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GEOLOGICAL FIELD TRIPS AND MAPS

From the Apulia Foreland to the Bradanic Trough: a one-day geological field trip "jumping" from Cretaceous to Pleistocene in the Murge area (Puglia, southern Italy)

Post-Congress field workshop of the XIV GeoSed Congress, Bari, 15th -16th of June 2022

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Geological Field Trips and Maps

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From the Apulia Foreland to the Bradanic Trough: a one-day geological field trip "jumping" from Cretaceous to Pleistocene in the Murge area (Puglia, southern Italy)

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Cover page figure: The spectacular unconformity exposed at Gravina in Puglia town. After having eroded the thin Bradanic Trough succession, *i.e.*, the Pleistocene foredeep succession, the stream cut the bedrock, made up of Cretaceous limestones. Note the angular unconformity between tilted Cretaceous strata and the overlying sub-horizontal younger sedimentary units. Photo by D. Belfiore, Ponte Di Gravina. Available online: https://commons.wikimedia.org/wiki/File:Ponte_di_Gravina.jpg. After Tropeano et al. (2023) and Lippolis et al. (2024).

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ABSTRACT

This one-day field trip offers the opportunity to investigate the stratigraphic and sedimentological features of an area within the Alta Murgia National Park that includes the geographic boundary between the foreland (Murge) and the foredeep (Premurge) of the southern Apennines orogenic system. The focus of this field trip is to show the facies associations forming the outcropping sedimentary units and the relationships between tectonics and sedimentation. The sequence of stops follow a temporal thread starting with the observation of the stratigraphic architecture of peritidal facies associations forming the Upper Cretaceous section of *Cava Pontrelli*, an international geosite hosting one of the largest dinosaur footprint sites in the world. Then, the second stop shows the role of syn-sedimentary tectonics on the deposition of shallow-marine carbonate deposits of the Calcarenite di Gravina Fm during the Pliocene-Pleistocene along some well-exposed natural outcrops. The third stop shows a Gilbert-type delta facies association in the Calcarenite di Gravina Fm formed at the base of an escarpment representing the structural element of conjunction between the foreland and the foredeep. This escarpment corresponds to an ancient fault plane in erosional recession formed into the Cretaceous bedrock. The last stop illustrates the historical use of local building and ornamental stones that form the UNESCO World Heritage Site of Castel del Monte.

Keywords: Adria Plate, carbonate platform, dinosaur footprints, syn-sedimentary tectonics, Gilbert-type delta, Castel del Monte, southern Italy.

PROGRAM SUMMARY

This one-day field trip, proposed for the XIV GeoSed meeting (held in Bari, Italy, on 15th-16th of June 2022), crosses an area within the Alta Murgia National Park and includes the localities of Altamura, Gravina in Puglia, Minervino Murge, and Castel del Monte (Puglia, southern Italy). From a geological point of view, the field trip follows the geographic boundary between the foreland (the Murge area of the Apulia Foreland) and the foredeep (the Premurge area in the Bradanic Trough) of the southern Apennines orogenic system (Figs 1 and 2).

Both the Apulia Foreland and the Bradanic Trough are uplifting at least from the beginning of the Middle Pleistocene, with uplift rates on the order of at least 0.2-0.3 mm/yr; this phenomenon is evidenced around Murge by the occurrence of uplifted shorelines (recorded by palaeocliffs, abrasion platforms, and/or by thin marine terraced deposits) and by the deep incision of a well-developed drainage network characterised by the occurrence of canyons, locally called “*lame*” and “*gravine*”. Walls of some of these canyons host rupestrian towns, like the old town of Gravina in Puglia, along whose “*gravina*” (the canyon crossing the town) we will walk during a stop.

This field trip includes four key stops located between the

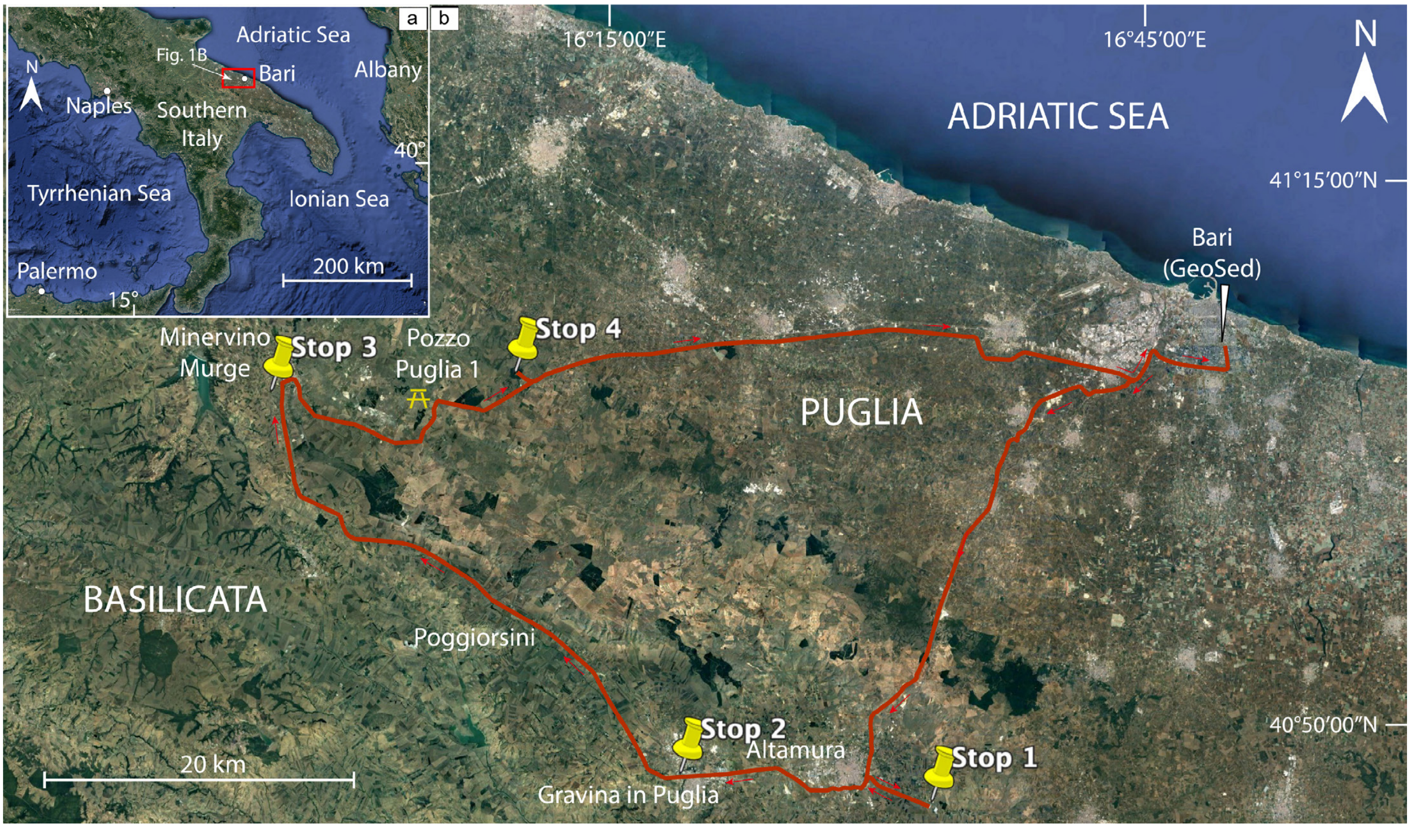

Fig. 1 - a) Location of field trip area in southern Italy; b) itinerary map of the field trip. Satellite images taken from Google Earth.

outer part of the Apulia Foreland and the outer sector of the Bradanic Trough, *i.e.*, the Premurge area. These four stops cannot include all the geological topics offered by the area and were selected in order to highlight some sites, close to each other, of international scientific interest. These sites can also serve as valuable resources for potential future educational and/or outreach activities. Additionally, they hold promise for geotourism in the Alta Murgia National Park (Lippolis et al., 2023; Tropeano et al., 2023).

For this purpose, an extensive geological setting precedes the description of the four stops, each addressing a different topic within the geological context of the area: i) the Altamura dinosaur tracksite of *Cava Pontrelli* (Late Cretaceous); ii) the relationships between tectonics and sedimentation in the Calcarenite di Gravina Fm at Gravina in Puglia (Early Pleistocene); iii) a carbonate Gilbert-type delta in the Calcarenite di Gravina Fm at Minervino Murge (Early Pleistocene); iv) Castel del Monte, a XIII century Castle of Frederick II. This last stop enhances the site with notes related to the use of the stones, adding to its significant historical interest.

SAFETY AND LOGISTIC INFORMATION

Outcrops are easily accessible and located close to the areas where a bus or a car will be parked. However, the use of hiking or trekking boots and comfortable clothing is strongly recommended. Outcrops are close to several towns where there are small shops, bars, restaurants, and pharmacies. The inland part of the Puglia region is usually dry during the summer, rains or rain showers are mostly concentrated during the autumn and winter seasons. Sunscreen protection is strongly recommended. The use of binoculars during outcrop panoramic observation to appreciate details from distant cliffs is suggested.

EMERGENCY CONTACT NUMBERS

112 – Carabinieri
113 – Police
115 – Fire Department
118 – Ambulance

HOSPITALS

Ospedale della Murgia “Fabio Perinei”, SS 96 Altamura-Gravina in Puglia Km 73.800, Altamura (BA). Tel. +39 080 3108225.

ACCOMMODATIONS

The field trip is one-day-long. We suggest to start from Bari at 7:00 a.m. and the return to the city is expected at 6:00 p.m.. Bari offers plenty of accommodation solutions. Information can be found on the website of the Tourist Office of the Puglia region website (https://www.viaggiareinpuglia.it/infopoint/6849/en/Info-point-Bari).

GEOLOGICAL SETTING

On a regional scale, the Apulia Foreland corresponds to a wide WNW-ESE trending antiform (Ricchetti, 1980; Ricchetti and Mongelli, 1980) developed on the Adria Plate (Doglioni et al., 1994, 1996; Cicala et al., 2021). Large deformation zones, striking oblique or perpendicular to the main antiform trend, divided the outcropping portion of the Apulia Foreland into three main blocks with different degrees of uplift, from highest to lowest, and towards SE: Gargano, Murge, and Salento (Ricchetti et al., 1988) (Fig. 2). According to data deriving from the Murge area, the Apulia Foreland shows a uniform crustal structure with a Variscan crystalline basement and an approximately 6 km thick Mesozoic sedimentary cover overlain by relatively thin and discontinuous Cenozoic and Quaternary deposits (Ricchetti et al., 1988). The sedimentary cover was drilled by exploration wells and is composed of a syn-rift and passive-margin succession whose upper part consists of about 3 to 5 km thick well-bedded Jurassic-Cretaceous carbonates (the Apulia Carbonate Platform). In the Murge area (Fig. 2), a 3 km-thick Cretaceous succession crops out, dipping SW and SSW (Pieri, 1980; Ricchetti, 1980).

The outcropping Cretaceous carbonate succession of the Murge area is mostly formed by monotonous, well-bedded, shallow-water lagoonal and peritidal carbonates deposited in low-energy inner-platform environments (*e.g.*, Ricchetti, 1975; Ciaranfi et al., 1988; Spalluto and Caffau, 2010; Spalluto, 2012; Spalluto et al., 2024). These carbonates developed in the inner sector of the Apulia Carbonate Platform,

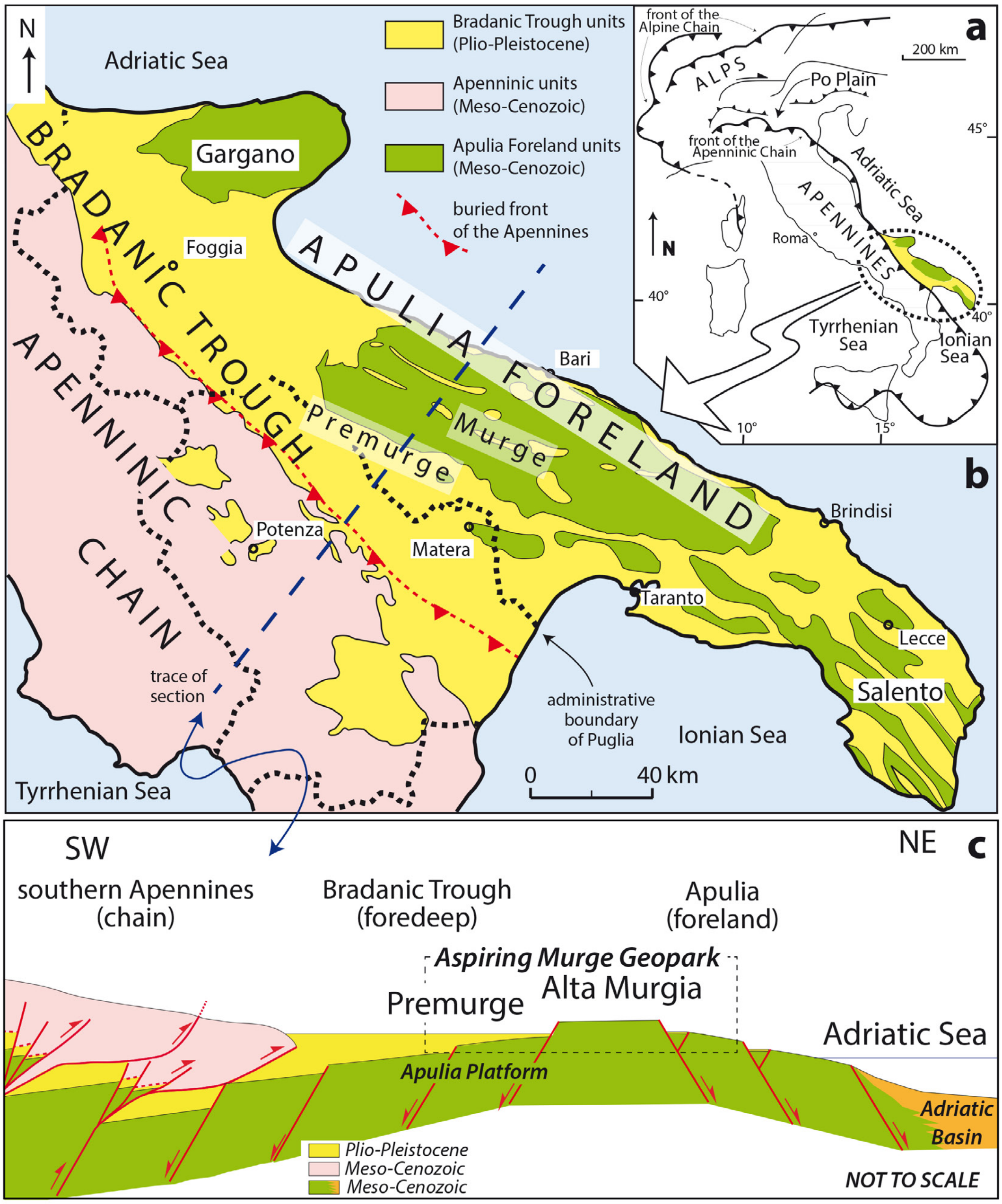

Fig. 2 - a) Schematic structural map of Italy; b) geological sketch-map of the Apulia Foreland in southern Italy; c) geological cross-section through the southern Apennines orogenic system (from Ghielmi et al., 2020 mod.).

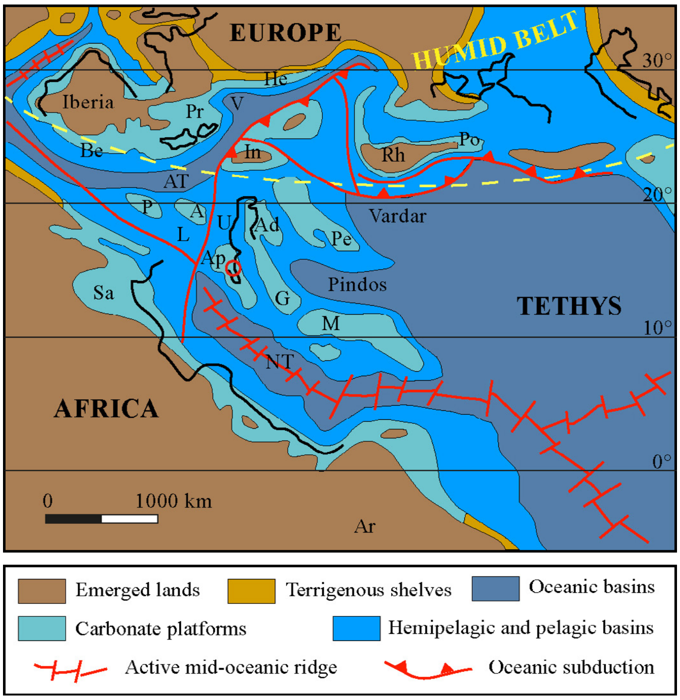

Fig. 3 - Palaeogeography and palaeoenvironmental map of the western-central Tethys in the early Aptian (modified after Masse et al., 1993; Stampfli and Kozur, 2006). Abbreviations: A, Apennine carbonate platform; Ad, Adriatic-Dinaridic carbonate platform; Ap, Apulia; Ar, Arabia; AT, Alpine Tethys; Be, Betic carbonate platform; G, Gavrovo carbonate platform; He, Helvetics; L, Lagonegro basin; M, Menderes carbonate platform; NT, Neo-Tethys; P, Panormide carbonate platform; Pe, Pelagonian carbonate platform; Po, Pontides; Pr, Provençal carbonate platform; Rh, Rhodope; Sa, Saharian carbonate platform; U, Umbria-Marche basin; V, Vocontian basin.

one of the so-called periadriatic platforms (D'Argenio, 1974; Zappaterra 1990; 1994). Periadriatic platforms were sites of nearly exclusive carbonate sedimentation from Late Triassic to the end of the Cretaceous (*e.g.*, Zappaterra, 1990; 1994) and mostly developed on a passive margin context characterised by almost constant subsidence rates (Channel et al.; 1979; D'Argenio and Alvarez, 1980). They were part of the Adria microplate (African Promontory *sensu* Channel et al., 1979), an Africa-detached element placed in the western Tethys (or Neotethys) between the African and Eurasian plates. This microplate formed during the Early Jurassic rifting, which dismembered a wide pericontinental carbonate platform (Southern Tethyan Megaplatform *sensu* Vlahovic et al., 2005) (Fig. 3). According to Eberli et al. (1993), periadriatic platforms should be considered analogous to the present-day Bahamas archipelago with regard to their internal architecture, carbonate facies, platform size and shape, and subsidence rate.

During middle/Late Cretaceous times, when collision between Africa and Eurasia began, the periadriatic domain was involved in the deformation processes induced by the propagation, in distal palaeogeographic domains, of the intraplate stress produced by the early stages of the Alpine orogenesis (D'Argenio and Mindszenty, 1991; Mindszenty et al., 1995). Tectonic deformation produced regional uplifting of shallow-water platforms resulting in the development of two major regional intra-Cretaceous unconformities, the former Albian/Cenomanian in age, the latter Turonian in age (*e.g.*, Mindszenty et al., 1995). These unconformities are stratigraphically marked by bauxite palaeosols pointing to a long-lasting subaerial exposure. Published stratigraphic data show that the sedimentary record of the Apulia Carbonate Platform recorded only the Turonian bauxite event (*e.g.*, Luperto Sinni and Reina, 1996), while no significant record of subaerial exposures is evident during Albian/Cenomanian times (Valduga, 1965; Ricchetti, 1975) except for a Cenomanian intraformational dolomitic breccia layer interpreted as the result of the development of a palaeokarst system (Spalluto, 2012).

The long history of the Apulia Carbonate Platform is that of a flat shallow-marine area characterised by carbonate sedimentation (deriving from a T factory *sensu* Schlager, 2005), cyclically exposed. During these phases of relative short exposition, the platform was crossed by dinosaurs, testified by the record of their tracks (Stop 1 – The Altamura tracksite of *Cava Pontrelli*).

Due to the presence of the Turonian unconformity, the Cretaceous carbonate succession cropping out in the Murge area was divided into two units (Fig. 4): the Calcare di Bari Fm (Valanginian *p.p.* to Early Turonian?) below, and the Calcare di Altamura Fm (Late Turonian? to Maastrichtian) above (Valduga, 1965; Azzaroli and Valduga, 1967). The Cretaceous succession of the Murge has been affected by extensive mining activity. The quarried blocks have been used as building stones for major historical buildings and are still used today as a valuable ornamental stone. Castel del Monte (Stop 4) is a typical example of the use of this stone in medieval times.

The Calcare di Bari Fm is the formal lithostratigraphic unit, Callovian *p.p.* - early Turonian? in age (according to Spalluto et al., 2005), cropping out in the Puglia region, including all the carbonate succession formed on the Apulia Carbonate Platform mostly made up of inner-platform carbonates lacking of significant internal stratigraphic unconformities. The base of this unit is not outcropping, while the top corresponds to a Turonian subaerial unconformity locally marked by bauxites or other continental deposits (Crescenti and Vighi, 1964; Luperto Sinni and Reina, 1996). The Calcare di Bari Fm crops out in the Puglia region, both in the western Gargano Promontory and in the Murge areas (Spalluto et al., 2005; Fig. 5). It forms a succession of over 2 km in thickness, comprising vertically stacked tabular beds where peritidal and shallow-subtidal lithofacies associations cyclically alternated, forming high-frequency small-scale (from a few dm- to few m-thick)

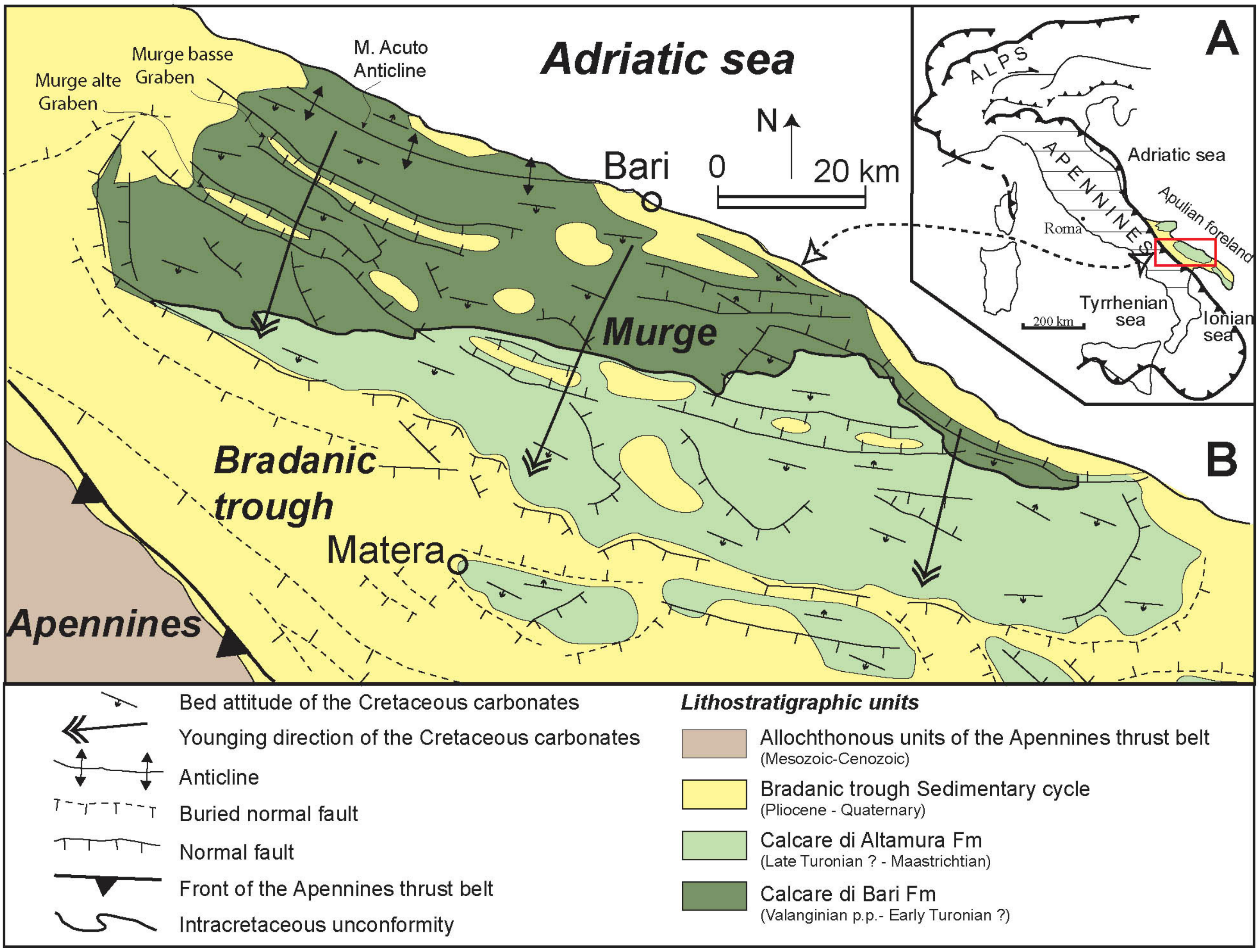

Fig. 4 - A) Schematic structural map of Italy; B) geological and structural sketch-map of the Murge area (modified and redrawn after Festa, 2003).

elementary sequences (Luperto Sinni and Borgomano, 1989; Spalluto, 2004; 2008; 2012; Spalluto et al., 2024). Moreover, elementary sequences stack into thicker (from few m- to few tens of m-thick) lower-frequency sequences (bundles and superbundles according to D'Argenio et al., 1997) exhibiting Milankovitch cyclicity (Spalluto, 2008; 2012; Spalluto et al., 2024). In spite of the apparent facies monotony of the entire Calcare di Bari Fm succession, there are a few stratigraphic intervals containing a peculiar macrofossiliferous association and/or a distinctive lithofacies association, which represents stratigraphic markers, useful for proposing a subdivision in lower rank lithostratigraphic units. Regarding the succession cropping out in the Murge area (about 1800 m in thickness according to Ricchetti, 1975 and following studies; Fig. 5), the few and laterally continuous stratigraphic concentrations of rudists and a layer rich in *Palorbitolina lenticularis*, all ranging in thickness from few to a few tens of meters, have been informally used as reference layers ("*Livelli guida*" in Valduga, 1965; Azzaroli and Valduga, 1967; Azzaroli et al., 1968; Ricchetti, 1969; 1975; Boenzi et al., 1971; Luperto Sinni, 1979; Figs 5 and 6) for lithostratigraphic correlations of stratigraphic sections and, coupled with biostratigraphic data based on benthic microfossils, for chronostratigraphic attributions. In addition, another important reference layer corresponds to a stratigraphic interval made up of stratified dolomitic and carbonate breccias (Ricchetti, 1975) (Figs 3 and 4). More recently some stratigraphic intervals of the Calcare di Bari Fm cropping out in the Murge area have been informally classified as members (Campobasso et al., 1972; Luperto Sinni and Masse, 1984; 1992; Luperto Sinni and Borgomano, 1989; Figs 5 and 6), but, unlike reference layers, their use for lithostratigraphic correlations is prevented because their identification and lateral continuity have not yet verified in the region.

The Calcare di Altamura Fm extensively crops out in the southern and southeastern sectors of the Murge area (Fig. 5) and transgressively lies above the Calcare di Bari

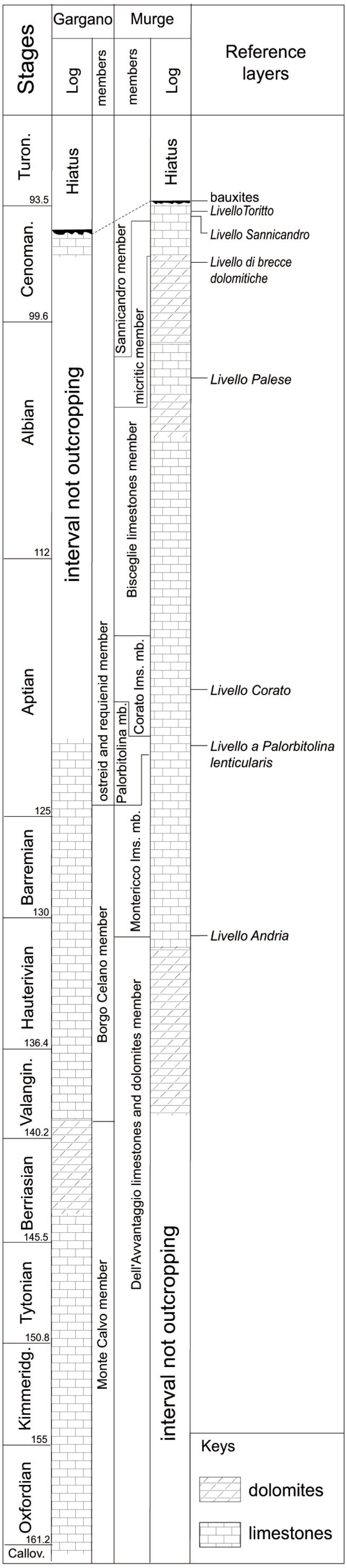

Fig. 5 - Stratigraphic correlation between the Calcare di Bari compound sections cropping out in Gargano and Murge areas (modified from Spalluto, 2004 and Spalluto et al., 2005).

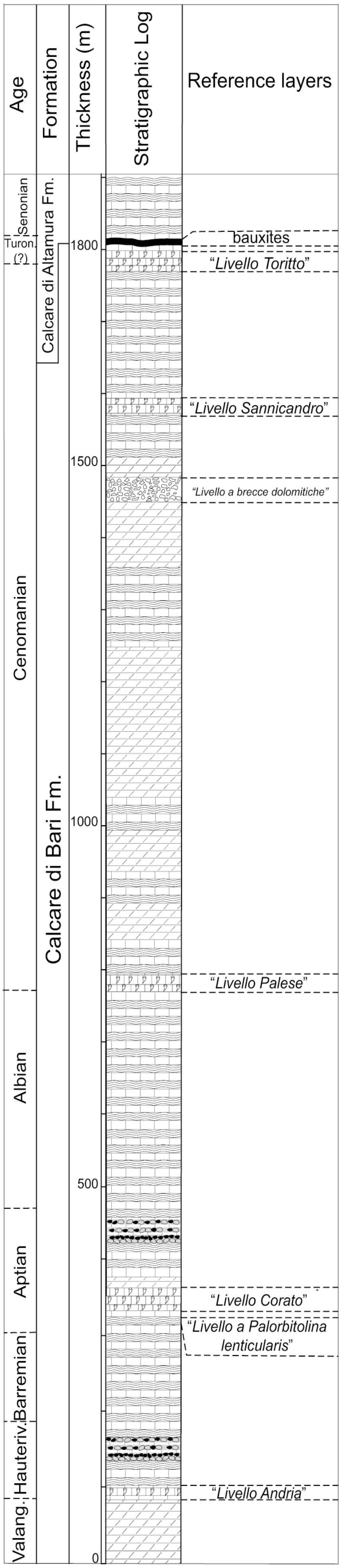

Fig. 6 - Compound stratigraphic section of the Calcare di Bari Fm compiled in the Murge area by Ricchetti (1975). Chronostratigraphic attribution of the succession is based on papers of Luperto Sinni and Masse (1984; 1992), Luperto Sinni and Borgomano (1989) and following studies.

Fm. This unit marks the return of marine conditions on the platform and the restoration of the carbonate factory deposition after a long period of subaerial exposure (*i.e.*, the Turonian bauxite event). Although this lithostratigraphic unit has not yet been formally classified, it is commonly used to indicate the entire carbonate succession from the Turonian? to Maastrichtian age, cropping out throughout the Puglia region (Gargano, Murge, and Salento). It is characterised mainly by mud-supported, shallow-water facies associations (Ciaranfi et al., 1988; Spalluto et al., 2005). The reference composite section is approximately 1000 m-thick, located within the 189 Sheet "Altamura" of the Geologic Map of Italy (scale 1:100,000). This succession consists mainly of shallow-water peritidal and shallow subtidal carbonates formed in the internal sector of the Apulia Carbonate Platform (Azzaroli et al., 1968; Ricchetti, 1975; Ciaranfi et al., 1988; Luperto Sinni and Borgomano, 1989; Reina, 1993; Checconi et al., 2008). These facies associations include bioclastic wackestone to floatstone, formed in lagoonal environments, cyclically alternated with biopeloidal mudstone/wackestone and stromatolitic bindstones formed in peritidal environments (from restricted subtidal to intertidal/supratidal). Residual deposits (palaeosols) are alternated to shallow-marine lithofacies indicating subaerial exposure and palaeokarstic features (Iannone, 2003). The skeletal component predominantly consists of rudists, benthic foraminifera, calcareous algae, and ostracods (Luperto Sinni and Borgomano, 1989; Spalluto et al., 2005; Checconi et al., 2008).

The lower part of the Calcare di Altamura Fm, cropping out in the southeastern Murge, was informally subdivided by Luperto Sinni and Borgomano (1989) into three members: the loferitic member (late Turonian? - Coniacian *p.p.*); the stromatolitic member (Coniacian *p.p.* – Santonian *p.p.*); the *Gorjanovicia* member (Santonian *p.p.* – early Campanian *p.p.*). Similar to the informal members of the Calcare di Bari Fm, also these members cannot be reliably used for lithostratigraphic correlations due to the lack of verified identification and lateral continuity in the region. The stratigraphic succession of these three members exhibits a deepening-upward trend related to the increasing abundance of rudist-dominated lagoonal lithofacies within peritidal and subtidal facies sequences (Luperto Sinni and Borgomano, 1989; Reina, 1993).

At the end of Cretaceous, the Apulia Carbonate Platform experienced an extensive period of exposure, spanning from the end of Cretaceous up to the Pliocene. This prolonged exposure facilitated the development of karstic features that still characterise both the surface and subsurface of the region. The Murge and Premurge area (*i.e.*, the area of the Bradanic Trough closest to the flank of the Murge) bear evidence of this long exposure. However, their present-day geological configuration results from the Apennines orogenesis, which started during late Oligocene (Boccaletti et al., 1990; Patacca and Scandone, 2007), when the Adria Plate began to subducting beneath the Alpine-Betic thrust belt and was progressively involved in the Apennines accretionary wedge (Doglioni et al., 1999). Apennines foredeep depocenters shifted towards east-northeast (Ricci Lucchi, 1986; Boccaletti et al., 1990) and Oligo-Miocene deposits were tectonized and incorporated in the accretionary wedge. Younger (Plio-Pleistocene) foredeep deposits are less deformed and are well exposed in southern Italy due to a significant Quaternary uplift that has affected the entire southern Apennines orogenic system, including the chain, the foredeep and the foreland settings (Tropeano et al., 2002a; 2002b). This allows to observe, during this field trip, stratigraphic, sedimentological, and tectonic features within foredeep successions as well as contrasting geomorphologic aspects developed along the outer margin of the southern Apennines foredeep system (*i.e.*, Premurge), particularly along canyons locally known as "*gravine*" in the Premurge area (Stop 2 – The Calcarenite di Gravina Fm of Gravina in Puglia). Here, thin marine deposits belonging to the Bradanic Trough sedimentary cycle overlie faulted blocks of the Murge Cretaceous limestones (Fig. 7). The return of the sea during the Late Pliocene on rocks exposed since the end of the Cretaceous has been attributed to subsidence induced by the eastward rollback of the Adria Plate (Doglioni et al., 1994; Cicala et al., 2021). This subsidence led to a significant transgression onto fault-displaced blocks of Murge, except for its highest part. This part forms a large NW-SE trending plateau (*i.e.*, the "Murge Alte" or "Alta Murgia"), approximately 15-20 km by 60-80 km and standing about 500-600 m above sea level. It is flanked by fault-bounded displaced blocks that represents, towards the southwest, the bedrock of the foredeep (starting with the Premurge area), and towards the northeast, a staircase of plateaux dipping towards the Adriatic Sea (*i.e.*, the "Murge Basse" plateau) (Fig. 2). Between the displaced blocks of the Murge Basse, two narrow and regionally elongated main grabens occur (Iannone and Pieri, 1982; Tropeano et al., 1997). During the transgression, ancient karstic surface-features of Murge were largely erased, except for those located in the uppermost part (*i.e.*, Murge Alte), which remained above the sea level. The transgression is recorded by a long-term ravinement surface (*sensu* Liu and Gastaldo, 1992) accompanied by the deposition of shallow-marine carbonates (the Calcarenite di Gravina Fm); this is followed, through a drowning unconformity (*sensu* Schlager, 1989), by silty clay hemipelagites (the Argille subappennine Fm), upward passing to coarse-grained deposits (Pieri et al., 1996; Sabato, 1996a; Sabato et al., 2004) recently defined as the Monte San Marco Fm (Pieri et al., 2017) (Fig. 7).

During the late Pliocene and early Pleistocene, coarse-grained, bioclastic and locally mainly lithoclastic carbonate

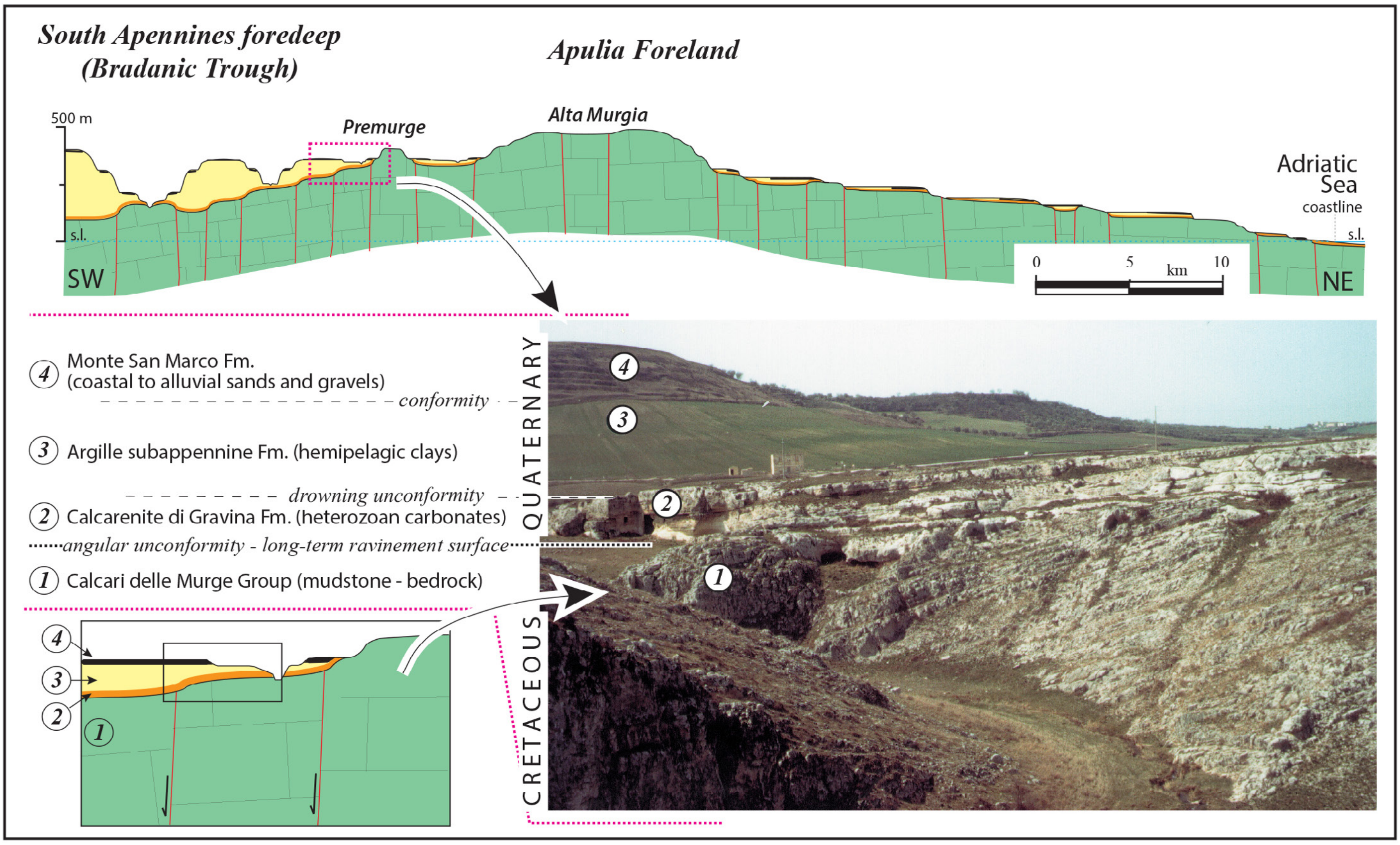

Fig. 7 - Above: geological section showing the close relationship between Alta Murgia and Premurge units; below: detail of the stratigraphy of Premurge. Photo: the outer foredeep geology is well exposed thanks to the river incision (from Tropeano and Sabato, 2000).

systems developed on faulted Cretaceous bedrock of the Apulia Foreland in southern Italy (Iannone and Pieri, 1979; 1982). This carbonate bedrock, representing the exposed outer foreland basin of the Apennines Chain, became a wide slow-drowning archipelago during Late Pliocene and Early Pleistocene foreland subsidence (Tropeano et al., 2002a; 2002b) (Fig. 8). The inherited faulted bedrock exerted significant control over the development of depositional systems, which varied both along strike and over time due to the diverse physiographic conditions encountered by the carbonate factories during the long-term subsidence-induced transgression (Tropeano and Sabato, 2000). In the Murge area, these deposits belong to the Calcarenite di Gravina Fm (Azzaroli, 1968; Azzaroli et al., 1968), but similar and coeval deposits cropping out in the entire Apulia Foreland are known by other formational names. The following description enclosed the entire suite of carbonate deposits developed during the Plio-Pleistocene subsidence of the Apulia Foreland, even though the field trip crosses the Murge area.

Pliocene-Pleistocene carbonate sedimentation in the Apulia Foreland developed in several bedrock-constrained settings: (i) in shallow-sea basins (grabens) separated by exposed morpho-structural highs (horsts) (Iannone and Pieri, 1979); (ii) on drowned morpho-structural highs (horsts), where flat top of submerged islands became sea-banks (Tropeano and Sabato, 2000); (iii) on variably inclined sloping sides of islands (Tropeano and Sabato, 2000; Pomar and Tropeano, 2001); (iv) on steep slopes flanking flat shallow-marine areas (Tropeano et al., 2004; Mateu-Vicens et al., 2008). These features were controlled by the vertical fault displacement (ranking from a few metres up to about 100 m) and by the horizontal spacing of block-bounding faults affecting the bedrock. Highly-spaced faults with a relatively small displacement led to the development of homoclinal ramps with bioclastic sedimentation (Tropeano and Sabato, 2000). Closely-spaced faults led to the development of relatively steeper ramps, where along-dip sigmoidal bodies composed of either bioclastic or mixed bio-lithoclastic carbonate sediments were deposited. Highly-spaced faults with displacements of few tens of metres create a step-like morphology associated with either bypassed cliffs or coarse-grained deltas made up of carbonate extraclasts (Sabato, 1996b; Tropeano and Sabato, 2000) (*i.e.*, Stop 3 – A carbonate Gilbert-type delta (Early Pleistocene) in the Calcarenite di Gravina Fm at Minervino); these settings also produced bioclastic "isolated" base-of-slope aprons or fan-shaped bodies if fed by a shallower carbonate factory (Tropeano et al., 2004; Mateu-Vicens et al., 2008; Longhitano et al., 2021; Tropeano et al., 2021).

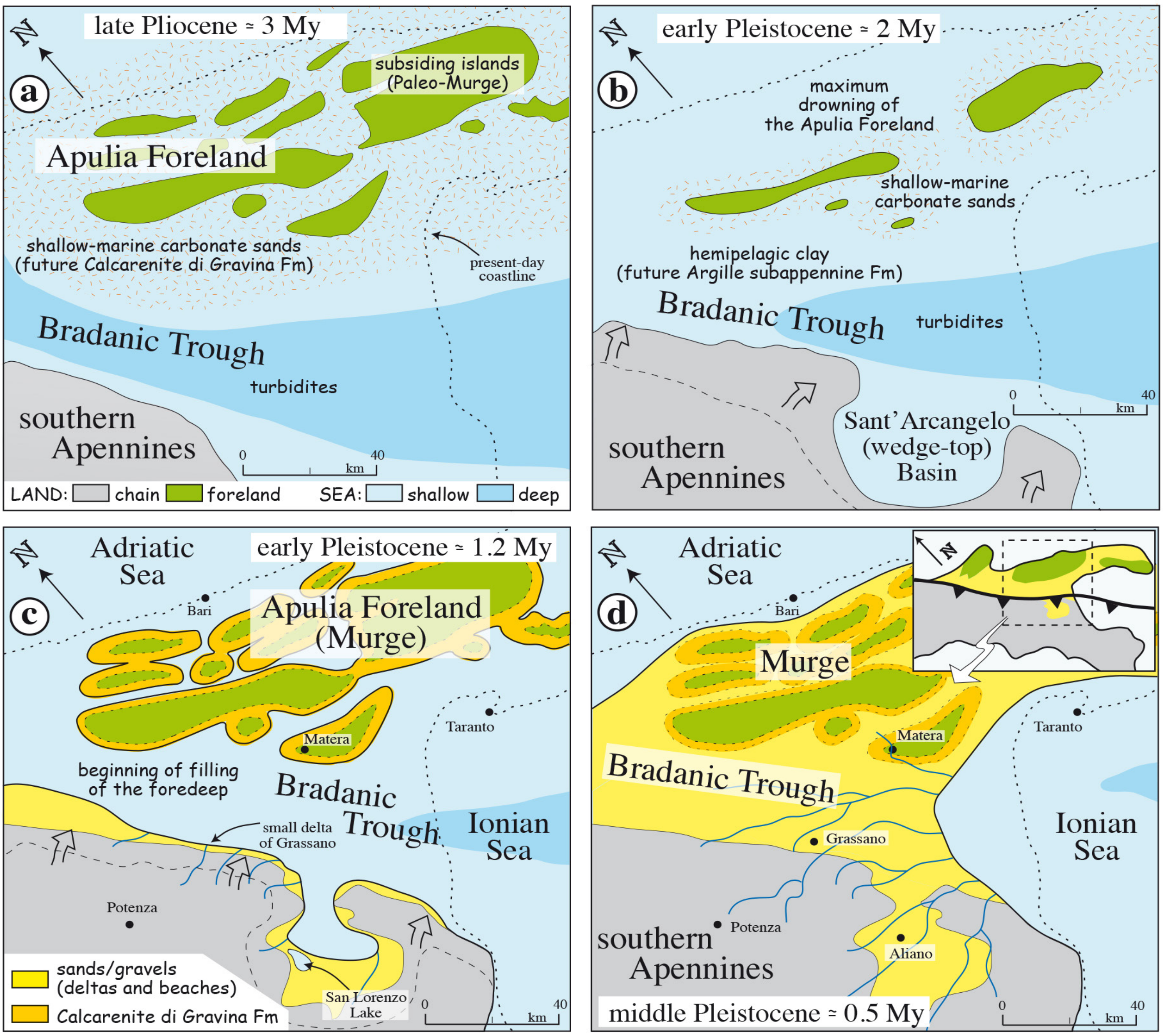

Fig. 8 - Palaeogeographic evolution of the southern Apennines foreland basin systems from Late Pliocene to Middle Pleistocene (from Sabato et al., 2019).

These carbonates, related to a subsidence regime induced by the flexure of the Apulia Foreland, show a clear relationship between tectonics and sedimentation. This relationship was firstly documented in the Matera area, where growth structures resulting from normal/transtensional faults were observed along the Bradano and Gravina di Picciano small canyons (Tropeano et al., 1994). Some examples of pre- and syn-tectonic structures in the Calcarenite di Gravina Fm will be observed at Stop 2, with a discussion on tectonics and sedimentation to follow at Stop 3.

Regarding composition, the carbonate grains of the Calcarenite di Gravina Fm are predominantly sand- to gravel-sized bioclasts whose factory, referred to a temperate-water realm (Pieri, 1975), was mainly located in shallow-water depositional environments, often colonised by seagrass. The skeletal components, often fragments and related to epiphytic seaweed production, include bivalves, echinoids, red algae, serpulids, barnacles, brachiopods, gastropods, bryozoans, with benthic foraminifera being much more common than planktonic ones. The distribution and abundance of these components vary depending on the observed depositional setting and/or facies depth. Although both depths of carbonate production and the original size of carbonate particles influence sediment redistribution in bioclastic sedimentary systems (Pomar, 2001; Pomar and Kendall, 2008), shallow-marine hydrodynamic processes within the factory area could produce traction currents, shedding carbonates from the production loci. When slopes were present along the depositional profile, these currents transformed into gravity flows, originating apron-like deposits.

ITINERARY

Stop 1 - The Altamura tracksite of Cava Pontrelli

Coordinates: 40°48'22.74" N, 16°37'28.79" E

The Altamura tracksite is located in a disused quarry pit known as *Cava Pontrelli*, about 30 m deep, in the municipality of Altamura (Fig. 9). To access this site, located 4 km east of Altamura (Fig. 1), it needs to take a country road at km 6 of the SP 235 road, which links the municipalities of Altamura and Santeramo in Colle. This road crosses the disused railway line near Masseria Pontrelli and stops at the quarry gate.

The quarry walls present a unique opportunity to analyse a 50 m-thick succession of well-exposed Upper Cretaceous shallow-water limestones of the Calcare di Altamura Fm (Iannone, 2003; VV.AA., 2020). This succession preserves a palaeosurface of about 17,500 m^2, containing about

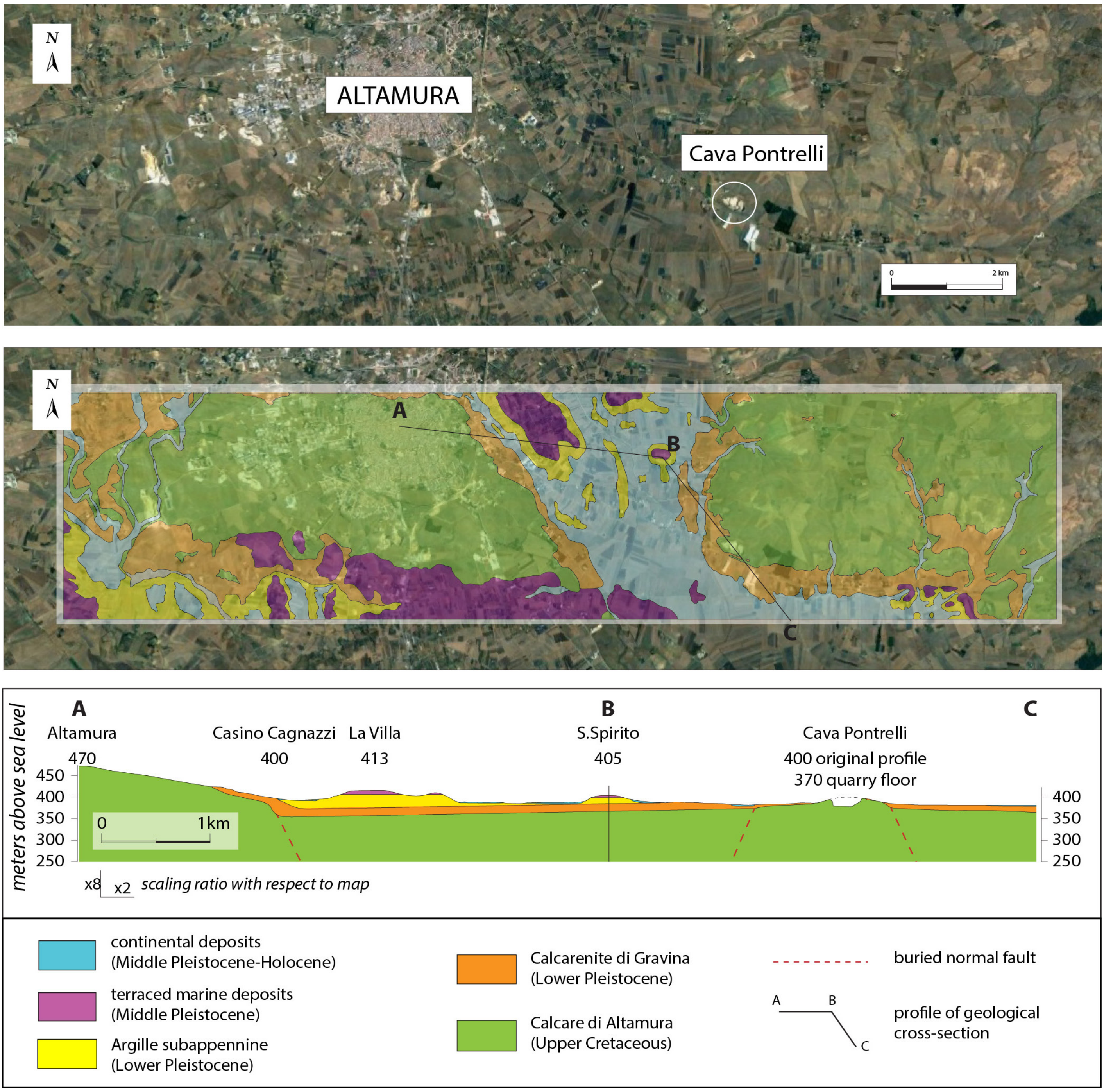

Fig. 9 - Schematic geological and structural map and subsurface stratigraphy of the tracksite area (from Petti et al., 2022).

26,000 footprints of quadruped herbivorous dinosaurs (Nicosia et al., 1999a; 1999b; Petti et al., 2020; VV.AA., 2020; Petti et al., 2022) (Fig. 10). The exceptionally high number of dinosaur footprints, coupled with a dinoturbation index of around 74.2%, and a high degree of trampling (around 13 footprints/m^2) make the largest surface studied worldwide with Upper Cretaceous dinosaur footprints (Petti et al., 2022). Consequently, the *Cava Pontrelli* track-bearing surface is recognised for its palaeontological and geological uniqueness as a geosite of international value. It has been included in both the geosites registry of the Puglia Region (http://193.206.35.15/geoportal/index.php) (Mastronuzzi et al., 2015) and in Italian Geosites Inventory of ISPRA (id: 1717; http://sgi.isprambiente.it/GeositiWeb/default.aspx?ReturnUrl=%2fgeositiweb%2f).

The track-bearing surface gently dips (from 5° to 10°) to S-SW, and is bounded, in plain view, by two NE-dipping, high-angle normal faults, the northeastern and southwestern ones, dominated by dip-slip kinematics (Fig. 11). Vertical offset of about 20 m has been estimated only for the northeastern fault, based on the vertical displacement of three beds of intraformational breccias, which represent a reliable stratigraphic marker (Figs 11 and 12). Due to this structural setting, the carbonate rocks forming the footwall block of the southwestern fault are the relatively older rocks of the whole succession cropping out in the quarry; meanwhile, the ones forming the hanging wall block of the northeastern fault are the relatively younger rocks of the displaced succession. A composite section, of about 50 m-thick (Fig. 12), has been reconstructed starting from the palaeosurface with dinosaur tracks and extending to the rudist beds cropping out at the top of the hanging wall block of the northeastern fault.

The age of this succession is early Campanian (upper part of the *Accordiella conica* and *Rotalispira scarsellai* biozone) based on the benthic foraminifera content (VV.AA., 2020; Petti et al., 2022). It is made up of the following facies association: i) floatstone showing abundant granule- to pebble-sized intraclasts (Fig. 13A); ii) fenestral mudstone/bindstone (Fig. 13B), showing also larger stromatactis-like structures (Fig. 13C); iii) densely-laminated microbial/peloidal bindstone (Figs 13D and 13E); iv) burrowed

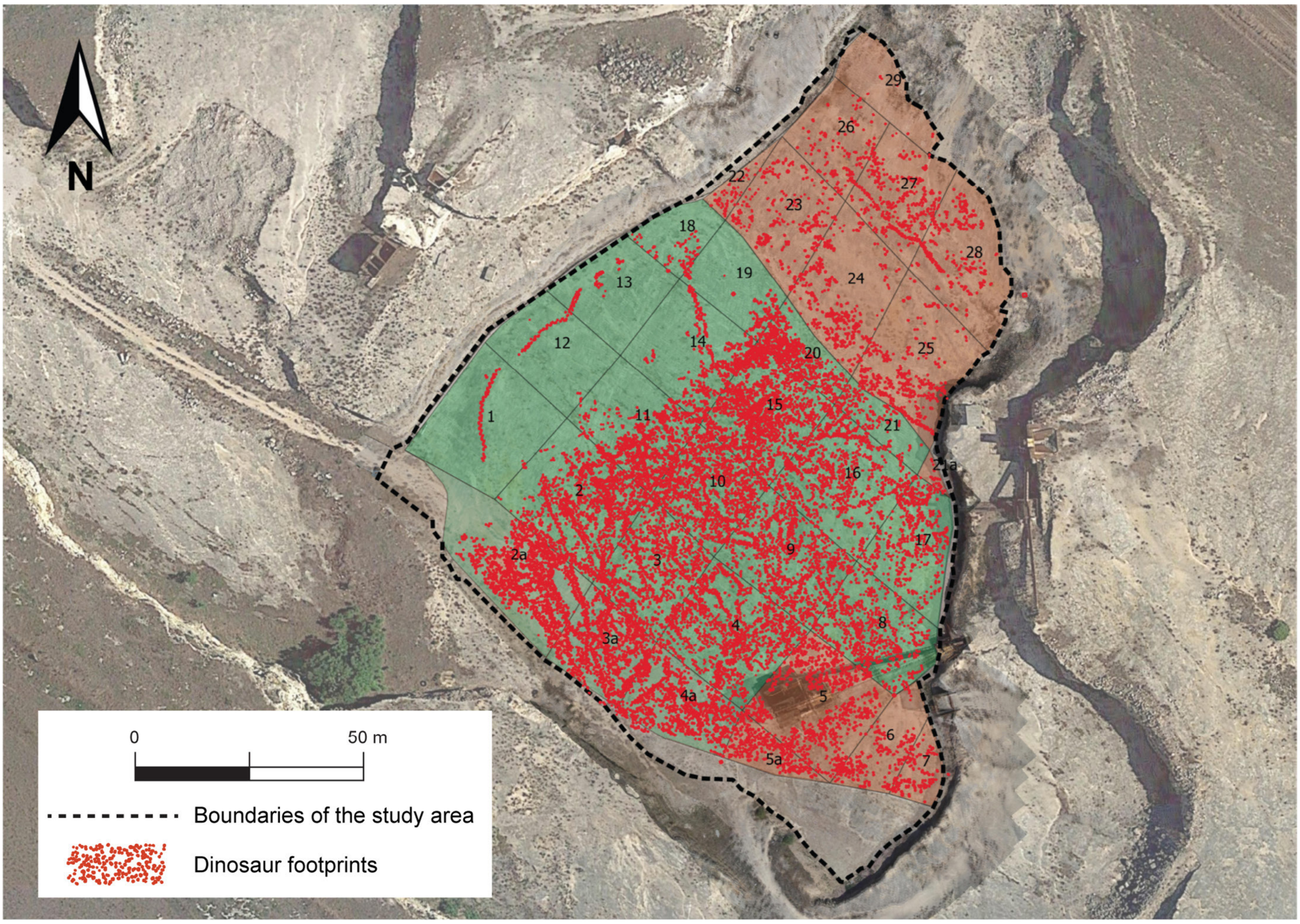

Fig. 10 - Dinosaur tracks distribution on the *Cava Pontrelli* palaeosurface (from Petti et al., 2022).

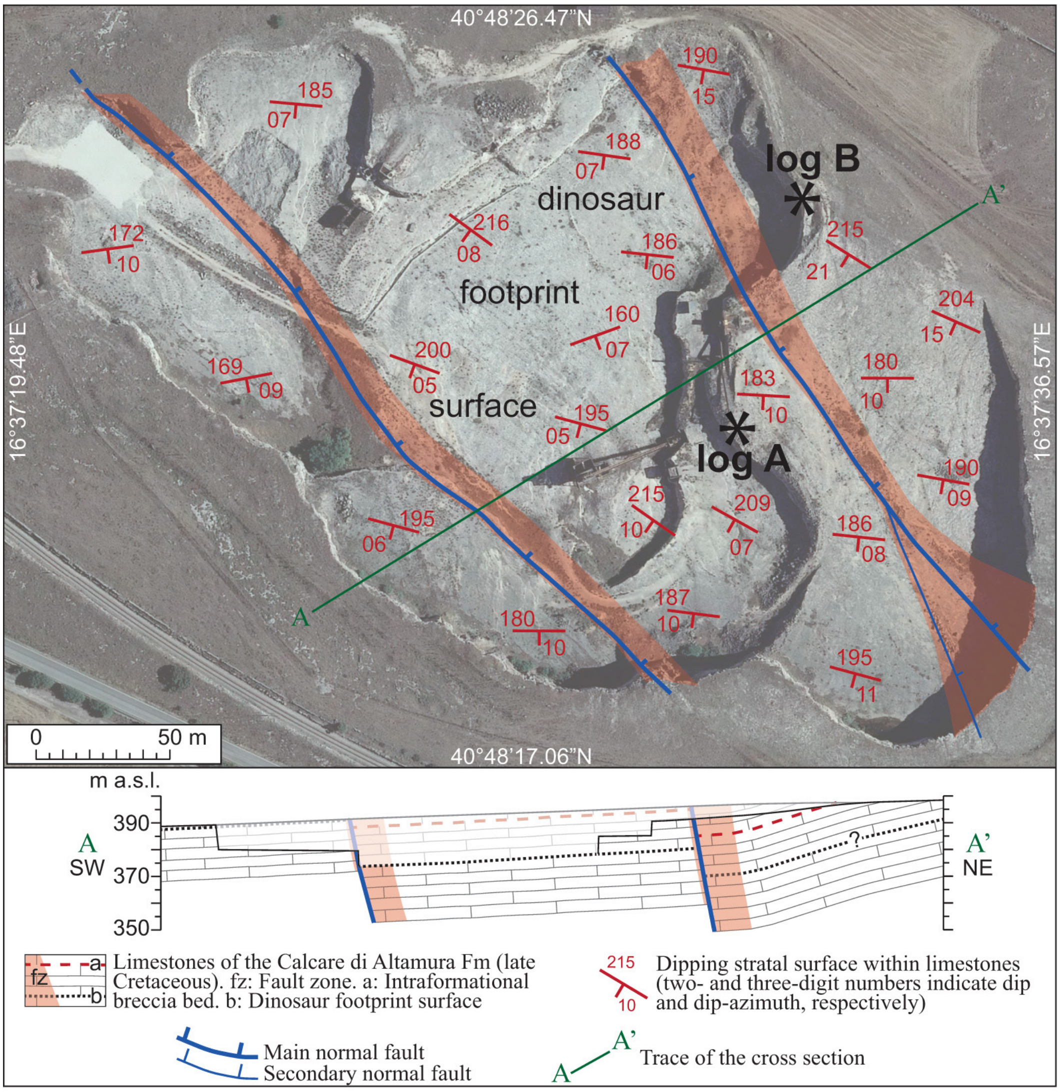

Fig. 11 - Structural sketch-map of *Cava Pontrelli* and cross-section (from Petti et al., 2022).

mudstone/wackestone with ostracods and *Thaumatoporella* sp. (Fig. 13F); v) bioclastic mudstone/wackestone with benthic foraminifera, calcareous algae, and ostracods (Fig. 14A); vi) biopeloidal packstone/grainstone with abundant peloids (mostly micritized bioclasts), small-sized benthic foraminifera (mostly rotaliids) and calcareous algae (Figs 14B, 14C and 14D); vii) bioclastic floatstone mostly formed by rudist debrites with a bioclastic wackestone matrix (Figs 14E and 14F). This facies association formed in shallow-marine, peritidal environments subjected to ephemeral (fenestral mudstone/bindstone) or prolonged (fenestral intraclastic floatstone) subaerial exposure. In such a context, the carbonate factory was productive mostly in the permanently submerged subtidal environment where bioturbated and pelleted lime muds (burrowed mudstone/wackestone) and bioclastic limestones stemming from benthic organisms such as bivalves, benthic foraminifera, and calcareous algae (bioclastic wackestone, bioclastic packstone/grainstone, and bioclastic floatstone) formed in restricted and open lagoons, respectively (VV.AA., 2020). The intertidal environment, alternatively exposed and submerged, represented a low-energy and low-relief repository of allochthonous calcareous particles, born in the subtidal carbonate factory, which can remain trapped in the mucilage of microbial mats (densely laminated microbial/peloidal bindstone). Within each bed or bedset, facies are mostly stacked in shallowing-upward (m-scale) sequences (Iannone, 2003) corresponding to 6th order depositional sequences. These latter are interpreted as the basic building blocks of larger-scale sequences (5th and 4th order small- and medium-scale sequences, respectively) reflecting Milankovitch cyclicity (VV.AA., 2020). Biostratigraphic data allow the correlation of hierarchically-organised depositional sequences with the eustatic cycle chart (Haq, 2014). Consequently, the cyclostratigraphic analysis has enabled a more precise dating of the succession by correlating the main evidence of subaerial exposure (dinosaur footprints, intraformational breccias) with the published cycle boundaries. Specifically, the palaeosurface showing dinosaur tracks developed during the lower part of the early Campanian, approximately 80 My ago (VV.AA., 2020; Petti et al., 2022).

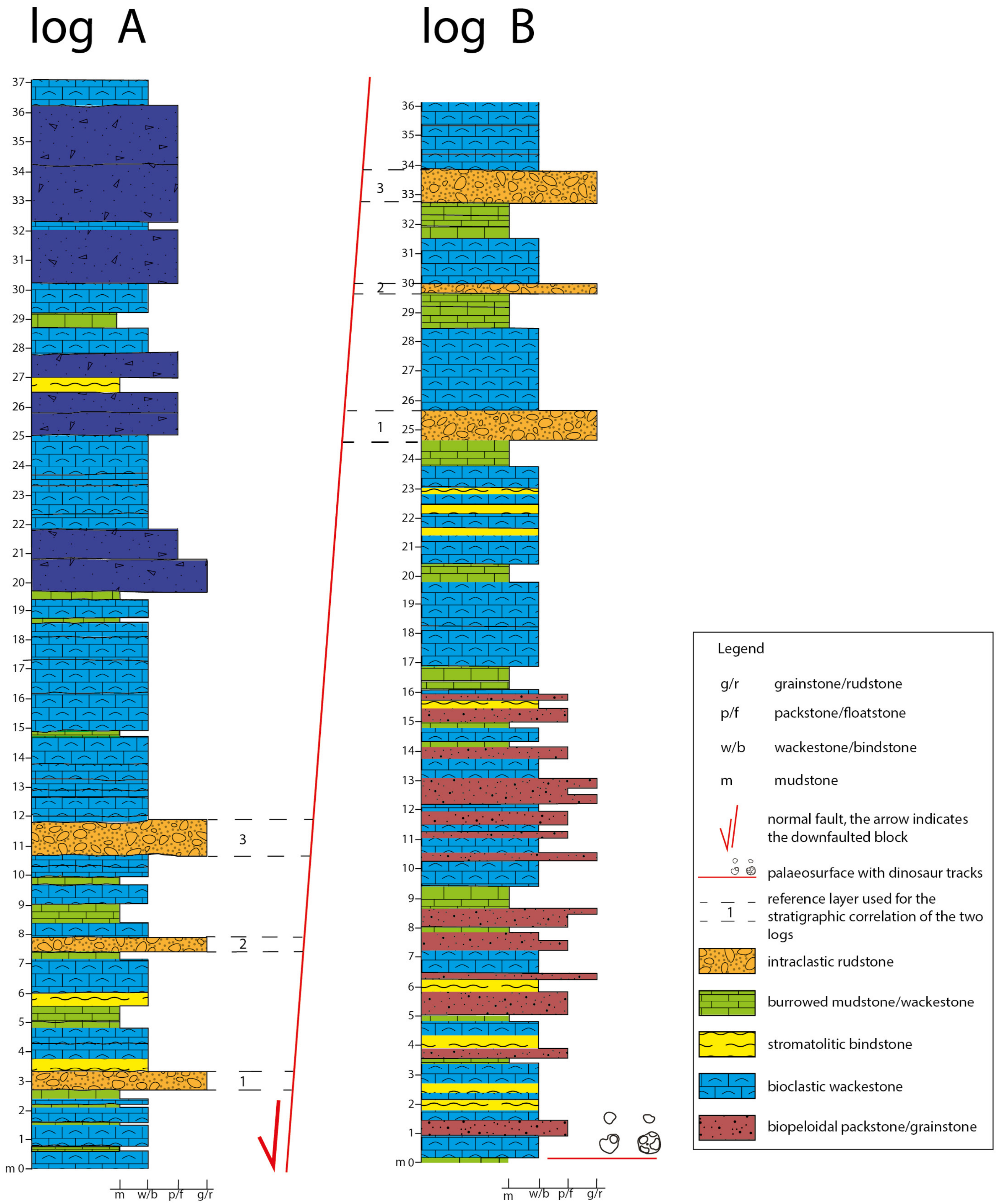

Fig. 12 - Stratigraphic logs of the shallow-water carbonate succession cropping out in the *Cava Pontrelli*. For location of the two logs see Fig. 11.

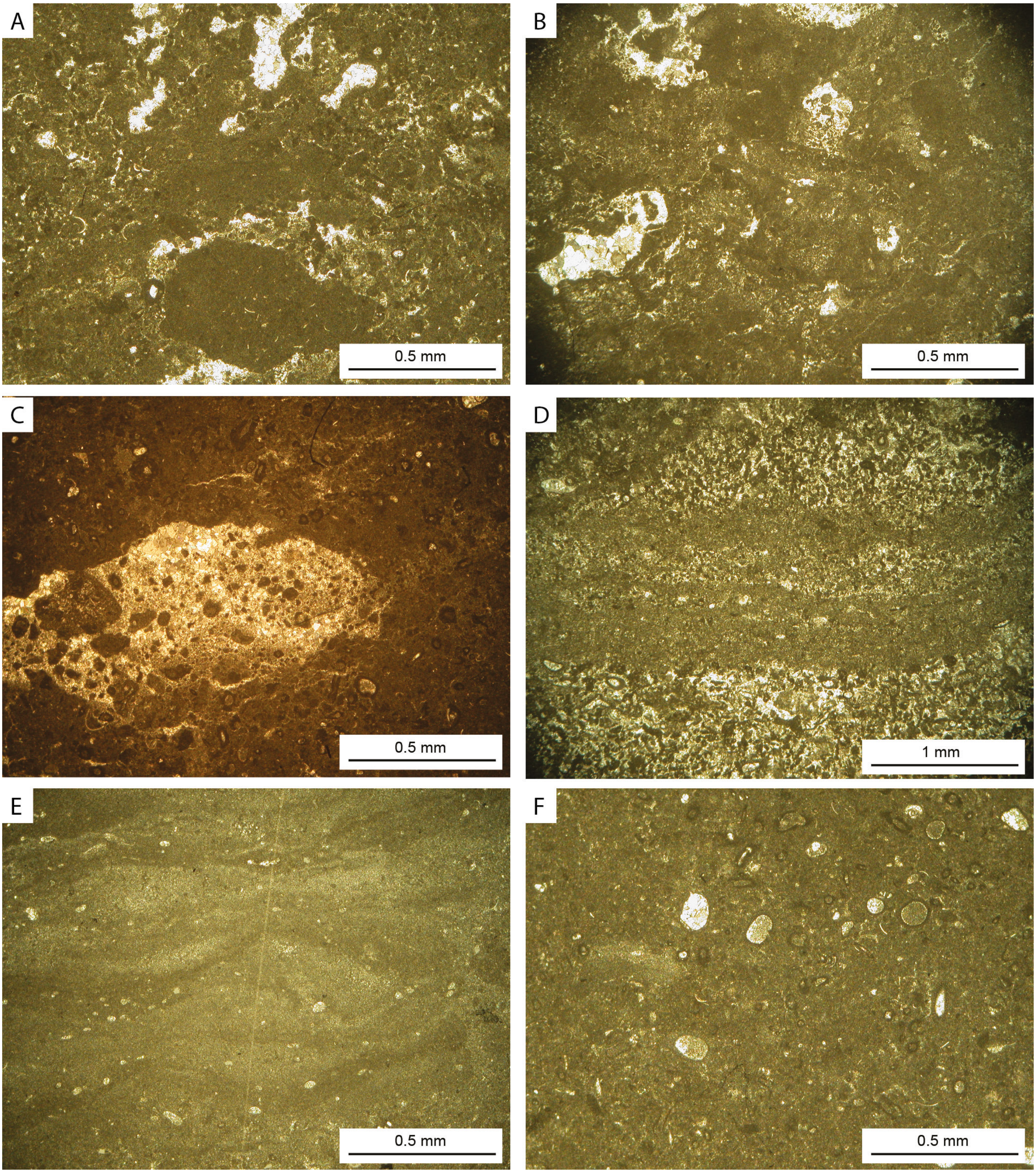

Fig. 13 - A) Fenestral floatstone showing abundant intraclasts; B) fenestral bindstone; C) fenestral mudstone showing stromatactis-like desiccation features; D) laminated peloidal bindstone; E) densely laminated microbial bindstone; F) mudstone/wackestone with abundant ostracod and *Thaumatoporella* sp.

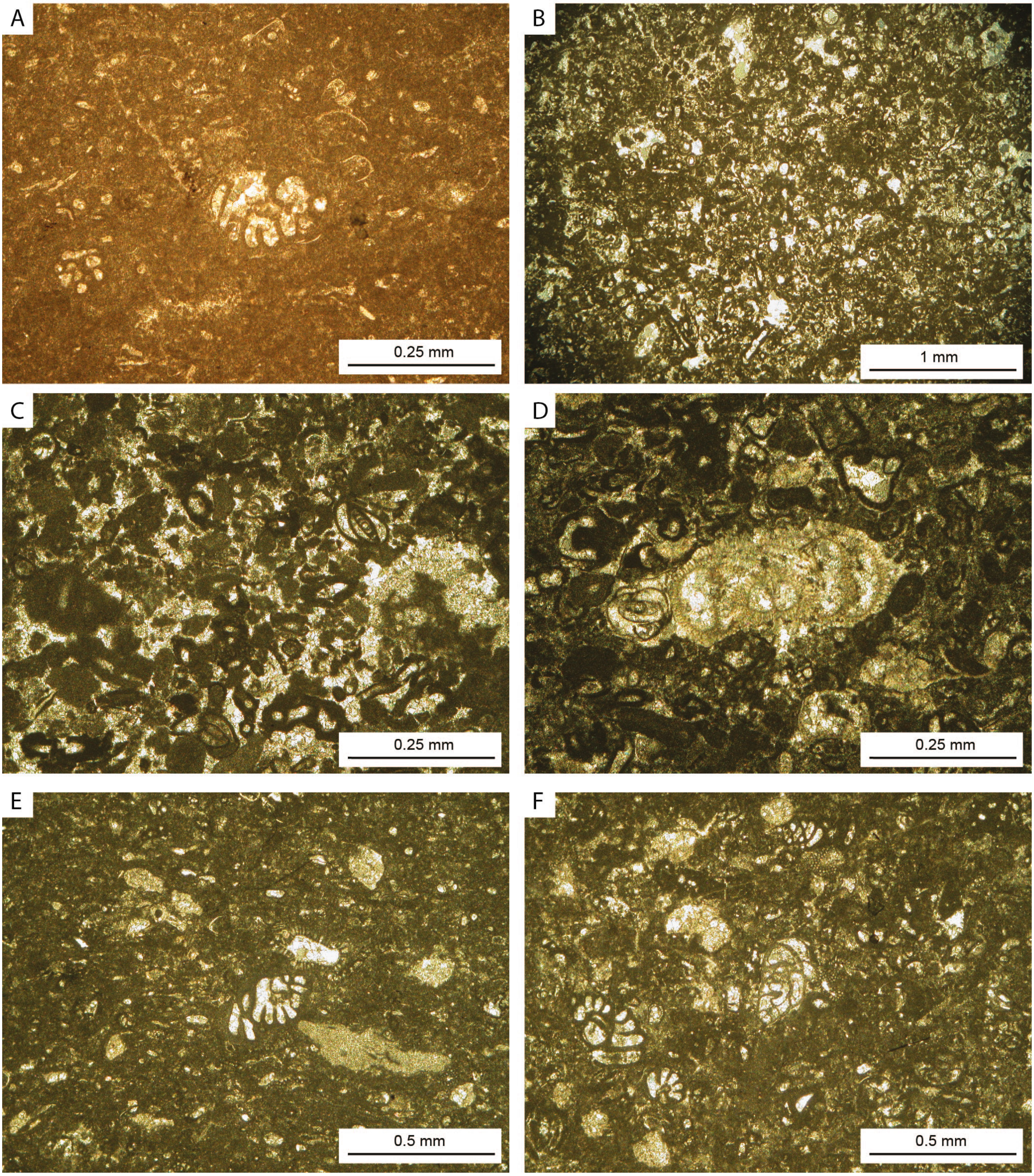

Fig. 14 - A) bioclastic mudstone with benthic foraminifera, calcareous algae and ostracods; B) biopeloidal packstone with abundant small-sized benthic foraminifera; peloids are the result of the micritization of bioclasts; C) biopeloidal packstone with small-sized benthic foraminifera and calcareous algae; D) biopeloidal packstone with rotaliids, miliolids and *Thaumatoporella* sp.; E) bioclastic wackestone with benthic foraminifera, rudist fragments and calcareous algae; F) bioclastic wackestone with rudist fragments and benthic foraminifera.

Stop 2 - The Calcarenite di Gravina Fm of Gravina in Puglia

Coordinates 40°49'32.87" N, 16°24'37.70" E

Gravina in Puglia is a town located in the southwest Metropolitan Area of Bari (Fig. 1), with about 44,000 inhabitants. The territory is characterised by the presence of the "*gravina*", term used in Puglia to indicate a peculiar karst superficial feature characterised by a deep, narrow V-shaped canyon with high and steep borders (Parise et al., 2003). This small canyon is named "*Gravina* di Gravina" (cut by the *Torrente Gravina* stream) (Figs 15A and 16), with the slopes reaching a maximum of ca. 65 m. The old town of Gravina in Puglia, dating from late Middle Ages up to XVIII century, is situated on the left side of the canyon (Fig. 15A), while, on both sides of the canyon, high Middle Ages rupestrian churches locally occur. The town is located at the boundary between the Apulia Foreland and the Bradanic Trough (Fig. 16), and the geological features of both these structural settings can be observed in the Gravina in Puglia area.

The canyon offers hundreds of meters laterally continuous natural-sections, where the main stratigraphic units characterising the area, *i.e.*, the Calcarenite di Gravina Fm (Pliocene-Pleistocene) unconformably overlying the Calcare di Altamura Fm (Cretaceous) (Fig. 15B and 15C), crop out. Throughout these natural sections, relationships between tectonics and sedimentation occurred before and during the deposition of the Calcarenite di Gravina Fm can be observed. A geological survey was carried out at 1:5,000 scale along the northern "*Gravina* di Gravina" area (Fig. 17). In order to highlight these features, mainly syn-tectonic ones, we propose an easy walk path starting from the stadium park (Fig. 17). The path includes two panoramic points (Stops 2a and 2b), with additional optional points suggested (Stops 2c, 2d, and 2e).

Stop 2a can be easily reached by descending the slope behind the stadium park (Fig. 17) and rising up to the top of a small, isolated hill. The natural section in front

Fig. 15 - a) Panoramic view of the "*Gravina* di Gravina" canyon. The old town (Piaggio and Fondovico districts in the photo) expanded from the late Middle Ages up to XVIII century. K=Cretaceous; P=Plio-Pleistocene. b) and c) respectively right and left walls of the "*Gravina* di Gravina" canyon. Middle Ages rupestrian churches, called *Madonna della Stella* and *San Michele delle Grotte* were dug in the Calcarenite di Gravina Fm. Note the angular unconformity between the Cretaceous and the Plio-Pleistocene formations.

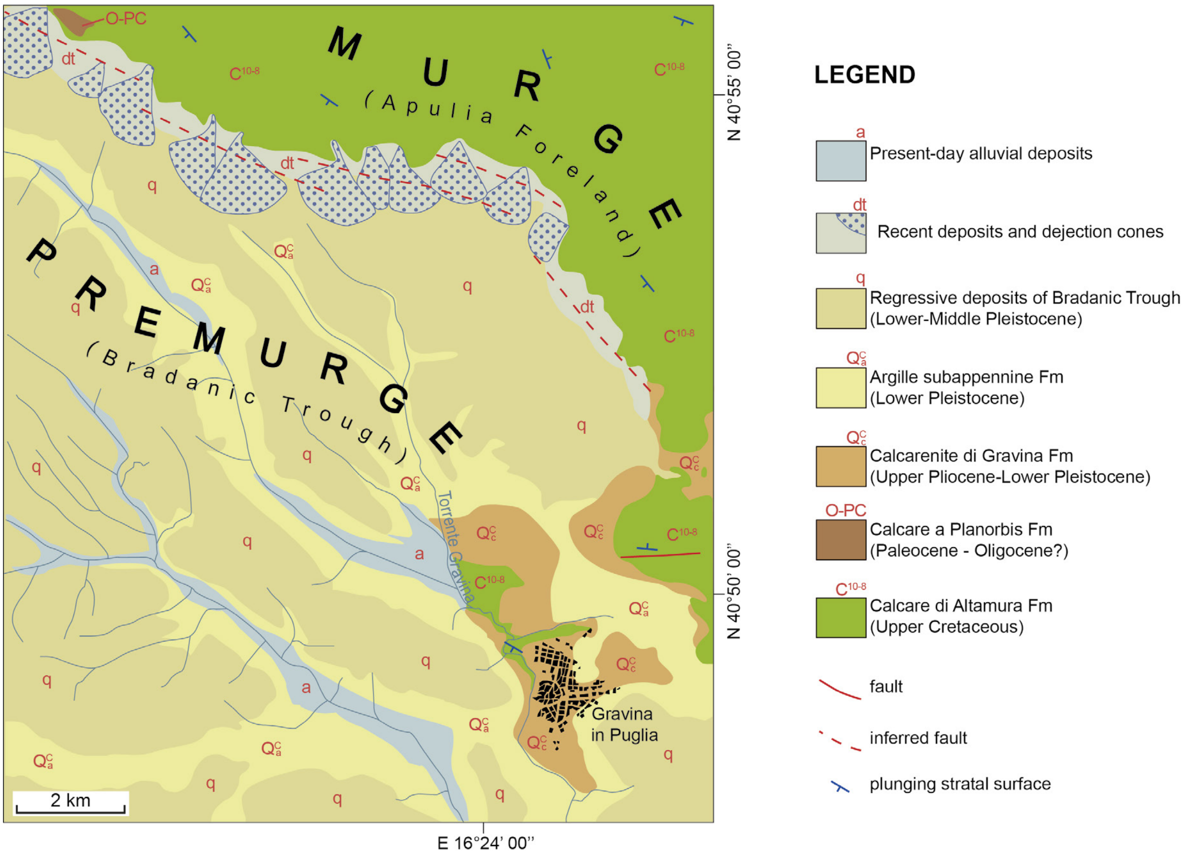

Fig. 16 - Simplified and redrawn Geological Map of Italy (Servizio Geologico d'Italia, 1966).

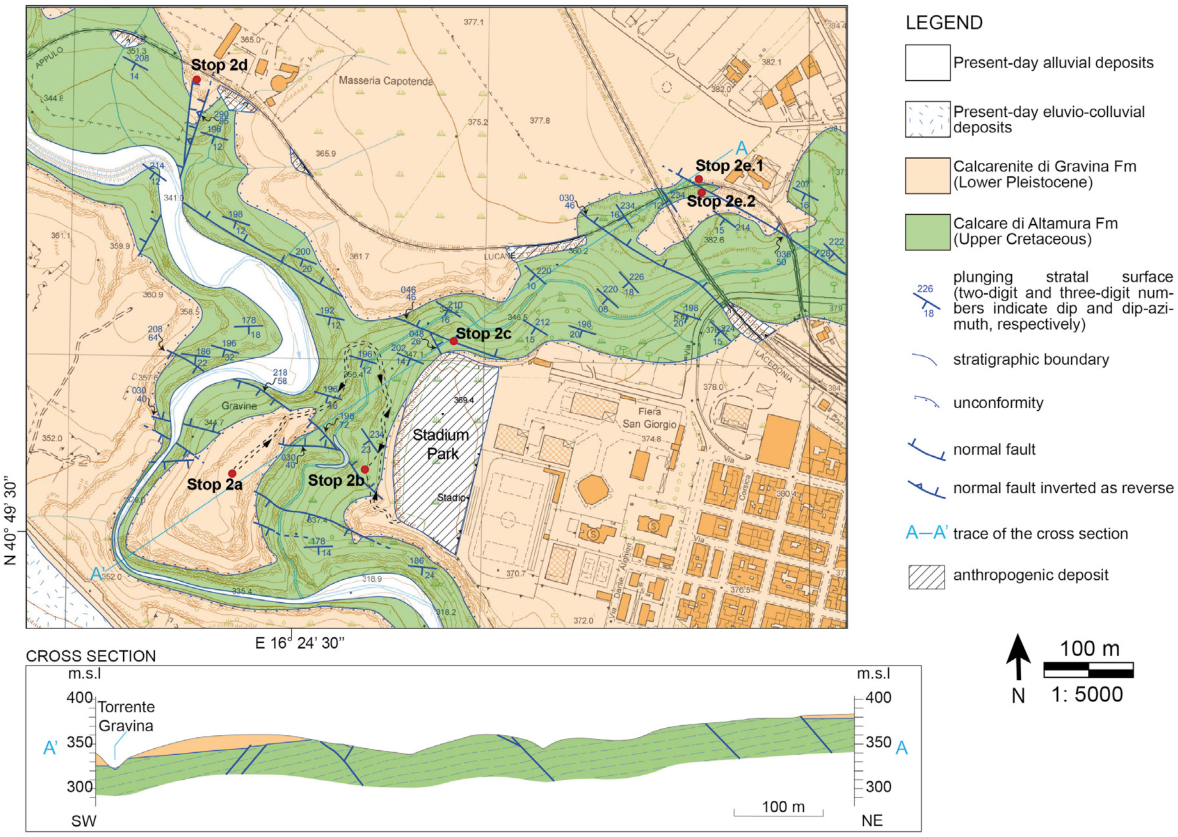

Fig. 17 - Geological map and related cross section of the northern part of the "*Gravina* di Gravina" canyon, surveyed at 1: 5,000 scale. See location in Fig. 16.

of us provides a wide panorama of the eastern side of the "*Gravina* di Gravina" canyon (Figs 7 and 18A). From here, the unconformity between Calcare di Altamura Fm and the Calcarenite di Gravina Fm (indicated by the blue line in Fig. 18B) is clearly visible in the foreground. Looking toward SW, a raised block of Cretaceous limestone is bounded by two faults; the NE-dipping normal fault to the right controls the deposition of the Pliocene-Pleistocene calcarenites, whose hanging wall is filled by syn-tectonic sediments (Fig. 18B). Further NE, a normal fault striking NW-SE and its related antithetic fault dislocate the contact between the Cretaceous bedrock and the Calcarenite di Gravina Fm (Fig. 18B).
Stop 2b can be reached by returning to the stadium park after a short path from the previous stop (Fig. 17). The most eye-catching structure of the panorama view is a high-angle NE-dipping normal fault cutting the Calcare di Altamura Fm and controlling the sedimentation of Calcarenite di Gravina Fm on the hanging wall of the fault (Fig. 19A). This represents an example of syn-sedimentary fault, where the accommodation space created on the hanging wall was filled by syn-tectonic sediments. In this case, the NE-dipping normal fault was active during the early stage of deposition of the Calcarenite di Gravina Fm. With respect to the NE-dipping fault, looking to the right, a SW-dipping fault (Fig. 19B) also displaces the bedrock and affects the deposition style in the lowest part of the Calcarenite di Gravina Fm. Furthermore, these two faults form a graben structure transferred from the Cretaceous limestones to the base of Pliocene-Pleistocene calcarenites. The crosscutting relationship between the two faults is challenging to

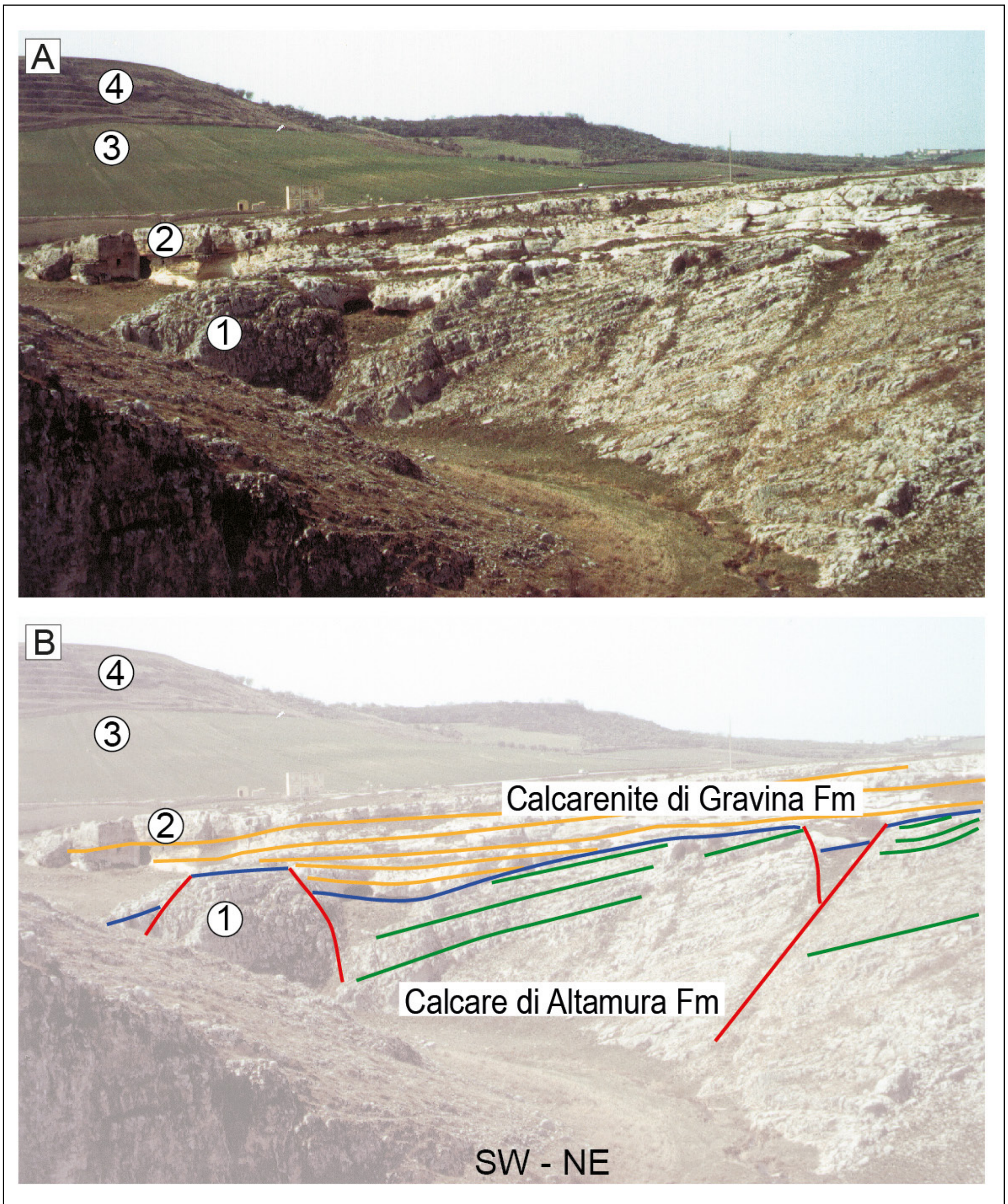

Fig. 18 - A) Panoramic view observed from Stop 2a (location in Fig. 17); B) note some steps in the unconformity (blue line) between the Calcare di Altamura Fm and the Calcarenite di Gravina Fm, corresponding to faults (red lines) controlling the deposition of the Plio-Pleistocene calcarenites, showing a slightly growth (orange lines).

interpret, as the intersection area is characterised by a thick volume of breccia and covered by present-day alluvial deposits. Looking further SW from this stop, two additional SW-dipping normal faults can be recognised, as they down through the top of the Cretaceous bedrock towards SW (Fig. 19B).

Optional Stop 2c (Fig. 17) is easily accessible descending the slope behind the stadium park (Fig. 17). The natural section in front of us (Fig. 20A) shows a NE-dipping fault dominated by dip-slip kinematics, affecting only the Calcare di Altamura Fm and being stratigraphically sutured by the Calcarenite di Gravina Fm (red line in Fig. 20B). This is an example of pre-tectonic activity respect to the sedimentation of the Calcarenite di Gravina Fm. Moreover, from this view, an angular unconformity between the Calcare di Altamura Fm and the Calcarenite di Gravina Fm can be clearly observed (blue line in Fig. 20B); above the unconformity, the Plio-Pleistocene calcarenites occur in sub-horizontal beds (orange lines in Fig. 20B).

Optional Stop 2d (Fig. 17) is located alongside the railway and shows some stratigraphic peculiarities of the Calcarenite di Gravina Fm (Fig. 20C). In the central part of the outcrop (Fig. 20D), the layers of Plio-Pleistocene calcarenite (orange lines) appear slightly folded, forming an anticline at macroscopic scale; the outcrop is affected by fractures (red dashed lines in Fig. 20D). Notably, younger strata on the flanks of the anticline became progressively sub-horizontal (Fig. 20D). The contact between the Calcare di Altamura Fm and the Calcarenite di Gravina Fm (blue line in Fig. 20D) occurs nearly at the ground level.

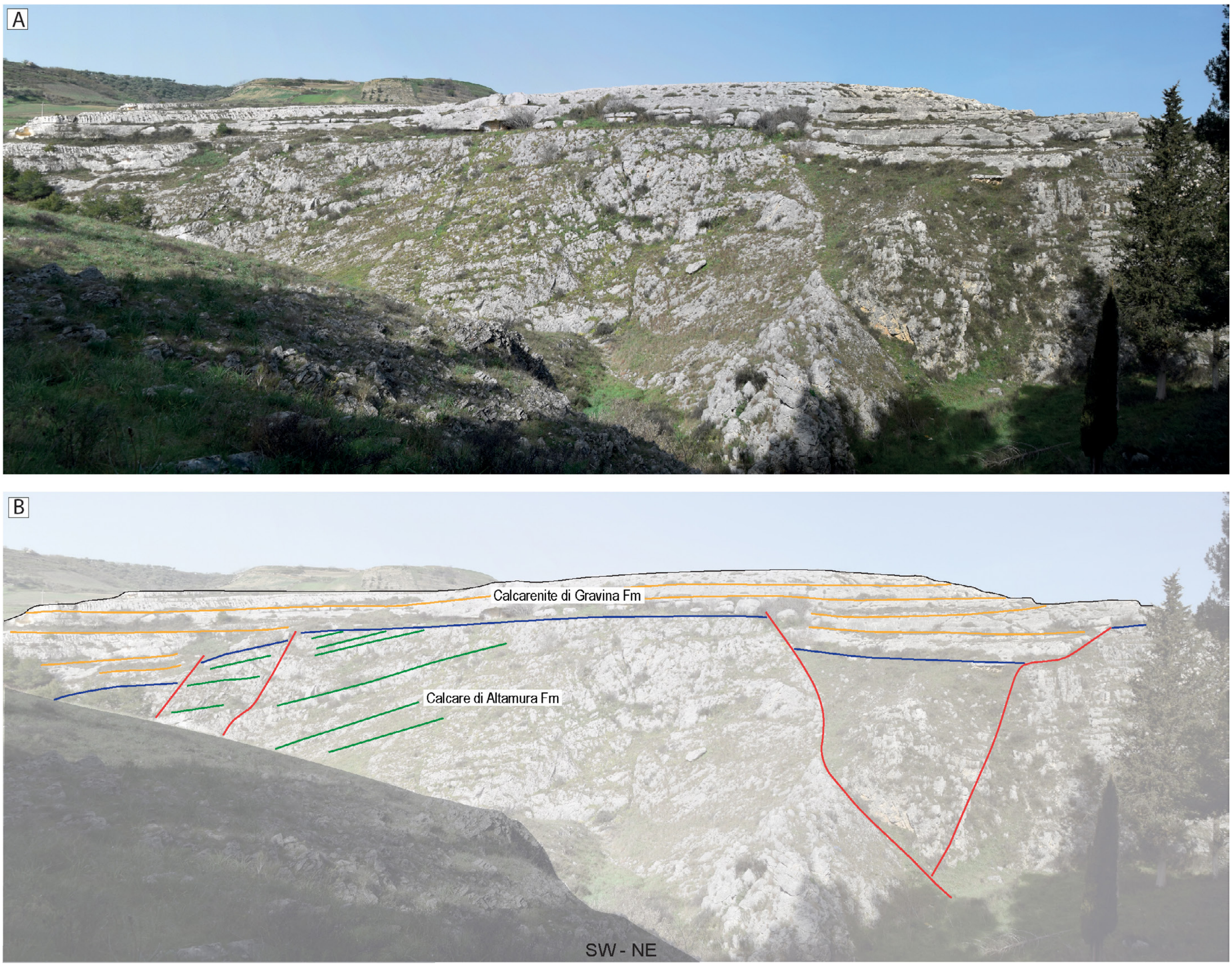

Fig. 19 - A) Panoramic view observed from the Stop 2b (location in Fig. 17); B) line drawing of picture A; the unconformity between the Calcare di Altamura Fm and the Calcarenite di Gravina Fm (blue line) is evident; the internal stratification of the two formations is highlighted by green lines and orange lines, respectively. Towards NE, opposite-dipping normal faults (red lines) controlled the syn-sedimentary deposition of Calcarenite di Gravina Fm, forming a graben structure in which the growth of calcarenite can be seen. Two SW-dipping normal faults can be noted in the SW part of the outcrop.

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Optional Stop 2e (Fig. 17) is located along a railway cut, showing two opposite and well-exposed sections (Stop 2e.1 and 2e.2). Focusing on the outcrop related to the Stop 2e.1 (Fig. 20E), a dip-slip normal fault striking NW-SE can be observed, with the related up to 50 cm thick fault breccia (red line and dotted area in Fig. 20F). This breccia is composed by chaotic limestones fragments embedded in a calcarenite matrix. The footwall (on the right in Fig. 20F) predominantly consist of the Calcare di Altamura Fm, with strata dipping towards SW (green lines in Fig. 20F), overlain by no more than a few decimetres of Plio-Pleistocene calcarenite (above the blue line,

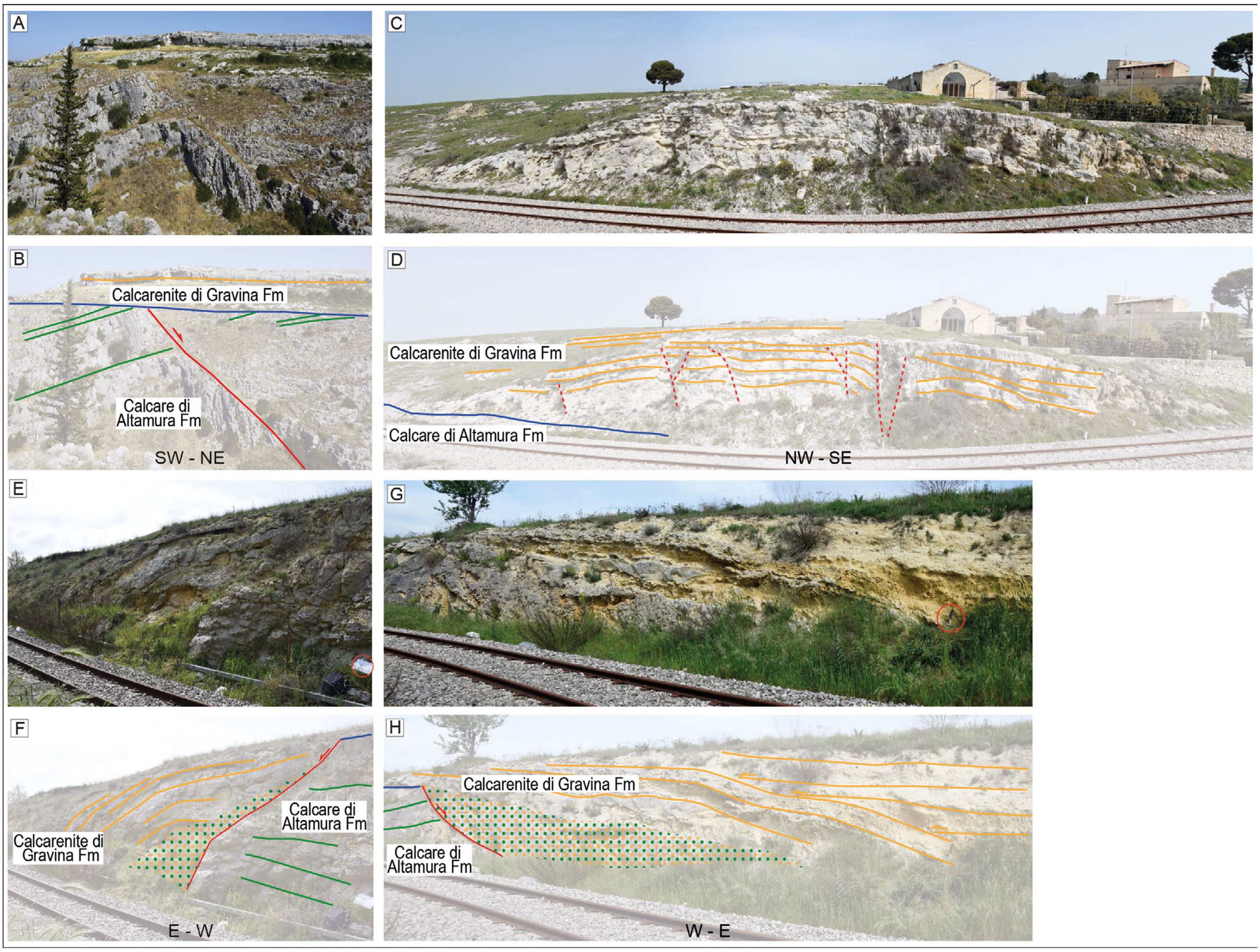

Fig. 20 - A) Panoramic view observed from the Stop 2c (location in Fig. 17); B) line drawing of the Stop 2c. Note the angular unconformity (blue line) between the Calcare di Altamura Fm (whose stratification coincides with green lines) and the Calcarenite di Gravina Fm (orange line). The NE-dipping fault in the Calcare di Altamura Fm (red line) is sutured by Pliocene-Pleistocene calcarenites, suggesting a pre-tectonic activity with respect to the deposition of Calcarenite di Gravina Fm; C) panoramic view of the outcrop observed from the Stop 2d (location in Fig. 18); D) the line drawing of the Stop 2d highlights the slightly folded layers of Pliocene-Pleistocene calcarenite (orange lines) forming an anticline, whose strata became progressively sub-horizontal, indicating the end of deformation during the sedimentation. At the ground level, towards NW, the contact between the Calcare di Altamura Fm and the Calcarenite di Gravina Fm is indicated by the blue line. E) panoramic view observed from the Stop 2e.1 (location in Fig. 18). F) the line drawing of the Stop 2e.1 shows the SW-plunging stratification of the Calcare di Altamura Fm (green lines), and the contact between the Calcare di Altamura Fm and the Calcarenite Fm (blue line). The Cretaceous limestones are disrupted by a dip-slip normal fault (red line) with the related fault breccia (dotted area). The hanging wall of the fault is entirely occupied by the Calcarenite di Gravina Fm, whose strata curve towards the fault plane and the related fault breccia (stratal surface of the Calcarenite di Gravina Fm indicated by orange lines). G) Panoramic view observed from the Stop 2e.2 (location in Fig. 18). H) the line drawing of the Stop 2e.2 shows that the outcrop is affected by the same fault as observed in the Stop 2e.2 (red line), passing sharply to a fault breccia (dotted area). The unconformity between the Calcare di Altamura Fm and the Calcarenite di Gravina Fm is defined by the blue line, whereas the stratification in the Cretaceous limestones and in the Plio-Pleistocene calcarenites are represented by the green lines and orange lines, respectively. It can be noted that, above the fault breccia, syn-tectonic layers of the Calcarenite di Gravina Fm are overlapped by the post-tectonic ones with an onlap configuration.

Fig. 20F). At the outcrop scale, the hanging wall of the fault is represented by the Calcarenite di Gravina Fm, which strata curve towards the fault plane and the associated fault breccia (orange lines in Fig. 20F). The Stop 2e.2 (Fig. 20G) shows the same fault of the Stop 2e.1 (red line in Fig. 20H), that sharply passes into the fault breccia (dotted area in Fig. 20H). The fault breccia forms a body up 1 m-thick at ground level and thinning towards nearly the top of the Calcare di Altamura Fm; moreover, striae due to the faulting on the Cretaceous limestones are clearly visible. On the footwall of the fault, the Calcarenite di Gravina Fm unconformably lies above the Calcare di Altamura Fm with a total thickness of about 30 cm, whereas on the hanging wall it spans the entire area of the outcrop. Looking eastward from the outcrop, above the fault breccia, syn-tectonic layers of the Calcarenite di Gravina Fm are overlapped by the post-tectonic ones in an onlap configuration (Fig. 20H).

Stop 3 - A carbonate Gilbert-type delta (Early Pleistocene) in the Calcarenite di Gravina Fm at Minervino Murge

Coordinates 41°.4’24.15” N, 16°3’40.32” E

Along the north-western edge of the Alta Murgia scarp, within the shallow-sea carbonate deposits that characterise the Calcarenite di Gravina Fm, a conglomerate deposit consisting exclusively of coarse limestone clasts eroded from the Cretaceous platform succession crops out in a small, abandoned quarry. This deposit has been interpreted as a Gilbert-type delta (Sabato, 1996b).

Near Minervino, a town famous also for a cave and a Sanctuary dedicated to Saint Michael (Cardia et al., 2024), located at the western edge of the Murge Alte plateau, towards the Ofanto Graben, there is a steep escarpment, about 175 m high and N-S oriented (Fig. 21A).

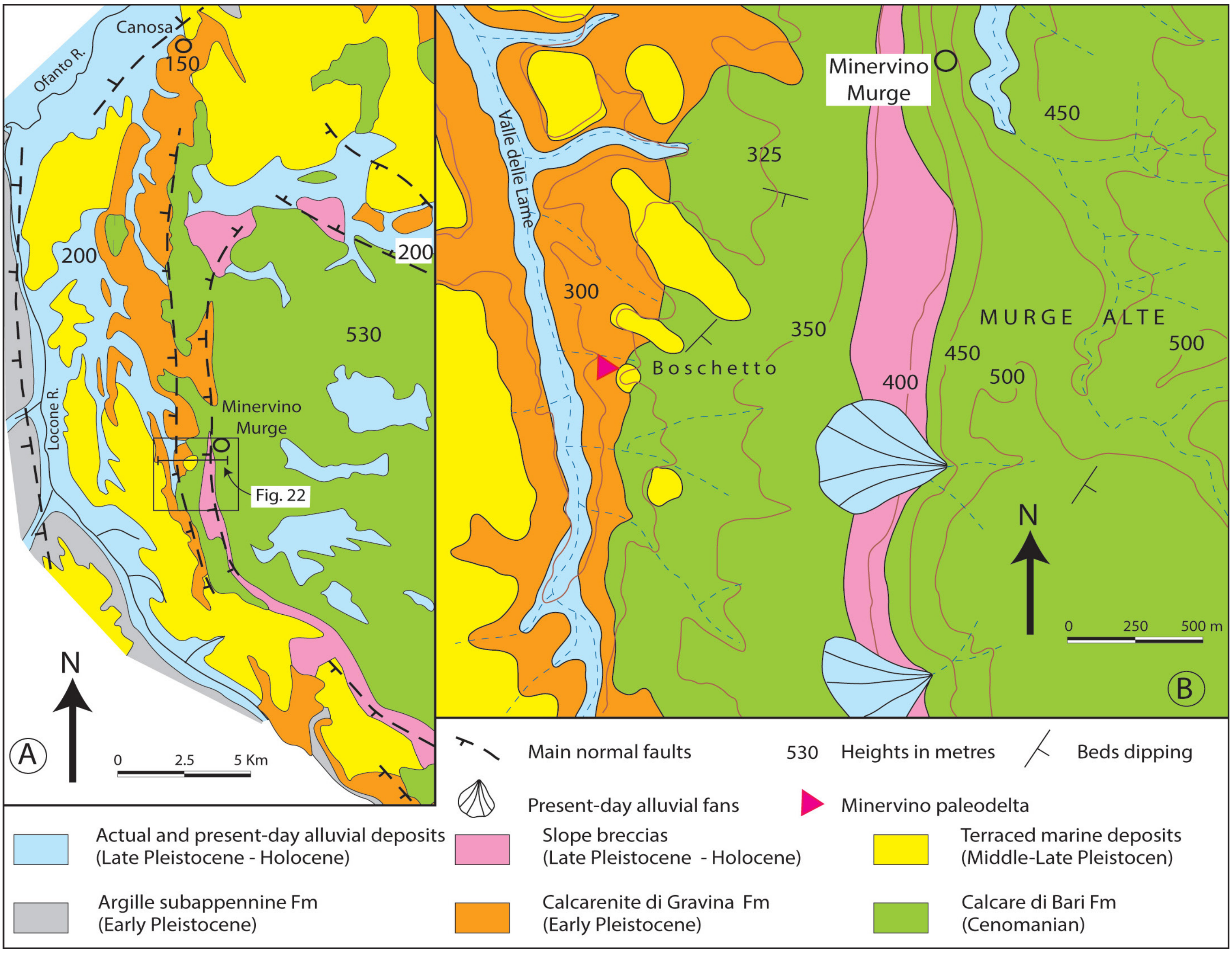

Fig. 21 - A) Simplified geological map of the Minervino Murge area (Ciaranfi et al., 1988, mod.). In the black box the studied area, visible in B: geological map of the studied area; the delta is indicated by a triangle.

This escarpment represents the structural element of conjunction between the Murge Alte plateau, located at an altitude of about 500 m, and the terraced surface at *Boschetto* locality, around 325 m in altitude (Fig. 21A). The escarpment is made up of the Cretaceous limestones of the Apulia Foreland (Calcare di Bari Fm, locally Cenomanian in age), and corresponds to an ancient fault plane receding due to erosion (Martinis, 1961; Pieri, 1980). This structure is also crossed by a series of buried fault escarpments, of smaller size and approximately parallel to each other, which form a stepped structure, W-SW dipping. At *Boschetto* locality, above this complex substrate, the Calcarenite di Gravina Fm onlaps the Cretaceous bedrock (Fig. 22). Here, the Calcarenite di Gravina Fm is Early Pleistocene in age, as indicated by the presence of *Arctica islandica*, and is represented by an about 40 m-thick succession with a conglomeratic body around 12 m thick in its upper part; this body is well-exposed in a small, abandoned quarry and interpreted as a wave-reworked Gilbert-type delta (Sabato, 1993; 1994; 1996b;1999; 2003).

The deposits below and above the conglomeratic body (unit *a* and unit *d*, Fig. 22) are characterised by carbonate offshore facies composed by coarse-grained bioclasts, and locally lithoclasts, organised in metre-scale beds. The unit *a* represents both a remnant of a previously eroded depositional sequence updip and, distally, the heteropic facies to the bottomset of the delta. The lower surface of these strata is often erosional, and is marked by layers, about 30 cm-thick, of *Lithophaga*-bored pebbles, and up to 20 cm disjointed valves of pectinids and oysters. These deposits are intensely bioturbated and contain abundant bioclasts including fragments of bivalves, echinoids, bryozoans, corals, balanids, as well as benthic foraminifera and rare planktonic foraminifera, within a calcarenitic matrix. Occasionally, the strata contain conglomerate layers with clasts up to 6 mm and rare oysters, red algae, and pectinids.

Despite the bioturbation, a widespread low-angle oblique stratification is visible. Such offshore deposits can be related to environments developed at the base of the fault scarp before the delta system was activated. The delta erosionally truncates the underlying Pleistocene carbonate sequences and, in the more proximal areas, it onlaps the rocky palaeoslope. This surface, dipping about 10° westward, is underlined by the presence of load structures and sponges, echinoids, and *Lithophaga*-bored pebbles (Fig. 23). The delta extends for over 200 m, is clinostratified with up to about 10 m-high foresets (unit *b*, Fig. 22), and distally passing to offshore deposits (Fig. 22). The most proximal part of the delta, unconformably lying on the Cretaceous substrate, is represented by conglomerates formed by large *Lithophaga*-bored blocks (up to about 70 cm in diameter) eroded from the Cretaceous substratum. The geometry of the delta body is sigmoidal, and the overall thickness increases distally, from a few tens of centimetres up to 10 m, and then decreases again (Fig. 22).

The dip of the foresets decreases westward from about 30° in the apical part to a few degrees distally (Fig. 22), passing to the bottomset. The foresets are wedge-shaped, showing a variable thickness from a few tens of centimetres up to 1 m; on the upper surface, oysters up to 20 cm in size are often found, while on the foot, clasts, oysters and pectinids of considerable size (up to 30 cm) are generally found. The foresets often cut each other along erosional surfaces at different angles; they are mostly normally graded (Fig. 24), although both massive foresets and those showing reverse gradation are observed. Moreover, both clast- and matrix-supported textures are distinguished within them. In the first case, the clasts are well-rounded and have an average size of 8 cm, with a maximum of 20 cm; in the second case, the clasts are sub-angular, smaller (3-5 cm), with abundant microconglomeratic matrix. Distally, the contact of the foresets with the underlying unit (unit *a*, Fig. 22) passes from angular to tangential, and the foreset layers pass to sub-horizontal ones. They represent the bottomset, made up of packstone interspersed with layers of carbonate gravels; in general, they have smaller clasts and abundant macrofossils compared to the foreset layers. Unit *c* truncates the foreset layers (unit *b*) and the Cretaceous substrate by an erosional surface (ravinement). On this unconformity, a lag-type deposit is observed, represented by *Lithophaga*-bored clasts of about 20 cm in size. Above this surface, the unit *c* (Fig. 22), 2 m thick and consisting of calcirudites and calcarenites with a coarse sandy matrix, lies. Inside this unit, low-angle clinostratified beds (1°-2°), approximately 30 cm thick, are found. The beds are normally graded, contain pebbles with an average diameter of 4-5 cm at the bottom and 1 cm at the top; in the upper part of the beds, small molluscs (1-2 cm) are found. Imbricated pebbles dip both land- and seaward. The unit shows normal gradation and bioturbation of echinoids towards the top.

The delta body (unit *b*) can be interpreted as a classic Gilbert-type delta (Gilbert, 1885), wave reworked on top with the development of a shoreface (unit *c*) followed by deposits that record a deepening transition to offshore environments (unit *d*). Both facies and size of the delta are comparable to those of the Gilbert-type delta found in Dalmatia and described by Babic et al. (1985) and Postma et al. (1988); the geometry and sedimentary features are also similar to those of a "terraced delta" defined for the first time by Postma and Cruickshank (1988) in Norway.

Furthermore, the whole area is currently crossed by short high-gradient streams ("*gravine*"); these courses could be compared to those that in the Pleistocene supplied the rocky coast of the Murge Alte along the Minervino escarpment, forming deltas like the one described above.

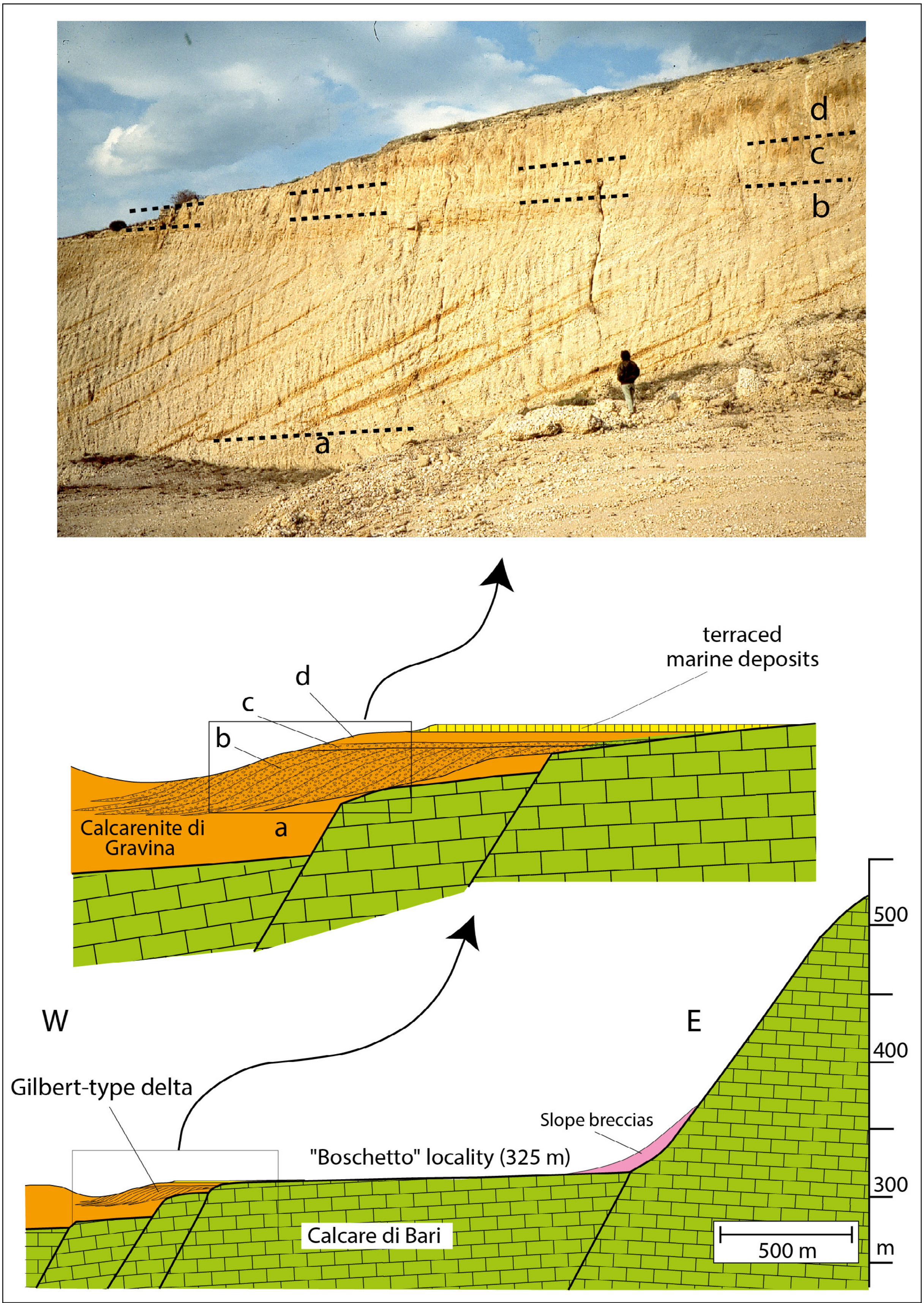

Fig. 22 - Below: the geological section shows the stratigraphic relationships between the Cretaceous substratum (Calcare di Bari Fm) and the overlying Pleistocene deposits (Calcarenite di Gravina Fm) near Minervino Murge. In the middle: detail of the coarse-grained palaeodelta. Above: the dashed lines separate the bioclastic facies in offshore facies (unit *a* and unit *d)* from the lithoclastic ones (unit *b* = delta body; unit *c* = shoreface/offshore transition deposits).

Fig. 23 - Pebbles and cobbles bioeroded by *Lithophaga* organisms along the erosional surface separating the coarse-grained delta deposit (unit *b*) and the underlying offshore deposits (unit *a*). Some clasts are composed of sub-angular fragments eroded by microconglomeratic carbonate layers.

Fig. 24 - Normal graded foresets made up of both sub-angular and well-rounded pebbles and cobbles.

Therefore, these particular deposits could represent a new kind of delta described for the first time in Puglia: a *gravina*-delta.

Stop 4 - Castel del Monte

Coordinates: 41°5'5.10"N, 16°16'14.93"E

Castel del Monte is a fortress located in the Municipality of Andria, built around 1240 by Emperor Frederick II, following a rigorous geometrical and mathematical scheme. The fortress has an octagonal plan, with the number eight being obsessively repeated, from the number of halls at the ground level to that of the towers at the first floor (Fig. 25). Described as a "unique masterpiece of medieval military architecture", Castel del Monte has been included on the UNESCO World Heritage List since 1996. The castle dominates the view of a significant part of the Murge, being erected at the top of a hill in a location highly visible from the surrounding areas. The site has been described as a residual hill due to the development of karst processes in nearby areas (Mastronuzzi et al., 2015), whilst other Authors relate its shape to geological structural features (De Giovanni, 2015).
Most of the eight towers present cisterns for the collection of rainwater, which is then partly conveyed toward a reservoir, dug into the limestones below the main courtyard. This has led some scholars to propose a possible function of the site as a hammam, following the custom of the Arab world, which had a strong influence on Frederick II. The site is among the most well-known in the Murge, attracting large numbers of tourists from around the world, draw by the history and mystery surrounding the figure of Emperor Frederick II.
The castle is a wonderful example of the use of local rocks as building and ornamental materials. The walls and all the supporting structures of the castle were built using the local Cretaceous carbonate rocks belonging to the Calcare di Bari Fm. In particular, the microfacies analysis of some samples from the original building stones showed that all the original blocks were extracted from the Cenomanian succession of this unit, which outcrops a few kilometers southwest of the Castel del Monte hill (*Monte Scorzone* quarries) (Zezza, 2005). In contrast, most of the blocks used to replace deteriorated rocks and to reconstruct collapsed parts of the castle were taken from quarries located in the northern Murge (Trani stone district) where the Lower Cretaceous succession of the Calcare di Bari Fm crops out (Luperto Sinni and Masse, 1982; 1984; 1992). Consequently, the restoration works of the castle were carried out using a stone with quite different chromatic characteristics compared to the original one (Zezza, 2005).
The ornamental stone used to adorn the portal, the windows,

Fig. 25 - Castel del Monte. Web source: https://madeinmurgia.org/new/wp-content/uploads/2016/02/castel-del-monte-1.jpg (2)

and other important architectural elements of the castle is composed of a carbonate breccia with a residual reddish matrix. This rock was improperly named "*breccia corallina*" (coral breccia) due to the chromatism of the matrix resembling that of the red corals. The provenance of this rock is still debated. However, the composition of the calcareous clasts and their fabric and sedimentary structures (cross-bedding, imbrication, gradation, etc.) suggest the most likely sites from which the carbonate breccias have been extracted are located in Puglia region (Zezza, 2005). As a matter of fact, in the western Gargano Promontory and the south-western Murge, carbonate breccias form thick successions of well-cemented Pleistocene debris fans, accumulated at the base of fault escarpments that separate the Apulia Foreland from the southern Apennines foredeep basin (Ciaranfi et al., 1988; Moretti et al., 2011). According to Zezza (2005), the microfacies analyses performed on calcareous clasts and the composition of the matrix indicate a Gargano provenance. This supported by the fact that the microfossiliferous association found in the clasts is Late Jurassic-Early Cretaceous in age, the same age of limestones and dolostones of the Calcare di Bari Fm cropping out in the western Gargano Promontory (Spalluto et al., 2005; Spalluto, 2008). The carbonate breccias of the Murge, on the other hand, were fed only by clasts deriving from the Cenomanian succession of the Calcare di Bari Fm. Despite this, the latter were used during the restoration work of the castle and as mentioned above, are distinguishable from the original ones by the rather different chromatism of both the clasts and the matrix.

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