# Q:1 ~~The Apulia Carbonate Platform in the Gargano Promontory (Upper Jurassic to Eocene,~~ Q:2 ~~southern Italy)~~

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Q:3 **Sergio Nardon, Erwin Adams, and Guido Bracco Gartner**

## ABSTRACT

The Upper Jurassic to Eocene carbonate rocks of the Gargano Promontory belong to the Apulia Carbonate Platform (ACP) and provide a spectacular and complete succession of slope and base-of-slope resedimented gravity flow carbonates with preserved Q:7 reservoir properties with its coeval carbonate platform, displaying various tectonostratigraphic architectures. The ACP margin is characterized by an overall aggrading architecture, ~~characterized by~~ different geometric and depositional features. Facies types and sedimentary dynamics of the carbonate slope and gravity deposits can be analyzed with respect to the stratigraphic architecture of the platform-to-basin transition. These outcrops are the only analogs of some important oil reservoirs and plays present in the equivalent slope to basin succession in the ~~offshore Adriatic~~ and elsewhere.

## INTRODUCTION

The Apulia Carbonate Platform (ACP) is one of the most extensive Mesozoic–Cenozoic isolated carbonate domains of the Tethyan Ocean (Bernoulli, 2001). This carbonate platform is partially comparable to the Bahamas banks in terms of facies, shape, size, subsidence rates, and internal architecture but illus-Q:8 trates many important differences from the late Cenozoic isolated platform model.

Though Cretaceous inner platform facies crop out extensively in the Apulia region, the platform margin of the ACP and transition to the coeval basinal succession are only visible in outcrop in the Gargano Promontory (for the Middle Jurassic to Eocene interval) and in the Maiella Mountain (for the Upper Cretaceous to


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Miocene) (Figures 1, 2). Elsewhere, the margin of this vast platform is located offshore in the Adriatic Sea to the east and beneath the Apennines foredeep to the west, covered by Cenozoic successions (Figure 1).

The ACP margin is characterized by an overall aggrading architecture, showing different geometric and depositional features (Bosellini et al., 1999; Borgomano, 2000; Hairabian et al., 2015). Facies and structural trends are directly linked to the main oil fields discovered offshore in the Adriatic basin along the eastern margin of the ACP or below the Apennines thrust belt (Val d'Agri oil field) along the western margin of the same paleogeographic unit (Caldarelli et al., 2013; Cazzini et al., 2015). The Gargano outcrops are also relevant as potential analogs of the specular counterpart of the Adriatic Carbonate Platform (AdCP) that crops out from Istria to Greece and in Adriatic offshore (Figure 1) (Bega, 2015).

The source rocks of the whole area are mainly Upper Triassic carbonate anoxic facies (Burano and Emma limestone formations). Reservoir rocks with preserved porosity and permeability (Hairabian et al., 2014) mainly consist of Cretaceous to Oligocene resedimented carbonates. Seal rocks in the Adriatic Basin are evaporites of Messinian age and Pliocene–Pleistocene siliciclastic deposits, in some places thousands of meters thick. In the western margin of the APC the seal is formed by foredeep deposits overlain by the Apennines thrust sheet.

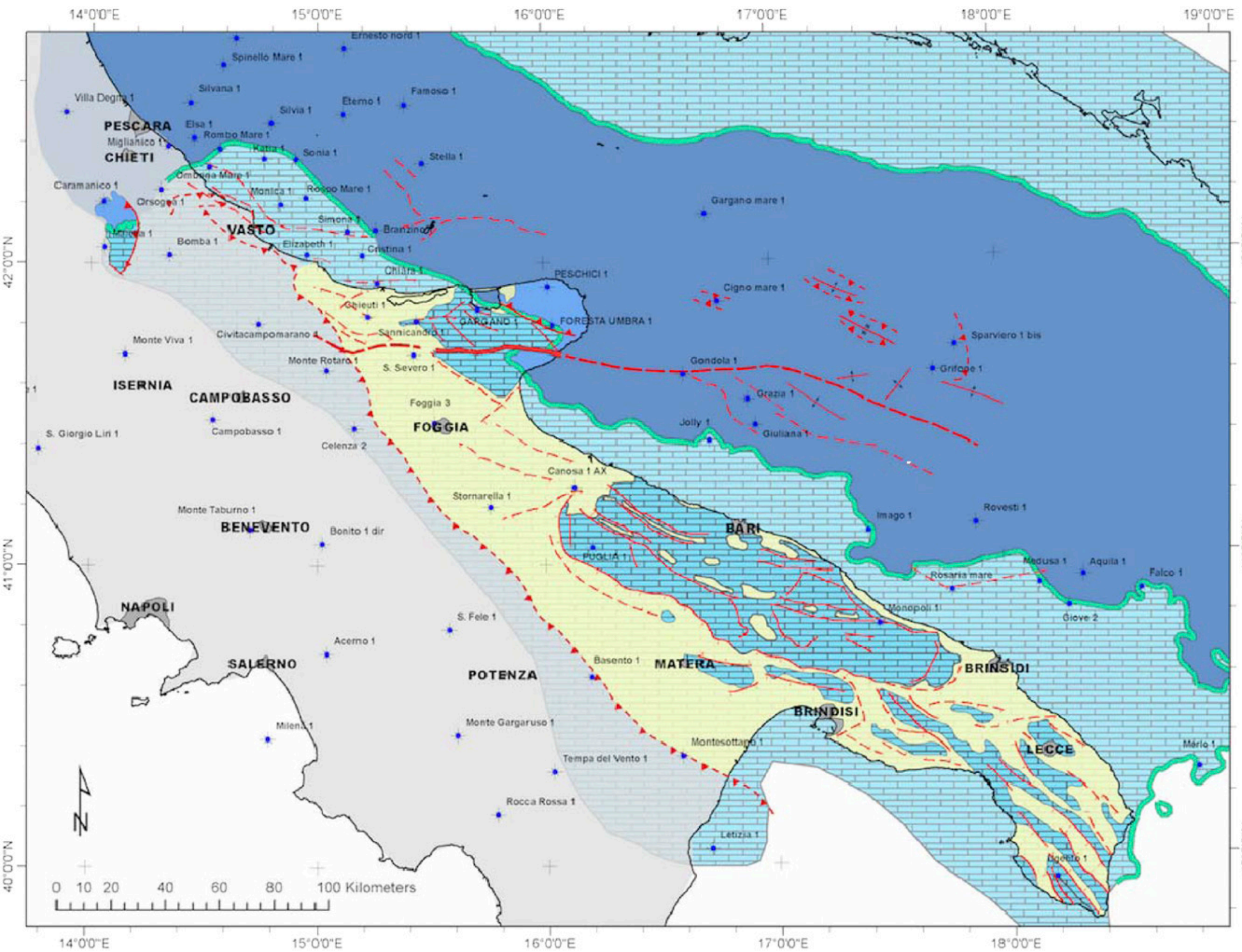



**Figure 1.** The Apulia Carbonate Platform (ACP) and adjacent Adriatic Basin. The ACP is a vast shallow-water carbonate platform including the Maiella Mountain at the northwestern tip. The eastern margin (green line) occurs some tens of kilometers offshore in the Adriatic Sea and is reconstructed through the public seismic lines and oil wells available in the project Visibilità Dati Esplorazione Petrolifera in Italia (2012); the western margin is buried under the southern Apennine thrust belt and associated to the Val d'Agri oil field. In the top right-hand corner, part of the large Adriatic carbonate platform margin in the northern Adriatic Sea is shown.

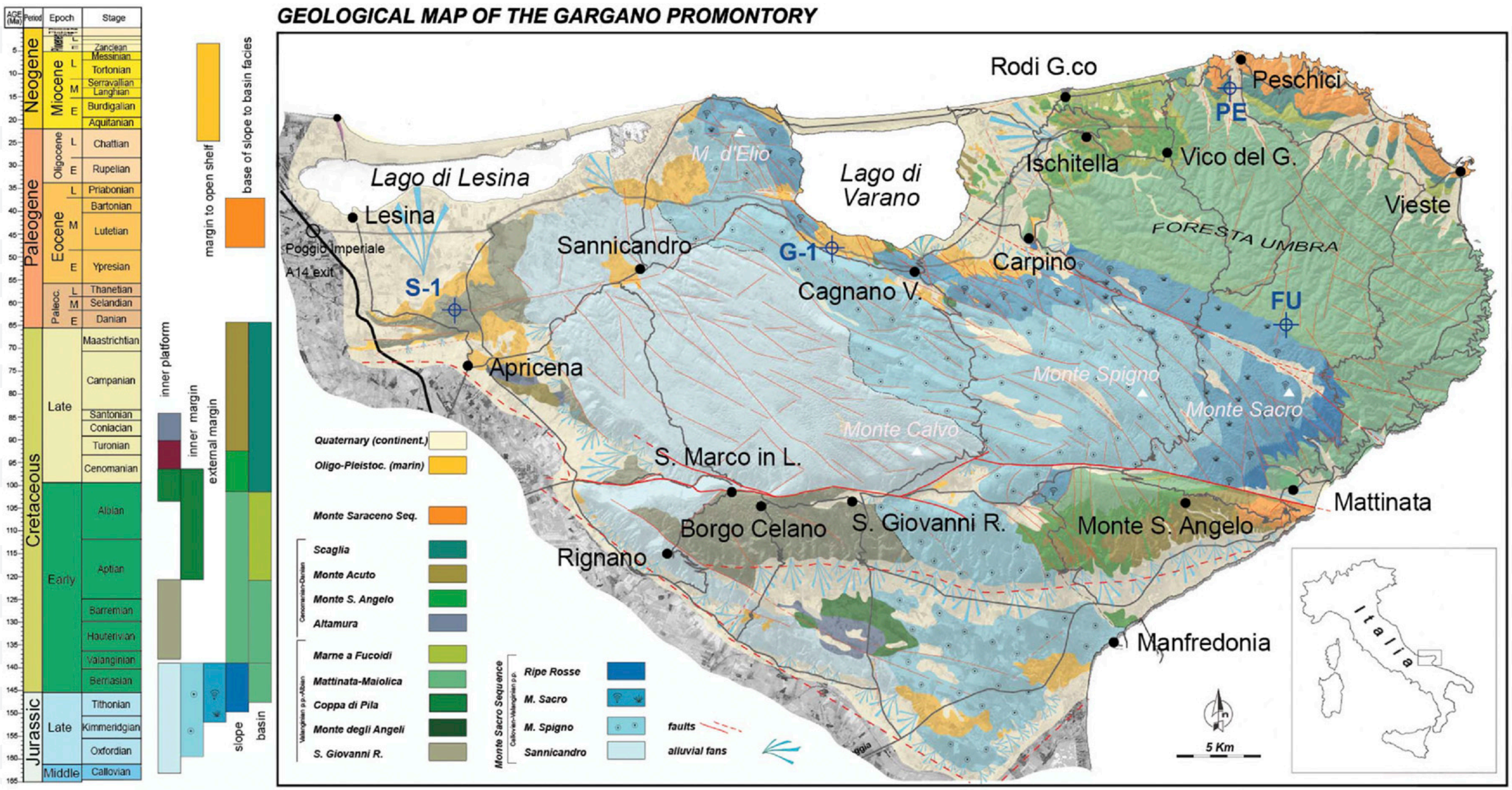



**Figure 2.** Simplified geological map of the Gargano Promontory (modified after Morsilli, 2011). Oil wells: FU = Foresta Umbra 1 (Eni); G-1 = Gargano 1 (Conoco); PE = Peschici 1 (Eni); S-1 = Sannicandro 1 (Eni). Q:22 Q:23

In this short guideline we propose some field trips that allow direct observation of a mostly complete transect from inner platform facies to their basinal counterparts, with observations on facies, stratigraphic organization, and evolution trough time and as an analog of the buried part of the platform (Figure 1) and its adjacent twin (AdCP).

The value of the Gargano outcrops and proposed excursions includes (1) easily accessible three-dimensional exposures; (2) complete transect from the inner platform to the basinal facies; (3) record of paleoceanographic changes and tectonostratigraphic events; (4) preserved genuine reservoir properties; (5) well-constrained stratigraphy, both offshore and onshore; (6) relatively weak deformation by Dinaric and Apenninic orogeneses; (7) models for hydrocarbon plays in different settings and stratigraphic units (e.g., inner platform paleokarst [Rospo Mare, Ombrina], subthrust setting [Monte Alpi, Tempa Rossa], slope, and base-of-slope resediments [Elsa, Miglianico, Aquila, Rovesti]); (8) similarities with other well-known deep-water reservoirs (e.g., Poza Rica oil field, Mexico); and (9) public subsurface data available and organized in a web geographic information system project called Visibilità Dati Esplorazione Petrolifera in Italia (ViDEPI; http://www.videpi.com). The ViDEPI data set includes approximately 1650 well data and 55,000 km of two-dimensional multichannel seismic profiles acquired since 1957 by several oil companies.

## GENERAL ACCESS AND SAFETY

From a logistical point of view the Gargano Promontory is a small and easily accessible area, and all the proposed excursions are close to the main roads; thus, physical effort is very limited, as well as security issues. The best time to visit is from March to June and September to October, avoiding the strong heat of the summer and harsh, cold weather of the winter.

This excursion requires 4 field days and a half-day transfer from local airports to outcrop locations and return. From Roma international airport it takes 5–6 hr drive to reach the Gargano outcrops by road, but from Bari airport it takes only a 2-hr drive. The best towns to organize the base are Monte Sant' Angelo or Manfredonia, situated halfway between the inner platform and the basin. Normal cars and coaches allow full access to outcrops.

Gargano is a touristic place, and many types of accommodations are available, as well as banking services, restaurants, pharmacy, general stores, and bars. A public hospital, with all patient care facilities, is located in the middle of the Promontory (Casa Sollievo della Sofferenza, San Giovanni Rotondo), and emergency room are located in many small cities with an active air ambulance service in case of serious disease.

The main safety issues are driving, and some outcrops are along roads. Ticks may be present depending on the heat and humidity.

## Geological Background

The Gargano Promontory represents the deformed foreland of the southern Apennine and of the Dinaric thrust belt. Structurally, it is a gentle and broad anticline with a northwest–southeast axis affected by many reverse and normal faults, as well as strike-slip faults (Figure 2). The most famous of these faults is the Mattinata Fault that crosses in east–west direction the whole Gargano Promontory and extends offshore (Gondola Line) and onshore for tens of kilometers (Figure 1). The Gargano Promontory has been interpreted as a Neogene contractional belt (Bertotti et al., 1999) with some thrust structures related to Dinaric compression or as a transpressional ridge kinematically decoupled from adjacent areas along strike-slip faults (Brankman and Aydin, 2004). Until the early Miocene, the Gargano was weakly deformed, but during Langhian to Tortonian times a tectonic phase induced the deformation of previous and syndepositional units with gentle folds and thrusts. The main tectonic uplift occurred between the late Miocene and the early (?) Pliocene. Post-Pliocene deformation consists of gentle northwest–southeast-trending folds and strike-slip faults.

The carbonate rocks of the Gargano Promontory and of the other adjacent area belong to the ACP and have an average thickness of 5 km for the Mesozoic shallow-water carbonate succession and a variable thickness of 1–2 km for the coeval basinal successions. Eocene slope to basin facies occur mainly in the northeastern tip of the Gargano between Peschici and Vieste. Scattered outcrops of marine carbonates of Oligocene to Pleistocene are present all around the promontory (Figure 2).

An overall inner platform to basin transect (Late Jurassic–Early Cretaceous) of a well-preserved accretionary carbonate margin is recognizable. The inner platform facies are characterized by typical peritidal cycles (Sannicandro Formation). They pass to sandy (oolitic and bioclastic) shoals that occupy a large part of the shallow margin area (Monte Spigno Formation). A deeper margin is colonized by bioconstructors (Monte Sacro Limestone) such as sponges *(Ellipsactinia* and stromatoporoids), with subordinate corals (Morsilli and Bosellini, 1997). The external margin passes gradually to the clinostratified slope facies (Ripe Rosse Formation) and to the basinal deposits (Maiolica Formation). The Berriasian–lower Valanginian slope is onlapped by a thick succession of white, thin-bedded cherty, lime mudstones (Maiolica Formation) of Valanginian–Hauterivian age interpreted as a drowning unconformity (Bosellini and Morsilli, 1997; Bracco Gartner et al., 2002). From Valanginian p.p. to early Aptian, normal platform and margin productivity prevailed. Approximately 500 m of inner platform deposits are preserved (San Giovanni Rotondo Limestone) and abundant calciturbidites are found in the adjacent slope succession (lower Mattinata Formation). However, the geometry of the platform–slope transition remains poorly constrained for this time interval. The ACP margin and the adjacent slope suddenly became inactive during the lower Aptian. During the following upper Aptian–Cenomanian interval, the ACP margin underwent major physiographic changes. Deep-seated faults induced significant vertical displacement and the backstepping of the platform margin. A steep submarine escarpment associated with erosion and bypass was created and characterized the ACP margin until the early Tertiary. Abundant megabreccias reworking inner platform to margin facies of Lower Cretaceous age were deposited at the toe of the escarpment from upper Aptian to Albian (upper Mattinata Formation) (Hairabian et al., 2015). During the upper Albian p.p.–Cenomanian, a highly productive carbonate factory dominated by rudists developed along the platform margin, which led to the redeposition of huge volumes of skeletal material at the toe of the slope (Monte Sant'Angelo Limestone). This unit forms a thick (up to 250 m) base-of-slope apron extending greater than 20 km toward the basin and highly continuous laterally along the ACP margin. Early lithified skeletal sands along the margin and slope were locally involved in huge collapses resulting in the deposition of thick intraformational megabreccias. Platform edge and slope collapses seem to have been a common feature of the whole ACP margin, as visible in outcrops (Gargano and Maiella) and from seismic profiles in the Adriatic offshore that create a typical scalloped bank margin with amphitheater-like shape (Figure 1). During the Albian–Turonian a series of tectonically induced relative sea level lowstands exposed the carbonate platforms of the southern Apennines to subaerial conditions with the development of diachronous bauxite horizons, considered as late Cenomanian?–Turonian p.p. in the Gargano area. Associated with the reflooding of the platform (Turonian p.p.–Coniacian?), several complexes of lobes mainly composed of bioclastic calcarenites were deposited onto the base of slope until the Danian p.p. (Monte Acuto Limestone) (Hairabian et al., 2015) (Figure 3). During the Paleocene to early Eocene, other failures occurred along the margin of the platform. A basal megabreccia (Grottone Megabreccia) followed by Lutetian clinostratified deposits (Monte Saraceno Limestone) and bioclastic turbidites (Peschici Formation) were deposited around the Gargano Promontory (Bosellini et al., 1999; Adams et al., 2002).

## ITINERARY

This itinerary covers 4 days but for convenience is divided into six discrete excursions designed to cover different stratigraphic setting and subjects that can be done separately according to the main interests of the visitors. Stops 5 and 6 can be combined in one full-day excursion.

### Excursion 1 (Half Day): Inner Platform Facies, Karst, and Fracture Patterns

This excursion consists of two main stops to observe the characteristics of the Lower Cretaceous inner platform facies (San Giovanni Rotondo Limestone) and fracture pattern and associated karst morphotypes and infilling as well as dinosaur footprints, important for paleogeographic reconstruction of the ACP. Main outcrops are located in some quarries of the Apricena–Poggio Imperiale area (stop 1.1; Figure 4A) and close to Borgo Celano area (stop 1.2).

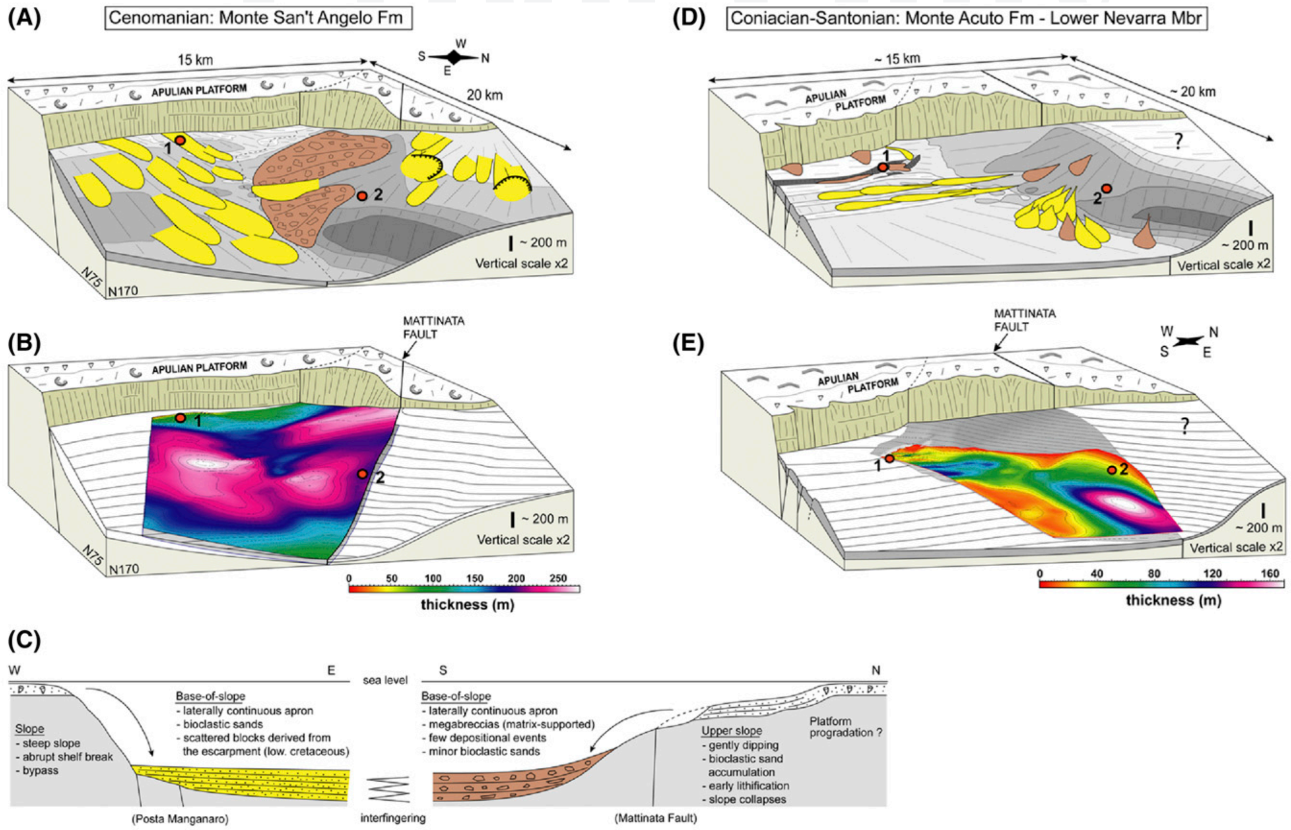


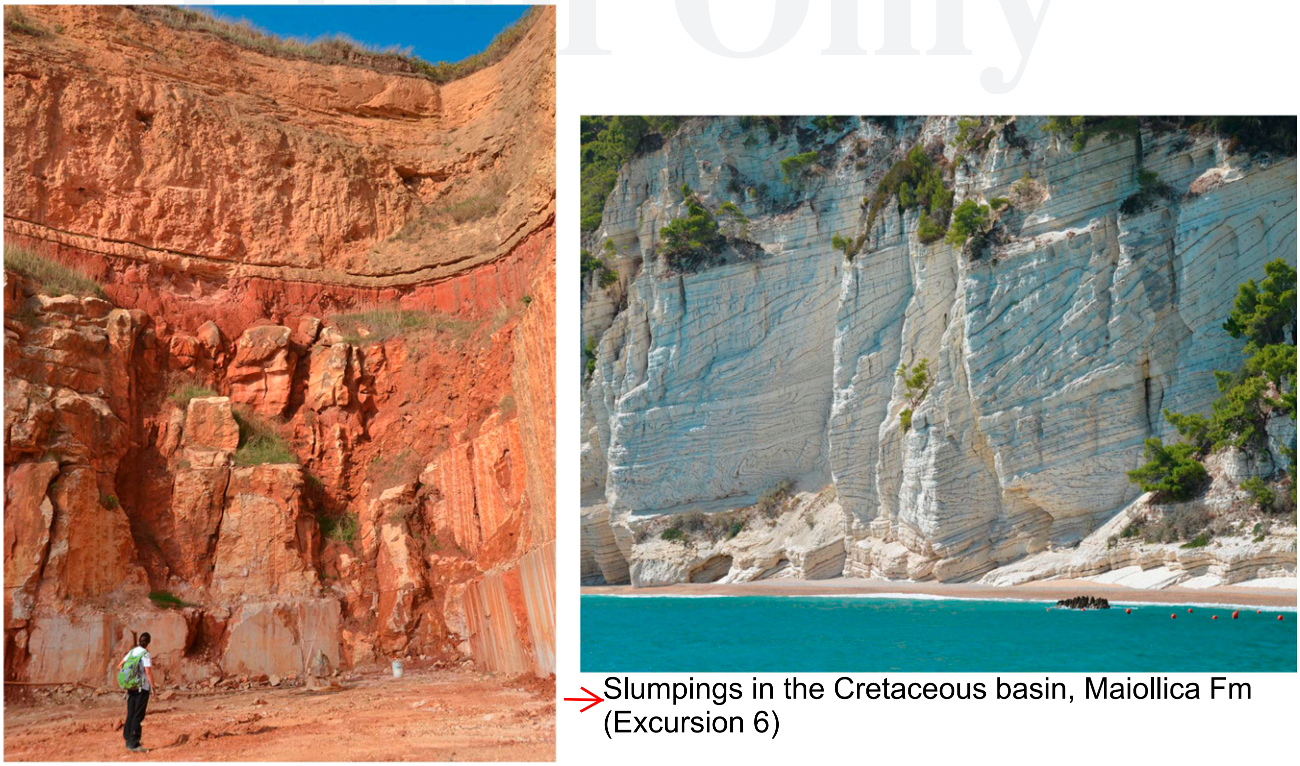

**Figure 3.** Reconstruction of the Upper Cretaceous paleogeography in southern Gargano based on three-dimensional numerical modeling and restoration in paleostate (Hairabian et al., 2015). Point 1 is Posta Manganaro, and point 2 locates the town of Monte
Q:24 Sant'Angelo. (A) Depositional model of the Monte Sant'Angelo Limestone (Lms). Bioclastic grainstones deposited as sheets (yellow) were mainly derived from the western platform domain, whereas intraformational megabreccias (brown) were sourced from a distally steepened slope to the north. (B) Isopach map of thickness of the Monte Sant'Angelo Lms. (C) Two-dimensional conceptual model showing the differences in slope geometry that could have controlled the spatial variations in lithology observed in the Monte Sant'Angelo Lms in southern Gargano. (D) Depositional model for the lower Nevarra Member (Mbr) of the Monte Acuto Lms. Bioclastic grainstone lobes (yellow) were derived from the north and locally funneled within elongated depressions of tectonic origin onto the basin floor. (E) Isopach map of thickness of the lower Nevarra Mbr of the Monte Acuto Lms showing the location of the different depocenters corresponding to
Q:25 complexes of lobes. Fm = formation.

Stop 1.1 (41°48.449′N, 15°22.130′E) is located on a structural relief made of Lower Cretaceous inner platform facies, uplifted and karstified at their top and covered by Pliocene and Pleistocene carbonate to siliciclastic units. These karstified limestones provide outcrop analogs of the Rospo Mare oil field located approximately 20 km northwest in the Adriatic offshore (Figure 1). Fracture patterns are another subject that can be explored in the Apricena quarries, interpreted as the result of overpressured fluid flows (Larsen et al., 2010).

Stop 1.2 (41°40′40.14″N, 15°40′0.09″E) consists of observations of subtidal to peritidal cycles of the San Giovanni Rotondo Limestone (Valanginian p.p.–Aptian p.p.) that reach an estimated thickness of approximately 550 m.

## Excursion 2 (1.5 Days): The Cretaceous Slope/Base-of-Slope Facies

The excursion focuses on the sedimentary succession exposed in the southern part of the Gargano between Ruggiano and Monte Sant'Angelo (Figure 2), which represents greater than 500 m of thickness of resedimented and autochthonous deep-water carbonates deposited at the toe of the steep submarine slope flanking the ACP from Aptian to early Tertiary.



Slumpings in the Cretaceous basin, Maiollica Fm (Excursion 6)

Tertiary paleo-karst in the Cretaceous platform,SG. Rotondo Fm. (Excursion 1)

**Figure 4.** (A) Stratigraphic units of the Passalacqua quarry (stop 1.1). Bari Limestones, karst, and terra rossa Pliocene carbonate unit and on top Serracapriola Formation (Fm.). (B) Panoramic view of the slump intervals in the Maiollica Fm. of the Baia delle Zagare outcrop Q:26 (southern side). Note the different style of deformation in the assorted slump intervals.

Stop 2.1 (41°39′15.96″N, 15°53′28.97″E) shows a panorama of the southern Gargano cliffs in the Belvedere di Ruggiano area and illustrates the abrupt, near-vertical contact between Berriasian shallow-water limestones of the Monte Spigno Formation and deep-water carbonate resedimentations of Albian (upper Mattinata Limestone).

The submarine escarpment bounding the ACP was most probably several hundreds of meters high at the end of the Lower Cretaceous, which is inferred from the age of the oldest limestone blocks (Berriasian) found in the upper part of the Mattinata Limestone (upper Albian) compared with the thickness of the coeval platform series preserved toward the west.

## Excursion 3 (Half Day): The Upper Jurassic to Lower Cretaceous Slope to Basin Facies Transition

This excursion is related to the observation of geometries, facies, and synthetic seismic outcrop model of the Upper Jurassic to Lower Cretaceous slope to basin transition in the Mattinata area (Figure 2).

From the panoramic view at stop 3.1 (41°44′2.92″N, 16° 4′7.75″E), it is possible to observe the physical transition between the platform external margin (Monte Sacro Limestone), the slope (Ripe Rosse Formation), and the basinal pelagic mudstone and cherts of the Maiolica Formation. The geometric relationships visible in the field support the interpretation that this facies association is a proximal to distal, clinostratified slope succession (Morsilli and Bosellini, 1997; Bracco Gartner et al., 2002). Also in this area a marked retreat of the Valanginian pelagic interval of the Maiolica Formation testifies the occurrence of a partial drowning of the ACP (Bosellini and Morsilli, 1997).

## Excursion 4 (Half Day): The Eocene Clinoforms and Their Transition to the Basin

This excursion is related mainly to the Eocene sequence formed mostly by Nummulitic clinobeds and their physical transition to the basinal Scaglia counterpart.

From the panoramic view toward Monte Saraceno ~~in stop 4.1~~ (41°41′24.28″N, 16°2′54.51″E), the clinostratified successions (Monte Saraceno Limestone) that pass tangentially to the coeval basinal sediments (Scaglia Formation) of the middle Eocene are visible.

## Excursion 5 (Half Day): The Maiolica Slumpings

~~Stop 5.1 is~~ Baia delle Zagare (41°44′51.94″N, 16°8′44.59″E). This excursion is related to the spectacular slumping features widespread inside the Maiolica Formation. This unit, 450–500 m thick, crops out throughout the northeastern part of the Gargano, and the most spectacular outcrops are along the sea cliffs between Vieste and Mattinata (Figure 4B) (Morsilli et al., 2004).

## Excursion 6 (Half Day): The Eocene Unconformity and Lithofacies

This excursion is proposed to see the spectacular unconformity between the Upper Cretaceous Scaglia Formation and the onlapping Eocene base of slope succession of the Peschici Formation.

From the panoramic view of the Vieste sea cliff ~~in stop 6.1~~ (41°52′43.68″N, 16°10′37.50″E), the erosional contact between the basinal, cherty lime mudstones of the Scaglia Formation (Coniacian p.p.) and the overlying Peschici Formation (Lutetian) is spectacularly exposed. The unconformity is not a transgressive contact, as interpreted previously, but a submarine unconformity onlapped by gravity-displaced and pelagic sediments (Bosellini et al., 1999; Morsilli et al., 2004).

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# AUTHOR QUERIES

## AUTHOR PLEASE ANSWER ALL QUERIES 1

Q:1 Please provide a short title for your article of no more than 80 characters, including spaces.

Q:2 If you have chosen to publish figures in color online, please review the print version of the proof on the following pages for accuracy and clarity of BW figures. If changes are needed, please upload revised BW versions of the figures or annotate for minor text corrections. There is no need to reannotate your other corrections on this second version of the proof.

Q:3 Please provide a brief biography for each author including education and work history and current research interests.

Q:4 Please provide e-mail addresses for all authors.

Q:5 In affiliations 2 and 3, please spell out "CEREGE," "UM," "CNRS," "UMR," and "IRD."

Q:6 Please provide street addresses for affiliations 4, 5, and 6.

Q:7 In the first sentence of the abstract, it is unclear what is being referred to by "its" in "its coeval carbonate platform." Please clarify.

Q:8 In the sentence "This carbonate platform is partially comparable to the Bahamas banks…," "Cainozoic" has been changed to "Cenozoic." Please confirm.

Q:9 In the sentence "The value of the Gargano outcrops and proposed excursions…," "webgis" was changed to "web geographic information system." Please confirm.

Q:10 In the sentence "The ViDEPI data set includes about 1650 well data…," "55.000" has been changed to "55,000." Please confirm.

Q:11 Please provide English unit equivalents in parentheses after metric measurements in the text and figures.

Q:12 In the sentence "The best time to visit is from March to June and September to October…," "bad-cold" was changed to "harsh, cold." Please confirm.

Q:13 In the sentence "The best towns to organize the base are…," "Monte San Angelo" has been changed to "Monte Sant'Angelo." Please confirm.

Q:14 Throughout the text, "Fm" has been spelled out as "Formation," and "Lms" has been spelled out as "Limestone." Please confirm.

Q:15 In the sentence "From Valanginian p.p. to early Aptian, normal platform…," please define "p.p."

Q:16 In the sentence "During the upper Albian p.p.–Cenomanian, a highly productive carbonate…," "Monte S. Angelo" has been changed to "Monte Sant'Angelo." Please confirm.

## AUTHOR QUERIES

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Q:17 Please provide accessed date (day, month, and year) for Caldarelli et al. (2013).

Q:18 Please indicate where in text Guerzoni (2016) should be cited.

Q:19 Please provide (1) location of university and (2) pages for Guerzoni (2016).

Q:20 For Morsilli et al. (2004), (1) please provide date of congress, (2) please provide the location (city and state/country) of the congress, and (3) please clarify what is meant by "APAT ed. Roma, Florence"; that is, is it a publisher name/location, or is it the sponsor and location of the congress?

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Q:22 Please provide latitude and latitude for the map in Figure 2.

Q:23 In the caption of Figure 2, please define "S.," "L.," "V.," "R.," "M.," and "G."

Q:24 In the caption of Figure 3, "S. Angelo" has been spelled out as "Sant'Angelo." Please confirm.

Q:25 In the caption of Figure 3, please confirm that "Fm," "Mbr," and "Lms" have been defined correctly.

Q:26 In the caption of Figure 4, please define "SG."

# *The Apulia Carbonate Platform in the Gargano Promontory (Upper Jurassic to Eocene, southern Italy)*

**Michele Morsilli, Alex Hairabian, Jean Borgomano, Sergio Nardon, Erwin Adams, and Guido Bracco Gartner**

## ABSTRACT

The Upper Jurassic to Eocene carbonate rocks of the Gargano Promontory belong to the Apulia Carbonate Platform (ACP) and provide a spectacular and complete succession of slope and base-of-slope resedimented gravity flow carbonates with preserved reservoir properties with its coeval carbonate platform, displaying various tectonostratigraphic architectures. The ACP margin is characterized by an overall aggrading architecture, characterized by different geometric and depositional features. Facies types and sedimentary dynamics of the carbonate slope and gravity deposits can be analyzed with respect to the stratigraphic architecture of the platform-to-basin transition. These outcrops are the only analogs of some important oil reservoirs and plays present in the equivalent slope to basin succession in the offshore Adriatic and elsewhere.

## INTRODUCTION

The Apulia Carbonate Platform (ACP) is one of the most extensive Mesozoic–Cenozoic isolated carbonate domains of the Tethyan Ocean (Bernoulli, 2001). This carbonate platform is partially comparable to the Bahamas banks in terms of facies, shape, size, subsidence rates, and internal architecture but illustrates many important differences from the late Cenozoic isolated platform model.

Though Cretaceous inner platform facies crop out extensively in the Apulia region, the platform margin of the ACP and transition to the coeval basinal succession are only visible in outcrop in the Gargano Promontory (for the Middle Jurassic to Eocene interval) and in the Maiella Mountain (for the Upper Cretaceous to


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Miocene) (Figures 1, 2). Elsewhere, the margin of this vast platform is located offshore in the Adriatic Sea to the east and beneath the Apennines foredeep to the west, covered by Cenozoic successions (Figure 1).

The ACP margin is characterized by an overall aggrading architecture, showing different geometric and depositional features (Bosellini et al., 1999; Borgomano, 2000; Hairabian et al., 2015). Facies and structural trends are directly linked to the main oil fields discovered offshore in the Adriatic basin along the eastern margin of the ACP or below the Apennines thrust belt (Val d'Agri oil field) along the western margin of the same paleogeographic unit (Caldarelli et al., 2013; Cazzini et al., 2015). The Gargano outcrops are also relevant as potential analogs of the specular counterpart of the Adriatic Carbonate Platform (AdCP) that crops out from Istria to Greece and in Adriatic offshore (Figure 1) (Bega, 2015).

The source rocks of the whole area are mainly Upper Triassic carbonate anoxic facies (Burano and Emma limestone formations). Reservoir rocks with preserved porosity and permeability (Hairabian et al., 2014) mainly consist of Cretaceous to Oligocene resedimented carbonates. Seal rocks in the Adriatic Basin are evaporites of Messinian age and Pliocene–Pleistocene siliciclastic deposits, in some places thousands of meters thick. In the western margin of the APC the seal is formed by foredeep deposits overlain by the Apennines thrust sheet.

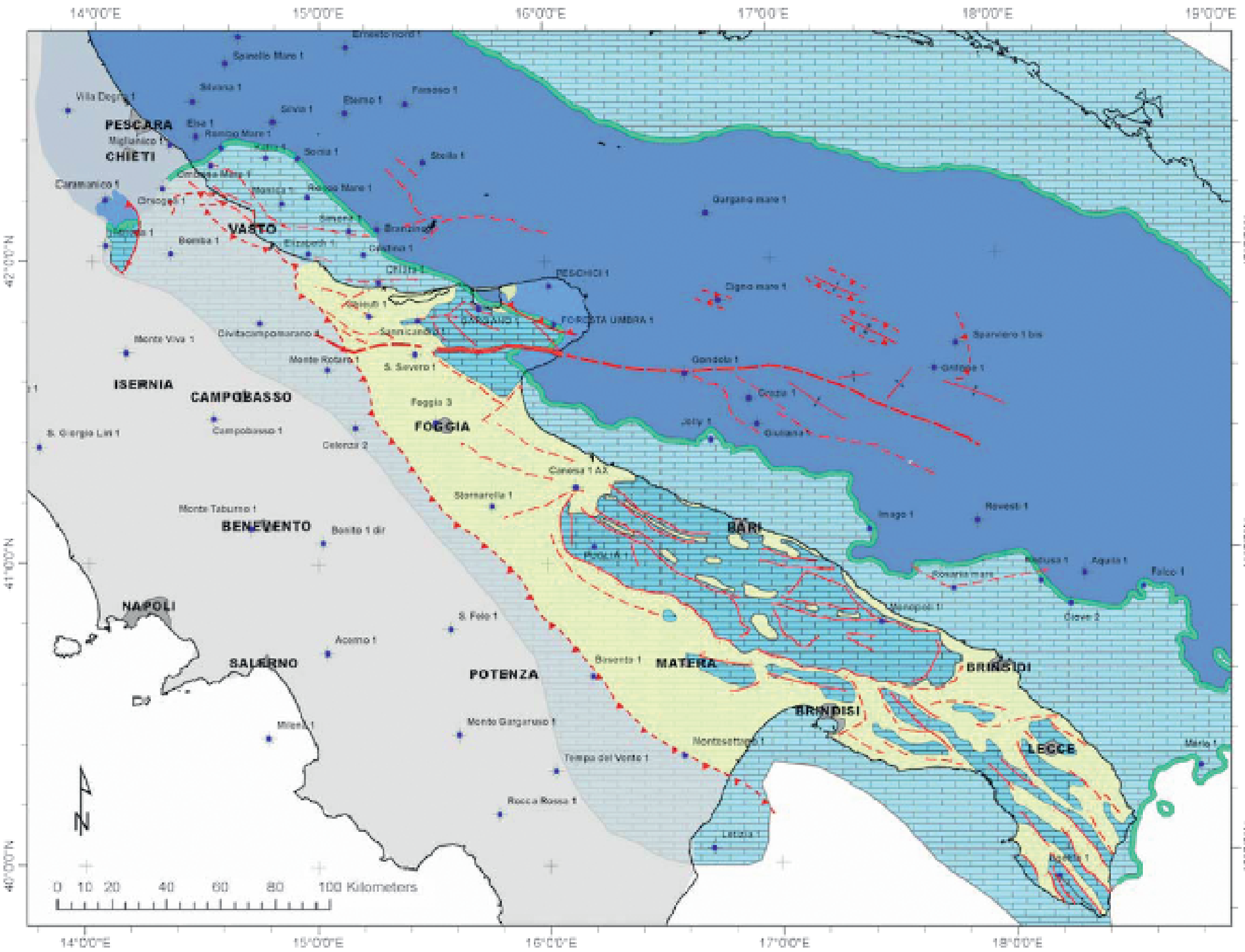



**Figure 1.** The Apulia Carbonate Platform (ACP) and adjacent Adriatic Basin. The ACP is a vast shallow-water carbonate platform including the Maiella Mountain at the northwestern tip. The eastern margin (green line) occurs some tens of kilometers offshore in the Adriatic Sea and is reconstructed through the public seismic lines and oil wells available in the project Visibilità Dati Esplorazione Petrolifera in Italia (2012); the western margin is buried under the southern Apennine thrust belt and associated to the Val d'Agri oil field. In the top right-hand corner, part of the large Adriatic carbonate platform margin in the northern Adriatic Sea is shown.

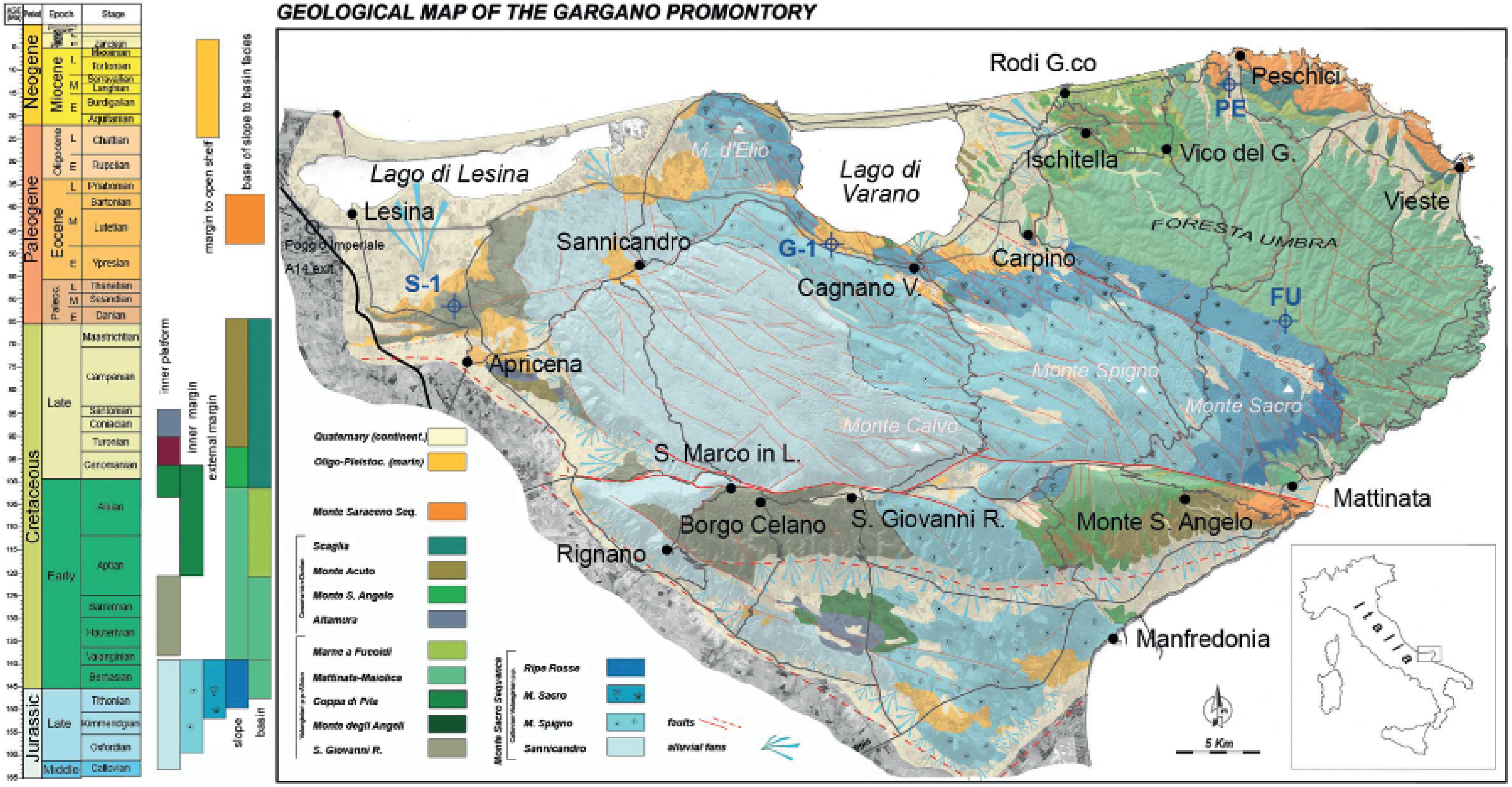



**Figure 2.** Simplified geological map of the Gargano Promontory (modified after Morsilli, 2011). Oil wells: FU = Foresta Umbra 1 (Eni); G-1 = Gargano 1 (Conoco); PE = Peschici 1 (Eni); S-1 = Sannicandro 1 (Eni).

In this short guideline we propose some field trips that allow direct observation of a mostly complete transect from inner platform facies to their basinal counterparts, with observations on facies, stratigraphic organization, and evolution trough time and as an analog of the buried part of the platform (Figure 1) and its adjacent twin (AdCP).

The value of the Gargano outcrops and proposed excursions includes (1) easily accessible three-dimensional exposures; (2) complete transect from the inner platform to the basinal facies; (3) record of paleoceanographic changes and tectonostratigraphic events; (4) preserved genuine reservoir properties; (5) well-constrained stratigraphy, both offshore and onshore; (6) relatively weak deformation by Dinaric and Apenninic orogeneses; (7) models for hydrocarbon plays in different settings and stratigraphic units (e.g., inner platform paleokarst [Rospo Mare, Ombrina], subthrust setting [Monte Alpi, Tempa Rossa], slope, and base-of-slope resediments [Elsa, Miglianico, Aquila, Rovesti]); (8) similarities with other well-known deep-water reservoirs (e.g., Poza Rica oil field, Mexico); and (9) public subsurface data available and organized in a web geographic information system project called Visibilità Dati Esplorazione Petrolifera in Italia (ViDEPI; http://www.videpi.com). The ViDEPI data set includes approximately 1650 well data and 55,000 km of two-dimensional multichannel seismic profiles acquired since 1957 by several oil companies.

## GENERAL ACCESS AND SAFETY

From a logistical point of view the Gargano Promontory is a small and easily accessible area, and all the proposed excursions are close to the main roads; thus, physical effort is very limited, as well as security issues. The best time to visit is from March to June and September to October, avoiding the strong heat of the summer and harsh, cold weather of the winter.

This excursion requires 4 field days and a half-day transfer from local airports to outcrop locations and return. From Roma international airport it takes 5–6 hr drive to reach the Gargano outcrops by road, but from Bari airport it takes only a 2-hr drive. The best towns to organize the base are Monte Sant'Angelo or Manfredonia, situated halfway between the inner platform and the basin. Normal cars and coaches allow full access to outcrops.

Gargano is a touristic place, and many types of accommodations are available, as well as banking services, restaurants, pharmacy, general stores, and bars. A public hospital, with all patient care facilities, is located in the middle of the Promontory (Casa Sollievo della Sofferenza, San Giovanni Rotondo), and emergency room are located in many small cities with an active air ambulance service in case of serious disease.

The main safety issues are driving, and some outcrops are along roads. Ticks may be present depending on the heat and humidity.

### Geological Background

The Gargano Promontory represents the deformed foreland of the southern Apennine and of the Dinaric thrust belt. Structurally, it is a gentle and broad anticline with a northwest–southeast axis affected by many reverse and normal faults, as well as strike-slip faults (Figure 2). The most famous of these faults is the Mattinata Fault that crosses in east–west direction the whole Gargano Promontory and extends offshore (Gondola Line) and onshore for tens of kilometers (Figure 1). The Gargano Promontory has been interpreted as a Neogene contractional belt (Bertotti et al., 1999) with some thrust structures related to Dinaric compression or as a transpressional ridge kinematically decoupled from adjacent areas along strike-slip faults (Brankman and Aydin, 2004). Until the early Miocene, the Gargano was weakly deformed, but during Langhian to Tortonian times a tectonic phase induced the deformation of previous and syndepositional units with gentle folds and thrusts. The main tectonic uplift occurred between the late Miocene and the early (?) Pliocene. Post-Pliocene deformation consists of gentle northwest–southeast-trending folds and strike-slip faults.

The carbonate rocks of the Gargano Promontory and of the other adjacent area belong to the ACP and have an average thickness of 5 km for the Mesozoic shallow-water carbonate succession and a variable thickness of 1–2 km for the coeval basinal successions. Eocene slope to basin facies occur mainly in the northeastern tip of the Gargano between Peschici and Vieste. Scattered outcrops of marine carbonates of Oligocene to Pleistocene are present all around the promontory (Figure 2).

An overall inner platform to basin transect (Late Jurassic–Early Cretaceous) of a well-preserved accretionary carbonate margin is recognizable. The inner platform facies are characterized by typical peritidal cycles (Sannicandro Formation). They pass to sandy (oolitic and bioclastic) shoals that occupy a large part of the shallow margin area (Monte Spigno Formation). A deeper margin is colonized by bioconstructors (Monte Sacro Limestone) such as sponges (*Ellipsactinia* and stromatoporoids), with subordinate corals (Morsilli and Bosellini, 1997). The external margin passes gradually to the clinostratified slope facies (Ripe Rosse Formation) and to the basinal deposits (Maiolica Formation). The Berriasian–lower Valanginian slope is onlapped by a thick succession of white, thin-bedded cherty, lime mudstones (Maiolica Formation) of Valanginian–Hauterivian age interpreted as a drowning unconformity (Bosellini and Morsilli, 1997; Bracco Gartner et al., 2002). From Valanginian p.p. to early Aptian, normal platform and margin productivity prevailed. Approximately 500 m of inner platform deposits are preserved (San Giovanni Rotondo Limestone) and abundant calciturbidites are found in the adjacent slope succession (lower Mattinata Formation). However, the geometry of the platform–slope transition remains poorly constrained for this time interval. The ACP margin and the adjacent slope suddenly became inactive during the lower Aptian. During the following upper Aptian–Cenomanian interval, the ACP margin underwent major physiographic changes. Deep-seated faults induced significant vertical displacement and the backstepping of the platform margin. A steep submarine escarpment associated with erosion and bypass was created and characterized the ACP margin until the early Tertiary. Abundant megabreccias reworking inner platform to margin facies of Lower Cretaceous age were deposited at the toe of the escarpment from upper Aptian to Albian (upper Mattinata Formation) (Hairabian et al., 2015). During the upper Albian p.p.–Cenomanian, a highly productive carbonate factory dominated by rudists developed along the platform margin, which led to the redeposition of huge volumes of skeletal material at the toe of the slope (Monte Sant'Angelo Limestone). This unit forms a thick (up to 250 m) base-of-slope apron extending greater than 20 km toward the basin and highly continuous laterally along the ACP margin. Early lithified skeletal sands along the margin and slope were locally involved in huge collapses resulting in the deposition of thick intraformational megabreccias. Platform edge and slope collapses seem to have been a common feature of the whole ACP margin, as visible in outcrops (Gargano and Maiella) and from seismic profiles in the Adriatic offshore that create a typical scalloped bank margin with amphitheater-like shape (Figure 1). During the Albian–Turonian a series of tectonically induced relative sea level lowstands exposed the carbonate platforms of the southern Apennines to subaerial conditions with the development of diachronous bauxite horizons, considered as late Cenomanian?–Turonian p.p. in the Gargano area. Associated with the reflooding of the platform (Turonian p.p.–Coniacian?), several complexes of lobes mainly composed of bioclastic calcarenites were deposited onto the base of slope until the Danian p.p. (Monte Acuto Limestone) (Hairabian et al., 2015) (Figure 3). During the Paleocene to early Eocene, other failures occurred along the margin of the platform. A basal megabreccia (Grottone Megabreccia) followed by Lutetian clinostratified deposits (Monte Saraceno Limestone) and bioclastic turbidites (Peschici Formation) were deposited around the Gargano Promontory (Bosellini et al., 1999; Adams et al., 2002).

## ITINERARY

This itinerary covers 4 days but for convenience is divided into six discrete excursions designed to cover different stratigraphic setting and subjects that can be done separately according to the main interests of the visitors. Stops 5 and 6 can be combined in one full-day excursion.

### Excursion 1 (Half Day): Inner Platform Facies, Karst, and Fracture Patterns

This excursion consists of two main stops to observe the characteristics of the Lower Cretaceous inner platform facies (San Giovanni Rotondo Limestone) and fracture pattern and associated karst morphotypes and infilling as well as dinosaur footprints, important for paleogeographic reconstruction of the ACP. Main outcrops are located in some quarries of the Apricena–Poggio Imperiale area (stop 1.1; Figure 4A) and close to Borgo Celano area (stop 1.2).

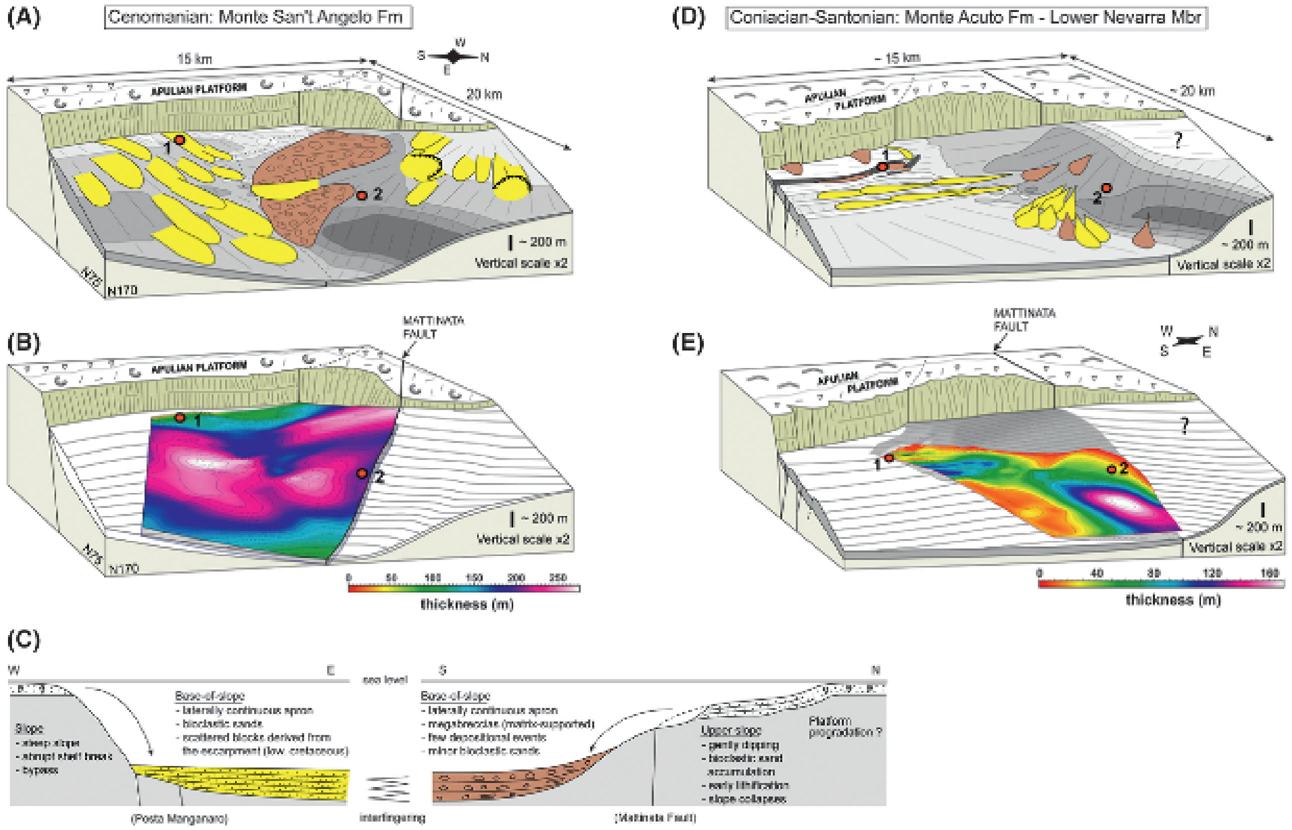


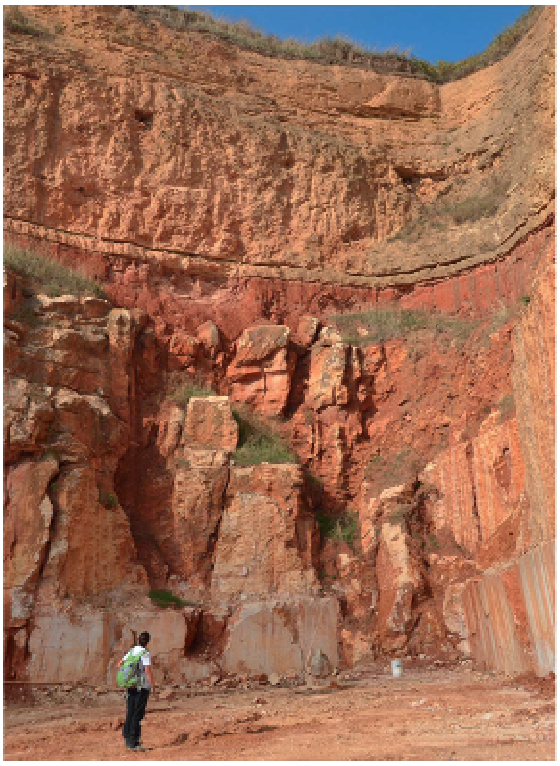

**Figure 3.** Reconstruction of the Upper Cretaceous paleogeography in southern Gargano based on three-dimensional numerical modeling and restoration in paleostate (Hairabian et al., 2015). Point 1 is Posta Manganaro, and point 2 locates the town of Monte Sant'Angelo. (A) Depositional model of the Monte Sant'Angelo Limestone (Lms). Bioclastic grainstones deposited as sheets (yellow) were mainly derived from the western platform domain, whereas intraformational megabreccias (brown) were sourced from a distally steepened slope to the north. (B) Isopach map of thickness of the Monte Sant'Angelo Lms. (C) Two-dimensional conceptual model showing the differences in slope geometry that could have controlled the spatial variations in lithology observed in the Monte Sant'Angelo Lms in southern Gargano. (D) Depositional model for the lower Nevarra Member (Mbr) of the Monte Acuto Lms. Bioclastic grainstone lobes (yellow) were derived from the north and locally funneled within elongated depressions of tectonic origin onto the basin floor. (E) Isopach map of thickness of the lower Nevarra Mbr of the Monte Acuto Lms showing the location of the different depocenters corresponding to complexes of lobes. Fm = formation.

Stop 1.1 (41°48.449′N, 15°22.130′E) is located on a structural relief made of Lower Cretaceous inner platform facies, uplifted and karstified at their top and covered by Pliocene and Pleistocene carbonate to siliciclastic units. These karstified limestones provide outcrop analogs of the Rospo Mare oil field located approximately 20 km northwest in the Adriatic offshore (Figure 1). Fracture patterns are another subject that can be explored in the Apricena quarries, interpreted as the result of overpressured fluid flows (Larsen et al., 2010).

Stop 1.2 (41°40′40.14″N, 15°40′0.09″E) consists of observations of subtidal to peritidal cycles of the San Giovanni Rotondo Limestone (Valanginian p.p.–Aptian p.p.) that reach an estimated thickness of approximately 550 m.

## Excursion 2 (1.5 Days): The Cretaceous Slope/Base-of-Slope Facies

The excursion focuses on the sedimentary succession exposed in the southern part of the Gargano between Ruggiano and Monte Sant'Angelo (Figure 2), which represents greater than 500 m of thickness of resedimented and autochthonous deep-water carbonates deposited at the toe of the steep submarine slope flanking the ACP from Aptian to early Tertiary.



Tertiary paleo-karst in the Cretaceous platform,SG. Rotondo Fm. (Excursion 1)

Slumpings in the Cretaceous basin, Maiollica Fm (Excursion 6)

**Figure 4.** (A) Stratigraphic units of the Passalacqua quarry (stop 1.1). Bari Limestones, karst, and terra rossa Pliocene carbonate unit and on top Serracapriola Formation (Fm.). (B) Panoramic view of the slump intervals in the Maiollica Fm. of the Baia delle Zagare outcrop (southern side). Note the different style of deformation in the assorted slump intervals.

Stop 2.1 (41°39′15.96″N, 15°53′28.97″E) shows a panorama of the southern Gargano cliffs in the Belvedere di Ruggiano area and illustrates the abrupt, near-vertical contact between Berriasian shallow-water limestones of the Monte Spigno Formation and deep-water carbonate resedimentations of Albian (upper Mattinata Limestone).

The submarine escarpment bounding the ACP was most probably several hundreds of meters high at the end of the Lower Cretaceous, which is inferred from the age of the oldest limestone blocks (Berriasian) found in the upper part of the Mattinata Limestone (upper Albian) compared with the thickness of the coeval platform series preserved toward the west.

## Excursion 3 (Half Day): The Upper Jurassic to Lower Cretaceous Slope to Basin Facies Transition

This excursion is related to the observation of geometries, facies, and synthetic seismic outcrop model of the Upper Jurassic to Lower Cretaceous slope to basin transition in the Mattinata area (Figure 2).

From the panoramic view at stop 3.1 (41°44′2.92″N, 16° 4′7.75″E), it is possible to observe the physical transition between the platform external margin (Monte Sacro Limestone), the slope (Ripe Rosse Formation), and the basinal pelagic mudstone and cherts of the Maiolica Formation. The geometric relationships visible in the field support the interpretation that this facies association is a proximal to distal, clinostratified slope succession (Morsilli and Bosellini, 1997; Bracco Gartner et al., 2002). Also in this area a marked retreat of the Valanginian pelagic interval of the Maiolica Formation testifies the occurrence of a partial drowning of the ACP (Bosellini and Morsilli, 1997).

## Excursion 4 (Half Day): The Eocene Clinoforms and Their Transition to the Basin

This excursion is related mainly to the Eocene sequence formed mostly by Nummulitic clinobeds and their physical transition to the basinal Scaglia counterpart.

From the panoramic view toward Monte Saraceno in stop 4.1 (41°41′24.28″N, 16°2′54.51″E), the clinostratified successions (Monte Saraceno Limestone) that pass tangentially to the coeval basinal sediments (Scaglia Formation) of the middle Eocene are visible.

### Excursion 5 (Half Day): The Maiolica Slumpings

Stop 5.1 is Baia delle Zagare (41°44′51.94″N, 16°8′44.59″E). This excursion is related to the spectacular slumping features widespread inside the Maiolica Formation. This unit, 450–500 m thick, crops out throughout the northeastern part of the Gargano, and the most spectacular outcrops are along the sea cliffs between Vieste and Mattinata (Figure 4B) (Morsilli et al., 2004).

### Excursion 6 (Half Day): The Eocene Unconformity and Lithofacies

This excursion is proposed to see the spectacular unconformity between the Upper Cretaceous Scaglia Formation and the onlapping Eocene base of slope succession of the Peschici Formation.

From the panoramic view of the Vieste sea cliff in stop 6.1 (41°52′43.68″N, 16°10′37.50″E), the erosional contact between the basinal, cherty lime mudstones of the Scaglia Formation (Coniacian p.p.) and the overlying Peschici Formation (Lutetian) is spectacularly exposed. The unconformity is not a transgressive contact, as interpreted previously, but a submarine unconformity onlapped by gravity-displaced and pelagic sediments (Bosellini et al., 1999; Morsilli et al., 2004).

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