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Final Degree Report

Study of Early Cretaceous Spinosaurids from Cabo Espichel and contemporaneous Theropods of the Iberian Peninsula. Morphometric Analysis of one tooth of Spinosaurid

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Degree on Biology

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Resum

Títol: Estudi dels espinosaurids del Cretaci inferior de Cabo Espichel i dels teròpodes contemporanis de la península Ibèrica. Anàlisi morfomètrica d'una dent d'espinosaure.

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Paraules clau: Teròpod, Spinosauridae*, Spinosaurinae,* Baryonychinae, *Baryonyx*, *Vallibonavenatrix*, Cabo Espichel, Formació de Papo Seco, Cretaci Inferior, Península Ibèrica, Morfología Dental.

S'han trobat fòssils de Teròpodes a tota la Península Ibèrica, l'edat geològica comuna d'aquests descobriments és el Cretaci Inferior. Aquests descobriments han reportat una excepcional diversitat de restes amb moltes distincions, que presenten adaptacions a diferents entorns. Un dels fòssils més habituals identificats és el *Baryonyx*. El grup de les Baryonychinae pertany a la família dels Spinosauridae i es caracteritza per dents còniques, llargs cranis semblants a cocodrils i una vela conformada per arcs neuronals en alguns d'ells. Un lloc que presenta una riquesa excepcional de materials fòssils d'espinosaures és a Cabo Espichel, a Setubal (Portugal), on al llarg dels anys s'han descobert diversos restes fòssils d'interès. Aquest informe té com objectiu desenvolupar una cerca bibliogràfica dels fòssils de teròpodes trobats a Cabo Espichel de Portugal, la cerca dels fòssils de Teròpodes contemporanis que s'ha trobat a la península Ibèrica; a més, l'anàlisi morfològica d'una dent aïllada d'un espinosaure del Museu de l'Institut Català de Paleontologia Miquel Crusafont". El recull bibliogràfics s'ha extret d'un centenar d'articles científics i en aquest treball es presenta en un estudi accessible. La investigació bibliogràfica reuneix els materials fòssils de teròpodes procedents de les capes del Cretaci inicial de la península Ibèrica, correlacionats amb els fòssils de Cabo Espichel. La part experimental es va dur a terme al "Museu de l'Institut Català de Paleontologia Miquel Crusafont", on es va es van prendre les mesures i imatges d'una dent d'espinosaure no ben identificada seguint la metodologia de Smith et al., (2005). Les imatges es van analitzar amb el programa de software lliure *"Image J*" que va permetre identificar la dent com a *Baryonyx sp.*

Summary

Title: Study of the Early Cretaceous Spinosaurids from Papo Seco Formation and correlative Theropods on the Iberian Peninsula. Morphometric Analysis of one tooth of Spinosaurid.

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Date: January of 2020

Keywords: Theropod, Spinosauridae, Spinosaurinae, Baryonychinae, *Baryonyx*, *Vallibonavenatrix*, Cabo Espichel, Papo Seco Formation, Early Cretaceous, Iberian Peninsula, Dental Morphometric.

Theropod fossils have been found across the Iberian Peninsula, the common geological age for these discoveries is the Early Cretaceous. Those findings have reported an exceptional diversity of remains with many distinctions, presenting adaptations to different environments. One of the most usual fossils identified, are the *Baryonyx*. The Baryonychinae group belongs to the Spinosauridae family, and are characterized by conical teeth, long crocodile-like skulls, and a sail conformed by neural archs in some of them. A site that presents an exceptional wealth of Spinosaurid fossil materials have been classified is in Cabo Espichel, in Setubal (Portugal), where several fossil samples of interest have been discovered across the years. This report aims to develop a bibliographic search of Theropod Fossils from the Cabo Espichel in Portugal, the search of the contemporaneous Theropod fossils that were found in the Iberian Peninsula; moreover, the morphometry analysis of an isolated tooth with the parameters by Smith et al., (2005). This collection has been gathered from a hundred reports, and presented in an accessible study. The bibliographic research assembles the Theropod fossil materials from Early Cretaceous layers in Iberian Peninsula, correlated to the fossils from Cabo Espichel. Also, the experimental part involved the visit to the "Museu de l'Institut Català de Paleontologia Miquel Crusafont", where the description was carried out, a series of images were taken from the sample, used to take measures with the *"Image J*", program which lead to identify it as *Baryonyx sp.*

Previous

This final degree project is targeted to the palaeontological study of Spinosaurid theropod fossils collection, found in Cabo Espichel (SW Portugal) and the comparison with the correlative theropods fossils found in in Iberian Peninsula. In the first instance, the idea was to develop a report about the taxonomy and the morphology of a Spinosaurid dentary collection gathered from Cabo Espichel and conserved in different museums in Portugal, with the supervision of Prof. Elisabete Malafaia from Faculdade de Ciências da Universidade de Lisboa. But, due to the exceptional situation caused by the COVID-19 global pandemic and all the subsequent effects, such as the closure of national and international borders, the experimental study of the fossil materials in Portugal was not possible. In order to overcome this drawback, the practical section evolved into an analysis of an isolated theropod tooth from the “Museu de l'Institut Català de Paleontologia Miquel Crusafont”, and a comparative study with teeth from the Papo Seco Formation. The tooth was investigated following the parameters of Smith et al., (2005).

Acknowledgments

I would like to thank Elisabete Malafaia for her help during the more complicated stages of the Project, and for the access to the material described in the present paper, sharing both fossil materials collected from museums and scientific papers about them, as well as suggesting the change of focus on the Project.

Thanks to the “Museu de l'Institut Català de Paleontologia Miquel Crusafont” and their Head of the Dinosaur Ecosystems Research Group, Angel Galobart, for yielding information regarding the tooth material used in the experimental part, and for defining the practical section of this work in its current state.

Index

Abbreviations

The following abbreviations are used through this text.

Institutional abbreviations:

CPGP - Centro Português de GeoHistória e Pré-História, Lisbon, Portugal
LAP - Laboratório de Arqueozoologia e Paleontologia do CPGP, Golegã, Portugal
MGLNEG - Museu Geológico do Laboratório Nacional de Energia e Geologia, Lisbon, Portugal
MG - Museu Geológico, Lisbon, Portugal; ML, Museu da Lourinhã, Lourinhã, Portugal
MNN - Musée National du Niger, Niamey, Niger
NHM - Natural History Museum, London, UK

Teeth abbreviations:

AFCCS - crown curve slope of the A face
AL - apical length
CA - crown angle
CA2 - crown angle corrected for size
CBL - crown base length
CBR - crown base ratio
CBW - crown base width
CH - crown height
CHR - crown height ratio
DA - distal apical denticle density
DAVG - average distal denticle density
DAVG2 - average distal denticle density corrected for size
DB - distal basal denticle density
DC - distal mid-crown denticle density
MA - mesial apical denticle density
MAVG - average mesial denticle density
MB - mesial basal denticle density
MC - mesial mid-crown denticle density

Geological age abbreviations:

HT – Hauterivian
BR – Barremian
AP - Aptian

Index of Figures

1.Introduction

This final degree project is targeted to the palaeontological study of Spinosaurid theropod fossils collection, found in Cabo Espichel (SW Portugal) and the comparison with the correlative theropods fossils found in the Iberian Peninsula.

The Spinosauridae were a diverse family of theropod dinosaurs including ten described genera (Taquet and Russell, 1998; Allain et al., 2012; Buffetaut, 2013; Malafaia et al., 2013, Evers et al., 2015) found across five continents (Barco, Canudo and Ruiz-Omeñaca, 2006; Barrett et al., 2011; Lakin and Longrich, 2019; Allain et al., 2012; Candeiro, Brusatte and De Souza, 2017; Gasca et al., 2018). They were present since the Early Jurassic, and diversified at the end of the Early Cretaceous, as they can be found from the sedimentary layer of Hauterivian to the lower Aptian in the Iberian Peninsula. Characterized for its skull and teeth morphology convergent with that of crocodiles (Sereno et al., 1998; Rayfield et al., 2007), as a result of the highly adaptable body plan and cranial modifications of the theropods, observed in the Fig. 1. The group of Spinosaurids is placed as part of Spinosaurid (Sereno et al., 1998; Rauhut, 2003), or Megalosauroid (BENSON, 2010), tetanurans, and includes the clades Baryonychinae with *Baryonyx walkeri* (Charig and Milner, 1986); *Suchomimus tenerensis* (Sereno et al., 1998), and Spinosaurinae with *Spinosaurus aegyptiacus* (Stromer, 1915) and *Irritator challengeri* (Martill et al., 1996).

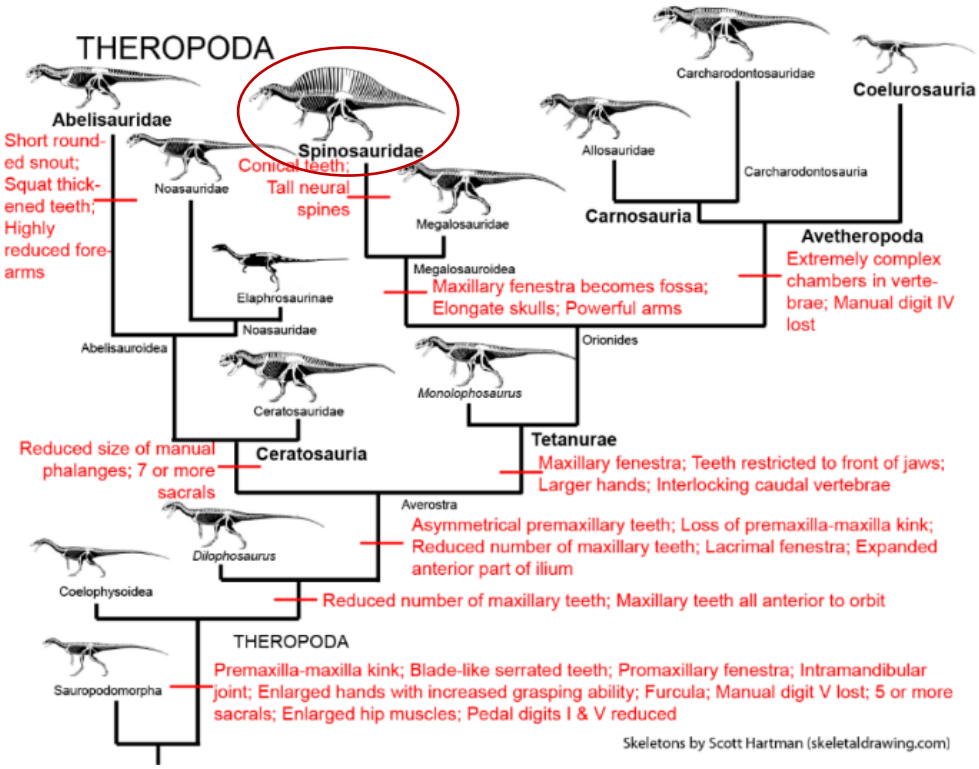

Fig. 1 Theropod Evolution Scheme.
Source: https://www.geol.umd.edu/~tholtz/G104/lectures/104therop.html

This report aims to develop a list of the Spinosauridae fossils that have been retrieved from the Papo Seco Formation in Cabo Espichel (Portugal) during last centuries and published elsewhere. This formation is formed by green marl and silty clays with lignite and plaster, presenting intercalations of sandstones with horizontal stratification. Papo Seco formation is rich in fossils, mainly, dinosaur bones of *Megalosaurus superbus*, *Astrodon valdensis*, crocodilians (cf. *Anteophthaosuchus*), pterosaurs (*Ctenochasmatoi*) and dinosaurs (*Baryonyx, lguanodon mantelli),* Figueiredo et al., (2019). The sedimentological analysis also demonstrates that those remains conformed a lagoon-like (cat's-eye pond) habitat, that was present next to the marine environment, as determined by its marly clays of the carbonate layers. This formation lies under Areia do Mastro Formation and is overlapped by the Boca do Chapim Formation, two carbonate-rich units. In Areia do Mastro Quarry, Papo Seco Formation, 18.50 m thick, preserves its entire sedimentary sequence.

The bibliographic part of this job consists in the search and study of published papers about Theropod's teeth from the Papo Seco Formation and morphometric analyses of some teeth remains from images. The collection of teeth fossils is preserved in different museums from Portugal, where it was intended to realize a visit to realize morphometric measurements following the guidelines established by Smith et al (2005). Due to limitations of the global pandemic COVID-19 situation and the mobility restrictions between countries, the current experimental part consists in the morphometric study of a single Baryonychinae fossilized tooth, loaned by the "Museu de l'Institut Català de Paleontologia Miquel Crusafont", known as *"IPS-919"*. The measures were taken following the guidelines established by the Study by Smith et al (2005) detailed in the mentioned report. Parameters were measured according to the "*Image J*" program, overlapping the images with a magnifying glass with disposed with a camera.

Moreover, a bibliographic search of correlative Theropods Samples Materials found in the Iberian Peninsula is presented and the comparison with Papo Seco fossils.

2. Objectives

The main objectives to achieve in this project are listed below:

- Bibliographic search of Theropod Fossils from diverse museum collections, that had been found in Papo Seco Formation.

- Bibliographic search of the contemporaneous Theropods fossils gathered in the Iberian Peninsula.

-The Implementation of methodology for Identification of Isolated Teeth proposed by Smith et al., (2005) in his work "The Dental Morphology and Variation in Theropod for the Identification of Isolated Teeth" using the software "*ImageJ*", in order to analyse and classify the fossil tooth from the "Museu de l'Institut Català de Paleontologia Miquel Crusafont".

3. Diversity

3.1 Theropod Classification

Theropods appeared during late Triassic period (231.4 Ma). It included a wide range of sole large carnivores during the Early Jurassic, until Late Cretaceous (66 Ma). The Theropods are a clade of bipedal Tetrapods among which birds and all strictly carnivorous dinosaurs are found (e.g. Sereno, 1997; Holtz & Osmólska 2004; Holtz 2012; Birn-Jeffery AV, Miller CE, Naish D, Rayfield EJ, Hone DWE (2012). They appeared in the Late Triassic and rapidly spread worldwide, and are considered one of the most successful groups of Tetrapods, and the most morphologically and taxonomically diverse clade of dinosaurs (Rauhut, 2003); Holtz 2012; (Foth and Rauhut, 2012). As detailed in the Fig. 2 the theropods were present since 231.4 Ma, and started to evolve, presenting different modifications in their body plan to further specialize in new habitats, conforming a wide range of diverse families in the Theropoda clade.

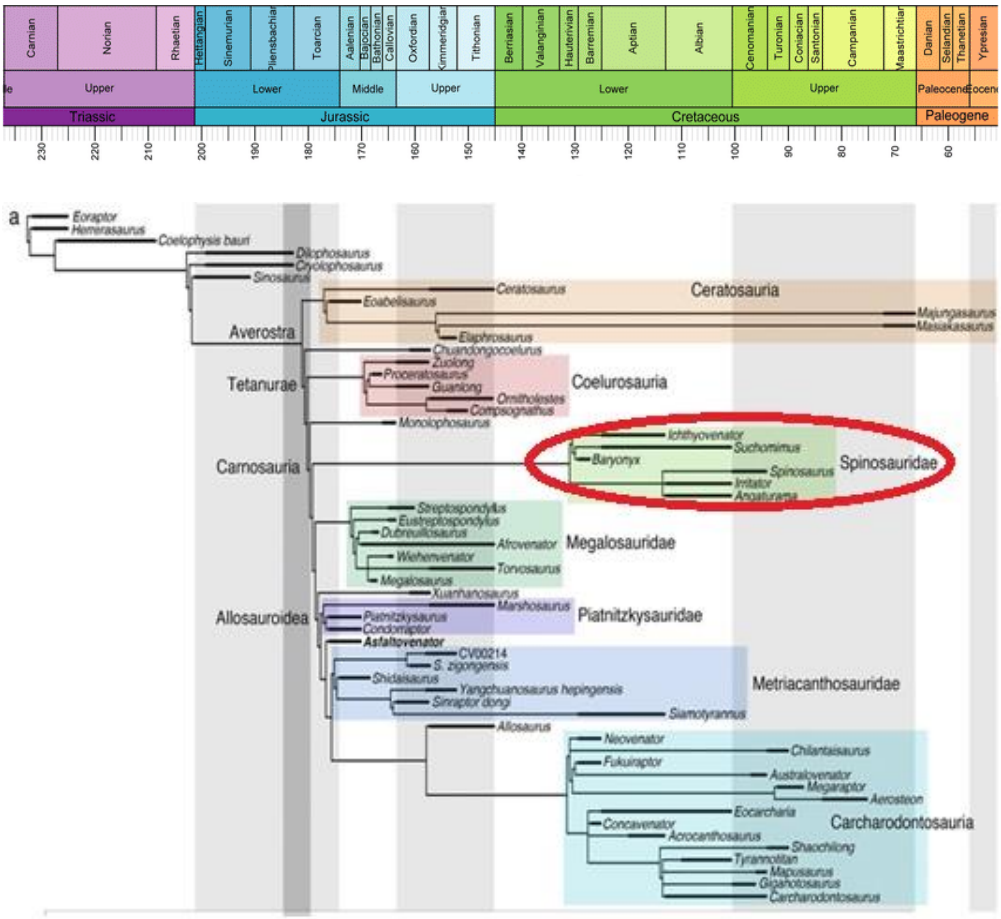

Fig. 2 The Theropoda Chronology
Source: [Rauhut, 2019]

The non-avian theropod body plan, presented in Fig. 3, went under relatively minimum modification during the evolution of the clade. The structure remained bipedal for the most part and, for most of them, with elongated necks and a tail projected horizontally. Modification in the post cranium section occurs (mostly) in the forelimb, manual and pelvic morphology, hind limbs proportion as well as the vertebral counts, and elongation of the neural spine. Some theropods like Abelisaurids had short stubby arms bearing four short fingers (Ruiz et al., 2011; Burch & Carrano 2012) whereas others like Therizinosaurids possess elongated forelimbs with three slender fingers bearing large claws (Zanno, 2010).

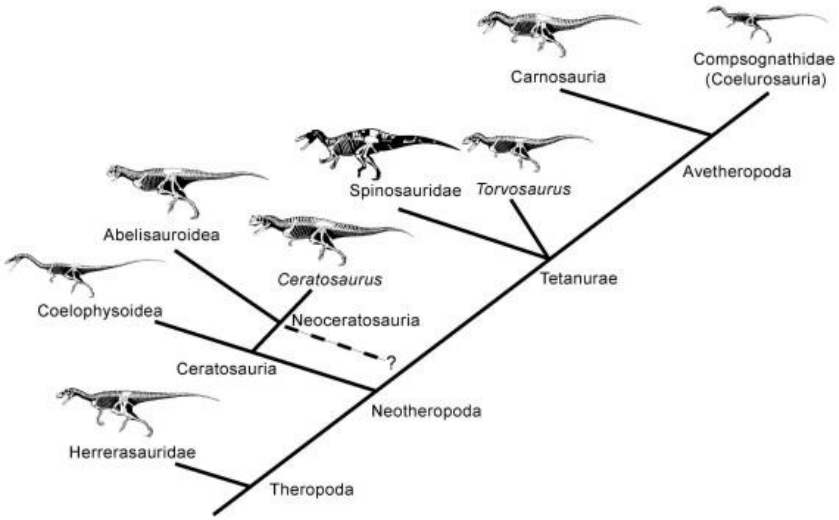

Fig. 3 Theropods clade.
Theropods were ancestrally carnivorous, although a number of theropod groups evolved herbivory, omnivore, piscivore, and insectivore. Theropods first appeared during the Carnian age of the late Triassic period 231.4 million years ago (Ma) and included the sole large terrestrial carnivores from the Early Jurassic until at least the close of the Cretaceous, about 66 Ma. In the Jurassic, birds evolved from small specialized Coelurosaurian *theropods, and are today represented by 10,000 living species. Source: https://alchetron.com/Spinosauridae*

Although a large majority of theropods exhibit short neural spines, some Spinosaurids, Allosauroids and deinocheirids have developed hypertrophied spines forming a hump or a sail on the back of these animals A. H. Lee, P. M. O'Connor 2013. Discoveries of Oviraptosaurian non-avian theropods such as the rodent-like *Incisivosaurus* Balanoff et al., (2010), the beaked *Limusaurus* (Xu et al., 2009) the crested *Guanlong* (Xu et al., 2006), the long snouted *Buitreraptor* (Makovicky, Apesteguía and Agnolín, 2005) and the duck-billed *Deinocheirus* Lee et al., (2014).; indicate a particularly high variety of skull morphologies among the theropod dinosaurs (BRUSATTE et al., 2012); (Rauhut et al., *20*12)).

Some clades developed secondarily adaptations to an herbivorous diet (Zanno, 2010), insectivores Longrich, N. R., & Currie, P. J. (2009), piscivores Cuff, A. R., & Rayfield, E. J. (2013), or seed eaters (Zhou et al., 2002). The body plan suffered minimum modification during its evolution, being considered, at a basic, a series of bipedal animals with elongated necks and a long, horizontally tail. However, they show a stunning diversity in regards of skull

morphology, from the elongated skull of Spinosaurids showing a terminal spatulate rosette (Charig, Charig and Milner, 1997; Dal Sasso et al., 2005) to the short parrot-like skull and edentulous jaws of oviraptorids (Lü et al., 2010). As observed in Fig. 4, the skull of *Spinosaurus aegyptiacus* presents a series of characteristics such as long narrow skull, conical tooth shape and elongated rostrum, specialized for a semi-aquatic lifestyle, eyes elevated atop of the skull, and a spatula terminal rosette.

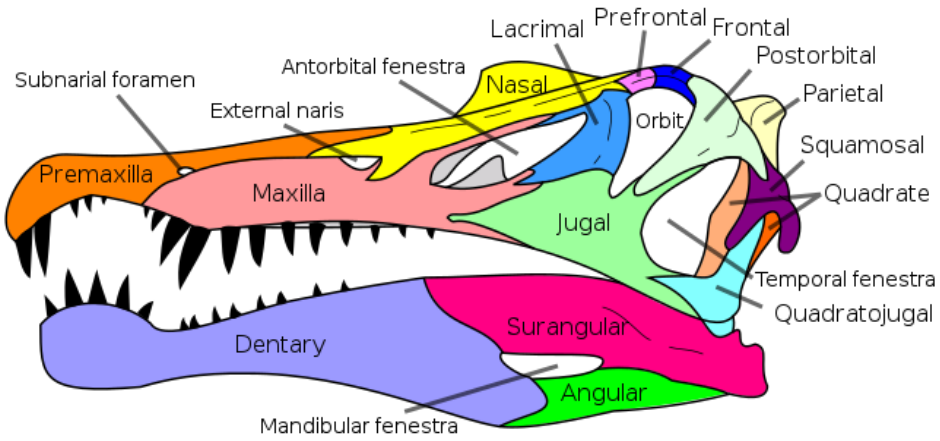

Fig. 4 The skull of Spinosaurus aegyptiacus.
Source: https://spinosauridae.fr.gd/Cr%E2ne-de-Spinosaurus--k1-Vue-lat-e2-rale-k2-.htm

3.2 Spinosauridae Definition

The Spinosauridae, derived from Latin "*spina*" (spine), and Greek "*sauros*" (lizard) and "-iae" (family), named for the anchor species *Spinosaurus*, forms part of the family of Megalosauroid. Most Spinosaurids dominated during the early to late Cretaceous, proven by the fossils that have been recovered worldwide. The Spinosauridae were very adaptable and a rather successful family of dinosaurs.

The first Spinosaurids appeared in the Late Jurassic and became dominant in the Early Cretaceous era, as represented by the Fig. 5. As far as the Late Jurassic record of Spinosaurids goes, it consists only of referred teeth, as dates 155 million years ago. The family declines abruptly in the Cenomanian, despite some are known to have persisted into the mid-Santonian, represented by a single Baryonychinae tooth found in the Majiacun Formation of Henan (China). Notably among other Theropod relatives, it is a family with a poor preserved fossil record, which has led to the fact that the information that exists about them is not very extensive or detailed. Nonetheless, in the last few years, the amount of discoveries of important Spinosauridae materials has increased rapidly.

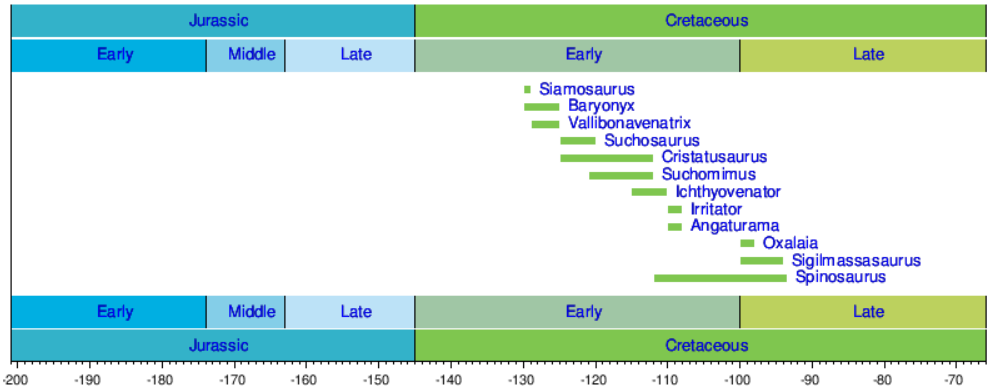

Fig. 5 Chronology of Spinosaurids
Source:https://wiki2.org/en/Spinosauridae

The first records of Spinosaurids date of Late Jurassic, until the abundancy in the Early Cretaceous. The Late Jurassic material consists only of referred teeth Buffetaut, (2013). Finally, the decline of the family is registered during the Cenomanian, until completely losing register after the mid-Santonian (Hone et al., 2010).

4.3 Spinosauridae Distribution

These Spinosaurids were successful predators, as they lived mostly in the entire Southern Hemisphere, spreading through all over Europe, Africa, South America, Asia, and Australia; but also, in the North Hemisphere of Europe and Asia. The Fig. 6 shows the confirmed Spinosaurids have been found on every continent with the exception of North America and Antarctica; this is due the different niche they occupied beside other predators, and the different diets they had (Amiot et al., 2010). Moreover, some Spinosaurids were common species, present during the Barremian stage of England, Spain or Portugal. Similar teeth were found from Hauterivian and later Aptian in Spain, but also recovered from the England's Hauterivian. Baryonychinae individuals were registered in the continent of Africa (*Suchomimus tenerensis*), *Baryonyx*-like isolated teeth from the zone of Aptian (Niger); moreover, individuals as *Suchosaurus girardi* were identified in England. *Baryonyx* were also present in Ashdown Sands of Sussex (England), and the Burgos Province (Spain). Currently, the theropod *"Camarillasaurus cirugedae*", is classified as European Spinosaurids from the Barremian of Spain. (Malafaia et al., 2020)

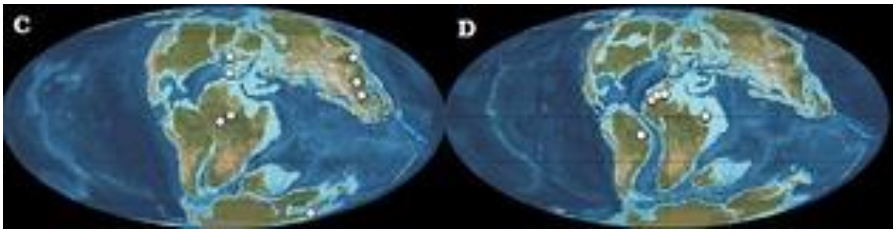

Fig. 6 Map with the locations of discoveries from different moments during Cretaceous Period. c) Barremian–Aptian, d) Albian–Cenomanian.
Source: https://wiki2.org/en/Spinosauridae

4.4 Specializations

Spinosaurids species presented the basic characteristics that defined the Theropods, but included specializations such as crocodile-like skulls lined with particular teeth. Some of the genera showed peculiar crests on top of their heads. Their spinosaurid's shoulders were robust, the forelimbs large, and with enlarged claws (Hone et al., 2017); something extremely rare through theropod species. This genus exhibited unusually elongated neural spines, as present in the reconstruction of the Fig. 7 The *Ichthyovenator* had a sail half a meter at its highest point, hat split into two at the vertebrae (Allain et al., 2012). The *Suchomimus*, another member, also had a low, ridge-like sail over its hips (Sereno et al., 1998). *Baryonyx* and the members of Baryonychinae, however, lacked the disposition of a sail. Despite the function of these structures are not known, they have been considered for many purposes: thermoregulation, to gather heat or to cool down, storing energy, displaying during mating, or possibly intimidating rivals.

Fig. 7 Spinosauridae representations
Source: https://wiki2.org/en/Spinosauridae

The Spinosauridae have had a phenomenon that it is not common among all known Theropoda; the Spinosaurids had large arms. They had sharp hook-shaped claws. Also, they

presented elongated neural spines, some even over a meter tall, which is considered as a sail or hump running down its back.

Spinosaurids ranged from medium-sized to large dinosaurs, with a high range of weight and height; this particular diversity can be observed further in Fig. 8. The smallest Spinosaurid species known was the *Irritator*, which it was between 6 to 8 meters in length and 1 tonne (1.1 short tons) in weight (Dixon, D. 2009). *Ichthyovenator*, *Baryonyx*, and *Suchomimus* ranged from 7.5 to 12 meters long, and weighing between 1 and 5.2 tonnes (1.2 and 5.7 short tons), Therrien et al., (2007). Spinosaurus was the largest known Spinosaurid species, capable of reaching lengths over than 15 meters (49 ft) and weighing between 8 and 20.9 tonnes (7.7 and 23.0 short tons), Ibrahim et al., (2014).

Fig. 8 The spinosaurid range of weight and height
Source: https://alchetron.com/Spinosauridae

4.5 Spinosauridae Paleoecology

The family of Spinosaurids were firstly considered as fish-eater dinosaurs, that lived alongside aquatic ecosystems, such as rivers and lakes, their main and first source of meat Amiot et al., (2010). They used their conical teeth to catch fishes from the water, and their huge claws supposedly to slash them, with quick and powerful strikes. A quick representation can be observed in the Fig. 9, as the point of living near the water, expresses the idea that Spinosaurids were pretty good swimmers. Previously considered, contemporary studies show Spinosaurids' jaws were not capable for big hunting. Nonetheless, some sauropods materials have been found in *Baryonyx* skeletons, expressing that Spinosaurids ate also other dinosaurs (Gimsa et al., 2015).

Fig. 9 Reconstruction of a S. aegyptacus
This reconstruction shows how Spinosaurids were semi-aquatic generalist-feeder's dinosaurs, that lived alongside rivers and lakes, their first source of food.
Source: https://wiki2.org/en/Spinosauridae

These represent that the *Baryonyx* was, whether in this case a hunter, or a scavenger, was an eater far more diverse and generalist rather than piscivore. Moreover, shown in Fig. 10 Irritator; has been another diverse carnivore; as a Spinosaurid teeth found to be embedded within the fossil vertebrae of a large pterosaur, found in the Santana Formation (Brazil), Buffetaut et al., (2004.) The researchers proposed that Spinosaurines from the formation may have also preyed on terrestrial and aquatic crocodyliforms, same-species juveniles, turtles, and small to medium-sized dinosaurs. Thus, the Spinosaurids seemed to have a mixed diet, with a wide variety of food sources: mostly-fish, with dinosaur and pterosaur kill/scavenging occasionally.

Fig. 10 The representation of an individual of Irritator challengeri.
Source: https://wiki2.org/en/Spinosauridae

3.6 Spinosauridae Classification

The family Spinosauridae, represented in Fig. 11, was named by Stromer (1915) to include a single genus *Spinosaurus*. Traditionally, it was divided into two subfamilies: Spinosaurinae, containing the genera *Icthyovenator*, *Irritator*, *Oxalaia*, *Sigilmassasaurus* and the *Spinosaurus*. It was defined by straight teeth without serration, and the external nares were further back on the jaws than in Baryonychinae. And Baryonychinae, which englobed *Baryonyx* and *Suchomimus*, characterized by serrated (one or both carina) with curved teeth, and that were smaller in size, and more teeth behind the terminal rosettes. Others, such as *Siamosaurus*, may belong to either Baryonychinae or Spinosaurinae, but are too incompletely known to be assigned with confidence. *Siamosaurus* was classified as a Spinosaurine in 2018, but the results are provisional and not entirely conclusive by Buffetaut et al., (1986).

Subfamily Spinosaurinae was named by Sereno (1998) and defined by Hone, David & Holtz, Thomas. (2017). The subfamily Baryonychinae was named by Charig & Milner (1986). They erected both the subfamily and the family Baryonychidae for the newly discovered *Baryonyx*, before it was referred to the Spinosauridae. Their subfamily was defined by Holtz et al., (2004), as the complementary clade of all taxa closer to *Baryonyx walkeri* than to *Spinosaurus aegyptiacus*. Examinations in Marcos Sales and Cesar Schultz (2017) indicate that the South American Spinosaurid *Irritator* were intermediate between Baronychinae and Spinosaurinae based on their craniodental features and cladistic analysis. Additionally, the similarity between *Baryonyx* and *Suchosaurus* was noted by Buffetaut in 2007. Remains long attributed to *Suchosaurus* are now assigned to *Baryonyx*, and it is difficult to distinguish between remains of these two dinosaurs.

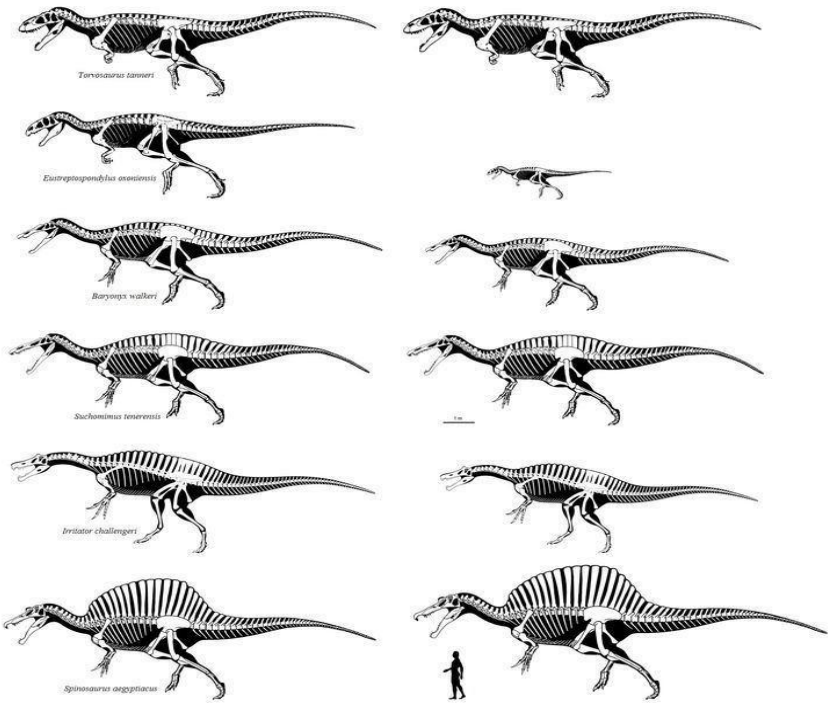

Fig. 11 The family Spinosauridae by Stromer 1915.

https://alchetron.com/Spinosauridae

3.7 Spinosaurids Teeth

To distinguish the teeth of the Spinosauridae family, certain particulars characteristics (or autapomorphies) must be considered, in order to reveal the particularities inherent in these and thus have a good established basis on which to make this statement. The following parameters, shown in Fig. 12, must be measured.

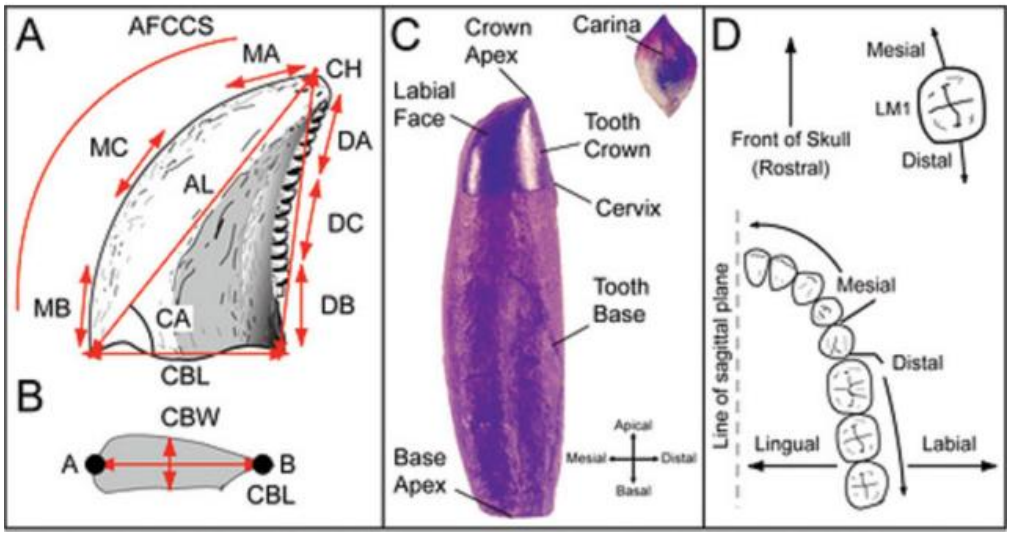

Fig. 12 Theropod dental anatomy and variables used in this study.
A: Saurornitholestes Sues, 1978 crown in lateral view showing CH (measured from apex to the base of the enamel); CBL (measured along line segment AB at the base of the enamel), mesial apical (MA), mesial mid-crown (MC), and mesial basal (MB) denticle densities (measured along the length of the mesial carina); distal apical (DA), distal mid-crown (DC), and distal basal (DB) denticle densities (measured along the length of the distal carina); and the trace of the mesial curvature profile from which crown curve slope of the A face (AFCCS) is calculated. B: The crown in A in basal view showing CBL and crown base width (CBW, measured perpendicular to CBL). Crown in A after Currie et al., (1990). LM1 left upper first molar. C: Labial view of Ld13 of T. rex (BHI 3033), showing general theropod tooth anatomy (inset shows tooth in occlusal view; the mesial carina is labelled). Since the crown and base meet at the cervix, in those teeth where the base is present, the crown base and cervix coincide. D: Schematic human dental arcade, in palatal view, showing mesial, distal, labial, and lingual directions. Source: Smith et al. 2005

Baryonychinae teeth are characterized by: Ziphodont conical tooth, curved, with the crown narrow and pointed, with longitudinal grooves in the apical and medial areas. The base has no microgranular ornamentation. It has a worn apex. The distal carina is sharp and micro-serrated, usually with very fine denticles, from the apex to the base, with very high density, with 7 denticles per mm. No labial fluting.

However, Spinosaurid teeth are unique among theropods (e.g. Smith et al., 2005). Spinosaurinae present the following dental characteristics: Tooth crowns flattened only slightly labio-lingually and lightly fluted on lingual side; anterior and posterior carinae finely serrated (about seven denticles per millimetre); exceptionally long and slender tooth roots.

Nevertheless, there are other tooth characters that must be assessed throughout all Spinosauridae, such as smooth or wrinkled enamel surface, enamel bearing apicobasal oriented striations at the base of the crown, irregular denticle size, presence and number of flutes, 45 degree orientation between more distal or mesial wrinkles and carina, and denticles with fluted apices. Less than 16 denticles per 5mm on the mesial carina in lateral teeth; more than five premaxillary teeth. Premaxillary tooth row anterior to external naris, maxillary alveoli subcircular in outline, mesial carina terminating well beneath the cervix in mesial most teeth. Flutes present on both labial and lingual sides in lateral teeth, and with deeply veined enamel texture in lateral teeth. Mesial margin of lateral crown slightly convex, almost straight, apex centrally positioned (Hendrickx et al., 2014).

4. Papo Seco Formation

4.1 Geographical Settings

The main dinosaurs discovered in the geological area that englobes Papo Seco formation correspond to the vast family of theropod dinosaurs. In this formation, most of the fossil material registered, presented isolated remains widely distributed. Nonetheless, the materials were mostly classified on the Theropod family. The fossils that will be described in this report have been localized in the small beach at the bottom area of the coastal cliffs on the anticline of Cabo Espichel (Fig. 13), and oriented SW of the Setubal Peninsula. In this site the Papo Seco Formation, preserves its entire sedimentary sequence. The Papo Seco Formation lies between Areia do Mastro and Boca do Chapim formations. The older layers, by the seashore, still belong to the Areia do Mastro Formation, showing marine carbonate limestone facies. On top of these layers' sandstones can be clearly observed, indicator of an estuarine environment, which correspond to the beginning of the Papo Seco Formation. Above these lay marly beds, which contain marine and terrestrial vertebrate remains (Figueiredo et al., 2019).

4.2 Geological Settings

4.2.1 Geological Settings of Areia do Mastro Formation

Areia de Mastro (125-122 m.a.) is a sedimentary formation that consists of clay limestones blue-gray in wavy and marl-lime nodular countertops. It presents an intercalation of sandstones and greenish silty loams. The formation presents a faunal association, at the top, formed by *Choffatella decipiens* compositions, accompanied by *Trochotiara bourgueti* at the bottom and *Trochotiara sculptilis*, *Heteraster Lepidus*, *Heteraster cou / ouni*, *Pseudotextulariella scarsellai* and *Neotrocholina friburgensis*. As observed in the Fig. 13, the mentioned association makes it possible to date the Areia do Mastro in the upper

Hauterivian-lower Barremian. The sedimentation of the unit takes place in an environment of an internal infralittoral platform. (Figueiredo et al., 2015).

The geological compositions of clay limestones at the upper limit of the formation are abruptly covered by deposits of fine yellow sandstones with matrix dolomitic, already belonging to the Papo Seco Formation.

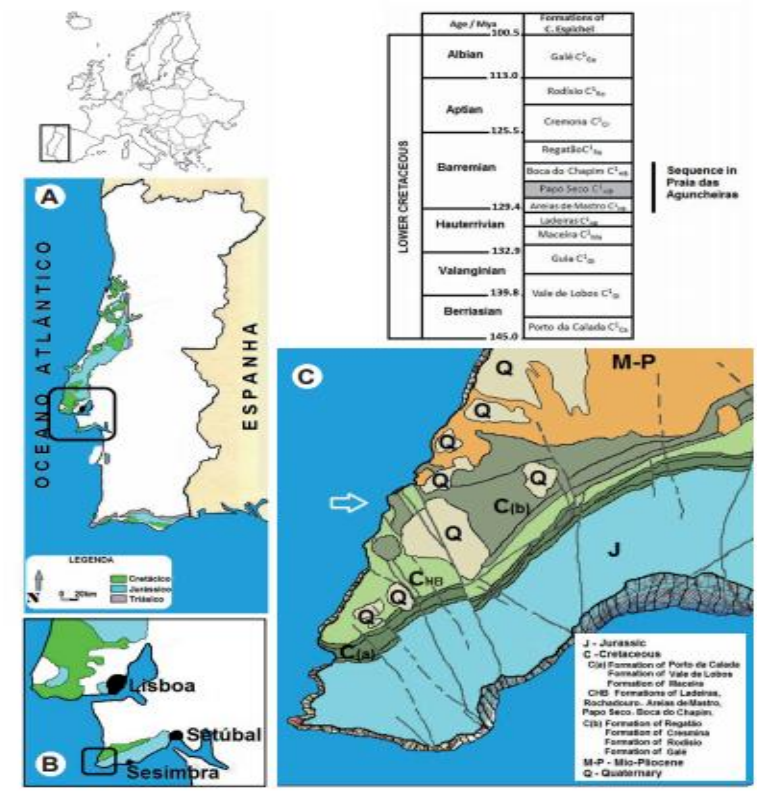

Fig. 13 Map of Portugal showing Mesozoic sediments
Geologic maps of Cabo Espichel and geologic time scale of Lower Cretaceous.
Source: [Figuereido et al. 2015.]

4.2.2 Geological Settings Papo Seco Formation

The Papo Seco formation, rich in dinosaurs, with 18.50 m thick, is formed by green marl and silty clays with lignite and plaster, presenting intercalations of sandstones with horizontal stratification. At the upper boundary of this formation, it can be observed bioturbated silty limestone layers with oyster remains. A coarse-grained sandstone bar is also visible where numerous dinosaurs' bones (Lapparent & Zbyszewski, 1957): *Megalosaurus superbus, Iguanodon mantelli, Astrodon valdensis.* The marls are rich in *lamellibranchs*, gastropods (among which *Gymnentone reyi* and *Gymnentone incisa*) and ostracods. The lowest layers of the Papo Seco Formation, in regards of the fauna, could have yielded a wide diversity of

faunistic species, that inhabited an environment similar to a lagoon next to a marine ecosystem.

Stratigraphy for its position: The Papo Seco Formation is attributed to the Lower_Barremian**,** and the sedimentation environment that characterizes is lagoon type. The Papo Seco Formation, as mentioned in the Fig. 14, is presented at the coordinates 38°24'50.8" N, 9°13'20.8" W. The sedimentological study that took place in the lowest exposed layers, revealed the occurrence of two main continental facies and an interbedded transitional one, all in horizontal association without any visible unconformity.

Papo Seco Formation

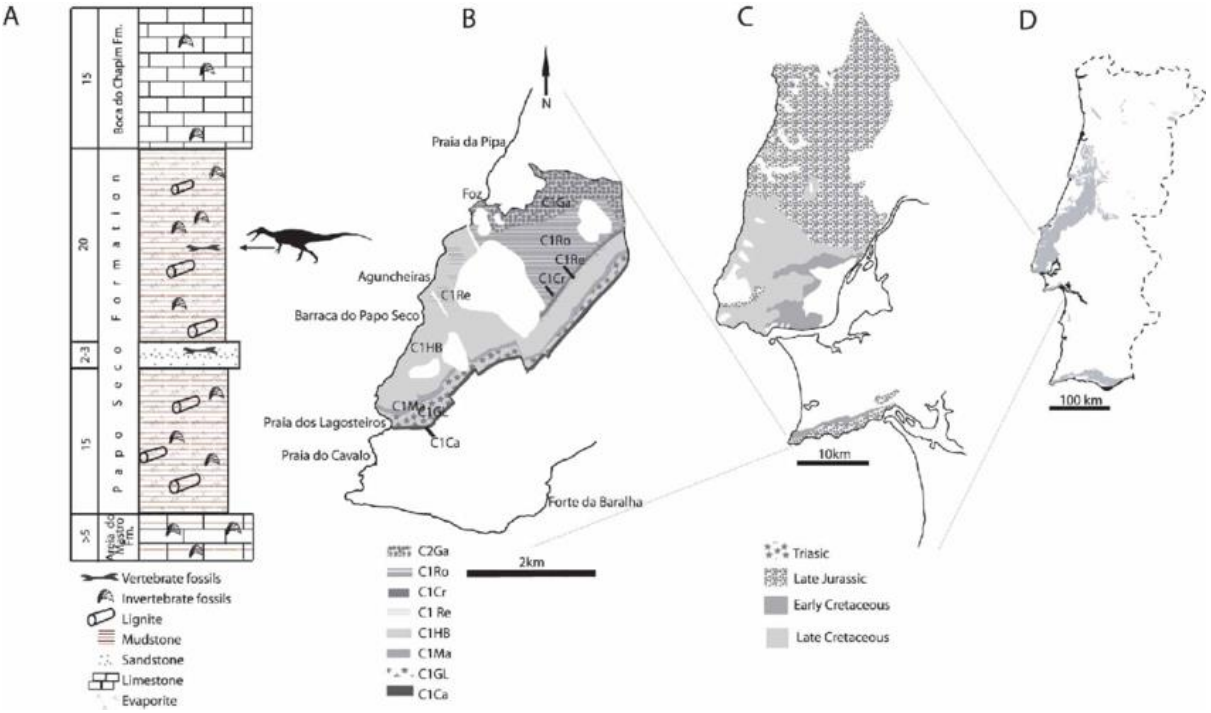

Fig. 14 The Papo Seco Formation stratigraphic column and map of Cabo Espichel.
Source: Mateus, et al 2011

The sedimentological analysis of intermeddled layers demonstrates the evolution from the lagoon-like (cat's-eye pond) environment in consideration. This ecosystem, as shown by the marly clays of the carbonate layers, was present next to the marine environment; the constant increase in the sandy fraction between the two phases, serves to indicate the opening of this lagoon. The concentration of organic matter could be related either to interplay of aerobic/anaerobic conditions during deposition, or on post depositional processes.

4.3 Areia do Mastro quarry

The Areia do Mastro Quarry showed in the Fig. 15, reveals considerable difference in the composition between the formations: The Boca Do Chapin Formation (S2) presents a mixed clayed sands and marls sands with carbonates composition. The Papo Seco Formation (S1), however, ranges a mixing of dark clays and sandstones.

Fig. 15 Areia do Mastro Quarry.

a) Areia do Mastro Quarry presents a stratigraphic sequence. DL: a deltaic and lagoon structure, combined with a DM: a deltaic and marine sequences. Also, T: a transgressive. And R: regressive phase.

b) The Papo Seco Formation and Boca do Chapim Formation.

Source: [Figuereido et al. 2020]

The Areia do Mastro quarry may be divided in the different origin of the component of the layers; they can be further observed in the Fig. 16 and Fig. 17.

Macroscopic field description and classification of the fossiliferous bioclastic marl unit (around 2 m thick):

- C1.a (lower unit): mudstone consisting of soft and usually wet blackish clay. It is a horizontal layered and homogeneous deposit, with grain size < 0.001 cm, and very thick bedded (> 50 cm thickness).
- C1.b (intermediate unit): a transitional layer of sandy clay thick to thin bedded (~70 cm-30 cm thick) with undistinguishable limits. At the bottom appears as dark grey clay. It gradually becomes upwards light grey, slightly sandier (10% grains) and better drained.
- C2 (top unit): sandstone that appears greyish to brown (ferruginous), carbonate-rich thick bedded (~30 cm) it is a quartz-rich arenite deposit (grain size ~2 millimetre in diameter). It consists of a dominant sand fraction (80%; mainly quartz and clay minerals) with a clayey matrix.

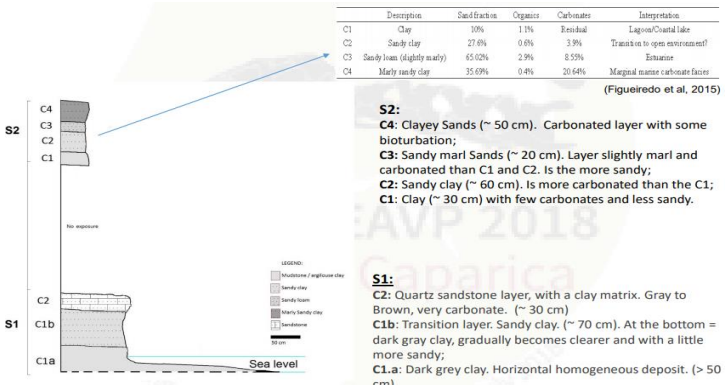

Fig. 16 Stratigraphic column of the Areia do Mastro Quarry
C1.a (lower unit): It is a horizontal layered and homogeneous deposit, and very thick bedded (> 50 cm thickness). C1.b (intermediate unit): a transitional layer of sandy clay. C2 (top unit): sandstone that appears greyish to brown, carbonate-rich thick bedded, it is a quartz-rich arenite deposit.
Source: Figuereido, et al 2016

Moreover, the sedimentological analysis indicates that, the layer "C1", was deposited in a lagoon environment. There were identified fishes that inhabited water lakes and shallow seas, shared habitats with the rest of crocodiles, turtles; tetrapod's fossils; turtles: semiaquatic to marine and dinosaurs: terrestrial and littoral zones (Figueiredo *et al.*, 2016).

As it is presented in Fig. 17, the sedimentological analysis is composed of a series of fossils materials that define an ancient ecological nix. This lagoon-like environment presented a trophic web, constituted of fishes and turtles on the base, these were being prey on by pterosaurs and dinosaurs as *Baryonyx sp., Baryonyx walkery* and other Theropods. The upper layers of the web were constituted by *Saurischians* as *Iguanodons*, that were consumed by large cocodrilians and other Carnosaurian Theropods (e.g. the *Baryonyx walkeri*), and hypothetically scavenged by smaller individuals or pterosaurs.

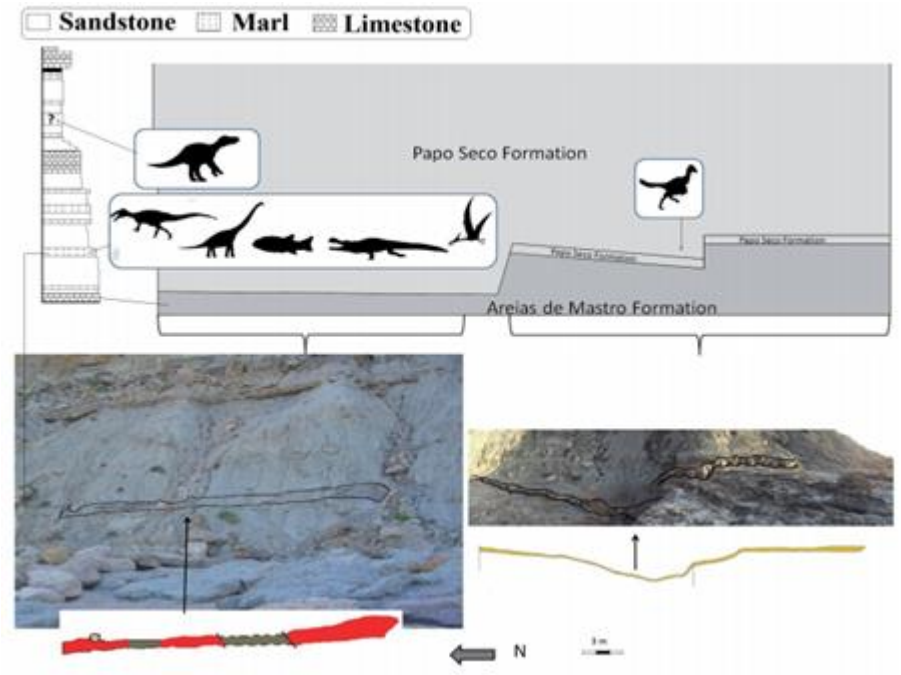

Fig. 17 Areia do Mastro outcrop showing vertebrate-bearing units.
Bottom: Sedimentary Layers showing fossiliferous beds highlighted.
Source: [Figuereido et al. 2015]

5. Results

5.1. Diversity of The Papo Seco Formation

The diversity of theropods that can be found in the Papo Seco Formation is composed by a series of fossils that range from the common isolated teeth, fragments of jaws and maxial dentary, and a collection of neural archs, and vertebrae. They are classified in 3 *Baryonyx sp.*, a *Baryonyx walkeri*, and two *Theropod sp.* materials.

5.1.1. Baryonyx sp (ref. CPGP.1.06.2)

Comments: Fragments of a maxilla and a jaw were found, in the Papo Seco Formation, in deposits from Cabo Epichel, by palaeontologist H. E. Sauvage (Sauvage, 1898). These remains were attributed to *Baryonyx sp.* based on similarities with the English Barremian holotype of *Baryonyx walkeri* (Buffetaut, 2007).

Material: **CPGP.1.06.2** (Sauvage, 1898). One tooth. Fig. 18.

Description: Ziphodont conical tooth, curved, with crown narrow and pointed, longitudinal grooves found in the apical and medial areas. The base has no ornamentation. It has a worn apex. The distal carina is sharp and micro-serrated. The mesial carina has a long and wide longitudinal groove, which seems to result from normal wear of the tooth. This tooth is

identified as *Baryonyx sp.*; this conclusion is based on its overall shape and surface ornaments, further confirmed by the biometric study: our measurements of CPGP.1.06.2 are within the range of values obtained by Smith et al., (2005).

This tooth shows the characteristics of the *Baryonyx* teeth that were described in several studies (Smith et al., 2005; Fowler, 2007; Buffetaut, 2007, 2012; Alonso and Canudo, 2015; Alonso et al., 2015). These characteristics are: subcircular cross section, moderate lingual curvature, carinae located on the mesiodistal axis of the crown, six ridges. The CPGP.1.06.2 does not have fluted enamel on the labial surface or any microgranular ornamentation on the edges, but it has very fine denticles, from the apex to the base, with very high density, with 7 denticles per mm. These last three characteristics are present in the morphotype of Baryonychine teeth but not in other Spinosaurids (Alonso and Canudo, 2015).

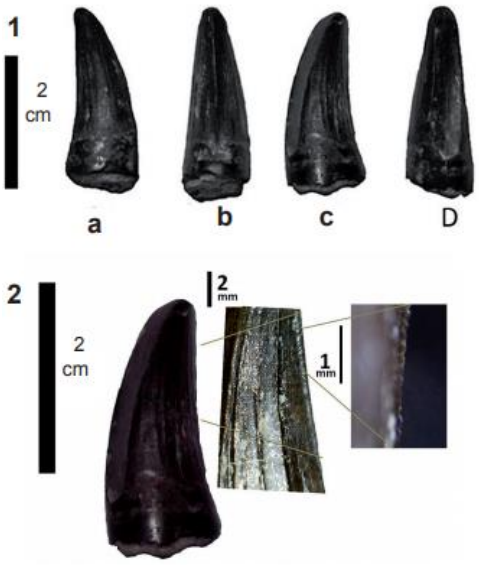

Fig. 18 Tooth of Baryonyx sp., CPGP.1.06.2.
In 1: a) labial surface; b) distal surface; c) lingual surface; d) medial surface. 2: Showing micro-serrations. Source: Figuereido et al. 2015

5.1.2. Baryonyx walkeri (ref. ML1190)

Comments: The Portuguese specimen, ML1190, is from the Praia das Aguncheiras, Sesimbra Municipality (Papo Seco Formation; early Barremian; 38.44N 9.20W). Besides the diagnostic features provided by Charig & Milner (1986, 1997), Sereno et al., (1998), and Martill & Hutt (1996), Baryonyx has an unique combination of characters of the teeth: carinae with high denticles density (6–7 denticles per millimetre), variable and non-gradual denticle size along the carinae, enamel surface with small and nearly vertical wrinkles (including at the base of the crown), and wrinkles forming a 45 degree angle near the carinae

Material: The collection presents a part of partial dentary, with two teeth, in addition to four dorsal neural arches, dorsal rib fragments, five caudal centre, right scapula, left ilium, two calcanea, fragments of chevrons, right pubic shaft, and one pedal ungual phalanx, that will not have a weight in the current description (**ML1190**) Papo Seco Formation (Barremian) Mateus et al., (2011).

Description: The specimen ML1190 presents signs of transport, indicated by the disarticulation. This might be due to the: the skeleton is incomplete; the specimen was disarticulated but closely associated; a significant loss of bone material, as a result of a stage of disarticulation. Left dentary, presented in Fig. 19 is 162 mm long, comprises the 12 anterior-most alveoli. The replacement teeth can be visible on medial side of the dentary at first, second, sixth and eighth alveoli. Majority of the teeth still present, but with the crown broken off (Mateus, et al 2011).

Ninth and tenth teeth are positioned in a more ventral position than the anterior teeth of the maxila. Moreover, dentary is straight and laterally compressed. The Meckelian groove is narrow (3 mm in dorsoventrally), and shallow. The lateral view of the dentary bears 28 defined and deep foramina presented for the nutrient supply, presented in the Fig. 20. The paradental plates are nearly absent, triangular and low (Mateus, et al 2011).

The cross section is eye-shaped or round, giving an appearance of a cone, with only few weak linguolabial compressions. The tooth crowns in the dentary exhibit fluting on the lingual surface only; in this case, it has been shown that the presence of fluting in Baryonychinae teeth is highly variable (Ruiz-Omeñaca et al., 1998: 206). The density of the denticle of the erupting teeth ranges between 6–7 denticles per each millimetre. However, the enamel is presented as densely wrinkled (apicobasal extending micro-ridges). There is a small, posterior dentary fragment that bears four alveoli (7 mm in diameter anteroposterior and 6 mm lateromedially).

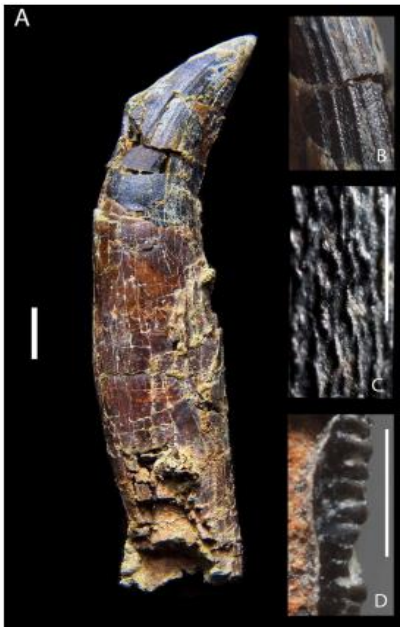

Fig. 19 Tooth of Baryonyx walkeri ML1190 individual
It presents a conical form with linguolabial compression, as it is typical from Baryonychinae, seen in the lateral view (a). The presence and number of flutes (b), however, is a value highly variable within the species. As it is norm within the group, the enamel is wrinkled, with the presence of micro-ridges (c), but the density of the denticle ranges between 6–7 denticles each millimetre (d).
Source: Mateus, et al 2011

Fig. 20 The material corresponds to the left dentary of ML11909.
It presents a size of 162 mm, with 12 anterior alveoli, seen in the labial perspective (c). The lateral view (d) of the dentary bears 28 defined and deep foramina, as paradental plates are nearly absent, triangular and low. The Meckelian groove presented a narrow, shallow, curve, with the teeth were straight, with linguolabial compression, seen in the frontal view (e). Source: Mateus, et al 2011

5.1.3. Baronyx sp (ref. MG 29A)

Comments: The teeth from Boca do Chapim differ little from those of *Baryonyx walkeri*, with the exception of the stronger development of ribs on the crown, specifically on the labial side; the teeth of the *Baryonyx walkeri* holotype, usually have a smooth labial surface, marked with subtle labial ribbing on certain materials. The Portuguese material is also reminiscent of the teeth of *Suchomimus tenerensis* (Milner, 2003), from the Aptian of Niger (Sereno et al., 1998), in the shape, the fine serrations and the wrinkling of the enamel.

Material: Fragment of a right dentary (**MG 29A**), fragment of a right dentary **(MG 29B**), fragment of a left dentary (**MG 29C**) Boca do Chapim (Setubal, Portugal) Lusitanian Basin, Papo Seco Formation (Barremian) Bufetaut (2007). Fig. 21.

Description: The most informative specimen is a jaw fragment (figured by Sauvage, 1897–1898, pl. IV), apparently a portion of a right dentary, showing four incomplete teeth, which are largely exposed, including the roots, because the lingual part of the bone has been destroyed. The anterior break shows the tip of a replacement tooth, with wrinkled enamel and very fine serrations on the carina. The following tooth is represented only by its root, which is long and mediolaterally flattened. The best-preserved tooth is the third from the front; its apex is broken, revealing a nearly circular cross-section, the crown being only weakly compressed mediolaterally. The crown has a slight curvature and bears ridges on both lingual (8 ridges) and labial (7 ridges) faces. The anterior and posterior carinae are in the same plane as the crow curvature; due to constant wear, they show only faint indications of serrations. The surface of the enamel is distinctly wrinkled, as noted by Sauvage (1897–1898). In the posterior alveolus, there could only been found fragments of a tooth. The labial face of the fragment of the jaw, however, is relatively vertical, and presents a concave dorsal margin. Surface is roughly preserved, with only a dorsoventral ridge, in its anterior part, slightly rugose Bufetaut (2007).

The other jaw fragment described by Sauvage between (1897–1898, pl. IV), is in all likelihood, from the right dentary part, but from a more posterior region, and it bears three teeth. The next material, only shows a poorly preserved root of the teeth. The following one has the apex of the replacement tooth, that has been split longitudinally, yet the anterior carina can be visible, clearly serrated, and with 6 to 7 serrations per millimetre. The enamel surface is strongly wrinkled. The relatively vertical labial face of the bone is poorly preserved, still showing two large vascular foramina.

The third, jaw fragment (29C) bears a dorsoventral ridge on the vertical lateral face. It seems to complement the above-described fragment (29A) on the left side. In labial view, it shows remains of four close-set alveoli, two of them are very incomplete, only very poorly preserved tooth remains are found, with laterally compressed roots resembling those described above.

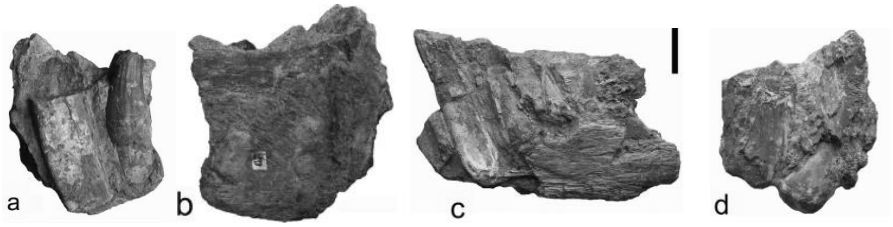

Fig. 21 Material of Baryonyx sp. MG29 collection
It was found in Boca do Chapim, Portugal, in the Museu Geologico, Lisbon. (a) Right dentary fragment MG29A in lingual view, a tooth with an incompletely preserved crown and another tooth. (b) Right dentary fragment MG29A in labial view, showing vertical ridge. (c) Right dentary fragment MG29B in lingual. Source: Source: Buffetaut, 2007

5.1.4. Baryonyx sp (ref. MNHN/UL.I.F2.176)

Comments: The tooth (MNHN/UL.I.F2.176) was located among some of the material, during research works on the collections of palaeontology of the "Museu Nacional de Historia Natural e da Ciência (MUHNAC)". This tooth was rescued from the fire that destroyed much of the museum on 1978 (Malafaia et al., 2013).

Material: Isolated tooth (**MNHN/UL.I.F2.176**) Boca do Chapim (Setubal, Portugal) Lusitanian Basin, Papo Seco Formation (Barremian) **Malafaia et al., (2013).** Fig. 22**.**

Description: The material corresponds to tooth Crown, without the apex, measuring 30 mm in height. The crown is conical-shaped, slightly labiolingually compressed, and slightly recurved distally; it has, at least, 5 well-developed vertical flutes on the labial surface. The base of the crown is oval in cross-section, measuring 14 mm mesiodistally and 9 mm labiolingually. Presence of the flutes on the lingual surface is not verified, considering the lack of preservation of the enamel. This enamel shows an ornamentation consisting on a series of thin crenulations, a rough aspect presents a t the crown. Due to fracture, distal carina is missing, but the mesial carina is covered by sediment; as a result, the presence of denticles cannot be verified. Isolated teeth from Boca do Chapim differ from those of *Baryonyx walkeri*

on the presence of vertical flutes on the labial and lingual surfaces (Charig and Milner 1997; Bufetaut 2007).

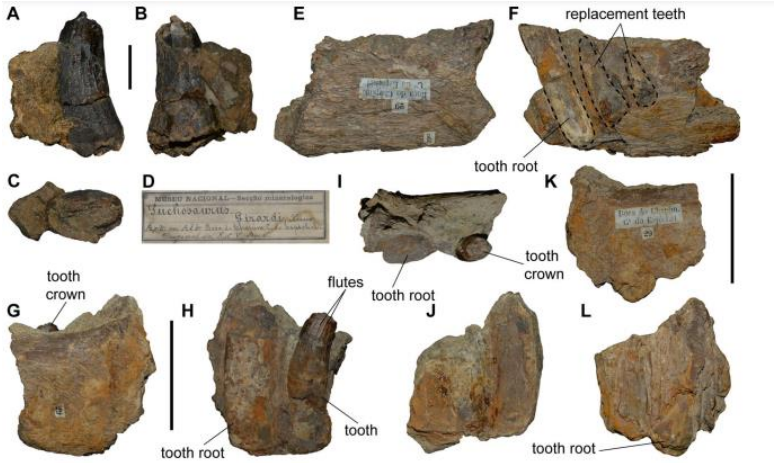

Fig. 22 Spinosaurid teeth of Boca do Chapim, MNHN/UL.I.F2.176
The sample can be seen in labial(a) and lingual(b), by cross-section of the base (c).The original name (d), next to the MG324(29B) sample, with the lateral (e), and medial (f) view, seen next to the lateral (g), medial (h) and dorsal perspective (i). The representation of the fragment from the jaw of MNHN/UL (j), and the counterpart of MG324(29A). MG324(29C), interpreted as the left dentary fragment in the lateral view (k), and medial perspective (l). Source: [Malafaia et al. 2020]

5.1.5. Theropod sp (ref. CPGP.1.16.21)

Specimens: CPGP.1.16.21 (dinosaurs).

Dinosauria (Owen, 1842), Ornithoscelida (Bardon et al., 2017), Cf. Theropoda Indet (Marsh 1881). Fig. 23.

Description: A fragment of a proximal end of a large theropod dinosaur femur (the most proximal bone of the hindlimbs); estimated to have 160 mm width. Fossil is well rounded with smoothed, curved surface due to the erosion of the sea waves. Osteons (concentric layers of compact bone that surrounds the haversian canals, that contains the bone's blood supplies) are very noticeable. Despite being much rolled, the head with sub rectangular shape, and horizontal trochanteric shelf, are slightly perceptible.

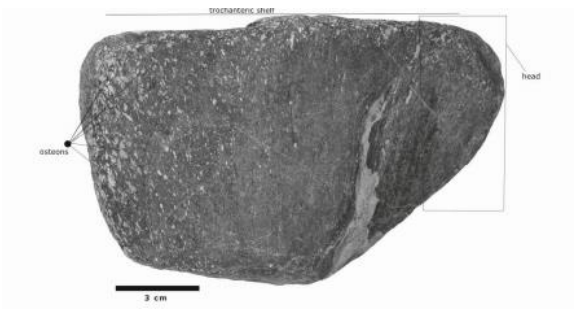

Fig. 23 Fragment of a Theropod indet.
It consists of a theropod femur, rounded and curved surface. Osteons are identified, within an subrectangular structure. Lateral view of the Theropod sp. material. Source: [Figuereido, et al. 2017]

5.1.6. Theropod sp. (ref. CPGP.1.16.22)

Comments: This fossil material had been classified as Dromaeosauridae, carnivorous theropods of small and medium size, from the Upper Jurassic to the Cretaceous Upper China, Mongolia, North and South America (Chatterjee, 2015), as well as in Europe (*Balaur, Variraptor, Pyroraptor*) and in Madagascar (*Rahonavis*). However, the different characteristics that are granted to this individual are not representative enough to consider a further and a distinctive classification with respect to the rest of the materials obtained.

Specimens: CPGP.1.16.22 (dinosaurs). Dinosauria (Owen, 1842). *Ornithoscelida* (Matthew et al., 2017), Theropoda (Marsh, 1881). Fig. 24.

Description: A fragment of the distal end of the radius. The fragment is 19 mm wide, and it is realized that the radius is straight, as the distal articulation is flat and expanded perpendicularly.

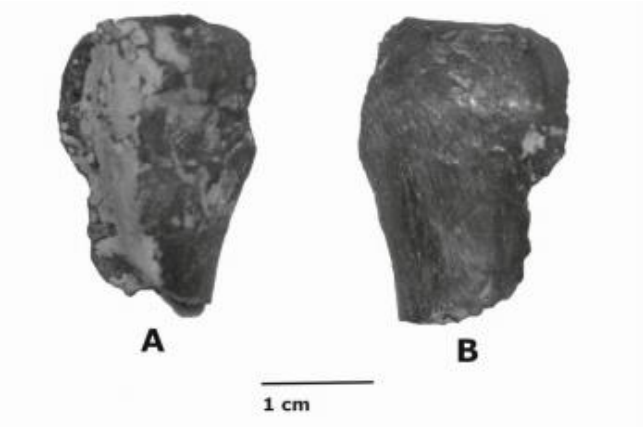

Fig. 24 Fragment of Dromaeosauridae indet.
It presents a distal end of the radius, classified as Dromaeosauridae. The fragment is straight, 19 mm wide. Source: Figuereido, et al. 2017

5.2 Contemporaneous Theropods of the Iberian Peninsula

The fossil remains of the Papo Seco formation are from the Early Cretaceous, Lower Barremian. This formation has shown an abundant record of dinosaurs (on which the study has been based on theropod remains), which interconnected an ecological niche near the sea. The lagoon ecosystem presented from small theropods like possible Dromaeosauridae, to a series of diverse Baryonychinae. However, this series of geological conditions differs from those that make up the Iberian Peninsula, both in structure and age. This section aims to compare and discuss the different fossil materials of theropods that have been found and described in the Iberian Peninsula.

At the moment, the Theropods cited in the Early Cretaceous consists of the following: (Theropoda indet., indeterminate spinosaurid, Baryonychinae indet*., cf. Baryonyx, Baryonyx sp.,* Coelurosauria indet., Ornithomimosauria? indet., Compsognathidae? indet.,

Dromaeosauridae indet., Velociraptorinae indet, indeterminate "paronicodontids", cf. *Paronychodon sp.* (Ortega et al., 2006). A geological map presenting the different locations of the species can be found in the Fig. 25.

In the Iberian Peninsula, there is found a remarkable diversity of the Theropod clade, presenting adaptations to fulfill specialized roles in the different environments they have successfully conquered. The group of Baryonychinae stands out among the others for being the most expanded in the Iberian Peninsula, proven by fossil records of their presence most of the quarries, only being absent in the localities of “Cuenca or Soria”, as their geological composition moves away from the Barremian age; also, that there are remains of cf. Spinosaurid*,* such as in “Morella” and “La Revilla-Ahedo”. Is closely followed by the Eudromaeosauria, which are localized in almost all the quarries with presence of Theropods by the fossil remains of Dromaeosauridae indet., Velociraptorinae indet. This marks an imaginary line that situates most of their presence at the North part of the Iberian Peninsula. Moreover, there has been described and irregular presence of Coelurosauria indet., Ornithomimosauria indet., Compsognathidae, indet "paronicodontids", *Paronychodon sp*. and *cf. Richardoestesia sp*.

Carcharodontosauridae family has only been found with definitive remains at the Las Hoyas area, represented by the unique specimen *Concavenator corcovatus*. In regards of the Ceratosauria group, there has only been registers of fossils materials belonging to *Camarillasaurus cirugedae*, in Camarillas quarry (“*Teruel*”). These materials, however, have undergone a recent investigation where it has been reconsidered a part of the Megalosauridae, but this argument is still a subject of debate and, therefore, it will remain as in the previous classification.

5.1.7. Spain: Aragon: Teruel

Castellote (BR-AP): In Castellote, there have been described fossils materials from Theropoda indet., Baryonychinae indet., Coelurosauria indet., Dromaeosauridae indet. This site, discovered in 1993 and published for the first time in 1995 (Cuenca Bescós et al., 1995), stratigraphically constitutes the base of the Artoles Formation, and it is formed by a conglomerate with a large accumulation of remains of vertebrates, visible in the field. The dinosaurs recognized so far, identified from isolated teeth are theropods (Theropoda indet., Baryonychinae indet., Coelurosauria indet., Dromaeosauridae indet., Canudo et al., 2003).

La Cantalera (HT-BR): La Cantalera, located in the municipality of Josa, is a site discovered in 1994 and released in 1997. It is stratigraphically located in Blesa Formation (Ruiz-Omeñaca et al., 1997 and Ruiz Omeñaca et al., 2001). The site has been dated as Upper Hauterivian-Barremian basal by the presence of fossil materials of Theropoda indet., Baryonychinae indet*.,* Coelurosauria indet., Dromaeosauridae indet. (Canudo et al., 2003).

Galve (HT-BR): In Galve, there have been described Theropoda indet., Coelurosauria indet., Dromaeosauridae indet., Paronychodon indet.

There are numerous deposits with vertebrates in the Titonian-Barremian interval, belonging

to the Villar del Arzobispo and El Castellar. The ceiling of the Castellar Formation is dated by charophytes (including the primitive form of *Atopochara trivolvis* variety triquetra) as Upper Hauterivian Barremian basal, and the Camarillas Formation is dated, also with charophytes (due to the typical form of *Atopochara trivolvis*) as Lower Barremian (Soria de Miguel, 1997).

Unlike the theropods from the Papo Seco Formation, the presence of the Ceratosaurian *Camarillasaurus cirugedae* specimen, was determined by the collection of associated bones, described by B. Hernandez, M. Benton (2012): a tooth, a cervical vertebra, two sternal plates, the proximal part of a right tibia, a broken right scapulocoracoid, an incomplete sacrum, caudal vertebrae, an isolated caudal neural arch, a chevron, an almost complete presacral rib with some fragments of vertebrae, ribs, among other elements.

5.1.8. Spain: Castilla-La-Mancha: Cuenca

In the province of Cuenca there are two important deposits from the Barremiam with dinosaur remains (Uña and Las Hoyas), as well as some isolated remains from other locations (Buenache de la Sierra, Masegosa, Vadillos). They all are classified in the "Calizas de La Huérguina" Formation and "Arenas y arcillas del Collado", as it is stratigraphically equivalent (Vilas et al., 1982), and considered Upper Barremian age (Gómez et al.,2001). Geologically they are found in the Serranía de Cuenca Basin.

Vadillos (BR): The Vadillos deposit, located in a detrital series with red clays and conglomerates (Lapparent et al., 1969) could be found in the “El Collado” Formation, which is a siliciclastic unit consisting of coarse-grained sandstones, red clays and some conglomerates subordinates. In Vadillos, there have been described fossil materials of Theropoda indet.

Uña (BR): The collection described in Uña (Rauhut, 1996, 2002a, 2002b, Rauhut et al., 1995), consists of theropod teeth: indeterminate Dromaeosaurids (Dromaeosaurs and Velociraptorinae), cf. *Paronychodon sp. and cf. Richardoestesia sp.* (initially assigned tocf. *Euronychodon sp.* in Rauhut et al., 1995, Canudo et al., 2002)

Las Hoyas (BR): In Las Hoyas, an indeterminate theropod tooth has been found (Buscalioni et al., 1988) in laminated limestone facies. In the laminated limestones have also provided an articulated skeleton of the Theropod *Ornithomimosaurus* (the holotype of *Pelecanimimus polyodon* Pérez-Moreno, Sanz, Buscalioni, Moratalla, Ortega et al., 1994. Also, the Carcharodontosaurid *Concavenator corcovatus* is represented by a single and almost complete and articulated skeleton by Ortega et al., (2010), founded in the Las Hoyas fossil site (Early Cretaceous, Spain).

5.1.9. Spain: Castilla-Leon: Burgos

Barbadillo del Mercado (HT-BR): In La Tejera-Valdesancho (Barbadillo del Mercado, *Upper* Hauterivian Lower Barremian*).* From this same site comes a description of a tooth from cf. *Baryonyx*, described by Torcida et al., (1997).

Cabezón de la Sierra (BR-AP): In La Solana (Cabezón de la Sierra, Upper Barremian-Aptian according to Torcida Fernández, 2003a), Torcida Fernández (2003a) a tooth of Baryonychinae indet. In Tenadas de la Rosa (Cabezón de la Sierra, Barremian-*Aptian* according to Torcida Fernández-Baldor, 1996), two teeth of *cf. Baryonyx* (Torcida et al., 1997). In Cabezon de la Sierra, there have been described fossil remains of Baryonychinae indet and *cf. Baryonyx.*

Hacinas (BR-AP): In Tenadas de la Rosada (Hacinas, Upper Barremian-Aptian), Torcida Fernández et al., (2003a) describe two theropod teeth that assign Theropoda indet. and Dromaeosauridae indet. In Hacinas, there have been described fossil remains of Theropoda indet., Dromaeosauridae indet.

La Revilla-Ahedo (BR-AP): The remains from the Fm. Castrillo de la Reina (Upper Barremian-Lower Aptian*)* are two cervical vertebrae of an indeterminate cf. Spinosaurid, but they have been not yet studied and publicized. (Torcida et al., in press).

Salas de los Infantes (HT-BR, BR-AP): Los Peñucos-La Ballesta (Salas de los Infantes) has an Upper Barremian-Aptian age (Torcida Fernández et al., 2003a), In Los Peñucos La Ballesta, Torcida Fernández et al., (2003a) described a theropod tooth (Coelurosauria indet.) From Los Peñucos, there have been described fossil remains of *Baryonyx sp.,* Theropoda indet., Baryonychinae indet., Coelurosauria indet., Dromaeosauridae indet.

El Juguete (Infant Rooms, HT-BR): on Pinilla de los Moros Formation, Fuentes Vidarte et al. (1999, 2001) describe cranial and postcranial elements from a *Baryonyx sp*.

Tenadas de Costalomo (Salas de los Infantes, HT-BR): Torcida et al., (1997) described an isolated tooth from cf. *Baryonyx* on the facies Weald *(*Barremian-Aptian). Torcida Fernández et al., (2003a) describe theropod teeth from different Upper Barremian-Lower Aptian deposits: Theropoda indet. in Camino de Salas-Villanueva, Baryonychinae indet. in Tenadas del Jabalí and Dromaeosauridae indet. in Costalomo.

5.1.10. Spain: Castilla-León: Soria

Golmayo (HT-BR): In Los Caños site was discovered by Clemente Sáenz García in 1917 in the town of Golmayo, located geologically in the Soria sector of the Western Cameros Basin, and stratigraphically within the Golmayo Formation (Clemente et al., 1993), dated as Upper Hauterivian-Lower Barremian (Martín-Closas et al., 1998). In Los Caños, it has been described a *Theropod sp*. tooth, which has been assigned to Dromaeosaurid sp. (Sources Vidarte et al., 2002a). Also, in Golmayo is the Zorralbo site, in which found teeth from two different *Theropod sp*. (Fuentes Vidarte et al., 2002).

5.1.11. Spain: Valencian Community: Valencia

Alpuente (BR): In the locality of Morella (Castellon's province), in the "Mas de la Parreta" quarry closely located to the Morella locality of Arcillas de Morella Formation, there have been registered isolated and undetermined Baryonychinaes, certain remains that were assigned to Allosaurids, and specific Dromaeosauridae Theropods materials. Most of the fossil

remains from the “Mas de la Parreta” Quarry” and described to undetermined Baryonychines are isolated teeth (Canudo et al., 2008). Moreover, the isolated postcranial remains from several specimens have been found including cervical and caudal vertebrae (Ortega et al., 2006) and a nearly complete left tibia (Gasulla et al., 2006).

Los Serranos (BR): All of the deposits are from the Cubeta de Aras de los Olmos, from the South-West part of Iberian Cordillera Diéguez et al., (2000). A *Carnosaur sp.* tooth is mentioned by Casanovas Cladellas (1993) in the Early Cretaceous of Benicatazara. The dentary fragment was studied in detail by Casanovas-Cladellas et al., (1993) and was assigned to Theropoda indet. In conclusion. The Serranos’ record presents a collection of both cranial (mainly isolated teeth) and postcranial material, which can be classified as members of Baryonychinae.

Vallibona (BR): A new Spinosaurid specimen shown by cervical, dorsal, caudal and sacral vertebrae, the ilia and the ischia have been described in the Arcillas de Morella Formation at Vallibona, Castellon (Gomez-Fernandez et al., 2007). The *Vallibonavenatrix cani* discovered at the Arcillas de Morella, presents special characteristics that were currently attributed to the taxon of Spinosauridae in the Spanish fossil, detailed by Malafaia et al., (2020).

5.1.12. Spain: La Rioja

Igea (BR-AP): At the Peña Carcena deposit (Igea, La Rioja) a fragment of toothless maxilla, which has been attributed *to Baryonyx walkeri* (Torres et al., 1995). The fossil remains from the Enciso group, dated with charophytes as Upper Barremian - Aptian (Martín-Closas et al., 1998: 265). Given the fragmentary of the material it is wiser to consider this remainder as *cf. Baryonyx sp.* (Canudo et al., 2003) Although a few more remains have been cited *(Baryonyx* in a current study in Soto de Cameros), more precise data, as it’s age, has yet not been published (Pérez-Lorente et al., 2001).

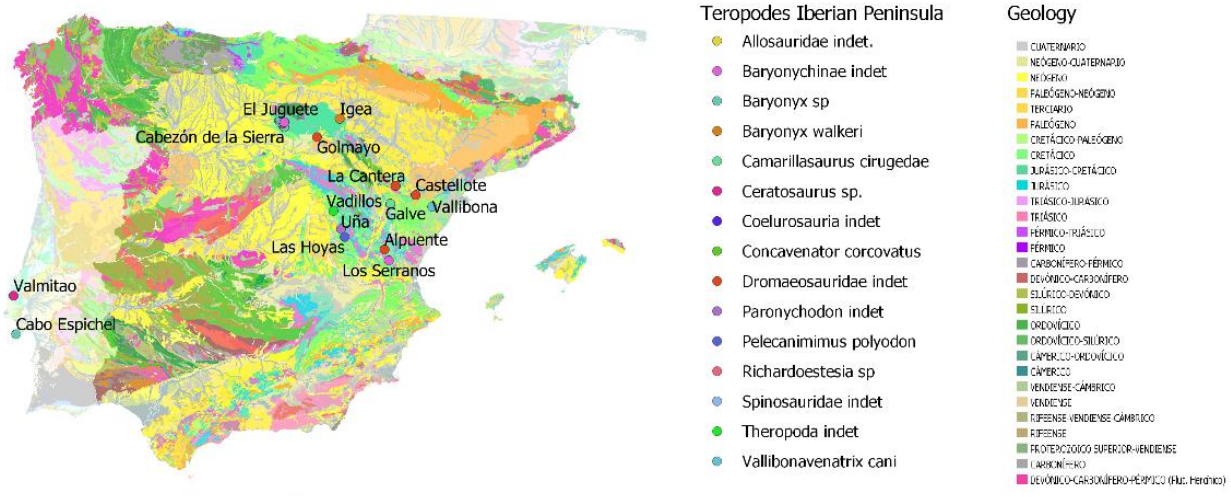

Fig. 25 Theropods from Early Cretaceous’ Iberian Peninsula.

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6. Morphometrical Analysis of one tooth of Spinosaurid from Miquel Crusafont Institute's

6.1 Methodology of the Analysis

In this section the experimental analysis of an isolated theropod tooth from the "Museu de l'Institut Català de Paleontologia Miquel Crusafont" is presented. This study has been performed thanks to Head of the Dinosaur Ecosystems Research Group, Angel Galobart, who yields the information regarding the tooth material and gives me the opportunity to take photos and measurements of the tooth.

The measurements of the *Baryonyx sp.* were taken following the guidelines established by the by Smith et al., (2005), on their study "Implications for the Taxonomic Identification of Isolated Teeth". These parameters were measured using the *"Image J"* software, by calibrating the photographic images taken the with an electronic magnifying glass equipped with a professional photographic camera.

"Image J" is a software developed by the company Java designed to processing digital images. The software has extended plugins (Java or custom) and recordable macros which allow to solve problems of statistical analysis or images, considering x-rays, microscopic captures or, in this case, comparison of data from one or more images. This tool, as presented in the Fig. 27(top), can analyse measures with inherent comparative length; thus, a calibration standard procedure was used firstly. At the same time, "*Image J*" could do editing, analysing, processing and saving 8 'bits' (256 standard colours), 16 'bit' (1 thousand or more standard colours), or 32 'bit' 1 million or more standard colours). Moreover, Image J has the ability to read image formats such as: TIFF, PNG, GIF, JPEG, BMP, DICOM, FITS, as well as RAW (format).

6.2 Analysis of Tooth Material

The analysed tooth was preserved individually, loaned via the *"*Museu de l'Institut Català de Paleontologia Miquel Crusafont*"*; without presumed simples to which its origin could be assign. The tooth has the Museum reference IPS- 919 and it is shown in Fig. 26 and Fig. 27.

Although the crown presents various fractures, it is considered almost complete, as it preserves part of the root base. The Dentary is laterally compressed but straight. The measurements taken are: Distal Apical (DA) measures 1.035 cm, the Distal Mid-Point denticle measures 1.038 cm (DC), and the Distal Basal denticle shows a length of 1.032 cm (DB); the distance might show some error range due to the irregularity of the tooth, Crown base, and the lack of the true root from the tooth material. Anterior and posterior carinae are present, in the same plane as the curvature of the crown; because of wear, they show only faint indications of serrations.

The tooth crowns in the dentary exhibit a slight fluting on both sides of the teeth. Due to the uncertain nature of the piece and, because It has been shown that the presence of fluting in

Baryonychinae teeth is highly variable (Ruiz-Omeñaca et al., 1998: 206), it cannot be discerned whether this was due to problems in the transport process, or due to wear. On the contrary, the Mesial Apical (MA) measures 1.234 cm, the Mesial Mid-Point denticle measures 1.487 cm (MC), and the Mesial Basal denticle measures a total length of 1.043 cm (MB). The Crown Height (CH), measures a total of 3.749 cm of length, and the Crown Angle (CA), measures the distance of approx. 68.067º of angulation. As a result of the crown being laterally compressed and curved, the Crown Base Length (CBL) shows a determined length of 1.789 cm, and the Crown Base Wide (CBW), presents a measured wide of 0.675 cm. Both surfaces are flat, and have the enamel wrinkled. The denticle density of the erupting teeth might present micro serrations that enter within the values of 6 or 7 per millimetre but cannot be confirmed for the lack of equipment; the enamel, in addition, is densely wrinkled (apicobasal, presumably extending superficial micro-ridges). Different ridges can be observed along the tooth surface. A deep fracture can be perceived in the union of the part of the base of the crown with the rest of the structure, this being the most noticeable of all. A series of lighter fractures mark the labial base, with a part of the enamel that has been lost in the process (the nature of these facts is unknown). Added to these is the possible loss of the root of the tooth base, which seems to show no damage beyond erosion on both sides of the root.

Fig. 26 The Isolated tooth of the Baryonyx sp. IPS 919
It is detailed the insets of verticals flutes, wrinkled enamel, denticles, and carina. The full size of the tooth corresponds to 4.933 cm.

Category	Data Values
Distal Apical (DA)	1.035 cm
Distal Mid-Point (DC)	1.038 cm
Distal Basal (DB)	1.032 cm
Mesial Apical (MA)	1.234 cm
Mesial Mid-Point (MC)	1.487 cm
Mesial Basal (MB)	1.043 cm
Crown Height (CH	3.749 cm
Crown Angle (CA)	68.067º
Crown Base Length (CBL	1.789 cm
Crown Base Wide (CBW	0.675 cm

Fig. 27 Tooth data values of IPS-919 measured using Image-J software.
The procedure to calculate the different lengths in the program "Image J", involved the standardization of the measurement of the tooth. First, it was necessary to set the correct scale(upper), with the help of a comparative ruler. The database of the different measures can be seen in the image (below). The values in centimetres, respectively, are: Distal Apical (1.035), Distal Mid-Point (1.038), Distal Basal (1.032), Mesial Apical (1.234), Mesial Mid-Point (1.487), Mesial-Basal (1.043), Crown Height (3.749), Crown Angle (68.067º), Crown Base Length (1.789) and Crown Base Wide (0.675).

6.3 Comparison with the Papo Seco Formation Teeth

The Baryonychinae teeth from Papo Seco presented a series of singular characteristics, that defined them among other Theropods. As can be observed by the different photographs loaned by Elisabete Malafaia from the collection of Baryonychinae fossil materials from the Cabo Espichel geological area, both teeth preen similarities on a superficial level. However, to further discuss this, it is necessary to study the material with the description presented in their respective reports.

The teeth material CPGP.1.06.2 (Fig. 28), presents conical tooth, curved, with the crown narrow and pointed, with longitudinal grooves in the apical and medial areas. The base has

no ornamentation. The distal carina is sharp and micro-serrated, and the mesial carina has a long and wide longitudinal groove, which seems to result from normal wear of the tooth. This tooth is identified as *Baryonyx sp.,* based on its overall shape and surface ornaments. Furthermore, this tooth shows the characteristics of the *Baryonyx* teeth described in different studies (Smith et al., 2005; Fowler, 2007; Buffetaut, 2007, 2012; Alonso and Canudo, 2015).

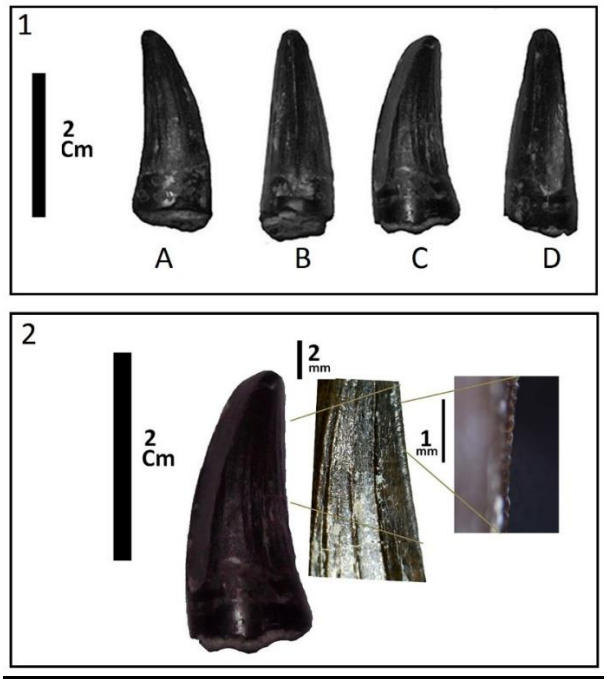

Fig. 28 Teeth material CPGP.1.06.2, Boca do Chapim
Source: Figueiredo et al. 2015

The teeth material (29A, Sauvage, 1897–1898, Fig. 29), consists of an anterior replacement tooth, with wrinkled enamel and very fine serrations on the carina. Moreover, is long and mediolaterally flattened. The crown is slightly recurved and bears distinct ridges on both the lingual (8 ridges) and labial (7 ridges) faces. Anterior and posterior carinae are present, in the same plane as the curvature of the crown; because of wear, they show only faint indications of serrations. Was identified as a *Baryonyx sp.* by Bufetaut (2007).

Fig. 29 Material of Baryonyx sp. MG29A collection
It corresponds to the teeth material 29A., from the report of Sauvage (1897–1898).
Source: Malafaia et al. 2020

The tooth material enters within the similarity parameters from the tooth presented as the experimental part, as those present remarkable characteristics of wrinkled enamel, diverse flutes in both labial and lingual faces, and the presence of carinae in mesial and distal part in both simples. Nonetheless, this characteristic may not be described in the "Museu de l'Institut Català de Paleontologia Miquel Crusafont" material, due to the irregularities in the dentary part, as it was previously explained. In regards of the measures, these two teeth present a similar patron of values, described within the data pool of Smith et al., (2005), and that are classified as *Baryonyx sp.* Thus, they can offer a wide base to consider the unknown tooth as part of the *Baryonyx* group.

6.4 Discussion

The bibliographic research about Spinosauridae fossils from the Early Cretaceous layers in the Papo Seco Formation recovered in Cabo Espichel, shows that fossils range from isolated teeth, fragments of jaws and maxial dentary, as well as a collection of neural archs and vertebras. They are defined as 3 *Baryonyx sp.*, a *Baryonyx walkeri*, and two *Theropod sp* materials. Compared to the common Theropod teeth structure, the Spinosauridae dentary is characterized by conical tooth, smooth or wrinkled enamel surface, enamel bearing apicobasal oriented striations at the base of the crown, irregular denticle size. Flutes present on both labial and lingual sides in lateral teeth, and with deeply veined enamel texture in lateral teeth. The bibliographic research, after exhaustive investigation of hundreds of reports, has concentrated the different reports about the Spinosaurids found in the Barremian layers of Cabo Espichel, in a concise and accessible collection. The materials also

serve to understand the reclassification of certain elements previously described, due to the similarities of the Spinosauridae traits with the crocodilians Geology from the Papo Seco Formation determine that it was an estuarine habitat in contact with the marine environment. Therefore, the Baryonychinae would prey on a wide range of animals or scavenge on them, as they are considered generalist feeders. Moreover, the presence of these fossil materials near a mass of water, fits with the idea that they would have been adapted to *a semiaquatic lifestyle.*

The Early Cretaceous stratigraphy layers are distributed across the Iberian Peninsula, ranging between the Hautiverian, Barremian and Aptian*,* in different localities and quarries. Although the Baryonychinae remains have being the most common ones, a quantity of other Theropods has been described and classified in the Iberian Peninsula. In accordance with the high adaptability of the theropods, it is not surprising that other lineages than Spinosauridae proliferated, showing other adaptations and characteristics, having a role as specialized predators in other habitats of the Early Cretaceous, and being correlatives to the Theropods described the Papo Seco Formation environment. Some of the most notorious include the Concavenator corcorvatus (Cuenca, Spain), the only known species of the Carcharodontosaurid in the Iberian Peninsula, defined by two extremely high vertebrae in front of the hips that formed a narrow and pointed crest, and identified by a single skeleton almost complete. Also, the *Camarillasaurus cirugedae* as Ceratosaurian described in Teruel province, Camarillas. But, it has been questioned for the reclassification as a member of Spinosauridae; nonetheless, it is subjected to a posterior debate (Malafaia et al., 2020).

However, the description and classification of the *Vallibonavenatrix cani* as a Spinosaurine, indicates that there were at least two Spinosaurid taxa in the Iberian Peninsula, and not only *Baryonyx*. The distribution of the Spinosauridae family was previously considered to diverge in two lineages in Early Cretaceous time, and the Baryonychinaes were present in the Laurasia continent, whereas Spinosaurines could only be found in the Gondwana continent, as what was considered the opening of the Tethys Sea. But, the presence of a Spinosaurine in the Barremian layers from the Iberian Peninsula has served to reconsider this hypothesis, and to tackle a bigger and more complex paleogeographic distribution of this family of Theropods (Malafaia et al., 2018). In regards to the restructuring of the Spinosauridae, the isolated tooth loaned by the “Museu de l'Institut Català de Paleontologia Miquel Crusafont”*,* despite presenting certain damages and the lack of previous information about its origin. Comparing it with the dentary material researched from the Papo Seco Formation and the measures taken, has been identified as a *Baryonyx sp.* Due to the lack of a bigger data pool of values and the unknown nature of it, could not be processed any further, and a posterior and a more focus study in this tooth is required.

7.Conclusions

The palaeontological study of the Early Cretaceous in the Cabo Espichel (Setubal, Portugal) has yielded some of the most unique and interesting fossils materials in the Iberian Peninsula. Alongside the different theropods described in the Papo Seco Formation, the most

characteristic are the remains of Baryonychinae*,* belonging to the Spinosauridae family, that were acknowledge as the apex predators in the lagoon-like habitat. The set of Therapod fossil record of Iberian Spinosaurid spans from the upper Hauterivian to the Aptian (Cretaceous), and it comprises, mainly, isolated elements, but with some more complete specimens identified.

The Iberian Peninsula theropod record has acquired, in contemporary times, a high level of knowledge thanks to the increase, both in research activity about the group, as in the attention given by the public administrations in charge of the management paleontological heritage. As a result of this improvement, it has been achieved a clearer understanding of their roles in their respective environment, their geographical distribution, their specializations among other. The theropod clade has been characterized for their high level of specialization, granting them a great capacity of adaptation to a wide variety of ambient and habitats. The specimens from the Cabo Espichel were not the first record from the Iberian Peninsula, since Baryonychinaes have been reported from a wide diversity of Spanish localities. Alongside the fossil materials of *Baryonyx*, there have been reports of correlative theropods dinosaurs, as *Concavenator corcorvatus, Camarillasaurus cirugedae*, and, notably, the identification of the Spinosaurid *Vallibonavenatrix cani*. These series of reports range from Hauteverian until Aptian, in the Early Cretaceous age Malafaia et al., (2020), Canudo et al., (2003), B. Hernandez, M. Benton (2012), Ortega et al., (2010), (Canudo et al., 2008), (Ortega et al., 2006; Gasulla et al., 2009), or (Rauhut et al., 1995, Canudo et al., 2002).

The description of this new-found taxon puts into perspective that there were least two Spinosaurid taxa in the Iberian Peninsula at a certain time and distribution: *Baryonyx* and the Spinosaurine *Vallibonavenatrix*. The anterior hypothesis for the distribution of the Spinosauridae family, was that they had a general distribution all around the world, and evolved divergently in two main lineages in Early Cretaceous time, the Baryonychinaes in Laurasia continent, and Spinosaurines in the Gondwana continent, as what was considered the opening of the Tethys Sea. Nonetheless, remains of Baryonychinae were found in Gondwana, as so other forms considered Spinosaurines in the Iberian domain. Thus, this data puts into question a greater scene that is yet not been tackled. The comparative study of the different Theropods in the Papo Seco Formation, as well as the fossil materials of the Iberian Peninsula, has become an unprecedented opportunity to extend the knowledge of the Spinosaurid genus, to collect all the relevant studies in order to present it in a clear and concise report.

The Taxonomic Identification of the isolated “Museu de l'Institut Català de Paleontologia Miquel Crusafont” tooth, was studied and classified based on the report presented by Smith et al., (2005), that presents a standard for the Dental Morphology and Variation of Theropods. Moreover, the “Image J” program allows to take precise measurements with relative ease. Despite the lack of a more detailed and greater data pool, the experimental part of this report has allowed to classify the dental material and a clear and convincing comparison which has opened the door to a greater debate regarding the distribution of Spinosauridae in the geographical and temporal scale.

7.1 Limitations and Improvements to be carried in future projects

The development of this experimental section has been limited within the unfortunate spectrum of the exceptional situation already mentioned. At the same time, factors of great value such as economic, the availability of certain equipment and materials, as well as restrictions in the field of movement and time, have closed several doors in this practical section. Having had the necessary laboratory equipment available, the marked tooth of the "Museu de l'Institut Català de Paleontologia Miquel Crusafont" would have been studied, expanding its characteristics with the values of serrations of the carina, denticles per millimetre, possible wear, and confirming the presence of micro-ridges. In the same case, the largest study of the origin and nature of the fossil piece is included, since it could not only provide valuable information (due to the scarcity of such materials), but also promote a change in the perception of the biogeography of the Spinosauridae family.

Following these considerations, the comparative study following the parameters proposed by Smith et al., (2005) has been deprived of a portion of the data. In this case, the taxonomic analysis of the fossil materials of the Cabo Espichel would have been carried out, in order to reinforce the statement that the material described would belong to a *Baryonyx sp*., Present in the Iberian Peninsula, and allow the discussion of intrinsic autapomorphies in a hypothetical Iberian subspecies.

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