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Middle Eocene *Nummulites* and their offshore re-deposition: A case study from the Middle Eocene of the Venetian area, northeastern Italy

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ABSTRACT

The Middle Eocene Calcari nummulitici formation from northeastern Italy, Venetian area, represents a shallow-marine carbonate ramp developed on the northern Tethyan margin. In the Monti Berici area, its main components are larger foraminifera and coralline red algal communities that constitute thick carbonate sedimentary successions. Middle ramp and proximal outer ramp environments are recognized using component relationships, biofacies and sedimentary features. The middle-ramp is characterized by larger flattened-lenticular *Nummulites* on palaeohighs between which rhodoliths formed. Larger *Nummulites* palaeohighs containing *Nummulites millecaput*, *Nummulites crassus*, *Nummulites discorbinus* and *Nummulites* cf. *gizehensis* developed more basinwards. The following relatively quiet environments of basin-wards of the palaeohighs represent areas of maximum carbonate production. The transition between the distal middle- and the proximal outer-ramp settings is marked in the study area by a large erosional surface which is interpreted to have been formed as a result of an erosive channel body filled in by deposits re-sedimented from shallower depths. These off-shore re-sedimented channelized deposits, ascribed to the Shallow Benthic Zone SBZ 15, lying on hemipelagic marls (planktonic foraminiferal zone E9 (P11)) allow for a biostratigraphic correlation to the Late Lutetian.
The studied deposits, represented by packstone to rudstones, were displaced whilst still unlithified. The Lutetian–Bartonian regression along with the local tectonic activity promoted the production of a high amount of biogenic shallow-water carbonates mainly produced in the Mossano middle-ramp settings. These prograded towards the basinal areas with high-sedimentation rate of carbonate deposits characterized by the larger *Nummulites* rudstones. Such high amounts of sediment led to sediment instability which potentially could be mobilized either by return currents due to occasional major storms or by earthquakes induced by tectonic activity. These will have led to the offshore re-deposition of the *Nummulites* sediments into deeper water setting via the observed channels. Since potential migration pathways are short, such distal re-sedimented channel-filled material surrounded by hemipelagic marls is optimally placed for the formation of potential subsurface oil reservoirs.

1. Introduction

During the Early Eocene to Early Oligocene, larger foraminiferal shells of *Nummulites* were dominating components of shallow-water sediments along the western Tethyan margins. During the Eocene, carbonate and mixed carbonate-siliciclastic platforms extended from the western Tethys, through the Indo-Pacific corridor (Middle East) to the western Pacific area (Rögl, 1998). These platforms developed under warm, nutrient-deficient trophic regimes (Hottinger, 1983, 1997; Hallock, 1985; Brasier, 1995) and form important hydrocarbon reservoirs in the northern and northeast African provinces (i.e. Tunisia, Libya, Egypt and Oman). The reservoir qualities are mostly induced by the preservation of intraskeletal porosity of *Nummulites* tests (Racey, 2001; Racey et al., 2001; Jorry et al., 2006) and vary markedly according to the nummulitic facies (Beavington-Penney et al., 2008). The depositional architectures of these shallow-water carbonate systems, developed in response to changes in sediment input, sediment dispersal and accommodation (e.g. Carannante et al., 1988; Jorry et al., 2003), therefore play a fundamental role in understanding and assessing the quality of the subsurface reservoirs.

The Eocene *Nummulites* sedimentary successions have been interpreted according to different sedimentary models, where *Nummulites* accumulated around palaeo-reliefs (sedimentary or structural highs, banks or bioherms) or along homoclinal carbonate ramps (see Jorry et al., 2006). Depending on the depositional model, *Nummulites* sediments are considered to be autochthonous or para-autochthonous to allochthonous deposits resulting from landward or seaward transportation (Jorry et al., 2006). The metabolic activity of microbial communities has been proposed to have induced the precipitation of peloidal micrite and the consequent syndepositional cementation of the larger grains in the nummulitic banks (Guido et al., 2011). Locally the original shape of the *Nummulites* banks seems to be preserved *in situ* and the resulting steep depositional

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angle of the banks has been interpreted as an indication that the *Nummulites* shells were not displaced (compare Jorry et al., 2006; Guido et al., 2011). The general absence of reef-building taxa in *Nummulites* bank settings, however, produced mainly loose carbonate deposits consisting of unlithified skeletal components, easily prone to re-mobilization. Few examples of re-deposited Middle Eocene larger foraminiferal sediments have been reported from the northern Tethyan margin (Lombardian Basin, Bernoulli, 1988; Gargano area, Arni and Lanterno, 1976; Majella Mountains, Vecsei et al., 1998; Zakynthos, Di Carlo et al., 2010).

Taphonomic studies on *Nummulites* suggest that their shells were easily reworked by waves and currents (Davies, 1970; Aigner, 1983, 1985; Martin and Liddell, 1991; Hohenegger and Yordanova, 2001a, 2001b; Yordanova and Hohenegger, 2002). *Nummulites* shells can be removed from the carbonate factories (areas of maximum carbonate production) and transported landward during storm maximums (Li et al., 1998) or seawards by the action of storm-driven currents and unconfined or confined (i.e. channelized) sediment gravity flows (Walker, 1984; Racey et al., 2001). Similar to their siliciclastic counterparts, submarine channels in carbonate systems are important conduits for redistributing the sediment from shallow- to deep-water settings (Braga et al., 2001; Nebelsick et al., 2001; Payros and Pujalte, 2008). No modern analogues of calciclastic submarine channels fill-up of larger foraminiferal shells, however, have been found to date (Payros and Pujalte, 2008).

The Venetian area (northeastern Italy; Fig. 1) is a classic area for the study of Paleogene marine platform communities, where the fossil record is well constrained due to centuries of intensive collection and study (see historical references in Bassi et al., 2008; Agnini et al., 2011). This study focuses on the Middle Eocene large foraminiferal-rich deposits that crop out in the Monte Berici region. Here, we present an example of a Lutetian channelized body lying on hemipelagic marls filled up with sediment from *Nummulites millecaput* and *Nummulites* gr. *gizehensis* shallower-water palaeohighs. Field observations, microfacies analysis and taphonomic and taxonomic study of the main bioclastic components are used to characterize this poorly-known type of *Nummulites* accumulations which represent the first report of these deposits at the northern margin of the western Tethys margin during the Eocene. A direct biostratigraphic correlation between the Shallow Benthic Zonation (SBZ; Serra-Kiel et al., 1998) based on larger foraminiferal species and planktonic foraminiferal zonation (P; Vandenberghe et al., 2012) is also possible. This study contributes to expand the spectrum of the depositional models of *Nummulites* accumulations which can also be used to understand the variability of petrophysical properties in *Nummulites* reservoir bodies.

2. Geological and stratigraphic setting

At the beginning of the Cenozoic, the Southern Alpine area corresponding to the present-day Venetian area was subdivided into two basins roughly separated by the present-day N–S alignment of the Brenta River (Bassi et al., 2008). The eastern basin corresponds to the Valsugana, Belluno/Feltre, Vittorio Veneto, and Alpago areas. The western basin includes the Monte Baldo and Monti Lessini, the Monti Berici (study area), Colli Euganei and the Vincenza Pre-Alps. This western basin is characterized by widespread Paleocene, Lower–Middle Eocene and Oligocene volcanic activities and by shallow-water carbonate deposition (Lessini Shelf; Figs. 1–2).

The distribution of Paleogene sediments in the Southern Alpine area was strongly influenced by the Alpone-Chiampo Graben (Zampieri, 1995; Bassi et al., 2008; Fig. 2). This graben was active during the Paleogene and extends along a NNW–SSE axis in the central–eastern Lessini Shelf. The graben divided the Lessini Shelf into two areas which evolved separately from early Thanetian onwards. The eastern margin of the graben encompasses the eastern Lessini Shelf and the western Monti Berici and comprises planktonic marls and re-deposited calcarenites (e.g. Bassi et al., 2008; Fig. 2). Further to the west, in the western Lessini Shelf, shallow-marine carbonates predominate. In the SE Monti Berici, starting from the Middle Eocene an important tectonic threshold separated the Berici–Lessini area, with mainly shallow-marine deposition, from the

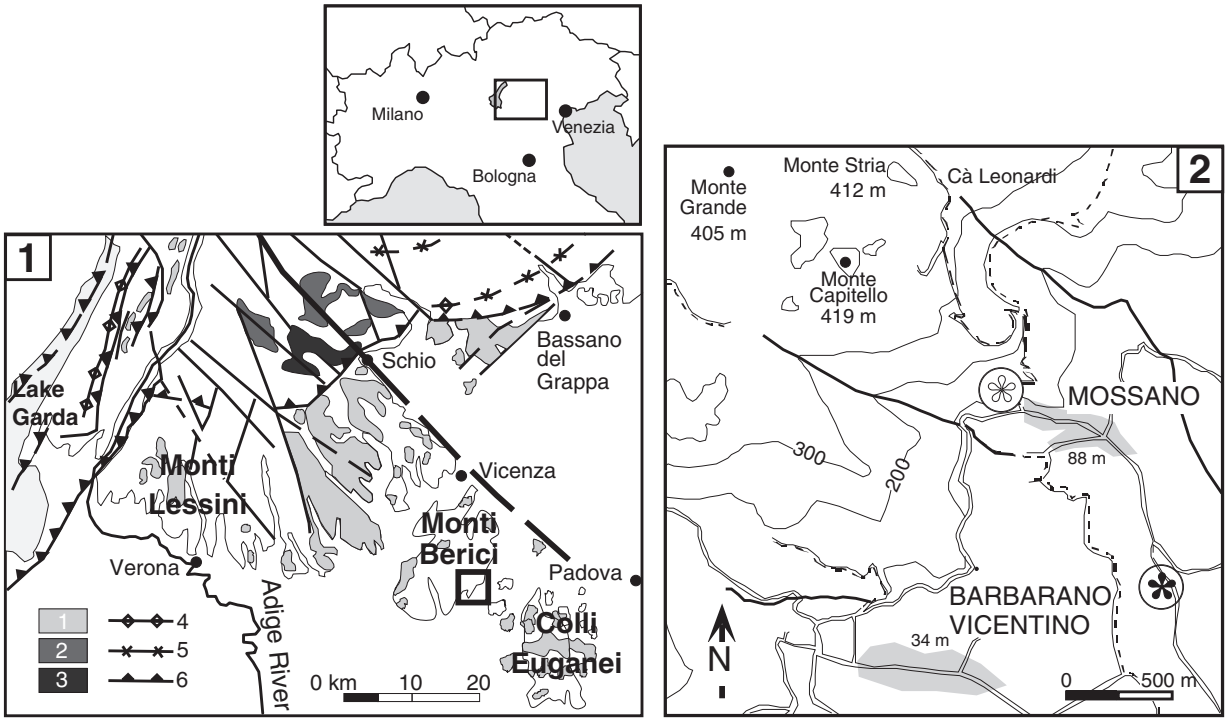

Fig. 1. (1) Geological setting of the study area showing position of the Monti Berici and Colli Euganei, western Veneto; during the Paleogene the Monti Berici were part of the Southern Alpine western basin (after Castellarin et al., 2006). (2) The San Pancrazio studied outcrop (black asterisk) is located about 1.5 km southeast the Mossano area, eastern Colli Berici, northeastern Italy. The white asterisk shows the base of the well known Mossano stratigraphic section which represents the proximal part of the Mossano carbonate ramp (see text for further details). 1, Paleogene basaltic and sub-volcanic rocks; 2, mainly Middle Triassic intrusive and effusive rocks; 3, metamorphic basement rocks; 4, anticline; 5, syncline; 6, thrust.