozoic limestone formations. C factory consists almost entirely of one category, i. e. biotically controlled precipitates. M and T factories are mixtures of all three categories with M factory richer in bio-induced and abiotic material, T factory richer in biotically controlled material. After Schlager (2005), modified.

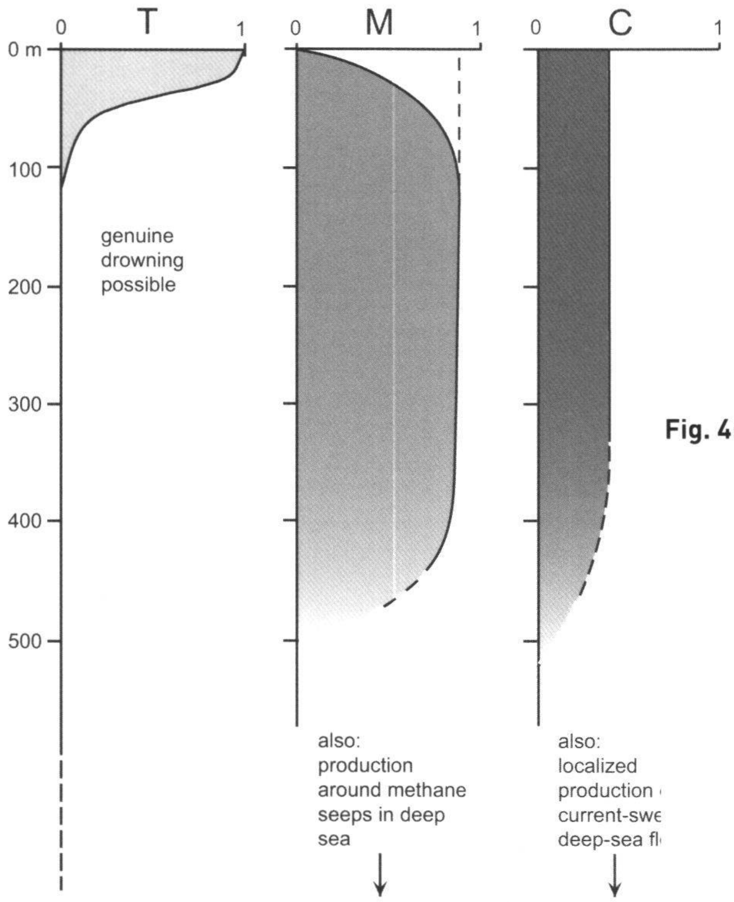

Fig. 4: Depth window of production and maximum growth rates of carbonate factories. Width of shaded bars represents estimated maximum growth rate expressed as a fraction of the T factory standard. Dominance of photo-autotrophic (i. e. light-dependent) organisms in the T factory leads to very high production rates but only in a narrow depth window. Production of the other factories is largely independent of light, the depth windows extend over hundreds of meters and their lower limits are poorly known. In modern oceans, production by the M factory is low at shallow depths, probably because of competition by the T factory. Based on Schlager (2005).

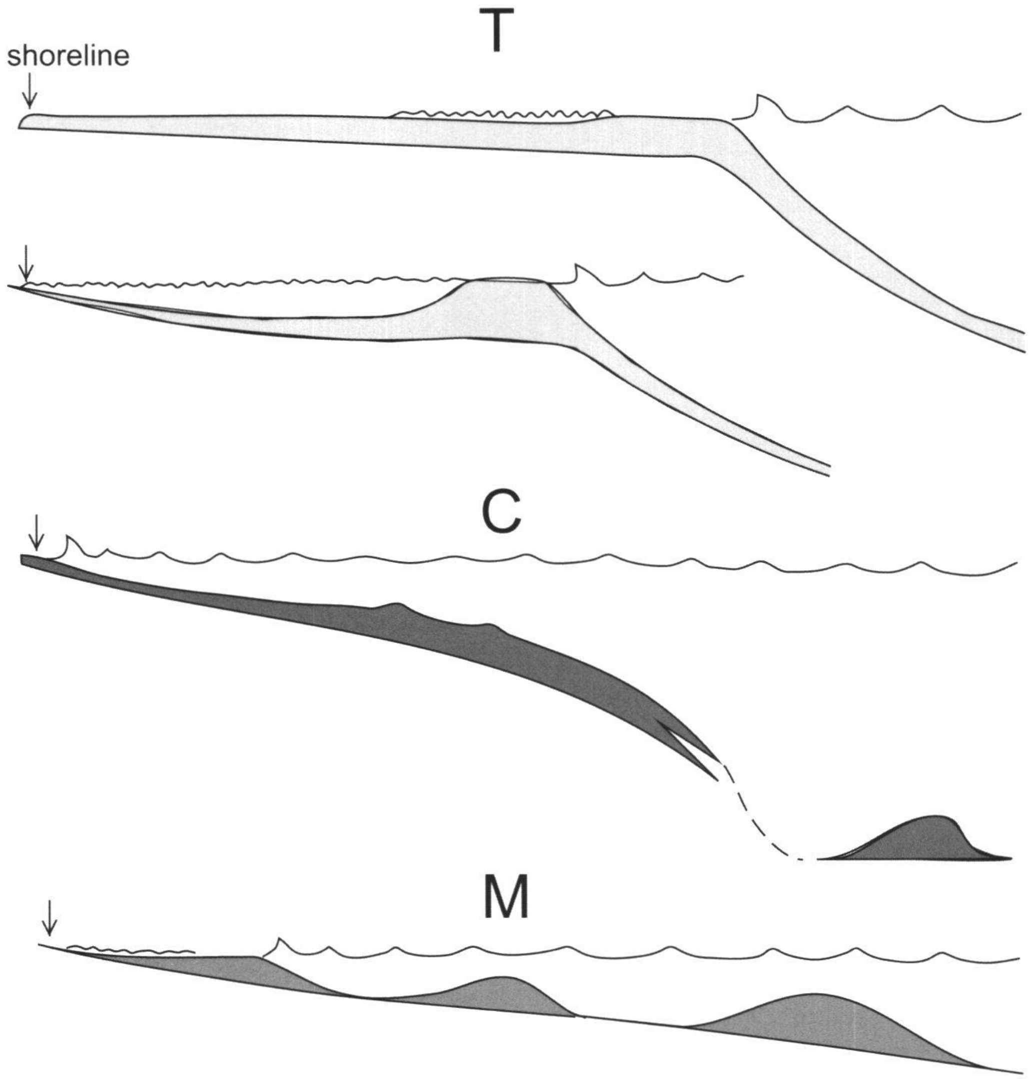

Fig. 5: Accumulation geometries of the factories reflect the differences in environmental setting and sediment composition. Flat platforms, sharp shelf breaks and steep slopes characterize the T factory. Raised rim and empty lagoon, the «empty bucket» is a hallmark of the T system under stress. Cool-water accumulations (C factory) show sea-ward sloping shelves and relatively gentle slopes, occasionally with minor reef structures. Geometries of the M factory are highly variable. Groups of upward-convex mounds are most common. Flat-topped mounds and proper platforms develop where mud-mound production extends into the shallow, wave-swept environments. Schlager (2003), modified.

trolled material, is but a minor constituent. The major building material of the platforms in the Dolomites turned out to be autochthonous micrite or «automicrite» (Fig. 6). This term denotes fine-grained carbonate that can be shown to have lithified at the place of origin. Judging from chemical indicators and the similarity with modern examples, precipitation probably was induced by bacteria and other microbes (Blendinger 1994, Russo et al. 1997). Quantitative studies by Keim & Schlager (1999, 2001) indicate that the dominance of biotically induced micrite (and abiotic cement) holds for all major environments – the platform interior, the margin and the upper slope. Thus, most of the platforms in the Dolomites were produced by the M factory rather than the T factory. Compositionally, the Dolomites platforms are close relatives of Paleozoic mud-mounds. They resemble reef-rimmed platforms of the T factory only with respect to overall geometry and facies zonation. Like modern platforms of the tropics, the

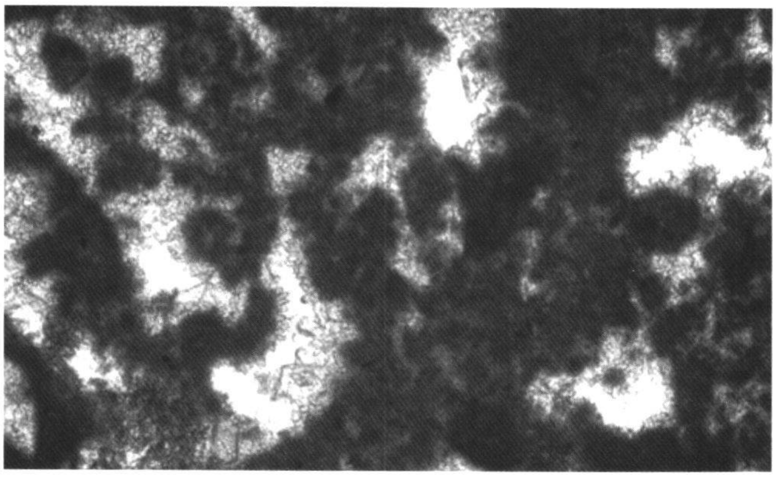

Fig. 6: Thin section of automicrite facies. Clotted and pelleted automicrite (dark) provides rigid framework supporting primary pores (light colored) that are partly filled by cement. (Long side = 4 mm). Triassic, Molignon Hut, Dolomites. Sample courtesy of L. Keim.

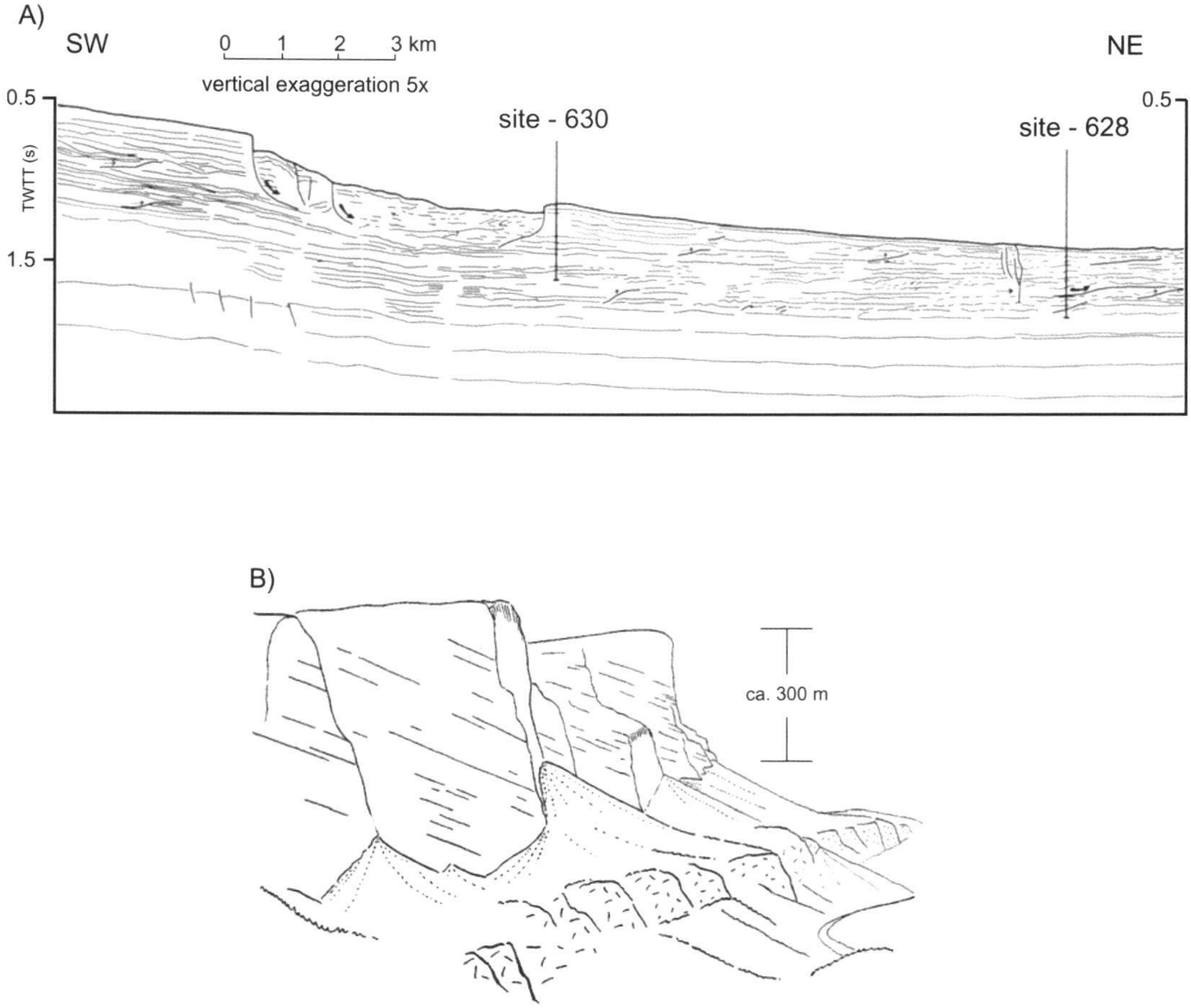

Fig. 7: Effect of sediment grain size on morphology of submarine slopes. A) Slope of extant platform dominated by muddy, cohesive sediment. Note low slope angle and indications of slumping. Line drawing from seismic profile, northern flank of Little Bahama Bank. B). Prograding carbonate platform slope composed of sand, rubble and over 50% of automicrite lenses and layers. Despite its abundance, automicrite was not able to build morphologically significant mounds; slope morphology is controlled by the angle of repose of the detrital material. Note similarity of Triassic slope angles with angle of modern scree, also composed of rubble and sand (difference between subaerial and subaquatic angles of repose of coarse material is very small). After Kenter (1990) and Schlager (2005), modified.

buildups of the Dolomites have flat tops built to sea level and a rigid platform rim. Unlike modern atolls, the rim is stabilized by automicrite and abiotic cement rather than coral reefs. The platforms are flanked by steep slopes where layers of sand and rubble alternate with lenses of automicrite formed in-situ. The steep, planar bedding surfaces often dip close to the angle of repose of sand and rubble (Fig. 7). Thus, deposition of coarse debris controlled slope geometry. The contribution of automicrite to the slopes was volumetrically significant but its effect on slope geometry was minor.

The platforms in the Dolomites closely resemble the Late-Devonian (Famennian) platform of the Canning Basin in Western Australia (Playford et al. 1989). There, the luxurious growth of reefs was abruptly terminated at the Frasnian-Famennian boundary by a mass extinction of carbonate biota. The Famennian carbonates assumed the geometry of the Frasnian forerunner but the production switched from the T factory to the M factory. Unlike the Australian example, the reason for the dominance of the M factory in the Dolomites remains unknown.

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