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Aptian dinosaur footprints from the Apulian platform (Bisceglie, Southern Italy) in the framework of periadriatic ichnosites

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ABSTRACT

New dinosaur tracks have been found near Bisceglie (Bari, Apulia), on loose blocks ascribed to the Corato Member (late Bedoulian to early Gargasian) of the Calcare di Bari Fm. The material consists of isolated footprints as well as of short trackways of quadrupedal and bipedal dinosaurs. The new tracksite has yielded a quite differentiated dinosaur ichnocoenosis, including theropod, sauropod, thyreophoran and ornithopod footprints.

The discovery of early Aptian dinosaur footprints in the limestone of the carbonate platform of southern Italy gives new insights on dinosaur distribution, and new palaeontological constraints for the palaeogeographic reconstruction of the Mediterranean Tethys during the Cretaceous. The analysis of this and others ichnosites of the periadriatic carbonate platforms, gives evidence of repeated emersions and of widespread land-vertebrates dwelling. The characteristics of the associations suggest that the trackmakers did not constitute a real coevolved association but the occasional co-occurrence of taxa after migration.

The results emphasize the need of both structural and environmental continuity and walking ways between a southern continent and the periadriatic carbonate platforms during the Early Cretaceous.

1. Introduction

A new dinosaur tracksite was discovered in carbonate platform deposits near Bisceglie, about 35 km north-west of Bari (Southern Italy). It is the fourth tracksite in the Apulia and the first Aptian discovered in the periadriatic region. The already known footprint bearing levels have been uncovered from the lower Santonian of the Altamura Limestone (Andreassi et al., 1999; Nicosia et al., 2000a,b; Perugini and Ragusa, 2004; Perugini et al., 2005), from the late Hauterivian-early Barremian of the S. Giovanni Rotondo Limestone (Gianolla et al., 2000a,b, 2001; Petti et al., 2008), and from the Late Jurassic Sannicandro Limestone, recognized from loose blocks on the piers of Mattinata (Conti et al., 2005). In a larger palaeogeographic frame and considering some still unpublished data, this is the eighth tracksite from Central and Southern Italy (Nicosia et al., 2007; Petti et al., 2008).

In this paper the meaning of the new tracksite and of the previously known ones will be examined in the framework of the palaeogeography of the periadriatic area.

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2. The Bisceglie outcrop

2.1. Geological setting

The finding site is located in an abandoned quarry (Lama Paterno quarry) close to the town of Bisceglie (Bari, Southern Italy). According to the 1:100.000 Geological Map of Italy (Sheet 177 Bari), the outcrop is referred to the Calcare di Bari, a formation ranging from Valanginian *p.p.* to Cenomanian or Early Turonian and subdivided in seven members (Delfrati et al., 2003 cum bibl., Spalluto et al., 2005) (Fig. 1). The footprint bearing beds pertain to the type section of the early Aptian "Corato member" of that formation (late Bedoulian to early Gargasian subages; Luperto Sinni and Masse, 1984, 1993).

Excavation works exposed a nearly 30 m thick section that extends laterally for hundreds of meters (Fig. 2). The whole outcrop consists of carbonate platform limestone with different textures. Footprints were scattered on several loose blocks on the quarry floor. The original position of some of the blocks within the section was reconstructed on the basis of sedimentologic analysis and with the help of quarry workers. Thus, three trampled horizons were recognized from the first 4 m of the section (Fig. 3). The first 2.5 m of the section can be subdivided in a lower part (about 1.2 m) characterized by grainstone with stylolithes and an upper portion

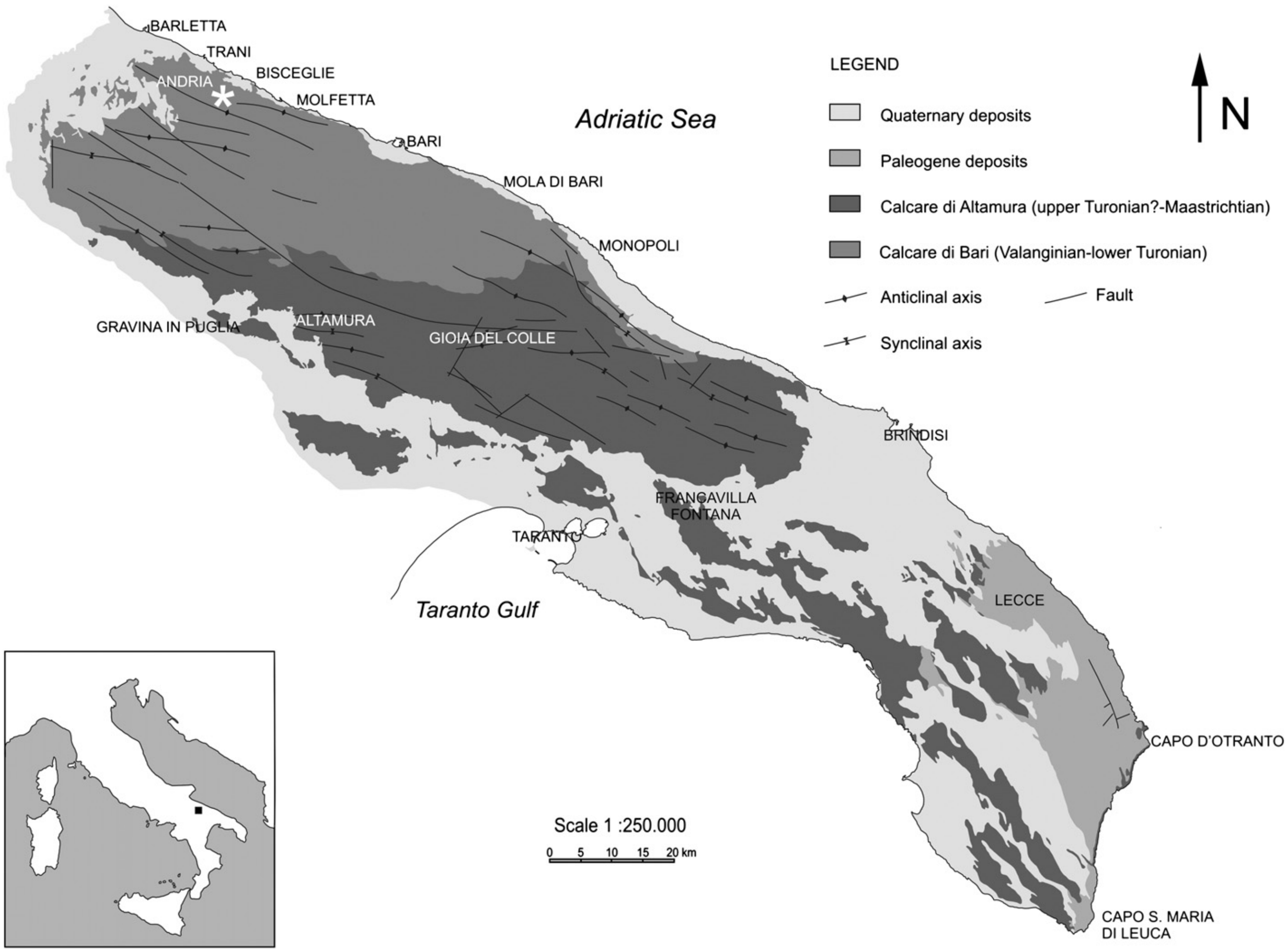

Fig. 1. Map showing the site location (*) and synthetic geological map of Murge and Salento area.

made by wackestone and mudstone with miliolids, gastropods and flaser bedding. At 1.8 m from the base the first trampled level occurs (BLP3), while the second has been recognized at 2.5 m from the base (BLP4, BLP5, BLP7). From 2.5 to 3.7 m, the section shows two strata: the first made of mudstone/wackestone with miliolids, shell fragments and Requienidae, and the second one made of grainstone with gastropods and Requienidae. At the top of this latter sequence the third trampled bed occurs (BLP2, BLP8). The succession continues upward with 30 cm of finely laminated mudstone followed by 40 cm of grainstones with shell fragments and Requienidae.

As a whole the succession is related to a carbonate platform depositional environment frequently shifting from supratidal to subtidal conditions up to inner lagoon.

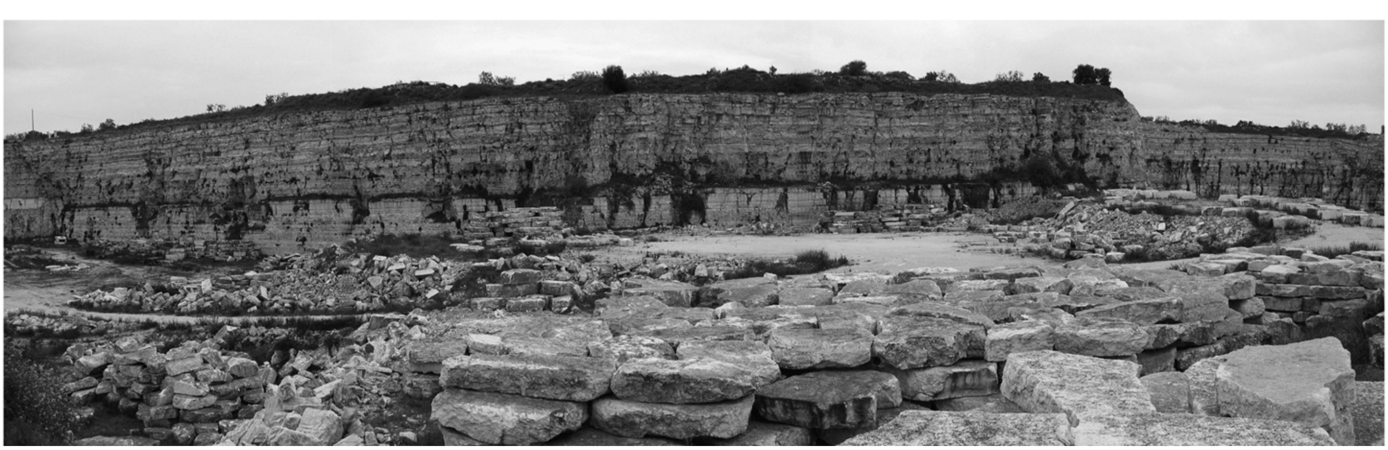

Fig. 2. Panoramic view of the Lama Paterno quarry-wall (Bisceglie, Apulia) showing the lateral continuity of the outcrop.

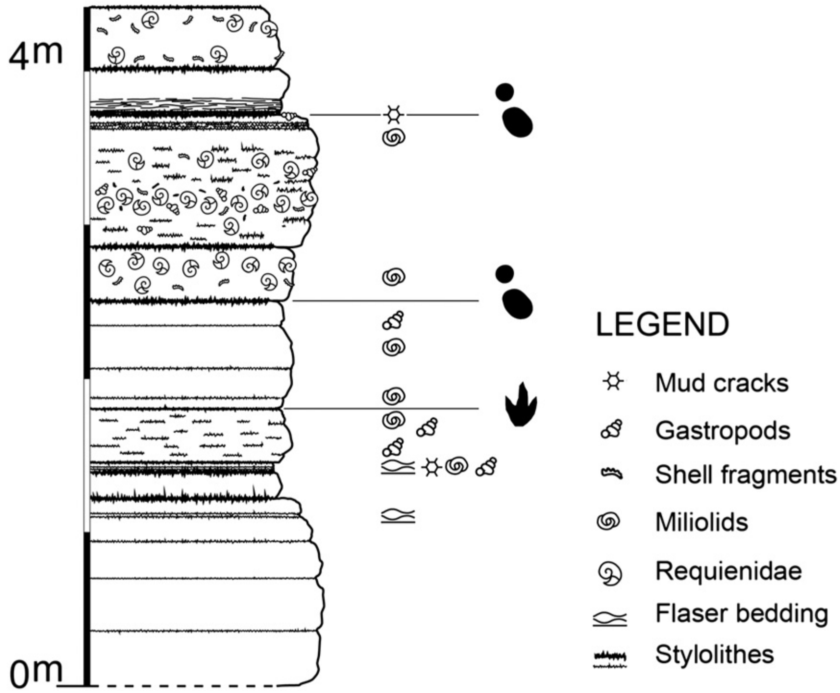

Fig. 3. Columnar section of the outcrop portion including trampled layers.

Intraclasts, benthic foraminifers, green algae and peloids as well as evidences of emersions (e.g. karstic structures, voids and geopetal fillings) are clearly identifiable in thin sections. The cement is fibrous and blocky. The recognized microfossil association includes *Sabaudia minuta* (Hofker, 1965), cf. *Praechrysalidina infracretacea* Luperto Sinni, 1979, cf. *Debarina hahounerensis* Fourcade, Roult and Vila, 1972, *Spiroloculina* sp., *Cuneolina* sp., *Salpingoporella* spp., nubecularids, miliolaceans, ostracods and undetermined calcareous algae. Macrofossils are also present, represented by scattered gastropods and more frequent shell fragments mostly referred to the genus *Toucasia*.

2.2. The dinosaur footprints

The material consists of many poorly-preserved isolated prints and some short trackways, preserved both as prints and natural molds. The printed blocks were labeled with the acronym BLP (Bisceglie Lama Paterno) from BLP1 to BLP10, surveyed, photographed and drawn. Some of the blocks were destroyed for industrial purposes and only few have been lately recovered by local authorities and are on display in a public garden at Bisceglie.

The trampled layers are biased by the effects of widespread pressure-solution processes; stylolithes characterize each bedding plane of this portion of the section, partly masking the actual morphologies. Moreover, the sediment underwent an early-hardening before dinosaur trampling, with mud-cracking of surfaces. Therefore most of the footprints show little morphological features and can not be described in detail. Although all the above limits or prevents at all the ichnotaxonomic assignment (Milàn and Bromley, 2006), the observed morphologies give adequate constraints to ensure a consistent zoological attribution. The zoological attributions have been based on trackway data (e.g., gauge, pace angulation, heteropody, relative footprint orientation) and on footprint features (e.g., digits number and shape), the resulting attribution are restricted to high taxonomic rank. Tracks examination has been provided with quantitative parameters (FL=Foot Length, FW=Foot Width, ML=Manus Length, MW=Manus Width, SL=Stride Length). The evaluation of the eight at the hip, general dimensions and body mass of trackmakers are based on Thulborn (1990).

The footprints have been subdivided into the following six morphotypes:

Morphotype 1 - A natural mold of three pes impressions associated with two manus prints are preserved on block BLP1 (Fig. 4). The pes (average length of about 34 cm) is mesaxonic with three large digits rounded distally and shows a FL/FW ratio near to 1, and FL/ML around 4. The FL/SL is around 0.25, and the pace angulation (pes) is 40°. The manus is small and lies anteriorly to the pes. This pattern is ascribed to ornithopods adopting quadrupedal gait (Thulborn, 1990; Lockley and Wright, 2001). The calculated height at the hip of the trackmaker is about 1.70 m and estimated body length is about 5–6 m.

Morphotype 2 - Five tridactyl footprints are preserved on block BLP3 (Fig. 5). The pes shows the clear marks of digit II and III while digit IV is in general less impressed. Digits taper distally, even if no distinct claw marks have been observed. Digit III is the longest, straight and pointed, while the base of digit IV lies slightly back relative to the base of other digits. The foot length ranges from 15 cm to 20 cm, the foot width is about 13 cm and the FL/FW ratio is about 1.3. These tracks are referred to small-sized theropods about 1 m tall. Total length of the animal is 4 m, according to Paul (1988).

Morphotype 3 - On BLP4 a quadruped trackway made of three manus-pes sets is preserved as a natural mould. The heteropody is nearly 1:1 (Fig. 6) with the manus print slightly smaller than the pes. The manus track is rounded with short and clumsy digit marks, the pes is oval-shaped, anteriorly-posteriorly elongated, with the long axis parallel to the midline of the trackway. Average pes length is 25 cm. The pes shows a FL/FW ratio near to 1.5, and FL/ML around 1.5. The FL/SL is around 0.25 and the pace angulations value is 114°. This morphotype is referred to a medium-sized obligate quadruped dinosaur. Heteropody values and medium gauge are consistent with an ankylosaur origin (McCrea et al., 2001). Trackmaker's height at the hip reaches about 60 cm while the estimated body length is about 4-5 m. Desiccation cracks were deformed by

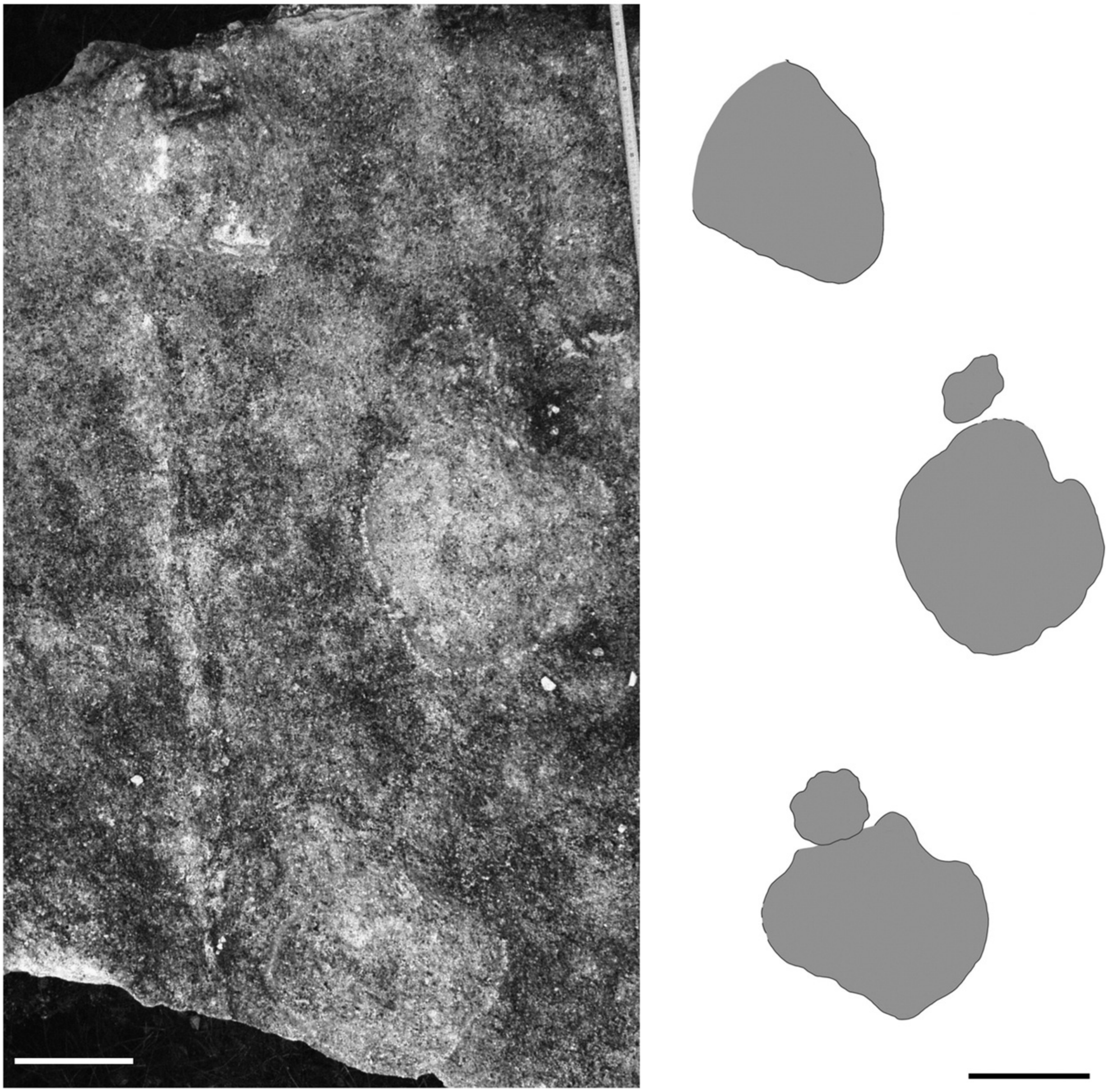

Fig. 4. Morphotype 1 - Block BLP1, with quadruped ornithopod footprints. Scale bars 20 cm.

the animal trampling, proving that the soil was hardened, at least on the surface.

Morphotype 4 - Footprints and natural mould of a huge quadruped dinosaur occurs on different blocks (BLP5, BLP7, BLP9, BLP10). On BLP5 (Fig. 7) nine natural casts, including manus and pes impressions, are preserved. Two partial trackways are preserved as natural mold on BLP7 (Fig. 8), the first trackway is made of two pes and a single manus, the second is made of a further manus-pes set and a bad preserved pes. A poorly preserved single footprint and a set occur on BLP9, BLP10.

The pes is oval-shaped and bigger than the manus (FL/ML ratio about 4). This latter is either close to the previous or to the subsequent pes, or placed halfway. The foot length is about 55 cm while the foot width is around 48 cm. The manus length is 40 cm while the manus width is about 44 cm. Pes and manus dimensions and morphology strongly suggest a sauropod trackmaker about 10 m long. Some footprints were impressed on an already hardened surface as testified by the fragments of the cracked surface pushed down into the track.

Morphotype 5 - A trackway of six footprints preserved as natural mould are preserved on block BLP6. The trackway is made of four pes and two smaller manus (Fig. 9). The foot is three or four times larger than the manus. Gauge is quite narrow and pace angulation ranges from 115° to 127°. The pes as well as the manus is rounded, and the manus lies nearly halfway between two successive footprints, inside the external border of the pes. The average foot length is 26 cm while the foot width is about 23 cm; the average manus length is 12.5 cm, while the average width is 9.5 cm. The stride length is about 67 cm. The height at the hip is 1.65 m, while estimated body length is around 4-5 m. A possible ornithischian origin is suggested based on heteropody values.

Morphotype 6 - Sub-triangular footprints represented on two distinct blocks, BLP2 and BLP8, characterized by similar sediment architecture and surface structures. On the BLP2 five tracks are organized in a short trackway. The pes track average length is 27 cm while the mean of the width is around 24 cm; the FL/SL ratio is 0.3, while pace angulation is nearly 120° (Fig. 10). On BLP8 are preserved three scattered footprints. This morphotype cannot be ascribed with

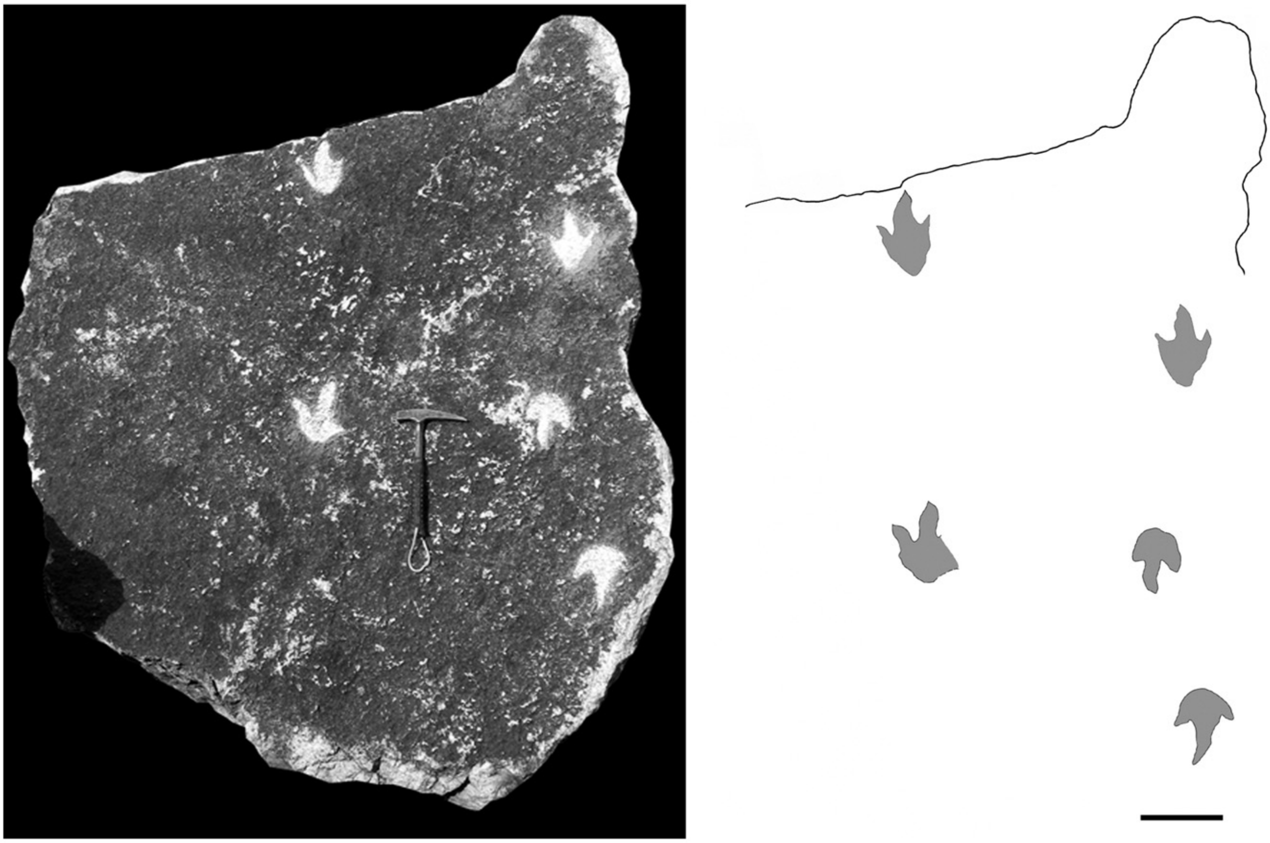

Fig. 5. Morphotype 2 - Small theropod footprints on BLP 3 block (hammer for scale). Scale bar in line drawing 20 cm.

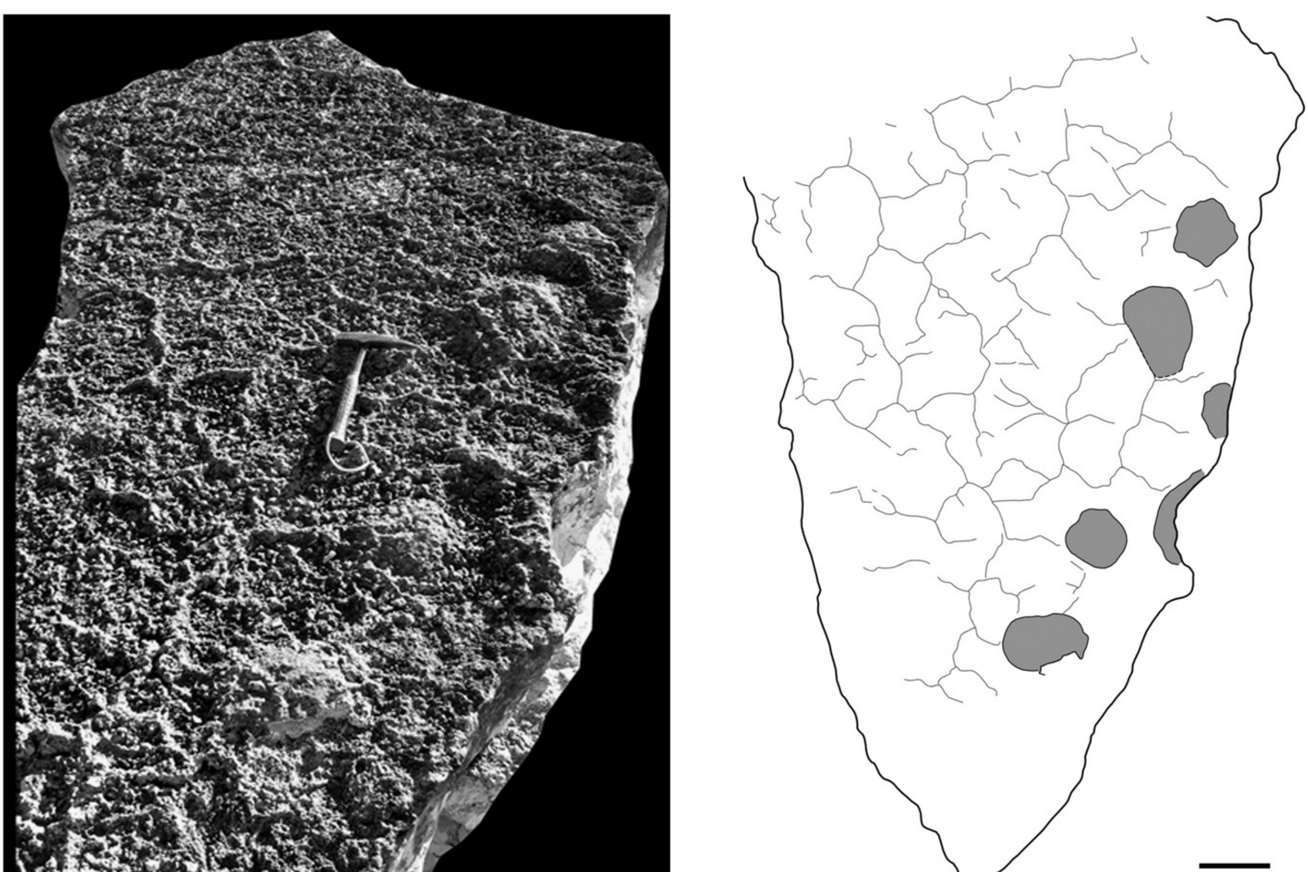

Fig. 6. Morphotype 3 - Photograph (hammer for scale) and drawing of the purposed ankylosaur trackway partially preserved on block BLP 4. Desiccation cracks are widespread. Scale bar 20 cm.

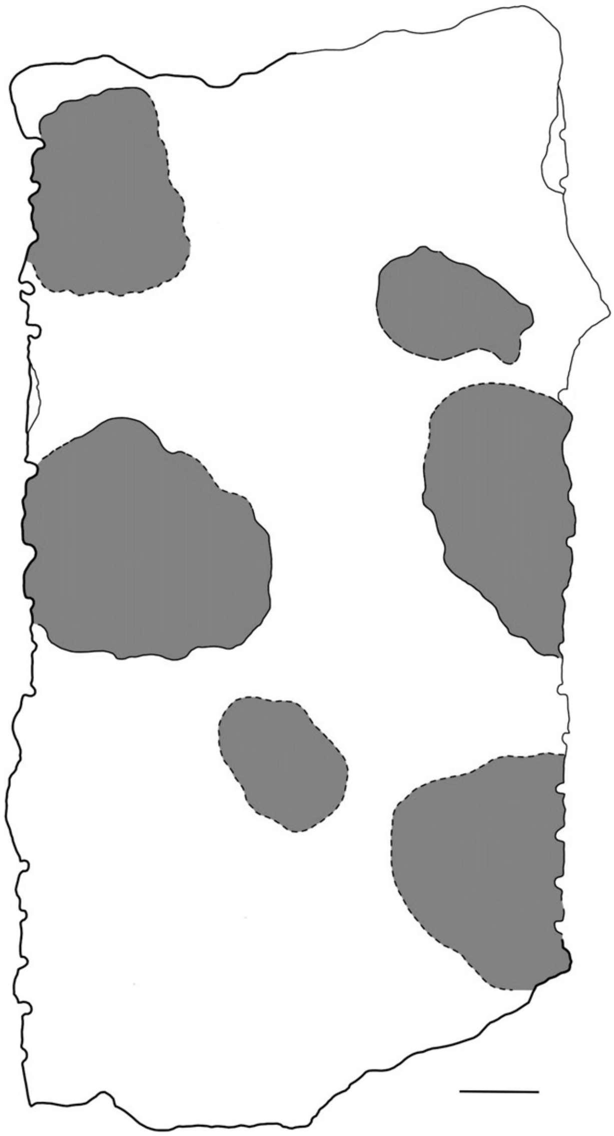

Fig. 7. Morphotype 4 - Two partial trackways preserved on block BLP 7. Scale bar in line drawing 20 cm.

confidence to any skeletal taxon, consequently even the trackmaker size cannot be estimated.

3. The ichnocoenosys

The Bisceglie ichnocoenosys includes tracks ascribed to saurischians (theropods and sauropods) and ornithischians (ornithopods and thyreophorans) (Fig. 11). It confirms the presence of thyreophorans in the Apulian carbonate platform, previously hypothesized for the lower Santonian footprints of Altamura (Petti, 2006) and for the ones from the upper Hauterivian-lower Barremian of Borgo Celano (Petti et al., 2008). Sauropod footprints of Bisceglie are the first ones pointed out in Apulia and the oldest in the Southern Italy carbonate platforms. Sauropod tracks were discovered in two different outcrops, from the Laziale-Abruzzese-Campana carbonate platform (LAC), respectively attributed to the Aptian and to the lower Cenomanian (Nicosia et al., 2007; Petti et al., 2008).

A further important feature of the ichnosite is its larger diversity with respect to the other periadriatic ichnosites, in which only one or two dinosaur groups are represented. In the Bisceglie association plant-eaters prevail in number although theropod footprints are usually prevalent within ichnoassociations (Lockley, 1997). Furthermore, as well as in the other sites of the area, large theropods are lacking. In front of the lack of large predators, pointed out in the Hateg association as well, Grigorescu (2003, p. 101) suggests that "…the relative large number of small theropods …. seems to replace the top predator at the top of the food pyramid.". Recent publications reject this solution, also excluding hunting cooperation among theropods (Roach and Brinkman, 2007).

4. Dinosaur tracks from the periadriatic region

4.1. Palaeogeographic framework

A palaeogeographic frame is basic to fully understand the meaning of the ichnoassociations of the periadriatic area.

The shallow-marine carbonate deposits of the Italian Apennines were laid down on Mesozoic carbonate platforms that, from long time, have been considered as exempla of classical Bahamian platforms (Zappaterra, 1990, 1994 cum bibl.), made by some small emergent areas, and large inner lagoons bordered by biogenic margins and ramps. Traditionally, there was the belief that they pertained to an archipelago made by some platforms (Laziale-Abruzzese-Campana Platform, Apulian Platform, Panormide Platform, Adriatic-Dinaric Platform, Kruja Platform, Mirdita Platform, Gavrovo-Tripolitsa Platform) ranging in dimensions from a few hundreds to thousands of square kilometers, and pulled apart by deeper areas, inside the western part of the Tethys Ocean (Zappaterra, 1990, 1994; Dalla Vecchia, 2002) (Fig. 12). Within them, as well as in the present time platforms, only some small portion could emerge. In some cases these ephemeral islands interpreted as "stepping stones" for north-south migrations of dinosaurs across the Tethys (Dalla Vecchia, 2002 cum bibl.), although different hypotheses were recently suggested (Bosellini, 2002; Vlahović et al., 2005; Petti, 2006; Nicosia et al., 2007; Canudo et al., 2007; Mezga et al., 2007).

As a whole, the present knowledge on the land vertebrates (bones and footprints) occurrences in the periadriatic platforms as well as of fresh water- or land-plant remains, is surprising and contrasts the idea of a continuous marine environment. Data concerning quite long emersion phases, such as the widespread bauxite levels (Crescenti and Vighi, 1964; Boni, 1972; Carannante et al., 1987; D'Argenio et al., 1987; D'Argenio and Mindszenty, 1991, 1992; Mindszenty et al., 1995), further weaken this long-held tenet. The number of evidences of subaerial emergences increases dramatically when the whole periadriatic region, including the Istrian Peninsula and the Croatia (Mezga and Bajraktarević, 1999; Dalla Vecchia, 2002; D'Orazi Porchetti et al., 2005; Mezga et al., 2006, 2007), is considered (Fig. 13).

4.2. Persistence or immigrations?

The frequently occurring footprint bearing levels, within exclusively marine successions, could represent the effect of dinosaur dwelling in two completely different scenarios: either the remaining traces of the long persistence of an autochthonous association or the attestation of repeated immigration events (Fig. 14).

The first scenario hypothesizes a nearly 70 My long-lasting association confined within an island (or a series of islands), pulled apart from the southern continent since the Early Jurassic Tethys rifting, and drifting northward with its inhabitants as a true "Noah's Ark". Such a long-lasting persistence could have been recorded only by relatively few punctuated evidences, the record being biased by preservation and by the scattered available outcrops with respect to the larger subaerial areas existing in the past.

The second scenario invokes repeated arrivals in the area from a near land mass. In this case the dinosaur trampled levels might represent isolate moments of dispersal and life of immigrants into

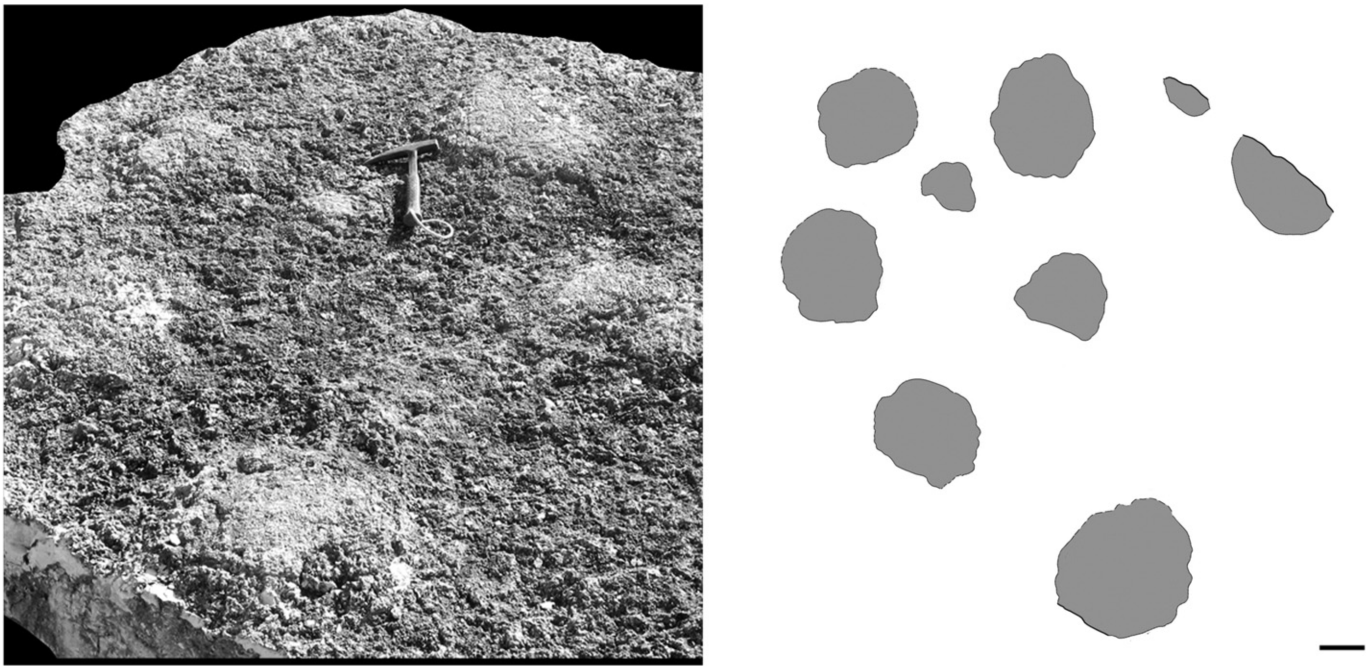

Fig. 8. Morphotype 4 - Photograph (hammer for scale) and drawing of the sauropod footprints preserved on block BLP 5. Scale bar 20 cm.

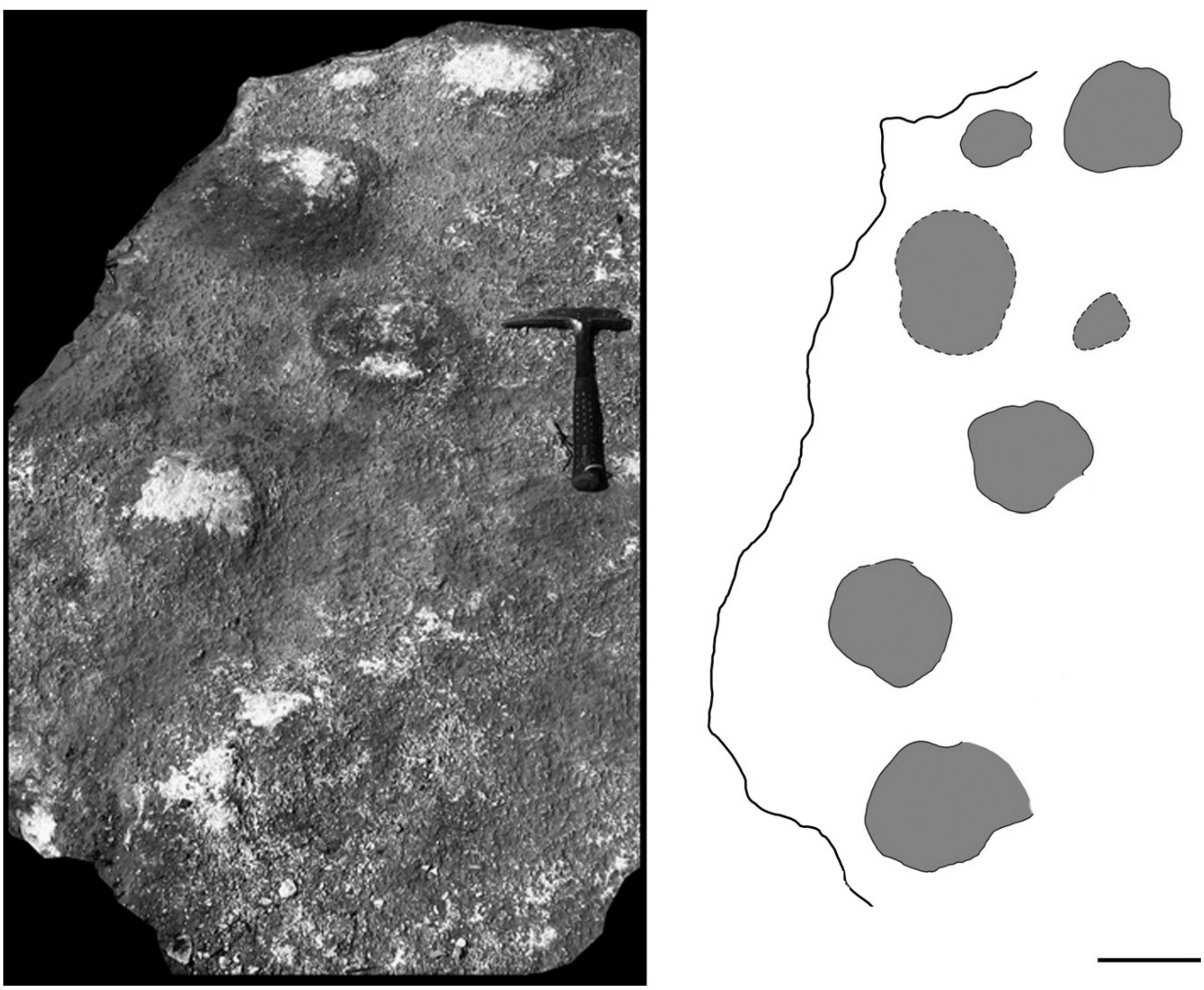

Fig. 9. Morphotype 5 - Photograph (hammer for scale) and drawing of an ornithischian trackway on the block BLP 6. Scale bar 20 cm.

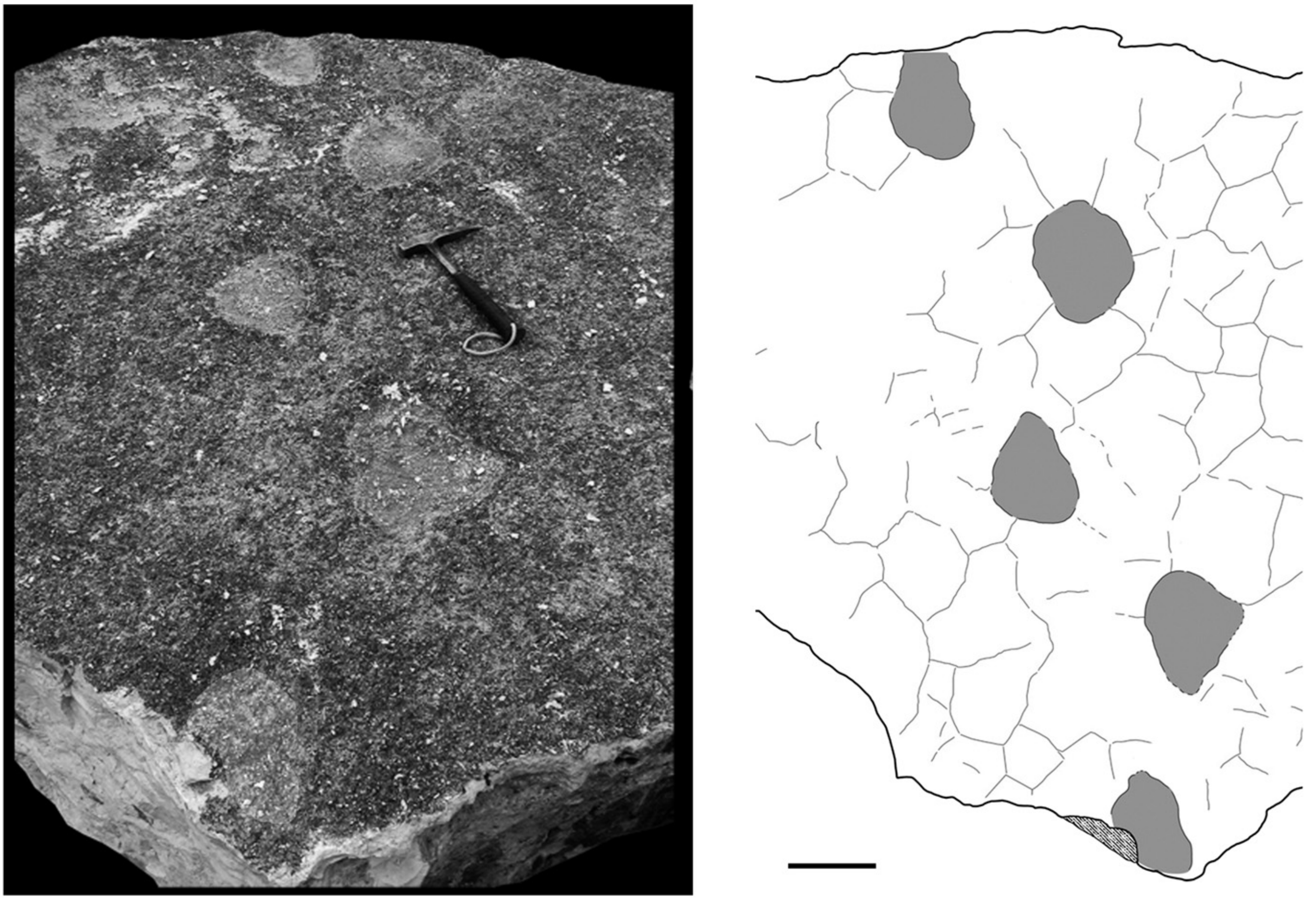

Fig. 10. Morphotype 6 - Photograph (hammer for scale) and drawing of a trackway of unknown origin preserved on block BLP 2. To note the occurrence of desiccation cracks. Scale bar 20 cm.

new available territories, before local disappearances. Consequently, the deposits on which footprints are impressed could have been laid down in marginal areas of a continent made by a huge land area closely linked to a belt of carbonate shelves. Moreover, only migration by walking must be considered, due to dinosaurs being probably able to swim only for a short time as most of the terrestrial animals (Ezquerra et al., 2007). In this hypothesis some crustal sectors, left untouched by the Early Jurassic tectonics, could have acted time to

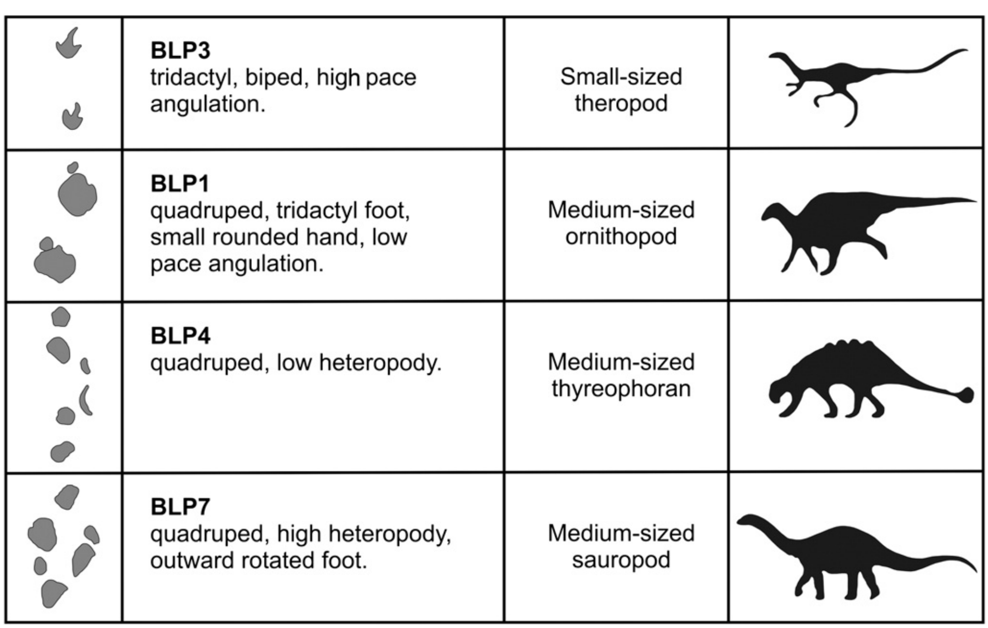

Fig. 11. Synthesis of the Lama Paterno dinosaur ichnocoenosis.

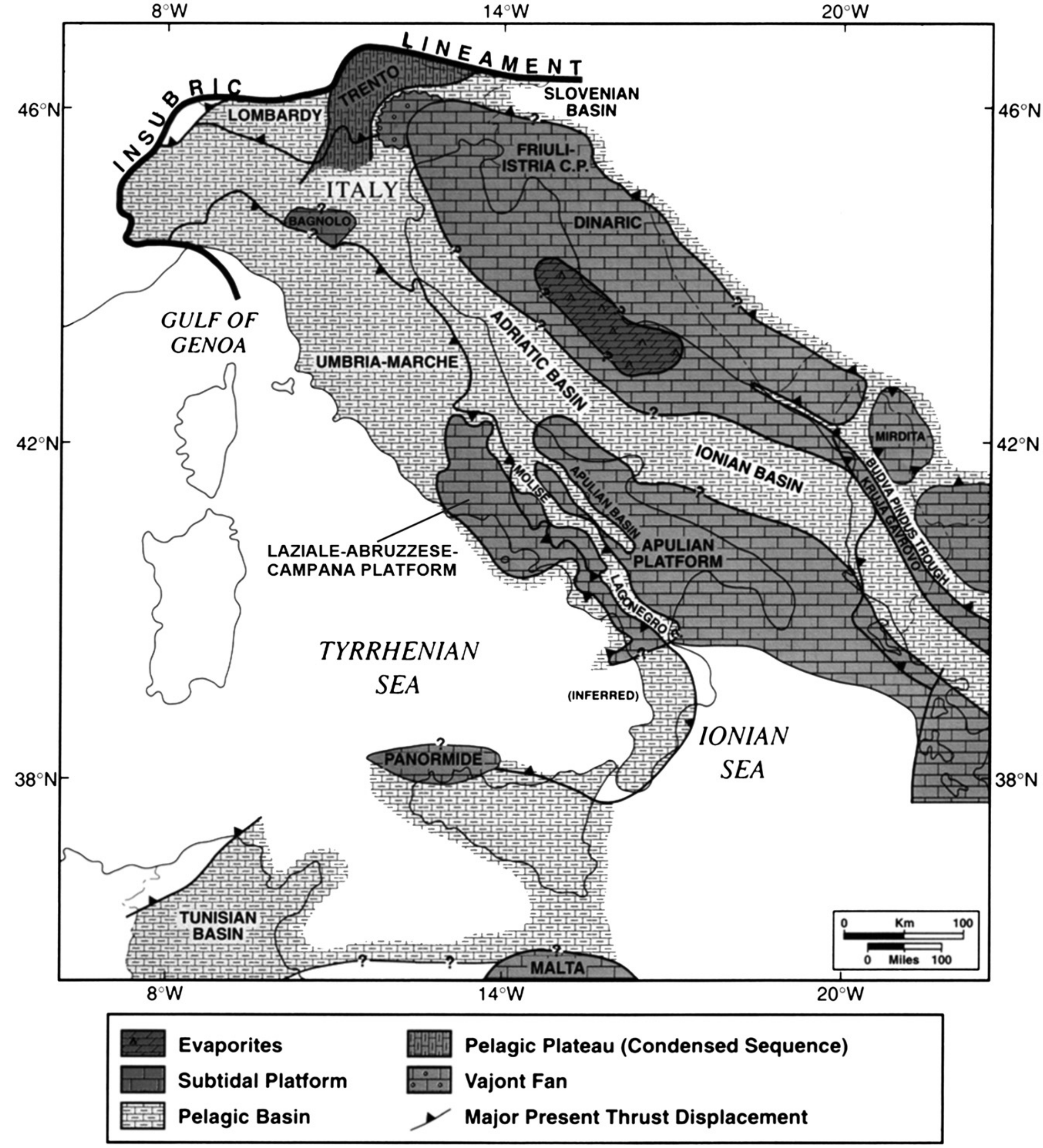

Fig. 12. The periadriatic carbonate platforms (after Zappaterra, 1994, simplified and redrawn).

time as walk-ways between a land mass and the emergent platforms during the Jurassic and the Cretaceous times (see Tattersall, 2006 for similar hypothesis concerning Madagascar).

4.2.1. Palaeobiological diversity

The diversity of the ichnoassociation of Bisceglie revealed to be a powerful tool in order to discriminate between the two hypothesized scenarios. A long lasting segregation in an extreme environment, as the carbonate platforms actually are, leads the whole biota to collapse and the species to extinguish in a time short, in geological terms. In our first hypothesis the interval under consideration spans from the last phase of the rifting, at about 189 Ma (Csontos and Vörös, 2004; Stampfli and Borel, 2004; Turco et al., 2007), to about 120 Ma ago (the age of the Bisceglie association), that is about 70 My.

In our opinion, to have been able to survive isolated on the platforms, the original association should have been evolved, in response to strong selective pressures, into a low diversity, highly specialized fauna and with a reduced number of types of survivors. The long-term survival of a diversified association of animals with high resource requirements, in a confined area with limited supplies, is thus not-parsimonious. Vice versa,

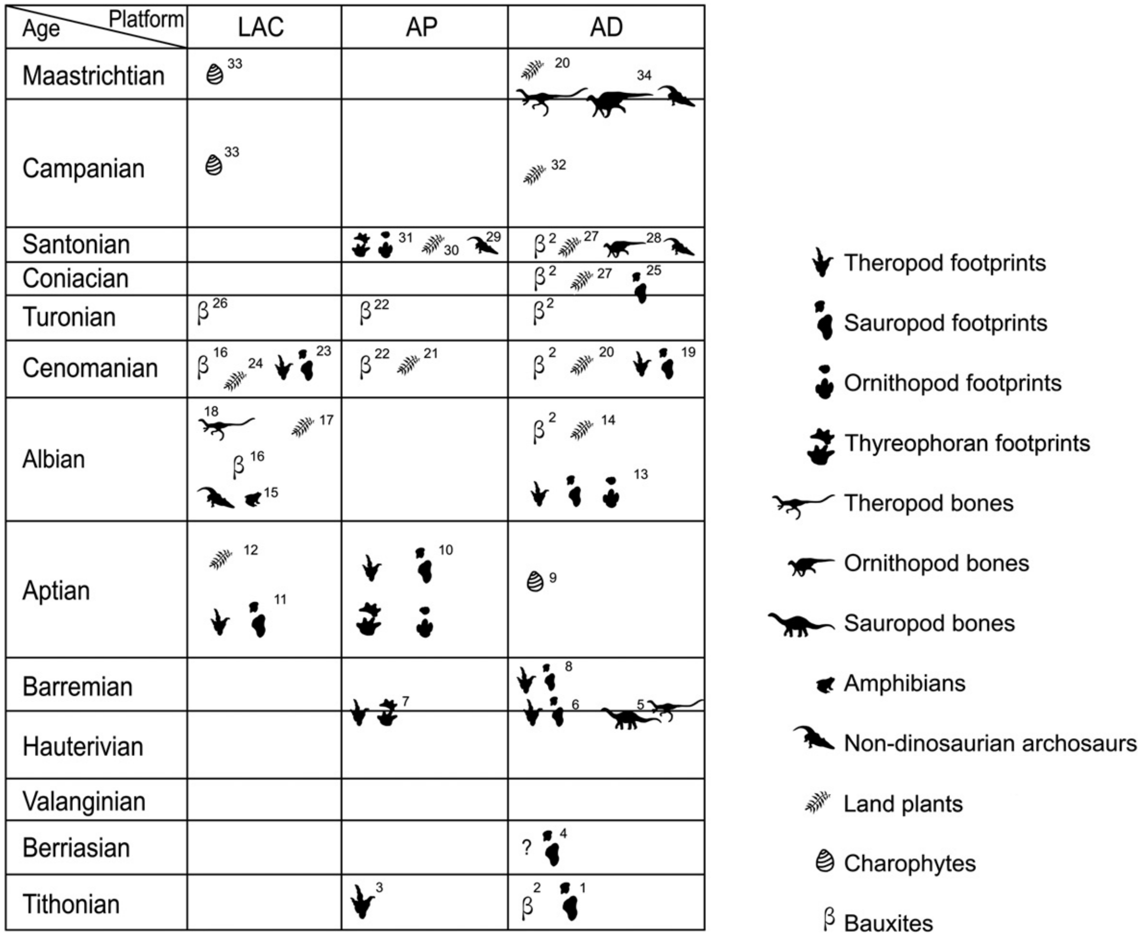

Fig. 13. Synoptic scheme of sedimentologic (bauxites) and paleontologic (land vertebrate footprints and bones, fossil plants) records of the periadriatic carbonate platforms during the Tithonian-Maastrichtian interval. (LAC – Laziale-Abruzzese-Campana Platform; AP – Apulian Platform; AD – Adriatic- Dinaric Platform). 1) Mezga et al., 2007; 2) Vlahović et al., 2005; 3) Conti et al., 2005; 4) Lockley et al., 1994; 5) Dalla Vecchia, 1998, 2000a, 2001a; 6) Dalla Vecchia and Venturini, 1995; Dalla Vecchia, 1999; 7) Petti et al., 2008; 8) Dalla Vecchia, 2000a; Dalla Vecchia et al., 2002; 9) Venturini, 1995; 10) This work; 11) Petti et al., 2007; 12) Bravi, 1995, 1997; 13) Dalla Vecchia and Tarlao, 2000; Dalla Vecchia et al., 2002; 14) Taramelli, 1873; 15) Evans et al., 2004; 16) Carannante et al., 1987, 1992; Mindszenty et al., 1995; Ruberti, 1992; 17) Bravi and Garassino, 1998a,b; 18) Dal Sasso and Signore, 1998; 19) Dalla Vecchia, 2001b; Dalla Vecchia et al., 2001; 20) Dalla Vecchia, 2000b; 21) Meleleo et al., 1984; Gomez et al., 2002; Marinosci and Bortoletto, 2003; 22) Crescenti and Vighi, 1964; 23) Nicosia et al., 2007; 24) Bravi et al., 2004; 25) Mezga et al., 2006; 26) Mindszenty et al., 1995; 27) Dalla Vecchia and Rigo, 1998; Rigo, 1999; Dalla Vecchia, 2000b; Dalla Vecchia and Tentor, 2004; 28) Buffetaut et al., 2001; Dal Sasso, 2003; Dalla Vecchia et al., 2005; 29) Varola, 1999; 30) Morsilli et al., 2002; 31) Nicosia et al., 2000a,b; Petti, 2006; 32) Muscio and Venturini, 1990; 33) Bravi et al., 1999; 34) Debeljak et al., 2002.

repeated sea-level changes and animal immigrations, consistently explain all the evidences (emersion phases followed by soil formation and plant colonization, unbalanced associations and the subsequent rapid collapses of this flash-ecosystems); the recurring marine condition will erase almost completely all the proofs of such events.

5. Conclusions

All the available evidences (e.g., the scattered occurrence, the diversity of dinosaurs, the type of recorded environment, the type of diets, the absolute and relative dimensions of trackmakers and the dimension of the available areas) bring to exclude the long-lasting association survival, favouring the hypothesis of repeated immigrations. The dinosaurs could have been able to immigrate into the carbonate platforms of the periadriatic area, but not to survive therein for a time long enough to allow their co-evolution. In this scenario the temporary land-connections that permitted the dispersal of the dinosaurs, can be considered a good example of filtering-bridge. The recognized repeated occurrence of complex biota, support a direct link with large, unstressed biological "reservoirs" able to re-inject plant and animal population after local extinction events. The ephemeral filtering-bridges, although leaving seaways to the east-west spreading of marine animals, allowed to pre-adapted dinosaurs to reach the periadriatic platforms in a north-south route.

Repeated connections among the platforms themselves can be hypothesized as well, even if the dimensions of the considered platforms and the small percentage of vegetated area allow considering all the platforms as a single area.

Thus, the dinosaur track findings stress the need of a nearly continuous geographic connection including both physical and environmental continuity and walking ways between a land mass and the periadriatic carbonate platforms during most of the Cretaceous. The hypothesized African origin for the titanosaurids (Russell, 1993; Nicosia et al., 2007) as well as the fact that periadriatic platforms were surely bordered to the north by the Ligure-Piemontese Ocean at least until the Turonian (Mindszenty et al., 1995), both places the dinosaur homeland on the northern margin of Gondwana. These data were used as constraints in drawing some palaeogeographic maps (Turco et al., 2007), eventually providing for the presence of a land bridge connecting Northern Africa and periadriatic platforms throughout the Panormide domain for the most of Cretaceous. Thus, we suggest that a crustal sector, including the

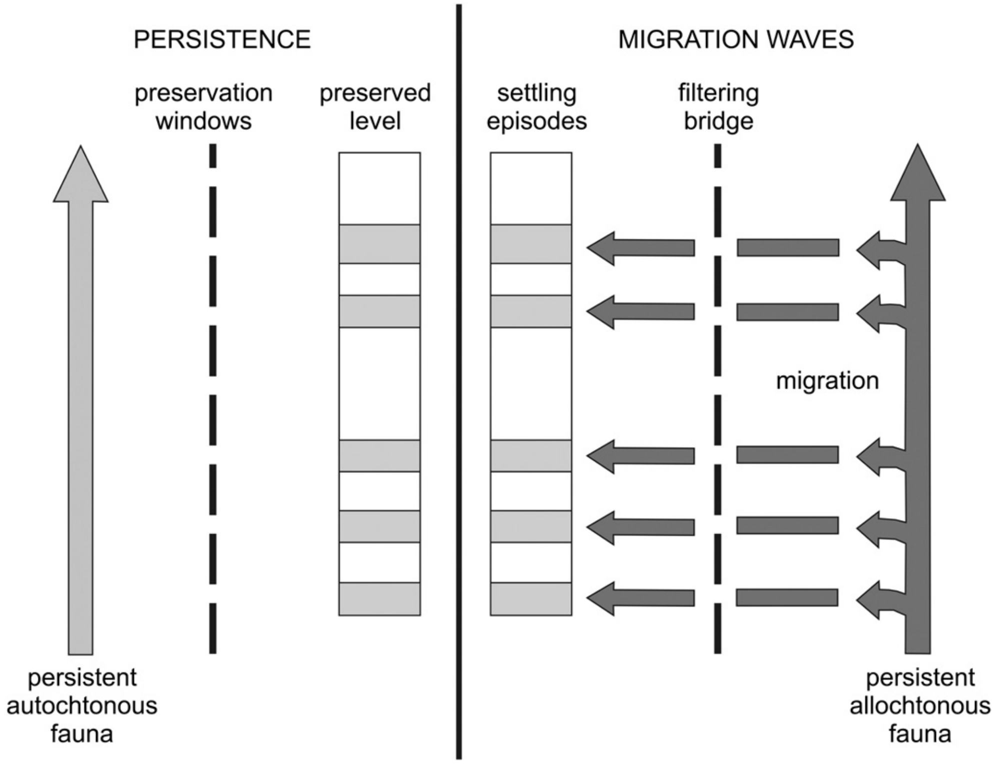

Fig. 14. Persistence *vs.* Immigrations models. a) The persistent autochtonous fauna (pale gray arrow) is testified in the stratigraphic record only in the discovered trampled layers. The stratigraphic record is biased by preservation windows (dashed line) b) Discovered trampled layers are the result of punctuated migrations events (dark gray arrows). The stratigraphic record is influenced by a filtering bridge (dashed lines).

North African margins and the periadriatic carbonate platforms, was leaved untouched by the Early Jurassic rifting.

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