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Research paper

The role of microbialitic facies in the micro- and nano-pore system of dolomitized carbonate platforms (Upper Triassic – Southern Italy)

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ABSTRACT

The pore system of two dolomitized Triassic carbonate platforms, named Lower and Upper Unit and cropping out in Southern Italy, has been investigated through mercury porosimetry and electron microscopy. Despite their variability, all facies show micro-to nano-pores systems composed of intra- and inter-crystal pore types; this is due to the prevalence of microbialites in the inner platform-margin settings together with an homogenous diagenetic history. Porosity and permeability are generally very low (<3% and <1 mD in average respectively) and, as the median of pores diameter is < 1 μm and the median of the nanopores volume is >60%, the porosity derived from nanopores is significant in all facies, and particularly in the shallow-water environments. A positive correlation between nanopores volume and porosity is present in the whole Upper Unit and in the shallow-water facies of the Lower Unit. Moreover, different sub-environments of the platforms show separated amount of nanopores and porosity; on the contrary, permeability does not seem to be influenced by the nanopores distribution. Regardless a wide spectrum of fabric and morphologies, microbialitic facies of both units show a confined range of porosity (average: 1,0% standard deviation: 0,6) and permeability (average: 0,4% standard deviation: 0,2), most probably because composed of syn-sedimentary microbial dolomite, which presents a high resistance to compaction during the burial history. Finally, despite the complete dolomitization, porosity and permeability ratio varies in function of the main depositional environments, and less of the precursor sedimentary facies, suggesting a control of the final pore-size distribution mainly linked with the presence/absence of the microbial primary dolomitic facies instead of the native fabrics of the other sedimentary facies.

1. Introduction

In the past years, great attention has been paid to the study of micro- and nano-porosity of siliciclastic mudrocks, in respect to fine grained (micritic) carbonate rocks (Pittman, 1971; Dravis, 1989; Moshier, 1989; Cantrell and Hagerty, 1999; Loucks et al., 2009, 2013; Volery et al., 2009a; Bera et al., 2012; Carpentier et al., 2015; Kaczmarek et al., 2015; Hasiuk et al., 2016; Milliken and Curtis, 2016; Olanipekun and Azmy, 2016; Słowakiewicz et al., 2016; Van Simaeys et al., 2016). Moreover, most of these studies on carbonate systems were focused on well data, whereas, works on outcrops are relatively few (e.g. Volery et al., 2009b, 2010; Eltom et al., 2013.), although they can provide a clearer evidence of the depositional architecture and facies variability of sedimentary bodies. In addition, dissolution-reprecipitation reactions and the prevailing calcitic composition of the original sediments are favorable for the formation, preservation and development of nano- and micropores within both micrite and grains (Volery et al., 2009b; Lucia and Loucks, 2013; Milliken and Day-Stirrat, 2013; Zhao et al., 2014); although precipitation of cements and breakage of grains are the main processes that lead to the destruction of pores (Loucks et al., 2013).

Two types of micrite can be distinguished in the rock record: allochthonous, i.e. detrital micrite and autochthonous, i.e. microbialitic micrite (Wolf, 1965), the latter the main component of microbialites. Microbialites are organosedimentary deposits that have accreted as a result of a benthic microbial community trapping and binding detrital sediment and/or forming the locus of mineral precipitation (Burne and Moore, 1987; Riding, 2011). It is now accepted that microbialites are a major component in many

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carbonate sedimentary systems of the geological record (Riding, 2011; Bosence et al., 2015).

Despite the large recent interest on marine and non-marine microbial carbonates, particularly fostered by the South Atlantic petroleum discoveries, relatively few works have been focused on microbialite petrophysical properties and pore systems characterization (e.g. Rezende and Pope, 2015; Corbett et al., 2015; Bosence et al., 2015; Słowakiewicz et al., 2016).

A large number of pore types develop in microbialites due to the various processes (sedimentary, chemical and biochemical) that can concur to their formation. Pore types will also vary depending on the subsequent diagenetic and post-diagenetic pathways, so that depositional pore systems can be completely replaced. Among these processes, dolomitization can produce a wide spectrum of alteration of the original pore system, up to its complete substitution (Lucia, 2004). Dolomite replacement of calcite has been reported to account a volume decrease of about 12% and a consequent increase of porosity, through mole-for-mole replacement equation (De Beaumont, 1837); however, in the past years different authors (e.g. Halley and Schmoker, 1983; Lucia, 2004) demonstrated that dolomitization, particularly in passive margin settings, does not create porosity; instead, dolostones inherit their porosity from the precursor limestones or, at least, precursor limestone fabrics control the new pore-size distribution. Only in the cases of over-dolomitization can be predicted a porosity reduction; and, as the dolomite crystal size of a mud-dominated dolostone may, however, be larger than the precursor carbonate mud size, a substantial improving of the porosity-permeability relationship can be expected (Lucia, 2004).

In contrast to the commonly reported process of secondary replacement dolomitization of limestones, the primary precipitation of microbially-mediated dolomite, leading to the synsedimentary formation of dolomitic microbialites, is a well-documented process in many modern and ancient carbonate depositional systems (Vasconcelos and McKenzie, 1997; Van Lith et al., 2003; Moreira et al., 2004; Spadafora et al., 2010; Bontognali et al., 2012; Perri et al., 2013; Gregg et al., 2015). The influence of these primary microbial dolostones in the original pore system, and their role in the diagenetic and post-digenetic pore system alteration has not been explored.

In this study we investigated the pore network of a microbialite-dominated Norian platform-to-basin dolomite system, in the north-western Calabria (Italy), by using mercury porosimetry and optical and electron microscopy. Primary peritidal microbial dolomites were well preserved, despite the successive complete dolomitization of the sedimentary body (Mastandrea et al., 2006; Perri and Tucker, 2007). Microbialites are considered a major contributor to the formation of many Triassic carbonate platforms (Blendinger, 1994; Russo et al., 1997, 1998; Keim and Schlager, 2001; Perri et al., 2003; Riding and Liang, 2005) and it seems they prevail in conditions of excess of organic matter which can be produced by O_2 decrease, nutrients influx, variation of the water saturation state and, decline of metazoans (Cirilli et al., 1999; Neuweiler et al., 1999; Wood, 2001; Riding and Liang, 2005).

This would be a first approach to the theme of petrophysical properties of ancient primary microbially mediated dolomite, in a dolomitized system, in order to better understand the different features affecting and controlling the pore system evolution, and to improve the still poor knowledge on the control on porosity and permeability of microbialite facies.

2. Geological setting

The study area is located in the northern sector of the Catena Costiera (Coastal Range) of the north-western Calabria (Fig. 1). Here crops out an Upper Triassic carbonate succession completely dolomitized and strongly deformed by diverse tectonic events during the Alpine and Apennine orogens (Amodio Moreli et al., 1976; Iannace et al., 2005). This succession is part of the Lungro-Verbicaro Unit, which reached high pressure and low temperature metamorphism (Iannace et al., 2007) and, despite its tectonic and metamorphic history, the rocks preserve significant sedimentary and palaeontological signals that allow a comparison with the Dolomia Principale Formation of the Alpine domain (Climaco et al., 1997; Mastandrea et al., 2003, 2006; Perri et al., 2003).

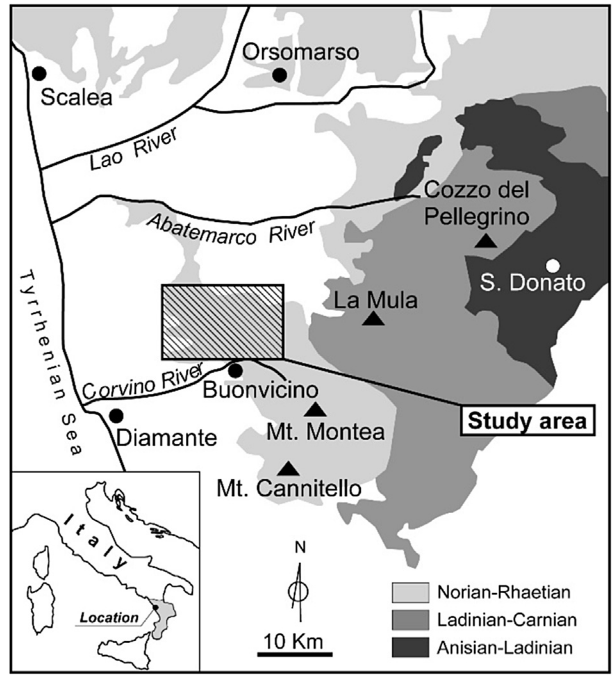

Fig. 1. Location map of the study area showing the distribution of Triassic deposits. Adapted after Mastandrea et al. (2006).

The Norian-Rhaetian of the western Tethyan rifting area was dominated by widely distributed shallow-water carbonate platforms flanking deep, open marine basins and dissected by intraplatfom troughs (Perrone et al., 2006; Critelli et al., 2008). According to the sedimentary features and fossil record, these intraplatform basins, in some cases, could be characterized by stressed environmental conditions. In this setting the biota distribution is very poor and characterized by atypical biofacies dominated by microbial-serpulid-sphinctozoan sponges mounds settled on the slope and outer margin (Flügel et al., 1984; Martin and Braga, 1987; Braga and Lopez-Lopez, 1989; Cirilli et al., 1999; Zamparelli et al., 1999; Flügel, 2002; Perri et al., 2003).

2.1. Depositional environment and stratigraphic framework

On the basis of biostratigraphic and sedimentological data, Mastandrea et al. (2003) and Perri et al. (2003) proposed a stratigraphic evolutionary model for the northern Calabria Norian-Rhaetian sedimentary succession that, successively, Spadafora (2006) amended, thanks to more detailed facies analyses on both previous and new stratigraphic sections (Fig. 2). The model distinguishes a Lower and an Upper Unit (Fig. 3), roughly corresponding with depositional sequences:

2.1.1. Lower unit

It consists of lower-middle Norian deposits representing a low-