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Geological Uniqueness and Potential Geotouristic Appeal of Murge and Premurge, the First Territory in Puglia (Southern Italy) Aspiring to Become a UNESCO Global Geopark

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Abstract: At the end of November 2021, a large area of Puglia (an administrative region in Southern Italy) was officially nominated as new aUGGp (aspiring UNESCO Global Geopark) by the Italian National Commission of UNESCO. This area comprises the northwestern part of the Murge territory, where a Cretaceous sector of the Apulia Carbonate Platform crops out, and part of the adjacent Premurge territory (where the southwestward lateral continuation of the same platform, being flexed toward the Southern Apennines Chain) is covered by thin Plio-Quaternary foredeep deposits. The worldwide geological uniqueness of the aspiring Geopark (Murge aUGGp) is that the area is the only in situ remnant of the Adria Plate, the old continental plate almost entirely squeezed between the Africa and Eurasia Plates. In such a context, the Murge area (part of the Apulia Foreland) is a virtually undeformed sector of Adria, while other territories of the plate are and/or were involved in the subduction/collision processes. In the aspiring Geopark, the crust of Adria is still rooted to its mantle, and the Cretaceous evolution of the continent is widely recorded in the Murge area thanks to the shallow-water carbonate succession of one of the largest peri-Tethys carbonate platforms (the Apulia Carbonate Platform). The aspiring Geopark also comprises the Premurge area, which represents the outer Southern Apennines foredeep, whose Plio-Quaternary evolution is spectacularly exposed thanks to an "anomalous" regional middle-late Quaternary uplift. Despite the presence of numerous geological singularities of international importance, it would be important, from a geotourist point of view, to propose a regional framework of the geology of the aUGGp before introducing visitors to the significance of the individual geosites, whose importance could be amplified if included in the geoevolutionary context of the Murge aUGGp.

Keywords: Southern Italy; Apulia Foreland; Murge aspiring UNESCO Global Geopark (aUGGp); Premurge; Adria; geotourism; Apulia Carbonate Platform; Bradanic Trough

1. Introduction

Starting from 2002, the executive of SIGEA-Puglia (the regional board of a national voluntary association of Italy that attempts to make citizens and public administrations

sensitive towards geology) has tried to direct public attention towards a knowledge, census, and cataloguing of regional geosites of Puglia, the easternmost administrative region in Southern Italy.

At the same time, the same small group of geologists has focused attention on the possibility of proposing a geopark in a selected part of the Murge area, the central sector of the Puglia Region (Figure 1). The activity of this group led to a presentation of the main regional geosites [1], to the organization of the VII International Geoheritage Symposium [2], and to the production of the first inventory of geosites of Puglia required by the Regional Administration [3].

At the beginning of 2019, the new management of the Alta Murgia National Park took charge to candidate its territory to become a Geopark, delegating to the "Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari Aldo Moro" (Earth and Geoenvironmental Sciences Department, Aldo Moro University of Bari, Italy) the task of highlighting the geology of the area. At the end of November 2021, a large area of Puglia was officially proposed as a new aUGGp (aspiring UNESCO Global Geopark) by the Italian National Commission of UNESCO. The aspiring Geopark comprises not only the National Park area, i.e., the northwestern Murge area, where a Cretaceous sector of the Apulia Carbonate Platform crops out (see later in the text), but also the adjacent Premurge area, where the southwestward lateral continuation of the same platform, being flexed toward the Southern Apennines Chain, is covered by thin Plio-Quaternary deposits (Figure 1c,d).

The aim of this work is to briefly report the synthesis carried out by the task force of Bari University to describe the geological uniqueness that led the area to be nominated as an aUGGp. This should be the introductory theme for geotourists visiting the aspiring Geopark.

2. Preliminary Geographic Information

To avoid confusion in the text, it is important to explain the meaning of two pairs of widely, and often alternately, used geographical terms: Puglia/Apulia and Murge/Murgia.

2.1. Puglia/Apulia

As noted before, Puglia is an administrative region in Southern Italy (Figure 1c), the boundaries of which do not exactly match those of Apulia, the old and more internationally known area between the "spur" (the Gargano promontory) and the "heel" (the Salento Peninsula) of Italy (Figure 2).

From a geological standpoint, researchers mainly assign the term Apulia to the area corresponding to the Apulia Foreland, sometimes including the Bradanic Trough (Figure 1c). In this broad sense, Apulia corresponds to the exposed area located east of the front of the Southern Apennines, and this is how we use Apulia in the present work. Apulia is also the name that is sometimes used to indicate the "small" continental plate located between the Africa and Eurasia ones (see later in the text). This small plate is better known as Adria, and this is the term we use in the present work.

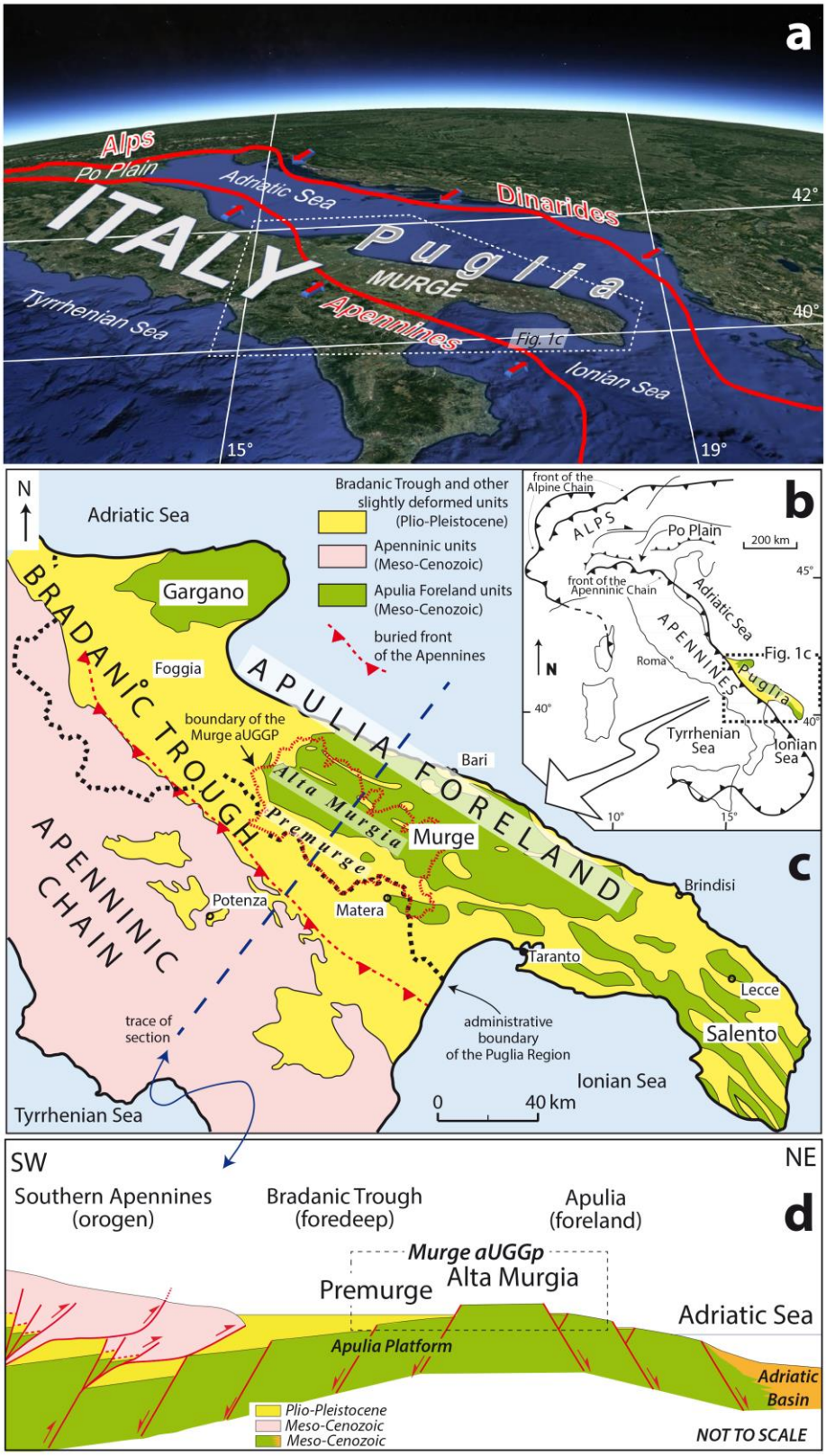

Figure 1. (**a**) Position of the Puglia Region along the Italian peninsula, with location of Figure 1c (dotted line); the Murge area corresponds to the central part of the region. Base map from Google Earth. (**b**) Simplified geological scheme of Italy ([4], mod.) with location of Figure 1c (dotted line). (**c**) Simplified geological map of Southern Italy ([5], mod.) with location of the Murge aspiring UNESCO Global Geopark (aUGGp) and trace of the geological section reported below. (**d**) Cross section showing relationships between Alta Murgia and Premurge in the Murge aspiring Geopark ([6], mod.). Geographic coordinates in the WGS84 system.

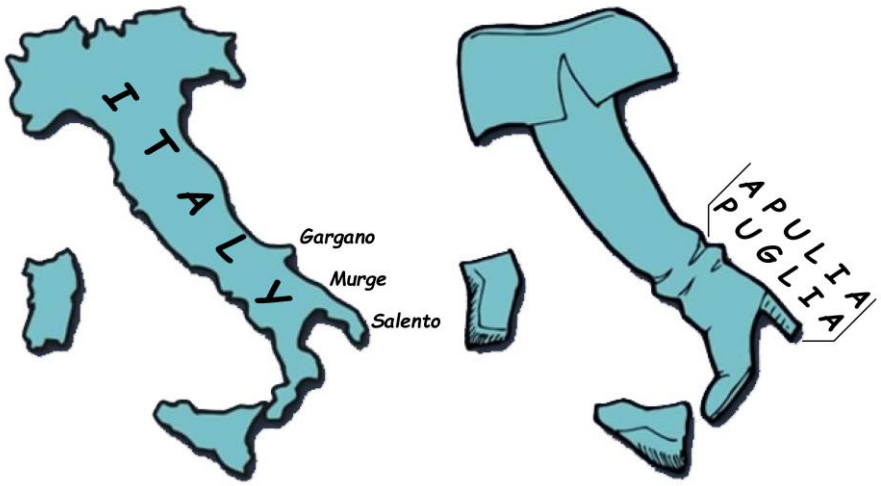

Figure 2. The shape of Italy recalls that of a boot, and the Puglia Region extends between the spur and the heel. This picture comes from [7]. (Compare with Figure 1b.)

2.2. Murge/Murgia

The word "murgia" (pl. "murge"), with the first letter in lowercase, is a term no longer used, and it indicates in Southern Italy a rocky hill, often with a steep slope bounding it from an adjacent area. The term probably comes from the Latin word "murex", meaning rock (cliff); it became a relatively used toponym that, as with other words and capitalizations of the first letter, has assumed a geographical meaning and indicates specific localities or territories. The plural term with the first letter in uppercase and always preceded by the Italian article "le" (le Murge) indicates the wide central area of the Apulia Foreland characterized by the presence of a series of plateaus made up of karstified carbonate rocks (Figure 3). The topographically highest plateau is named "Murge Alte" or "Alta Murgia" (literally: high part of Murge), and it is split into two sectors by a morphotectonic depression (the Gioia del Colle saddle). The northwestern sector of this highest plateau roughly corresponds to the Alta Murgia National Park. Eventually, Premurge literally means "before Murge" (Figure 3).

2.3. The Proposed Geopark Name

For the name of the aUGGp, in order to suggest an easy term to indicate and remember the geopark, we proposed to use only the geographic toponym "Murge", even if the selected area was that of the Alta Murgia National Park plus part of the Premurge area. This led us to play with words proposing the crasis "MurGEopark", which seems to indicate that it is "the last piece of Adria, the (almost) lost continent" (see the reason below), with the idea that plate tectonics are seen as a puzzle, and thereby igniting the imagination regarding the lost continent.

3. Geological Evolution of Apulia: The Leitmotiv of the Murge aUGGp

To understand the geology of Apulia, to which the Murge and Premurge areas belong, it is necessary to consider the geodynamic scenario in which the rocks that form Southern Italy developed and/or were involved over time.

This implies that we need to consider the plate tectonics theory [8–10], a scientific paradigm formulated to explain mountain building and many other phenomena distributed at the planetary scale. The idea that this territory of the Puglia Region is a candidate for being a Geopark starts from this paradigm because the area can be interpreted as a part of the little exposed remnant (the Apulia Foreland) of a plate that has almost completely disappeared by subduction [11,12] (Figure 4), the latter process being one of the main tenets of the theory [13,14]. Since the late 19th century, long before the formulation

of the plate tectonics theory, it had been assumed that the Mediterranean region now occupied by the Italian peninsula and the Adriatic Sea was previously occupied by Adria, an old continent [15]. The complex distribution of the mountain chains around the Mediterranean Sea led to Adria being considered as a wider continental area, i.e., a promontory of the African continent [16] originally occupying the area east of the present day Baetic Cordillera, south of the present-day Alpine Chain, and the present-day Carpathian-Pannonian region up to large parts of the present-day Balkans and Anatolia [17].

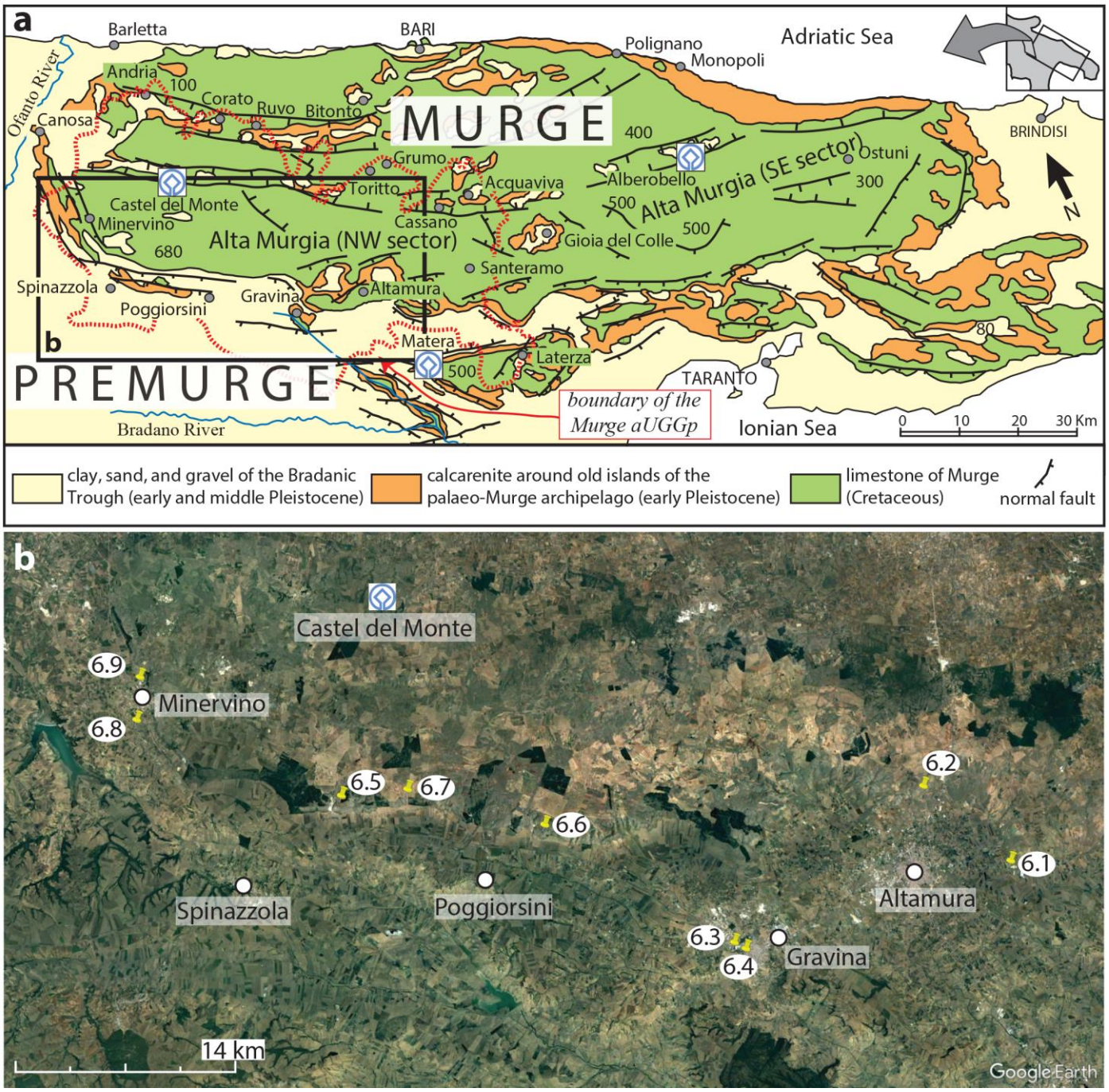

Figure 3. (**a**) Structural sketch of the Murge area (see inset for the location). Note the location of the three UNESCO World Heritage sites (Castel del Monte, Matera and Alberobello) quoted in chapter 5. The approximate boundary of the Murge aspiring UNESCO Global Geopark (Murge aUGGp) is reported. After [18,19]. (**b**) Location of the geosites (numbers 6.1–6.9) described in chapter 6. Geographic coordinates are reported in the same chapter. Base map from Google Earth.

This "Greater Adria" was firstly included in plate tectonics scenery by [20], and it was considered a relatively small continental plate split from Africa (the parent plate) that never totally disconnected from the latter [17,21]. This small plate was also called Apulia Plate [22], or Greater Apulia, which, according to a more complex palaeogeographic interpretation, resulted from two different microcontinents welded together during the Late Permian-Early/Middle Triassic to the northern sector of that part of the Pangea Supercontinent, which, in turn, later became the Africa Plate [23,24]. In the framework of the breakup of Pangea, from the middle Jurassic [25], the Alpine Tethys Ocean progressively separated the Eurasia Plate from the Africa-Adria ones, given that Adria connected to Africa through a narrow bridge ([17,21,26], among many others) (Figures 5 and 6a), and is comparable to the present-day terrestrial geographic relationship between Arabia and Africa plates.

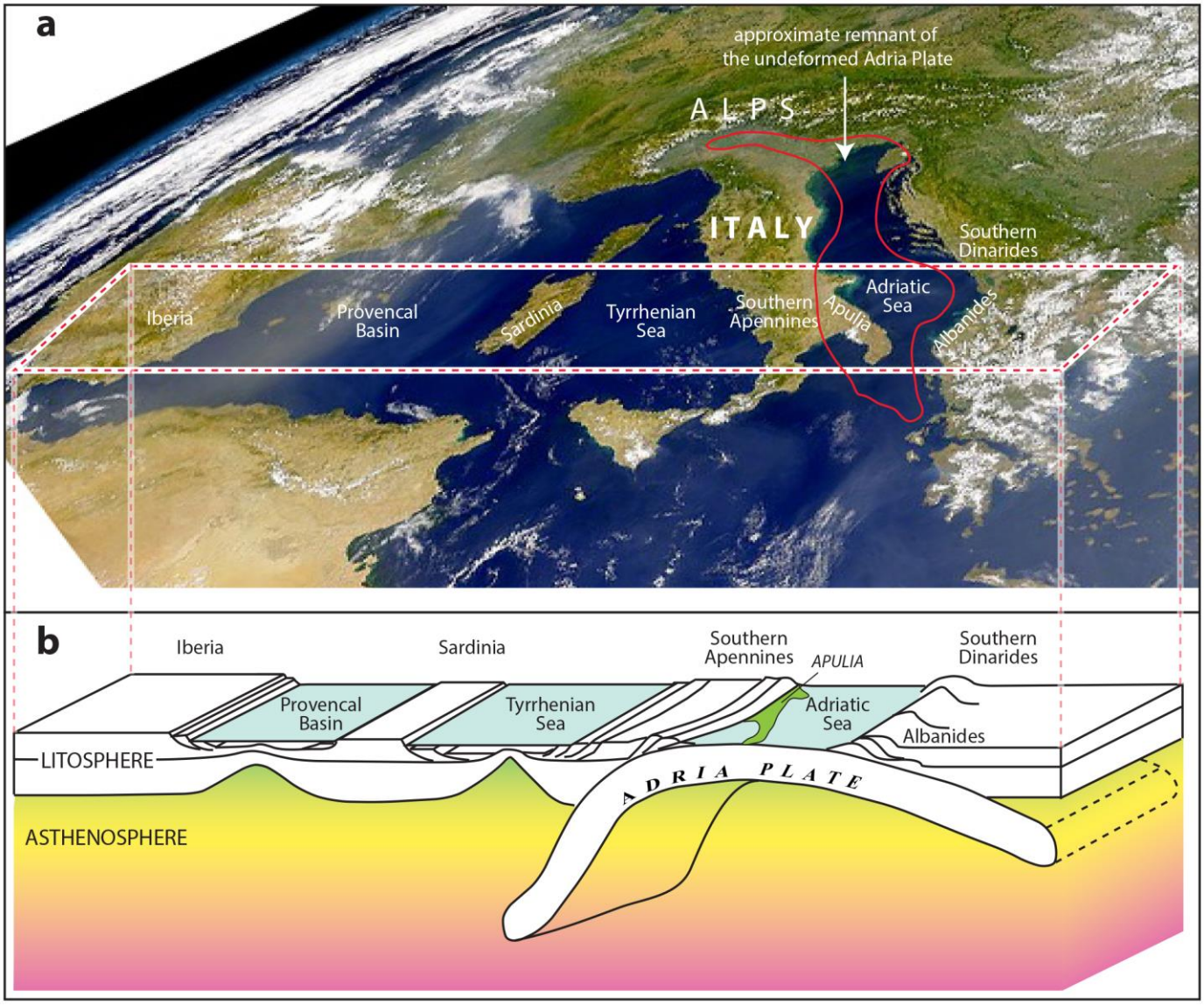

Figure 4. (**a**) Western Mediterranean Sea and surrounding regions, showing the approximate present-day shape of Adria and the portion of Earth surface, to which the 3D sketch refers (Figure 4b). NASA-Shuttle view of the central-western Mediterranean ([27], mod.); (**b**) 3D geodynamic model showing the double subduction of the Adria Plate (from [28], mod.).

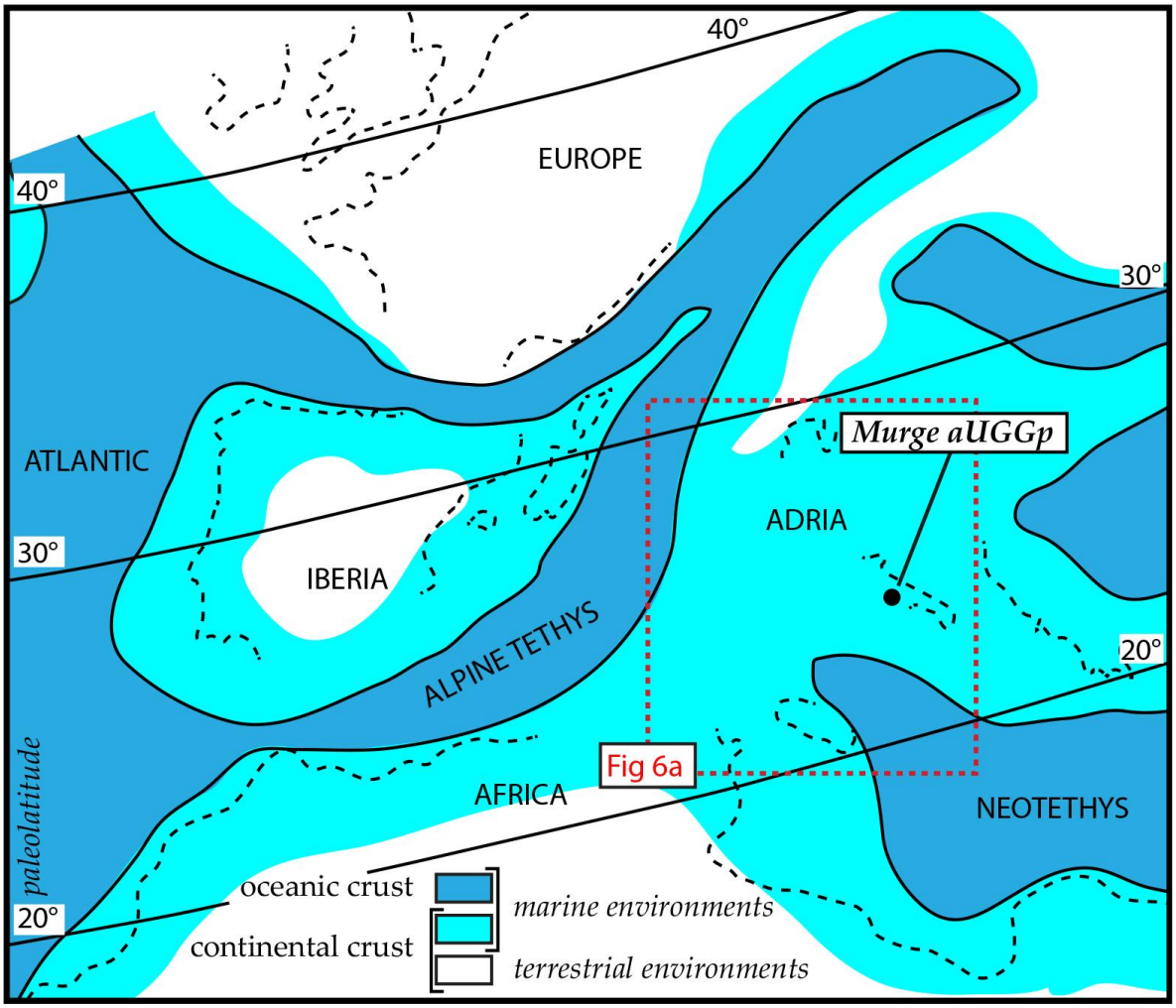

Figure 5. Palaeogeographic map of Adria at the beginning of the Late Cretaceous. Deeply simplified after [26], among many others.

During the Mesozoic, the portion of the Adria Plate later involved in the Southern Apennines orogenic system represented a passive margin [29,30] characterized by an alternation of deep basins and carbonate platforms (peri-Adriatic platforms) [31–33] (Figure 6a). In this context, slow subsidence rates compensated by shallow-water carbonate sedimentation favored the progradation and aggradation of these platforms [34–36], which, although flanked by deep-sea basins, were periodically connected to each other by continental bridges that allowed the migration of dinosaurs [17,20,21] (Figure 6a). As far as Puglia is concerned, it is important to underline the presence of one [37–39] of these platforms, known as the Apulia Carbonate Platform, whose vestiges can be recognized in the large carbonate rock masses of Gargano, Murge, and Salento [29] (Figure 1c).

Even if the Adria Plate originated as a consequence of the breakup of Pangea and a subsequent continental drift, the current configuration of Southern Italy is due to the following process of plate convergence and mountain building [21,40,41]. In particular, Apulia is today affected by a double subduction, producing the Apennine orogenic system to the west of the Adria Plate and the Dinaric/Hellenic orogenic system east of the same plate [28,42–44] (Figures 4 and 6). This dynamism can be appreciated only keeping in mind the deep-time concept, since the present-day geological framework should be considered a fixed frame of a long geodynamic movie, whose known stages for the development of Apulia date back to the Permian-Triassic (Puglia 1 well [29]), well before the beginning of the Apennines orogenic processes, which were taking place since the Oligocene (at least), and which still affect Southern Italy [45,46].

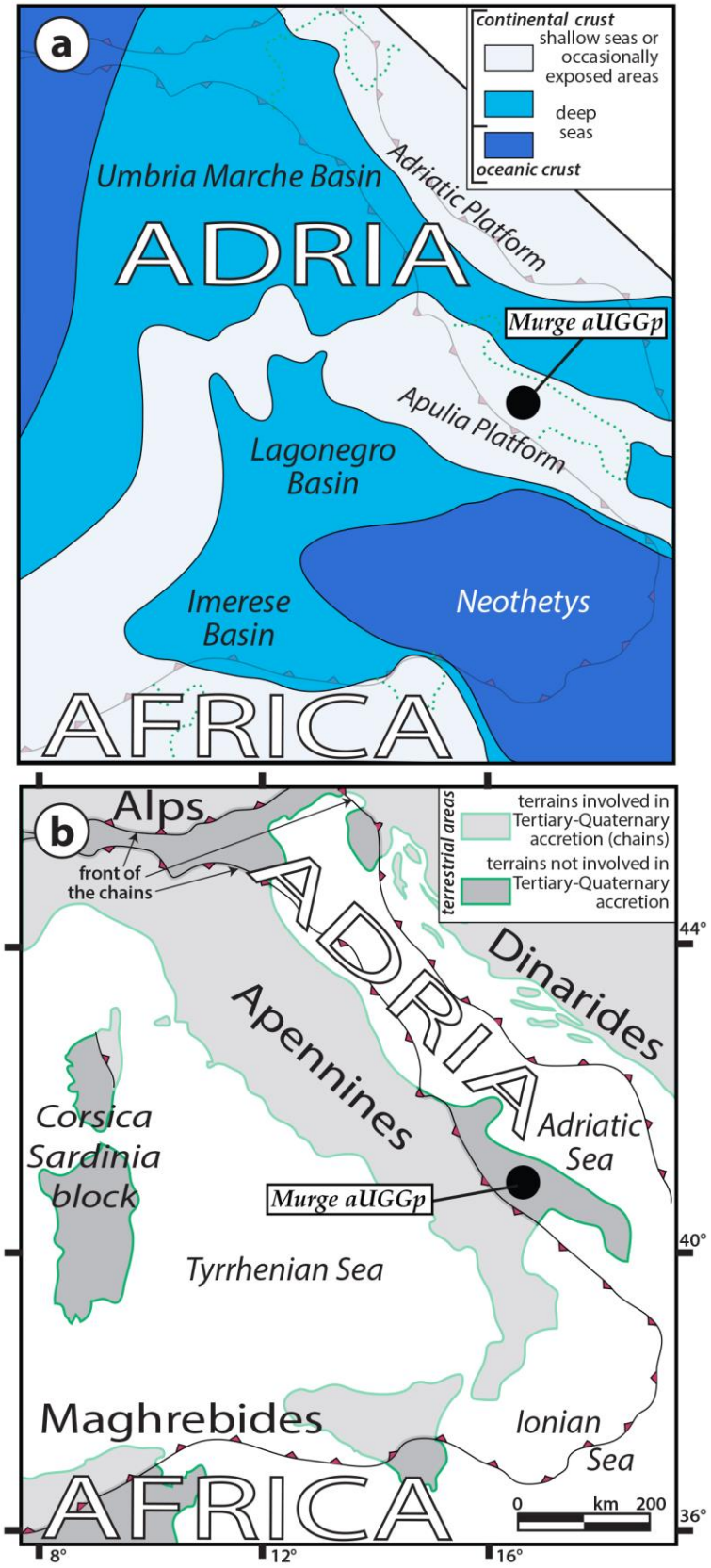

Figure 6. (**a**) Cenomanian paleogeography, according to [47]. Note the position of Murge within the Apulia Carbonate Platform. (**b**) Present-day structural sketch of Italy. Note the small size of the remnant of Adria Plate, surrounded by active chains. After [48], mod. Geographic coordinates in the WGS84 system.

It is worth recalling that the three main domains of an orogenic system are: (i.) the foreland, i.e., the area not yet reached by mountain deformations; (ii.) the foredeep (or, the "foreland basin", which is the more stringent definition used if what is being referred to is the Apennines foredeep), i.e., the flexed area at the foot of the mountain chain that receives sediment eroded from the reliefs; and (iii.) the chain, i.e., the mountainous area whose rocks are tectonically superimposed on each other and strongly deformed [9,49–52]. In such a dynamic context, the chain migrates towards the foredeep, progressively incorporating it into the mountain reliefs; at the same time, the foredeep migrates towards the flexing foreland, which becomes the bedrock of the foredeep itself; and the foreland "observes" this migration, waiting to be involved in the flexure in its area facing the chain (migrating foredeep in [53–55]). As regards the Apennines orogeny, it involved the western sector of the Adria Plate; as a consequence, the Italian peninsula shows the present-day three domains of the orogenic system (chain, foredeep, and foreland) corresponding, from west to east, respectively, to the Apennines Chain, the Apennines foredeep (i.e., from north to south, the Po Plain, the central-northern Adriatic Sea, and the Bradanic Trough, comprising the Premurge area), and the Apulia Foreland (i.e., Gargano, Murge, and Salento) (Figure 1b,c) [56–59].

During the Apennines orogeny, the upper crust (mainly the sedimentary cover) of the Mesozoic palaeogeographic domains of the western side of the Adria Plate was delaminated from its basement; several thrust sheets were tectonically stacked along the western portion of the Apulia Carbonate Platform, progressively forming the Southern Apennines Chain [46] (Figures 1 and 6b). The eastern portion of the Apulia Carbonate Platform, the sector still not involved in thrusting, corresponds to Apulia (i.e., the Apulia Foreland and the bedrock of the Bradanic Trough), where the crust of Adria is still rooted to its mantle [60,61]. During the formation of the Apennines, the Apulia Foreland itself was arched (e.g., [43], and references therein) and divided into blocks, which underwent relative lowering and uplift. The most raised areas correspond to the Gargano (a promontory reaching altitudes of about 1000 m), to the Murge (a plateau system that reaches altitudes of about 680 m), and to the Salento (formed by hilly reliefs, the Serre Salentine, with maximum elevations of about 200 m) (Figure 1). Normal faults affecting the Apulia Foreland formed two morphostructural staircases, respectively, dipping towards the east and into the Adriatic Sea, and towards the west as far as below the Southern Apennines [62,63] (Figure 1). This last morphostructural staircase corresponds to the bedrock of the Bradanic Trough, representing the most recent Southern Apennines foredeep [64].

4. Main Geological Features of the Murge aUGGp

The Murge aUGGp comprises the Alta Murgia area, where a Cretaceous sector of the Apulia Carbonate Platform crops out, and the adjacent Premurge area, where the southwestward lateral prosecution of the same platform, being flexed toward the Southern Apennines Chain, is covered by Plio-Quaternary foredeep deposits (Figure 1).

The Murge anatomy reflects part of the long geological history of Puglia, documented by field evidence that dates back to about 140 million years ago, i.e., the early Cretaceous [29,65]. At that time, the region that was going to be the Apulia Foreland was a wide shallow-marine inter-tropical area basically comparable to the present-day Bahamas [36]. There, on the Apulia Carbonate Platform, carbonate muds, which gradually were becoming limestones, deposited over millions of years up to about 66 million years ago (end of the Cretaceous), when, as mentioned, the platform underwent subaerial exposure. Later, in the area now corresponding to the Murge, these limestones were affected by extensional tectonics and a horst and graben structure, roughly NW-SE striking, leading the area to be characterized by topographic highs and lows [19,48,63,66]. Subsequently, during late Pliocene (about 3 million years ago), this region was affected by subsidence, induced by the eastward migration of the Apenninic orogenic system, which caused the return of the sea on limestones that had been exposed for a long time, previously experiencing several phases of karstification [67,68]. Occupying a region made up

of highs and lows, this relative sea-level rise created a wide archipelago whose islands corresponded to the structural highs of the previously described faults system [59,69,70] (Figure 7).

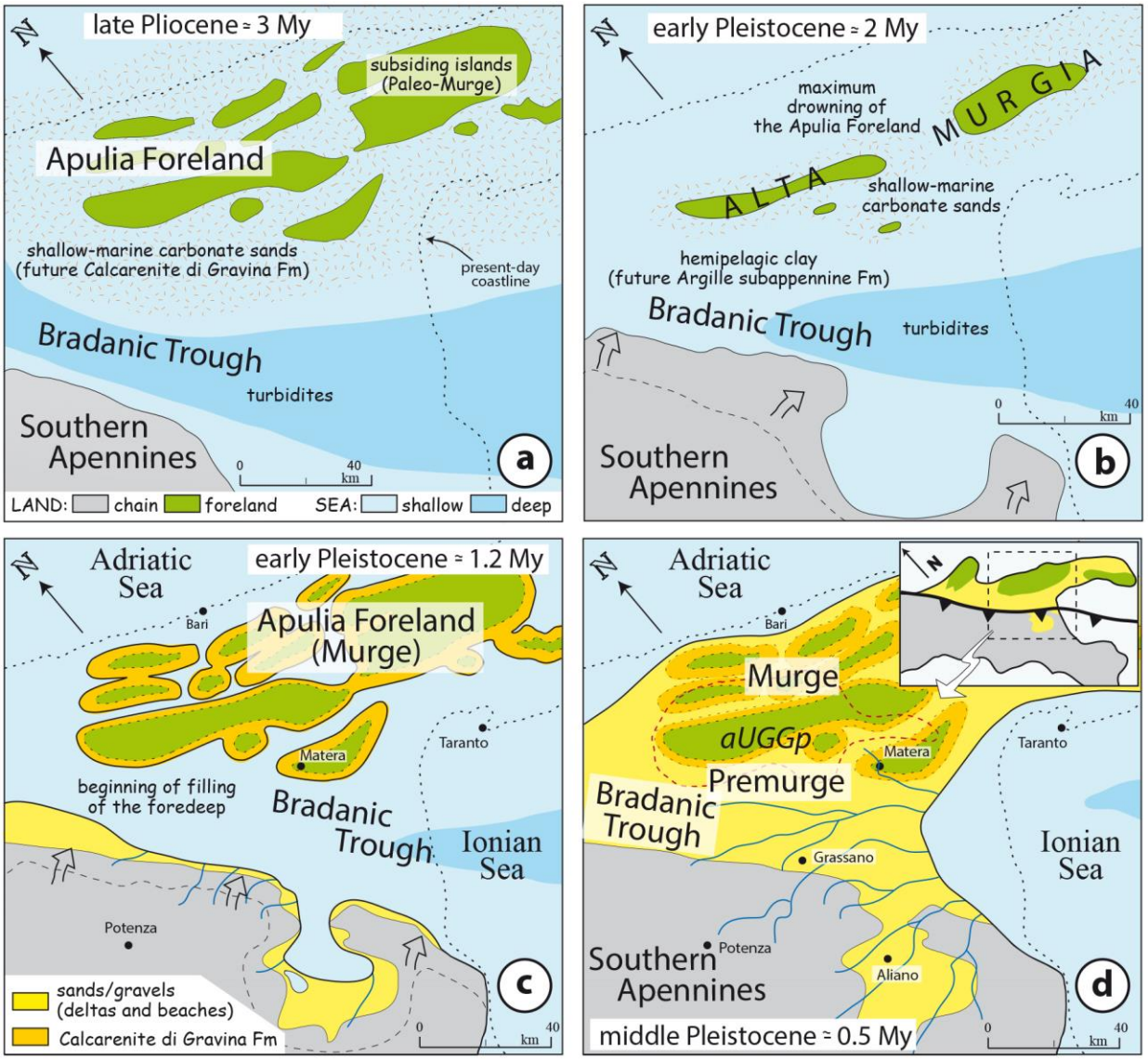

Figure 7. The late Pliocene to middle Pleistocene evolution (**a**–**d**) of the Southern Apennines foredeep system. From [5], mod. (Compare each picture with Figures 1c and 3.)

Cretaceous limestones that today characterize the Murge karst landscape were the bedrock of both the islands and the structural depressions (straits and seaways) among islands (Figure 7a). A more important and deeper seaway, the Bradanic Trough, connected the central-northern Adriatic Sea to the Ionian Sea between the migrating Apennines and the Murge archipelago (Figure 7a). The slow subsidence of the whole Murge region caused the progressive submersion of the archipelago and coarse-grained coastal deposits, formed by a mix of skeletal carbonate fragments and detritus eroded from the exposed limestones, accumulated on island flanks [69,71,72] (shallow-marine carbonate sands in Figure 7a,b). Since palaeoenvironments were controlled by morphotectonic features of the Cretaceous bedrock, carbonate systems with different geometries and facies distribution developed (see examples in [71–74]).

After diagenesis, these carbonate sediments would become the easily-dug porous carbonate soft-rocks representing the bedrock on which rupestrian towns in the Murge

and Premurge areas (e.g., Gravina in Puglia, Matera, Laterza, and Ginosa) developed [75,76] (Figure 8).

Figure 8. The thin Bradanic Trough (foredeep) succession along the Gravina (canyon) of Gravina in Puglia town, at the toe of Murge. After having eroded the Quaternary 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 [77].

About 1.5 million years ago, the maximum relative rise of the sea on the islands of the palaeo-Murge archipelago was reached; this phenomenon left subaerially exposed only the highest reliefs of the Murge, corresponding to Alta Murgia (Figure 7b). At the same time, the sediments transported by rivers crossing the Apennines began to feed the Bradanic Trough seaway, which was progressively reached by offshore clays and filled with coastal sands and gravels [78–81] (Figure 7c). These same sediments also reached areas of the old archipelago, filling the narrow straits between the old islands; the latter were almost completely buried by sediment, with the exception of the most elevated ones [59,70] (Figure 7d). At the passage between the early and middle Pleistocene, the Apulia Foreland began to undergo a still active tectonic uplift [82–84], which would have progressively led the Murge to exceed 600 m of altitude. The beginning of uplift was the geological "moment" when the hydrographic network that now characterizes the Murge area established [85]. At the same time, the drainage network began to dissect the original flat top of the Premurge area, today at more than 450 m of altitude. Here, the rivers running on sands and gravels (uppermost deposits of the foredeep infill) progressively cut these topmost sediments, reaching the underlying clays. Locally, the drainage network also reached deeper and more ancient carbonate rocks, creating canyons locally called "gravine" (the plural of "gravina") [86–88] and disclosing how the Premurge bedrock corresponds to outcropping rocks of the Murge (Figure 8).

The "anomalous" middle-upper Quaternary uplift of Murge and its flanks was attributed to the presence of a thick lithosphere in correspondence with the present-day

foreland that led to the buckling of the plate [83,84]. As a consequence: i) old rocks of Adria crop out in the Alta Murgia, the latter being the hinge of the largest lithospheric antiform of the world (i.e., [43]); ii) stratigraphic and structural features of the outer side of a subsiding foredeep are exposed today in the Premurge area [79].

5. The Geotouristic Appeal of the Murge aUGGp

The 2011 Arouca Declaration [89] defines geotourism "as tourism which sustains and enhances the identity of a territory, taking into consideration its geology, environment, culture, aesthetics, heritage and the well-being of its residents." There is a close connection between geotourism and geoparks since, according to the official UNESCO site [90], "UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. […] While a UNESCO Global Geopark must demonstrate geological heritage of international significance, the purpose of a UNESCO Global Geopark is to explore, develop and celebrate the links between that geological heritage and all other aspects of the area's natural, cultural and intangible heritages."

In accordance with [91], geology should also represent a cultural and social discipline and the first activity to pursue this objective is the scientific research on geosites understood as "one of the components of a given territory, on a par and together with fauna and flora or with cultural heritages such as works of art, monuments … etc." Therefore, well-studied (and correctly proposed) geosites would represent key points to suggest ecotouristic trips in which geology could be one of the main cultural interests for visitors (geotourism). A large number of geosites of international and national relevance characterize the Murge aUGGp but, at the moment, many individual geosites of the Murge aUGGp, even if listed for their geological importance, are either not open to the public or are proposed to tourists based upon other subjects far from (or ignoring) the geological ones. As suggested in this paper, the most interesting approach to propose geotourism activities in the area would be to preface any visit or tour with a geological regional view and to select some sites trying to follow the geological history of the area. Keeping in mind this aspect, each geotour or geosite could represent the opportunity to discover a geological world not strictly linked to a local peculiarity. In this regard, it is important to reiterate that:

1. The area represents a virtually undeformed sector of Adria, a continental plate located between Africa and Eurasia Plates and almost totally involved in subduction/collision processes [21,92].
2. The crust of Adria is still rooted to its mantle, as suggested by the analysis of several seismic lines crossing Apulia ([60] and quoted references), and the Cretaceous evolution of the plate is spectacularly recorded in the Murge area due to the outcropping shallow-water carbonate succession of one of the biggest peri-Adriatic carbonate platforms (the Apulia Carbonate Platform) [32].
3. An "anomalous" regional middle-late Quaternary foreland uplift led to spectacular exposition from the bedrock of a complete foredeep succession, pointing out that the latter can commonly be observed only after being deformed and involved in the mountain chain or visualized from subsurface data (i.e., seismic lines), especially in marine settings [42,43,54,93].

Geosites were described following a geochronologic criterium. Accordingly, the main geosites recognized within the Murge aUGGp have been divided into eight main categories, each characterized by at least one geosite of international value. Since several sites offer more than one significant geologic feature, the identified geosites can fall in one or more of the following categories: Spatial and/or Panoramic geosites; Apulia Carbonate Platform geosites; Bradanic Trough geosites; Quaternary Uplift-related geosites; Karst geosites; Tectonics-related geosites; Hydrogeology-related and Water-related geosites; and Man and Geology geosites. The presence of three UNESCO World Heritage Sites (Figure 3), one within the boundary of the aUGGp (Castel del Monte) and two in its surroundings

(Trulli di Alberobello and Sassi di Matera), represents further tourist attractions that add value to the Murge aUGGp. Specifically, the Sassi di Matera rupestrian districts, after being the European Capital of Culture in 2019, saw an outstanding increase in tourism that reverberated in the adjacent Murge area, and that could also be oriented towards geotouristic targets [5,75,76].

6. Some Examples of Geosites of the Murge aUGGp

In the following sections, some geosites of potential geotouristic interest, and falling into one or more of the eight categories mentioned above, will be proposed. The concise geological description of each site is just sufficient to represent the scientific reasons underlying their importance. These geosites rest in the western sector of the Murge aUGGp, at the turn of Murge and Premurge, and are described moving from SE to NW (see quoted localities in Figure 3). Moreover, regarding the choice of how to link in an ideal geotouristic route, these sites are left to the sensitivity of both the guides and the visitors, and to logistical constraints as well.

6.1. Apulia Carbonate Platform Geosites: The Disused Quarry "Cava Pontrelli" of Altamura

40°48′24.92″N; 16°37′14.48″E

- *The dinosaur tracksite*

In May 1999, in the vicinity of Altamura, on the bottom of a disused quarry ("Cava Pontrelli"), one of the world's largest dinosaur track sites was discovered (Figure 9) [94].

Figure 9. (**a**) The bottom of a disused quarry ("Cava Pontrelli") is one of the world's largest dinosaurs track sites. It records the passage of hadrosaurs and ankylosaurs on an original muddy surface during late Cretaceous. Note the impressive number of tracks, most of them not always referred to a trackway. (**b**) A detail of the surface showing, among many tracks, three coloured dinosaur trackways [94].

Up until this discovery, the Apulia Carbonate Platform was considered as a Bahamian-type isolated platform, but the presence of several dinosaur footprints in the carbonate succession led to a deep palaeogeographic revision, suggesting the presence of bridges between Periadriatic Platforms and the main continents of that time (Africa and Eurasia) to justify the occurrence of these terrestrial vertebrates [37–39,95]. Studied quadrupedal trackways suggest the passage of hadrosaurs and ankylosaurs on an original muddy surface during the late Cretaceous (early Campanian) [94,96,97].

4. *Orbitally-controlled shallowing-upward peritidal sequences*

The carbonate succession cropping out along the walls of "Cava Pontrelli" is made up of about 50 m thick peritidal and shallow subtidal facies associations showing a

shallowing-upward cyclic arrangement [98]. The occurrence of cyclic variations in the stratigraphic record is a widespread feature, and its study (cyclostratigraphy) in Mesozoic carbonate platform successions led to the improvement of the accuracy and resolution of geochronologic timetables [99,100]. This kind of study has been proposed in some selected portions of the Apulia Carbonate Platform succession [101–103] and is in progress in the lower Campanian section of "Cava Pontrelli" [96]. It is important to highlight that this easily accessible abandoned quarry with high walls could be used to discuss past climate change, cyclicity, and sea-level variations, comparing past and present-day climate change, and showing how environments change over time.

At the moment, the visit is possible exclusively through contacts with the Altamura Municipality.

6.2. Karst Geosites/Man and Geology Geosites: The "Grotta di Lamalunga" (Lamalunga Cave), in the Vicinity of Altamura

40°51′55.20″N; 16°34′54.13″E

The "Grotta di Lamalunga" (Figure 10) is one of the many underground karst features in the Altamura territory. With its entrance located on the right side of a typical karst valley (lama), the cave gained international recognition after 1993, when a complete Neanderthal skeleton was discovered by cavers in a small chamber of the karst system [104,105].

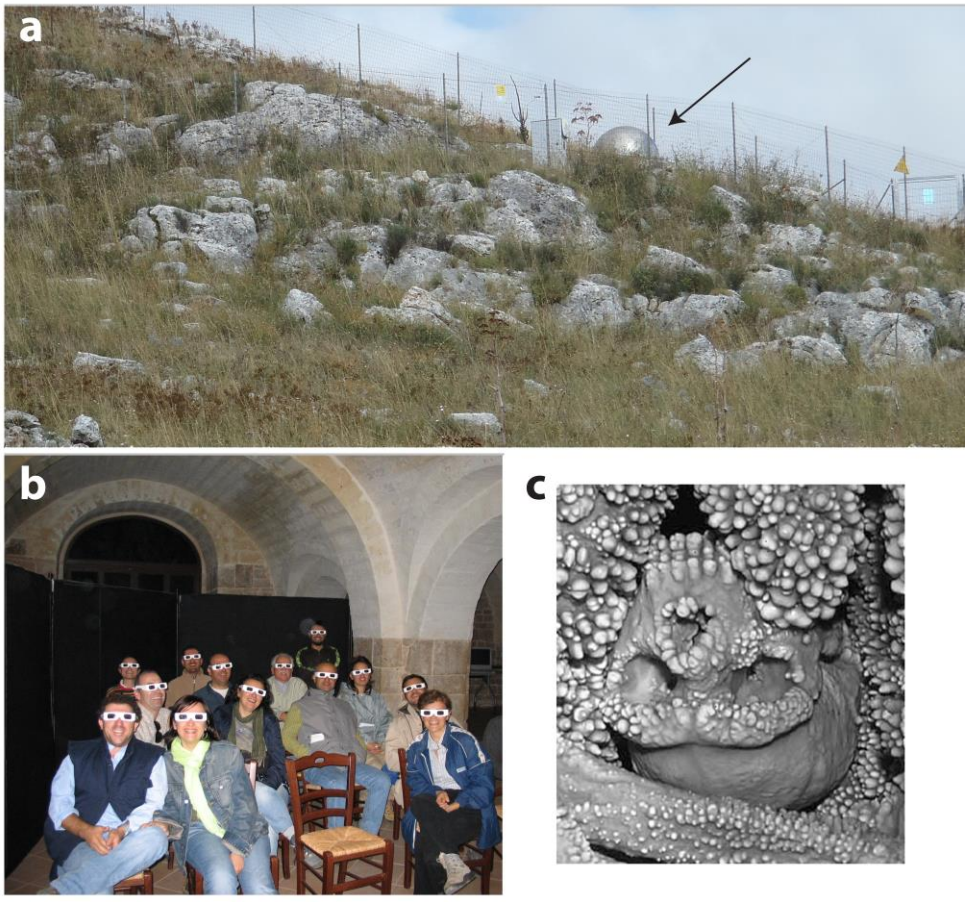

Figure 10. (**a**) Entrance of the "Grotta di Lamalunga" closed by a metal dome. (**b**) Group of geotourists with 3D glasses in the Lamalunga Visitor Center. (**c**) The skull of the Neanderthal skeleton discovered in 1993 [104].

Dating the calcite coatings above the bones provided an age comprised between 128 and 170 ka, whereas analysis of DNA revealed that this human belonged to Homo

neanderthalensis [106]. In addition to the remarkable importance of the "Altamura man", the Lamalunga Cave hosts within the system many palaeontological remains and fossils yet to be studied, which cover several passages of the karst systems and are totally embedded in calcite crusts. The site is therefore of high relevance for analysis of the palaeoclimatic and environmental conditions for this sector of the Murge [107].

For information and a 3D virtual tour of the cave, it is possible to contact the "Centro Visite Lamalunga" (Lamalunga Visitor Center) (Figure 10).

6.3. Spatial and/or Panoramic Geosites/Bradanic Trough Geosites/Quaternary Uplift-Related Geosites: The Panoramic Point of Gravina in Puglia

40°49′32.46″N; 16°24′27.68″E

In addition to being a meaningful portion of the small remnant of the Adria Plate, Murge and Premurge represent one of the few worldwide examples in which different evolutionary steps of the transition from foreland to external foredeep (foreland ramp) are well exposed. As mentioned above, in some places of the Premurge area, it is possible to observe both the bedrock of the foreland basin, i.e., the same limestones of Alta Murgia, and the whole foredeep sedimentary wedge pinching-out the foreland (Figure 11; see also Figure 1d). This relatively condensed lower Pleistocene succession is basically characterized by shallow-marine deposits comprising mainly, from the bottom to the top, bioclastic temperate-water (heterozoan) coastal-carbonates (Calcarenite di Gravina Fm), silty clay shelfal hemipelagites (Argille subappennine Fm), and coastal/alluvial sandy and gravelly deposits (Monte San Marco Fm) (Figure 11b,c) [59,79–81,108].

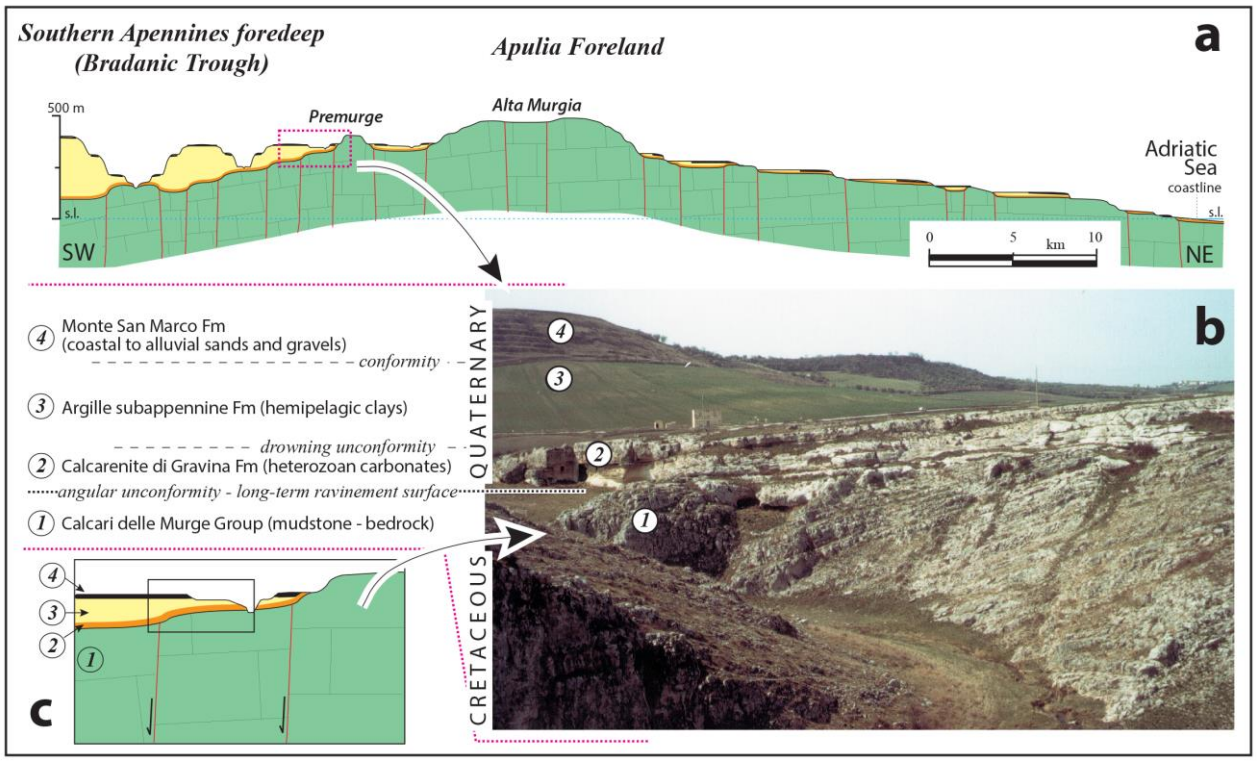

Figure 11. (**a**) Geological cross-section of Murge (Apulia Foreland) and Premurge (Bradanic Trough), showing the relationships between Cretaceous and Quaternary deposits. Compare with Figure 1d. (**b**) Photo from the panoramic point in the vicinity of the stadium parking of Gravina in Puglia town. Note the relationships between the faulted Cretaceous bedrock and the Quaternary foredeep succession. (**c**) Geological cross-section showing (inset) the virtual position of the outcrop of Figure b and how to appreciate the foredeep sedimentary wedge pinching-out the foreland. The whole figure from [42,69,74,109] mod.

One of the best places to observe the whole foredeep stratigraphy and to understand its location within the geological framework of the entire region is from the town of Gravina in Puglia and its surroundings (Figures 8 and 11b). At these panoramic points, a significant synthesis of the whole history of the outer foredeep can be appreciated, from subsidence (the succession filling the basin) to uplift (the deepening of the canyon).

Some panels in the town explain the geology of the area (Figure 12). Other panoramic points are from the stadium parking [42,109].

Figure 12. The Aqueduct Sant'Angelo—Fontana della Stella (corresponding to the bridge at Gravina in Puglia town). Note the explanatory panel in front of the panoramic point. Photo courtesy of Giusy Schiuma.

6.4. Hydrogeology- and Water- Related Geosites: The Sant'Angelo—Fontana della Stella Aqueduct, an Example of Tapping and Distributing Water since Middle Age

40°49′11.50″N; 16°24′49.58″E

Presence of water in karst areas has always been a serious problem for the local communities: the peculiar aspects of karst hydrogeology [110–112], with most of the water being rapidly drained underground, to create the complex subterranean network of conduits and caves, caused past inhabitants to face seriously the issue of looking for water, and preserving it during the summer season [113–115]. For these reasons, evidence of historical management of water resources is of extreme importance and represents a remarkable heritage to preserve.

At Gravina in Puglia, the Aqueduct Sant'Angelo—Fontana della Stella is a wonderful example of the ability to build underground hydric works, able to function for centuries (Figures 8 and 12).

As documented by historical sources, construction of the aqueduct started in 1743 [111,116], even though possibilities of a likely older origin have been postulated. With an overall length of some 3.5 km, the aqueduct is one of the best preserved underground man-made works for the collection and transport of water resources in Southern Italy [117]. A system of underground galleries (average height 1.75 m, width 0.77 m), connected to the surface by inspection wells (to clean periodically and to manage the hydraulic work), allowed the waters to flow toward the town. The subterranean system ends up at the right valleyside of the Gravina canyon; to pass the deep valley, and let the water reach

the final destination, a 90 m long bridge-canal was built across the canyon. The Sant'Angelo—Fontana della Stella aqueduct is a very important heritage [118,119], since it is one of the most significant ancient subterranean water-system in the Puglia Region (Figure 8).

A panel displayed on the abutment of the bridge provides some information on the aqueduct (Figure 12).

6.5. Spatial and/or Panoramic Geosites/Tectonics-Related Geosites: The Alta Murgia (or Murge Alte) Scarp

40°58'35.75"N; 16°13'45.32"E

As described before, the Apulia Foreland represents the edge of a wide WNW-ESE trending antiform whose flanks correspond to down faulted blocks of the Apulia Carbonate Platform. The Murge and Premurge areas are also characterized by the extensional activity of these faults, generally attributed to Pliocene and early Pleistocene times [66,120]. One of the most important of these faults is the NW-SE striking fault of "Valle del Bradano" [121], corresponding to the scarp that separates the Murge from the Premurge (i.e., from the Bradanic Trough) (Figure 13). The steep and straight Alta Murgia scarp (ca. 35 km long and up to 200 m high, from ca. 450 m up to ca. 650 m a.s.l.) includes the most impressive morphotectonic evidence of early Pleistocene tectonics. The faulted bedrock (Cretaceous limestones of the Apulia Platform) is exposed in the higher free face of the slope and covered, downwards, by Pleistocene deposits. These deposits are slope carbonate breccias organized in steep and short fans often coalescing and forming a long string bordering the northwestern part of the Murge area, and they record the interaction of active tectonics with climate change [122,123]. Only some quarry walls show the presence of the normal-fault plain (Figure 14).

The scarp is the scenery of almost all touristic itineraries straddling Murge and Premurge areas. Breccia deposits crop out along road cuts or not accessible (active or abandoned) quarries. Explanatory panels have not yet been realized.

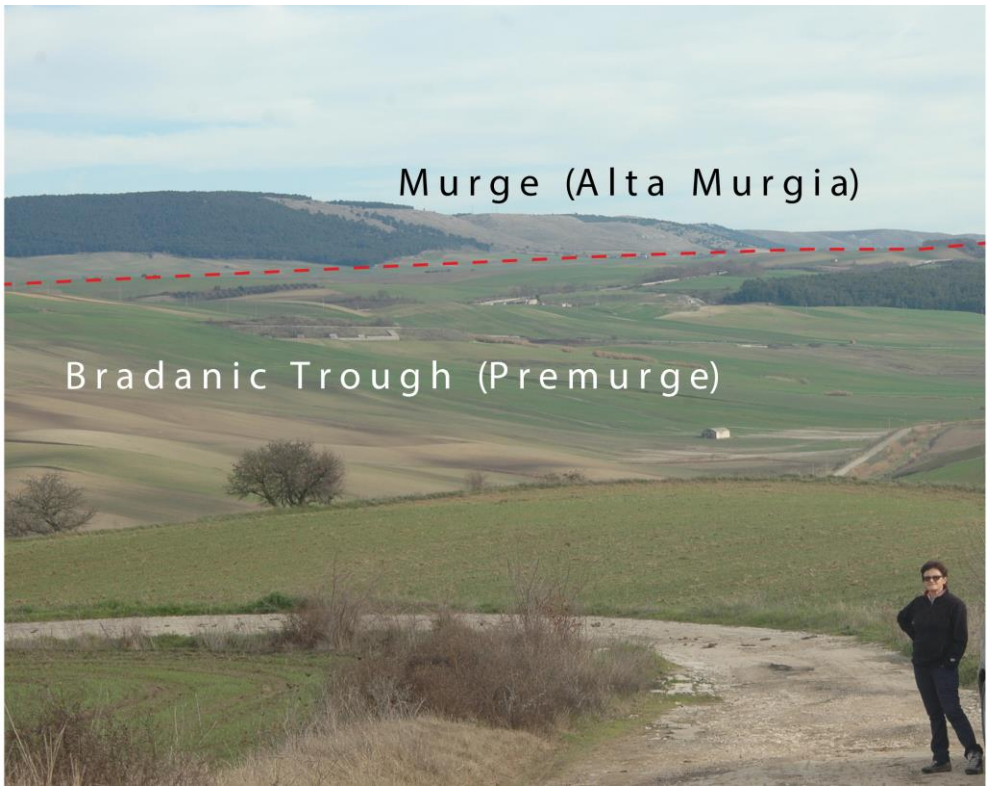

Figure 13. The Alta Murgia scarp, bounding the Murge from the Bradanic Trough (Premurge), corresponds to a receded fault plane (dashed red line). Landscape seen from the Premurge area.

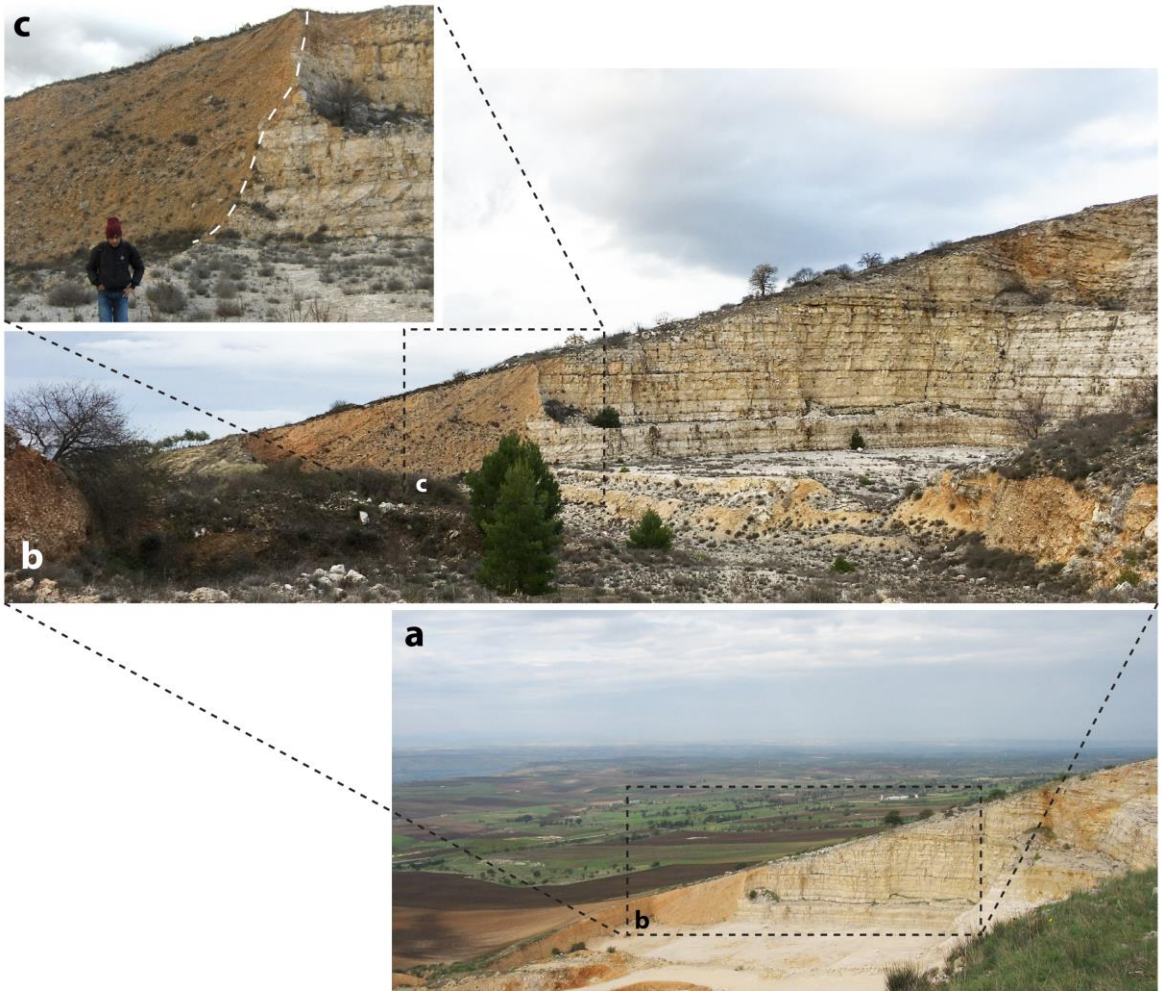

Figure 14. (**a**) The Alta Murgia scarp cut in an abandoned quarry and seen from the top of the Murge. Note the regularized sloping surface and the beginning of the Premurge area at its toe. (**b**) Clinostratified reddish breccia deposits (on the left of the quarry wall) pinching out against the fault plain bounding the white sub-horizontal Cretaceous beds (on the right of the quarry wall). (**c**) Detail of the contact between the Pleistocene breccia deposits (on the left) and the Cretaceous bedrock (on the right) (dashed white line).

6.6. Apulia Carbonate Platform geosites/Tectonics-Related Geosites: The Oligocene Calcare a Planorbis Formation

40°55′43.33″N; 16°18′43.24″E

The Oligocene Calcare a Planorbis Fm crops out at the top of the Alta Murgia scarp (Jazzo Madama locality), unconformably resting on Cretaceous carbonates (Figure 15); from a panoramic point of view close to Poggiorsini, it is possible to appreciate that the formation developed on two different and not coeval depocenters [124] (Figure 15). This stratigraphic architecture can be attributed to the synsedimentary development of an active strike-slip basin [125]. The geosite has an international value both for its tectonic meaning in the area (the only record of tectonics between Cretaceous and Pliocene in the Apulia Foreland) and for the possibility that correlates its continental paleontological content to the distant Paratethys. As suggested by [125], the site could offer a link with a similar setting in the Apennines, where a geosite with lacustrine succession linked to strike slip tectonics [126] is proposed in a touristic path devoted to promoting geology, following the writings and the paintings of Carlo Levi (a famous Italian artist, who suffered a political exile during the fascist era) [5].

The lacustrine succession can be observed from panoramic points along the road linking Gravina in Puglia and Minervino. Explanatory panels have not yet been made.

Figure 15. The Oligocene lacustrine succession perched at the top of the Alta Murgia scarp. After [125].

6.7. Apulia Carbonate Platform Geosites/Tectonics-Related Geosites: The intra-Cretaceous Unconformity

40°59′15.85″N; 16°10′55.92″E

The oldest tectonic phase recognized in the Murge area is Turonian in age and is highlighted by a regional unconformity in the Cretaceous succession and by the presence of bauxites along the unconformity. The abandoned bauxite mines (open pits) of Murgetta Rossa (Figure 16), in the vicinity of Spinazzola village, represent a touristic attraction, too, since the variety of uncommon intense colours of the outcropping rocks (reddish, brownish, yellowish, greenish), due to the abundant presence of oxide and phyllosilicate minerals, immediately excites and intrigues any visitor ("Murgetta Rossa" literally means "small red rocky area").

Outcropping residual rocks are hosted in palaeokarst (canyon-like) features [67] and the relationships between faulting and residual rock formations can be easily observed in the field. This peculiarity makes the site an ideal stratigraphic, mineralogical, and tectonic case study of international attractiveness in different fields of the Earth Science [127–133].

The site is equipped with panels for visits, but information is basically devoted to its aesthetic value, to biodiversity, and to industrial archeology.

Figure 16. One of the abandoned bauxite mines of "Murgetta Rossa".

6.8. Bradanic Trough Geosites: A Gilbert-Type Delta in Carbonate Succession

41° 4′22.98″N; 16° 3′39.48″E

During the early Pleistocene, as a consequence of the migration of the Southern Apennines orogenic system, the Apulia Foreland underwent a relatively rapid increase in regional subsidence, and regional transgression resulted on the flexed foreland, i.e., the paleo-Premurge (Figure 7). The return of the sea on this karst area led to the deposition of a thin (no more than a few tons of metre-thick) mantle of carbonates (the Calcarenite di Gravina Fm) on the Cretaceous bedrock (Figures 11 and 17).

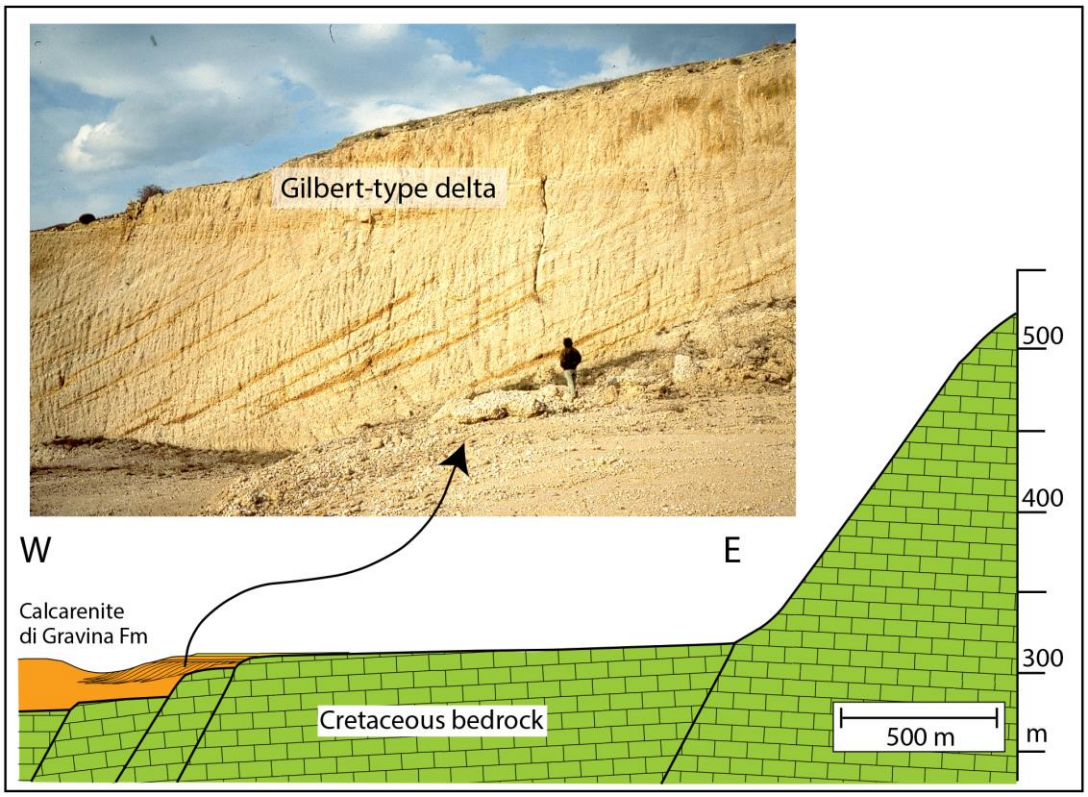

Figure 17. The Minervino delta and its location at the toe of the Murge Alte scarp. [134] mod.

A lower Pleistocene Gilbert-type delta, encased in offshore facies, outcrops along the western margin of Alta Murgia, west of Minervino town, and is well visible along the walls of an abandoned quarry, with a total thickness of about 12 m. This kind of delta shows a characteristic tripartite geometry with an upper part characterized by sub-horizontal strata, and a middle part composed of inclined beds (up to 30°/35°) passing to a lower part with sub-horizontal strata (Figure 17). Basically, this kind of delta develops at the foot of uplifting mountain regions directly facing the sea. The uniqueness of the Minervino delta comes from the fact that it developed on a flexuring and a subsiding karst setting, affected by tensional tectonics rather than at the foot of an uplifting mountain chain affected by compressional tectonics; further, it is composed only of carbonate extraclasts, i.e., rounded fragments of Cretaceous limestones [69,109,134]. Only one other gravelly carbonate delta has been described in international literature: it was observed in Croatia and developed during the Eocene at the base of an uplifting carbonate thrust [135].

The geosite is not equipped for visits, even if it is easy to access and can be reached with a short walk through the olive fields.

6.9. Karst Geosites/Man and Geology Geosites: The "Grotta di San Michele" (San Michele Cave) at Minervino

41° 5'39.25"N; 16° 4'34.75"E

An important aspect of the relationship between man and geology in the Murge is represented by religious and worship issues. As in many other parts of the world, karst caves have become worship sites for different cults. One of the best examples is the Michaelic worship; several towns in the Murge area host such sites with rupestrian churches, such as at Gravina in Puglia, Altamura, and Andria. However, its more remarkable expression is represented by a natural limestone cave at Minervino Murge, which was later transformed into a church dedicated to the Archangel Michael ("Grotta di San Michele") (Figure 18).

Figure 18. The interior of San Michele Cave during recent studies.

Recent studies were performed to define the stability assessment in the rock mass of the cave [136,137], since this rupestrian place is visited by Italian and foreign tourists. Nowadays, a picturesque procession takes place on the occasion of the patronal feast in honor of Saint Michael, on 29th September, whilst on 8th May a pilgrimage starts from the town and ends in the church with a religious ceremony. It brings to mind a famous path connecting different places of worship dedicated to the Archangel (in Puglia, in Italy, and in the world), all closely linked to geological features. In Puglia, many karst caves are dedicated to the Archangel Michael, the most important being the oldest shrine in Western Europe at Monte Sant'Angelo, in the Gargano Promontory, which became a UNESCO World Heritage Site in 2011.

The San Michele Cave is opened to public and can be visited, with information provided by searching the web with the words, "Grotta di San Michele, Minervino".

7. Conclusions

Due to its geodiversity, the Murge aUGGp represents a good opportunity to disseminate geological knowledge to a wide and diversified audience. It also represents a study

area that still contains a great variety of geological items to be discovered and/or described. Several geological topics can be followed both by researchers and geotourists, but each of them should be traced back to the geological history of the Puglia region, which is in turn closely related to the evolution of the Adria Plate, a piece of the plate tectonics puzzle that played a pivotal role in the Thetys and later in the development of the Mediterranean realm. For this reason, the local geological singularities should not distract us from the unifying geological reasons that led to its candidacy for being a geopark.

A General Remark

In our experience, most of the protected areas in Italy suffer from a lack of geological knowledge and/or related dissemination and, even when the geological reason is the predominant for the establishment of a protected area, this boils down to the production of a report often lost in the back of a drawer, with further activities almost exclusively devoted to biological aspects of the area (biodiversity largely prevailing over geodiversity). Furthermore, the link between the geological heritage and all other aspects of the territory is often attributed only to the landscape, meant as a scenography with only an aesthetic value. Taking into account that in our territories it could be difficult to find landscapes not influenced or modified by human activity, this means that the dissemination interests (among many others) mainly concern prehistory, history, architecture, agriculture, rurality, and gastronomy, all proposed without any concrete link with geology.

Our paper represents an introduction to the scientific grounds that led to the nomination of the Murge and Premurge areas as an aspiring UNESCO Global Geopark due to the realization of a scientific dossier. The dossier was produced by a working group of the "Dipartimento di Scienze della Terra e Geoambientali" (Department of Earth and Geoenvironmental Sciences) of the "Aldo Moro" University of Bari (Italy), corresponding to the first authors of the present paper (M.A.C., V.D.S., V.F., M.P., L.Sa., L.Sp., R.F., V.I. and G.A.M., coordinated by M.T.). The dossier and the present paper derive both from thirty years of experience and study in the Murge and Premurge areas made by the working group and from other data collected and interpreted thanks to the collaboration with all the other authors. After these efforts, we hope that visitors and geotouristic operators realize that a holistic approach is not just about eating a sandwich in front of a silent geosite.

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didactic/geotouristic nature-trails in the context of the candidate Geopark of Murge (aUGGp): the stratigraphy of the carbonate successions outcropping in the municipalities of the internal areas of Murge (Poggiorsini, Spinazzola and Minervino Murge) as a basis for geo-scientific dissemination"] aimed at the correct transfer of geological topics to a non-expert audience. PhD Grant concessed by the "Agenzia per lo Sviluppo Territoriale" ("D.M. 725, 22-06-2021—Dottorato Comunale"); (ii.) F. Bellini: "Valorizzazione del 'capitale naturale geologico' a fini turistici (geoturismo) del Parco Nazionale Alta Murgia (candidato Geoparco UNESCO) e realizzazione di piattaforme e siti digitali dedicati ai visitatori e alla comunità degli smartworkers" ["Enhancement of the 'geological natural capital' for tourism purposes (geotourism) of the Alta Murgia National Park (UNESCO Geopark candidate) and creation of platforms and digital sites dedicated to visitors and the community of smartworkers"], in collaboration with the Everywhere TEW Company, aimed at identify geotouristic routes linking geosites of broad interest; and (iii.) U.S. D'Ettorre: "Fenomeni di desertificazione nelle Murge pugliesi ed analisi quali-quantitativa delle risorse idriche" ["Desertification phenomena in the Apulian Murge, and quali-quantitative analysis of hydric resources"]. Research funds to the project "GeoSciences: un'infrastruttura di ricerca per la Rete Italiana dei Servizi Geologici—GeoSciences IR" (codice identificativo domanda: IR0000037); CUP: I53C22000800006. Piano Nazionale di Ripresa e Resilienza, PNRR, Missione 4, Componente 2, Investimento 3.1, "Fondo per la realizzazione di un sistema integrato di infrastrutture di ricerca e innovazione" finanziato dall'Unione Europea—Next Generation EU (to V. Festa). research funds to the project "Interventions for exploration of karst phenomena", Apulia Region, Environmental Division, 2019–2021 (to M. Parise).

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