Marine and Petroleum Geology 78 (2016) 621–635

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Does compaction-induced subsidence control accommodation space at the top of prograding carbonate platforms? Constraints from the numerical modelling of the Triassic Esino Limestone (Southern Alps, Italy)

Fabrizio Berra [a,*], Eugenio Carminati [b], Flavio Jadoul [a], Marco Binda [a]

[a] Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy
[b] Università di Roma "La Sapienza", Dipartimento di Scienze della Terra, Roma, Italy

ARTICLE INFO

Article history:
Received 28 February 2016
Received in revised form
1 September 2016
Accepted 30 September 2016
Available online 30 September 2016

Keywords:
Carbonate platform
Triassic
Paleokarst
Terra rossa soil
Accommodation
Differential compaction
Numerical modelling

ABSTRACT

The demise of the high-relief, steep-slope, prograding Ladinian-Early Carnian carbonate platforms of the Esino Limestone (Central Southern Alps of Italy) is marked by subaerial exposure of the platform top associated with different erosional (mainly karst-related), depositional and diagenetic processes (Calcare Rosso). The exposure-related deposits consist of three major facies associations: 1) residual soils with thin lenses of conglomerates with black pebbles, and, locally, weathered vulcanites; 2) chaotic breccia lenses irregularly distributed in the uppermost part of the Esino Limestone carbonate platform, interpreted as collapse breccias in karstic setting: 3) inter-supratidal carbonate cycles with dissolution and development of paleosols and tepee structures.

Facies distribution follows the sub-environments of the underlying Esino Limestone. Facies 1 and 2 typically characterize the core of the platform, covering the underlying inner platform facies. Facies 3 instead develops toward the edge of the platform, above reef-upper slope facies of the prograding facies of the Esino Limestone. The thickness of facies 3 decreases toward the core of the platform. Facies distribution reflects differences in the accommodation space and sedimentary processes from the rim (highest accommodation, favouring the deposition of peritidal-supratidal carbonates) to the core (reduced accommodation, causing pedogenesis and karstification) of the carbonate system.

The observed thickness changes may be controlled by different factors: 1) syndepositional tectonics, 2) subsidence induced by magmatic activity or 3) differential subsidence controlled by the stratigraphic architecture of the Esino Limestone platform and adjoining basins. As evidence of tectonics was not observed and the presence of volcanic bodies is only documented tens of km away from the study area, the scenario involving the creation of accommodation space by compaction of the basinal sediments (resedimented, fine-grained calciturbidites) during the progradation of the carbonate platform is here investigated. Numerical modelling was performed to verify the compatibility of compaction-induced subsidence with the observed depositional architecture. The models were built to simulate the architectural evolution of the platform by progressively adding layers from deepest to shallowest, while compacting the underlying sediments, in order to evaluate compaction-induced subsidence (and accommodation space for the Calcare Rosso) after the deposition of the youngest platform strata. Modelling results allow us to conclude that the wedge geometry of the Calcare Rosso, deposited on top of the extinct Esino carbonate platform, can be explained by subsidence controlled by compaction of the basinal sediments present below the early-cemented, fast prograding platform slope deposits.

1. Introduction

Subaerial exposure of the top of carbonate platform are typically marked by hiatuses associated with karst features (Esteban and Klappa, 1983). The entity, thickness of the platform affected by

* Corresponding author.
E-mail address: fabrizio.berra@unimi.it (F. Berra).

http://dx.doi.org/10.1016/j.marpetgeo.2016.09.033
0264-8172/

karst phenomena and facies (depositional vs. erosional/dissolution events) is controlled by different factors, such as duration of the subaerial exposure, amplitude of the relative sea-level fall, architecture of the exposed platform and climate conditions (typically controlling temperature and precipitations).

For bathymetric reasons, flat-topped, high-relief carbonate platforms are especially prone to record subaerial exposure events on wide areas. Karst features on high relief carbonate platforms, frequently marking the demise of carbonate platforms, have been observed and described both at surface and in subsurface.

To understand the processes that control the effects of the subaerial exposure and the distribution of the associated facies, which are extremely important for the hydrocarbon research as enhanced porosity is frequently associated with these surfaces, it is necessary to describe the types of karstic associations on a platform top and their areal distribution. The distribution of karstic associations is fundamental to identify local vs. regional factors controlling karst development. Changes in facies and thickness of karst deposits on the platform top may reflect uneven distribution of accommodation space of a carbonate system, able to enhance or smooth the effects of a sea-level fall. Distribution of accommodation space in a carbonate platform may be essentially controlled by syndepositional tectonics, magmatic activity and compaction-induced subsidence.

Compaction-induced subsidence, although less detectable from outcrop evidence, is most effective in high-relief prograding platforms, where early-lithified sediments prograde over unconsolidated basinal deposits (Hunt et al., 1996). Due to different compositions and early-diagenetic processes, carbonate platform and basinal sediments follow markedly different depth-porosity curves, basinal lithologies being more prone to compaction (Sclater and Christie, 1980; Goldhammer, 1997). The role of differential compaction in creation of accommodation space is known as an important factor potentially controlling the geometry of sedimentary wedges (e.g., Shinn and Robbin, 1983; Suppe, 1985; Doglioni and Goldhammer, 1988; Skuce, 1994; Carminati and Santantonio, 2005), and can be understood coupling numerical modelling with field observations. Differential compaction between reefal rocks and internal lagoon or slope sediments has been recognized either in the subsurface (e.g., the Devonian carbonate platform from Canada; Anderson and Franseen, 1991) or in outcrop (e.g., the Cretaceous-Oligocene Maiella Platform margin; Rusciadelli and Di Simone, 2007).

The distribution of different type of karst-related features on a prograding carbonate platform can mirror changes in accommodation space potentially resulting from differential compaction of basinal sediments. The demise of the high-relief, steep slope, prograding Ladinian-Early Carnian carbonate platforms of the Esino Limestone (Central Southern Alps of Italy) was triggered by a regressive event (Mutti, 1994; Gaetani et al., 1998; Berra, 2007), marked on the platform top by a subaerial exposure associated with different erosional (mainly karst-related), depositional and diagenetic processes (Calcare Rosso). Favourable exposures and a well-preserved platform architecture (Fig. 1) permit the reconstruction of the relationships between the carbonate platform facies deposited before the subaerial exposure and those related to the exposure event. This provides the opportunity, rare in the geological record, to unravel the possible relationships between the paleogeography of a high-relief carbonate platform and the types of karst features related to a sea-level fall. In this study, we discuss the importance of post-depositional compaction-related subsidence in the creation of accommodation space during the demise stage of the Ladinian Esino Limestone carbonate platform and evaluate its feasibility with ad-hoc numerical models.

2. Geological setting

The Southern Alps represent the south-verging part of the collisional Alpine belt (Handy et al., 2010), storing a Permian-Tertiary succession deposited after the Variscan orogeny (Bertotti et al., 1993; Berra and Carminati, 2010). The Late Anisian to Early Carnian succession of the Southern Alps is characterized by the presence of thick carbonate platform sediments separated by basinal troughs and seaways onto which they prograde (Fig. 1). These platforms, isolated toward the Dolomites, frequently merge into wider flat-topped carbonate platforms in Lombardy (Esino Limestone, Western Southern Alps; Fig. 1). The depositional architecture of the Lombardy platforms (Assereto and Casati, 1965; Assereto and Kendall, 1971; Assereto et al., 1977; Jadoul et al., 1992; Berra, 2007) reflects different evolutionary stages (Berra et al., 2011): an inception stage followed by an aggradational stage with increasing water depth in the basins and a later progradational stage. The flat-topped Esino Limestone platform reaches a maximum thickness of about 800 m and rapidly pinches out basinward with steep slopes (dipping about 35°) consisting of clinostratified breccias, with a platform to basin relief that reaches about 600–700 m (Berra et al., 2011).

This evolution reflects changes in accommodation space, which control the type and storage sites of the sediments produced by the carbonate factory as well as the geometry of the carbonate platform. The aggradational stage of the Esino Limestone corresponds to reduced sedimentation in the basins (i.e. sediments are stored on the platform top) whereas during progradation resedimented limestones are more common in the basin (Berra et al., 2011).

Close to the Ladinian-Carnian boundary, a major sea-level fall is recorded in Lombardy by a lithostratigraphic unit characterized by regressive carbonate facies with evidence of subaerial exposures ("Calcare Rosso", Assereto et al., 1977; Assereto and Kendall, 1971, 1977; Assereto and Folk, 1980; Jadoul and Rossi, 1982; Gaetani et al., 1998; Mutti, 1994; Berra, 2007; Vola and Jadoul, 2014), covering the flat top of the carbonate platform of the Esino Limestone. The Calcare Rosso builds a wedge, thickest (and well exposed) in middle Brembana Valley, where it consists of up to 60 m of cyclic peritidal limestones characterized by prevailing supratidal facies and evidence of multiple-stage karstification associated with lenses of carbonate breccias, precipitation of different generations of early carbonate-cement, internal sediments and development of mature tepees, loferitic breccias and terra rossa paleosols. The Calcare Rosso rapidly thins out northward to a few meters of red to grey paleosols and carbonate breccias, both related to superficial deposition and collapses of karst cavities. Locally (toward the east), volcanic deposits are present at the top of the Esino Limestone. The subaerial exposure of the Ladinian platforms can be traced, despite strong differences in thickness and facies associations, throughout the Lombardy Basin and probably all over the Southern Alps (Jadoul et al., 2002). Subaerial exposure rapidly halted the carbonate production on the platform top, while a major input of clay (probably reflecting a climate change and/or lowering of the base level) is recorded in the basin. Clay deposits onlap the slope of the previous carbonate system. The age of this event, constrained by biostratigraphic data in basinal successions (Balini et al., 2000), is early Carnian. Mutti (1994) interprets the Calcare Rosso as a complete third order sequence, bounded at the base and at the top by two major erosional surfaces that represent the sequence boundaries.

This fall in sea level occurring close to the Ladinian-Carnian boundary is well known in shallow-water carbonate platform settings of the western Southern Alps and produced a starvation episode in the basin (Berra, 2007, 2012) due to the demise of the carbonate platform caused by the subaerial exposure of the