

Sesimbra Geocircuit and dinosaur tracksites

Pegadas de dinossáurios no Geocircuito de Sesimbra

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Abstract: In Portugal since the XVth century, or even earlier, people from the Sesimbra region looked at and interpreted the dinosaur footprints on the cliffs of Cabo Espichel as having been produced by a “giant mule” that carried the Virgin Mary from the stormy sea to safety at the top of the cliffs. This became a religious myth and gave origin to the construction of the Cabo Espichel Sanctuary during the XVIIIth century. Centuries later these footprints were finally recognized as what they indeed are: Upper Jurassic sauropod footprints. Over the last 50 years fieldwork in the region has allowed the recognition of several levels with dinosaur trackways between Cabo Espichel and Lagosteiros bay and in the area of Zambujal. At present, there are five dinosaur tracksites in Portugal designated as Natural Monuments, three of them in the Sesimbra area. Besides their scientific interest, they play an important role to enhance public awareness of geological heritage and, consequently, it will be possible to attain more success on geoconservation strategies in order to protect and to value the geological and palaeontological heritage. These geosites are an important and well known component of the *Sesimbra GEOcircuit* that aims to catalogue, to characterize, to interpret and to promote the geological heritage of Sesimbra.

Keywords: dinosaur ichnology, geological heritage, science outreach, Sesimbra, Portugal

Resumo: Em Portugal desde o século XV, ou mesmo antes, as pessoas da região de Sesimbra percebiam que havia pegadas de animais nas lajes do Cabo Espichel e julgaram tratar-se das pegadas uma “mula gigante” que levou a Virgem Maria do mar tempestuoso para a segurança no topo das falésias. Esta ocorrência paleontológica deu origem a um mito religioso e à construção do Santuário do Cabo Espichel durante o século XVIII. Séculos mais tarde as pegadas foram finalmente reconhecidas como pertencentes a dinossáurios saurópodes do Jurássico Superior. Ao longo dos últimos 50 anos de trabalho de campo nesta região foi possível reconhecer a existência de vários níveis com pegadas de dinossáurio entre o Cabo Espichel e a baía dos Lagosteiros e na área da povoação de Zambujal. Atualmente existem cinco jazidas com pegadas de dinossáurio classificadas como Monumento Natural em Portugal e três delas localizam-se na região de Sesimbra. Além de seu interesse científico, estas jazidas desempenham um papel importante para aumentar a consciência pública do património geológico e, consequentemente, contribuem para o sucesso das estratégias de geoconservação que têm como objectivo conseguir proteger e valorizar o património geológico e paleontológico. Estas jazidas são elementos importantes e bem conhecidos no *Geocircuito de Sesimbra* que visa catalogar, caracterizar, interpretar e promover o património geológico de Sesimbra.

Palavras-chave: icnologia de dinossáurios, património geológico, divulgação científica, Sesimbra, Portugal

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1. Dinosaurs are “known” in Sesimbra since very early times

Dinosaur footprints have been heard of or talked about in Portugal as early as the XVth century (or even earlier) but they were, for centuries, misinterpreted as the footprints of a “giant mule” that carried the Virgin Mary from the stormy sea to safety at the top of the cliffs at Cabo Espichel, near Sesimbra (Fig. 1), where they have been preserved. The tracks in question, which are now known to be sauropod footprints from the Upper Jurassic of Cabo Espichel (e.g. Antunes, 1976; Lockley *et al.*, 1994a), are associated to a religious legend and to the building of a chapel, presumably in the year 1410, known as *Capela da Memória* (Memory Chapel), and also of the Sanctuary of Cabo Espichel, built a few hundred years later, during the XVIIIth century. This religious legend is illustrated in a mid XVIIIth century set of tiles placed inside this chapel (Fig. 2). Truly, what this illustration represents are the dinosaur footprints of the *Pedra da Mua* tracksite, although at the time it was painted dinosaurs were not known yet.

Following the discovery of the *Pedra da Mua* tracksite in the 1970's, Antunes (1990) made a contribution to the knowledge of the dinosaur fauna from the Sesimbra region with a paper concerning the Avelino Quarry tracksite which included an illustration by Fátima Antunes that is considered the first illustration of a sauropod and its footprints that was produced in Portugal.

The research carried out since then in this area has allowed the emergence of several scientific and outreach publications and of scientific dissemination activities (e.g. Galopim de Carvalho and Santos, 1992, 1993a,b; Galopim de Carvalho *et al.*, 1994; Lockley and Santos, 1993; Lockley *et al.*, 1992, 1994a,b; Meyer *et al.*, 1994; Rodrigues and Santos 2003; Santos, 2000, 2003, 2008; Santos *et al.*, 1995, 2008). Moreover it still is a motive to new research and to promote and enhance this geoheritage (e.g. Castanera *et al.*, 2012, 2014a,b; D'Orazi Porchetti *et al.*, 2016; Pereira and Santos, 2010; Pólvora *et al.*, 2014; Santos, 2014; Santos *et al.*, 2015).



Fig. 1. Location of the three dinosaur tracksites from the Sesimbra Geocircuit: Pedra da Mua Natural Monument and Lagosteiros Natural Monument at Cabo Espichel and Avelino Quarry Natural Monument at Zambujal (Sesimbra, Portugal).

Fig. 1. Localização das três jazidas com pegadas de dinossaúros no Geocircuito de Sesimbra: Monumento Natural da Pedra da Mua e Monumento Natural de Lagosteiros, no Cabo Espichel, e Monumento Natural da Pedreira do Avelino perto da povoação de Zambujal (Sesimbra, Portugal).

2. Dinosaur tracks from Cabo Espichel (Sesimbra)

Pedra da Mua tracksite (Upper Jurassic)

On the cliffs below the Sanctuary of Cabo Espichel (Lagosteiros bay) dinosaur track levels from the uppermost part of the Upper Jurassic, with different sorts of information on theropod and sauropod palaeobiology and palaeoecology were identified and described (e.g. Lockley *et al.*, 1994a,b; Meyer *et al.*, 1994). This site, known as the *Pedra da Mua* tracksite, revealed evidences of herd behaviour among adult and sub-adult sauropods (Lockley *et al.*, 1994a; Castanera *et al.*, 2012, 2014b). Two sets of parallel trackways reveal herd behaviour in two groups of sauropods: seven small (sub-adult) animals were followed at some distance by three larger ones, as the prints left by one of these overlaps the first ones (Fig. 3). This is actually the first convincing example of herd behaviour in Europe and the best known amongst what seem to be juveniles. The hip height of the seven small sauropods ranges from 1.5 to 1.8 m and they probably walked at a speed between 3.6 and

5 km/h. For the larger animals, their hip height ranged between 2.8 and 2.9 m and their speed between 3.4 and 4.1 km/h. There is evidence that an even larger sauropod once walked in this place: calculations give the value of 3.2 m for his hip height.

This tracksite also yielded information about theropod and sauropod manus and pes structures as well as about locomotion. Here, one example of limping gait in a sauropod was clearly identified through the observation of irregularities in the length of both left and right steps. The reasons for this kind of behaviour are still unknown. Regarding these sauropods, their manus and pes print morphology together with an area ratio between 1/3 and 1/4 correspond to the defined *Brontopodus* ichnogenus characteristics. These sauropod trackways are all wide-gauge (*Brontopodus* type) and some of the best-preserved *Brontopodus* pes morphologies, showing four claw marks, can be observed in this tracksite (Meyer *et al.*, 1994).

Evidences of limping gait have become more common in the Portuguese sauropod track record and also in one theropod trackway preserved on a level at Praia do Cavalo, the bay right just south of



Fig. 2. Glazed tile artwork from the mid-XVIIIth century (left) inside the *Capela da Memória* (right) of the Sanctuary of Cabo Espichel (Sesimbra, Portugal), showing footprints on a cliff behind a “giant mule” carrying the Virgin Mary. Photograph: Luís Quinta.

Fig. 2. Paineis de azulejos de meados do século XVIII (à esquerda) no interior da Capela da Memória (à direita) no Santuário do Cabo Espichel (Sesimbra, Portugal), exibindo pegadas no penhasco atrás de uma “mula gigante” que transportou a Virgem Maria. Fotografia de Luís Quinta.

Lagosteiros bay (Dantas *et al.*, 1994). Beneath the Sanctuary of Cabo Espichel there are also five incomplete sauropod trackways (only manus prints) with slight pes marks that corroborate preservation factors instead of behaviour as a cause for this phenomenon.

Lagosteiros tracksite (Lower Cretaceous)

The Portlandian stratigraphic sequence is followed by the Cretaceous sedimentary record and on the top of the north cliff of Lagosteiros Bay a huge and steep Hauterivian limestone slab revealed dinosaur tracks described by Antunes (1976). At that time, the author interpreted a trackway whose prints were sub circular and poorly preserved as a trackway made by a quadruped dinosaur. Later, measurements of the pace angulation value suggested that they were made by a bipedal animal (Fig. 4) (Santos *et al.*, 1992, 2013). The value of this parameter does not change with the conservation state and allows an identification of the trackmaker, even when the footprint morphology is unrecognizable. At

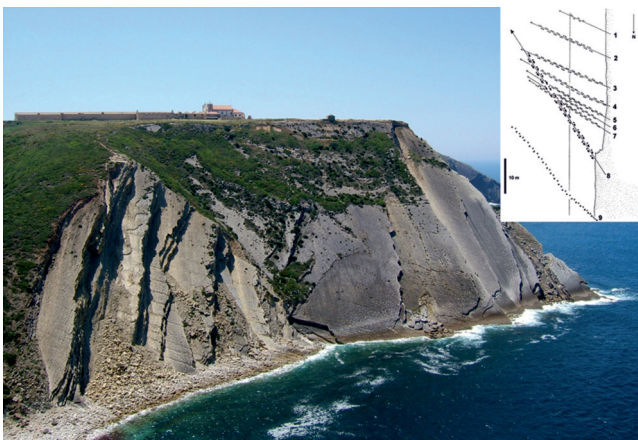


Fig. 3. *Pedra da Mula* tracksite (Cabo Espichel, Portugal) revealed theropod and sauropod trackways on eight levels (*Pedra da Mula* Natural Monument by Decree n° 20/97 of May 7th). On one of these levels there are evidences of herd behaviour among adult and sub-adult sauropods (map with parallel sauropod trackways adapted from Lockley *et al.*, 1994a).

Fig. 3. A jazida da Pedra da Mula (Monumento Natural da Pedra da Mula por Decreto n.º 20/97 de 7 de Maio; Cabo Espichel, Portugal) apresenta pegadas de terópodes e de saurópodes em oito níveis. As pistas de saurópodes paralelas são consideradas uma evidência de comportamento gregário entre animais adultos e juvenis (mapa adaptado de Lockley *et al.*, 1994a).



Fig. 4. Overview of Lagosteiros tracksite (Cabo Espichel, Portugal) showing the main ornithomimid trackway (Lagosteiros Natural Monument by Decree n° 20/97 of May 7th); well preserved theropod tracks in a trackway that suggests a speed value of 14 km/h (Photograph by Luis Quinta).

Fig. 4. A jazida de Lagosteiros (Monumento Natural dos Lagosteiros por Decreto n.º 20/97 de 7 de maio; Cabo Espichel, Portugal) apresenta uma longa pista de um ornitópode, algumas pegadas de terópodes e uma pista que indica um terópode a deslocar-se a cerca de 14 km/h (Photograph by Luis Quinta).

Lagosteiros tracksite there are also tridactyl impressions of small unknown theropods. A theropod trackway suggests a speed value of 14 km/h (Fig. 4) that is considered the unique evidence of a fast dinosaur in the Portuguese track record (*e.g.* Santos, 2003, 2008).

3. Dinosaur tracks destroyed in a quarry (Sesimbra)

Ribeira do Cavalo tracksite (Upper Jurassic)

Ribeira do Cavalo quarry revealed tracklevels from the Upper Oxfordian to Upper Kimmeridgian with theropod and sauropod trackways (Lockley *et al.*, 1992). The main tracklevel (Fig. 5) was found on a fantastic vertical slab which, until its complete collapse in 1995 (Santos *et al.*, 1995), showed a manus dominated dinosaur trackway with digit impressions and well preserved theropod trackways (Lockley *et al.*, 1992). This tracksite was a perfect place to receive children and general public in regular field trips to teach Geology and Palaeontology issues. However, here at this site no footprint has lasted to be witness of the Jurassic fauna (Santos *et al.*, 1995). Each track levels were nice windows to an ancient past that were shutdown forever. Luckily other windows are open and we can get a glimpse of that fauna and their palaeoenvironment.



Fig. 5. An almost vertical slab with well-preserved theropod tracks was the main level at Ribeira do Cavalo tracksite (Sesimbra, Portugal) until its collapse in 1995.

Fig. 5. Uma laje quase vertical com pegadas de terópodes bem preservadas foi o nível principal da jazida da Ribeira do Cavalo (Sesimbra, Portugal) até colapsar em 1995.

4. Dinosaur tracks at Zambujal (Sesimbra)

Avelino tracksite (Upper Jurassic)

The quarry activity at this site exposed four Upper Jurassic limestone levels with dinosaur tracks. The main tracklevel (Fig. 6) has five narrow-gauge sauropod trackways that were described and assigned to *Parabrontopodus* isp. (Lockley and Santos, 1993). These trackways present pes prints length ranging from 30 to 100 cm which reveal different sized animals. The smallest sauropod would have 1.2 m to the hip whilst the largest would have about 4 m to the hip. There is no evidence of gregarious behaviour among them because they all show different movement directions - these five sauropods were travelling separately in different directions. The estimated travel speed for these sauropods varies from 2.2 km/h to 3.9 km/h indicating a usual stroll slower than the average travel speed of a human adult which is about 5 km/h.

5. How a “divine evidence” became a natural monument

Portugal has a rich geological and palaeontological heritage and several occurrences deserve to be preserved and protected due to their exceptional scientific and educational value. In fact, there are many remarkable places where Science and scientific culture can be explored in order to contribute to the knowledge and respect for



Fig. 6. Overview of the main limestone slab of Avelino tracksite in July 2000 (Avelino Quarry Natural Monument by Decree n.º 20/97 of May 7th) with four narrow-gauge sauropod trackways (Sesimbra, Portugal).

Fig. 6. Aspecto da laje principal na jazida da Pedreira do Avelino em Julho de 2000 com quatro pistas estreitas de saurópodes (Monumento Natural da Pedreira do Avelino por Decreto n.º 20/97 de 7 de maio; Sesimbra, Portugal).

natural heritage. Dinosaur tracksites in Portugal have given a significant contribution to dinosaur studies and some of them have very good conditions to be geological and palaeontological education centres with activities for school children, at different levels, and to the general public.

The scientific, educational, cultural and touristic values recognized at the dinosaur tracksites from Sesimbra allowed their designation as Natural Monument (Decree n.º 20/97 of May 7th).

Despite their formal designation in 1997, Avelino Quarry Natural Monument, Pedra da Mua Natural Monument and Lagosteiros Natural Monument, an effective strategy doesn't exist to put the scientific information gathered with the ongoing studies accessible to public common use. A simple outdoor panel has been insufficient for a good understanding of the geosite.

The Avelino Quarry was, unfortunately and for many years, completely neglected until the Sesimbra municipality submitted an application to ADREPES with the project for its musealization (Fig. 7). The application was approved and, in 2012, the formerly abandoned quarry was rehabilitated and is presently an excellent example of conservation, enhancement and management of the natural heritage of Sesimbra (Pólvora *et al.*, 2014; Santos *et al.*, 2015).

Dinosaur tracks must be observed *in situ*, incorporated in their geological context, and the musealization of the tracksites is necessary to allow an autonomous visit (Fig. 7). The promotion of environmental education projects in schools can take a good advantage of these adapted geological and palaeontological sites, which give an important contribution to science education.

The educational purpose of the activities performed at dinosaur tracksites is fundamental to the success of the geoconservation strategies in order to protect and to value the geological and palaeontological heritage.

Unfortunately, sometimes we have lost: Ribeira do Cavalo tracksite (near Sesimbra) was lost due to the quarry activity (Santos *et al.*, 1995) because as often happens, private interests speak louder than the environmental public aims, even when nature conservation may minimize the impact of non-sustained exploitation of natural resources. To inform is the best way to modify school children and general public attitudes concerning the scientific and cultural value of geoheritage. That is the most correct way to really protect and value natural heritage in general. Creating the appropriate legislation is a necessary step, but it is not enough.



Fig. 7. Avelino Quarry Natural Monument in May 2014 after been rehabilitated with the Sesimbra municipal project to promote its geoheritage. There are outdoor panels with information about the dinosaurs, their palaeoenvironment and Arrábida geological background.

Fig. 7. O Monumento Natural da Pedreira do Avelino em Maio de 2014 após intervenção de reabilitação efectuada através do projeto da Câmara Municipal de Sesimbra para promover o seu património geológico. Há painéis exteriores com informações sobre os dinossáurios e os paleoambientes, bem como sobre aspectos da Geologia da Arrábida.

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