Cretaceous Research 40 (2013) 158–169

Contents lists available at SciVerse ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

# Dinosaur footprints from the Lower Cretaceous of the Algarve Basin (Portugal): New data on the ornithopod palaeoecology and palaeobiogeography of the Iberian Peninsula

Vanda F. Santos [a,b,*], Pedro M. Callapez [b,c], Nuno P.C. Rodrigues [a]

[a] Museu Nacional de História Natural e da Ciência, Rua da Escola Politécnica 58, 1250-102 Lisboa, Portugal
[b] Centro de Geofísica da Universidade de Coimbra (FCT – MCTES), Av. Dr. Dias da Silva, 3000-134 Coimbra, Portugal
[c] Departamento de Ciências da Terra da Universidade de Coimbra, Lg. Marquês de Pombal, 3001-401 Coimbra, Portugal

ARTICLE INFO

*Article history:*
Received 30 December 2011
Accepted in revised form 2 July 2012
Available online 3 August 2012

*Keywords:*
Dinosaur footprints
Iguanodontia
*Iguanodontipus*
Lower Cretaceous
Algarve Basin
Portugal

ABSTRACT

Fieldwork carried out during the past few years in the Algarve region (Portugal) has allowed the description of dinosaur tracks for the first time in the Mesozoic Algarve Basin. Five track levels of Early Barremian age have been described from the Santa and Salema tracksites situated near Vila do Bispo (southwest Algarve). These comprise theropod and iguanodontian footprints (*Iguanodontipus* isp. was identified at the Santa tracksite). A sequence of subcircular and tridactyl impressions with a characteristic morphology of ornithopod footprints with a high pace angulation value made it possible to determine how erosion changes the print morphology and to understand the sequences of subcircular impressions with a high value of pace angulation in the track record. These dinosaur footprints are preserved in marginal-marine carbonate sediments of a large inner shelf palaeoenvironment with shoals and tidal-flat areas that were periodically exposed. The warm and dry climate favoured extensive growth of algal mats and the deposition of dolomitic sediments. The discovery of these track levels has also enabled the palaeobiogeographical data available for the Early Cretaceous Iguanodontia of the Iberian Peninsula and southwestern Europe to be refined.

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## 1. Introduction

The presence of vertebrates in the Mesozoic Algarve Basin (Portugal) was first reported by Palain (1975, 1976) followed by Russell and Russell (1977). They mentioned the existence of fish, primitive amphibians and unknown reptiles in at least five levels of the Triassic "Grés de Silves" Formation. Recently, Kasprak et al. (2010) have recognized terrestrial vertebrate material, including remains of large stereospondyl temnospondyls, close to the Triassic/Jurassic boundary. Dinosaur osteological remains were first identified by Pedro Terrinha at Porto de Mós beach (Lagos) in 1992 (Santos et al., 2000a). Here, in an Aptian layer (Clansayesian–Gargasian according to Rey, 1983), dinosaur teeth and longitudinal sections of vertebrae were recognized. An analysis based on visible morphological aspects in section allowed its assignation to theropods (Santos et al., 2000a). Dinosaur tracksites are still scarce in Mesozoic rocks of the Algarve Basin when compared with the well-documented dinosaur track record from the Mesozoic Lusitanian Basin (Fig. 1), which has been yielding significant palaeobiological and palaeoecological information from abundant tracks and trackways (e.g., Madeira and Dias, 1983; Santos et al., 1992, 1994, 2009a, b; Lockley and Santos, 1993; Lockley et al., 1994b, 1998; Meyer et al., 1994).

Five Cretaceous dinosaur tracksites have been described from the Lusitanian Basin (Fig. 1, Table 1). These contain sauropod, theropod and ornithopod tracks. Among the best evidence of this fossil record are two track levels (Lagosteiros A) in a Berriasian clastic sequence that overlies the Upper Jurassic (Tithonian) limestones in Lagosteiros Bay, north of Cabo Espichel (Sesimbra), which were discovered by José Luís d'Orey in 1996. Here, dinoturbation and bipedal dinosaur tracks of probable theropod origin were identified (Santos, 2003). In the north cliff of Lagosteiros Bay, theropod footprints and a probable ornithopod trackway were documented in a single track level (Lagosteiros B) of Hauterivian age (e.g., Antunes, 1976; Santos et al., 1992; Meyer et al., 1994; Santos, 2003). An Early Aptian tracksite at Praia Grande (Sintra) consists of an upper level with sauropod, theropod and ornithopod

* Corresponding author. Museu Nacional de História Natural e da Ciência, Rua da Escola Politécnica 58, 1250-102 Lisboa, Portugal.
*E-mail address:* vsantos@museus.ul.pt (V.F. Santos).

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http://dx.doi.org/10.1016/j.cretres.2012.07.001

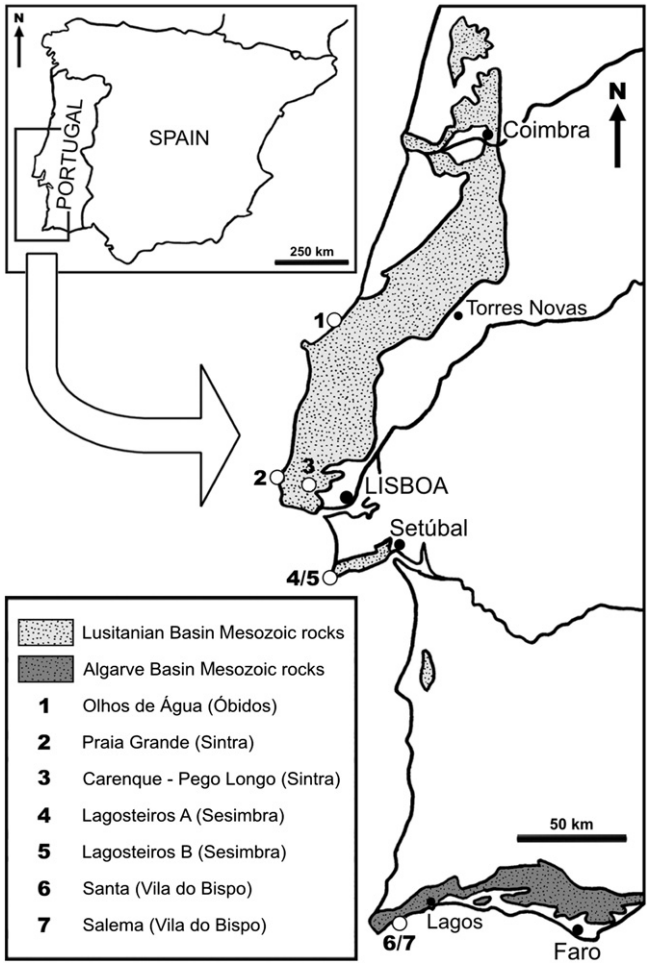


**Fig. 1.** Cretaceous dinosaur tracksites in the Mesozoic Lusitanian and Algarve basins (Portugal).

tracks, and a lower level with dinoturbation (Madeira and Dias, 1983; Lockley et al., 1994a; Santos, 2003). At the Olhos de Água tracksite (Óbidos), theropod and ornithopod trackways of Aptian–Albian age were described by Mateus and Antunes (2003).

**Table 1**
Cretaceous dinosaur tracksites known in Portugal.

| Tracksite | Age | Trackmakers | References |
|---|---|---|---|
| Carenque–Pego Longo | Cenomanian | Theropoda and ?Ornithopoda | Santos et al. (1991, 1992) |
| Olhos de Água | Aptian–Albian | Theropoda and Ornithopoda | Mateus and Antunes (2003) |
| Praia Grande | Early Aptian | Sauropoda, Theropoda and Ornithopoda | Madeira and Dias (1983); Lockley et al. (1994a); Santos (2003) |
| Santa | Early Barremian | Ornithopoda (Iguanodontia) | Santos et al. (2000a, b); Santos (2003) |
| Salema | Early Barremian | Theropoda and Ornithopoda (Iguanodontia) | Santos et al. (2000a, b); Santos (2003) |
| Lagosteiros B | Hauterivian | Theropoda and ?Ornithopoda | Antunes (1976); Santos et al. (1992); Meyer et al. (1994); Santos (2003) |
| Lagosteiros A | Berriasian | ?Theropoda | Santos (2003) |

It is also worth mentioning the Cenomanian Carenque–Pego Longo tracksite, situated near Sintra, which is the only Late Cretaceous dinosaur tracksite known in Portugal. This tracksite consists of a long bipedal dinosaur trackway. It was the world's longest dinosaur trackway (127 m) when first described (Santos et al., 1991, 1992). It comprises a sequence of subcircular tracks that is reinterpreted herein on the basis of additional ichnological evidence resulting from a better understanding of its particular preservational features.

So far only two Early Cretaceous dinosaur tracksites are known in the Algarve Basin. These are near Vila do Bispo, 17 km to the west of Lagos (Fig. 1, Table 1). In 1995, dinosaur footprints were discovered for the first time in this onshore area by Carlos Coke during a geological fieldtrip (Santos et al., 2000a). At that time, seven small tridactyl and mesaxonic footprints were identified in the eastern sector of Salema beach. Subsequent discoveries at this beach include an ornithopod trackway identified by high-school children during a fieldtrip organized by Celestino Coutinho in 1996. In 1997, ornithopod trackways were found at Santa beach by Sebastião Pernes (Santos et al., 2000a).

In this paper we discuss the palaeobiological significance of the *Iguanodontipus* tracks and their association with specific marginal-marine depositional environments. At the same time, as a result of their location and age, these new findings also have implications for the palaeobiogeographical distribution presently assumed for the Early Cretaceous Iguanodontia of the Iberian Peninsula and southwestern Europe.

## 2. Material and methods

Non-metrical and metrical ichnological parameters were considered to characterize tridactyl tracks and trackways. The first provides indirect evidence of anatomical manus and foot features such as marks of pads and interdigital webs, heel shape and the shape of distal claws (rounded or sharp). The metrical parameters are: *L*, total footprint length; *W*, footprint width; $\lambda$, stride; *S*, step; TW, trackway width; $\gamma$, pace angulation. Two angular parameters are also considered: $\alpha$, angle measured between the axis of digits II and III; $\beta$, angle measured between the axis of digits III and IV (e.g., Leonardi, 1987; Moratalla et al., 1988; Thulborn, 1990; Lockley, 1991; Moratalla, 1993).

The measurements were made on each of the ornithopod tracks and trackways at the Santa and Salema tracksites using these parameters. The Salema tracksite initially yielded eight ornithopod footprints, but recent studies have led to the accumulation of new data and the description of at least 13 very lined-up footprints. Six footprints are clearly tridactyl and mesaxonic. The others have an almost subcircular shape and do not reveal any morphological features. At the Santa tracksite there is one main level with at least four trackways and also some isolated footprints in a total of 16 tracks.

It was considered important to make a cast of the best footprint assigned to the *Iguanodontipus* isp. discovered at the Santa tracksite, because this outcrop is being continually damaged by marine coastal erosion. This cast is part of the collections of the Museu Nacional de História Natural e da Ciência (Universidade de Lisboa), reference MNHN.UL.II 513.

## 3. Geographical and geological settings

The two Early Cretaceous dinosaur tracksites in the Algarve Basin (Santos et al., 2000a, b) are present in coastal exposures of the western sector, near the village of Salema (Vila do Bispo, southwest Algarve). They consist of two track levels preserved on the beach together with a set of three others at Santa beach, a small bay 2 km to the west (Fig. 2).

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