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Environmental control on the end of the Dolomia Principale/Hauptdolomit depositional system in the central Alps: Coupling sea-level and climate changes

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A B S T R A C T

The Norian in the Western Tethys is characterised by the deposition of early-dolomitised inner platform facies (Dolomia Principale/Hauptdolomit, DP/HD), bordered on the landward side by terrigenous coastal deposits (Keuper) and on the seaward side by calcareous backreef and reefal facies (Dachstein Limestone) passing basinward to open-sea sediments (Hallstatt facies). The inner carbonate platform is locally (Lombardy Basin, Carnic Alps, Central Austroalpine) dissected by normal faults leading to the development of intraplatform troughs.

Close to the Norian–Rhaetian boundary, sedimentation records an abrupt environmental change both on platform top and basins all over the Western Tethys (e.g. Western Carpathians, Transdanubian Range, Alps, Central Apennine). The top of the Dolomia Principale locally emerged, reflecting a major eustatic sea-level fall. Emersion is recorded in favourable settings by the development of polycyclic paleosols up to 30 m thick. In the Norian intraplatform basins, the succession is capped by 4 to 8 m of thin-bedded, fine-grained limestones yielding abundant remnants of fishes and terrestrial reptiles. Fossil concentration as well as sedimentological features is indicative of reduced sedimentation rates due to decreased carbonate production, induced by the emersion of the platform top. The sea-level fall was followed by deposition of mixed fine-grained siliciclastic–carbonate successions (e.g. Riva di Solto Shale, Kössen beds, "*Rhaetavicula contorta* beds", Fatra Formation).

Stratigraphic evidence indicates a dry climate in the Western Tethys during the Norian, as indicated by the presence of evaporites (Burano, Apennine) and arid to semi-arid coastal to playa settings (Upper Keuper, Germany). In contrast, the basal layers of the basinal shales show evidence of wet climate.

The end of the Norian depositional system records two different phenomena: (1) an important sea-level fall was responsible for the emersion of the platform top and deposition of a condensed horizon in the basins; and (2) transition from dry to humid climate. The observed evolution is explained with a global cooling which caused the rapid sea-level fall responsible for the abrupt end of the DP/HD depositional system and the shift of the boundary between arid and temperate climate belts, which modified the distribution and amount of rainfall, triggering the deposition of shales along the Western Tethys margin.

1. Introduction: climate, rainfall, sea-level changes and sedimentation

Sea-level falls are recorded by facies changes which are often associated to subaerial exposure and to shifts in the depositional environment, resulting in a forced regressive trend (i.e. Coe et al., 2003). Glacialism represents the most efficient process to explain rapid sea-level falls, even in greenhouse conditions. It has been recently demonstrated (Bornemann et al., 2008; Miller et al., 2003) that even during the supergreenhouse Cretaceous period, rapid eustacy was driven by polar ice. Major and rapid sea-level falls are therefore mainly related to global cooling episodes which affected sea-level because of increase of volume of the polar ice, to the increase in the amount of fresh water stored in continental settings (in underground water tables or lakes; Jacobs and Sahagian, 1993) or to thermal expansion/retraction of oceanic waters (Schulz and Schäfer-Neth, 1997). Relatively small changes in ice volume coupled with climate-induced changes in ground water storage and changes in the temperature of sea-water could have the potential to induce eustatic changes which may be of the amplitude recorded in the global curves of sea-level changes even in time intervals, as the Triassic, when evidence of large ice caps is missing (Price, 1999; questioned evidences of ice caps during the Triassic are described from Southern Gondwana, Australia; Spenceley, 2001).

Global cooling is therefore responsible for the changes in sea-level, but also for the shift of the zonal climate belts (Matthews and Perlmutter, 1994; Perlmutter and Matthews, 1989). In a zonal climate pattern, the transition from maximum to minimum conditions changes the relative size of the Hadley circulation cells. The simple

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zonal model is complicated by the presence of azonal climate patterns which are the result of local effects, such as the position of oceans and large landmasses, coast orientations, wind directions, oceanic currents and elevation of continental areas. Major azonal effects are recorded near the margins of land and sea. Global climate changes, besides shifting zonal climate belts, enhance or diminish the effects of azonal climate patterns (Matthews and Perlmutter, 1994). Duration, frequency and intensity of global climate changes are functions of the interaction, constructive and destructive, of orbital cycles with different frequency (cycles can be in phase or not) and also to non-periodic events (i.e. volcanic events; impacts). When positive interactions occur, global climate changes force Hadley circulation cells to shift latitudinal positions, thus, changing the position of dry vs. humid belts (Matthews and Perlmutter, 1994).

This model is supported by the measured effects of the present-day global warming. Recent studies indicate that warming caused a small increase in global mean precipitation (Zhang et al., 2007) but significantly affected its distribution. Warming is responsible for increasing precipitation at high latitudes and decreasing precipitation at sub-tropical latitudes (Dore, 2005; Zhang et al., 2007). This effect is extremely important for the position of the tropical belt which is now shifting toward the north (Seidel et al., 2008). This line of evidence suggests that the opposite situation can be expected with a global cooling. In this scenario, the transition zone between climate belts is extremely sensitive to climate changes, in terms of temperature and amount of rainfall. Climate may shift from arid/semi-arid conditions during warm periods to semihumid/humid conditions during cold intervals between 25° and 35° latitude (belts 4A and 4B of Matthews and Perlmutter, 1994), but at higher or lower latitude the climate shift is opposite. This situation can be complicated by the presence of azonal effects. Climate changes heavily affect the precipitation patterns, which play a major role in sediment delivery, as changes in precipitation are locally more efficient than sea-level fall (i.e. lowering of the depositional base level) in mobilising sediments toward the sea (Matthews and Perlmutter, 1994).

Sedimentary environments highly sensitive both to climate (dry vs. humid) and to sea-level changes are represented by shallow-water carbonate platform systems. Tropical carbonate factories bordering emerged lands (attached platforms) are able to record both the changes in the efficiency of the factory itself and in the quantity of the clastic delivered from the emerged lands, as a response to increased rainfall and/or changes of the erosional base level. Furthermore, emersion of rimmed, flat-topped platforms is reflected also by major facies changes of platform-derived carbonates in basinal settings, allowing to trace the evidence of a sea-level fall from the platform top to the basins (i.e. Berra, 2007). In flat-topped carbonate factories even reduced sea-level fall can lead to the emersion of vast parts of the carbonate system.

Sedimentological analyses in these settings could help to determine how clastic input postdating a sequence boundary in carbonate systems is related to/enhanced by climate changes. The Norian–Rhaetian succession of the Western Tethys margin records important changes in carbonate production and facies association, both on platform top and intraplatform basins, resulting from the interaction of sea-level fall and climate change (from dry and warm to humid and cooler).

2. Geological setting

Influence of climate on basin stratigraphy is a function of the geographic position of the basin itself (Matthews and Perlmutter, 1994). It is thus essential to frame the latitudinal position of the DP/HD depositional system close to the Norian–Rhaetian boundary. During the Norian and Rhaetian the present-day Alpine successions were placed at about N 25° (Marcoux et al., 1993). Sedimentation on the Tethys margin was characterised for most of the Norian by a wide, early-dolomitised carbonate platform succession (Dolomia Principale/Hauptdolomit, DP/HD) which is presently preserved from different domains: Southern Alps, Central and Northern Austroalpine, Transdanubian Range, Western Carpathians and Southern Apennines (Fig. 1). Landward, sedimentation changed to coastal and playa deposits (Keuper). Toward the Tethys, the wide inner platform of the DP/HD was bordered by calcareous backreef and margin facies (Dachstein Lst.) which pass basinward to deep water sediments (Hallstatt Lst.). The evolution of the DP/HD platform is locally controlled by syndepositional tectonics which were responsible for the development of fault-controlled intraplatform basins, both in the Austroalpine and South Alpine domains during the Middle–Late Norian (Jadoul, 1985); Bechstädt et al., 1978; (Berra, 1995; Berra and Jadoul, 1996; Berra and Jadoul, 1999; Jadoul et al., 1992, 2004; Cozzi et al., 2002; Fig. 2). Due to the extensional tectonics, the top of the DP/HD system is characterised by domains where the flat-topped platform persisted and domains where tectonically-induced drowning is recorded by thick basinal successions. The syndepositional tectonics was responsible for major thickness changes of the Norian succession, from a few hundreds of meters (carbonate highs, e.g. Dolomites) to more than 2 km (intraplatform troughs). The major basinal areas are developed in the Central Southern Alps (Lombardy Basin), in the Eastern Southern Alps (Carnia;

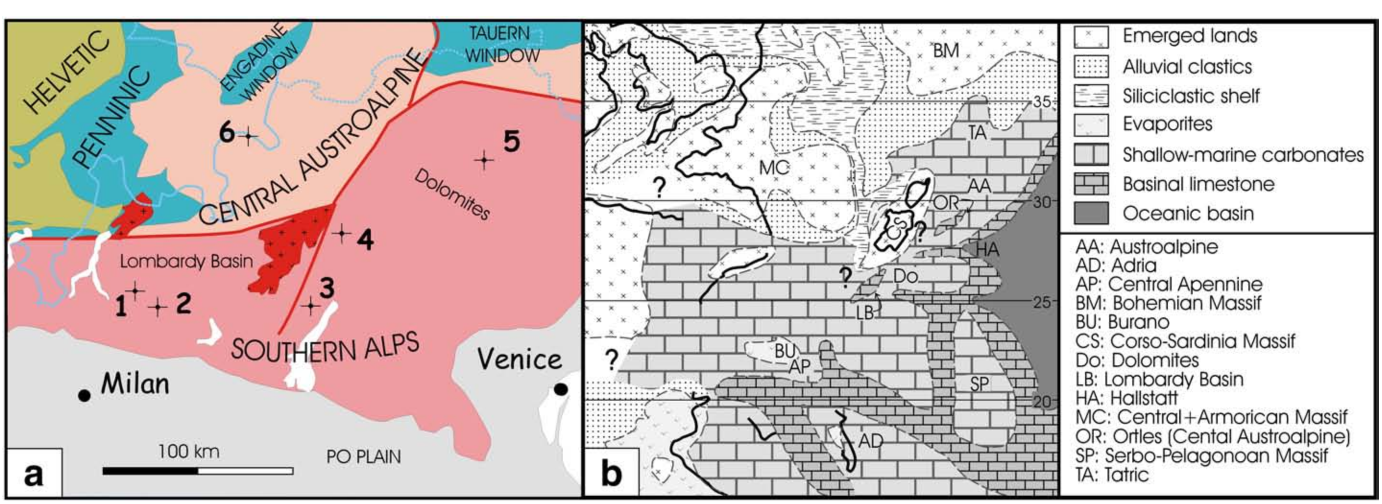

Fig. 1. Geographic (left) and paleogeographic (right) settings of the study area. Paleogeography modified from Marcoux et al. (1993). Numbers refer to sites mentioned in the text. 1: Val Taleggio; 2: Bracca; 3: Tremalzo; 4: Brenta Massif: 5: Sella; 6: Ortles and Quattervals Nappes (Central Austroalpine).