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The Inception and Evolution of the Late Cretaceous Rudist Bearing Carbonate Platforms in the Mediterranean Tethys: Mirror of Geodynamically Induced Biosphere-Geosphere Interactions.

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Middle Cretaceous (Aptian-Turonian) was a period of unusually intense geodynamic activity that lead to sustained volcanism, elevated seafloor spreading and major paleogeographic/paleoceanographic changes. These are coincident with relevant geological events as turnovers of biotic communities, oceanic anoxic events (OAEs), thermal maximum and disruptions of geochemical cycles in seawater.

The middle-Late Cretaceous evolution of rudist-rich carbonate platforms of the Mediterranean Tethys has been investigated to derive possible genetic links between geodynamically induced environmental changes and the observed stratigraphic record. Stratigraphic and palaeoecologic data from the northern Tethyan margin (Sardinia) and central Mediterranean Tethys (central-southern Apennines and Apulia) have been coupled to available geochemical proxies to fulfil a detailed integrated approach to event and genetic stratigraphy. A preliminary comparison between the long-term facies evolution of shallow- and deep-water depositional environments of the Mediterranean Tethys has been also attempted to derive better constraints for causal links between biosphere and geosphere interactions.

Large scale changes of temperature and major geochemical cycles (mostly pCO_2 and Mg/Ca ratio) through middle-Late Cretaceous represent the basic premise for the onset (latemost Albian) and following development of rudists carbonate platforms during a major mineralogical shift (latemost Cenomanian) from aragonite- (latemost Albian-latemost Cenomanian) to calcite-dominated (Turonian-Campanian *p.p.*) rudist shells

in a context of generally high sea level and warm equable climate. Many lines of evidence support the assumption that the most prominent events in middle-Late Cretaceous evolution of rudists and rudist carbonate platforms are correlatable with changes in $p\mathrm{CO}_2$, temperature, ocean chemistry (mostly Ca^{2+} concentration and alkalinity), climate and paleogeographic arrangement of plates. The trophic levels of the oceans and their oxic/dysoxic states have been certainly important. By contrast short-term sea level fluctuations seemingly played a minor role whereas it is almost impossible to disclose in a great detail the relative importance of the various processes originating the observed stratigraphic evolution. Four distinct evolutive phases have been individuated in the latemost-Albian-Campanian $p.p.$ on the basis of an integrated paleoecologic, stratigraphic and geochemical approach applied to several successions exposed in the studied areas.

Phase 1 (latemost Albian-latemost Cenomanian). The onset of this phase corresponds to a major change of the productivity mode of Tethyan carbonate factories. Notably, it records the first widespread pulse of rudists as relevant lithogenetic taxa in the Tethyan seaway occurring when: a) temperature passed the threshold of 28˚/29˚C; b) Ca^{2+} concentration reached 50 meq/l and Mg/Ca mole ratio declined to about 1. The values above represent effective fatal thresholds for corals. Owing to their biologic requirements, rudists were able to occupy the most different habitats thus outpacing k-mode specialists as corals. The shallow-water deposits shifted from former prevailing muddy carbonates to essentially bioclastic, rudist-rich facies (mostly radiolitids and caprinids). A parallel increase of shallow-water sediment production fostered a marked progradational trend over the basins. There the late Early Aptian-Late Albian meso-eutrophic, locally euxinic conditions which had drove the deposition of polychrome basinal marls, shales and black-shales (Fucoid Marls) were rapidly replaced by oligotrophic, oxic conditions resulting in white, cherty limestones (Scaglia Bianca). As a matter of fact the shallow-water carbonate factories of the Mediterranean Tethys shifted from a Late Jurassic-Early Cretaceous Chlorozoan-Chloralgal mode (with Foramol and Microbial episodes around OAEs) to a latemost Albian-latemost Cenomanian rudist-rich Chlorozoan mode. This phase strictly corresponds to overall increasing Ca^{2+} concentration, possibly provided by alteration of new oceanic crust and a greenhouse-induced weathering of continental areas, raising $p\mathrm{CO}_2$ and temperature as well as to dropping organic C burial.

Phase 2 (latemost Cenomanian-Middle Turonian). The sudden environmental changes linked to the OAE2, namely the $p\mathrm{CO}_2$ and thermal maximum, as well as the following elevated alkalinity, are assumed to have terminated the former rudist- and aragonite-rich Chlorozoan factories (mostly caprinids and ichthyosarcolitids) which turned to an Early-Middle Turonian Microbial mode. An intriguing association of cyanobacteria and calcite shelled rudists (hippuritids, radiolitids) flourished especially in central Mediterranean Tethys (e.g.: central-southern Apennines) calling upon marked hyper-greenhouse conditions. According to our data and observations, rudists appear to be eurhythermic, r-mode opportunists which were adapted to low Mg/Ca ratios, alkaline waters and high-to-moderate $p\mathrm{CO}_2$.Carbonate fixation by Cyanobacteria, hippuritids and radiolitids is interpreted to have prevented an alkalinity crisis at surface oceanic waters buffering excess Ca^{2+} and carbonate-bicarbonate anions. Possibly they shared their role with the coeval r-mode opportunists (e.g.: calcisphaerulids) and r/k intermediate forms (e.g.: whiteinellids) blooming in the pelagic stock.

Phases 3 (Late Turonian-Coniacian p.p.) **and 4** (Coniacian p.p.-middle Campanian). Starting in the Late Turonian a long-term cooling phase as well as a persistently low Mg/Ca ratio, decreasing alkalinity and, possibly, salinity drove rudists to largely predominate among the carbonate secreting biota in the Foramol factories of central Tethys. Coeval basinal limestones and marls deposited during these phases are typically reddish in the subequatorial, possibly equatorial Tethys (Cretaceous Oceanic Red Beds) owing to a sustained oxygenation of deep and intermediate ocean by sinking of moderately coold surface waters. Major regional variabilities in the productivity modes of post-Turonian Foramol shallow-water factories have been observed in the Tethyan ocean. They possibly proxy paleolatitudinal gradients of physical-chemical factors as well as the physiographic settings of platforms. As a consequence, the epicontinental carbonate platforms of Sardinia (northern Tethyan margin) supported rudists-rich, impoverished Chlorozoan assemblages (Late Turonian-Coniacian p.p.) and successively rudist-bearing rhodalgal deposits. By contrast, the epioceanic platforms of central-southern Apennines and Apulia (central Tethys) produced rudist-dominated Foramol deposits starting the Late Turonian.

The Late Santonian-middle Campanian interval represents a major stratigraphic turning point within a main Late Turonian-Maastrichtian transgressive-regressive cycle. This interval, locally represented by regional drownings of shallow-water factories, was linked to complex environmental changes and possibly induced by a volcanic and tectonic pulse related to the ongoing alpine orogeny in the Mediterranean Tethys. Middle Campanian rudist-dominated depositional environments were probably unable to provide sufficient amount of sediments to counterbalance the effects of the relative rise of sea-level and the consequences of a major environmental turnover including: a) rising Mg/Ca ratio above the biogeochemical threshold of 1.0; b) decreasing temperature; c) attainment of the minimum $p\mathrm{CO}_2$of the whole Cretaceous. Notably, the species richness of Late Cretaceous rudists records an evident drop starting the middle Campanian and aragonite secreting organism like corals and green algae appear again as meaningful sediment producers in the investigated shallow-water factories.

Late Cretaceous rudist-rich carbonate platforms may be viewed as a geological product which has closely recorded the changing environmental conditions of the oceanic realm as well as the partition of the ecologic factors in different areas of the Mediterranean Tethys. Their distinct sedimentary, mineralogical and ecologic features changed over time coherently reflecting the fluctuations of the physical and chemical state in the oceanic waters induced by large-scale, long-term geodynamic forcings. These latter obviously originated in the interiors of the Earth during middle-Late Cretaceous times and provide a prominent clue for a direct link between Earth's geodynamics and the fluctuation of the major bio-sedimentary cycles.