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Depositional setting, paleogeography, and sequence stratigraphy of the Salento Peninsula from the Paleogene to the Pleistocene

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ABSTRACT - The Salento Peninsula constitutes an outcropping portion of the Apulia Carbonate Platform that was investigated through field analysis, and a database of 350 wells in order to construct correlation panels and to define paleogeographic schemes of this area during the Paleogene and Neogene. The Salento Peninsula constitutes the foreland sector of two chain belts migrating in opposite directions (the Dinarides-Albanides-Hellenides chain moving from NE to SW and the southern Apennines chain moving from SW to NE) whose movements influenced the carbonate sedimentation and paleogeographic evolution of this area during the Cenozoic. The analyzed stratigraphic succession is constituted of shallow-water carbonate sediments that were deposited along reef complexes and variously articulated homoclinal ramps. These environments developed mainly along the eastern margin of the Peninsula and under the influence of tectonic uplift/subsidence and eustatic sea level changes. Herein, we propose several paleogeographic schemes of the area and discuss how the interference between the two migrating chains, together with eustatic sea-level changes influenced the Cenozoic stratigraphic organization of the Salento Peninsula.

Starting from the end of the Cretaceous the Salento area experienced uplift and erosion related to the flexural bending of the subducting lithosphere under the Dinarides-Albanides-Hellenides and southern Apennines belts respectively. This process produced an initial extensional fracturing and faulting in the uppermost part of the lithosphere during the Paleocene-early Eocene and an interruption of the shallow-water carbonate deposition; the latter was re-established starting from the middle-late Eocene up to the Pleistocene, with the onset of flexural subsidence, that became more accentuated during the Miocene. This process together with the eustatic sea-level variations induced by the Cenozoic climatic changes conditioned the carbonate sedimentation that is characterized by formal and informal lithostratigraphic units bounding by several unconformity surfaces constituting the expression of complete and incomplete simple and composite low- and high-rank depositional sequences.

Keywords: Depositional setting; paleogeography; sequence stratigraphy; Salento Peninsula; Apulia; Italy.

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1. INTRODUCTION

In the last 50 years, several studies conducted on carbonate platforms (CPs) have proposed their classification utilizing different criteria. On the one hand, some authors considered the basinal and tectonic setting as the main factors controlling the morphology and the physical stratigraphy of the CPs (Bosence, 2005), while other authors have used the geometry of depositional profile to distinguish two main end members: the flat-topped platforms (FTPs) with a pronounced slope break and steep margin and the ramps (Rs) both homoclinal with low-gradient profile and distally-steeped with a slope break offshore (Ahr, 1973; Wilson, 1975; Read, 1982, 1985, 1998; Eberli and Ginsburg, 1989; Tucker and Wright, 1990; Burchette and Wright, 1992; Handford and Loucks, 1993; Wright and Burchette, 1996). A genetic approach to classify the CPs was proposed by Pomar (2001, 2020), which considered the variability of the CP depositional profiles as a function of a series of factors such as sediment types, locus of sediment production, hydraulic energy, and types of biota based on their dependence upon light. On this basis, the author recognized two main platform types: the rimmed platforms that fundamentally coincide with the flat-topped platforms and the nonrimmed shelves or physical accommodation-predominant platforms (e.g., ramps; see Pomar, 2020). In a previous paper, Williams et al. (2011) pointed out that the classification of CPs based on their deposition profile constitutes an oversimplification because facies and environments distribution as well as sequence stratigraphic organization varied significantly between the end-members of the FTPs and the Rs. The same authors also highlighted that the euphotic versus oligophotic is not a significant control on carbonate production profile and suggested, based on field and modeling observations, that sediment production, diffusional sediment transport, antecedent topography, tectonic subsidence, and relative sea-level changes are the main factors whose interaction control the depositional profile of the CPs. This would suggest a continuum of platform types ranging from low gradient and transport-dominated CPs (see ramps) to in situ accumulation-dominated CPs (e.g., rimmed and non-rimmed FTs) (Williams et al., 2011). The same concepts could be applied to isolated platforms.

What has been said previously suggests that all the different types of CPs are closely related to each other both temporally and spatially and that the same platform may develop, on opposite margins, different depositional profiles that reflect the close interaction among the processes above mentioned.

With this in mind, we analyzed the stratigraphic setting of the Cenozoic deposits of the Salento Peninsula (i.e., the southern portion of the Apulian foreland), a sector essentially characterized by carbonate sedimentation, that constitutes the foreland of two chains migrating in opposite directions: the Dinarides-Albanides-Hellenides chain that moves from NE to SW and the southern Apennines chain that moves from SW to NE. We propose several paleogeographic schemes of the area and discuss how the interference of these two chains, together with eustatic sea-level changes, must have influenced the sedimentation and stratigraphic organization of the Cenozoic succession of the Salento Peninsula in which high- and low-rank simple and composite depositional sequences were recognized.

2. GEOLOGICAL AND STRATIGRAPHIC SETTING

2.1. GEODYNAMIC AND GEOLOGICAL STRUCTURAL SETTING

The Salento Peninsula constitutes an outcropping portion of the Apulia Carbonate Platform, which represents one of the carbonate platforms developed along the southern margin of the Tethys Ocean since the Triassic (Eberli et al., 1993; Zappaterra, 1994; Bosellini, 2004; Morsilli et al., 2017) (Fig. 1a). This NW-SE oriented platform is about 650 km long and 180 wide and consist of a 5 to 7 km thick Meso-Cenozoic undeformed carbonate succession that develops in emerging and submerged areas (D’Argenio et al., 1973; Rossi and Borsetti, 1974); the eastern margin of the Apulian Platform crops out in the Maiella and Gargano peninsula (Bosellini, 1989; Eberli et al., 1993; Borgomano, 2000), while the western margin is largely incorporated in the southern Apennines thrust belt.

The Apulian Platform occupies the southern end of the Adria microplate (Fig. 1b) which is considered by some authors to be the northern promontory of the African plate (Channel et al., 1979; Muttoni et al., 2001; Schettino and Turco, 2011; see also the most recent interpretation of Adria in Mediterranean paleogeography by Channel et al., 2022), and by other authors an independent plate, placed between the African and European plates, whose movements would be strongly influenced by the relative movement of the two bigger plates (Doglioni, 1991; Catalano et al., 2001; Guerrera et al., 2005; Carminati et al., 2012).

The Salento peninsula constitutes, together with its submerged portion offshore of the Ionian Sea (Apulian swell), the culmination of a lithospheric anticline, about 100 km wide, whose genesis is linked to the subduction of the Adria plate below two chains with opposite vergence: the Dinarides-Albanides-Hellenides verging SW and the Southern Apennines verging NE (Channel et al., 1979; Ricchetti et al., 1988; Doglioni et al., 1994, 1996; de Alteris, 1995; Argnani et al., 2001; Bernoulli, 2001; Maesano et al., 2020; Cicala et al., 2021; Fig. 1c). Consequently, the Salento Peninsula and the Apulia Swell constitute the Cenozoic foreland (i.e., the Apulian Foreland) of both chains and as such is considered to be the peripheral bulge formed as the result of the flexural bending induced by the loading of the two previously mentioned chains (Moretti and Royden, 1988).

The result of this structural setting of the Apulian Foreland is 1) the presence of E-W strike-slip faults in the northern sector and a NW-SE oriented extensional faults in the Salento Peninsula (Fig. 2) and Apulia swell, giving rise to a horst and graben systems (Martinis, 1962; Tozzi, 1993) whose genesis and age has been discussed in several papers (Doglioni et al., 1994, 1999; Gambini and Tozzi, 1996; Argnani et al., 2001; Butler, 2009; Del Ben et al., 2010, 2015; Volpi et al., 2017; Maesano et al., 2020; Cicala et al., 2021), and 2) the presence of two foredeep basins showing opposite polarity. Most authors consider the migration of the two chains responsible for the extensional tectonic regime developed during the Pliocene and Quaternary (Ciaranfi et al., 1988; Doglioni et al., 1994; Argnani et al., 2001; Finetti and Del Ben, 2005) as well as for the significant block rotations as recognized in the Salento Peninsula area (Gambini and Tozzi, 1996). According to Di Bucci et al. (2011), a radial extension after the Late Pleistocene may be envisaged, indicating a bulge of the foreland area in place of the Middle Pleistocene SW-NE extension. The bulge should be the consequence of the coexistence of SW-NE contraction caused by the advancing of the

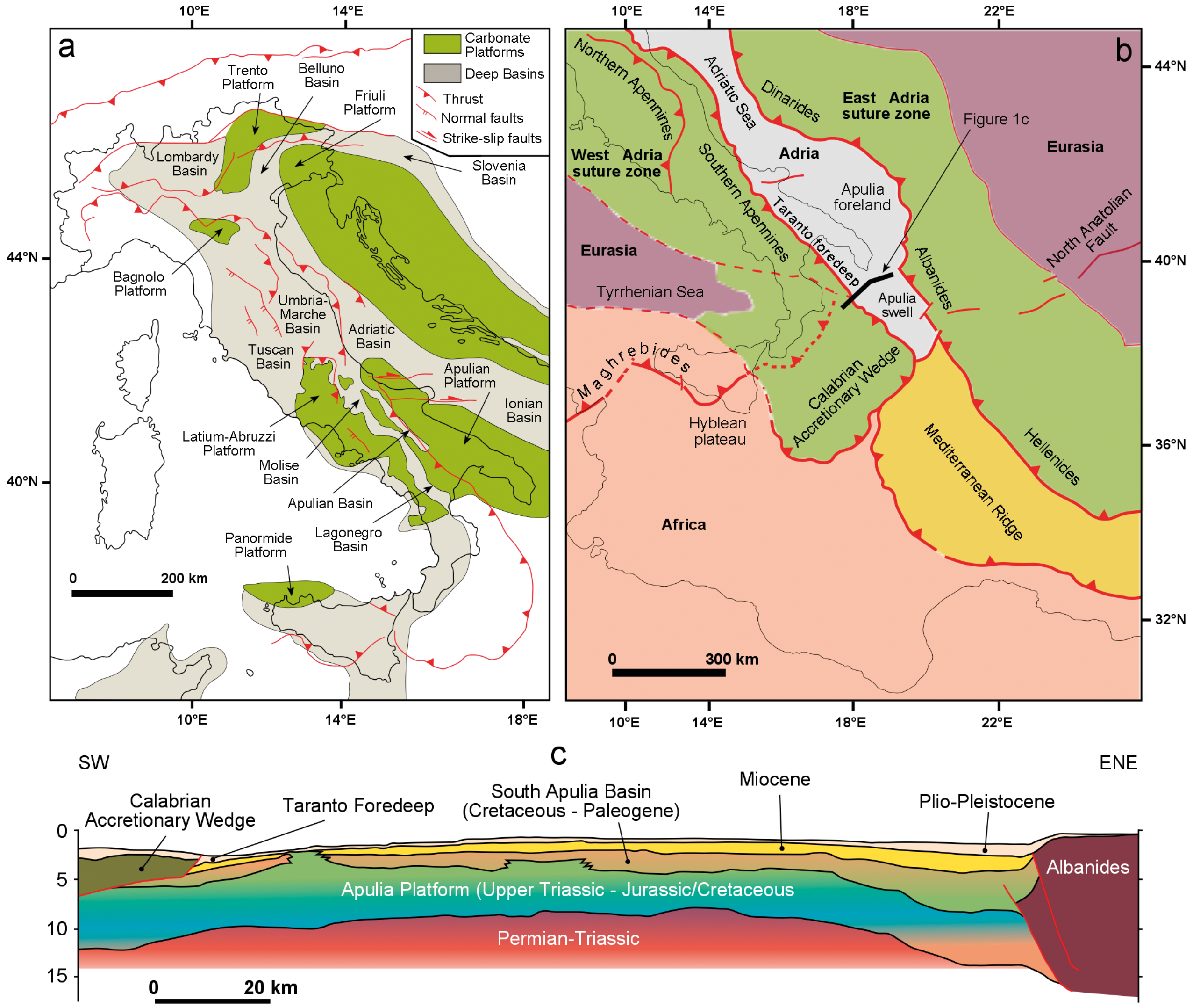

Fig. 1 - a) Early Giurassic- Early Cretaceous paleogeographic map of the Italian peninsula (redrawn from Zappatera (1994; Carminati and Doglioni, 2012); b) Simplified geodynamic framework and plates of the Mediterranean area (redrawn and modified from Basso et al., 2021); c) Crustal scale geological section across the submerged lowermost sector of the Salento peninsula (redrawn and modified from Maesano et al., 2020).

Apennines and Dinarides-Albanides-Hellenides and the concomitant northward movement of the African plate (see also Argnani et al., 2001). Consequently, the Middle-Upper Pleistocene deposits cropping out on both the Ionian and Adriatic sides of the Salento Peninsula show a deformation characterized by NW-SE, SW-NE, and SSW-NNE oriented extensional faults with small displacement. These structures are strictly related to the uplift of the Apulia region, which began during the Middle Pleistocene according to Doglioni et al. (1994, 1996). This tectonic uplift occurred contextually with the Quaternary eustatic sea-level changes and together determined a more complex Quaternary evolution of the area, which was marked by relative sea level rise and fall. The latter are considered responsible for the formation of the coastal terraces developed along the Ionian and the Adriatic margin of the Salento peninsula (see Ciaranfi et al., 1988; Ricchetti et al., 1988; Di Bucci et al., 2011; Mastronuzzi et al., 2011; Ricchetti and Ciaranfi, 2013 with references therein).

2.2. LITHOSTRATIGRAPHIC UNITS

The stratigraphic succession of both the Apulia region and the Salento Peninsula shows a basement constituted of a continental crust on which a thick sedimentary cover, essentially represented by Meso-Cenozoic carbonate rocks, is present (Mostardini and Merlini, 1986 and references therein). In particular, the sedimentary cover, about 7000 m thick, consists of a basal portion characterized by fluvio-deltaic deposits of Permo-Triassic age, passing upward to an anhydrite-dolomitic succession of Triassic age. Above a thick shallow-water Bahamian-type carbonate platform with associated slope and basinal facies of Jurassic-Cretaceous age (Apulian Platform) developed (D'Argenio, 1974; Ricchetti et al., 1988; Eberli et al., 1993; Bosellini, 2004; Morsilli et al.,

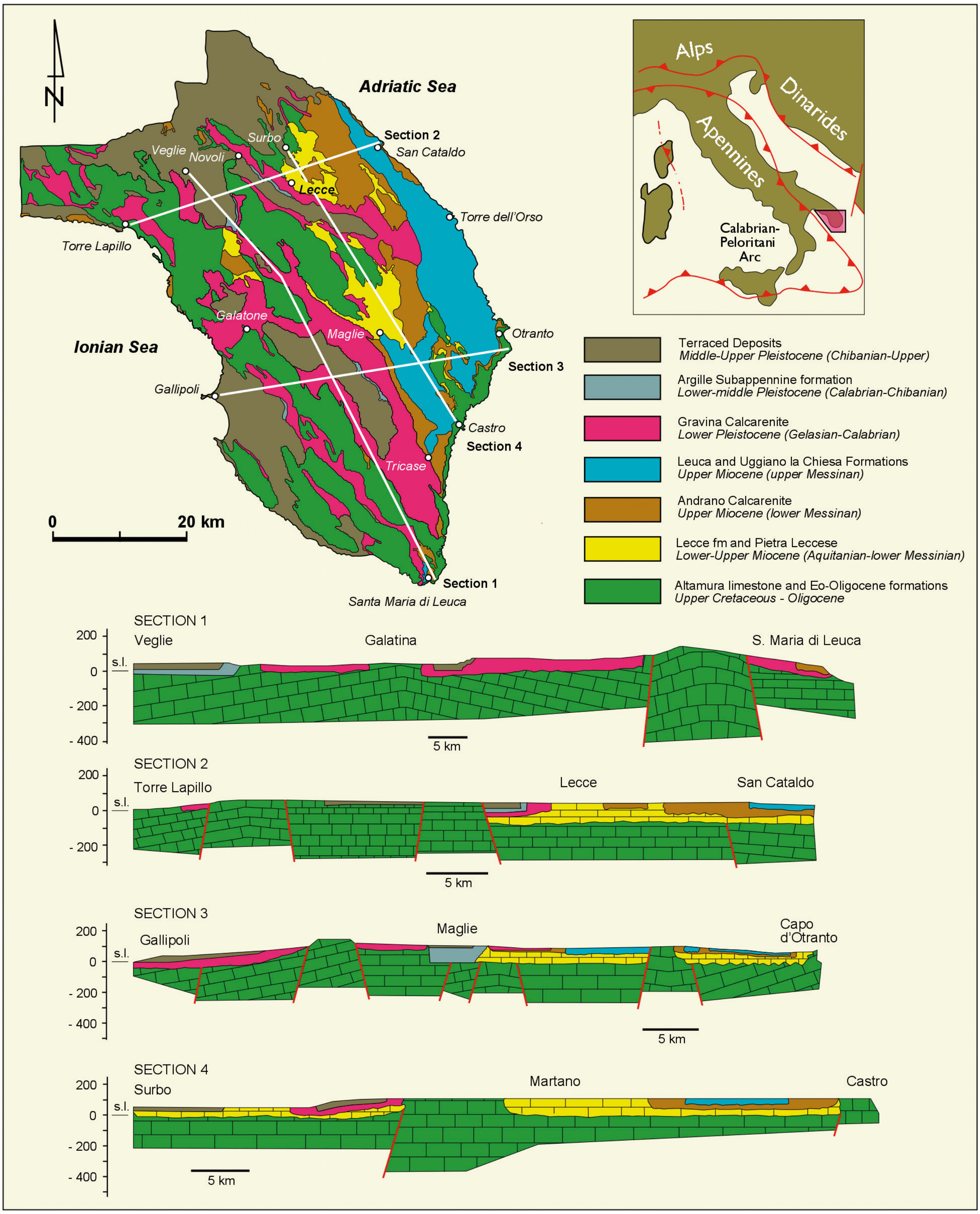

Fig. 2 - Simplified geological map and profiles of the Salento Peninsula.

2017), which is unconformably covered by thin and discontinuous Eocene to Quaternary deposits on the Adriatic side and by Pliocene and Pleistocene deposits on the Ionian side (Ciaranfi et al., 1988). A similar stratigraphic succession occurs in the Salento offshore sector. The eastern side is occupied by the Dinarides-Albanides-Hellenides foreland basin whose filling is characterized by an Oligocene-Miocene carbonate and terrigenous succession, Messinian evaporites, and Plio-Quaternary marls and clays (Monopolis and Bruneton, 1982; Robertson and Shallo, 2000; Zelilidis et al., 2003; Del Ben et al., 2010; Karakitsios, 2013); the western side is instead occupied by the Southern Apennines foreland basin whose filling is mainly constituted by terrigenous Plio-Quaternary deposits (Rossi et al., 1983; Merlini et al., 2000; Butler, 2009; Basso et al., 2021).

The outcropping succession in the Salento peninsula is constituted of Upper Cretaceous to Quaternary deposits subdivided into lithostratigraphic units with variable thickness and bounded by unconformities (Ciaranfi et al., 1988; Bosellini et al., 1999) (Fig. 3).

The Paleogene and the Neogene sediments crop out discontinuously in the area and were essentially deposited in several structural depressions originated as a result of the horst and graben structural setting occurring in the Salento Peninsula (Martinis, 1962; Tozzi, 1993). On the contrary, the Eocene to Miocene deposits cropping out along the southeast margin of the peninsula show a different evolution being characterized by carbonate units with well-developed depositional clinoforms indicating that these sediments were deposited along and at the base of steep rocky slopes that should correspond to the margin of the Mesozoic Apulia Platform (Bosellini and Parente, 1994; Bosellini et al., 1999; Bosellini, 2006; Pomar et al., 2014; Del Ben et al., 2015). A similar depositional context was also described by Tropeano et al. (2022) for the Lower Pleistocene carbonate deposits occurring along the south-east Salento, between Otranto and Santa Maria di Leuca.

The Torre Tiggiano limestone and Specchia la Guardia limestone are the only units of Eocene age (Bosellini and Russo, 1992; Parente, 1994; Bosellini et al., 1999; Russo, 2006). We considered separately these units as they are represented by different facies types: clinostratified bioclastic sediments (Torre Tiggiano limestone) and reef slope deposits (Specchia la Guardia limestone). These informal formations have limited distribution, and the few outcrops are only localized along the eastern coast of the Salento Peninsula. Ricchetti and Ciaranfi (2013) include both these two units in a single formation called Torre Tiggiano limestone. The Oligocene deposits are represented by the Castro limestone and Porto Badisco calcarenite that crop out on the eastern Salento coast, whereas in the internal part of the peninsula the coeval unit is represented by the Galatone Formation. The Miocene deposits are represented by the Lecce formation, Pietra leccese and the Andrano Calcarenite. These units crop out essentially in the peninsula's internal sectors, whereas along the eastern coast the Andrano Calcarenites are replaced by the Novaglie formation. The Pliocene deposits of the Salento Peninsula are represented by the Leuca and Uggiano la Chiesa formations that crop out prevalently on the eastern sector of the peninsula. As to the Quaternary deposits, the more developed units are represented by the Gravina Calcarenites and the Argille Subappennine that crop out extensively on the entire region. The more recent Quaternary units are instead represented by the marine terraced deposits that crop out extensively or in limbs along the coastal sector of the Salento peninsula. A brief

Pleistocene	Chibanian-*Upper*	Marine terraced deposits	
	Calabrian-Chibanian?	Argille subappennine	
	Calabrian (Sicilian)	Gravina Calcarenite	
	Gelasian	Uggiano la Chiesa formation	
Pliocene	Piacenzian		
	middle Zanclean	Trubi	Leuca Formation
Miocene	upper Messinian	Leuca Breccia	
	lower Messinian	Andrano Calcarenite - Novaglie fm.	
	upper Burdigalian-lower Messinian	Pietra leccese	
	Aquitanian	Lecce formation	
Oligocene	upper Chattian	Porto Badisco calcarenite	Galatone Fm.
	middle-upper Chattian	Castro limestone	
Eocene	upper Priabonian	Torre Specchia la Guardia limestone	
	lower Lutetian-upper Bartonian	Torre Tiggiano limestone	
Upper Cretaceous	Campanian-Maastrichtian	Altamura limestone	

Fig. 3 - Lithostratigraphic units cropping out on the Salento Peninsula.

description of these lithostratigraphic units from literature data and field observations is reported below.

2.2.1. Altamura limestone

This unit (Valduga, 1965; Azzaroli, 1967), about 1000 m thick, is the oldest outcropping formation of the Salento Peninsula (Campanian-Maastrichtian) and constitutes the substrate that is disconformably covered by the different Paleogene, Neogene, and Quaternary deposits (Ciaranfi et al., 1988; Ricchetti and Ciaranfi, 2013). This formation is exclusively made up of shallow-water facies, referable to the internal part and to the high-energy margin of a platform, as slope or basinal facies have not been identified in the area.

Overall, this unit is characterized by numerous meter-thick peritidal cycles of the internal platform showing locally the presence of stromatolites and the presence of several dinosaur footprints (see Nicosia et al., 1999 a,b; Petti et al., 2020 with references therein). Furthermore, discontinuous strata with high concentrations of rudist fragments occur, which give rise to bioclastic grainstones, interpreted as storm layers. In the most marginal areas of the platform, coarse bioclastic calcirudites and calcarenites prevail with fragments of rudists, larger foraminifers, corals, bryozoans, and calcareous algae. The rudist faunas indicate a late Campanian-Maastrichtian age (see detailed descriptions of this unit in Cestari and Sirna, 1987; Pons and Sirna, 1994; Bosellini and Parente 1994; Parente, 1994 a,b, 1997; Reina and Luperto Sinni, 1994; Laviano, 1996).

The top of this unit is locally characterized by karst structures and by the presence of thick residual soils with bauxite and pisoids, suggesting a long periods of emersion at the end of the Cretaceous following the collision between the African and the European blocks and the westward migration of the Dinarides-Albanides-Hellenides chain (Bosellini et al., 1999; Ricchetti and Ciaranfi, 2013; Maesano et al., 2020; Cicala et al., 2021 and references therein).

2.2.2. Torre Tiggiano limestone

This limestone constitutes the first unit of Eocene age deposited along the margin of the Apulian Platform when its internal sector was subaerially exposed. It discontinuously crops out along the eastern coast of the Salento Peninsula having a thickness of 10-15 meters and lies on the Upper Cretaceous deposits through an erosional unconformity (Bosellini and Russo, 1992; Parente, 1994a; Bosellini et al., 1999).

The deposits of this formation consist of parallel- and cross-laminated grainstone/packstone forming units 1-2 m thick with lenticular geometry. The biogenic component is represented by abundant smaller and larger benthic foraminifers (miliods, alveolinids, and nummulitids) which are associated with encrusting foraminifers, coralline red algae, subordinate echinoids, and green algae. Other less frequent bioclasts include bivalves and bryozoans (Bosellini and Russo, 1992; Parente 1994a; Bosellini et al., 1999; Tomassetti et al., 2016). Based on this biota assemblage and considering bodies geometry, and sedimentary structure Tomassetti et al. (2016) interpreted these deposits as the product of deposition in a high-energy and wave-influenced shallow-water environment developed in a tropical to subtropical vegetated context (seagrass) and in oligotrophic conditions (Fig. 4).

Although Bosellini et al. (1999) did not indicate a specific depositional context, their stratigraphic analysis suggests that this unit, dated lower Lutetian-lower Bartonian (middle Eocene), was probably thicker and continuous and constituted by two depositional sequences separated by an erosional unconformity. The more recent biostratigraphic analysis of Tomassetti et al. (2016) assigned to this unit an early Lutetian-late Bartonian age.

2.2.3. Torre Specchia la Guardia limestone

This unit is the second formation of the Eocene age that crops out fragmentarily along the Salento eastern coast. It

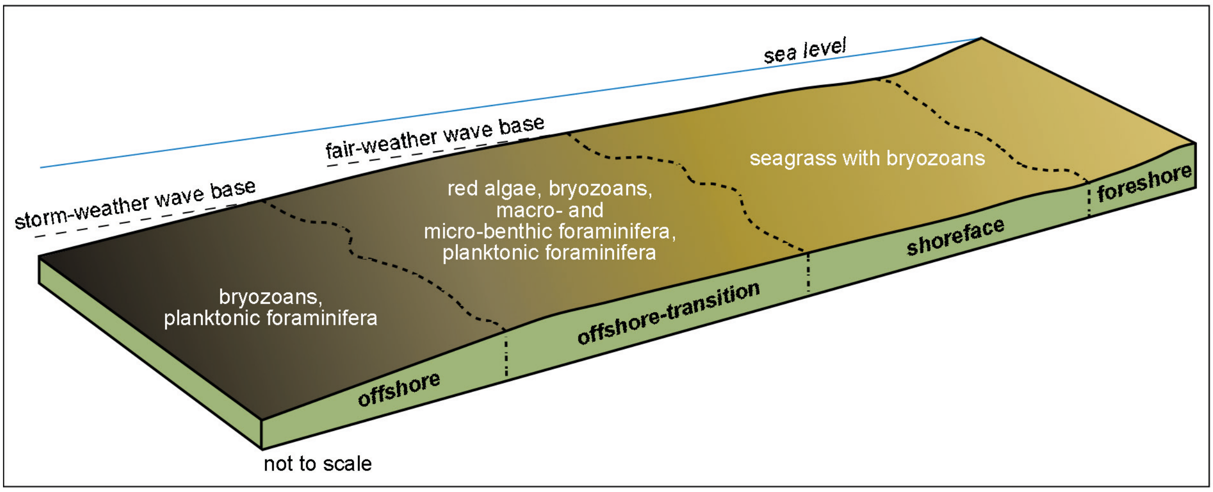

Fig. 4 - Depositional model of the Middle Eocene Torre Tiggiano limestone (redrawn and modified from Tomassetti et al., 2016).

is a reef slope deposit constituted by breccias and bioclastic sediments onlapping onto the Cretaceous substrate and/or on the middle Eocene deposits through an angular unconformity. The bioclastic component is constituted by coral fragments, calcareous algae (Corallinaceae, Dasycladales, and Halimeda), and benthic foraminifers whose assemblage, characterized by the presence of *Asterocyclina priabonensis* and *Heterostegina gracilis*, permit to attribute to these deposits a late Priabonian age (Bosellini and Russo, 1992; Parente, 1994a; Bosellini et al., 1999; Russo, 2006).

2.2.4. Castro limestone

This upper Oligocene formation, (Bosellini and Russo, 1992; Parente, 1994a), crops out along the eastern coast of the Salento Peninsula from Capo d'Otranto to S. Maria di Leuca and overlies unconformably the underlying Upper Cretaceous and Eocene formations. Such unit, whose thickness ranges from 5 to 80-100 m, was initially described by Rossi (1969) and successively studied by Bosellini and Russo (1992, 1994), Bosellini and Perrin (1994), Bosellini et al. (1999), Bosellini (2006) who interpreted these deposits as a fringing reef complex having recognized the subenvironments of back reef, reef flat, reef crest, reef front and reef slope. Successively, Pomar et al. (2014) have interpreted the Castro limestone as the product of deposition along a meso-oligophotic distally steepened ramp with a distal talus resting on a paleo-escarpment of the Cretaceous substratum. The authors highlighted that the production of bioclastic sediments is attributed to the presence, in the inner ramp (shallow water euphotic zone), of a seagrass meadow where epiphytic biota and sediment dweller organisms proliferated. The coral fauna was considered confined to the mesophotic zone with no wave influence, where it formed scattered mounds above an escarpment 25°-30° inclined, at the bottom of which a talus constituted by bioclasts (essentially coral fragments) occurred.

More recently, the original interpretation of the Castro limestone as a fringing reef complex has been confirmed by Bosellini et al. (2021) (Fig. 5) who reconstructed the palaeobathymetric profile of this depositional system, highlighting how these deposits show homogeneity of reef-building biota, being characterized by a high diversity and abundant coral fauna associated with a moderate presence of coral algae (essentially Corallinaceae) and by the presence of benthic and planktic foraminifers and calcareous algae. This study has also refined the age of these deposits that have been reassigned to the middle-late Chattian (Pomar et al., 2014 attributed the Castro limestone to the lower Chattian), a timespan coincident with the Late Oligocene Warming Event (LOWE) (Zachos et al., 2001).

2.2.5. Porto Badisco calcarenite

This informal unit crops out along the eastern coast of the Salento peninsula from Capo d'Otranto to Cala Ciolo; it is constituted by a poorly cemented bioclastic calcarenite that reaches 50-60 meters of thickness in the locality of Porto Badisco, where it seems to fill a paleo-depression (Nardin and Rossi, 1966; Bosellini and Russo, 1992; Brandano et al., 2010).

This formation overlies disconformably the Upper Cretaceous, Eocene, and upper Oligocene formations, having always an erosional base on which, locally, a rhodolith horizon 1-2 m thick occurs. On top of

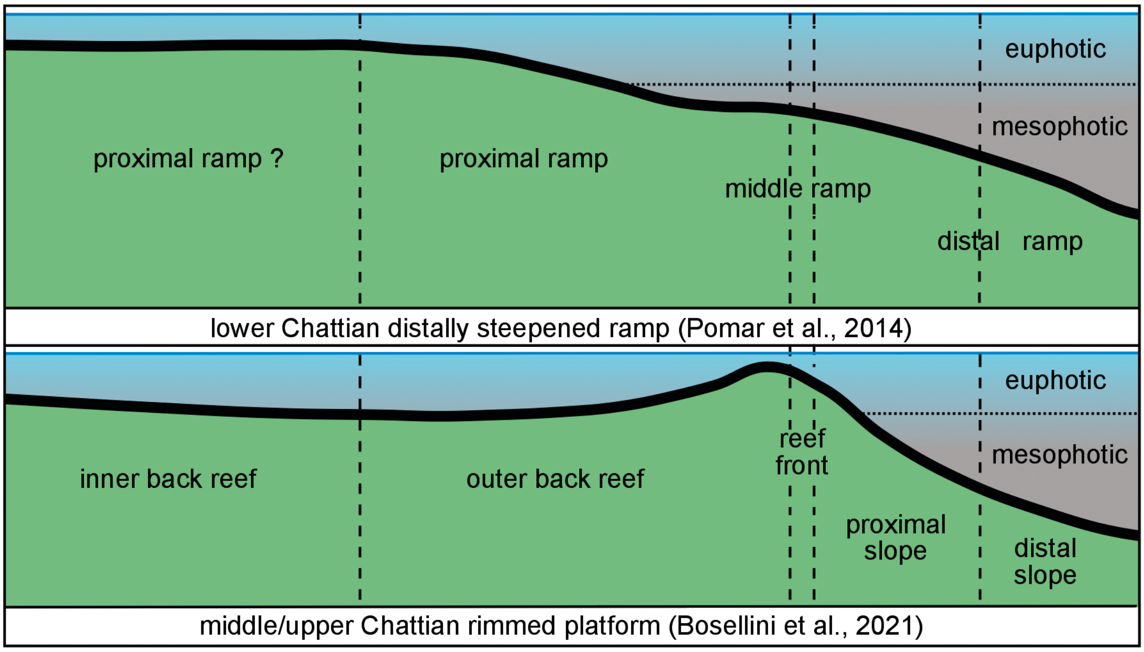

Fig. 5 - Comparison between the depositional models and ages of the Castro limestone proposed by Pomar et al. (2014) and Bosellini et al. (2021).

the calcarenites a Miocene (Serravallian-Tortonian) phosphate-glauconite horizon, 5-30 cm thick, known in the literature as "*Aturia* level" (Bosellini and Russo, 1992; Parente, 1994a; Föllmi et al., 2015; Vescogni et al., 2018) occurs. The significance of this level in the sequence-stratigraphic context of the area will be discussed in a following paragraph.

Recently the Porto Badisco calcarenite has been investigated by Pomar et al. (2014), that subdivided this unit into six main lithofacies considered as the product of sedimentation on a homoclinal ramp (Fig. 6). Packstones are the dominant textures having a skeletal component consisting of larger benthic foraminifers with red algae. The authors described also in this unit the presence of corals, forming distinct mounds a few meters to tens of meters in diameter, and scattered colonies. They evidenced that sedimentation of Porto Badisco calcarenites formed in an euphotic zone characterized by a productive seagrass meadow of skeletal component, and an oligophotic zone where small and discontinuous coral mounds, larger to smaller benthic foraminifers, rhodoliths, and red-algae fragments accumulated. Based on the presence of *Miogypsinoides,* Pomar et al. (2014) attributed the Porto Badisco calcarenite to the late Chattian.

More recently Parente and Less (2019) analyzed in detail the larger benthic foraminiferal assemblage of this unit that is mainly constituted by *Eulepidina*, *Heterostegina* and *Spiroclypeus* and subordinately by *Nummulites*, *Operculina* and *Nephrolepidina*. They also analyzed this formation through Sr isotope stratigraphy and attributed an age of 23.6±0.5 Ma to the lower portion of this formation which corresponds with the latest part of Chattian, almost at the boundary between the Oligocene and the Miocene. This study together with that of Bosellini et al. (2021) shows that both the Castro limestone and the Porto Badisco calcarenite belong to the same biozone (Shallow Benthic Zone 23, Cahuzac and Poignant, 1997) although stratigraphically the latter is superimposed on the former.

2.2.6. Galatone Formation

The Galatone Formation, whose maximum thickness is about 100 m in correspondence with graben areas and of the nuclei of small synclines (Bossio et al., 2006a; Giudici et al., 2012), lies unconformably on the Cretaceous substrate, directly or through the interposition of residual deposits rich in pisolites and bauxitic nodules (Bossio et al., 1998). In recent years the stratigraphy of this unit has been described in detail by Esu et al. (1994, 2005), Bossio et al. (1998, 2006 a,b, 2007, 2009), Margiotta and Ricchetti (2002), Margiotta and Negri (2008). It consists of whitish-greyish micritic limestones that are interbedded with centimeter-scale layers of whitish limestone and laminated yellowish calcareous marls, silt, and clays. Paleosols and lignite layers, from a few centimeters to several decimeters thick, occur at different levels in this unit thus suggesting a sedimentary cyclicity and frequent subaerial exposure. Bivalves, gastropods, and ostracods of different environments (freshwater, brackish and marine) are the most common fossils occurring in this formation, and together with the assemblages of benthic foraminifers living in a seagrass environment (planktonic foraminifers are absent), indicate a lacustrine to marshy/swampy restricted lagoonal environment, locally open to the sea. These environments characterize the thickest portion of this unit which only in its terminal part records the presence of mesohaline and marine carbonate facies (Margiotta and Ricchetti, 2002; Esu et al., 2005)

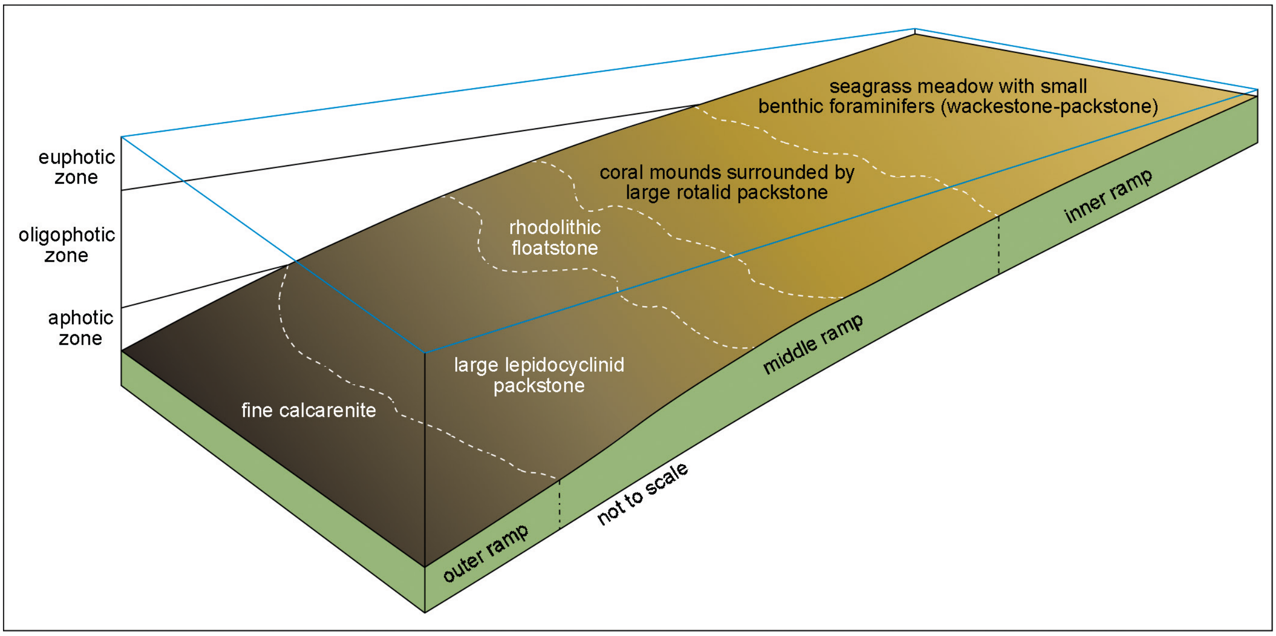

Fig. 6 - Carbonate ramp depositional model of the Porto Badisco calcarenite (redrawn and modified from Pomar et al., 2014).

indicating a major marine influx related to progressive marine ingression in the Salento hinterland.

The bio-chronostratigraphic framework of the Galatone Formation based on the ostracofauna permit to attribute the entire unit to the Chattian (upper Oligocene) (Bossio et al., 1998, 2006 a,b, 2009). Based on what was suggested by Bosellini et al. (1999), and Bossio et al. (2006 a,b, 2007, 2009) and considering the most recent studies by Bosellini et al. (2021) and Parente and Less (2019) on the Castro limestone and the Porto Badisco calcarenite respectively, as well as our field observations and correlations, we retain that the Galatone Formation is heteropic of both formations whose age, as previously mentioned, covers the time interval of the middle-late Chattian. The Galatone Formation represented the product of deposition in the internal parts of the Salento Peninsula where a lacustrine-lagoonal environment occurred, passing seaward to the carbonate facies of the Castro limestone and the Porto Badisco calcarenite (Fig. 7). This topic will be further discussed in the following paragraph where the sequence-stratigraphic framework of the entire Paleogene-Quaternary succession of the Salento Peninsula will be analyzed.

2.2.7. Lecce formation

The Lecce formation (Margiotta, 1999; Margiotta and Ricchetti, 2002; Bossio et al., 2006a, 2007, 2009; Margiotta, 2015) crops out to the south-west of the town of Lecce and lies unconformably on the Galatone Formation, through the interposition of a paleosol from a few tens of centimeters to about 2 m thick (Figs. 7 and 8). This unit, about 60 meters thick, consists of whitish massive calcarenites with gray marly and micritic limestone intercalations which show extensive bioturbation (Fig. 9a). The faunal assemblage is characterized by rare bivalves (especially *Cardium*), echinoids (*Scutella*), gastropods, and larger foraminifers (*Operculina*) (Fig. 9b). The microfauna is represented by microforaminifers and calcareous nannofossils. All these features indicate a deposition of these sediments in a shallow water marine environment where the good preservation of larger foraminifers and the presence of *Scutella* living on sandy backdrops suggest reduced transport and low hydrodynamic conditions.

From a chronostratigraphic and biostratigraphic point of view, the assemblages of planktonic foraminifers and calcareous nannofossils allowed Bossio et al. (2006a) to assign the upper portion of this formation to the basal Aquitanian (early Miocene), while the lower portion was doubtfully attributed to the late Chattian. However, considering the recent age attributed to the underlying Porto Badisco calcarenite by Parente and Less (2019) (latest portion of the Chattian) we suggest attributing to the Aquitanian the Lecce formation. The marine character of this unit highlights the transgressive trend characterizing the Neogene deposits with respect to the underlying lacustrine-lagoonal Galatone Formation, although the latter formation records in its uppermost portion a major marine influence. This transgressive trend culminates with the deposition of the subsequent stratigraphic unit represented by the Pietra leccese formation.

2.2.8. Pietra leccese

The Pietra leccese formation constitutes a lithostratigraphic unit extensively occurring both in

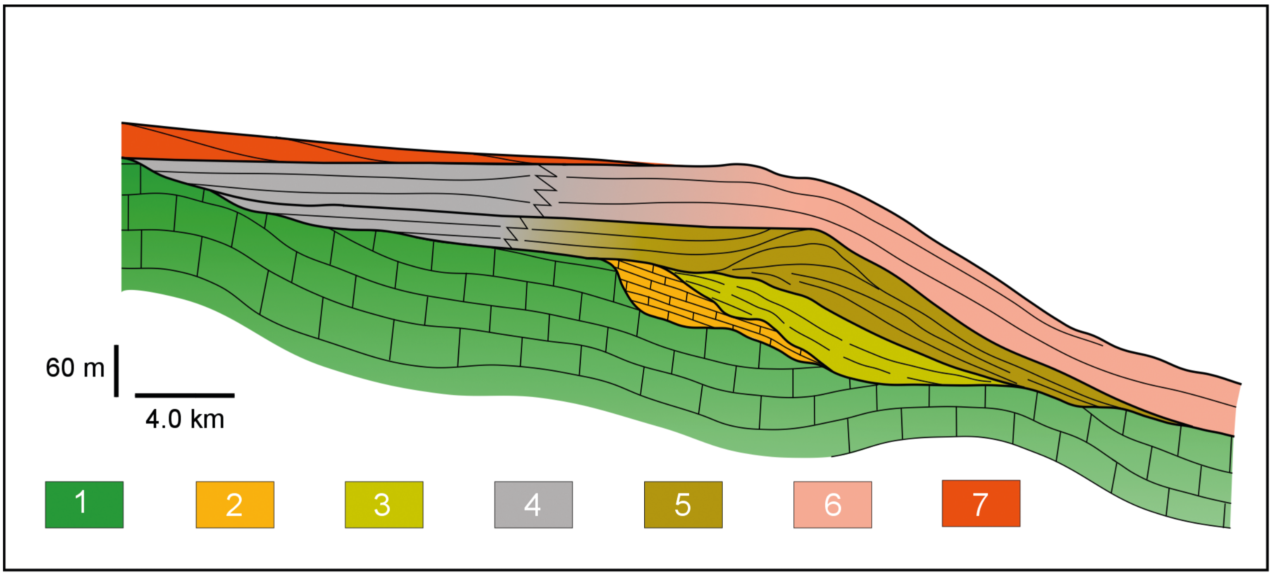

Fig. 7 – Schematic profile showing the stratigraphic relationships among the Castro limestone, the Porto Badisco calcarenite and the coeval Galatone Fm. Note the transgressive character of the Lecce fm. respect to the underlying lithostratigraphic units. 1: Altamura limestone; 2: Torre Tiggiano limestone; 3: Torre Specchia la Guardia limestone; 4: Galatone Fm.; 5: Castro limestone; 6: Porto Badisco calcarenite; 7: Lecce fm.

outcrop and in the subsurface in the Salento Peninsula, and spanning an interval of about 11 My, from the late Burdigalian to the early Messinian (see Mazzei et al., 2009 and references therein). It reaches a maximum thickness of about 90 m in the Lecce area, whereas towards the Ionian and Adriatic coasts the Pietra leccese is extremely thin or entirely absent. This unit lies unconformably both on the Cretaceous substrate (Fig. 10) and the Lecce formation (see also Cazzato and Margiotta, 2021). It is separated from the former either by a 20-30 cm thick limestone breccia or by a thin phosphatic layer in which apatite nodules are found. On the eastern margin of the Salento Peninsula, this thin phosphatic layer is replaced by a 10-30 cm thick layer, which constitutes a reddish or greenish-brown hardground containing phosphatized pebbles known in the literature as "*Aturia* level" (Föllmi et al., 2015; Vescogni et al., 2018 and references therein).

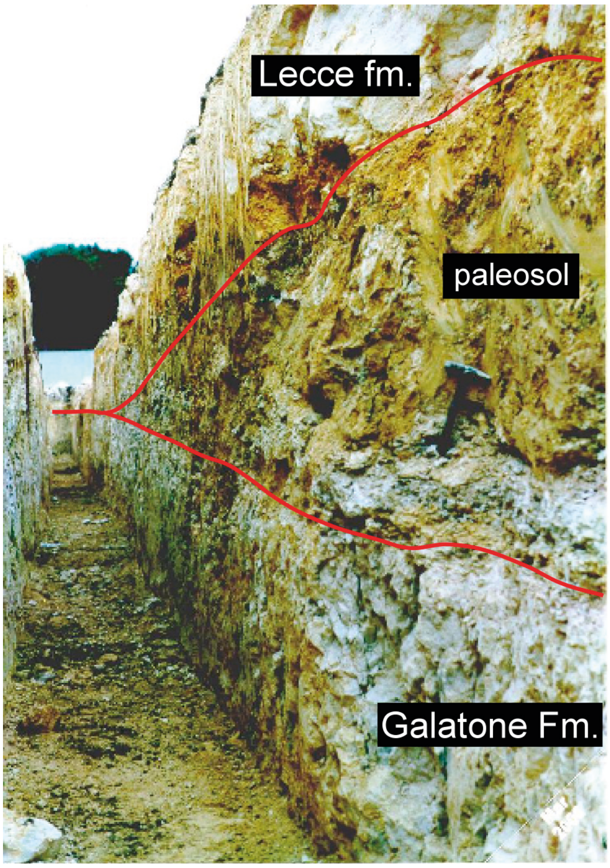

Fig. 8 - Transgressive erosional contact between the Lecce fm. and the underlying Galatone Fm. Locally these stratigraphic units are separated by a paleosol.

In its typical appearance, the Pietra leccese consists of a pale-yellow soft and friable biomicrite rich in planktonic foraminifers and nannofossils (Mazzei, 1994) and with macrofossil assemblages rich in pectinids, echinoids, bivalves, and brachiopods (Margiotta, 2006) (Fig. 11a). Overall, the sediment is very bioturbated and the stratification, poorly distinguished, appears in banks with thickness ranging from 50 to 100 cm (Fig. 11b). One of the features characterizing this unit is the presence of a high percentage of phosphatic and glauconitic grains whose frequency and abundance allowed the authors (see Foresi et al., 2002; Balenzano et al., 2003; Bossio et al., 2006a; Margiotta, 2006; Mazzei et al., 2009; Chieco et al., 2021) to subdivide this unit into different intervals separated by three hiatuses with a duration variable from 1.2 to 3.7 Ma.

From older to younger, the first hiatus with a duration of about 2.5 Ma separates the upper Burdigalian non-glauconitic interval from the Langhian weakly glauconitic interval. The second hiatus, with a duration of about 2.5 Ma, separates the upper Langhian weakly glauconitic interval from the lower Tortonian glauconitic-rich interval. The third hiatus, with a duration ranging from 1.7 to 3.7 Ma, separates the lower Tortonian glauconite-rich interval from the middle Tortonian weakly glauconitic interval. A fourth hiatus was also recognized, but only in the area north of Lecce where the uppermost Tortonian deposits directly overlie the middle Tortonian deposits. In the Cursi-Melpignano area the lower Tortonian glauconitic-rich interval is overlain by a lower Messinian weakly glauconitic interval constituted by a marly calcarenite

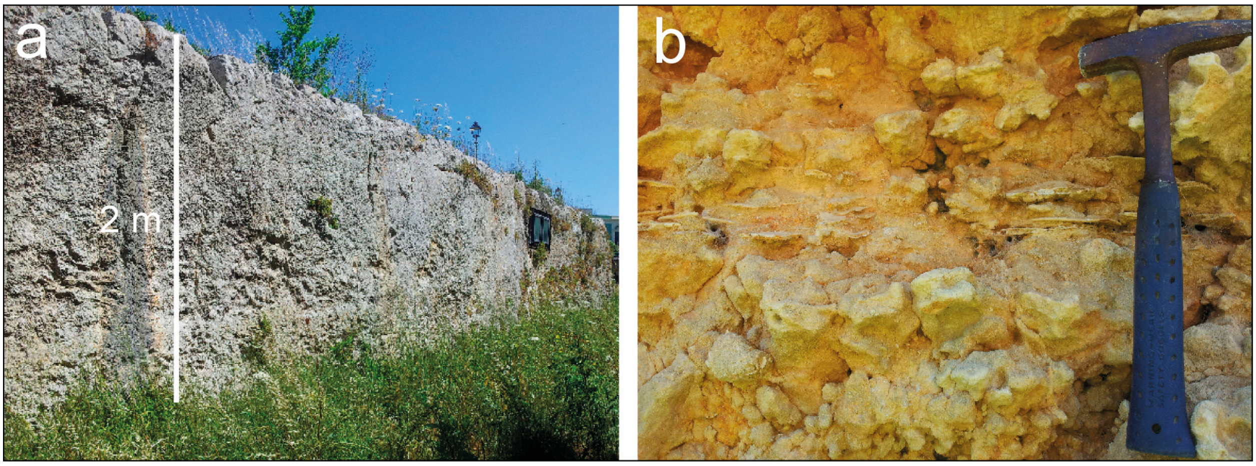

Fig. 9 - a) calcarenites of the Lecce fm. cropping out along the moat adjacent to the Copertino Castle (1540); b) Detail showing the presence of *Scutella* specimen in Lecce fm. calcarenites.

Fig. 10 - Unconformity surface between the Pietra leccese and the Altamura limestone (north-east of Lecce). The passage between the two lithostratigraphic units is often marked by a 20-30 cm thick phosphatic layer with small nodules of apatite.

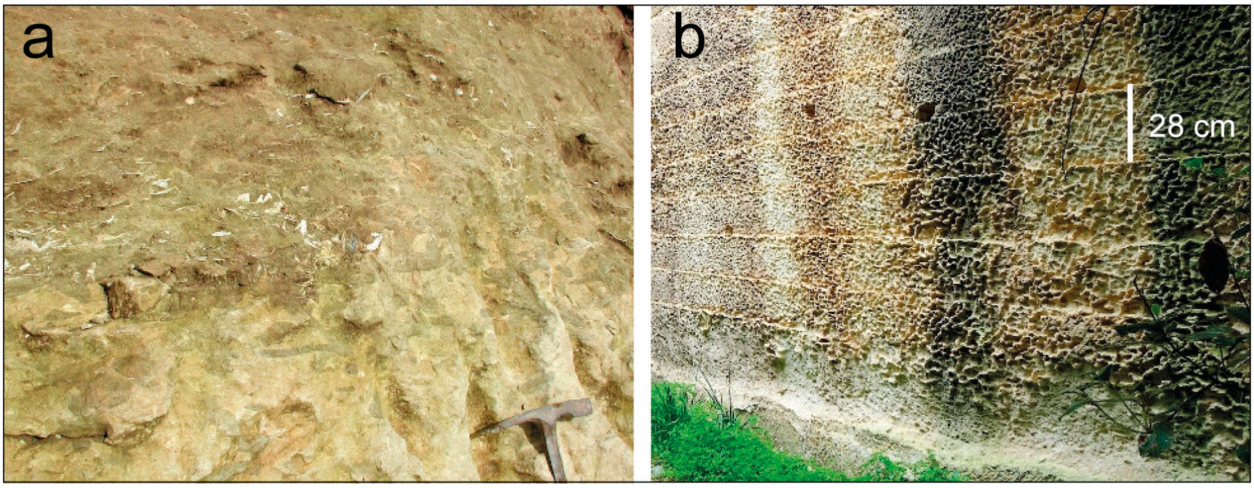

Fig. 11 - a) disarticulated valves of bivalves in the glauconite-rich calcarenite of the Pietra leccese; b) highly bioturbated fine-grained calcarenite of Pietra leccese.

rich in pectinids and brachiopods and with hummocky cross-stratification. This last interval of the Pietra leccese suggests a decrease in water depth and a deposition in a shallow-marine or nearshore environment; it grades transitionally upward to the Andrano Calcarenite (Bossio et al., 2006a; Margiotta, 2006). Overall, the sedimentological and palaeoecological data indicate for the Pietra leccese a deposition on an inner shelf passing towards the top of the succession to a lower shoreface.

Although the Pietra leccese spans a time interval of 11 Ma, its overall thickness is small with respect to its duration. Balenzano et al. (2003), and Mazzei et al. (2009 and references therein) indicate that this reduced thickness could be interpreted as a consequence of a nondeposition and/or erosion induced by marine currents sweeping the seabed. The hiatuses occurring in this formation are interpreted to be an effect of these processes. We agree that marine currents can be particularly effective erosive agents, however, we believe that the hiatuses occurring in this lithostratigraphic unit can be more coherently explained in the sequence-stratigraphic context of the entire Paleogene-Quaternary succession of the Salento Peninsula.

2.2.9. Andrano Calcarenite

This unit, originally defined by Martinis (1967), crops out with reduced thickness along the internal and the eastern sectors of the Salento Peninsula (Bossio et al., 1994), whereas it reaches a thickness of about 90 meters in the subsurface (Margiotta, 2006). In the Leuca area, the Andrano Calcarenites extensively crop out and lie discordantly, both on the oldest Miocene sediments and on the Cretaceous substrate (Bossio et al., 1994; Mazzei, 1994; Ricchetti and Ciaranfi, 2013). This unit shows a gradational boundary with the underlying Pietra leccese (Fig. 12a) and is constituted at the base by thin-bedded whitish fine-grained marly calcarenite with rare greenish granules of glauconite grading upward to wavy, subparallel bedded (30-40 cm) whitish/yellowish medium-grained marly calcarenites. Fossils are very abundant and dispersed in the deposits or forming concentrated layers; the most frequent fossils are represented by annelids, serpulids, balanids, bryozoans, gastropods (mainly *Turritella* sp.), bivalves (*Chlamys* sp., *Cardium* sp., *Ostrea* sp., *Modiola* sp.), brachiopods and calcareous algae (Fig. 12b). The uppermost portion of the Andrano Calcarenite is a light gray fine-grained marly calcarenite with locally intercalated a thick greenish clay bed showing a rich assemblage of brackish macrofossils with small gastropods (*Cerithium* sp.) and bivalves (*Cardium* sp.) (Margiotta, 2006). All these data indicate a vertical and transitional environmental change of the Andrano Calcarenite, passing from an inner shelf to a beach environment with local presence of brackish lagoonal conditions in the uppermost part of this succession. The latter feature is also evidenced by the presence of some benthic foraminifers such as *Cribrononion articulatum*, a species living in lagoonal areas with fresh water supplies (Bossio et al., 2006a).

Based on micropaleontological data the age of the Andrano Calcarenite is attributed to the early Messinian (Mazzei, 1994; Mazzei et al., 2009 and references therein) and most likely to the pre-evaporitic stage, although it is not excluded that these sediments may have been deposited during the initial phase of the Stage 1 Messinian Salinity Crisis (MSC) (see Hilgen et al., 2007; CIESM et al., 2008; Roveri et al., 2014 a,b).

2.2.10. Novaglie formation

This unit was introduced by Bosellini et al. (1999), but it has not yet been formalized. It crops out discontinuously along the eastern coast of the Salento Peninsula from Porto di Tricase to Cape S. Maria di Leuca where it is also known by the name of Gagliano del Capo formation (Ricchetti and Ciaranfi, 2013). This such unit lies discordantly on the pre-Miocene-units through an erosional surface on which a 10-50 cm thick phosphatic hardground occurs (the above-mentioned *Aturia* level). Based on benthic foraminifers and ostracod assemblages, the Novaglie formation was dated to the early Messinian by Bosellini et al. (1999, 2001), and considered by authors as heteropic of the Andrano Calcarenite.

The Novaglie formation shows a well-developed reef complex with coral reefs, and clinostratified breccias forming prograding slope and base-of-slope deposits (Bosellini et al., 2001, 2002) (Fig. 13). Palaeoecological data suggest that this Messinian reef was characterized by a heterogeneous reef-building biota, with *Halimeda* bioherms, *Porites* reefs, coralline algae and vermetid-microbial bioconstructions along with encrusting foraminifera, bryozoans and serpulids (Bosellini et al., 2002; Bosellini, 2006).

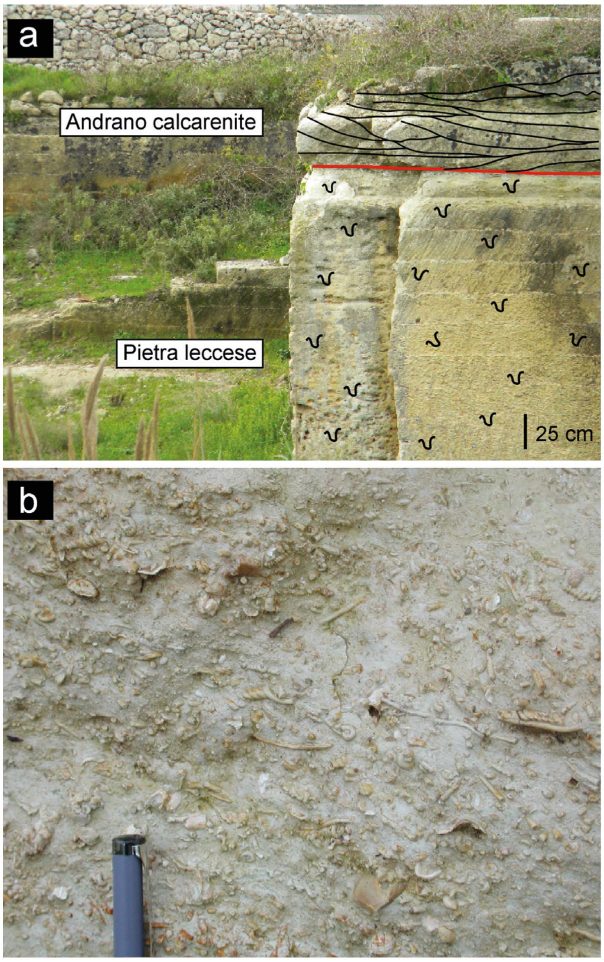

Fig. 12 - a) Stratigraphic contact between the Andrano Calcarenite showing a hummocky cross-stratification and the underlying highly bioturbated fine-grained calcarenite of the Pietra leccese; b) highly concentrated fossiliferous layer with serpulids, balanids, bryozoans, gastropods, bivalves, brachiopods and calcareous algae in the Andrano Calcarenite.

A more recent study indicates that this formation consists of three superimposed units called NF1, NF2, and NF3 that are separated by erosional surfaces colonized by microbial-vermetid bioconstructions (Vescogni et al., 2022) (Fig. 13). The lower units are early Messinian in age (7.3-5.97 Ma); NF1 unit is 120 m thick and shows a complete margin-to-slope reef tract with reef rubble, *Halimeda* bioherms and packstones, rhodolith floatstones/rudstones, and bioclastic calcarenites. The overlying NF2 unit, 20 m thick, consists of coral bioconstructions of *Porites* reefs with a reduced thickness of proximal slope deposits. NF3 unit, 10 m thick, consists

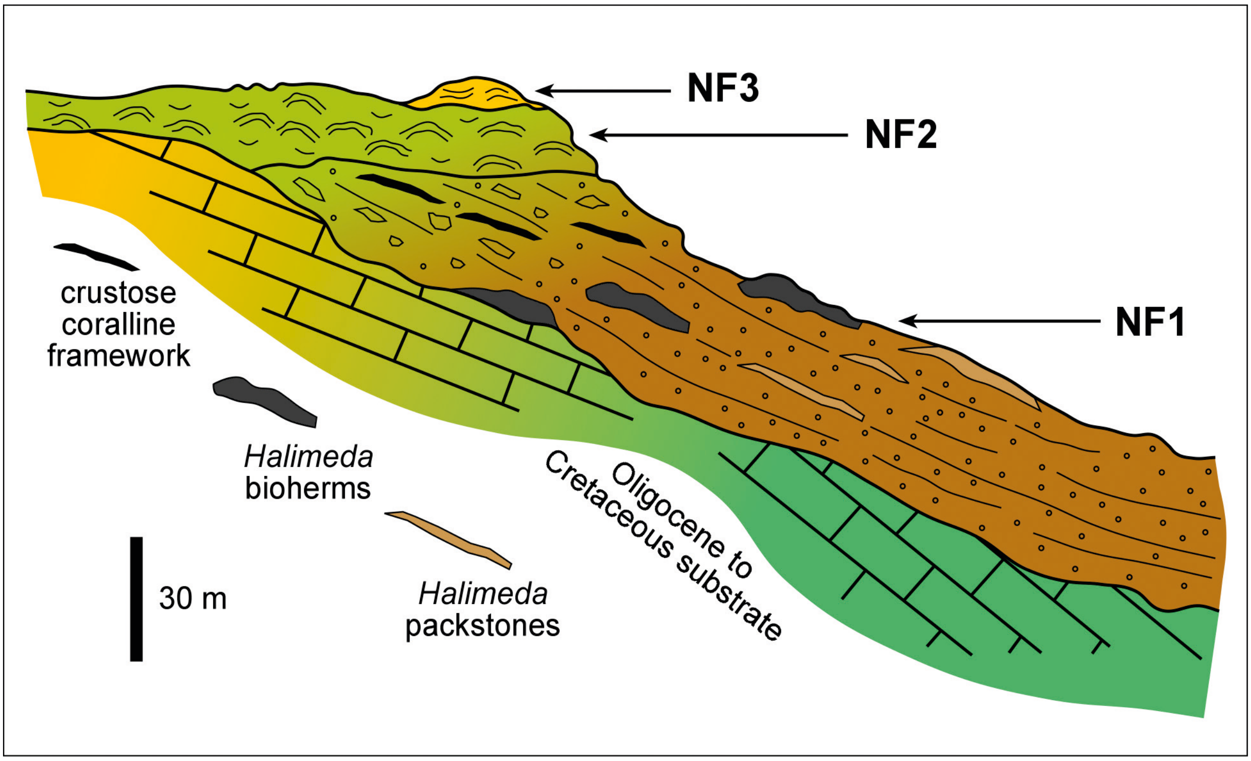

Fig. 13 - Deposition profile showing the reef-building biota and reef types characterizing the lower and upper Messinian deposits of the Novaglie fm. Note the subdivision of this formation into the three units NF1, NF2 and NF3 as proposed by Vescogni et al. (2022) (Redrawn and modified from Bosellini et al., 2006).

of oolitic deposits associated with microbialites, colonies of *Porites*, and small vermetid and serpulid bioherms (Bosellini et al., 2001, 2002). NF3 unit is upper Messinian in age (5.97-5.60 Ma) (Vescogni et al., 2022) and is equivalent to the Terminal Carbonate Complex (TCC), a shallow-water carbonate unit strictly related to the Messinian Salinitiy Crisis, that characterizes the terminal portion of the upper Messinian in several sectors of the Mediterranean area (Krijgsman et al., 2001; Bourillot et al., 2020; Roveri et al., 2020 and references therein).

2.2.11. Leuca Formation

The Leuca Formation formalized by Bossio et al. (2002) is considered by them as the first Pliocene unit of the Salento Peninsula. It has been subdivided into two members, from bottom to top: 1) a lower breccia/conglomerate member with a sandy matrix forming a thicker and more conspicuous chaotic unit with carbonate clasts (10 to 100 cm of diameter) (Fig. 14) derived, essentially, from the underlying Andrano Calcarenite and Novaglie formation; on this basis, Ricchetti and Ciaranfi (2013) attributed this member to the Andrano Calcarenite and hypothesized its successive post-diagenetic redeposition through slumping mechanism. The rare fossils occurring in this member are mainly represented by bivalves (*Ostrea* and *Chlamys*); 2) an upper marly unit passing upward to a glauconitic mudstone rich in planktonic foraminifers with subordinate benthonic forms (Palmariggi member by Bossio et al., 2005), that would correspond to the Trubi unit by Bosellini et al. (1999) and Ricchetti and Ciaranfi (2013) (Fig. 15). The thickness of this formation is highly variable ranging from 1-2 m to 30 m. A particular recurring feature that has been recognized at the base of the formation, below the breccia/conglomerate member, is the presence of a compact dark vacuolar limestone that is locally laminated. The scarce benthic microfauna present just above the base of the formation indicates very modest bathymetry that increases rapidly in the lower portion of the upper member whose microfauna and macrofossil assemblage suggests deposition in an inner shelf (offshore-transition) below the fair-weather wave base, as it is characterized by the presence of shell layers concentrations indicating multiple phases of storm-wave reworking (D'Alessandro et al., 2004; Massari et al., 2009). The glauconitic mudstone of the upper member with its rich microfauna indicates instead an outer shelf environment (Bossio et al., 2006a).

The scarce microfaunal assemblage recognized in the lower member may indicate that this portion could be referred to as the initial part of Zanclean (Bossio et al., 2006a). However, the same authors evidence in these deposits also the presence of *Globigerinoides seigliei*, a form occurring from the Tortonian to the Zanclean. It is evident that the age of the Leuca Formation is still debated due to the lack of accurate biostratigraphic markers. Bosellini et al. (1999) considered the breccia and conglomerate member a single formation of late Messinian age whose genesis would be related to the sea-level fall associated

Fig. 14 - Breccias constituting the lower member of the Leuca Formation, which consists of clasts derived prevalently by the Andrano Calcarenite and partly by Novaglie fm., immersed in a predominantly matrix calcarenite.

with the late phase of the Messinian Salinity Crisis (MSC). The same authors attributed the second member of this unit to another formation of the lower Pliocene (Zanclean) age on the basis of the faunal assemblage (see Bosellini et al., 1999; Ricchetti and Ciaranfi, 2013). These age attributions for the two members of the Leuca Formation are supported by this work (see paragraph Discussion), and by the recent paper of Vescogni et al. (2022) that also assigns the vacuolar limestone occurring at the base of this formation and below the breccia deposits to the Terminal Carbonate Complex (TCC) of upper Messinian in age (5.97-5.60 Ma).

2.2.12. Uggiano la Chiesa formation

This unit of Pliocene age crops out along the eastern coast of the peninsula and overlies mostly the Leuca Formation (Fig. 15) and locally older units; its thickness is variable reaching a maximum value of about 50 m in the Poggiardo area (Bosellini et al., 1999; Bossio et al., 2006a) and 90 m in the Cesine area (Chieco et al., 2021).

This formation is constituted in the lower portion by a discontinuous basal conglomerate 30-70 cm thick with phosphatic pebbles (Fig. 15) passing upward to fine-grained marly calcarenite in turn replaced by a yellow and well-stratified medium-grained calcarenite rich in foraminifers, ostracods, echinoderms, mollusks, bryozoans, and red algae.

Foraminifers and ostracods together with other fossils suggest for the lower portion of this formation

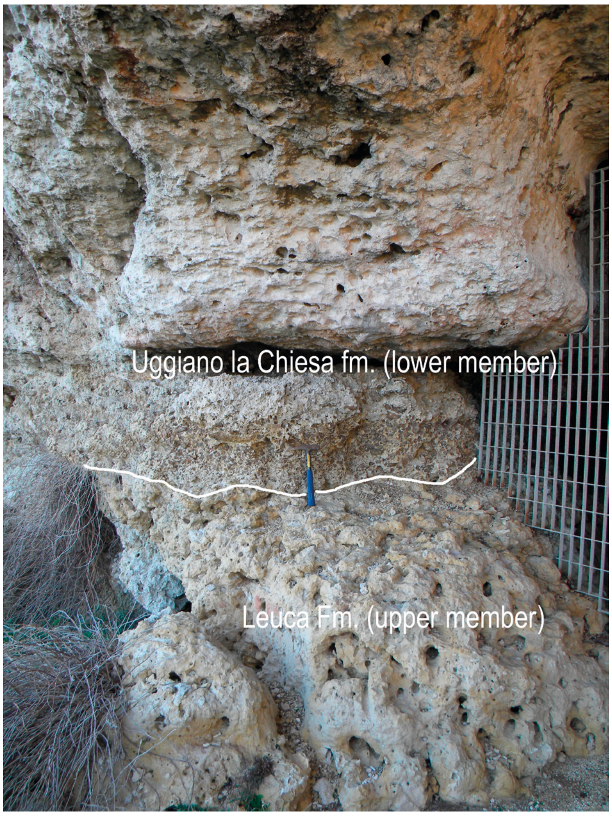

Fig. 15 - Outcrop showing the vertical passage between the Leuca Fm. and the overlying Uggiano la Chiesa fm. through an erosional unconformity surface (white line) marked by the presence of a discontinuous conglomerate bed with phosphatic pebbles.

an inner shelf/outer shelf environment characterized by low to moderate water energy, only episodically affected by storm-induced winnowing that gave rise to shell concentrations (D'Alessandro et al., 2004; Massari et al., 2009) (Fig. 16). An inner shelf environment is also suggested for the upper portion of this formation characterized by a progressive decrease in both the quantity and the number of species. The fossil assemblages indicate a shallow-water environment where a stirring of the sea floor due to highly turbulent flows gave rise to the mixing of fauna and the formation of graded beds (D'Alessandro et al., 2004; Massari et al., 2009). All this suggests an initial deepening of the depositional environment passing upward to a shallower environment indicating a regressive depositional setting (Fig. 16).

The planktonic foraminiferal assemblage suggests an upper Piacenzian-Gelasian age for the Uggiano la Chiesa formation (Bossio et al., 2005), although the same authors (Bossio et al., 2006a) extend the base of this formation in other areas of Salento to the Zanclean considering that planktonic foraminiferal and calcareous plankton content is ascribable to the *Globorotalia puncticulata* and *Discoaster tamalis* zones.

2.2.13. Gravina Calcarenite

This formation, established by Azzaroli et al. (1968), has an age variable from the Gelasian to the Calabrian (Early Pleistocene) in the Murge area (Ciaranfi et al., 1988; Richetti et al., 1988), while its corresponding deposits in the Salento area, originally known as "Salento Calcarenite", have been attributed to the Calabrian (probably Sicilian substage) by Bossio et al. (2006a) on the basis of the rich fossil assemblages (macrofossils are represented by bivalves as *Arctica islandica*, *Mya truncata*, and *Panopea norvegica*, and micro- and nannofossil are referred to the *Globorotalia truncatulinoides excelsa* and "small" *Gephyrocapsa* zones). The different age of this formation indicates its time-transgressive character moving from the Murge (NW) to Salento (SE), thus covering a large area of the Apulia region, from the outer margin of the Bradanic trough to the internal (inland depressions) and coastal sectors of the Salento Peninsula (Tropeano and Sabato, 2000; Pomar and Tropeano, 2001; D'Alessandro et al., 2004; Massari et al., 2001; Bossio et al., 2006a; Tropeano et al., 2004, 2022). This formation shows thicknesses variable from 10 to 40-50 m in outcrop and reaches 70-80 m in the subsurface (Giudici et al., 2012). In the Salento area it lies unconformably on an articulated substrate constituted by

Fig. 16 - Torre Sant'Andrea's rocky coast showing the vertical transitional passage between the lower portion (outer shelf) and the upper portion (inner shelf) of the Uggiano la Chiesa fm.

the variously faulted older units and consists of medium-to coarse grained fossiliferous bioclastic shelfal packstone/grainstone made up of heterozoan organisms (Fig. 17).

2.2.14. Argille Subappennine

This formation lies transgressively on but in the continuity of sedimentation with the Gravina Calcarenite from which is often separated by a thick and fossiliferous marly calcarenite bed rich in brachiopods (*Terebratula scillae*) (Ricchetti and Ciaranfi, 2013). This unit has a widespread distribution along the western sector of the Murge area where it crops out extensively from the present-day sea level to an elevation of about 500 m. In the Salento area this formation crops out with a reduced thickness (a few meters) in very small areas; whereas in the subsurface the thickness increases to about 230 m towards the western sector, in the direction of the Bradanic Trough, within the depressions placed between the structural highs of the Cretaceous substrate (Margiotta and Negri, 2004; Giudici et al., 2012; Ricchetti and Ciaranfi, 2013).

In the Murge sector, this formation consists of gray-light blue clays and marl-clays, deposited in a relatively deep-water environment (from bathyal to shallow sublittoral zone). In the Salento area, it is represented by blue-gray marly-silty clay with a macrofossil assemblage consisting of by bivalves, brachiopods, corals, algal nodules, and arborescent bryozoans (D'Alessandro and Massari, 1997) and with a microfossils-rich fauna represented by benthic and planktonic foraminifers. Due to the morphological variability of the depositional areas related to structural setting of the Salento Peninsula, this formation shows different types of deposits, with marginal facies showing clinoform and a rich assemblage of macrofossils (bivalves, brachiopods, corals, and bryozoans), passing to basinal facies towards the more distal and deeper sectors where macrofossils are represented only by bivalves and gastropods (D'Alessandro and Massari, 1997). Both fossiliferous assemblages and sedimentological data suggest a circalittoral environment where the seafloor was affected by low sedimentation rates and episodically swept by storm-induced currents which probably locally accelerated their velocity due to the seaway confinement; such storm events winnowed the bottom redistributing the bioclastic detritus both over a wide area or concentrated it in single beds (D'Alessandro and Massari, 1997).

The age of this unit, based on the microfaunal assemblage, has been referred to as a generic Calabrian (Ciaranfi and Ricchetti, 2013), although considering the age of the underlying Gravina Calcarenites attributed to the Sicilian substage (Bossio et al., 2006a), it should be referred to the end of the Calabrian and to the beginning of the Middle Pleistocene.

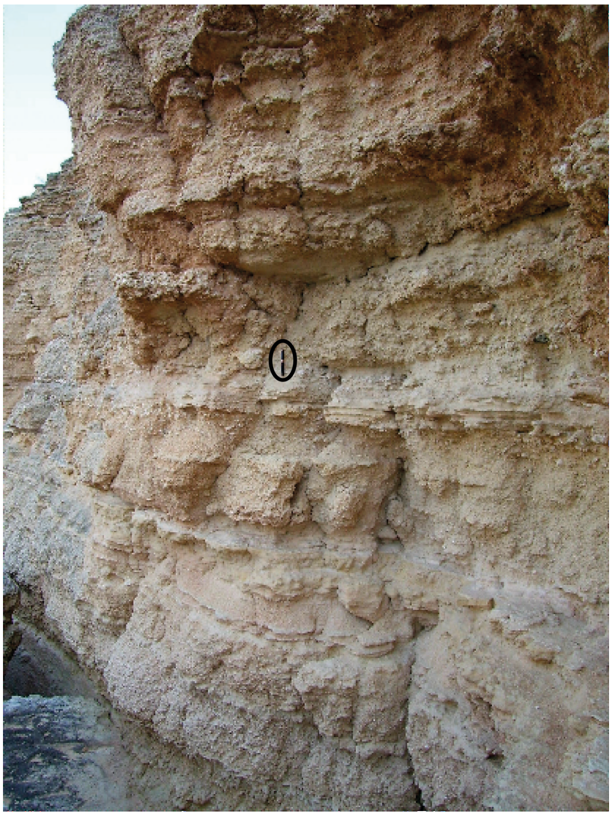

Fig. 17 - Outcrop of Gravina Calcarenite in the Porto Miggiano sector showing a medium-coarse grained fossiliferous bioclastic calcarenites, locally bioturbated, attributable to a lower shoreface/offshore-transition zone. Inside the ellipse a pen for scale.

2.2.15. Pleistocene marine terraced deposits

These deposits consisting of different lithostratigraphic units ranging in thickness from a few to ten meters are separated by unconformity surfaces constituting marine abrasion surfaces on which these deposits lie transgressively and with an onlap geometry. These units crop out at different highs and with different extensions or in reduced limbs both on the Murge and in the Salento area where they essentially consist of coastal coarse-grained bioclastic carbonate sediments ranging from backshore to shoreface and open shelf environments. Recently these units have been grouped into a single supersynthem named "Supersintema salentino" by Ciaranfi and Ricchetti (2013). The genesis of these marine terraces has been attributed by various authors (Ciaranfi et al., 1988; Richetti et al., 1988; Ciaranfi and Ricchetti, 2013) to the strong interaction between glacio-eustatic sea level changes and the coeval regional uplift affecting the Apulia foreland during the Middle-Late Pleistocene (Ricchetti et al., 1988; Doglioni et al., 1994, 1996). Ciaranfi et al. (1988) singled out sixteen terraced deposits placed at decreasing quotes from the inland to the coastal areas and highlighted how the distribution of these deposits was strongly controlled by preexisting substrate morphology. On this basis they indirectly constrained the formation of these marine terraces to an interval of time comprised between the late Sicilian and the present (the last 750 kyr).

More recently a detailed study has been conducted on the marine terraces of the Salento Ionian coast

(De Santis et al., 2021 and references therein). These authors applying the synchronous correlation technique and amino acid racemization have refined with more detail the Middle-Late Pleistocene terrace phases and the uplift history of this sector of the Apulia region, proposing two possible hypotheses that could explain the geomorphological evolution of the area. The first hypothesis indicates an uplift rate of 0.15 mm/yr between 590 and 130 kyr BP (Middle Pleistocene, between MIS 15 and 6), and an uplift rate of 0.7 mm/yr from 130 kyr BP to the present (Late Pleistocene/Holocene, between MIS 6 to 1). The second hypothesis considers a constant uplift rate of about 0,12 mm/yr for the entire period of the Middle-Late Pleistocene. The authors also individuate six positions of the paleoshorelines developed during the highstand phases that were dated to 119 kyr BP (MIS 5.5 second peak), 125 kyr BP (MIS 5.5 first peak), 240 kyr BP (MIS 7.5), 340 kyr BP (MIS 9.3), 478 kyr BP (MIS 13.1), and 560 kyr BP (MIS 15.3) and 550 kyr BP (MIS 15.1) for the first and the second hypothesis respectively. De Santis et al. (2021) highlighted that the number of preserved paleoshorelines is controlled by the uplift rates and the preservation capacity of these deposits considering the probable cannibalization and re-occupation of the areas from the younger sea level highstands over the older sea-level highstands.

3. DATA AND METHODS

The stratigraphic architecture and paleogeography of the Salento Peninsula during the Cenozoic was reconstructed through field observations and utilizing a database of 350 wells (depth variable from 30 to 220 m) from public administrations and private companies, which are well-distributed on the peninsula covering an area of about 2500 km^2. All the wells have provided a description of the stratigraphy and lithological and textural information. Among these, the deepest and more representative wells of the subsurface sedimentary succession (140 wells), covering the entire study area, were chosen for the construction of thirteen correlation panels (nine WSW-ENE and four NNW-SSE oriented) to depict the present stratigraphic-structural of the investigated area (Fig. 18). Each well was geolocated using the Qgis software; later, following manual correlation and interpretation we built the correlation panels using the Lithotec 5000 software. For this last scope we also utilized all the well stratigraphic descriptions closest to those used for the construction of the correlation panels.

In order to assess the Cenozoic stratigraphic evolution of Salento peninsula we applied the flattening procedure to the correlation panels by using as datum plane the top of the all formations from the Oligocene to the Pleistocene: 1) Galatone Formation and the heteropic Castro limestone and Porto Badisco calcarenite (upper Oligocene), 2) Lecce formation (upper Oligocene-lower Miocene), 3) Pietra leccese (lower-upper Miocene), 4) Andrano Calcarenite (upper Miocene), 5) Leuca Formation (upper Miocene-Lower Pliocene), 6) Uggiano la Chiesa formation (Lower Pliocene-Lower Pleistocene), 7) Gravina Calcarenite (lower Pleistocene), 8) Argille Subappennine (Lower-Middle Pleistocene). This procedure was not applied to the Eocene deposits due to their reduced thickness and to their small areal distribution. This flattening procedure allowed us to remove the effects of the tectonic deformation subsequent to the datum plane and to highlight the previous one. In this way, it was possible to construct 117 correlation panels showing the possible original stratigraphic relationships among the different stratigraphic units over time. Finally, these panels were utilized to reconstruct eight paleogeographic schemes of the Salento Peninsula, from the Oligocene until the Pleistocene, by using 3D modeling software (Move 2017). Each scheme is linked to each stratigraphic unit and shows the areal extension of the emerged and submerged sectors during its deposition.

The correlation panels, together with the paleogeographic schemes and the general stacking pattern of the entire Cenozoic sedimentary succession, allowed us also to produce a sequence-stratigraphic scheme of the Salento Peninsula where we recognized composite and simple high- and low-rank depositional sequences.

4. RESULTS

As has been previously evidenced 140 wells were utilized for the construction of 117 correlation panels 29 of which were utilized in this study in order to show the stratigraphic-structural relationships among the lithostratigraphic units forming the framework of the Salento Peninsula starting from the end of the Cretaceous to the present. These units which are separated by erosional surfaces are only partially superposed on each other, as they occur with a reduced number and thickness in the internal sectors of the Peninsula and with a greater number and thickness along the margin. In general, the stratigraphic record is more complete, but still discontinuous, on the eastern side of the Peninsula (Adriatic) with respect to the western side (Ionic). This stratigraphic architecture conditioned the construction of the correlation panels and the paleogeographic schemes showing the articulated morphology of the Cretaceous substrate limestones (Altamura limestone) (Fig. 24), at the time of deposition of each stratigraphic unit, starting from the late Oligocene to the present. Paleocene deposits are neither present in the subsurface, nor in outcrop, whereas the Eocene ones are found in outcrop and for a reduced thickness only along the coastal eastern margin of the peninsula. In figures 18 and 19 a,b,c are reported the tracks of the correlation panels (those with Arab numerals are ENE-WSW oriented and those with Roman numerals are NNW-SSE oriented) and the current stratigraphic-structural setting, whereas, in figures 20, 21, 22, and 23 are reported the paleogeographic schemes and the correlation panels referred to the different lithostratigraphic units. These show, respectively, the

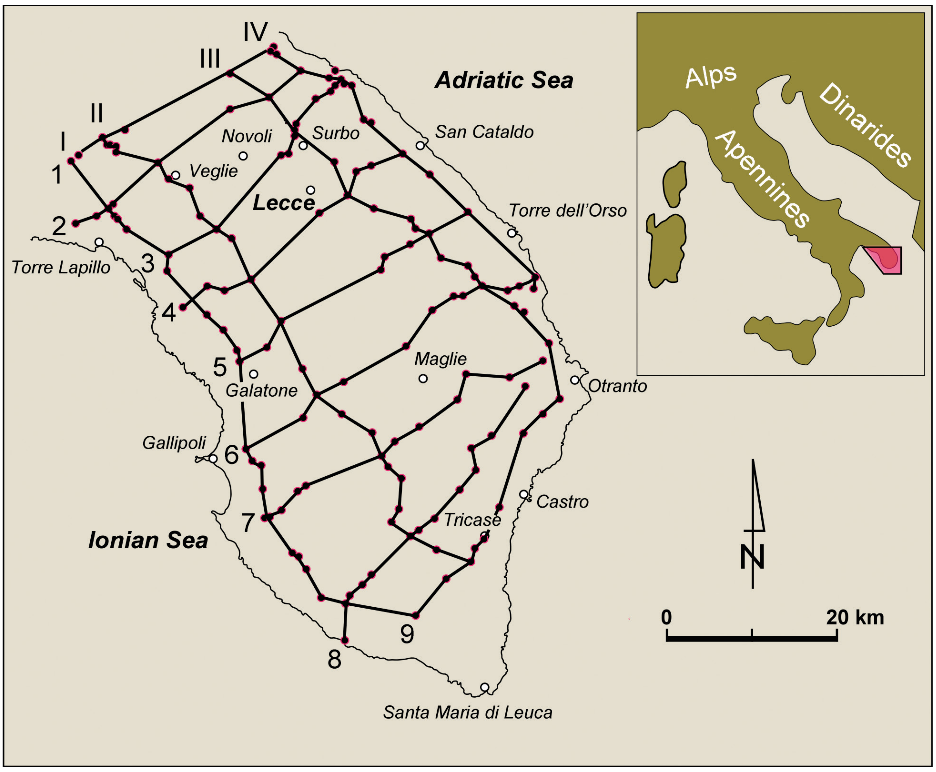

Fig. 18 - Location of the wells (black-red points) and tracks of the correlation panels of figures 19 a,b,c.

emerged and submerged areas and the stratigraphic-structural setting of each considered formation at the time of its deposition. We also enclose the maps of the Cretaceous substrate at the time of deposition of each stratigraphic unit (Fig. 24).

4.1. THE PRESENT STRATIGRAPHIC-STRUCTURAL SETTING

Panel 1 (Fig. 19a) shows the Cretaceous substrate affected by normal faults that produced a little deep and tabular depression in the central portion, which contains reduced thicknesses of the Pleistocene Gravina Calcarenites, Argille Subappennine, and marine terraced deposits. A relatively similar situation is also found in panel 2 (Fig. 19a), although in the western and eastern sectors two structural depressions are present. The latter are well-developed in panel 3 (Fig. 19a) and filled with the Miocene Pietra leccese and Andrano Calcarenite. The faults movement is sealed by the subsequent deposition of the Pleistocene units.

Panel 4 (Fig. 19a) shows a more articulated stratigraphic setting with a western sector where the Cretaceous substrate crops out with a thin cover of Oligocene and Miocene deposits and the central and eastern sectors characterized by the presence of a faulted and deep structural depression filled with the Oligocene and Miocene units. The pinch-out geometries showing the deposits indicate that the sedimentation was coeval to normal faulting whose activity continued up to the Pliocene along the Adriatic coast and up to the Pleistocene in the central sector of Salento Peninsula.

Panel 5 (Fig. 19a) further differs from the previous one and shows an elevated fault block in the central portion of the panel where the Cretaceous substrate is covered only by the Gravina Calcarenite, and with two deep structural depressions on the eastern and western sides filled with units ranging in age from the early Chattian to the Pleistocene.

Panel 6 (Fig. 19b) shows, on the eastern side, the continuation of the structural depression found in panel 5. This structure, active since the early Chattian, continued to deepen until the early Pleistocene. In the central and western sectors, the Cretaceous substrate generally appears very superficial. Above the deposits of the Pietra leccese and sporadically, the Gravina Calcarenites and the Argille Subappennine are present with very reduced thickness. This raised area of the Cretaceous substrate represents the northernmost portion of the Serre Salentine.

Panel 7 (Fig. 19b) shows a very articulated structure with the Cretaceous substrate affected by several normal faults with various meters of displacement. The western and eastern depressed sectors are always recognizable and filled with Miocene to Middle Pleistocene deposits. The Cretaceous substrate crops out in the central sector forming a well-pronounced horst (Serre Salentine) on the sides of which the Middle-Upper Pleistocene deposits onlap.

Panel 8 (Fig. 19b) like panel 7 shows a strongly articulated geometry with several normal faults forming a classic horst and graben structure. The grabens are several

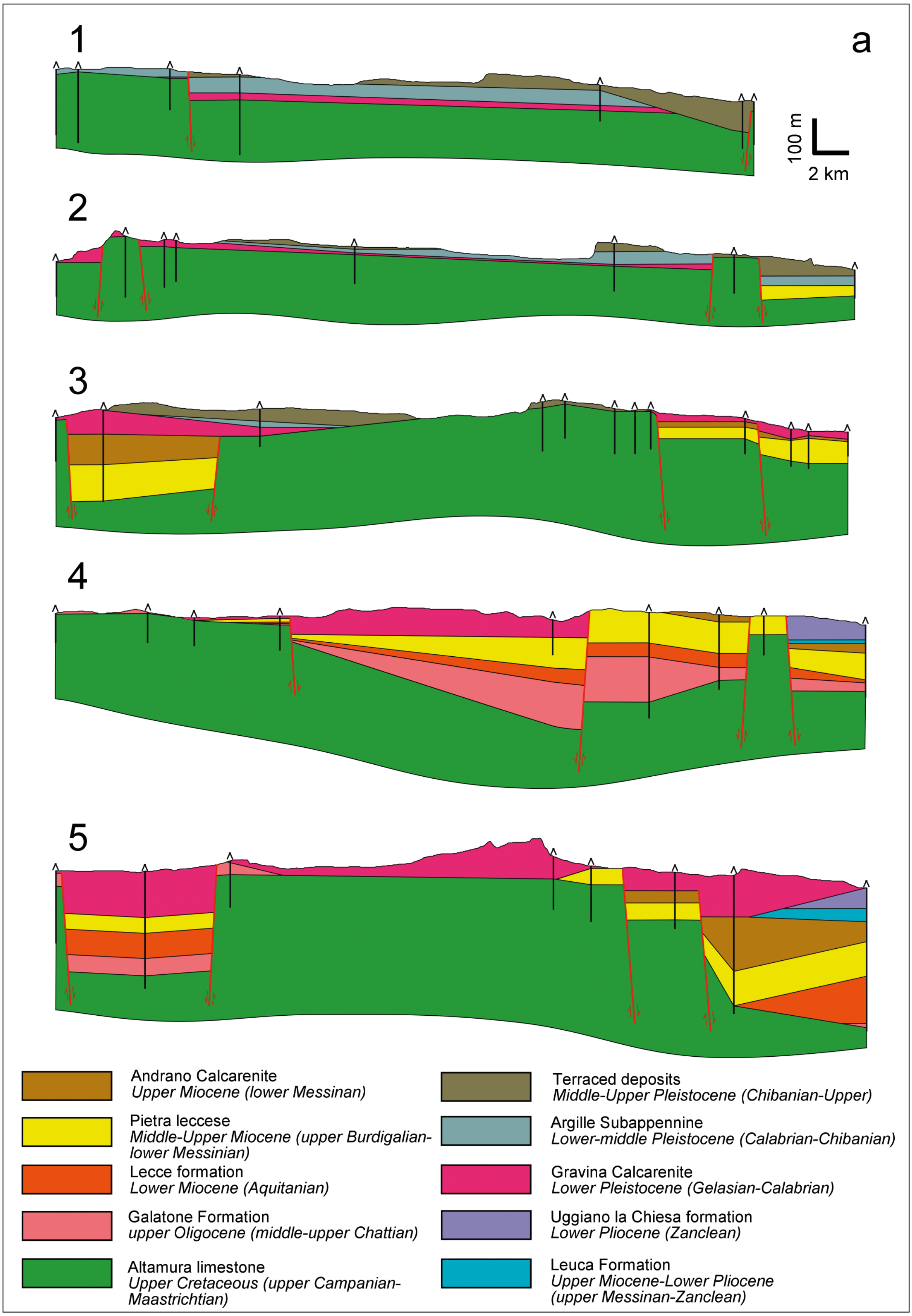

Fig. 19 - a, b) Correlation panels ENE-WSW and c) NNW-SSE oriented showing the present stratigraphic and structural setting of the lithostratigraphic units forming the backbone of the Salento Peninsula.

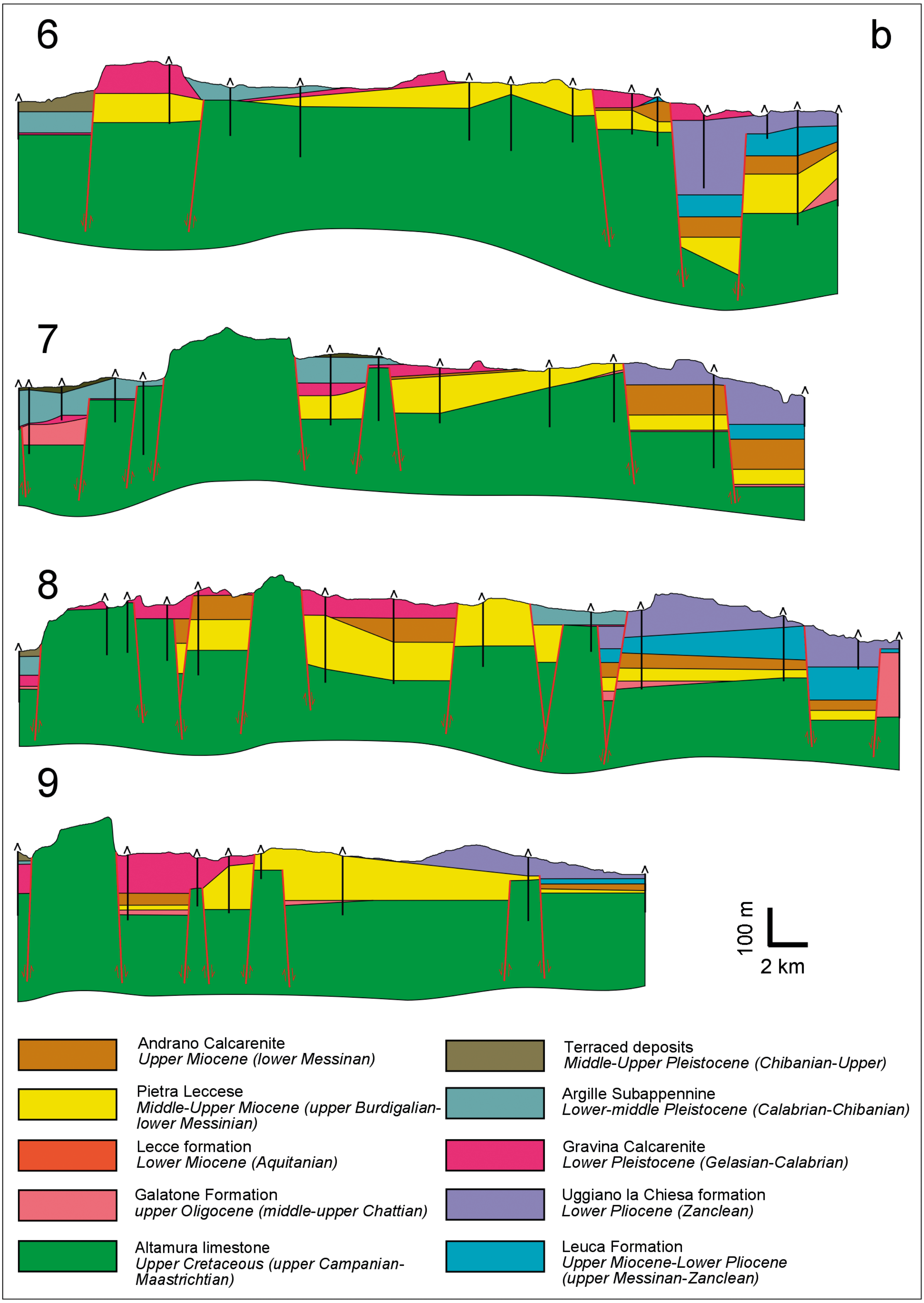

Fig. 19 - ...Continued

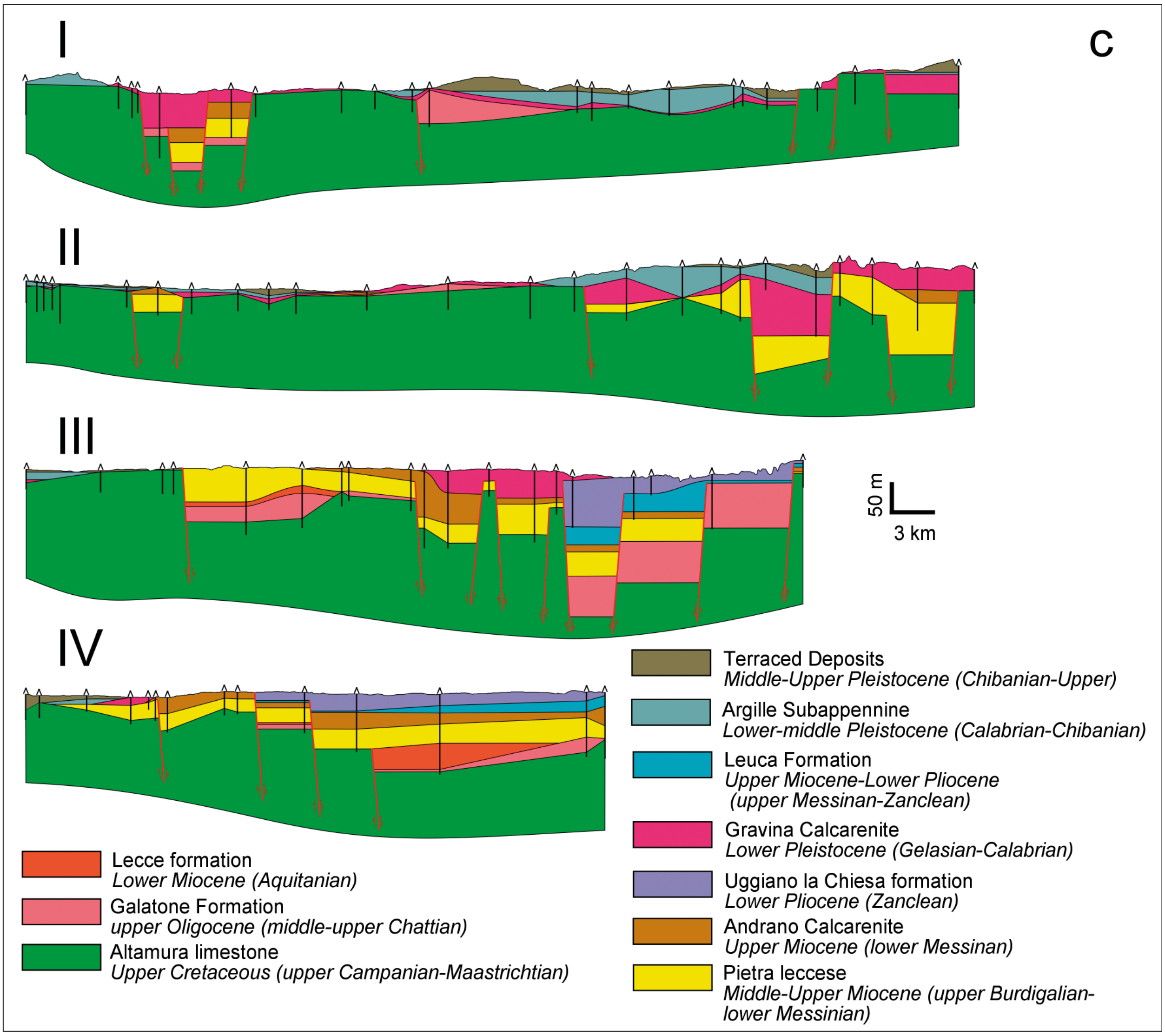

Fig. 19 - ...Continued

hundred meters deep and are mainly filled with variable-thickness deposits having age between the early Miocene and the Pleistocene. Single horsts of the Cretaceous substrate are representative of the Serre Salentine.

Panel 9 (Fig. 19b) although of smaller extension, shows the same geometric characteristics as panel 8. The more depressed central sector hosts the greater thicknesses of Pietra leccese and Gravina Calcarenite. The western sector is characterized by the presence of the Cretaceous horst attributed to Serre Salentine.

Panel I (Fig. 19c) extend along the Salento Ionian coast and shows a horst and graben structure of the Cretaceous substrate. A graben is more pronounced in the northern sector and hosts deposits from the Oligocene to the Early Pleistocene in age.

Panel II (Fig. 19c) has the northern sector where the Cretaceous substrate crops out that is covered by a very thin thickness of more recent deposits. Moving south the Cretaceous substrate deepens thanks to a series of normal faults with pronounced displacement and is covered by deposits ranging in age from the Middle Miocene to the Middle Pleistocene.

Panel III (Fig. 19c) shows a structural setting similar to panel II. Towards the south, the stratigraphic architecture is more complex and characterized by a horst and graben structure, with several high-angle normal faults having displacements of several tens of meters. Grabens are filled with deposits ranging in age from the Oligocene to the Early Pleistocene.

Panel IV (Fig. 19c) is located on the Adriatic coast and shows a structural setting characterized by a faults system with a similar orientation to those recognized in the previous panels whose displacement deepens the Cretaceous substrate moving from north to south. Consequently, the thickness and age of the units filling this structural depression increase from north to south, a fact that is consistent with the stratigraphic data indicating a progressive transgression of the deposits from the Oligocene to the Miocene.

4.2. THE PALEOGEOGRAPHIC SETTING OF THE DIFFERENT LITHOSTRATIGRAPHIC UNITS

The reconstructed paleogeographic schemes of the investigated area span a time interval from the Oligocene to the Pleistocene and are referred to: 1) Galatone Formation and the heteropic units of the Castro limestone and Porto Badisco calcarenite; 2) Lecce formation; 3) Pietra leccese; 4) Andrano Calcarenite; 5) Leuca Formation; 6) Uggiano la Chiesa formation; 7) Gravina Calcarenite and 8) Argille Subappennine (Figs. 20, 21, 22, and 23).

The oldest formation is the Cretaceous Altamura limestone which is tectonically tilted although at places it is horizontal or inclined seaward or landward. The Torre Tiggiano limestone (middle Eocene) shows a structural attitude like the Cretaceous substrate on which it lies through a strongly discordant erosional surface. This unit that consists of bioclastic sands probably formed a rather continuous belt along the entire eastern coast of Salento. It was deposited in a shallow-water high-energy wave-influenced environment, affected by reworking and transport by currents (Bosellini et al., 1999; Tomassetti et al., 2016). The second unit of the Eocene age is represented by the Priabonian Torre Specchia la Guardia limestone. This formation constitutes a clinostratified not tilted or tectonically deformed clastic wedge which lies on Cretaceous or middle Eocene platform deposits through an angular unconformity (Bosellini et al., 1999). These last authors interpret these sediments as forereef slope facies and do not recognize internal platform facies. It was impossible to produce a paleogeographic scheme for the Eocene deposits due to the scanty and discontinuous outcrops.

The paleogeographic scheme depicting the Galatone Formation (upper Oligocene) shows two well-differentiated emerged areas separated by a shallow water seaway forming a restricted lagoon/lacustrine environment, connecting the Adriatic and Ionian sectors of the Salento Peninsula (Fig. 20a). This unit sedimented in this seaway and prevalently along the eastern sector of the Peninsula (see also Esu et al., 2005; Bossio et al., 2009) where it laterally passes seaward to the units of the Castro limestone and Porto Badisco calcarenite (middle-upper Chattian in age) (Fig. 7). Similarly to the latter units the Galatone Formation lies unconformably on the Cretaceous substrate from which it is separated by a thick (up to 17 m) bed of residual red clay; moreover as revealed by the stratigraphy of deep wells, this unit can be subdivided into a lower and an upper portions (about 50 and 20 m thick respectively), being its lacustrine/lagoonal carbonate deposits separated by a 5 m thick residual clay bed (see Bossio et al., 2006a) that we maintain constituted the deposit formed during the emersion and subsequent erosion responsible for the formation of the unconformity surface separating the Castro limestone and the Porto Badisco calcarenite.

The Castro limestone is separated from the underlying Eocene and Cretaceous deposits by a major unconformity; this unit was interpreted as a fringing reef complex with depositional facies ranging from back reef to reef slope by Bosellini et al. (1999) and Bosellini (2006), and as deposited along distally steepened ramp by Pomar et al. (2014). Based on our paleogeographic scheme and considering the stratigraphic relationships with the Galatone Formation and with the Eocene-Cretaceous substrate, the model of the fringing reef complex of the Castro limestone recently documented by Bosellini et al. (2021) results more appropriate than to the Pomar et al. (2014) model. The presence of seagrass meadows as evidenced by these last authors and their landward passage to the lagoonal/lacustrine facies of the Galatone Formation is not in contrast with the environmental context suggested by Bosellini et al. (1999), Bosellini (2006), and Bosellini et al. (2021), considering that seagrasses (growth and productivity) coexist and interact with the coral reefs as they served as nurseries and shelter for reef fish and for other species of organisms (Björk et al., 2008; Carlson et al., 2021).

The Porto Badisco calcarenite is separated by the underlying Castro Limestone by an unconformity erosional surface whose physical expression has been also recognized in the Galatone Formation (see above) (Fig. 7). The depositional model of the Porto Badisco calcarenite proposed by Pomar et al. (2014) includes a homoclinal carbonate ramp where six lithofacies distributed from the inner to the outer ramp have been recognized, and where the authors did not observe any slope break. In particular, the inner ramp would have been characterized by wackestone/packstones with small benthic foraminifers suggesting the presence of a seagrass meadow; the middle ramp would be dominated by packstones with large rotaliids and small coral mounds interfingering basinwards with rhodolithic floatstones/rudstones and large lepidocyclinid packstones; the outer ramp would have been characterized by the presence of fine calcarenites rich in skeletal debris fragments originating from the inner and middle ramp. Pomar et al. (2014) (see also Tomassetti et al., 2018) explain the distribution of these lithofacies along their "homoclinal ramp" as a result of a hydrodynamic setting essentially due to the propagation of internal waves. According to these authors, this ramp system does not show the characteristics of a wave-dominated system that can explain events with high turbulence capable of eroding, redistributing, and depositing coarse-grained deposits (their four lithofacies, rhodolithic floatstone to rudstone) located in the middle ramp sector. Although these authors provide a sound explanation for this lithofacies, it is not excluded that this assemblage can be explained also with the revised ramp model proposed by Moscariello et al. (2018), where the passage from the middle to the outer ramp takes place through a ramp slope with a very low gradient. Here the rhodolithic floatstone to rudstone lithofacies would accumulate, forming lobate deposits filling erosional depressions, the deposition of which would take place because of storm currents that would transfer sediments from the inner ramp to the ramp slope/outer ramp through density flows in supercritical conditions. However, this is not the place to discuss this topic, which needs further investigation. Instead, we can observe that the passage from the Castro limestone to Porto Badisco calcarenite evolves from a carbonate system with a well-developed fringing reef complex typical of a flat-topped rimmed platform to a carbonate ramp system where the production of sediment and the increase in the diffusion of transported sediment play a fundamental role in controlling the geometry of the platform (see discussion in Williams et al., 2011). Regarding this latter aspect, the formation of ramp systems would be favored during phases of relative sea level rise which would tend to move the places of sediment production by distributing them along the depositional profile, thus favoring the development of carbonate ramps with a low gradient. The transgressive character that both the upper portion of the Galatone Formation (see Bossio et al., 2006 a,b) and the heteropic Porto Badisco calcarenite show vertically is consistent with this type of interpretation and with the transgressive trend that continues even with the deposition of the subsequent units represented by the Lecce formation and by the Pietra leccese respectively.

The paleogeographic scheme for the Lecce formation (Fig. 20b) is similar to that of Galatone Formation showing again a well-developed seaway connecting the Ionian with the Adriatic sectors. The Lecce formation consists of marine deposits and lies unconformably on the lacustrine/lagoonal deposits of the Galatone Formation. As observed in the correlation panel (Fig. 20b), the greatest thickness of this unit is on the eastern sector of the Salento Peninsula where it infills a series of structural depressions that continuously deepened during the sedimentation of this formation. The thickness of this unit tends to thin out westwards where it onlaps on the Cretaceous substrate and the Galatone Formation. This is coherent with the general transgressive trend characterizing the uppermost Chattian/lower Miocene deposits indicating progressive landward flooding of the Salento Peninsula moving from the eastern to western sectors.

The transgressive phase from east to west is particularly evident in the paleogeographic scheme and the correlation panels for the Pietra leccese (Fig. 21a). This formation was deposited during a long period of time (about 11 Ma, from the late Burdigalian to the early Messinian) showing a maximum thickness of about 100 m in the eastern sectors, whereas westward the thickness tends to reduce and this unit onlaps directly onto the Cretaceous substrate (Fig. 10). The reduced thickness of this formation with respect to the time span during which it was deposited can be explained by the presence of a series of disconformities marking significant physical and temporal gaps in sedimentation. The paleogeographic scheme and the correlation panels show how the Salento Peninsula was almost completely submerged at that time. Exceptions are visible in the northern sector of Lecce, where subaerial conditions persisted, and in the southwestern sector where the Cretaceous substrate directly crops out (Serre Salentine). To the south and southeast, the Pietra leccese is widely represented by a phosphoritic hardground, known in the literature as "*Aturia* Level" (Vescogni et al., 2018 and reference therein), that constitutes an important sequence-stratigraphic element of the investigated area.

The last upper Miocene formation to which the paleogeographic scheme of figure 21b refers is the Andrano Calcarenite; this unit, about 90 m thick, occurs in the subsurface and mainly crops out on the eastern side of the peninsula. It shows a regressive depositional trend and together with the underlying transgressive Pietra leccese formation constitutes a transgressive-regressive cycle closing the Miocene in the whole Salento Peninsula (see also Bossio et al., 2006a) at the top of which an important unconformity surface occurs that can be traced basin-wide in the Mediterranean area. The paleogeographic scheme (Fig. 21b) shows that the central portion of the Salento Peninsula was emerged from the north to south while the submerged areas of the platform were located along the western and eastern coasts. The edge of the eastern coast was characterized by the presence of a reef complex whose deposits, attributed to a new and informal lithostratigraphic unit named Novaglie formation (Bosellini et al., 1999; Bosellini, 2006), mantling discordantly the underlying Cretaceous to Oligocene formations. This reef complex is exposed for about 17 km between Tricase Porto and Capo S. Maria di Leuca and was hosted within the paleo-embayment of the rocky coast having a complete coral reef tract and the associated clinostratified fore-reef slope developed only locally (Bosellini, 2006). The stratigraphic relationships between the Andrano Calcarenites and the Novaglie formation have never been perfectly defined, although in the stratigraphic schemes of Bosellini et al. (1999) and Bosellini (2006) these units are considered heteropic. Although both these formations are early Messinian in age, our fieldwork and other stratigraphic evidences suggest a different stratigraphic relationship between these two units which will be discussed in the paragraph regarding the sequence stratigraphic framework of the entire sedimentary succession.

The paleogeographic scheme and the correlation panels for the Leuca Formation (Fig. 22a) (upper Messinian-Lower Pliocene) show the central sector of the Peninsula in subaerial condition and the Ionian and Adriatic sectors submerged. This unit lies unconformably on the Andrano Calcarenites and occurs both in outcrop and in the subsurface along the Adriatic sector thus suggesting subsidence of this margin under the effect of the westward migration of the Dinarides-Albanides-Hellenides. This unit, as described previously, is characterized by a lower breccia/conglomerate member with carbonate clasts derived essentially from the underlying Andrano Calcarenite and an upper marly unit passing upward to a glauconitic mudstone (Bossio et al., 2006a).

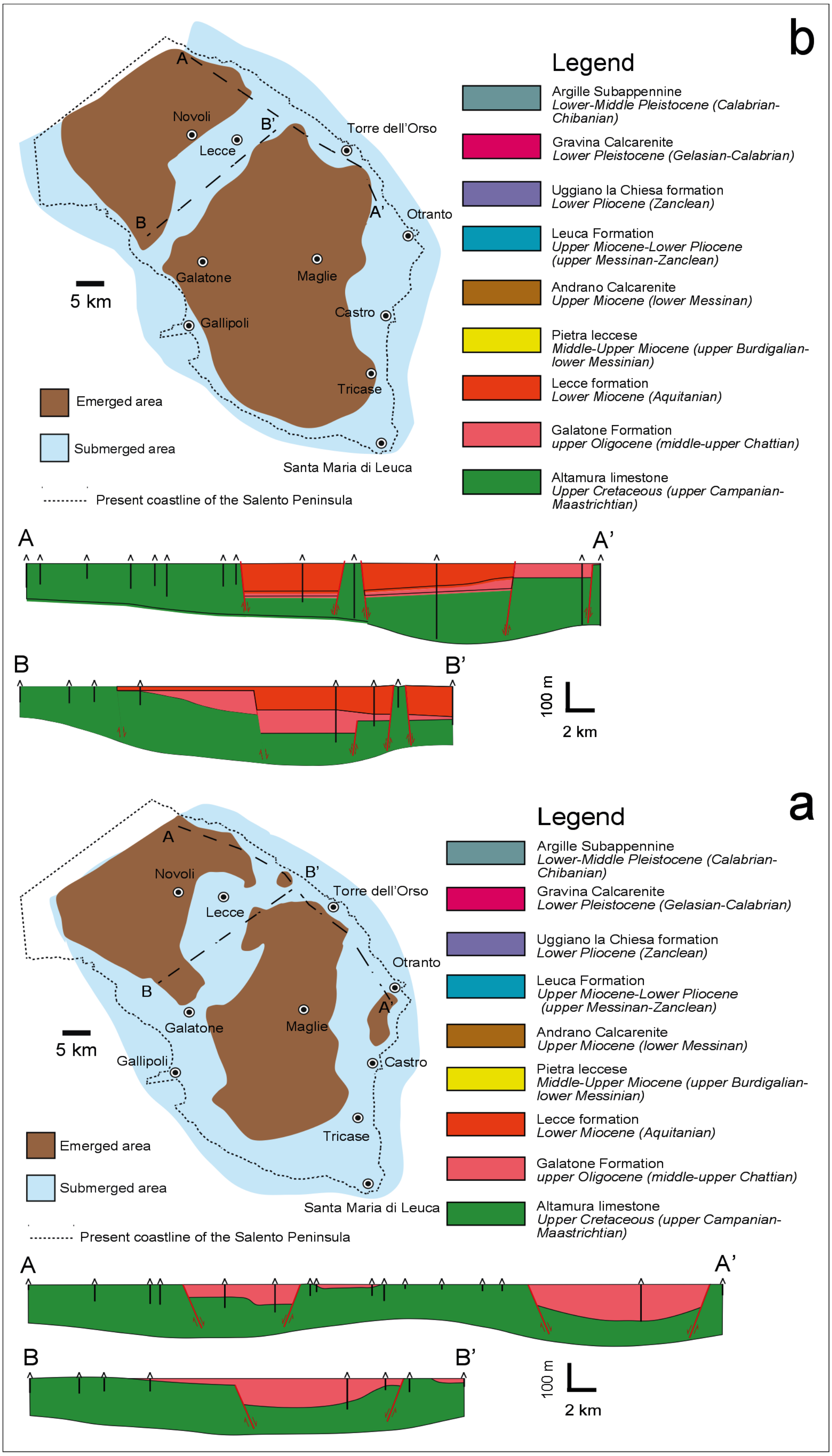

Fig. 20 - Paleogeographic setting and correlation panels at the deposition time of Galatone Fm. (a) and Lecce fm. (b) respectively.

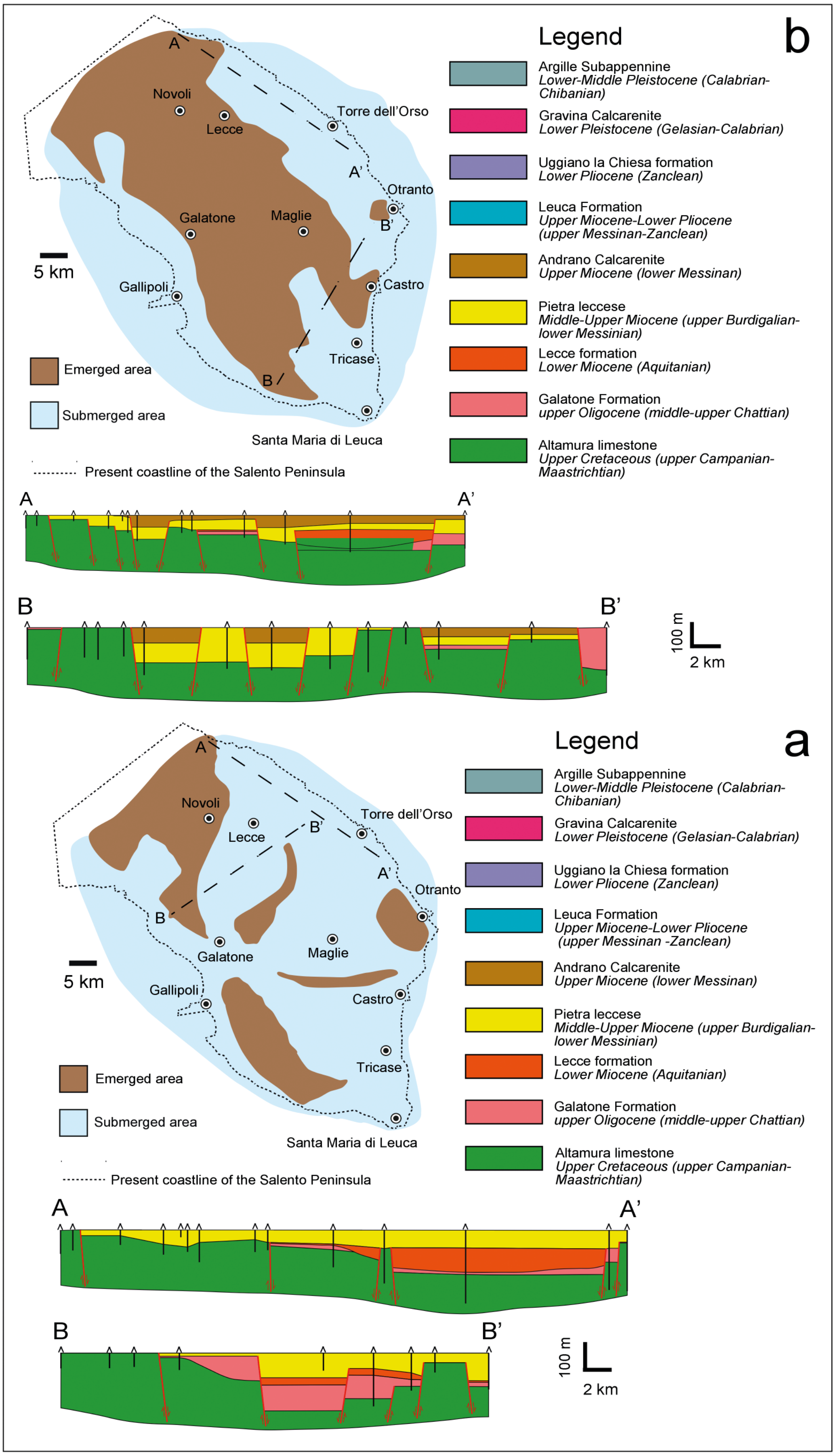

Fig. 21 - Paleogeographic setting and correlation panels at the deposition time of Pietra leccese (a) and Andrano Calcarenite (b) respectively.

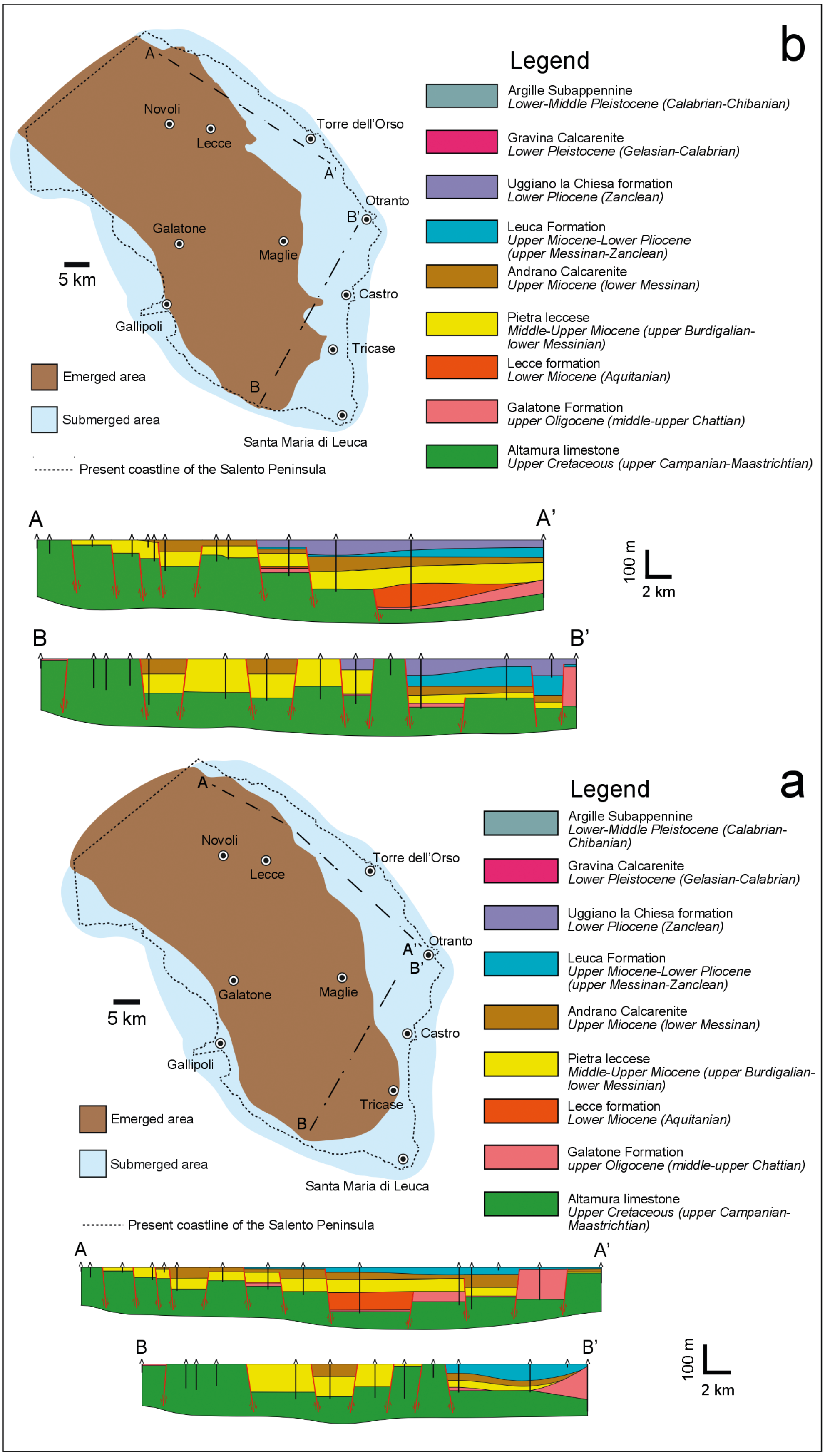

Fig. 22 - Paleogeographic setting and correlation panels at the deposition time of Leuca fm. (a) and Uggiano la Chiesa fm. (b) respectively.

The association of two very different members constituting the Leuca Formation raises some questions. A possible explanation has been proposed by Ricchetti and Ciaranfi (2013) who attribute the breccia/conglomerates member as belonging to the Andrano Calcarenite. Based on our field observations and stratigraphic correlations, taking into account the age of microfauna occurring in the Leuca Formation (Bossio et al., 2006a), and considering the suggestions reported in Bosellini et al. (1999), we retain, in agreement with these last authors, that the vacuolar limestone occurring at the base of the Leuca unit as well as the breccia/conglomerates member may represent the terminal portion of the Messinian and the lower boundary of the formation should be attributed to the Messinian Erosional Surface (MES) (Lofi et al., 2005). This surface marks the acme of the Messinian Salinity Crisis (Stage 2 of MES; CIESM et al., 2008; Roveri et al., 2014 a,b) that was triggered by a combination of a Mediterranean tectonic phase related to the movements between the African and Eurasian plates, associated to climatic change (glacial period related to the TG14 and TG12 oxygen isotope stages). The combined action of these processes would have produced a relative sea-level fall, the magnitude of which is still under discussion (Roveri et al., 2016 and Manzi et al., 2018 indicate a fall of 100-200 m; up to 800 m are suggested by Druckman et al., 1995; 800-900 m by Amadori et al., 2018, while Lofi et al., 2005 and Bache et al., 2009 indicate a fall of more than 1500 m) and the formation of large-scale mass wasting processes along the Mediterranean margins, leading to the accumulation of resedimented evaporites, carbonate and clastic deposits (Lofi et al., 2005; Roveri et al., 2008 a,b; Bertoni and Cartwright, 2007; Gorini et al., 2015; Roveri et al., 2018). In this light, the breccia/conglomerate member of the Leuca Formation may represent a slope-to-base-of-slope deposit formed during a lowstand phase representative of Stage 2 and partially of Stage 3 of the MSC, while the upper member of this formation would record the post-Messinian flooding of Pliocene age. This interpretation will be resumed later and contextualized in the sequence-stratigraphic scheme that we propose for the Paleogene to Quaternary sedimentary succession of the Salento Peninsula.

The figure 22b shows the paleogeographic reconstruction and the correlation panels of the Salento Peninsula during the sedimentation of the Uggiano La Chiesa formation (Lower Pliocene-Lower Pleistocene). These sketches show a paleogeographic setting similar to the previous one but with a more articulated coast. This unit onlapping the Leuca Formation and locally older units crops out only along the eastern coast of the peninsula (see A-A' and B-B' panels, Fig. 22b); it is characterized by outer/inner shelf deposits at the base evolving upward to a shallower environment indicating a regressive depositional trend. In this context, the Uggiano la Chiesa formation constitutes the last unit recording a major influence of the Dinarides-Albanides-Hellenides on the eastern coastal sedimentation of the Salento Peninsula.

The paleogeographic reconstruction for the Gravina Calcarenite (Lower Pleistocene) (Fig. 23a) shows a clear depositional change of the Salento Peninsula compared to the previous one. The emerged areas were essentially localized along the eastern coast whereas the central and the western sectors were completely submerged. This setting shows a change in the geological evolution of Salento Peninsula that reflects the major influence of the eastward migration of the Apennine chain on the Apulian Platform foreland. Indeed the Gravina Calcarenite represents the opening of the Pleistocene sedimentary cycle on the western margin of the Apulian foreland and marks the progressive transgressive phase on an articulated substrate from the western sectors towards the eastern ones of the Salento Peninsula.

Both the paleogeographic sketch and the A-A', B-B' panels show a very articulated paleo-coast with the presence of well-developed bays. Based on the literature data (see Massari et al., 2001; D'Alessandro et al., 2004; Tropeano et al., 2004, 2022 and references therein) and considering the reconstructed paleogeography here presented, we suggest two different depositional setting for the Gravina Calcarenite in the Salento area (see also Bosellini et al., 1999): 1) a well-developed shelf environment on the western side of the peninsula (essentially an inner shelf with depositional profile dipping southwestward of about 12°), where the seafloor was swept by bottom currents and episodic storm-driven flows. The vertical record of these deposits evidences a transgressive to regressive trend evolving from nearshore to inner/mid shelf and back to inner shelf. The progradational trend characterizing the upper portion of this unit is locally substituted by an aggradational stratal pattern that grades in the uppermost part in a low-angle progradational trend on top of which is present an unconformity surface that has been interpreted as a karstified subaerial surface (D'Alessandro et al., 2004); 2) a faulted rocky coast on the eastern margin of the peninsula forming escarpments made up of older carbonate units (from the Cretaceous to the Miocene) on which slope and base-of-slope deposits formed (Tropeano et al., 2004, 2022; Mateu-Vicens et al., 2008). The latter developing within the morphostructural indentations of the cliffed coast consist of 25°/30°seaward dipping clinobeds forming isolated fan-shaped bodies. These bodies about 1 km wide and 40-50 m thick, were fed by a shallower carbonate factory characterized by a fossil assemblage dominated by coralline algae and subordinately by encrusting bryozoans, echinoids, and benthic foraminifers, which suggest the presence of seagrass meadows and a deposition in a euphotic/mesophotic zone. Moreover, the high inclination and the internal architecture of the clinobeds suggest a more or less continuous formation of gravity flows as well as of slumps and other soft-sediment deformations that were probably triggered by coeval syn-sedimentary tectonics (Tropeano et al., 2004, 2022; Mateu-Vicens et al., 2008).

The last paleogeographic reconstruction (Fig. 23b)

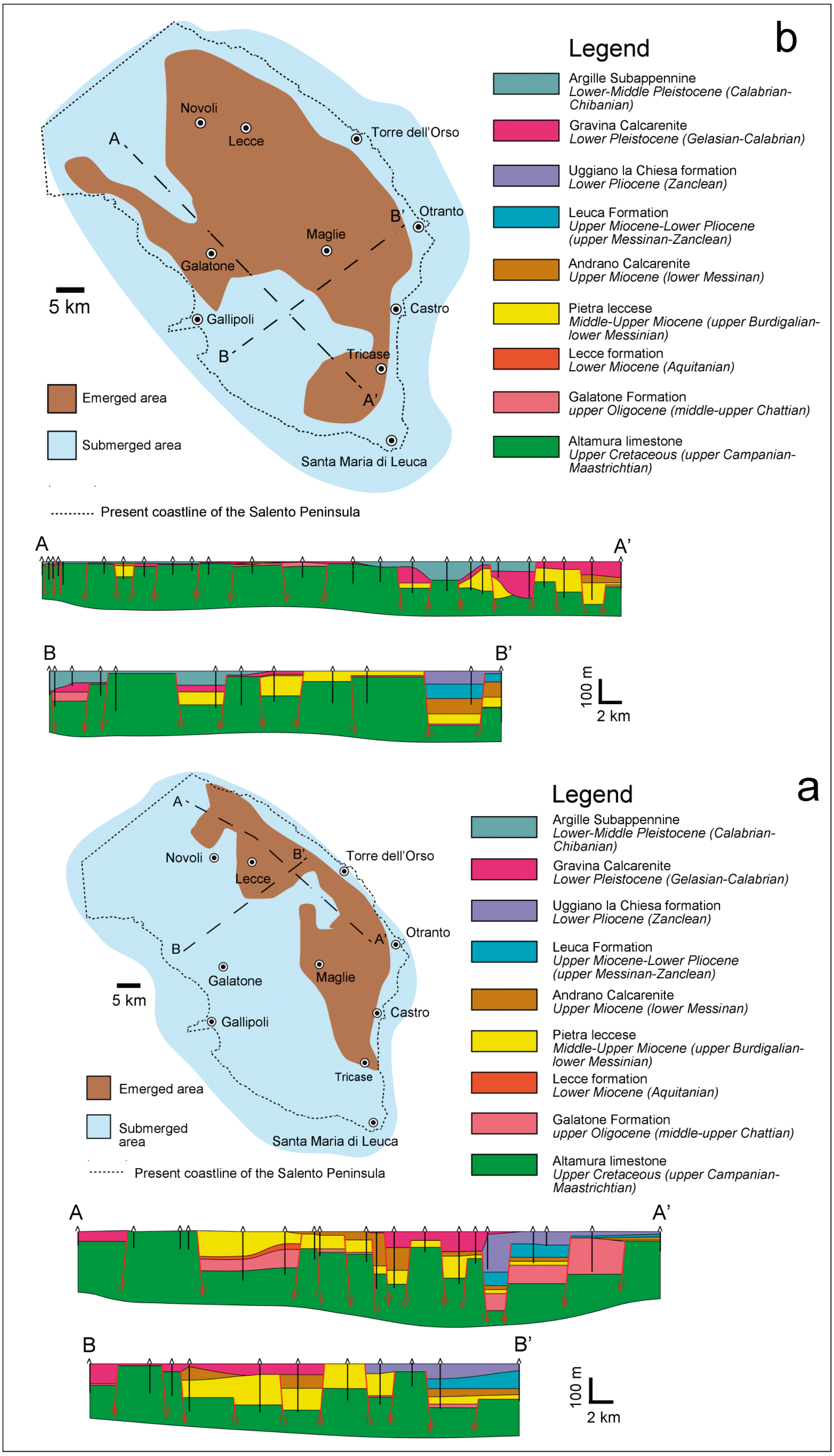

Fig. 23 - Paleogeographic setting and correlation panels at deposition time of Gravina Calcarenite (a) and Argille subappennine (b) respectively.

refers to the Salento Peninsula during the deposition of the Argille Subappennine (latest Calabrian-early Chibanian). This unit lies on the Gravina Calcarenite in continuity of sedimentation and reaches its maximum thickness in the Bradanic foredeep, whereas it is reduced to a few meters on the eastern sector of the Salento Peninsula. Two large gulfs opened to north and south along the Ionian sector, where this unit fills the articulated morphology of the substrate inflecting westwards due to the load induced by the eastward migration of the Apennine chain (see correlation panels A-A' and B-B').

5. DISCUSSION

The peculiarity of the Apulian foreland and the Salento Peninsula, in particular, is that it constitutes the foreland of two chains that migrate in opposite directions: the Dinarides-Albanides-Hellenides towards W-SW and the Apennines towards E-NE respectively. However, the role played by these two belts in terms of control over sedimentation in the Salento area did not occur in the same way and at the same time. This is recorded in the different stacking pattern of the deposits, in their reduced thickness, in their areal distribution, in their different degree of preservation, in their sedimentary trends reflecting relative sea level changes and carbonate productivity, and finally in the presence in this sedimentary succession of several unconformity surfaces and stratigraphic discontinuities, spanning a time of several million years.

5.1. THE GEODYNAMIC CONTEXT

The previous field data and paleogeographic reconstructions show how the Cenozoic carbonate deposits of the Salento peninsula sedimented in shallow-water conditions, having a preserved overall thickness of about 200 m considering the subsurface and the outcrop deposits. Most outcrops occur on the eastern margin of the peninsula whereas they are missing or have small thicknesses on top of the platform and on the Ionian margin. What factors influenced the carbonate sedimentation and why is the thickness of these deposits so reduced considering that this succession spans the time interval of the last 65 Ma?

It is here suggested that the timing of migration and deformation of both belts occurring on the Adriatic and Ionian sectors of the Salento Peninsula (Dinarides-Albanides-Hellenides and Apennines respectively) assumed an important role, considering that such migration should be responsible for the downward flexing of the lithosphere and consequently of the formation 1) of forebulge uplift that caused erosion and stratigraphic condensation; 2) of the forebulge unconformity (Crampton and Allen, 1995), separating the pre- from the syn- and post-orogenic sedimentary succession; 3) of the onlap of the syn-orogenic wedge-shaped shallow-water carbonates onto the Upper Cretaceous pre-orogenic carbonate substrate.

Anyway, considering the thickness of the Adria Plate (about 100 km) (Doglioni et al., 1994) (see also figure 1c), the large radius of curvature, and the reduced thickness of the post-orogenic sedimentary succession, it can be inferred that starting from the Oligocene subsidence rates were relatively low along the Adriatic margin of the peninsula, whereas they increased during the Miocene. On the contrary, on the Ionic margin of the peninsula the flexural bending was more pronounced with a faster subsidence rate at least starting from the Early Pleistocene, due to the load of the Apennine chain and to the eastward roll-back of the Adria Plate (see also Cicala et al., 2021). Consistent with these inferences are also the indications of Dorobek (1995) about the distribution of the carbonate platform and reefal facies developing in the distal foreland area far from terrigenous influx. The author points out that the most important factor controlling carbonate platform morphology and sedimentation in foreland basins is the lithosphere flexure rate that influences three main and important elements: i) the ramp depositional gradient; ii) the subsidence rate, and iii) the water depth along the depositional profile. He also suggests that high flexural rigidity would favor the formation of large carbonate platforms with ramp profile; the latter were able to keep up with the subsidence rate for long periods of time without being subject to drowning but only to aggradation and retrogradation processes, and in some cases also progradation, as recorded on the Adriatic side of the Salento Peninsula during the deposition of this carbonate succession. On the contrary, plates with low flexural rigidity should give rise to narrower carbonate platforms which should be more prone to drowning.

Previous considerations suggest that the two margins of the Salento Peninsula behaved differently with respect to the migration and convergence rates of the two orogenic belts and the proximity of the foreland to the chains themselves. As pointed out by Galewski (1998), the convergence rate exerts an important control over the rate of tectonic subsidence being the latter directly proportional to the convergence rate. In particular, the effects of the load and deformation induced by the westward advance of the Dinarides-Albanides-Hellenides produced tectonic subsidence which, although it did not lead to the drowning of the platform, allowed a general phase of progradation/aggradation during the Eocene and the Oligocene and a transgressive/retrogradation phase starting from the beginning of the Miocene (Lecce formation) which peaked during the deposition of the Pietra leccese. During this whole phase, the effects of the eastward migration of the Apennine chain were practically irrelevant on the stratigraphy of Salento Peninsula, which shows greater sedimentary preservation only on the side facing the Dinarides-Albanides-Hellenides, while on the raised Ionic side the carbonate sedimentation and, subsequently, the siliciclastic sedimentation began only from the Pleistocene. From the beginning of the Middle Pleistocene, the Salento area was then subject to uplift (Doglioni et al., 1996; Spalluto et al., 2010) and the thin

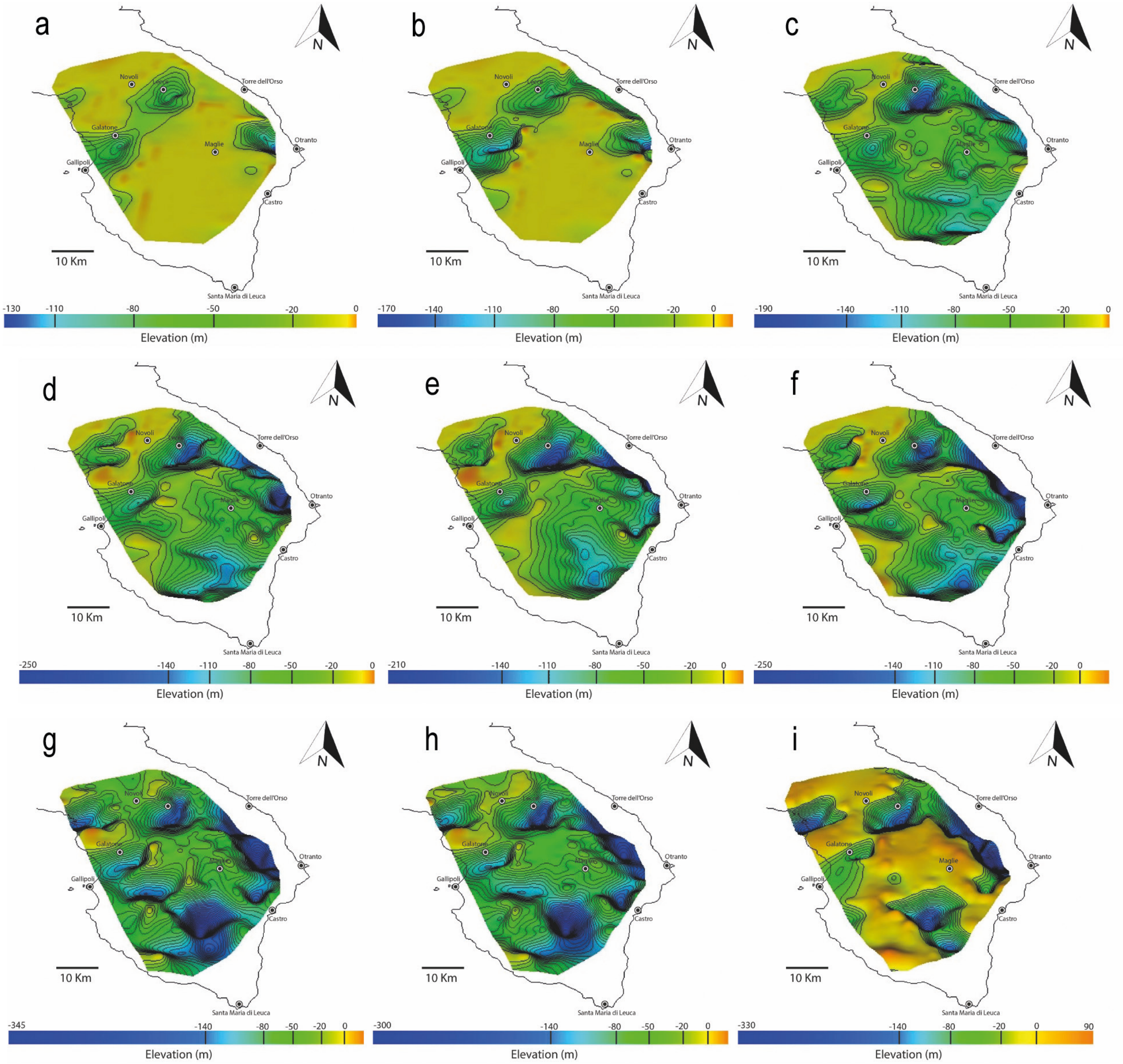

Fig. 24 - Maps of the Cretaceous substrate at the deposition time of each lithostratigraphic unit: a) Galatone Fm.; b) Lecce fm.; c) Pietra leccese; d) Andrano Calcarenite; e) Leuca Fm.; f) Uggiano la Chiesa fm.; g) Gravina Calcarenite; h) Argille Subappennine; i) Present.

shallow-waters carbonate deposits of Lower Pleistocene age were subaerially exposed and subjected to erosion.

Summing up, starting from the end of the Cretaceous the Salento area experienced uplift and erosion induced by the isostatic loading related to the flexural bending of the subducting lithosphere and the W-NW-ward and E-NE-ward migration of the Dinarides-Albanides-Hellenides and southern Apennines belts respectively (see also Sabbatino et al., 2021; Maesano et al., 2021; Cicala et al., 2021). This process produced a regional unconformity (forebulge unconformity), extensional fracturing, and faulting in the uppermost part of the lithosphere during the Paleocene-early Eocene and stasis of the shallow-water carbonate sedimentation. The latter was re-established starting from the late Eocene up to the Pleistocene, with the onset of flexural subsidence, that became more accentuated during the Miocene (see also Sabbatino et al., 2021 and references therein). The onset of the flexural subsidence is recorded by the onlap of the shallow-water carbonate time-transgressive deposits overlying the pre-orogenic substrate whose age is different along the Adriatic (older) and Ionian (younger) sectors of the Salento Peninsula. This carbonate sedimentation was marked by several hiatuses bounding the stratigraphic units forming the sedimentary succession cropping out in the Salento Peninsula. Consequently, most of these deposits are almost absent in the internal areas of Salento, whereas they are better preserved on the eastern margin with respect to the western margin of the peninsula. This suggests that the transgressive/retrogradation phase that started from the beginning of the Miocene proceeded from the south-eastern sector to the north-western one (see paleogeographic schemes) under the influence of the tectonic subsidence induced by the migration of the advancing Dinarides-Albanides-Hellenides thrust belt.

5.2. CLIMATIC INFLUENCE AND EUSTATIC SEA-LEVEL CHANGES

The period of time (last 65 Ma) during which the discontinuous carbonate sedimentation affected the inland, margins and currently submerged portion of the Salento Peninsula, was characterized by deep climatic changes associated with fluctuations of global mean sea level (GMSL) of different frequency and amplitude (Fig. 25). In fact, during the Cenozoic, changes in climate, and CO_2 concentrations marked the transition from a warm greenhouse long-term global climate characterized by high values of atmospheric CO_2 and ice-free conditions to a cold icehouse with low atmospheric CO_2 concentrations and large extension of ice sheets and ice caps (Zachos et al., 2001 a,b; Bohaty and Zachos, 2003; Miller et al., 1991; 2011, 2020; De Vleeschouwer et al., 2017 and references therein).

There is consensus upon the following points (see

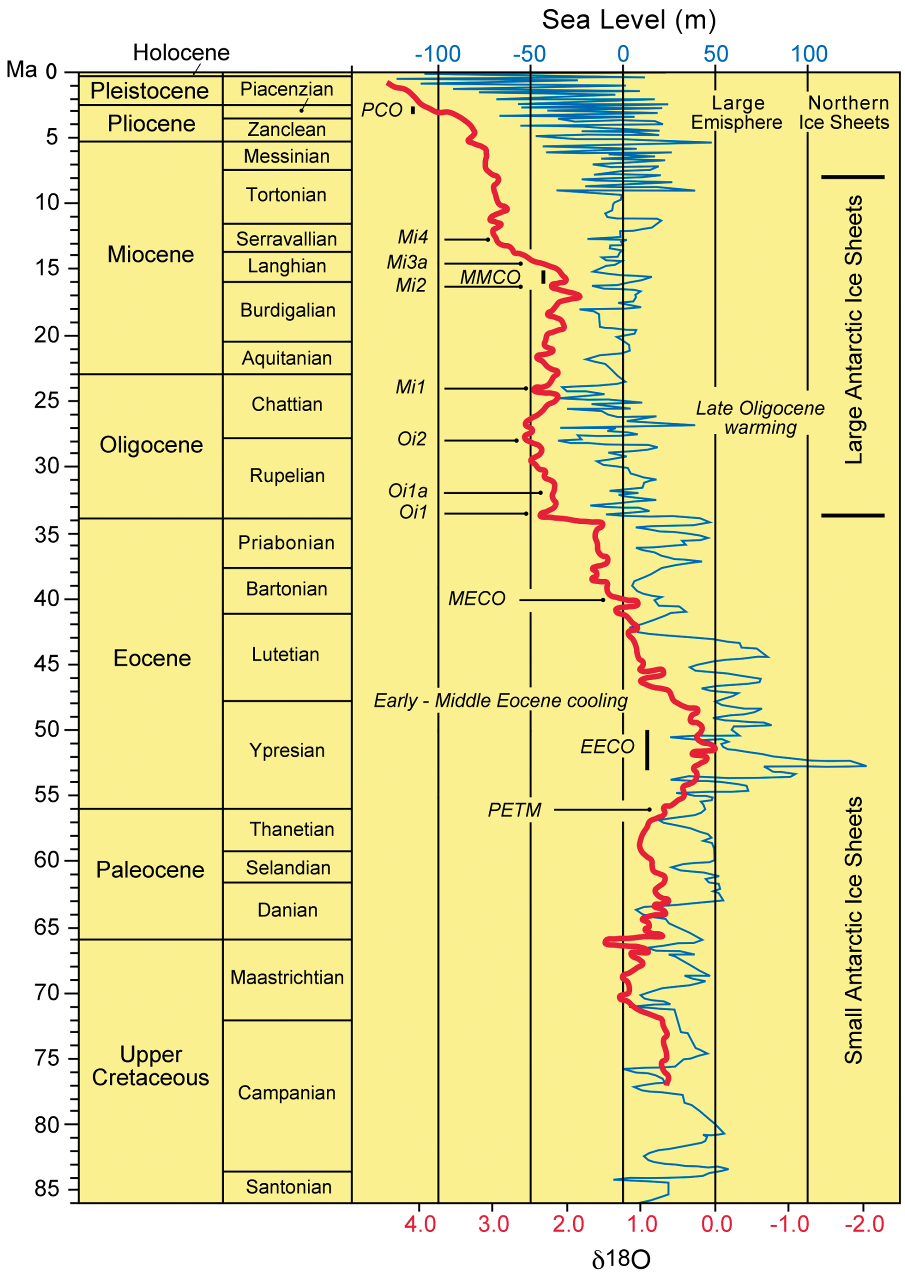

Fig. 25 - Sea level record for the past 85 million years derived by the New Jersey continental margin (see Miller et al., 2011 with references therein) with a synthesis of the oxygen isotopic record of Cramer et al. (2009). The main climatic events are also reported. PETM (Paleocene-Eocene Thermal Maximum); EECO (Early Eocene Climatic Optimum); MECO (Middle Eocene Climatic Optimum); MMCO (Middle Miocene Climatic Optimum); PCO (Pliocene Climatic Optimum). Redrawn and modified from Miller et al. (2011).

figure 25).

1) The hothouse early Eocene (56.0-47.8 Ma) was characterized by peak warmth, peak sea levels, and high CO_2 concentrations suggesting mostly ice-free conditions (Lowenstein and Demicco, 2006; Foster et al., 2013). Nevertheless, at least four global sea-level falls of ~15 to 30 m are recorded and considered related to ice-volume increase (Miller et al., 2020).

2) The middle Eocene was characterized by optimum climatic conditions (Middle Eocene Climatic Optimum, MECO; Zachos et al., 2001), which led the Earth to be almost completely free of ice. Sea level changes of 15 to 40 meters occurred during the middle to late Eocene as a result of the growth and collapse of small ice sheets, which led to the final phase of deglaciation during the late Eocene (Fung et al., 2019; Miller et al., 2020).

3) The most important and most impacting climatic event occurred at the transition between the Eocene and the Oligocene (EOT) (the Oi1 event; Miller et al., 1991; Zachos et al., 1996, 2001) with the transition from warm greenhouse to cold icehouse conditions due to the development of the Large Antarctic Ice Sheets, which led to a minimum sea-level fall ~50 m. From the Oligocene to the early Miocene large-ice volume variations occurred giving rise to sea-level changes of ~ 50 to 60 m (Coxall et al., 2005; Miller et al., 2020); in particular, sea-level falls of ~25 m and ~50 m are estimated at 33.9 and 33.65 Ma (Rupelian) respectively, that were followed by a sea-level rise of ~35-44 m at ca. 32 Ma (Boulila et al., 2011). The Oi2 event (passage from Rupelian to Chattian and the Mi1 event (passage from Chattian to Aquitanian) produced sea-level falls of a similar amplitude of the Oi1 with a sea-level rise of 30-40 m in between, suggesting phases of expansion and retreat of the Antarctica ice sheets with 1.2 Ma cycles (Boulila et al., 2011; Miller et al., 2020).

4) The Middle Miocene Climatic Optimum (MMCO) between 17.0 and 14.8 Ma (Holbourn et al., 2013) was in general characterized by small sea-level changes (<20 m), with the only exceptions of the Mi2 (16.0 Ma), Mi3a (14.8 Ma), and Mi3 (13.8 Ma) events during which falls of sea-level of ~40 m, ~30 m, and ~50 m respectively occurred.

5) Starting from the MMCO three main cooling phases Mi3a (14.8 Ma), Mi3 (13.8 Ma), and Mi4 (12.8 Ma) with sea-level falls of ~30 m, ~50 m, and ~20-30 m respectively occurred, all related to the growth and permanent presence of the East Antarctic Ice Sheet (Kennett, 1977). All the literature data suggest that the sea level in the late middle to late Miocene remained surprisingly steady, rarely exceeding 20 m above the present, and only a fall of - 30 m occurred at ~8.2 Ma (Miller et al., 2020). Dominant sea level cyclicity was the 41-ka tilt (De Vleeschouwer et al., 2017) that persisted during the Messinian Salinity Crisis with little sea-level change.

6) During the Early Pliocene (about 5.33 to 3.60 Ma), the amplitude of Milankovitch-driven sea-level oscillations increased, with progressively greater peak sea levels above the present one of about 10 to 20 m. The Pliocene Climatic Optimum (PCO) was reached during the interval 3.3-2.85 Ma (Late Pliocene) (Dowsett et al., 1999; Raymo et al., 2018) with a sea-level peak of ~20 m above the present one ca 3.0 Ma (Miller et al., 2012; Dumitru et al., 2019). Such sea-level fluctuations were strongly controlled by the growth and decay of the East Antarctic and Northern ice sheets.

7) The greatest variations in the sea level amplitude were reached within the last 2.7 Ma (Quaternary), due to the growth of the large Northern Hemisphere ice sheets. This was a continuous process punctuated by a progressive increase of glacial and interglacial periods (Shackleton et al., 1984; Miller and Wright, 2017; Miller et al., 2020; Jacob et al., 2020) with sea-level lowering reaching 120-130 m below present. The cyclicity associated with the 41-ka tilt forcing characterized the sea level fluctuations (20-50 m) from 2.5 Ma to 1 Ma, whereas sea level changes up to 130 m below the present and with cyclicity of 100-ka have been dominant in the last 800 ka. In the same period, sea level lowering of 10 to 60 m was related to the precessional (19 and 23 ka) and tilt (41 ka) scale (Miller et al., 2020).

5.3. SEQUENCE STRATIGRAPHY

All the climatic and related eustatic sea-level changes together with the geodynamic context affected the stratigraphic and paleogeographic evolution of the Salento Peninsula. Consequently, relative sea-level changes of different frequencies and amplitude developed, although the definition of the influence of these processes on the variation of accommodation space is not easy to distinguish.

Overall, it is evident by eustatic sea-level and oxygen isotope curves (see figure 25) that the last 50 Ma coincide with a long-term eustatic fall in sea level punctuated by several cycles of different orders and amplitude. Climate changes were generated by periodic and quasi-periodic variations of the Earth's orbital parameters (eccentricity, obliquity, and precession) and produced high-frequency eustatic sea-level oscillations with amplitude ranging from tens to hundred meters. During these periods both global deep-sea oxygen and carbon isotopes records show some important climate changes, that exclude the early Eocene climatic optimum the others, starting from the Oligocene to the present, reflect the strong influence of the expansion and decay of Antarctica and Northern Hemisphere ice sheets. In fact, the growth and retreat of these ice sheets caused 50-60 m sea-level variations on the 10^6 -year scale beginning at 33.5 Ma (at the transition from Eocene to Oligocene), which were amplified during the last 2.6 Ma due to the growth /decay of the Northern Hemisphere ice sheets. The latter produced sea-level changes <60 m with a cyclicity of 41,000 years (obliquity cycles) during the Early Pleistocene, whereas during the Middle and Late Pleistocene sea-level changes were more than 100 m with cyclicity of 100,000 years (eccentricity cycles) (see Miller et al., 2020).

Consequently, during this long period of time, the eustatic fall counteracted at first the effects of the subsidence related to the flexural bending of the Salento

Adriatic foreland due to the migration of the Dinaric-Albanides-Hellenides chains and, starting from the end of the late Miocene, the flexural bending of the Salento Ionian foreland due to migration of the Apennine chain, on the coastal onlap record.

On this basis and thanks to the conspicous literature data and our field data, it was possible to frame the stratigraphic architecture of Salento Peninsula into a sequence stratigraphic scheme that allowed us to highlight and better clarify the stratigraphic relationships between the different lithostratigraphic units recording relative sea-level variations of different frequency and amplitude. The final stratigraphic architecture is not just a simple vertical overlap of the lithostratigraphic units but rather a complex lateral-vertical organization of the different units which constitutes the expression of the strong interactions between tectonic and climatic/eustatic changes. These two processes worked both simultaneously and out of phase during time producing variations of accommodation space and influencing carbonate sedimentation. The result of this was a sedimentary succession with a reduced thickness (~200 m) if compared to the interval time during which it was deposited (the last 60 Ma), where the various lithostratigraphic units are bounded by unconformity surfaces associated with erosional hiatuses, indicating significant breaks in the stratigraphic record of the Salento Peninsula. These units that could reasonably be called UBSU (unconformity-bounded stratigraphic units) (Salvador, 1987; 1994), show facies types and a stratal architecture that allowed us to define them as depositional sequences.

On this basis, the post-Cretaceous succession of the Salento Peninsula has been subdivided into two high-rank composite sequences named Lecce 1 and Lecce 2 which have very different durations and within which, lowstand (LST), transgressive (TST), and highstand (HST) systems tracts occur with rather reduced thicknesses. Both these sequences consist of several and low rank simple and composite depositional sequences (*sensu* Mitchum and Van Wagoner, 1991; Catuneanu et al., 2011 with references therein) with a duration ranging from hundreds of thousands to a few million years that have a good correspondence with the formal and informal lithostratigraphic units of the investigated area (Fig. 26).

5.3.1. The high-rank composite sequence Lecce 1

This sequence (Fig. 27) is bounded below and above by two unconformity surfaces placed on top of the Cretaceous Altamura limestone and on top of the Andrano Calcarenite and Novaglie formations respectively. In particular, the basal unconformity of the Lecce 1 sequence is tectonically controlled and represents the forebulge unconformity, a discontinuity placed between the pre-orogenic and the syn- to post-bulge deposits, that is the first stratigraphic expression of the foreland flexural stage (Crampton and Allen, 1995). The genesis of this unconformity led to subaerial exposure the innermost sectors of the Apulian platform and to the formation of a karstic landscape and a thick reddish residual deposit. The Lecce 1 sequence has a duration of ~60 Ma although the stratigraphic gaps within span about 35 Ma. It consists of six low-rank composite sequences with a variable duration from 1.6 to 12 Ma, the boundaries of which are represented by sharp erosional surfaces, recording basin and downward shift of facies, and local subaerial exposure with paleosols formation. All these sequences basically occur along the eastern sectors of the Salento, whereas they are absent or with very reduced thickness in the central portion and on the western margin of the Peninsula.

Based on their depositional characters and stacking pattern the Torre Tiggiano limestone and the Specchia la Guardia limestone together with the Castro limestone, Porto Badisco calcarenite and the Galatone Formation stack to form the LST of Lecce 1 sequence. Lecce formation and Pietra leccese are referable to the TST, while the Andrano calcarenite and the Novaglie formation developed entirely during the HST of the Lecce 1 sequence (Fig. 27).

A hiatus spanning an interval of ~18 Ma (the whole Paleocene and the early Eocene) separate the Cretaceous substratum from the first unconformity-bounded unit known in the literature as the Torre Tiggiano limestone. This unit, in agreement with Bosellini et al. (1999), formed part of a low-rank composite depositional sequence onlapping onto the Cretaceous substrate, that spanned probably along the easter margin of the Salento Peninsula from Otranto to S. Maria di Leuca. The deposition of this sequence named therein Lecce 1a occurred at the turn of the MECO and as such we suggest that the preserved deposits could belong to the TST and/or the HST of the Lecce 1a sequence. These deposits are tectonically tilted and probably follow a deformation phase related to the westward migration of the Dinarides-Albanides-Hellenides belt (see also Bosellini et al., 1999). This process occurred before the deposition of the overlying clinostratified reef slope deposits of Torre Specchia la Guardia limestone (upper Priabonian). We consider the latter another incomplete sequence, named Lecce 1b, whose deposition occurred before the Oi1 event. For this reason and considering also the oxygen and eustatic curves (see figure 24) we retain that Torre Specchia la Guardia limestone onlapping onto the Cretaceous and middle Eocene deposits belong to the TST/HST of Lecce 1b sequence.

Both these Eocene sequences were deposited only along the eastern coast of the Salento Peninsula, suggesting that the western and internal portions of the Salento were in subaerial conditions. Also, considering that both sequences were deposited during the eustatic sea-level fall trend following the EECO we retain that both sequences belong to the Early Lowstand Systems Tract of the high-rank Lecce 1 sequence.

The EOT constitutes an important climatic phase during the development of the Lecce 1 sequence coincident with the Oi1 event (Miller et al., 1991; Zachos et al., 1996, 2001) recording the passage from warm greenhouse to cold

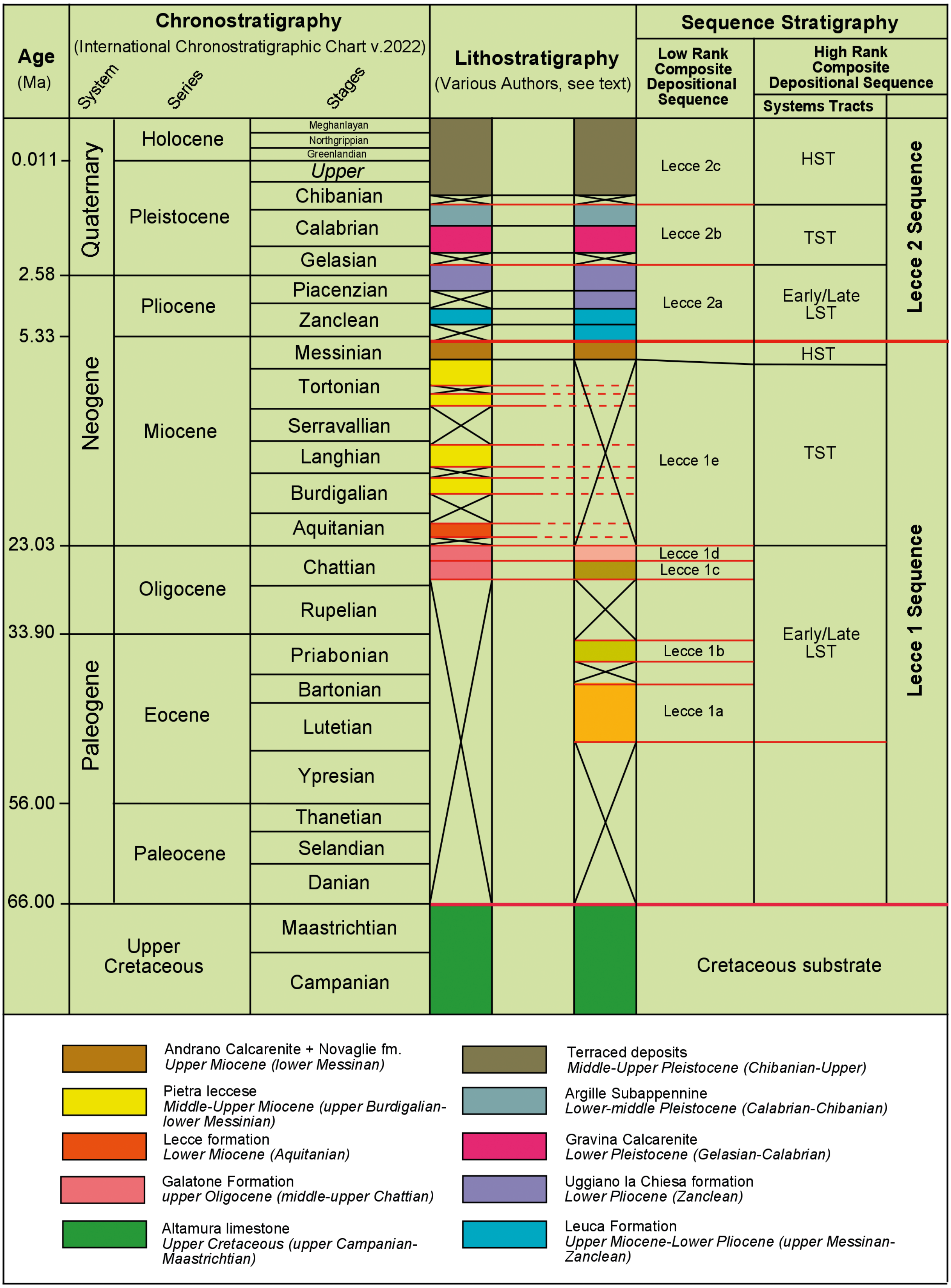

Fig. 26 - Chronostratigraphic and sequence-stratigraphic scheme of the Cenozoic deposits of the Salento Peninsula. HST: Highstand Systems Tract; TST: Transgressive Systems Tract; LST: Lowstand Systems Tract.

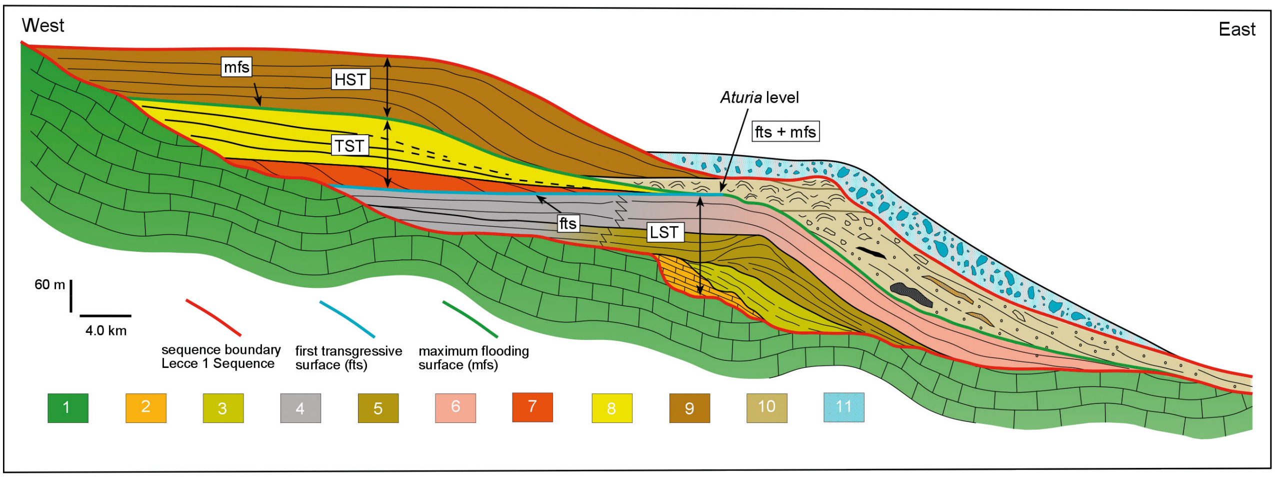

Fig. 27 - Stratigraphic cross-section showing the depositional architecture of the composite high rank Lecce 1 Depositional Sequence between the central and eastern sectors of the Salento Peninsula. 1: Altamura limestone; 2: Torre Tiggiano limestone; 3: Torre Specchia la Guardia limestone; 4: Galatone Fm.; 5: Castro limestone; 6: Porto Badisco calcarenite; 7: Lecce fm.; 8: Pietra leccese; 9: Andrano Calcarenite; 10: Novaglie fm.; 11: Leuca Fm. (breccia member); HST: highstand systems tract; TST: transgressive systems tract; LST: lowstand systems tracts; fts: first transgressive surface; mfs: maximum flooding surface. For a further explanation the readers are referred to the text.

icehouse conditions. Two eustatic sea-level falls at 33.9 Ma (25 m) and 33.65 Ma (Oi1 event) (50 m) are recorded at this passage (Coxall et al., 2005; Miller et al., 2020); these falls together with the other eustatic variations of several tens of meters characterizing the lower Oligocene (Rupelian) (see figure 24) did not permit preservation of the deposits in the Salento area which only records the formation of three lithostratigraphic units of Chattian age that rest on the underlying Upper Cretaceous and Eocene deposits: the fringing reef complex of the Castro limestone and the ramp system of the Porto Badisco limestone both passing landward to the lacustrine-lagoon deposits of the Galatone Formation (see figure 27). These units are bounded above and below by unconformity surfaces and are interpreted as two low-rank composite depositional sequences named Lecce 1c and Lecce 1d respectively. The outcropping portions of these sequences constitute according to our interpretation the preserved deposits of the late lowstand and the transgressive systems tracts. Both these sequences developed during a stationary phase of the eustatic sea level between the Oi2 and Mi1 events. More in detail, the deposition of the Castro limestone occurred at the turn and immediately after the Late Oligocene Warming and records through the facies belt shift a prograding coral reef complex (see also Bosellini et al., 2021). The latter show internal erosional surfaces recording relative sea-level variation and the deposition of a stack of stratigraphic units interpreted as depositional sequences (see also Bosellini et al., 2021), that we attribute to the late lowstand systems tract of the Lecce 1c sequence, being the TST and HST completely eroded by the successive relative sea-level fall.

Deposition of the Castro limestone was followed after a short period of time by the deposition of the Porto Badisco calcarenites which are separated by an erosional unconformity. The Porto Badisco calcarenites show internally the presence of further unconformity surfaces, bounding units interpreted as low-rank depositional sequences with a retrogradational stacking pattern (Fig. 28). The strike and dip correlation panels of the Porto Badisco calcarenite derive by the integration of literature data (see detailed facies analysis conducted by Pomar et al., 2014 and Tomassetti et al., 2018) and by field data with new survey and measure of stratigraphic sections whose facies subdivision and nomenclature follow the same of the previous authors.

Based on what said previously and taking into account the general progradational and aggradational stacking pattern showing the Lecce 1c and Lecce 1d sequences we attribute the deposition of these composite sequences to the Late Lowstand Systems Tract of the high-rank Lecce 1 sequence (Figs. 26 and 27).

The deposition of the Lecce formation (lower Aquitanian) occurred during an eustatic sea-level rise subsequently to Mi1 event. This unit bounded by unconformity surfaces, lies unconformably on the underlying Galatone Formation and constitutes the expression of a single depositional sequence where only the transgressive systems tract deposits are preserved. This unit records, in fact, a transgressive phase in the Salento area (Fig. 27) that may be linked to the contextual long-term flexural subsidence induced by the migration of the Dinarides-Albanides-Hellenides belt (see also Bosellini et al., 1999), a process that continued also during the deposition of the Pietra leccese. The latter, upper Burdigalian-lower Messinian in age, was deposited in an inner shelf to lower shoreface environments and is characterized by the presence of a high percentage of phosphatic and glauconitic grains whose frequency and abundance increase upward and then decrease towards

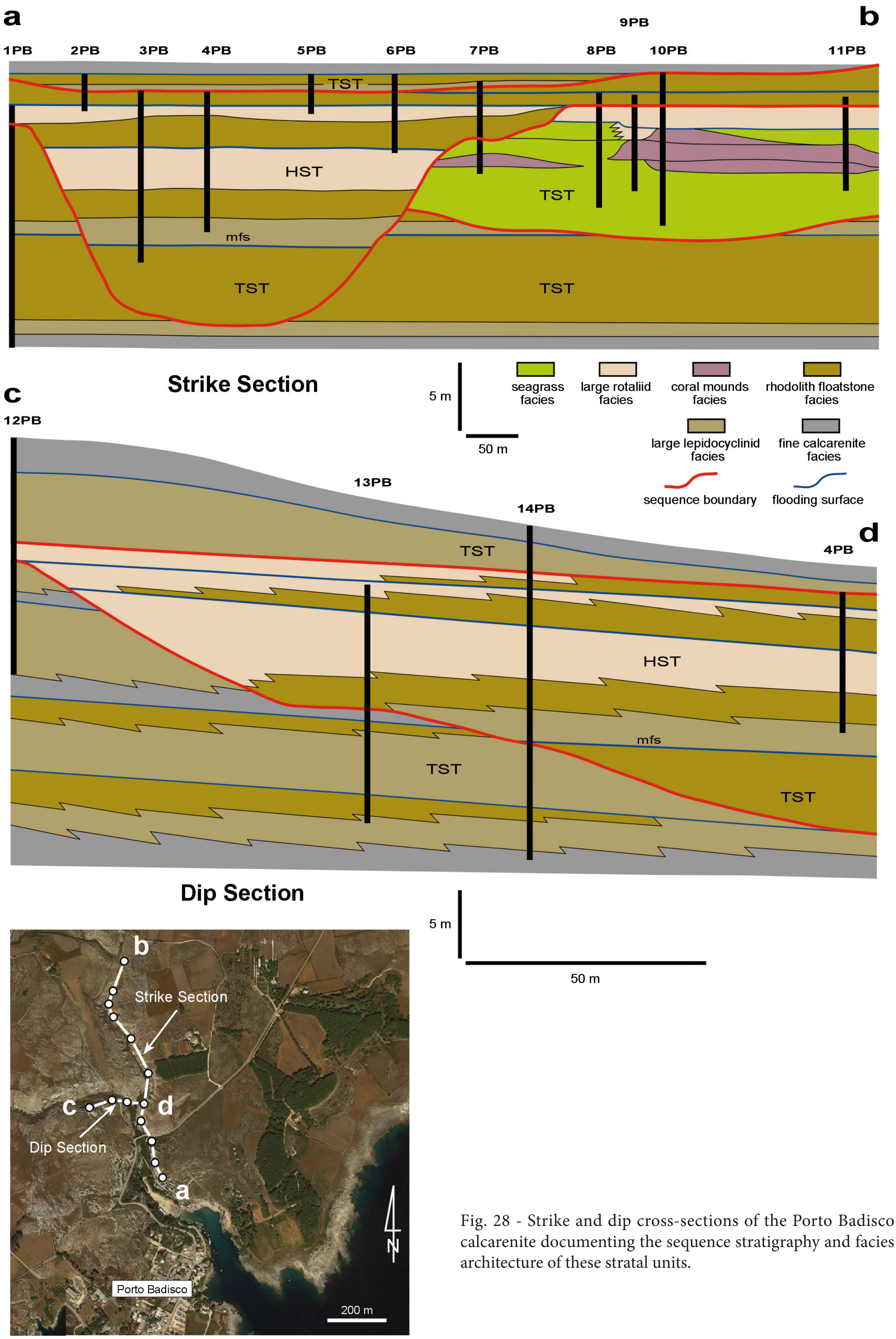

Fig. 28 - Strike and dip cross-sections of the Porto Badisco calcarenite documenting the sequence stratigraphy and facies architecture of these strata units.

the top of this formation, where the Pietra leccese transitionally passes upwards to the shallow-water deposits of Andrano Calcarenite. Mazzei et al. (2009) subdivided the Pietra leccese into three different intervals separated by three hiatuses with a duration ranging from 1.2 to 3.7 Ma. The formation of these hiatuses was attributed to the action of marine currents that swept the seabed. Although marine currents can be very effective to erode the seabed, we maintain that the recognized long-lasting hiatuses can be better explained by relative sea-level falls. The latter, in shelfal areas, would have favored the erosion through wave scouring induced by a decrease in bathymetry, a process that would have increased the erosive action of the currents on the seafloor. Basically, we interpret the hiatuses and the associated erosional surfaces occurring in the Pietra leccese as the expression of regressive surfaces of marine erosion (Plint, 1988; Posamentier and Allen, 1999; Catuneanu et al., 2011) that form during forced regression in wave-dominated shallow-water settings. In sequence stratigraphy, these surfaces have the role of sequence boundaries that become correlative conformities towards the sea where starved sedimentation occurs. Consequently, we consider the Pietra leccese unit as constituted by the superimposition of three depositional sequences, each with a duration of ~1 Ma, and with a clear retrogradational stacking pattern, of which only the deposits of the transgressive systems tracts are preserved (Fig. 27). Such backstepping setting is thought to be the result of the submerged phase of the Salento Peninsula during the deposition of Pietra leccese. This process proceeding from east to west produced the migration of the depositional depocenter towards the internal sector of the Peninsula, and a coeval starvation phase in the eastern sector. Here a condensed phosphatic layer (10-20 cm thick), known in literature as the "*Aturia* level" (Giannelli et al., 1965; Bosellini et al., 1999; Bossio et al., 2000-2001) was deposited between the early Serravallian-late Tortonian (Föllmi et al., 2015; Vescogni et al., 2018), in a period of time when the oceanographic circulation in the Mediterranean basin changed due to the intermittent connection with the Indian Ocean (see Popov et al., 2004). This process that modified the seawater chemistry of the basin and the faunal assemblages produced after the Burdigalian the disappearance of the large benthic foraminifera that had dominated carbonate production in the Aquitanian and the increase of red algae and bryozoans, which colonized most of the carbonate ramp systems during the middle and upper Miocene (see Cornacchia et al., 2020, 2021 with references therein). In the external sector of the Salento Peninsula the "*Aturia* level" level lies between the carbonate sequences of Oligocene age (Castro limestone and Porto Badisco calcarenite) and the lower Messinian Andrano Calcarenite and reef unit of the Novaglie formation, while in the internal sector of the Peninsula it rests directly on the Cretaceous substratum (Fig. 27). Consequently, this level incorporates, in a very reduced thickness, all the sequence boundaries occurring in the Pietra leccese, in the form of correlative conformities; as such this level constitutes the expression of the condensed section (maximum flooding surface, mfs) that separates, the TST from the HST of the high rank sequence Lecce 1 (Fig. 27). Furthermore, where this level rests directly on the Porto Badisco calcarenite, it overlaps on the first transgressive surface that separates the LST from the TST of the Lecce 1 sequence (Fig. 27). Based on the previous discussion we consider both the Lecce formation and the Pietra leccese as deposited during the TST of the high rank sequence Lecce 1.

The Pietra leccese grades upward, through the interposition of the "*Aturia* level" to the Andrano Calcarenite (lower-upper Messinian) whose sedimentological and paleontological characters suggest deposition from inner shelf to beach environments with the local presence of brackish lagoonal deposits at the top of this unit. On this basis we consider this formation to be the product of deposition during the HST of the Lecce 1 sequence. Of the same age is the Novaglie formation a coral reef complex cropping out along the eastern coastal border of the Salento Peninsula, from Porto di Tricase and S. Maria di Leuca. This unit which has been recently investigated with great detail by Vescogni et al. (2022), lies unconformably onto the pre-Miocene formations through an erosional surface on which the "*Aturia* level" occurs; it has been considered as heteropic of the Andrano Calcarenites by Bosellini et al. (1999, 2001, 2002) and Bosellini (2006). These works suggest that this unit constitutes a composite sequence formed by superimposition of three low-rank depositional sequences having thicknesses variable from tens to hundred meters (see Vescogni et al., 2022 for further details). Although the Novaglie fm. was deposited during the HST of the Lecce 1 sequence, the lateral passage to the Andrano Calcarenite has never been described in outcrop; also, the type of deposits of these formations, their stratigraphic relationships with the underlying units and the data derived from our paleogeographic reconstruction seem to suggest a different scenario. On this basis we interpret the Novaglie fm. as a composite low-rank depositional sequence (Fig. 29) that developed during the deposition of the HST of the Lecce 1 sequence as a result of high-frequency relative sea-level fluctuations that characterized the early Messinian of the Mediterranean area (see also Esteban,1996; Pedley (1996) under the control of climatic changes (see also Vescogni et al., 2022). Also, considering that the thickness of the three small sequences forming the Novaglie fm. tend to decrease upward, we interpret this as the product of the deposition during the late lowstand systems tract of this low-rank composite sequence being the transgressive and highstand deposits represented by the Andrano Calcarenite (see figure 27). Summing up, the final portion of the high-rank Lecce 1 sequence is represented by a composite sequence, named Lecce 1e, that includes the following lithostratigraphic units: Lecce fm., Pietra leccese, Andrano Calcarenite, Novaglie fm. All these units are representative of the TST (Lecce fm.

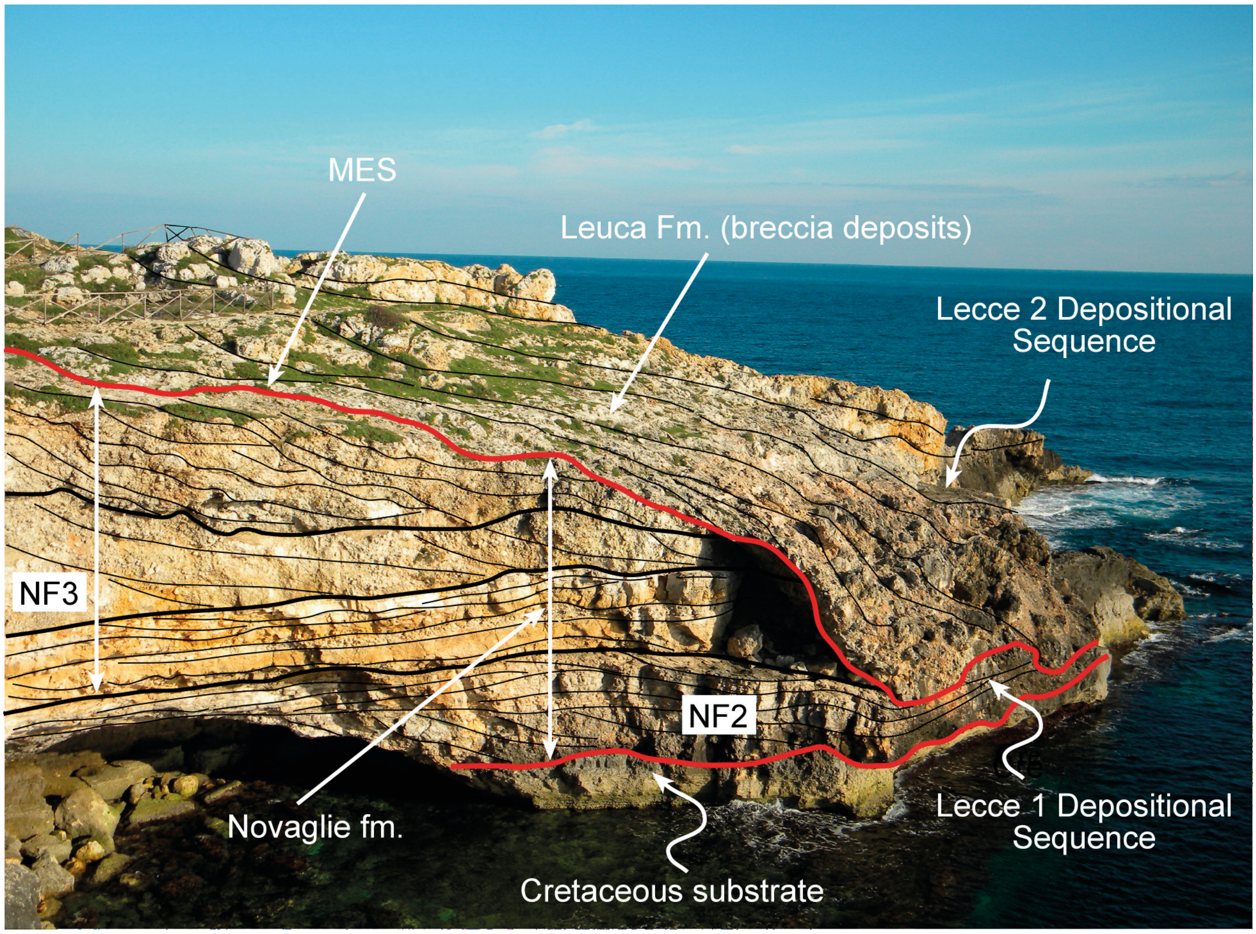

Fig. 29 - Stratigraphic succession cropping out in correspondence of Punta Ristola (Santa Maria di Leuca) showing the superimposition of the two composite high-rank depositional sequences Lecce 1 and Lecce 2 (red lines). Moving seaward the sequence boundaries of the two sequences merge due to the erosion related to the sea-level fall connected to the formation of the MES. For further explanation, the readers are referred to the text.

and Pietra leccese) and HST (Andrano Calcarenite and Novaglie fm.) of the high-rank Lecce 1 sequence (Fig. 27).

5.3.2. The high-rank composite sequence Lecce 2

The high-rank sequence Lecce 2 is bounded below by the unconformity surface corresponding to the Messinian Erosional Surface (MES) (Fig. 29) which is overlain by the breccia deposits of the Leuca Formation (Figs. 26 and 27). The upper boundary of this composite sequence is represented by the present subaerial and submerged depositional surface. Thus, this sequence comprises the sedimentary succession that developed during the last 5.6 Ma; it constitutes an incomplete and still evolving sequence that contains three low-rank sequences named Lecce 2a, Lecce 2b, and Lecce 2c stack to constitute the LST, TST, and HST of the Lecce 2 sequence respectively. All these sequences developed during the Pliocene and Pleistocene and are strongly influenced by the high frequency and high amplitude glacio-eustatic sea-level changes; consequently, considering the foreland setting of the area, the genesis of the sequence boundaries and the general stacking pattern of these sequences reflect the close interaction between tectonic uplift/subsidence and glacio-eustatic sea-level oscillations with typical Milankovitch cyclicities.

The sequence boundary of the Lecce 2a coincides with the MES while the top is represented by an unconformity surface at the base of the Gravina Calcarenite. The Lecce 2a sequence comprises the Leuca Fm. and the Uggiano la Chiesa fm. The former shows, after the breccia deposits, a general upward deepening trend recording the passage from the inner to the outer shelf at the top of which a glauconitic mudstone rich in planktonic foraminifers occurs. On the latter, a discontinuous conglomerate with phosphatic pebbles occurs passing upward to shelfal fine-grained marly calcarenite in turn replaced by shallow-water and coastal medium-calcarenite with a diverse assemblage of foraminifers, ostracods, mollusks, and red algae of the Uggiano la Chiesa fm. We interpret this succession as the expression of a depositional sequence in which the deposits of the Leuca Fm. are representative of the LST and the TST, while the deposits of the Uggiano la Chiesa fm. are considered to represent the final portion of the TST and the HST. We place the first transgressive surface (fts) at top of the breccia deposits while the maximum flooding surface with the condensed section should coincide with the glauconitic mudstone and the discontinuous conglomerate with phosphatic pebbles.

The Lecce 2b sequence is made up of the deposits of the Gravina Calcarenite and the Argille Subappennine. It constitutes an incomplete sequence where are only the TST deposits are present, being the LST deposits probably preserved in the Ionian submerged sector of the Salento Peninsula, while most of the HST deposits were eroded due to the high-frequency and high-amplitude relative sea-level changes occurring starting from the Middle Pleistocene. As such most of these sediments record a clear transgressive trend moving from NW to SE and from SW to NE reflecting the influence of the Apennine thrust migration starting from the Early Pleistocene. On this basis, we attribute the Gravina Calcarenite to the TST, while the Argille Subappennine that are in the continuity of sedimentation with the Gravina Calcarenite should record the final phase of the TST and the initial phase of the HST of the Lecce 2b sequence. Consequently, the mfs of this sequence could be placed at the passage from the Gravina Calcarenite and the Argille Subappennine formation.

The Lecce 2c sequence is a composite sequence that groups the Pleistocene marine terraced deposits forming the Salentino Supersinthem, a unit constituted by at least seven synthems bounded above and below by unconformity surfaces (Ciaranfi and Ricchetti, 2013). Such synthems that are essentially constituted by calcarenite coastal deposits can be interpreted as incomplete depositional sequences that together form the composite low-rank sequence Lecce 2c. The latter is bounded below by a diachronous and composite (polygenic) erosional surface that disconformable overlies the older units of Cretaceous, Miocene, Pliocene, and Early Pleistocene age, and above by the present emerged and submerged depositional surface. Overall, the Lecce 2c sequence covers a large area extending from depressed sectors interposed between the reliefs forming NW-SE elongated structural highs of Cretaceous age (Serre Salentine) and the coastal sector of the Peninsula.

The most important feature of the Lecce 2c sequence is represented by its internal stratigraphic organization that shows a general trend characterized by a seaward stack of the incomplete low-rank depositional sequences forming the terraced deposits developed along the coastal sector of the Salento Peninsula. This trend is considered to be the result of the interaction of two main factors: (i) the high-frequency sea-level fluctuations related to glacio-eustasy; and (ii) the discontinuous and different regional tectonic uplift that affected the Salento Peninsula starting from the Middle Pleistocene. This uplift recognized by Ricchetti et al. (1988) was more recently interpreted by Doglioni et al. (1994, 1996) as being due to the variable degree of flexure of the central Adriatic lithosphere (70 km thick) with respect to the thicker Apulia (110 km). This would have produced an uplift rate of the Apulia region of ~0.5 mm/yr that would have forced the seaward migration of the low-rank sequences, thus contributing to define the final stacking pattern of the Lecce 2c sequence.

6. CONCLUSIONS

In foreland basins most of the carbonate platforms generally occur along the forebulge, a sector formed in response to flexural loading of the orogenic wedge; such platforms record with their deposits the variation of accommodation space induced not only by uplift and flexural subsidence but also by eustatic sea-level changes. The Salento Peninsula is unique under this point of view as it constituted an initial pre-orogenic carbonate platform that was affected by deformation and flexural subsidence during the orogenic events (syn-orogenic platform, *sensu* Dorobek, 1995) due to the construction of two chains that migrate in opposite directions: the Dinarides-Albanides-Hellenides chain that moves from NE to SW and the Apennine chain that moves from SW to NE. How the migration rates of these two chains influenced the sedimentation and stratigraphic organization of the Tertiary/Quaternary succession of the Salento Peninsula is the subject of this paper in which different paleogeographic schemes covering this time interval are presented. The schemes show how the structural setting of the area changed over time giving rise to a sedimentary succession showing a pervasive multifold cyclicity and internally characterized by a stack of composite and simple depositional sequences of different duration and frequency.

Following the considerations and the reconstructed paleogeographic evolution of the Salento Peninsula the main conclusions derived from our work are the following:

1) The Apulia platform, at the end of the Cretaceous and during most of the Paleogene, emerged as a result of the collisional phase between the European and African plates. This process was responsible for the formation of the NW-SE extensional faults that affected the emerged and submerged sectors of the Salento Peninsula since the end of the Cretaceous.

2) During the Eocene sedimentation occurred only in the eastern sector of the Salento Peninsula between Otranto and S. Maria di Leuca, while the internal sector was probably in subaerial condition.

3) During the Oligocene, sedimentation continued in the eastern sector of the peninsula, although reduced thicknesses of lacustrine/lagoonal sediments (Galatone Fm.) began to deposit in the internal and western sectors. The effects of an initial transgression are expressed by the deposition of the Lecce fm. of Aquitanian age.

4) In the Miocene, with the deposition of the Pietra Leccese, the effects of this transgressive phase are better expressed. The transgression proceeded from the eastern to the western sectors and is well recorded by three main subunits developing in the Pietra leccese which show an increase in the content of glauconite from the bottom to the top and a clear retrogradational stacking

pattern. The increase in accommodation space is believed to be connected to the flexural subsidence induced by the westward migration of the Dinarides-Albanides-Hellenides thrust belt.

5) During the eastward progradation of the Andrano Calcarenite (Messinian) the accommodation space was reduced as a consequence of the reduced migration rate of the Dinarides-Albanides-Hellenides thrust belt; contextually the Ionian margin recorded an increased migration rate of the Apennine thrust belt.

6) In the Salento area the unique deposits referable to the Messinian Salinity Crisis are represented by the reef complex of the Novaglie fm. Strictly related to the Messinian Erosional Surface (MES) are the breccia deposits of the Leuca fm. whose deposition occurs following the sea-level fall giving rise to the formation of the MES.

7) The effects of the eastward migration of the Apennine thrust front are well highlighted by the initial deposition of the Gravina Calcarenite, and by the successive deposition of the Argille Subappennine marking a deepening trend due to the increase of flexural subsidence related to the migration of the Apennine chain.

8) The final phase of the geodynamic evolution of the Apulian area in general and of the Salento in particular is still in progress. A discontinuous and uneven uplift of the entire chain-foredeep-foreland system starting from the Middle Pleistocene produced a general retreat of the sea towards the present coastline due to the interaction between tectonic uplift and glacio-eustatic sea-level changes that are to be considered the main factors responsible for the current terraced modeling of both coastal sectors of the Salento Peninsula.

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