Dinosaurs “re-write” the geodynamics of the eastern Mediterranean and the paleogeography of the Apulia Platform

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Abstract

Evidence of a sizeable population of large dinosaurs on the Apulia carbonate platform calls for a revision of the current paleotectonic and paleogeographic scenario of the eastern Mediterranean area. A review of geophysical and geological data of the Ionian Sea and surrounding areas leads to envisage the Late Jurassic–Early Cretaceous Ionian Sea region as a “cul-de-sac”-type basin enclosed by shallow-water carbonate banks, connecting the Apulia carbonate platform to Peloponnesus, northern Cyrenaica, Cyrene Seamount and Medina Ridge. These banks were repeatedly and periodically exposed to subaerial conditions, and offered vast land areas for migration of dinosaurs. As regards the nature of the Mesozoic Ionian basin, interpretations are quite controversial. The “continental” vs. “oceanic” crust debate will likely be solved only when the Ionian basin crust will be reached by drilling. The conclusion of the present review leads to consider Adria as a true African Promontory and the Apulia Platform as a sort of Florida Peninsula, attached to North Africa (Cyrenaica spur), subdividing the oceanic(?) “Mesozoic Mediterranean” into a western Ionian basin and an eastern Levantine basin.

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1. Introduction

The plate-tectonic setting of the eastern Mediterranean has been controversial for the last three decades. In particular, the position and connection of the so-called Adria block (independent microplate or promontory) with respect to Africa and the nature of the Ionian basin of the eastern Mediterranean have engendered lively debates (Dewey et al., 1973; Biju-Duval et al., 1976; Channell et al., 1979; Cloething et al., 1979; Farrugia and Panza, 1981; Finetti, 1982; Dercourt et al., 1986; Anderson, 1987; Casero and Roure, 1994; Finetti et al., 1996; Catalano et al., 2001; Wortmann et al., 2001, among others) (Fig. 1). By contrast, no controversy exists about the paleogeography of the Jurassic–Cretaceous carbonate platforms of the Adriatic Sea and adjacent countries (the so-called peri-Adriatic carbonate platforms), unanimously considered as past analogs of the present-day Bahama Archipelago (D’Argenio, 1971, 1976; Bemoulli, 1972; D’Argenio et al., 1975).

Evidence of a sizeable gathering of large dinosaurs on the Apulia carbonate platform is a new constraint on our reconstruction of the paleotectonic and paleogeographic history of the eastern Mediterranean area. This occurrence forces us to reconsider the paleogeography and leads to the view that the Apulia...
Fig. 1. Adria, the two main hypotheses. (A) African Promontory (Dercourt, 1972) vs. (B) independent microplate (Stampfli and Mosar, 1999; redrawn and simplified).
Platform was a carbonate peninsula (like modern Florida or Yucatan) directly attached to the Cyrenaica spur of Africa during the Jurassic and Early Cretaceous, thus subdividing the eastern Mediterranean into a western Ionian basin and an eastern Levantine basin.

Fig. 2. Interpreted distribution of Cretaceous peri-Adriatic carbonate platforms (from Zappaterra, 1994; redrawn and simplified).
1.1. About terminology: Adria vs. Apulia

Geologists and geophysicists working on the Mediterranean region during the last several decades have used different approaches (plate tectonic, structural, stratigraphic, paleontologic, marine geologic and geophysical) with a resulting confusion in terminology that needs to be clarified. The confusion arises over two terms, Adria and Apulia.

Adria is the name given by Suess (1883) and Canavari (1885) to a previously emergent area in the position of the present-day Adriatic Sea. Channell et al. (1979) used the term to refer not only to the area now submerged beneath the Adriatic Sea, but also to the elements of the surrounding orogenic belt originally underlain by continental crust (external zones of Apennines–Southern Alps–Dinarides–Hellenides). According to this definition, fully accepted by the present author, it is clear that Adria is a structural element involving the crust and lithosphere, whether considered an independent microplate or a promontory of the African plate.

Given this definition, it follows that, from the paleogeographic point of view, a variety of environments including dry land, flat carbonate islands, tidal flats, marshes and shallow lagoons, deep sounds and basins may have coexisted on Adria.

Many authors used the name Apulia for the same tectonic element, thereby generating considerable confusion. Apulia is a geographic region of southern Italy (the heel of the boot) largely composed of Mesozoic shallow-water carbonates. Italian geologists and many others use the term Apulia to identify this carbonate province: the Apulia Platform is a Jurassic–Cretaceous shallow-water carbonate bank bounded by deep-water basins and is one of the so-called peri-Adriatic carbonate platforms (D’Argenio, 1971, 1976; Zappaterra, 1994) (see Fig. 2). It belongs to Adria, like other Jurassic–Cretaceous platforms and deeper basins. The Apulia carbonate platform is essentially a Mesozoic paleogeographic element, which, in large part, acted as a rigid block during Alpine (Tertiary) orogenesis. Now, it is partly buried under the Apennine thrust sheets and partly constitutes the weakly deformed foreland of both the Apennine and Dinaric chains (Channell et al., 1979; Mostardini and Merlini, 1986; Underhill, 1989; Picha, 1996; Bosellini et al., 1999a,b).

2. Geological setting

Adria proper, in the sense used in this article (see Channel et al., 1979), was a resistant median block that acted as a foreland in peri-Adriatic orogeny. Several authors have suggested that Adria was a promontory of the African continent (plate) (Canavari, 1885; Argand, 1924; Staub, 1951; Stille, 1953; Dercourt, 1972; Caire, 1975; Channell, 1976; Channell et al., 1979, among others) (Fig. 1A). The occurrence of Middle Jurassic–Early Cretaceous ophiolites in the peri-Adriatic belt implies that Adria was separated from Europe by an ocean, but no evidence has been available as to the connection of Adria to the south, with the African plate. In fact, several authors consider Adria to be a continental fragment separated from Africa by oceanic crust in the Ionian Sea (Dewey et al., 1973; Biju-Duval et al., 1976, 1977; Makris, 1981; Finetti, 1982, 1985; Dercourt et al., 1986, 1993; Ziegler, 1988; De Voogd et al., 1992; Finetti et al., 1996; Stampfli and Mosar, 1999, among others) (Fig. 1B), but the age of this supposed oceanic crust remains controversial. Some authors suggest Early Cretaceous (Dercourt et al., 1986; Catalano et al., 2001), while others assume Late Triassic (Hsu, 1977) or even Permian (Finetti and Del Ben, 2000; Finetti et al., 1996; Stampfli and Mosar, 1999).

During the Mesozoic, the easternmost platform of central-southern Italy, the Apulia Platform (Bosellini et al., 1999a) (Fig. 2), extended from the southeastern Abruzzi region across Apulia and probably across the Strait of Otranto to the Greek islands of Cephalonia and Zante, where it abruptly terminates against the Cephalonia transform fault (Finetti et al., 1996; Sackpazi et al., 2000). According to current literature, the Apulia Platform was an isolated carbonate bank situated along the southern margin of the Mesozoic Tethys ocean and was created during Early Jurassic rifting of the margin (Eberli et al., 1993).

3. The dinosaur site

Many dinosaur footprints have recently been discovered in a limestone quarry near Borgo Celano (Gianolla et al., 2000), on the Gargano Promontory, on the eastern margin of the Apulia Platform (Fig. 3). The footprints occur in a peritidal carbonate succession, known as the S. Giovanni Rotondo limestone. This unit
belongs to the inner part of the platform and is characterized by a peritidal cyclicity.

3.1. The stratigraphic section

The Borgo Celano section (Claps et al., 1996), exposed in a continuous outcrop along the Borgo Celano–Foggia road, between kilometres 1.5 and 6, has a thickness of 550 m, encompassing a time interval spanning from the late Valanginian to the early Aptian. In the last 10 years, a large quarry has been opened on the Chiancata La Civita hill (local toponomy), 200–300 m to the west of the road. Here, a 60-m-thick tract of the succession is spectacularly exposed (Fig. 4). The pack of strata, in which the dinosaur footprints have been discovered, belongs to Member 2 of Claps et al. (1996) and to the “Loferitic Member” of Luperto Sinni and Masse (1986). This member consists of a thick pile (about 310 m) of peritidal carbonate cycles, typified by the rhythmic repetition of beds of subtidal limestone rich in gastropods, bivalves, dasycladacean algae and miliolids, layers of stromatolitic and fenestral limestone, and green clayey layers (illite–smectite mixed layers and montmorillonite associated with microcrystalline dolomite) ranging from less than 1 to 15–20 cm in thickness. These three lithologies are arranged into metre-scale cycles. The occurrence of *Campanellula capuensis* De Castro in the quarry interval of the succession dates it as late Hauterivian–early Barremian (Claps et al., 1996).

3.2. The dinosaur footprints

To date, about 60 footprints have been found on three distinct layers. The first layer is composed mainly of peloidal wackestone-packstone with a cap of very thin (2 mm) green clay on which the reptile passage was impressed. This lithofacies lies on a 40-cm-thick bed heavily bioturbated with burrows infilled with green and pink clay. The footprint casts occur also at the base
of the second layer, a thick (about 1 m) microbial laminite with small domal features in some parts, that lies on a centimetre-thick green clay bed. The third layer, where there are only true footprints, is composed mainly of bioturbated wackestone with some emersion features on top (oxidation films and locally black pebbles).

A preliminary study of the footprints (about 60) and short tracks (Fig. 5) (G. Leonardi, personal communication) testifies to the presence of middle

Fig. 4. The peritidal succession of the S. Giovanni Rotondo limestone (upper Hauterivian–lower Barremian), where dinosaur footprints and tracks have been found (quarry near Borgo Celano, Gargano Promontory).

Fig. 5. Large limestone block with a theropod dinosaur track and some footprints (Borgo Celano quarry).
to large-size bipedal dinosaurs, with a foot length ranging from 15 to 40 cm. Many footprints can be attributed to theropod predators of three or four different forms, some of which are very large (Allosaurus type). Bipedal herbivorous forms are represented by Iguanodontian ornithopods.

4. Geological implications

4.1. Paleoecology and evolutionary implications of a dinosaur fauna on a small “oceanic island”

In addition to the Gargano findings, about 30,000 dinosaur footprints and tracks occur also in the Upper Cretaceous limestone succession of Altamura, in central Apulia, about 40 km south of Bari (Nicosia et al., 2000), and in the Lower Cretaceous of the Friuli–Dalmatia platform (Istria Peninsula) (Dalla Vecchia et al., 1993, 2000). The presence of so large a number of dinosaurs, both carnivorous and herbivorous, some of them quite big, imposes several environmental and paleogeographic questions.

First, from an evolutionary point of view, it is impossible that a new genus, like Iguanodon, can appear contemporaneously (Early Cretaceous) in two distinct and separated areas such as the European continent (England, Belgium, France and Spain) and a small isolated island (portion of the Apulia Platform). A deep-water trough separated the two areas. Many dinosaurs, similar to the Apulian ones, are common in the Lower Cretaceous continental and paralic formations of North Africa (Morocco, Algeria, Tunisia, Lybia, Egypt, etc.) (Benton et al., 2000). Colonization of islands by terrestrial organisms may take place through three main means of dispersal (Azzaroli, 1996): (a) vicariance, in which part of a continent splits off and becomes an island, with its (future endemic) animals and plants; (b) migration over a land bridge, continuous or formed by temporarily emerged islands and “stepping stones”; (c) migration by swimming or by passive transport on natural rafts.

As far as we know (geologically), it is quite reasonable to assume that model (b) is the only possible in our case. In any case, connection between Africa and the “Apulian Islands” must have been long lasting; otherwise, the dinosaur fauna should have become endemic and dwarfed. It is well known that large insular vertebrates become dwarfed in a very short time. The exiled elephants of the Channel Islands (California) became dwarfed during the Pleistocene (Stock, 1935; Roth, 1996) and the dwarf elephants of the Mediterranean islands (Sicily, Malta, Sardinia, Crete and Rhodes) became endemic and dwarfed during the middle-late Pleistocene (Caloi et al., 1996). Even better documented, by 14C dating, is the dwarfing of Mammuthus primigenius, which survived on the island of Wrangel (NE Siberia) from the last glaciation until the Bronze Age (Vartanyan et al., 1993), but underwent a considerable size reduction in a few thousand years. Even for reptiles, it seems quite reasonable that the large Apulian dinosaurs should have become dwarfed if they were insular. This is especially plausible if we keep in mind that the time the Apulian dinosaurs survived (from Early to Late Cretaceous) was not a few thousand but tens of millions of years.

Lastly, there is the problem regarding food and water. All available geological and sedimentological data indicate that the sparse (scattered) Apulian Islands were flat and surrounded by tidal flats and shallow sounds and lagoons (D’Argenio, 1971; Bernoulli, 1972; D’Argenio et al., 1975; Bosellini et al., 1999a). No major relief, with abundant woods and fresh water, which are required to support and feed hundreds of huge animals, is documented. Eolian dunes, beaches and ponds (possibly with fresh water) were certainly present, but if islands like Sicily or Sardinia could not support Pleistocene elephants to survive without becoming dwarfed, it is very difficult to accept, for our dinosaurs, a normal evolution through millions of years in a flat, Bahamian-like island.

Dinosaurs were not swimmers. How could they move across an Apulia Platform that was largely a submerged intraoceanic bank? The Mesozoic carbonate platforms of southern Italy display a typical peritidal cyclicity throughout the Jurassic–Cretaceous time interval (D’Argenio et al., 1999; Buonocunto et al., 1999) (Fig. 6). The cycles consist of metre-scale shallowing-upward units capped by features related to subaerial exposure, including microkarst to more mature karst and paleosoils. In particular, the peritidal cyclicity of the Hauterivian–Barremian interval of the carbonate platforms of southern Italy has been documented by Longo et al. (1994), Claps et al. (1996), D’Argenio et al. (1997), Ferreri et al. (1997) and Raspini (1998). Moreover, a hierarchical organization
of the elementary cycles into bundles and superbundles appears ubiquitous in these strata (D’Argenio et al., 1999). Cycles are interpreted to reflect the 20–100–400 ka periodicities of the earth’s orbital perturbations. This implies that the southern Italy Mesozoic carbonate platforms were periodically exposed to subaerial conditions, offering vast land areas, most probably interconnected, for migration of dinosaurs. The duration of these times of subaerial exposure is unknown, but it can be estimated as of the order of 1/3 of the total time of a eustatic cycle, i.e. several thousand years (B. D’Argenio, personal communication).

Paleoecological and evolutionary constraints thus strongly suggest that the Apulian dinosaurs (and of the easterly positioned Istria–Dinaric carbonate platform) (Fig. 2) were not endemic but must have migrated periodically from a southern continental land mass, most probably North Africa.
4.2. The Ionian Sea region during the Jurassic–Cretaceous: oceanic vs. continental crust

The nature of the crust and lithosphere under the Ionian Sea is crucial for the understanding of the relationships between Adria and Africa and of the geodynamic evolution of the eastern Mediterranean (Fig. 7). Here, despite intense study, interpretation, models and ideas are controversial. Being not a geophysicist, but a stratigrapher, I shall try to make a neutral review of the current literature. Generally speaking, there are two different groups of interpretations that we can call “oceanic” and “(stretched) continental”, respectively.

The “oceanic crust” interpretation of the Ionian sea floor (Fig. 8) is supported by a group of geophysicists, including, among others, Makris (1981), Finetti (1982, 1985), Makris and Stobbe (1984), Del Ben and Finetti (1991), De Voogd et al. (1992), Finetti et al. (1996) and Finetti and Del Ben (2000). Several geologists agree with this interpretation, including, among others, Dewey et al. (1973), Biju-Duval et al. (1976, 1977), Dercourt et al. (1986, 1993), Ziegler (1988), May (1991), Robertson et al. (1996), Stampfli and Mosar (1999) and Catalano et al. (2001). According to this group of workers, the Ionian abyssal plain is floored by oceanic crust, which is postulated to be about 14 km thick (Makris and Stobbe, 1984; Finetti et al., 1996) and to be covered by 8 km of flat-lying sediments. Moreover, Finetti (1982), Finetti et al. (1996), Stampfli and Mosar (1999) and Finetti and Del Ben (2000) believe that the Ionian oceanic crust is Permo-Triassic in age, but Catalano et al. (2001) suggest a Mesozoic (most probably Early Cretaceous) age for the opening of this Ionian ocean.

The “continental crust” interpretation is supported by a group that considers the crust of the Ionian basin of intermediate type (thinned, stretched) and includes, among others, Weigel (1978), Papazachos and Comninakis (1978), Biju-Duval et al. (1978), Morelli (1978), Cloething et al. (1979), Farrugia and Panza (1981), Calcagnile et al. (1982), Boccaletti et al. (1984), Panza (1987), Suhadolc and Panza (1989), Robertson and Grasso (1995), Ismail-Zadeh et al. (1998) and Nicovich et al. (2000).

According to Panza (1987), the available seismological data leave little doubt that the present situation
is due to the foundering of a lithosphere of continental or continental margin type: only a crustal thickness exceeding 30 km is consistent with seismic data, a figure much thicker than normal oceanic crust. Moreover, the same group points out that in the Ionian region, the heat flow is almost everywhere low to normal and the free-air gravity anomalies are mainly negative, as should be expected if the idea of a cold Adriatic Promontory being related to the African continent is accepted.

Among the geologists supporting a Jurassic–Cretaceous link of the continental crust of Africa and Adria are Klitzsch (1970), Erico (1981) (Fig. 9), Sestini (1984), Gealey (1988) and Hirsch et al. (1995). Sestini (1984) assumes that the Mesozoic under the Mediterranean Ridge is represented by carbonate platform facies and belongs to the African Plate, like the Mesozoic under the Ionian Sea north of the Sirte Gulf, and that the Jurassic and later basin development was confined to the north of Crete and did not

Fig. 8. The Ionian oceanic crust and surrounding tectonic elements, according to Del Ben and Finetti (1991) (redrawn and simplified).
extend south. Gealey (1988) presents a Valanginian paleotectonic map showing Apulia attached to Sicily and Africa (Fig. 10). According to Hirsch et al. (1995), geological, paleontological and geophysical data support the assumption that, during Paleozoic and Mesozoic times, the area of the present-day east-
ern Mediterranean Sea was part of the African–Apulian–Arabian Plate (Fig. 11).

This general review of the various interpretations of the Ionian basin crust shows that, after about 30 years of research, there is still a controversial and unresolved debate. It is clear that almost any solution or interpretation is possible and acceptable until the crust of the Ionian basin will be reached by drilling. The problem can be emblematically summarized in the results of two recent studies that can be considered representative of the two different interpretations.

On the basis of recent seismic and stratigraphic data, Ismail-Zadeh et al. (1998) presented conceptual and quantitative models for the Ionian basin evolution based on a large geological and geophysical data set. They assume that the Ionian basin started to form in the Late Jurassic owing to extension of continental lithosphere. During the extension, accompanied by thinning of the crust and of the lower part of the lithosphere, the underlying asthenosphere moved upward. The mantle material rose and partially melted when the geotherm moved up crossing the solidus. Part of the magmatic melt flowed up, partially crystallizing within the lower crust and partially reaching the surface and leading to active volcanism in the Late Jurassic. Ismail-Zadeh et al. (1998) conclude by proposing that the Late Jurassic extension of the region did not lead to oceanic opening, but strongly attenuated the continental crust and lithosphere.

Catalano et al. (2001) made a review of the geophysical data on the Ionian basin that led them to believe that the Ionian Sea is an oceanic basin bounded by two conjugate passive continental margins, the Malta Escarpment to the southwest and the Apulian Escarpment to the northeast (Fig. 12). Their reasoning is based on the assumption of the oceanic nature of the Ionian abyssal plain and from that follows the idea of the two conjugate margins and of the disappearance of the original median ridge by thermal cooling and later burial by Tertiary sediments. However, the Malta and the Apulia escarpments cannot be considered conjugate margins as they record quite different histories.
Fig. 11. Paleogeographic map of the Mediterranean region showing Adria directly connected with Africa to form the well-known “African Promontory”. No ocean is envisaged between the Apulia carbonate platform and Africa (from Hirsch et al., 1995; simplified and redrawn).

Fig. 12. Reconstruction of the Ionian Ocean and of its two conjugate passive margins (Malta and Apulia escarpments), according to Catalano et al. (2001).
Whereas the Pelagian block (including its eastern Malta margin) abruptly drowned during the Middle Jurassic (Scandone et al., 1981; Groupe Escarmed, 1982), the Apulia Platform was continuously a shallow-water domain during the entire Cretaceous and Paleogene (Bosellini et al., 1999b). Moreover, and more important, it is the pre-breakup story which shows that the Ragusa–Malta zone and the Apulia Platform underwent a very different paleotectonic evolution during Mesozoic times (Patacca et al., 1979, p. 334). In particular, (1) the Upper Triassic “basement” of the Malta shelf succession consists of dolostones, whereas the Apulia Platform is “floating” on Upper Triassic evaporites (Mostardini and Merlini, 1986; Bosellini et al., 1999a) and (2) the entire Jurassic–Cretaceous succession of the Malta shelf and adjacent escarpment is punctuated by several volcanic episodes (Patacca et al., 1979; Pedley et al., 1993), which are totally absent in the Apulia succession.

4.3. The Apulia Platform and its southern extension

The Apulia carbonate platform was a major paleogeographic element of the southern margin of the Mesozoic Tethys ocean (Fig. 2). It is one of the previously cited peri-Adriatic platforms comparable to the Bahama banks in their carbonate facies, shape, size, subsidence rate and internal architecture.

The Apulia Platform, which is part of the stable and relatively undeformed foreland of the Apennine thrust belt, was bounded to the north (Marche–Umbria), to the east (Adriatic Sea) and to the west (Molise–Lagonegro) by Jurassic and Cretaceous deep-water deposits (Mostardini and Merlini, 1986; De Dominicis and Mazzoldi, 1989; Eberli et al., 1993; Zappaterra, 1994) (Fig. 2). In contrast, the southward extension and boundary of the platform are not so obvious. According to geophysical data, industrial wells and submersible observations, the platform reaches the Cephalonia fault, which is abruptly truncated and displaced to the southwest. At the southwestern end of the Apulia submerged ridge, a 1000-m-high escarpment of horizontally stratified Upper Cretaceous shallow-water limestones is present (Groupe Escarmed, 1983) (Fig. 13). Clearly, this escarpment is not a carbonate platform margin or the southern end of the platform or its transition to a basinal setting: the margin, if any, must have been localized more to the south, beyond the Cephalonia fault and southwest toward the Ionian abyssal plain. In fact, seismic profiles in the northern Ionian Sea distinctly show that the Apulia Platform bends toward Greece and disappears, plunging beneath the Peloponnesus (Scandone et al. 1974). The northeastern margin of the Apulia Platform is instead well known on the Ionian islands of Cephalonia and Zakynthos (IGRSS-IFP, 1966; British Petroleum, 1971; Underhill, 1989; Accordi and Carbone, 1992); the Apulia element has been encountered in the well Filiatra-1 of western Peloponnesus (IGRSS-IFP, 1966, p. 3) and is also present in central Peloponnesus (Jacobshagen et al., 1978). In this area, according to unpublished company reports, the Apulia and Gavrovo platforms join together with disappearance of the intervening Ionian basin. Finally, shallow-water limestones of Early to Middle Cretaceous age have been recovered at DSDP Site 127, west of Crete (Maync, 1973) (Fig. 7) and dredged in the Hellenic Trench, about 100 km south of Crete (Area Heat II, Mascle et al., 1986).

On the southern margin of the Mediterranean, offshore from Cyrenaica (A1/NC120 well Agip-Name), the Valanginian–Barremian succession is represented by the Qahash Formation, a quartz sandstone laterally equivalent to the Nubian sandstone, representing fluvial flood plain, mixed continental and coastal to delta-top environments (Duronio et al., 1991). This facies association implies that in the north of the Cyrenaica spur, there must be a belt of transitional terrigenous sediments south of the carbonate platforms, which are documented 200 km north of Benghazi. Here, just on the border of the deformation front of the Mediterranean Ridge, the Cyrene Seamount (Fig. 7) consists of almost 2000 m of Cretaceous platform carbonates, including a Lower Cretaceous interval (Groupe Escarmed, 1982, 1987). The Cyrene Seamount and the neighbouring Medina Ridge represent advanced posts of the former Mesozoic African carbonate platform (Groupe Escarmed, 1982). Several authors (Rossi and Zarudski, 1978; Finetti, 1982; Groupe Escarmed, 1982; Vanney and Gennusseaux, 1985) interpret the Sirte embayment, the largest reentry on the North African margin, as a wide collapsed block, consisting largely of Cretaceous platform carbonates.

The various steep escarpments (Fig. 14) bordering the Ionian abyssal plain (southwestern margin of the
Apulia Platform, Medina Ridge and Cyrene Seamount), largely composed of Cretaceous platform carbonates (except the Malta Escarpment), do not show any evidence of margin or slope facies. Subaqueous photographs, seismic profiles and very steep morphologies indicate that the present-day boundaries of the Cretaceous carbonate platforms surrounding the Ionian abyssal plain are erosional. Support for an erosional origin of the margin of the Apulia Platform (and the Cyrene Seamount; Groupe Escarmed, 1987) is given by the scalloped morphology (Fig. 15) of its southwestern margin and by its documented width on the Italian Peninsula, where it extends westward under the Apennine thrust belt as far as the Lucania region (Val d’Agri) (Mostardini and Merlini, 1986; Picha, 1996). On the African platform, the submarine exposure of horizontal carbonate layers and the slope (15–20°) of the Medina Ridge and of the Cyrene Seamount cannot be related to fault planes (see Figs. 12–16 in Groupe Escarmed, 1987).

According to Groupe Escarmed (1982), the various escarpments bordering the Cyrene Seamount and the Medina Ridge originated during the Late Cretaceous. The present author believes instead that the main erosional retreat of the Cretaceous carbonate platforms surrounding the Ionian basin occurred during the Messinian lowstand. In either case, it seems fair to assume that the original extent of both the North African and Apulia platforms was considerably larger, further reducing the available space for an Ionian “ocean”. In fact, an abrupt passage from a 1000–2000-m-high erosional escarpment (southwest margin of the Apulia Platform, Medina and Cyrene seamounts) (Fig. 14), exposing subhorizontally stratified Cretaceous carbonates, to an abyssal plain floored by oceanic crust is unlikely. A similar interpretation has been recently presented for the Blake Escarpment, which lies about 400 km east of Florida (Dillon et al., 2001). According to this study, the face of the original bank has been eroded back by as much as 15 km.

In sum, we can trace the Cretaceous Apulia Platform southward as far as Peloponnesus (IGRSS-IFP, 1966; Jacobshagen et al., 1978) and, as a wider paleogeographic element (united with the Gavrovo...
Platform), to the Hellenic Trench, south of Crete (Mascle et al., 1986). To the west, the Apulia Platform was more extended than the present-day margin, most probably occupying the entire area of the Gulf of Taranto. A similar carbonate platform of Early to Middle Cretaceous age (Groupe Escarmed, 1987) bordered the North African continental margin, from the Medina Ridge to the Cyrene Seamount and the Cyrenaica offshore as far as the Mediterranean Ridge. The present-day limit of this carbonate province is also a recessive, erosional boundary.

For the Malta Escarpment, several lines of evidence (Scandone et al., 1981; Groupe Escarmed, 1982) clearly show an abrupt deepening of the Pelagian block during the Middle Jurassic. Nonetheless, Cretaceous shallow-water skeletal material, including rudist fragments, occurs along the Malta Escarpment (Scandone et al., 1981; Casero et al., 1986; Pedley et al., 1993; Casero and Roure, 1994), thus suggesting the former vicinity of Cretaceous shallow-water environments. To the west, on the Pelagian platform, the Lower Cretaceous is represented by deep-water sediments (Hybla Formation; Scandone et al., 1981; Catalano et al., 1996). Thus, it is necessary to admit an eastern provenance for this shallow-water skeletal material from some carbonate platform in the present-day Ionian area. According to Groupe Escarmed (1987), a platform succession of Aptian age followed by pelagic Upper Cretaceous is present in the Medina Ridge.

This stratigraphic review of the Cretaceous carbonates surrounding the Ionian basin leads us to envisage a vast area of shallow-water carbonate banks, from Apulia to Cephalonia, Peloponnnesus, Crete, Cyrene Seamount and Medina Ridge, probably enclosing a
“cul-de-sac”-type basin, open to the west, where it was directly connected with the NS-oriented Jurassic Ligurian Ocean. This basin probably formed during the Jurassic drowning of the shallow-water carbonate platforms documented on the Pelagian block and along the Malta Escarpment (Scandone et al., 1981; Groupe Escarmed, 1982; Casero and Roure, 1994). However, how deep it was and what kind of crust was present in

Fig. 15. The deeply indented and scalloped morphology of the southwestern margin of the Apulia Platform (see also Fig. 13) (from Groupe Escarmed, 1982).
Fig. 16. Restored (conservative) distribution of Cretaceous carbonate platforms of the Adriatic and Ionian Region. Due to the presence of the Calabrian arc and of the Mediterranean ridge, the original extent of these platforms toward the Ionian basin is unknown, also because their boundaries are mainly erosional.
Fig. 17. Paleogeographic map of the central-western Mediterranean area during the Early Cretaceous. The Ionian Sea basin is interpreted as a “cul-de-sac” deep sound foundered in Middle Jurassic time, contemporaneously with the opening of the Ligurian Ocean. The Apulia carbonate platform is considered a spur of the African platform, separating two deep-water basins, the Ionian to the west and the Levantine to the east. Location of mid-oceanic ridges and transform faults is hypothetical. The continuously fluctuating Cretaceous sea level exposed large tracts of the shallow-water banks of the Apulia and associated carbonate platforms, giving ample opportunity to the African dinosaurs to migrate northward, across shallow lagoons, tidal flats and marshes.
this basin are still matters of conjecture. Fig. 16 shows the distribution of Cretaceous shallow-water carbonates in the eastern Mediterranean, from Malta to Crete. It is a conservative attempt even if some extrapolation, necessary in my opinion and clearly discriminated from the objective data, is used. The interpreted map is shown in Fig. 17.

5. Discussion and conclusions

As can be realized from the previous pages, this is not a geophysical contribution. The present author is not a geophysicist but a stratigrapher. It would be useful, however, to review why the seismological data are interpreted by so many authors to indicate an oceanic basement. Does the velocity structure of the basement allow the distinction between an oceanic basement and a thinned continental basement? Or are these workers influenced by supposed models for Tyrrhenian Sea evolution?

The new data and arguments presented here are essentially of paleontologic (dinosaur footprints) and stratigraphic (carbonate platforms surrounding the Ionian basin) nature. Nevertheless, I believe they are equally important and crucial if we want to reconstruct the geodynamic and paleogeographic evolution of the Ionian area.

A Mesozoic opening of the eastern Mediterranean was suggested by Dewey et al. (1973), and the idea has been followed in many subsequent studies (e.g. Biju-Duval et al., 1976, 1977; Dercourt et al., 1986; Ziegler, 1988) in which a southern Tethys branch, the so-called Mesogea, opened in Aptian (Dercourt et al., 1986; Catalano et al., 2001) Jurassic, Triassic (Hsü, 1977) or even Permian times (Finetti, 1982; Finetti et al., 1996; Stampfli and Mosar, 1999; Finetti and Del Ben, 2000). On the other hand, many geophysicists and geologists (Boccaletti et al., 1984; Panza, 1987; Sestini, 1984; Gealey, 1988; Hirsch et al., 1995; Ismail-Zadeh et al., 1998; Nicolich et al., 2000, among others) believe that no oceanic crust is present in the Ionian abyssal plain. Some additional arguments to consider include: (1) the absence of magnetic anomalies in the entire eastern Mediterranean, whereas this could be explained by a period of magnetic quiescence during the Cretaceous, it is difficult to explain if the Ionian oceanic crust was of Jurassic or Triassic age; (2) the absence of a recognizable mid-oceanic ridge is very suspicious. Catalano et al. (2001) tried to explain this anomalous situation by postulating thermal and lithostatic subsidence of the ridge; (3) the deposition of an enormous thickness of pelagic sediments (8 km in the Ionian basin, 14 km in the Levantine basin) above Jurassic or Cretaceous oceanic crust is far beyond anything known elsewhere; (4) it is also problematic to accept the idea that in an area, the eastern Mediterranean, positioned between two gigantic land masses, Africa and Eurasia, approaching each other since the Cretaceous, there is still a consistent strip of undeformed remnant Mesozoic oceanic crust.

Finally, there is the problem of the Cretaceous carbonate banks surrounding the Ionian basin. Stratigraphic and sedimentologic analysis of these carbonate successions gives some important clues. Geophysical, morphological and sedimentological data indicate that the present-day margins are erosional and that the original area occupied by shallow-water carbonates was once considerably wider. These data leave little space for an oceanic area and strongly suggest the idea of the Ionian basin as an area founded in Jurassic times to the west (Sicily Channel, Malta Escarpment and western Ionian Sea) and in Middle-Late Cretaceous to the east, where the Aptian–Albian shallow-water carbonates are replaced by deep-water carbonates (Medina and Cyrene) (Groupe Escarmed, 1987).

Therefore, following Panza (1987), Hirsch et al. (1995), Ismail-Zadeh et al. (1998) and many others, the data in this paper support the hypothesis of the Ionian basin as a stretched, attenuated continental crust area, generated during a Jurassic extensional phase and associated with the opening of the Ligurian Ocean (Western Tethys). The setting envisaged for the Ionian basin is a sort of “cul-de-sac”, enclosed by shallow-water carbonate banks to the north, east and south and open westward, where it was connected with the NS-directed Ligurian Ocean (Fig. 17). According to this view, and structurally speaking (crust and lithosphere), Adria was, and still is, a true African Promontory (Channel et al., 1979; Channell, 1996).

The North Africa continental margin was deeply indented and characterized by shallow-water “spurs” and deep-water “grooves”. To the west, the Pelagian Sea and Sicily are the first advanced salient of the African continent. Eastward follows first the basinal
area of the Sirte Basin and Ionian Sea and then the Cyrenaica spur, a sort of Florida Peninsula. This paleogeographic element, according to the stratigraphic data presented in this report, was directly connected with the shallow-water banks of Apulia and Gavrovo (Fig. 17). This continental bridge subdivided the eastern Mediterranean into an eastern Levantine basin and a western Ionian basin.

This paleogeographic picture is supported by recent findings, which document a sizeable gathering of large dinosaurs, carnivorous and herbivorous, on the Apulia carbonate platform. Such huge animals would have needed lots of fresh water and land on which to graze and hunt in order to survive. Moreover, evolutionary constraints and models of island colonization by terrestrial organisms need to consider a necessary connection of the Apulian shallow-water banks with a major landmass. Therefore, contrary to what has been so far envisaged, the dinosaur evidence suggests that the Apulia carbonate platform was not an isolated oceanic bank, like the Bahamas. As in Late Jurassic and Cretaceous time, the Apulia Platform was bounded to the north, east and west by deep-water basins (see Fig. 2); it must have been attached through a continental bridge and subaerially connected, at least periodically, with a southern landmass, i.e. the African continent.

What I envisage is a series of shallow-water carbonate banks, lagoons and associated tidal flats occupying large parts of present-day Apulia, the eastern Ionian Sea and northern Africa (Cyrene Seamount and Medina Ridge) (Fig. 17). During the Early Cretaceous, this area was repeatedly and periodically exposed to subaerial conditions, as shown by the bauxite horizons and the Milankovitch cyclicity of the platform successions, which bear hundreds of exposure surfaces (D’Argenio et al. 1999). These lowstand periods most probably offered vast land areas for the migration of dinosaurs.

We can thus say that the dinosaur footprints and tracks found in the Apulia carbonate platform put strong constraints to plate tectonic and paleogeographic reconstructions of the eastern Mediterranean area: Adria was an African Promontory and the Apulia Platform was not an isolated “Bahamian” bank, but rather a sort of Florida Peninsula, subdividing the “Mesozoic Mediterranean” into a western Ionian basin and an eastern Levantine basin.

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