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Research paper

An extensional syn-sedimentary structure in the Early Jurassic Trento Platform (Southern Alps, Italy) as analogue of potential hydrocarbon reservoirs developing in rifting-affected carbonate platforms

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A B S T R A C T

This work focuses on the 3D modeling and structural analysis of the Monte Testo syn-sedimentary structure, developed in the Early Jurassic Calcari Grigi Group of the Trento carbonate platform (Southern Alps, Italy). Significant changes in the facies architecture of the platform sedimentary units, occurred across a global perturbation of the Carbon cycle at the Sinemurian-Pliensbachian boundary, are associated with evidences of syn-sedimentary tectonics. In particular, an early cemented oolitic sedimentary body with a high initial porosity (Loppio Oolitic Limestone) was broken-up and tilted by a pulse of rifting and overlain by tight marls and marly limestones (lower Rotzo Formation) that display sharp changes in thickness across the syn-sedimentary faults. This complex setting creates conditions potentially favorable to hydrocarbon accumulation. In this work, the Monte Testo structure is presented as a conceptual analogue of a hydrocarbon reservoir that may develop thanks to the overlap of the effects of extensional tectonics and climate change-induced modifications in the carbonate platform facies. A 3D geo-model was realized to obtain information about the genesis and tectonic evolution of the structure. Hence, a potential porosity distribution in the 3D model was evaluated showing that such extensional structure, which has a vertical extent of 500 m and covers an area of 15 km^2, could have been associated to a total pore volume of 2.24×10^7 m^3 at the time of its formation. Results suggest that in rifting contexts the combined effect of syn-sedimentary faulting and facies variations related to perturbations in the global carbon cycle could generate potential reservoirs in carbonate platforms.

1. Introduction

Carbonate platforms can represent important hydrocarbon reservoirs because, although in a context of a strong facies variability, they are made of rocks characterized by high porosity and permeability (e.g. Moore, 2001). Over the time, this has generated great interest in carbonate platform geometries, facies distribution, fracturing and diagenesis (e.g. Bigi et al., 2015; Hardebol et al., 2015; Jacquemyn et al., 2015; Kleipool et al., 2016; Koeshidayatullah et al., 2016). These factors are indeed fundamental in reservoir characterization, because they control the distribution and mobility of hydrocarbons within geological bodies. Peculiar types of carbonate reservoirs are found in oolitic limestones and examples are reported worldwide (Fan, 2005; Zhao et al., 2007; Luo et al., 2008; Ma et al., 2011; Tan et al., 2012). Particularly notable are the Jurassic Smackover Formation in Arkansas, USA (Bliefnick and Kaldi, 1996), the Jurassic Manusela Formation in Seram Island, Indonesia (Carnell and Wilson, 2004), the upper part of the Middle Triassic Muschelkalk Formation in Europe (Schauer and Aigner, 1997; Borkhataria et al., 2005), the Albian Pinda Formation in Angola (Eichenseer et al., 1999) and the Lower Triassic Feixianguan Formation of the Sichuan Basin in southwest China (Wei et al., 2004; Ma et al., 2005, 2007; Wang et al., 2007, 2008; Guo, 2010). Oolitic limestones can have very high porosity and permeability values, two petrophysical properties that are critical for a hydrocarbon reservoir (Robinson, 1967; Moore. 2001). In the mentioned cases, porosity is related to sorting and dimensions of the ooids or to the

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diagenetic processes.

When carbonate platforms develop on future passive margins, pulses of rifting activity can induce syn-sedimentary extension, which can play an important role in determining the distribution of facies and petrophysical properties. For instance, differential subsidence can lead to lateral variation in the thickness of sedimentary units, producing variations in the associated rock volumes or putting in contact porous and tight facies thus creating potential hydrocarbon traps.

The Southern Alps of Italy expose the Trento Platform (Fig. 1), an Early Jurassic example of carbonate platform that includes a large oolitic body, the Loppio Oolitic Limestone (e.g. Masetti et al., 1998, 2012) and grew under active syn-sedimentary extensional tectonics connected to the break up of the Pangea mega-continent (Bertotti et al., 1993; Berra and Carminati, 2010; Santantonio and Carminati, 2012). The effects of syn-sedimentary tectonics are especially evident in the Calcari Grigi Group that comprises the shallow water carbonate succession deposited on the Trento Platform between the Hettangian and the Pliensbachian.

Isotope stratigraphy revealed that the Calcari Grigi deposited during a phase of instability of the carbon cycle that comprises two negative perturbations of the $\delta^{13}C$ record. The first ("Arnioceras time" Event) is mid Sinemurian in age (Masetti et al., 2016) and precedes the deposition of the Loppio Oolitic Limestone. The Loppio Oolitic Limestone was interpreted as a progradational body that represents the high-stand systems tract of a prominent depositional sequence and infilled the accommodation space that was created by a turnover in carbonate production coincident with the mid-Sinemurian isotope perturbation (Preto et al. this volume). The second negative $\delta^{13}C$ shift onset in the uppermost Sinemurian, is named Sinemurian-Pliensbachian boundary Event and is considered of global scale (Korte and Hesselbo, 2011). Across the S–P Event the Trento Platform shows relevant facies changes that share analogies with the evolution of other shallow water carbonate systems in the geologic record in correspondence of major negative C-isotope perturbations (Weissert et al., 1998; Morettini et al., 2002; Wissler et al., 2003; Marino and Santantonio, 2010; Dal Corso et al., 2015; Gattolin et al., 2015). The platform switches from an open marine subtidal (Monte Zugna and Loppio Oolitic Limestone Formations) to a lagoonal carbonate environment (Rotzo Formation), meso-eutrophic conditions onset and a sharp increase in the terrigenous fraction is observed in the Rotzo Formation with respect to the underlying units (Fig. 2B). This latter feature was linked to enhanced runoff coincident with the S-P Event (Franceschi et al., 2014a).

Syn-sedimentary faulting overlapped to the stratigraphic evolution causing brittle deformation of the Loppio Oolitic Limestone and inducing important thickness changes in the overlying marly Rotzo Formation (Zampieri and Massironi, 2007; Franceschi et al., 2013; Franceschi et al., 2014b). The detailed investigation of the time relationship and possible cause-effect links between tectonics and sedimentological changes is beyond the scopes of this paper, however, the unquestionable coupling of these processes created a peculiar structural and stratigraphic setting. This work aims at describing a tectono-stratigraphic configuration that was thus far poorly described for reservoirs in oolitic limestones and at evaluating its relevance in creating hydrocarbon traps. To this end focus is put on the syn-sedimentary structure of the Monte Testo (Fig. 2A; Tobaldo et al., 2004), located on the central Southern Alps of Italy. The structure displays the rigid dissection of the Loppio Oolitic Limestone and the thickness variations of the overlying marly Rotzo Formation that seals the synsedimentary faults. The outcropping conditions allow the 3D reconstruction of the Monte Testo structure from field data. Porosity analysis was carried out to estimate the porosity conditions shortly after the sealing of the syn-sedimentary faults and porosity values were associated to the model. Results allow evaluating the potential of formation of significant hydrocarbon traps in carbonate systems undergoing a complex evolution in rifting contexts where the effects of syn-sedimentary faulting may overlap with climate change-induced facies modifications.

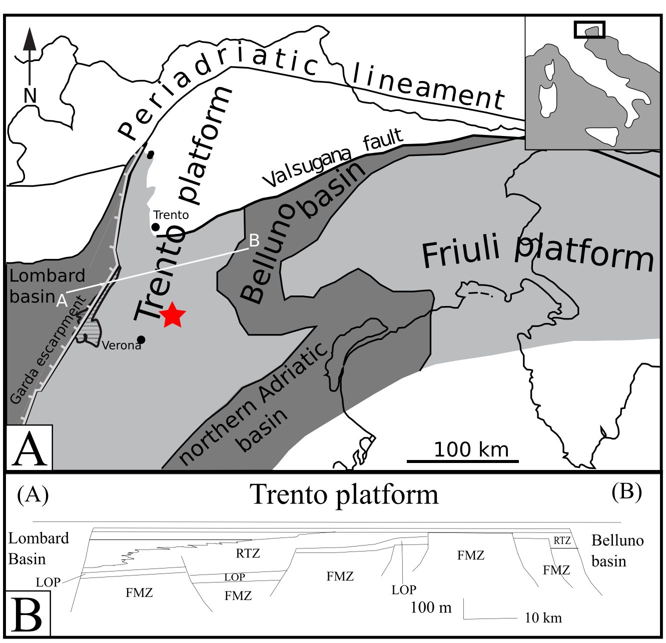

Fig. 1. A) Paleogeography of the Southern Alps during the Early Jurassic (modified from Masetti et al., 2012). The red star indicates the location of Monte Testo (45°49′07.2″N 11°08′25.5″E). B) Section A-B shows the stratigraphic architecture of the Calcari Grigi Group. FMZ = Monte Zugna Formation; LOP = Loppio Oolitic Limestone; RTZ = Rotzo Formation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Geological setting

2.1. Early Jurassic tectonic evolution of the Trento Platform

The Monte Testo structure outcrops on the western flanks of the Pasubio Plateau, in the southernmost part of the Southeastern Alps in northern Italy (Fig. 1) and was first described by Tobaldo et al. (2004). The Southern Alps represent the south-vergent sector of the Alps (Fig. 1), which escaped alpine metamorphism and is separated from the north-vergent collisional wedge by the Periadriatic Lineament (e.g. Dal Piaz et al., 2003). During the opening of the Piedmont and North Atlantic Oceans, the area now pertaining to the Southern Alps was part of the passive margin of the Adria plate (Bertotti, 2001; Berra and Carminati, 2010). In particular, during rifting a large peritidal platform (Upper Triassic Dolomia Principale) was fragmented into N-S trending paleo-structural domains. From west to east: the Lombard Basin, the Trento Platform, the Belluno basin and the Friuli Platform (Bosellini at al. 1981) (Fig. 1). The Trento Platform delineated as a shallow-water domain bordered to the W and E by deeper basins in the Hettangian-Sinemurian (Masetti et al., 2012).

The units belonging to the Calcari Grigi show evidences of differential syn-sedimentary subsidence linked to extensional tectonics, testified by large thickness variations within the platform and by the presence of syn-sedimentary faults and dykes (Avanzini and Masetti, 1992; Avanzini, 1994; Zampieri, 1995; Franceschi et al., 2014b). At least two phases of extension were identified (Avanzini