The migration path of Gondwanian dinosaurs toward Adria: new insights from the Cretaceous of NW Sicily (Italy)

Vincenzo Randazzo (1); Pietro Di Stefano (1, 4); Felix Schlagintweit (2)
Simona Todaro (1); Simona Cacciatore (3); Giuseppe Zarcone (1)
1) University of Palermo, Department of Earth and Marine Sciences, 90123 Palermo, Italy
2) Lerchenauerstr. 167, 80935 Munich, Germany
3) Eni S.p.A. Upstream and Technical Services, 20097 San Donato Milanese, Italy
4) Istituto Nazionale di Geofisica e Vulcanologia (INGV), 90100 Palermo, Italy

Abstract

The increasing dinosaur record from Italy questioned classic paleogeographic scenarios for the Central Mediterranean area and suggest the proximity of landmass areas and a geographical connection between Gondwana and Laurasia during Cretaceous times. Besides several track-sites and exceptionally-preserved specimens (e.g. *Scipionyx samniticus*), the Italian dinosaur record also consists of isolated bones, among which the bone fragment of a theropod discovered in north-western Sicily. The bone occurs in a shallow-water carbonate succession (i.e. Pizzo Muletta, Palermo Mountains) pertaining to the Panormide Carbonate Platform (PCP). The bone was previously ascribed to the Cenomanian, strongly supporting the hypothesis of a land bridge connecting Gondwana and Adria via PCP. More recently, new sedimentological and biostratigraphic studies on the Pizzo Muletta succession have been carried out. The obtained results allow to predate the stratigraphic position of the dinosaur bone to the late Aptian–early Albian and to assess a detailed Aptian–Cenomanian evolution of this sector of the PCP. In particular, the karstic overprint of Cenomanian rudist limestones indicate a subaerial exposure of the platform preceding its drowning during latest Cenomanian times. The new assumptions allow to extend the temporal duration of the intermittent land bridge between Gondwana and Laurasia at least from

Aptian to Cenomanian times and to add further evidences of the dominant tectonic control affecting the Western Tethys during Cretaceous times.

Corresponding author: vincenzo.randazzo04@unipa.it

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1. Introduction

The geodynamic history and the Mesozoic palaegeography of the Mediterranean area were broadly debated during the last four decades (Anderson, 1987; Biju-Duval et al., 1976; Bosellini, 2002; Casero and Roure, 1994; Channell et al., 1979; Finetti, 1982, 2005; Frizon de Lamotte et al., 2011; Masse et al., 1993; Nicosia et al., 2007; Patacca and Scandone, 2004; Rosenbaum et al., 2004; Wortmann et al., 2001; Zarcone et al., 2010). Classic palaeogeographic reconstructions depicted the Western Tethys as punctuated by a number of restricted and isolated shallow-water areas separated from Gondwana and Laurasia by deep seaways (Biju-Duval et al., 1977; Catalano et al., 2001; Dercourt et al., 1986; Dewey et al., 1973; Finetti, 1985; Finetti et al., 1996; Passeri et al., 2005; Patacca and Scandone, 2007; Stampfli and Borel, 2004; Stampfli and Mosar, 1999; Yilmaz et al., 1996; Ziegler, 1988). Several evidences of dinosaurs (e.g. Dal Sasso, 2003; Dal Sasso and Signore, 1998; Dal Sasso et al., 2016; Garilli et al., 2009), especially track-sites (Dalla Vecchia, 1999, 2001; Dalla Vecchia and Venturini, 1995; Nicosia et al., 2000; among others see Petti et al., 2020 for an exhaustive review), from the latest Jurassic to Late Cretaceous carbonate-platform domains of the peri-Adriatic region (e.g. Panormide, Apennine, Apulian platforms) have questioned the classic palaeogeographic models of the Mediterranean area. Indeed, the dinosaur record from Italy provided evidence for a structured and diversified dinosaur assemblage needing freshwater availability, food supply and potential nesting sites implying a certain amount of landmass area (Nicosia et al., 2007). The age of dinosaur tracks and bones from Italy substantially agrees with structural, sedimentological and stratigraphic evidences in suggesting that the peri-Adriatic carbonate platforms constituted a wide land-mass area (Adria *sensu* Channel et al., 1979) connected to Gondwana during the early Cretaceous throughout an intermittent geographical connection (Bosellini 2002; Dal Sasso et al., 2016; Frizon de Lamotte et al., 2011; Nicosia et al., 2000, 2007; Petti et al., 2006, 2008, 2020; Vitale et al., 2018; Zarcone, 2008; Zarcone and Di Stefano, 2008; Zarcone et al., 2010). The migration path of Gondwanian dinosaurs toward Adria is supported, among other evidences, by a theropod bone discovered in the Cretaceous shallow-water limestones of the Panormide Carbonate Platform (PCP hereafter). This finding at Pizzo Muletta, near Capaci (Palermo Mountains, Sicily) is ascribed to the Cenomanian (Garilli et al., 2009) and has pointed the PCP as key area to the knowledge of the land bridge between Africa and Adria (Canudo et al., 2009; Zarcone and Di Stefano, 2010; Zarcone et al., 2010). The present paper deals with the sedimentological and biostratigraphic re-study of the Pizzo Muletta section. The obtained results allow to redefine the stratigraphic position of the theropod bone and to discuss the tectono-sedimentary evolution of the PCP in the frame of the geodynamic context of the Western Tethys.

2. Geological setting

Shallow-water limestones of Cretaceous age from northern Sicily belong to tectonic units of the Maghrebian thrust-and-fold belt (Fig. 1A) and pertain to the PCP, a palaeogeographic unit located at the westward termination of the Ionian Tethys during the Triassic (Todaro et al., 2017). Thousand metres of shallow-water limestones pertaining to this paleogeographic unit crop out in the Madonie and Palermo Mountains (Fig. 1B), and were deposited until Eocene times (Abate et al., 1978, 1982a; Broquet, 1968; Caflish, 1966; Catalano and D'Argenio, 1982; Catalano et al., 1996, Di Stefano and Ruberti, 2000). The PCP-derived series also occur offshore western Sicily, along the Tyrrhenian margin (D'Argenio, 1999; Finetti, 2005; Gattacceca and Speranza, 2002; Pepe et al., 2004) and in north-eastern Sicily in the subsurface of the Nebrodi Mountains (Maragone and Bellafontana boreholes, Bianchi et al., 1987; location in Fig. 1B).

INSERT FIG. 1

During Late Triassic-Early Jurassic times, the PCP was part of a wider rimmed Bahamian-like carbonate platform (Siculo-Tunisian platform *sensu* Di Stefano et al., 1996) leading to the emplacement of a thick succession of peritidal limestones and dolostones (Todaro et al., 2017; 2018). The PCP fed throughout the Triassic–Eocene times the adjacent slope-to-basin areas namely Imerese Basin (Abate et al., 1982b; Camoin, 1982; Catalano and D'Argenio, 1982; Grasso et al., 1978; Ogniben, 1960) and Western Sicily Cretaceous Escarpment (WSCE hereafter; Randazzo et al., 2020a, 2020b). Subaerial exposures related to tectonic uplifts (Basilone and Sulli, 2018; Zarcone and Di Stefano, 2010) caused two major unconformities in the Middle Jurassic and Late Cretaceous (Di Stefano and Ruberti, 2000) pointing to an anomalous subsidence history for the PCP during the Mesozoic (Zarcone, 2008; Zarcone and Di Stefano, 2008) when compared to the adjacent palaeogeographic domains of Sicily (e.g. Hyblean, Yellin Dror et al. 1997).

3. Material and methods

The carbonate succession exposed at Pizzo Muletta has been logged and sampled. The complex morphology of the outcrops hinders to study and sample a single continuous section, the whole studied succession thus consists of three distinct transects being sections M, PM and MZ (Fig. 2A), whose total thickness is about 135 m. The lower part of the succession (section M) is well exposed along the E-W oriented cliff of Pizzo Muletta facing north (Fig. 2B). A second segment (section PM) has been studied inside an abandoned quarry adjacent to Pizzo Muletta (Fig. 2C) that extracted the Cretaceous limestones to produce calcareous gravels and sands. A third upper segment (section MZ) has been studied along a road known as Via Zarcate, south of Pizzo Muletta (Fig. 2A). The correlation between the three sections has been based on bed attitude, distance and topographic elevation between correlative points, ta~~e~~king also into account some extensional faults with metre-scale displacement that occur between the first and second section. Facies and textural analysis were based on the classifications proposed by Dunham (1962) and Embry and Klovan (1971). The accurate analysis of about 50 thin sections allowed to complement the field observations. The microfacies characterisation was performed together with the identification of skeletal and non-skeletal components (Flügel, 2004), under an optical microscope (Leitz Laborlux 12 Pol). Photomicrographs were taken using the camera Zeiss AxioCam ICc 5. New age constraints for the Pizzo Muletta limestones were defined on the base of the observed foraminifera and algae assemblages following the biostratigraphic schemes proposed for the Western Tethys realm (Chiocchini, 2008; Chiocchini et al., 2008; Mancinelli and Chiocchini, 2006; Premoli Silva and Verga, 2004; Velić, 2007; see Fig. 3).

Comprehensive photographic documentation, rock samples and thin sections are stored in the Laboratory of Stratigraphic Geology at the Department of Earth and Marine Sciences, University of Palermo, Italy (collection V. Randazzo).

INSERT FIG. 2

INSERT FIG. 3

4. The Pizzo Muletta Section

This chapter reports the previous contributions on the Cretaceous succession of Pizzo Muletta and describe new sedimentological data concerning the identified carbonate facies and their stacking patterns.

4.1. Previous contributions

The theropod bone was found in a wall of Grotta Lunga, a small cave located on the northern side of Pizzo Muletta (38°10'11.08"N 13°13'55.01", Fig. 4). Grotta Lunga has a horizontal development of about 10 m and a variable height ranging between 4 and 2 m. The Pleistocene and Holocene sediments filling the cave were excavated by Fabiani (1928) which recovered a fossil assemblage of Pleistocene mammalian vertebrates. The histology of the dinosaur bone from Pizzo Muletta and the main sedimentological and biostratigraphic features of the Pizzo Muletta limestones were addressed by Garilli et al. (2009). An about 80 m thick carbonate succession was described as consisting of mudstone/floatstone alternating to wackestone to rudstone/packstone. The age attribution was based on the identified rudists *Sauvagesia nicaisei* (COQUAND), *Eoradiolites* sp., *Ichtiosarcolites bicarinatus* (GEMMELLARO), *I. monocarinatus* (SLIŠKOVIĆ) and gastropods (nerineids) *Eunerinea ernesti* (PARONA) *Multiptyxis olisiponensis* (SHARPE) and *Iteria* sp., thus suggesting a Cenomanian age for the whole Pizzo Muletta section. The rudist assemblages mainly occur in the upper part, while the nerineid species are widespread along the Pizzo Muletta section. In particular, the co-occurrence of *Eunerinea ernesti* and *Multiptyxis olisiponensi* with rudist fragments suggested a backreef depositional environment (Garilli et al., 2009; Sirna, 1995). A good match with another section of Cenomanian age pertaining to the Panormide domain and exposed at Mt. Pellegrino (Di Stefano and Ruberti, 2000) has been assessed by the authors on the base of the macrofossil assemblage and sedimentological features. With regard to the dinosaur bone, analyses on the tissue carried out by Garilli et al (2009), revealed specific microanatomical features that point to a theropod affinity (i.e. “the open medullary cavity and the laminar organization”; see Bybee et al., 2006; Chinsamy, 1990, Horner et al., 2001; Horner and Padian, 2004) and a non-juvenile stage for the Pizzo Muletta specimen (i.e. “well-developed primary osteons in the laminar fibro-lamellar bone”; see Klein and Sander, 2008; Sander, 2000).

INSERT FIG. 4

4.2 Facies analysis of the Pizzo Muletta succession

Seven different facies types have been distinguished, being: stromatolitic bindstone, gastropod floatstone, gastropod rudstone, black-pebble floatstone, black-pebble rudstone, rudist floatstone and rudist rudstone. Their stratigraphic distribution (see Fig. 5) provide information about the depositional environments of the three sections constituting the Pizzo Muletta succession (i.e. sections M, PM and MZ).

Facies descriptions and related environmental interpretations for the three sections follow. The main macro- and microfacies features are depicted in Figs. 6 and 7 respectively.

INSERT FIG. 5

Section M

This section crops out along the northern cliff of Pizzo Muletta and exposes about 80 m of metre-scale, parallel-bedded grey limestones, dipping 30° to SE (Fig. 2B). Along the cliff several other caves of marine origin and parallel-bedded discontinuity surfaces occur along the section. The latter appear as regular and sometimes open fissures a few cm thick. In most cases, the original filling is replaced by Pleistocene calcarenites (Fig. 6A). These discontinuity surfaces are usually overlain by thin levels of laminated bindstones (Figs. 5 and 6B) that alternate to skeletal floatstone, less often rudstones, rich in small gastropods (Figs. 5 and 6C). The bindstones consist of micritic laminae of microbial origin alternating with thin peloidal levels with ostracods. *Fenestral fabric* is commonly associated to the laminated bindstones (Fig. 6B). In the lower and uppermost parts of the section some levels of rudstone with black pebbles occur (Fig. 6D). Thin section analysis of the gastropod rudstone/floatstone mainly revealed a packstone/wackestone texture rich in gastropods, benthic foraminifers, ostracods and, alternatively, rudist fragments (Fig. 7A and B). Grotta Lunga and the theropod bone occur in the upper part of section M (Fig. 5). The alteration/encrustation of the wall surfaces of the cave hampers the direct observation of the facies type in which the bone occurs. However, the correlative bed outside the cave is a floatstone/rudstone about 50 cm thick with reverse grading, rich in mollusc and echinoderm fragments, orbitolinids, and bacinellid textures *sensu* Maurin et al. (1985). This facies is intercalated in muddier facies (i.e. floatstones) rich in benthic foraminifers and dasycladalean algae (Fig. 5). Rare vug-type dissolution cavities filled up by barren micrite were randomly observed (Fig. 8A).

Environmental interpretation.

The facies association in this tract of the Pizzo Muletta succession is typical of a low energy peritidal environment. The sharp discontinuity surfaces were most probably created by the

Pleistocene erosion of marly horizons related to paleosoils, as commonly observed in coeval successions showing comparable facies (e.g. Raffo Rosso, Nicchitta, 1999).

The facies stacking pattern shows a cyclical arrangement of both symmetric and asymmetric deepening-shallowing cycles. This low-energy environment appears randomly punctuated by higher-energy events as suggested by the occurrence of mollusc (Fig. 6C) or black-pebble (Fig. 6D) rudstones (storm layers). In particular, the rudstone/floatstone bed containing the theropod bone can be interpreted as a tempestite on the base of the observed reverse grading. This supports the idea that skeletal components of the dinosaurs were most probably transported by a tidal or subaerially-exposed area adjacent to the lagoon.

Section PM

This segment of the Pizzo Muletta section is about 37 m thick and has been logged inside the abandoned quarry (Fig. 2C). The lower part consists of parallel beds of skeletal rudstones alternating with floatstones containing dominant black pebbles and, alternatively, rudist fragments (Fig. 6E-G). Average bed thickness is of about 80-90 cm. Upwards, there is a gradual increase of black pebble rudstones facies (Fig. 5), to such an extent that were observed distinctive beds almost completely made up of black-pebble conglomerates (Fig. 6E and F). In thin section, the black-pebble rudstone/floatstone mainly consists of grainstone/packstone with radiolitid fragments often affected by microboring, abundant orbitolinids (Fig. 7C and D), and calcareous algae (Fig. 7E).

Centimetre-scale, dissolution vugs are randomly observed. They show a thin isopachous rim of calcite cements and a subsequent filling of micrite (Fig. 8B and C).

Environmental interpretation.

The facies stacking in this section shows a gradual shifting of lagoonal environments to more open and high-energy conditions that accounts for a relative sea-level rise. The subsequent flooding of adjacent emerged lands with ponds could also explain the observed increase of black pebbles in the sediment composition.

Section MZ

The last segment of the studied section at Pizzo Muletta (ca. 18 m thick) was logged along a road namely “via Zarcate” (Fig. 2A) and mostly consists of alternating rudist floatstone and rudstone (Figs. 5 and 6H). Rudist fragments are the main constituent, though loose and well-preserved specimens often occur (Fig. 6I). Rudist-rich beds are thicker and more frequent in the upper part of section MZ. Gastropods are also abundant and widespread along the whole section, while large Chondrodonta mainly occur in the lower beds. Corals are rare. Thin section analysis of the rudist rudstone/floatstone mainly revealed a grainstone/packstone texture with rudist fragments and benthic foraminifers (Fig. 7G). The whole section is crosscut by neptunian dykes with irregular and smoothed walls, filled up by laminated mudstones and wackestones with planktonic foraminifers (Figs. 7H and 8D-G).

Environmental interpretation.

The facies associations of section MZ are well tuned with that of the section PM as they record a progressive shifting towards more external and high-energy zones of the platform that consist of biostromal bodies dominated by large rudists associated with huge amounts of skeletal debris. Rudists often appear as toppled specimens, thus suggesting a continuous sediment removal between the organisms as described from different Upper Cretaceous Periadriatic platforms (Ruberti et al., 2006). The neptunian dykes suggest a tectonic uplift of the platform and a karstic dissolution overprint followed by a subsequent drowning into deeper marine settings.

INSERT FIG. 6

INSERT FIG. 7

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5. Biostratigraphy

The whole Pizzo Muletta succession shows an abundant and well-diversified fossil content consisting of various systematic groups (e.g. rudists, calcareous algae, benthonic and planktonic foraminifers). These assemblages allow the correlation of the three studied sections comprising the Pizzo Muletta succession (Fig. 9). The observed assemblages are shortly described below; the related biomarkers and the most representative taxa are shown in Figs. 10 and 11.

INSERT FIG.9

5.1 Section M assemblage

The floatstone to rudstone beds of Section M show a diverse assemblage of benthic foraminifers (Fig. 10), which are commonly associated with gastropods and ostracods. Calcareous algae such as *Cayeuxia* sp., *Salpingoporella* sp., as well as bryozoans and bacinellid textures, are occasionally present. The foraminifers are represented by *Spiroloculina* sp., *Spiroloculina cretacea* REUSS (Fig. 10A), Haplophragmoididae indet (?*Debarina hahounerensis* Fourcade et al.) (Fig. 10B), *Haplophragmoides* sp., *Nezzazata isabellae* ARNAUD VANNEAU AND SLITER (Fig. 10C and D), *Bolivinopsis* sp., *Quinqueloculina* sp., *Quinqueloculina histri* NEAGU (Fig. 10E), *Glomospira* sp. (Fig. 10F), *Pseudocyclammina* sp., *Pseudonummoloculina* sp., *Akcaya* sp., *Vercorsella* gr. *camposaurii-laurentii* (SARTONI AND CRESCENTI), *Cuneolina* sp., *Cuneolina* aff. *sliteri* ARNAUD VANNEAU AND SLITER (Fig. 10G-I), *Simplorbitolina aquitanica* (SCHROEDER), ?*Paracoskinolina* sp. (Fig. 10J) and other undetermined orbitolinids (Fig. 10K). The bindstone beds of Section M are sometimes rich in ostracods while completely lack benthic foraminifers or other biota. Greenish marls are barren.

5.2 Section PM assemblage

In this section rudist fragments become dominant and mainly refer to Radiolitidae family. Section PM also shows a rich and diversified benthic foraminifereral assemblage similar to what is observed through the section M. These include *V.* gr. *camposaurii-laurentii*, *Cuneolina* sp.*, C.*

sliteri, ?*Debarina hahounerensis*, *Haplophragmoides* sp., *Quinqueloculina* sp., *Q. histri*, *Nezzazata isabellae* (Fig. 10L), *Akcaya* sp., *Akcaya minuta* (HOFKER) (Fig. 10M), *Pseudonummoloculina* sp. (Fig. 10N). Orbitolinids are represented by different genera: *Simplorbitolina aquitanica* (Fig. 10O and P), Orbitolinidae indet. (Fig. 10Q), *Mesorbitolina birmanica* (SAHNI) (Fig. 10R and S), ?*Paracoskinolina* sp. (Fig. 10T), *Orbitolinopsis cuvillieri* MOULLADE (Fig. 10U and V). The occurrence of *Mesorbitolina* specimens is restricted just to a specific interval (samples PMA3 and PM12), in which the corresponding microfacies texture is a grainstone and the assemblage becomes oligotypic and dominated by the representatives of the genus. Calcareous algae are present and mostly occur in the upper part of the section. They include *Triploporella* sp. (Fig. 10W), *Morelletpora turgida* (RADOIČIĆ) (Fig. 10X), *Cylindroporella*? *lyrata* MASSE AND LUPERTO-SINNI (Fig. 10Y). Ostracods, gastropods and *bacinella* structures were also observed.

INSERT FIG. 10

5.3 Section MZ assemblage

The assemblage is rich in molluscs such as rudists, gastropods and chondrodonta, though the assemblage is dominated by the rudists (Garilli et al., 2009). The latter mostly refer to Caprinidae family (Fig. 6I). Benthic foraminifers such as *Spiroloculina* sp. (Fig. 11A, B) *Pseudonummoloculina*? sp. (Fig. 11C) *Vercorsella* sp. (Fig. 11D), ?*Debarina hahounerensis* (Fig. 11E), *Nezzazata isabellae* (Fig. 11F), *Cuneolina* sp. (Fig. 11G-I), Orbitolinidae indet. (Fig. 11J-M), *Coscinophragma*? sp. (Fig. 11O), as well as calcareous algae e.g. *Triploporella* sp. (Fig. 11N), *Heteroporella*? *graeca* CONRAD, PAVLOPOULUS, PEYBERNES AND RADOIČIĆ (Fig. 11P) are also abundant. The pelagites filling the neptunian dykes show a sharply different assemblage that almost exclusively consists of planktonic foraminifers such as *Rotalipora* sp. (Fig. 11Q), *Rotalipora* cf. *appenninica gandolfi* LUTERBACHER AND PREMOLI-SILVA (Fig. 11R), *Rotalipora* cf., *cushmani* (MORROW) cf. *greenhornensis* (MORROW) (Fig. 11S), *Rotalipora* cf. *reicheli* MORNOD (Fig. 11T), *Whiteinella* cf. *praehelvetica* (TRUJILLO) (Fig. 11U), *Whiteinella* sp. (Fig. 11V), *Whiteinella* cf. *paradubia* (SIGAL) (Fig. 11W, X), *Whiteinella baltica* DOUGLAS AND RANKIN (Fig. 11Y, Z), though resedimented benthic foraminifers (e.g. orbitolinids) may occasionally occur.

INSERT FIG. 11

6. Discussion

The new sedimentological and biostratigraphic data from the Pizzo Muletta section allow to re-define the age of a migration pulse of African dinosaurs towards Europe and to trace a detailed evolution of a sector of the possible land bridge represented by the Panormide Platform.

6.1. *Time constraints for the dinosaur bone and biostratigraphy remarks*

The assemblages coming from Section M and Section PM show good matches with the associations observed in coeval inner platform/backreef environments belonging to the Apennine Platform (Chiocchini et al., 2008; Mancinelli and Chiocchini, 2006; Ruberti et al., 2013). These similarities do not surprise since as this palaeogeographic domain was neighbouring and connected to the Panormide Platform during the Early Cretaceous (Zarcone et al., 2010). Although the assemblages of sections M and PM share several biota, some remarkable differences have been observed. The rare record of rudists characterizing Section M is consistent with an inner-platform environment as suggested by the observed alternation of peritidal facies. In contrast, rudist fragments and loose specimens are common in Section PM, though no *in situ* bouquet have been observed as it would be expected in a reef/fore-reef environment (Cestari and Sartorio, 1995). Furthermore, representatives of the genus *Mesorbitolina* only occur in mud-free skeletal streams coming from the margin area and emplaced by storm/high-energy events. These data suggest more open marine conditions for Section PM when compared with section M and an open lagoon environment can be thus inferred in agreement with the sedimentological interpretation. A gradual transition toward more open marine conditions is also supported by the increase in calcareous algae and the occurrence of biota typical of reefal-platform margin environment (i.e. *Triploporella* sp.) observed in the uppermost strata of Section PM. The biostratigraphic ranges of some of the main characteristic biota found in Section M and Section PM is rather uncertain (e.g. *Cuneolina sliteri, Mesorbitolina birmanica, Nezzazata isabellae, Morelletpora turgida*; see Chiocchini et al., 2008; Di Lucia, 2009; Mancinelli and Chiocchini, 2006; Schlagintweit and Wilmsen 2014; Schmitt et al., 2019; Velić, 2007). However, the different interpretations remain constrained to the late Aptian–early Albian interval. In particular, the occurrence of *Simplorbitolina aquitanica* would suggest a late Aptian–?earliest Albian age for Section M and Section PM (Chiocchini et al., 2008; Fourcade, 1978; Moullade and Peybernès, 1979; Schroeder and Poignant, 1964). As a consequence, the dinosaur bone occurring in the uppermost strata of section M and considered until now Cenomanian in age (Garilli et al., 2009), should be dated back to the late Aptian–(?early Albian). Furthermore, the inferred time interval is consistent with the age of the titanosaurid bones recently discovered in the northern sector of the Apennine platform (i.e. Latium-Abruzzi platform) (Dal Sasso et al., 2016) and strongly supports the Adria bridge dispersal model.

Upsection the microfossil assemblage of the Section MZ shows the presence of *Spiroloculina sp.*, *Cuneolina sp.* and, undeterminable orbitolinids. This assemblage suggests a late Albian–middle Cenomanian age, in agreement with age and the macrofossil assemblage determined by Garilli et al. (2009). The neptunian dykes crosscutting section MZ are filled up with calcilutites containing planktonic foraminifers pertaining to the *Dicarinella algeriana* sub-biozone (Premoli Silva and Verga, 2004) that suggests a latest Cenomanian age. This constrains the emersion and karstification of the platform to the late Cenomanian.

6.2. *Black pebbles conglomerates*

Black pebbles are widespread in the Mesozoic carbonate platforms from southern Italy (Bosellini, 2002; Eberli et al., 1993; Spalluto, 2012) and Sicily (Todaro et al., 2017), though they normally occur as thin and sporadic lag levels at the base of peritidal shallowing-upward cycles. These intraclasts likewise occur in the peritidal limestones of section M, but they represent the main constituent of the lagoonal facies of the section PM. Organic plant material acts as the "blackening" agent (Lang and Tucci, 1997; Platt, 1992; Strasser and Davaud, 1983) according to three models (Strasser, 1984) implying (i) anoxic conditions, (ii) uplift stages of the carbonate platform (Leinfelder, 1987; Strasser, 1984) and (iii) the absorption of organic matter at the surface of calcretes during pedogenetic micritization processes (Săsăran, 2006; Strasser, 1984). A partially different hypothesis ascribes the blackening rather to "instantaneous" forest fire heating (e.g. Florida Keys, Shinn and Lidz, 1988) as supported by heating experiments demonstrating that limestone pebbles can be blackened at temperatures between 400 °C and 500 °C (Flügel, 2004). Besides the actual blackening agent, all these hypotheses call into question the contemporaneous presence of nearby subaerial environments. Black-pebble occurrences are thus diagnostic indicators for partial to complete subaerial exposure of subsequently reworked carbonate deposits (Strasser and Davaud, 1983) as well as relative fluctuations of the sea level (Mircescu et al., 2013). The widespread occurrence of black pebbles in section PM is thus a clear evidence of a relatively long-lasting emergent land adjacent to this sector of the PCP during Aptian–Albian times.

6.3 Cretaceous tectono-sedimentary evolution of the Panormide Carbonate Platform and the fate of the connection between Africa and Adria

Looking in detail to the Pizzo Muletta section, the whole stacking pattern of the facies associations indicate a progressive shifting from peritidal (i.e. Section M), to lagoonal environments (i.e. section PM) during late Aptian–early Albian (Fig. 12A) and, successively, to a high-energy, rudist-dominated open shelf (i.e. section MZ) during late Albian–middle Cenomanian (Fig. 12B). The Cretaceous global sea-level curve displays a long-term period of stable and high sea-level during Aptian and early Albian followed by a progressive rise during late Albian (Haq, 2014). This eustatic rise could justify the observed facies shifting at Pizzo Muletta toward more open environments even though the global trend is punctuated by third-order fluctuations that could have caused the periodical emersion of the platform.

Both the theropod bone found in the upper part of section M and the widespread occurrence of black pebbles in the upper Aptian–?lower Albian strata point to the presence of a landmass area close to Pizzo Muletta (Fig. 12A). This nearby landmass could have provided nesting sites and fresh-water to the dinosaur community inhabiting the carbonate platform (Nicosia et al., 2007).

Although, the origin of the vugs occurring in both Section M and Section PM remains doubtful, the neptunian dykes on top of the Pizzo Muletta suggest that the platform was affected by subaerial dissolution phenomena before being filled by pelagic wackestones. This intense dissolution accounts for an emersion phase (Fig. 12C) experienced by this sector of the PCP during Cenomanian times and could have allowed a further pulse of dinosaur migration from Gondwana toward Adria (Citton et al., 2015). The pelagic infill of neptunian dykes accounts for a sudden drowning of this sector of the platform during latest Cenomanian times (Fig. 12D). This event matches the reactivation of transtensional crustal shears during latest Cenomanian–earliest Turonian as documented by the tectonically-driven submarine volcanism in the adjacent WSCE. Since than, the progressive fragmentatiom of the platform is documented by the huge input of calciclastic sediments into the escarpments (Randazzo et al., 2020a and b).

INSERT FIG.12

Although the drowning and step-back of the Cretaceous PCP and other coeval carbonate platforms may be related to the increase of ocean-crust formation (up to 50%- 70% between 120 and 80 Ma; Larson, 1991) and to the subsequent rise of sea level (Mullins et al., 1991), there are several lines of evidence that tie the dismembering of most of the carbonate platforms pertaining to the southern sector of Adria to the Late Cretaceous extensional regime induced by the opening of the Sirte Basin (Capitanio et al., 2009; Frizon de Lamotte et al., 2011). Tectonically induced variation in the sedimentary basins are documented both in deep (e.g. north Africa: Grasso et al., 1999; Jongsma et al., 1985; Sicily: Di Stefano et al., 1996; Randazzo et al., 2020a) and shallow-water settigs (e.g. Apulia: D'Argenio and Mindszenty, 1995; Graziano, 2000; Masse and Borgomano, 1987. Apennine Platform: Carannante et al., 2009; Capotorti et al., 1997; Tavani et al., 2013; Vitale et al., 2018).

As a consequence, the platforms of the southern sector of Adria area were progressively dismembered in isolated smaller carbonate platforms, by the drowning of discrete sectors, as in the case of the Pizzo Muletta succession. This event was in turn responsible of the break-down of the continental connection linking Gondwana to Adria (Fig. 13C).

INSERT FIG.13

7. Conclusions

New sedimentological and biostratigraphic data from the Pizzo Muletta section allow to constrain facies and stratigraphic position of the dinosaur bone found in the Panormide Carbonate Platform as well as to depict the complex dynamic of the platform across the Aptian–Cenomaian interval. On the base of the facies associations three different zones can be recognized along the succession: i) the lower part (c.a. 80 m thick) consists of peritidal facies, stacked in more or less regular peritidal cycles. This part contains the theropod bone at about 20 m from the top and this part of the succession can be assigned to the upper Aptian–?lower Albian. Upward, the second part consists of a thick interval (about 40 m) of lagoonal packstone and grainstone dominated by black pebbles and orbitolinids. The microfossil assemblage allows to assign also this part of the succession to the upper Aptian–?lower Albian. The presence of a large amount of black pebbles in this part of the succession suggests the presence of a persistent exposed land adjacent to the nearshore area. The third portion of the section (about 20 m) consists of rudist floatstone and rudstone with abundant and a well-diversified assemblage of rudist, Chondrodonta, and gastropods. This tract of the studied succession can be assigned to the upper Albian–lower/middle Cenomanian. In the whole, the facies sequence shows a trend from peritidal environments to high energy, rudist dominated, shelf margin environments. Dissolution cavities filled up by pelagic wackestone on top of this succession account for an emersion and subsequent drowning of this sector of the carbonate platform during upper Cenomanian. The Cenomanian uplift could be tuned to the pulse of dinosaur migration from Africa. The contemporary submarine basalt emissions in the adjacent slope namely Western Sicily Cretaceous Escarpment, suggest the activity of deep-rooted crustal shears dissecting the PCP and, more in general, the carbonate platforms of the central Mediterranean area.

Besides retro-dating the presence of dinosaurs in the Panormide Platform to the late Aptian–early Albian interval, the complex dynamics observed throughout the Pizzo Muletta section documents the irregularity of the connections between Africa and Adria through this land bridge.

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FIGURE CAPTIONS

Fig. 1. (A) Simplified structural map of Sicily and the Southern Apennines. (B) Present-day distribution in northern Sicily (see black rectangle in A) of 1) Cretaceous and 2) Triassic-Jurassic

PCP carbonates, 3) WSCE slope carbonates, 4) slope to deep-water carbonates and cherts pertaining to the Imerese Basin (IB).

Fig. 2. (A) Google-Earth view of the Pizzo Muletta area and locations of sections M, PM and MZ. (B) Panoramic view of section M, sampling points and Grotta Lunga location. (C) The abandoned quarry on the southern side of Pizzo Muletta and the sampling points of section PM.

Fig. 3. Biozonal schemes for the Aptian–Cenomanian interval (pelagic basins: Premoli Silva and Verga, 2004; periadriatic carbonate platforms: Chiocchini et al., 2008; Velić, 2007).

Fig. 4. (A) The entrance to Grotta Lunga and (B) the theropod bone occurring inside the cave.

Fig. 5. Stratigraphic logs of the Pizzo Muletta succession showing sample and facies distribution and the stratigraphic position of the dinosaur bone. Notice the different scale between section M and sections PM and MZ.

Fig. 6. Main facies types of section M (A-D), section PM (E-G) and section MZ (H, I). (A) Sharp stratal surface filled up by Pleistocene calcarenites. (B) Bindstone with fenestral fabric overlying black pebbles conglomerate. (C) Gastropod floatstone to rudstone. (D) Black-pebble level occurring in section M. (E) Decimetre-thick beds of black-pebble rudstones and floatstones. F) Close-up of black-pebble floatstone (down) and rudstone (up). G) Rudists scattered in a black-pebble rudstone. H) Rudist rudstone to floatstone crosscut by a neptunian dyke filled up by pelagic calcilutites. I) Well-preserved caprinids in section MZ.

Fig. 7. Main microfacies types of section M (A, B), section PM (C-E) and section MZ (F-H). (A) Skeletal packstone with miliolids and cuneolinids, sample M11, (B) Wackestone with gastropods,

benthic foraminifers, and ostracods, sample MG3, (C) Skeletal packstone with radiolitid fragments and orbitolinids. Microboring (green arrows) is evident in places, sample PM5, (D) Well-sorted skeletal grainstone with rudist fragments and orbitolinids. The elongated grains show a rightward imbrication, sample PM12, (E) Grainstone showing micritized skeletal grains of calcareous algae, sample PM15, (F) Grainstone with orbitolinids and micritized radiolitid fragments. Microboring (green arrows) is evident in places, sample MZ3, (G) Grainstone-packstone with rudist fragments and benthic foraminifers, sample MZ4, (H) Wackestone rich in planktonic foraminifers occurring as filling of neptunian dykes, sample MZ1. Scale bar is 500 μm.

Fig. 8. Dissolution overprint on the Pizzo Muletta succession. (A-C) Dissolution cavities (vugs) pervading section M (A) and section PM (B, C). (D, E) Section MZ hostrock consisting of rudist floatstones and rudstones crosscut by neptunian dykes showing internal laminations that suggest the progressive fill of open cavities. (F) Original and (G) interpreted images of an irregular dissolution cavity filled up by pelagic limestones.

Fig. 9. Composite column of the Pizzo Muletta succession paralleled to the distribution of the main identified taxa.

Fig. 10. Section M (A-K) and section PM assemblages (L-Y). (A) *Spiroloculina* cf. *cretacea* REUSS*,* sample M2, (B) Haplophragmoididae indet (?*Debarina hahounerensis* Fourcade et al.), sample M3, (C, D) *Nezzazata isabellae* ARNAUD-VANNEAU AND SLITER*,* samples M3, M11, (E) *Quinqueloculina histri* NEAGU, sample M11, (F) *Glomospira* sp., sample M13, (G-I) *Cuneolina* aff. *sliteri* ARNAUD-VANNEAU AND PREMOLI SILVA, samples M7, M11, M16, (J) ?*Paracoskinolina* sp., sample MG1, (K) Orbitolinidae indet., sample MG3. (L) *Nezzazata isabellae,* sample PM10, (M) *Akcaya minuta* (HOFKER), sample PM6, (N) *Pseudonummoloculina* sp., sample PM11, (O, P) *Simplorbitolina aquitanica* (SCHROEDER)*,* samples PM11, PM5, (Q)

Orbitolinidae indet., sample PM12, (R-S) *Mesorbitolina birmanica* (SAHNI), sample PM12, (T) ?*Paracoskinolina* sp., sample PM12, (U, V) *Orbitolinopsis gr. cuvillieri* MOULLADE, sample PM5, (W) *Triploporella* sp., sample PM15, (X) *Morelletpora turgida* (RADOIČIĆ), sample PM13, (Y) *Cylindroporella*? *lyrata* MASSE AND LUPERTO SINNI, sample PM6. Scale bar is 200 μm.

Fig. 11. Section MZ assemblage (A-P hostrock, Q-Z neptunian dyke). (A, B) *Spiroloculina* sp., sample MZ7, (C) *Pseudonummoloculina*? sp., sample MZ7, (D) *Vercorsella* sp., sample MZ7, (E) Haplophragmoididae indet (?*Debarina hahounerensis* Fourcade et al.), sample MZ7, (F) *Nezzazata isabellae*, sample MZ4, (G-I) *Cuneolina* sp., samples MZ4, PM3, MZ3, (J-M) Orbitolinidae indet., samples MZ4, MZ2, (N) *Triploporella* sp., samples MZ7, (O) *Coscinophragma*? sp., sample MZ3, (P) *Heteroporella*? *grecae* CONRAD, PAVLOPOULUS, PEYBERNES AND RADOIČIĆ, sample MZ3. (Q) *Rotalipora* sp., sample MZ5, (R) *Rotalipora* cf. *gandolfi* LUTERBACHER AND PREMOLI-SILVA, sample PM1, (S) *Rotalipora* cf. *cushmani* (MORROW) cf. *greenhornensis* (MORROW), sample MZ1, (T) *Rotalipora* cf. *reicheli* MORNOD, sample MZ1, (U) *Whiteinella* cf. *praehelvetica* (TRUJILLO), sample PM2, (V) *Whiteinella* sp., sample PM2, (W, X) *Whiteinella* cf. *paradubia* (SIGAL), samples PM3F, MZ1, (Y, Z) *Whiteinella baltica* DOUGLAS AND RANKIN sample MZ1. Scale bar is 200 μm.

Fig. 12. Pizzo Muletta tectono-sedimentary evolution. (A) Environmental interpretation of section M and PM during Aptian–Albian. (B) Environmental interpretation of section MZ during early–mid Cenomanian. (C) Subaerial exposure and genesis of dissolution cavities in response to the tectonic uplift during late(?) Cenomanian. (D) Tectonic drowning and filling of the dissolution cavities with pelagic sediments during latest Cenomanian. Not to scale.

Fig. 13. (A) Palaeogeographic map of the Mediterranean area during Cretaceous times showing: i) the continental connection between Africa and Adria (black square), ii) the subduction zones in the

Ionian and Alpine Tethys, and iii) the extensional stress field in the Sirte Basin (modified after Frizon de Lamotte et al., 2011). Not to scale. (B, C) Evolution of the continental connection between Africa and Adria during Early (B) and Late Cretaceous (C). Not to scale. Red dashed lines are deep-rooted extensional faults. Not to scale. APCP=Apennine Carbonate Platform; AP=Apulian Platform; CCP=Constantine Carbonate Platform; IB=Imerese Basin; LB=Lagonegro Basin; PCP=Panormide Carbonate Platform; TB=Trapanese Basin; UMB=Umbria-Marche Basin; WSCE=Western Sicily Cretaceous Escarpment.