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The Cristo Rei section (Lower Miocene) Distal fluviatile environments in a marine series, plants, vertebrates and other evidence, age

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RESUMO

Palavras-chave: Miocénico inferior; Bacia do Baixo Tejo; Cristo Rei; idade; plantas; vertebrados; ecologia e ambientes.

O corte de Cristo Rei permite observar camadas arenosas com lentículas argilosas (divisão IVb). Correspondem a importante episódio de regressão (aprox. entre ca. de 17.6 e 17 Ma) e a uma posição distal (em relação às facies tipicamente fluviais representadas em Lisboa) e mais próxima do eixo da bacia. Os dados geológicos e a análise paleontológica (plantas, peixes, crocodilos, mamíferos terrestres) permite reconstituir ambientes então representados na área em causa: estuário com canais e ox-bows; a montante, áreas ocupadas com águas salobras onde se constituiram bancos de *Gryphaea griphoides;* ainda mais acima, águas doces, ladeadas de florestas próprias de áreas húmidas e de florestas subtropicais de baixa montanha, em condições de clima temperado quente e pluvioso, mas também por ambientes sazonalmente secos, com cobertura florestal ou arbustiva pouco densa, ou de estepe.

ABSTRACT

Key words: Lower Miocene; Lower Tagus basin; Cristo Rei: datation; plant fossils; vertebrates; ecology and environments.

The section at Cristo Rei shows sandy beds with intercalated clayey lenses (IVb division from the Lisbon Miocene series) that correspond to a major regression event dated from between ca. 17.6 and 17 Ma. They also correspond to a distal position (relatively to the typical fluviatile facies in Lisbon), nearer the basin's axis. Geologic data and paleontological analysis (plant fossils, fishes, crocodilians, land mammals) allow the reconstruction of environments that were represented in the concerned area: estuary with channels and ox-bows; upstream, areas occupied by brackish waters where *Gryphaea griphoides* banks developped; still farther upstream, freshwaters sided by humid forests and low mountain subtropical forests under warm temperate and rainy conditions, as well as not far away, seasonally dry environments (low density tree or shrub cover, or steppe).

1. INTRODUCTION

Continental deposits are intercalated in the mainly marine Miocene infillings of the Lower Tagus Basin. These are of utmost stratigraphic interest as reference levels in Western Europe for high-resolution marine-continental correlation.

However, time and space distribution of these deposits are not uniform. Fluviatile, feldspar sands are best represented in the Lisbon area, where there

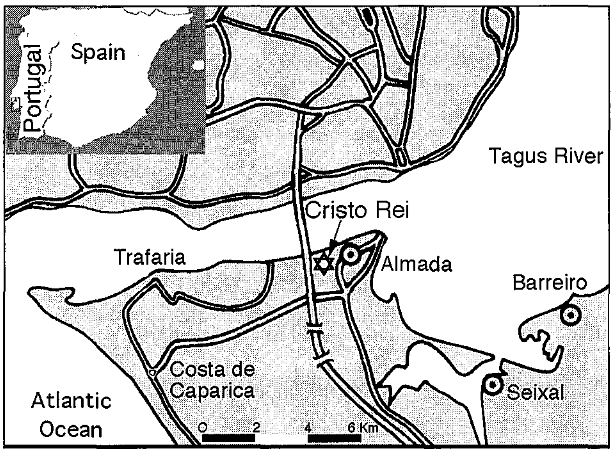


Fig. 1. Position of the Cristo Rei section.

is a marked reduction in thickness of the more often dealt with marine levels. The latter are also shallower than southwards closer by the basin's main axis.

The Almada area (fig. 1) is closer to the deepest part of the basin. Marine facies prevail even more than in Lisbon. Continental influence is much lesser. There are not yet fully known but important lateral shifts of facies, owing to hiatuses between outcrops and to insufficient knowledge of borehole evidence (Antunes *et al.,* 1996, fig. 6 / updated version).

The best section where the Lower Miocene units outcrop is probably that at the Tagus' southern bank under the Cristo Rei monument, that was described in detail (Antunes *et al., loc. cit.,* p. 62-65, fig. 2-3).

Continental influence is obvious as far as coarse sands with scattered valves of *Gryphaea griphoides* (IVb division of Lisbon's Miocene series, Burdigalian) are concerned. The upper part of the IVb unit shows some lenticular occurrences of silty clays with plant fossils. One of these lenses (ca. 100 meters W of the geodetic point at Pau da Bandeira), UTM coordinates MC 815.0 853.5, according to the Military map of Portugal 1: 25000, sheet n.° 431 / Lisboa) yielded a large number of leave impressions.

Similar sands in Lisbon had been productive for small mammals research. Washing and sieving coupled with bromoform reconcentration yielded salt water fish, crocodilian and other vertebrate remnants, among which rodents are most interesting for marine / continental correlation.

Previous experience led us therefore to try at Cristo Rei (fig. 2). As prospections were positive, some cubic meters of sands were subsequently exploited for vertebrate remains, both under (level 1) and over (level 2) greenish, intercalated silty clays often rich in impressions of land plant leaves. However, age or other differences between these two levels – both with vertebrates – is minimal and all can be taken together. Vertebrate remnants are often reworked and somewhat abraded. An account of the small mammals has been given by J.-P. Aguilar (Aguilar, 1981).

The coarse sands overlie blue, pyritous silts and clays (IVa division) where the beautiful guide-fossil *Pereiraia gervaisi* occurs among many others. Planktic foraminifera indicate N5 (at the base) and N6 zones of Blow. Calcareous nannoplankton seems to correspond to Martini's NN4. Evidence points out to Haq *et al.*'s 2.1 eustathic cycle.

The distribution of ostracoda shows a striking contrast between the marine IVa div. associations, their absence at the "continental" beds, and the associations of the uppermost part of the section that shift from shallow marine (Va$_1$ subdivision) to oligohaline (Va$_2$ subdiv.), reverting again (Vb div., Langhian) to shallow marine (infra- / circalittoral) ones.

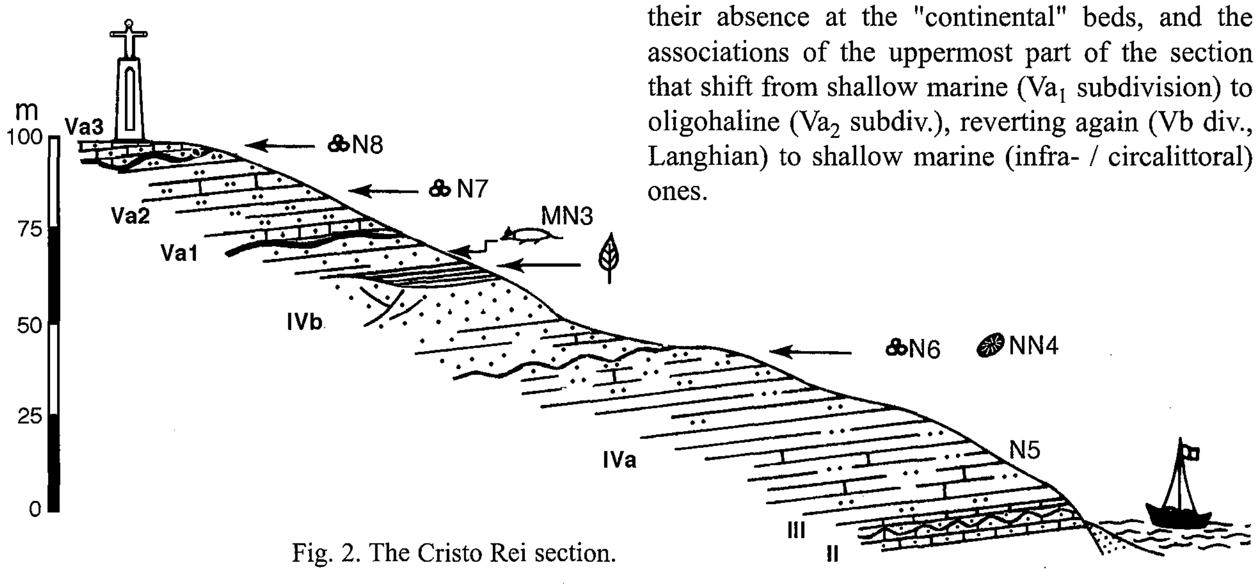


Fig. 2. The Cristo Rei section.

The data concerning the Cristo Rei section, coupled to data about other sections and to much progress of knowledge on Sr and K-Ar dating, biochronology and magnetostratigraphy, allow us to frame accurately in time the paleontologic and stratigraphic evidence.

General data are mostly based on a previous note (Antunes *et al.,* 1996). Plant fossils were accounted for by J. Pais, fishes by A.Balbino and M. T. Antunes, crocodilians by M. T. Antunes, and mammals by P. Mein, J.-P. Aguilar and M. T. Antunes, who ensured the coordination and the redaction.

The characterization of a regression event rather accurately dated at 17.5 Ma (Antunes *et al.,* 1999) in the distal part of the basin and the corresponding environments are our current aim.

2. PLANT REMNANTS (Plates I-III)

Except for the lack of cuticles, impressions of plant leaves are quite well preserved. These were ascribed to the following forms (table 1).

Table 1

Cristo Rei section, IVb unit (Fig. 2)

PLANT TAXA

Lygodium gaudini Heer
Comptonia acutiloba (Unger) Saporta
Myrica cf. *lignitum* (Unger) Saporta (*)
Populus serrulatus (Heer) Pais
Ulmus bronnii Unger
Podogonium oeningense (Koenig) Kirchheimer
Zelkova zelkovaefolia (Unger) Buzek & Kotlaba (*)
Sapindus falcifolius (Braun) Braun
Magnolia oedipa (Heer) Pais
Daphnogene polymorpha (Braun) Knobloch & Kvacek
Cf. *Engelhardtia orsbergensis* (Wessel & Weber) Jahnichen, Mai & Walther (*)
Gleditschia knorrii (Heer) Gregor

Some taxa are common in Central Europe but new as far as Portugal is concerned (*), i.e. *Zelkova zelkovaefolia, Myrica lignitum* and cf. *Engelhardtia orsbergensis. Comptonia* occurs in the Plio-Pleistocene at Quinta do Jardim near Óbidos (Teixeira, 1973; Teixeira & Pais, 1976, p.174) as well as in the upper Middle Miocene at Póvoa de Santarém.

The commonest species is *Podogonium oehningense,* followed by *Populus serrulatus.* The remaining species are represented but by 2 or 3 specimens, and a few by a single fossil.

The analysis of foliar physiognomy shows, for the macroremains collected at the IVb unit, 5.6% leptophyll, 22% nannophyll, 61.1 % microphyll and 11.1% notophyll (Pais, 1981; 1989). On the other side, the leaves' morphology from the IVb unit shows a large (55%) majority of entire leaves.

Stratigraphic correlation shows that the Cristo Rei plant fossils are younger than the already known plant sites from the lower part of the IVb unit in Lisbon (Quinta do Bacalhau and Quinta do Fidié, near Campo Grande) under the fluviatile sands with mammals and other vertebrates. It compares well in time with plant sites at Quinta das Pedreiras and Areeiro da Barbuda, Lisbon, both being a little later than the IVb sands. Anyway the time span between the lower and upper IVb plant sites is not great, nor are there any meaningful differences as far as plant associations are concerned.

These matters were accounted in a synthesis on the evolution of the vegetation and climate during Miocene times (Pais, 1986).

3. FISHES

Fish remnants (mostly teeth) belong to teleosteans as well as selachians.

Among the former, teeth from Sparidae largely outnumber any other bony fish parts. One may assume that there is a huge majority of sea-breams. Among Sparids, a number of teeth can be reported to *Sparus,* especially the larger molariform ones. Determination of other teeth is more uncertain, as they may belong to *Sparus* as well as to other genera, i.e. *Pagrus, Pagellus* or even *Sargus* and allied forms. The presence of *Sargus* is certain on the basis of its incisiviform anterior teeth. On the other side, barracudas (several species of *Sphyraena,* common in other sites) are poorly represented, as coral-eaters or reef-dwellers as *Balistes* and *Tetrodon.*

Fresh- to brackish-water fishes are unknown except perhaps *Lates,* if a few bone fragments really belong to these fishes. However *Lates* (that is common elsewhere in the same basin in association with land mammals) may have been more or less euryhaline (Antunes, 1989).

The corresponding environments may have been rich in benthic molluscs, whose shells would easily have been destroyed through intensive abrasion on sand bottoms under agitated waters coupled with $CaCO_3$ chemical, diagenetic elimina-tion. Only the large and by far the more resistant oyster valves subsisted.

The selachian fauna is shown (table 2; see Fig. 3).

Table 2

Cristo Rei section, level with mammals (Fig. 2)

SELACHIANS - SHARKS, SKATES AND RAYS

(Number of teeth)

SQUALOMORPHII

Pristiophorus sp. (5)

GALEOMORPHII

Megascyliorhinus miocaenicus (Antunes & Jonet) (3)
Scyliorhinus joleaudi Cappetta (23)
Paragaleus pulchellus Jonet (24)
Hemipristis serra Agassiz (1)
Galeocerdo aduncus Agassiz (1)
Rhizoprionodon sp. (7)
Carcharhinus priscus Agassiz (92)
Sphyrna sp. (19)

BATOMORPHII

Rhynchobatus pristinus Probst (20)
Rhinobatos sp. (70)
Dasyatis gr. *centroura* Mitchill (123)
Dasyatis gr. *gigas* Günther (194)
Myliobatis sp. (10)
Pteromylaeus sp. (2)
Rhinoptera sp. (3)

Even if numbers of teeth cannot be converted into numbers of individuals, they give indications about relative numbers. The sandy levels under study yielded teeth from nine shark taxa plus seven batoid ones, as well as several teleosts referred to above.

Two forms were known in the basin, but in much later (Serravallian and lower Tortonian) beds: *Pristiophorus* and *Megascyliorhinus*.

Small Carcharhinids *(Carcharhinus priscus, Paragaleus pulchellus)* prevail along with *Scyliorhinus joleaudi*. Hammer-heads *(Sphyrna)* are rather common.

Larger Carcharhinids *(Hemipristis, Galeocerdo)* are exceedingly rare. No Lamniforms were found, even the often very common sand sharks *(Carcharias)*. Other large-sized Lamniforms (as *Carcharocles, Isurus,* and *Alopias)* are conspicuously absent. Of course, granulometric selection may in part account for this, but it can be but a minor factor to reckon with.

The commonest batoids are *Rhinobatos* sp., *Dasyatis* gr. *gigas,* and *Dasyatis* gr. *centroura.*

Nearly all selachians point out to moderately warm waters. The sawshark *Pristiophorus* is the sole apparent discordance, to be discussed later. The rarity of the larger Carcharhinids as well as the absence of other stenotherm, warm water forms as lemon shark *(Negaprion)* and nurse-shark *(Ginglymostoma)* may be related to very shallow environments. That rarity does not point out to even warmer waters. On the other hand, temperate or cold water dwellers as Squaliforms *(Squalus, Deania)* and *Raja* are unknown.

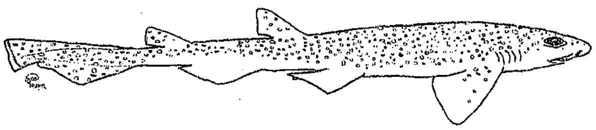
The selachians point out to very shallow waters. The sole exception (deeper environments, lower temperatures) is that of *Pristiophorus,* but its presence may result from upwelling currents that either displaced live animals or corpses. Its rarity is not enough to change the moderately warm water interpretation.

4. CROCODILIANS

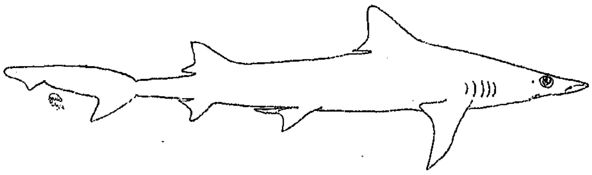
Rare crocodilian teeth from the Cristo Rei section indicate the common association in littoral or estuarine areas during the Lower and early Middle Miocene of the basin (Antunes, 1987, 1994): this comprises a very large and heavy Tomistomine, *Tomistoma lusitanica,* probably a large-prey predator; and an also large-sized but very slender-snouted and sharp-teethed *Gavialis* sp., mainly ichthyophagous. Both genera seem to have immigrated from Asia into western Europe, *Tomistoma* at least since the upper Oligocene (Antunes & Cahuzac, 1999), and *Gavialis* in the lower Miocene. Migrations seem correlative of transgressive (and warmer) events.

Crocodilians are stenotherm, warm and humid area dwellers, but not evenly so. Extant alligatorines and certain small crocodylines are (or may have been) somewhat more tolerant to less high temperatures. It may be accepted that crocodilians do not live in otherwise suitable environments

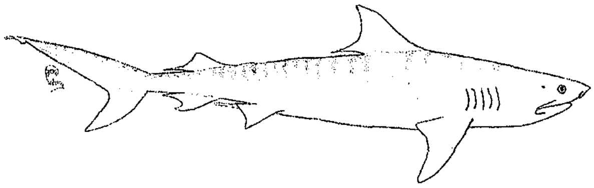
Fig. 3. Sharks and Rays: some extant representatives of genera identified from the levels with mammals (see Fig. 2)



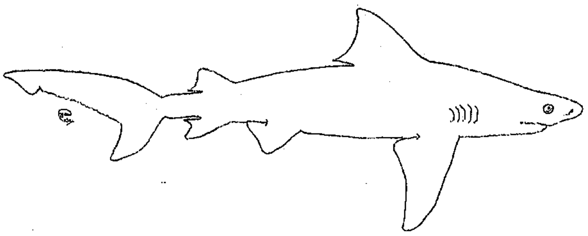
Scyliorhinus canicula
(max. length 100 cm)



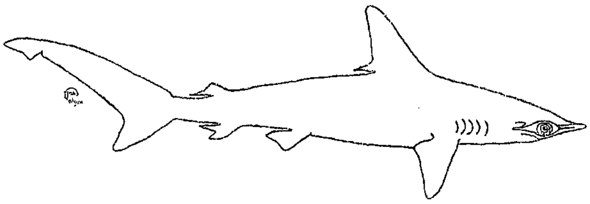
Paragaleus pectoralis
(max. length 138 cm)



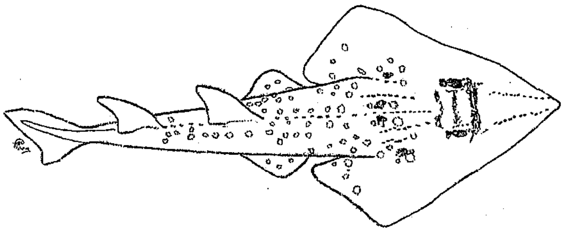
Galeocerdo cuvieri
(max. length 480 cm)



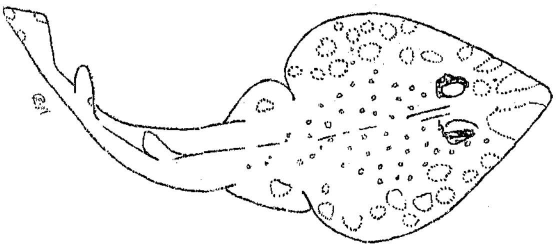
Carcharhinus leucas
(max. length 340 cm)



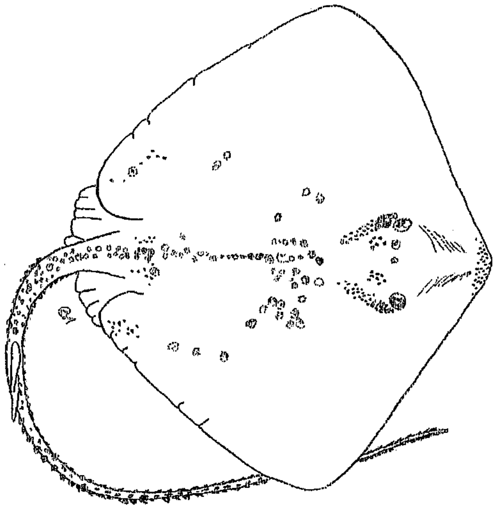
Sphyrna zygaena
(max. length 370 cm)



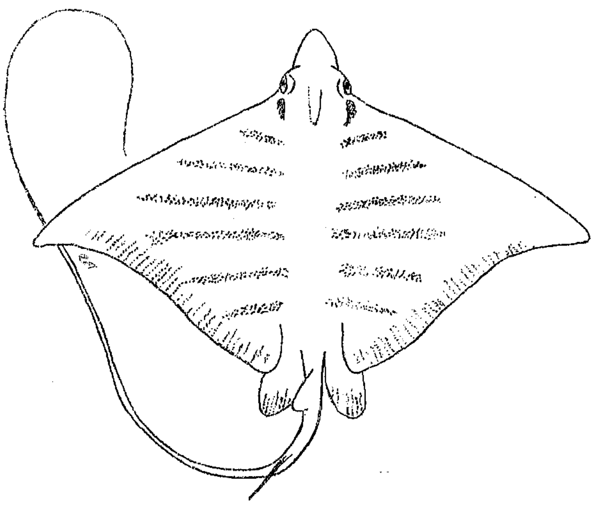
Rhynchobatus lüberti
(max. length 300 cm)



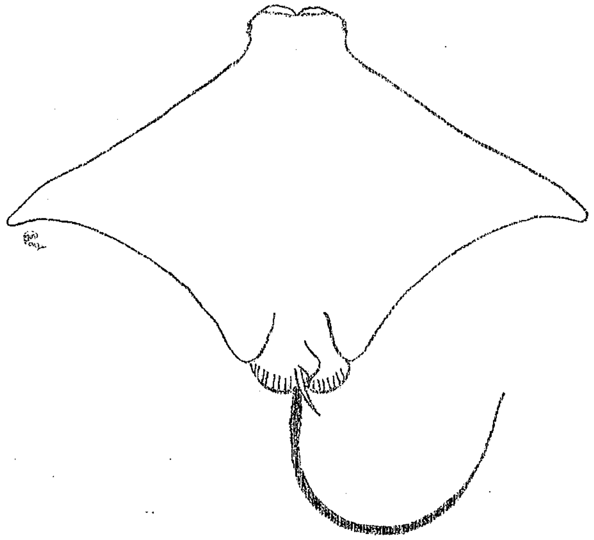
Rhinobatus blochii
(max. length 100 cm)



Dasyatis centroura
(max. length 330 cm)



Pteromylaeus bovinus
(max. length 150 cm)



Rhinoptera javanica
(max. length 213 cm)

where temperatures fall under about 10 degrees at the coldest time of the year. Past evidence seems compatible with this. Furthermore, *Tomistoma* and *Gavialis* are strictly tropical today, as most probably they were before. Their decadence and local extinction during lower Upper Miocene in the concerned region is related to a marked temperature decrease during Middle Miocene times.

5. MAMMALS

As it can be recognized by correlation with the Lisbon area, the Cristo Rei sands (about 17.2 Ma) are a little higher stratigraphically than the IVb feldspathic sands (ca. 17.4 Ma) in Lisbon. The latter yielded a mammalian fauna with *Gomphotherium angustidens* (but still no *Prodeinotherium),* a number of other medium to large forms and especially the last Anthracothere, *Brachyodus onoideus* (Antunes, 1984; for a full check-list see Antunes in Antunes *et al.*, 1996, Addendum, p. 72). No small mammals are known at exactly these deposits. There is only an hitherto unpublished minor locality just under the feldspathic sands at Avenida Professor Vieira de Almeida, in Lisbon, where a Glirid, *Pseudo-dryomys simplicidens,* was collected.

The Cristo Rei mammalian taxa are as follows (table 3).

Table 3
Cristo Rei section
MAMMALIAN TAXA
(List of rodents revised by J.-P. Aguilar, July 97)

ARTIODACTYLA
- *Cainotherium miocaenicum* Crusafont & Villalta (see Fig. 4-5)
- *? Lagomeryx ruetimeyeri* Thenius

LAGOMORPHA
- *Lagopsis peñai* (Royo)

RODENTIA
- *Pseudodryomys simplicidens* de Bruijn
- *Pseudodryomys robustus* de Bruijn
- *Peridyromys murinus* (Pomel) ou *biradiculus* Mayr
- *Ligerimys antiquus* Fahlbusch (whose evolution stade can be compared to those from Beaulieu and Moratilla)
- *Heteroxerus* sp.

According to P. Mein, the association of small mammals points out to the MN3 mammal-unit, as all the IVb sites with large mammals.

The MN4 mammal-unit is represented by the fauna from the overlying Va_2 subdivision at important sites as Quinta das Pedreiras (Lumiar) and Quinta do Pombeiro (Chelas), in Lisbon. It is marked by the arrival of *Amphicyon giganteus, Bunolistriodon lockarti, Prodeinotherium bavari-*

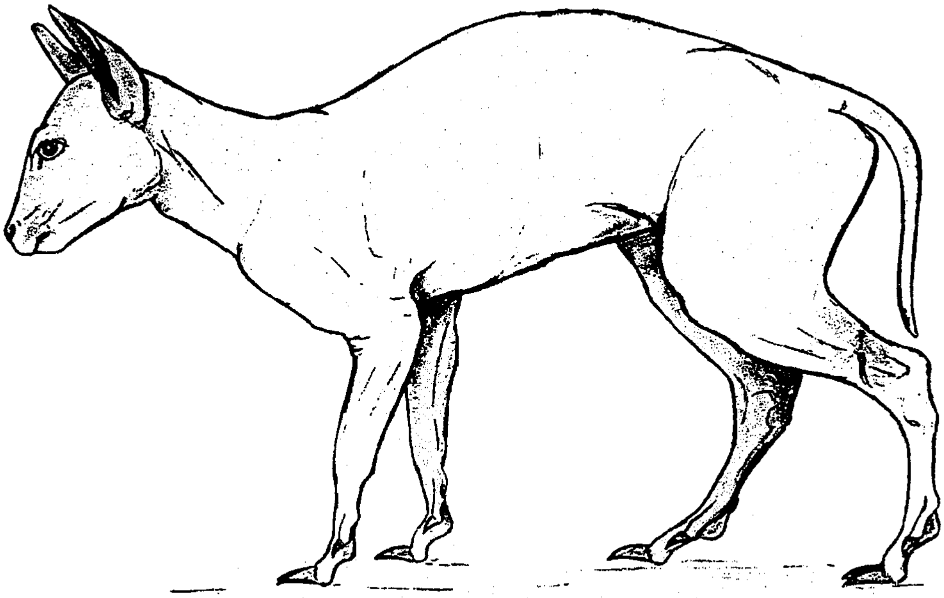


Fig. 4. Reconstitution of *Cainotherium*

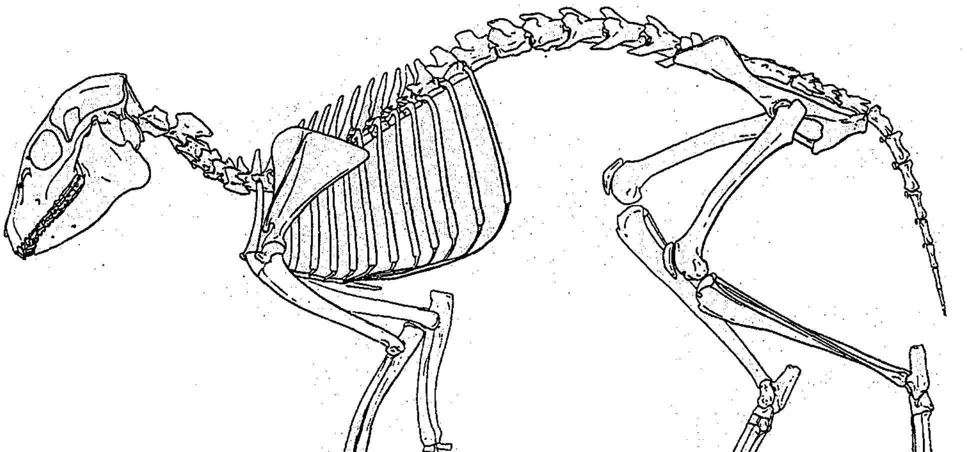


Fig. 5. Reconstitution of *Cainotherium* skeleton

Fig. 4-5 according to Hürzeler, J. (1936) – Osteologie und Odontologie der Caenotheriden. *Abh. Schweiz. Paläont. Ges.*, 58-59, 1-111.

cum, *Megacricetodon primitivus* and *Democricetodon hispanicus* (for a full check-list see Antunes, *ibid.)*. Age is ca. 16.7 Ma. Hence the mammal-unit changed sometime in a span of about an half million years.

Cristo Rei mammals provide information of environmental interest (Antunes & Mein, 1986, p. 132-133; Antunes & Mein, 1992, p. 138-139): *?Lagomeryx ruetimeyeri,* a small Cervid, probably was a dweller of forest, or of forest with open spaces; *Pseudodryomys simplicidens* – terrestrial, open spaces; *Pseudodryomys robustus* – maybe terrestrial, open spaces; *Peridyromys muri-nus* ou *biradiculus* – terrestrial, steppe environ-ments; *Ligerimys antiquus* – forest; *Heteroxerus* sp. – terrestrial, forest with open spaces.

6. SYNTHESIS

The Cristo Rei fossils (plants, fishes, mammals) from the sands with intercalated silty clays are older than the overlying Va marine unit dated at ca.17.2 Ma, the lower time limit being about 17.5 Ma. Evidence seems compatible with an estuary where there was an influx of coarse sands related to transportation by a large river.

Under a biogeographic viewpoint, plant affinities are asiatic *(P. serrulatus, Z. zelkovaefolia,* cf. *E. orsbergensis, ? S. falcifolius),* american *(M. oedipa, C. acutiloba),* and maybe african *(P. oehningense* and *M. lignitum).* Most fishes have huge geographic distribution and hence are not characteristic. Crocodilians have asian affinities. Mammals are common in western Eurasia and thus not very characteristic either.

In comparison with extant data, foliar physiognomy and foliar morphology point out to low mountain, subtropical forests under warm temperate and rainy, or seasonally dry environments. The plant association suggests warm temperate to subtropical conditions. It mostly reflects humid areas close or not far from a river, and not far away low mountain subtropical forests under warm temperate and rainy (seasonally dry) conditions. More inland plants had poorer chances to be present in the clayey lenses.

The generalized small size of the fishes suggests that most were juvenile. This also seems to discard strictly marine, open environments. It points out to estuarine or close-by, very shallow waters. Transported, more or less abraded valves of *Gryphaea griphoides* reveal the existance of oyster banks in brackish waters not so far upstream.

No deep sea fishes occur except perhaps *Pristiophorus,* whose scarce remnants could mean an eventual influence of upwelling. Large numbers of salt water fishes stress the greater proximity of the open sea than in Lisbon, where there are fluviatile, feldspathic sands in the IVb division. The ichthyologic fauna points out to at least moderately warm, very shallow, littoral or even estuarine salt water environments.

Crocodiles and especially the *Tomistoma* plus *Gavialis* association are maybe the best thermal indicators for a warm, never cold in the coldest season, climate and humid environments.

Mammals correspond to several ecological niches. Some were forest dwellers (Cervid, *Ligerimys);* this corroborates plant evidence of forests. Others are terrestrial, living in forest with open spaces *(Heteroxerus),* in open spaces *(Pseudodryomys* spp.), or steppe *(Peridyromys).* Mammals show that there were also more open ones with a less dense tree and shrub cover, or even steppe. Humid areas did not occupy the whole region.

The banks of the river and channels, as well as nearby areas were forested. Humid, freshwater areas were quite extended, hygrophyll plants as *Populus* being very common. Shifting channels left oxbows with often stagnant waters, where clays and plant leaves carried in by low-energy waters accumulated. As no *in situ* roots were found, these salinity non-tolerant plants mean that they lived somewhere in upstream areas.

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PLATE 1

(Scale in millimeters)

Fig. 1 - *Lygodium gaudini* Heer
Figs. 2, 3 - *Comptonia acutiloba* (Unger) Saporta
Fig. 4 - *Sapindus falcifolius* (Braun) Braun
Fig. 5 - *Zelkova zelkovaefolia* (Unger) Buzek & Kotlaba
Fig. 6 - *Polpulus serrulatus* (Heer) Pais
Fig. 7 - *Myrica* cf. *lignitum* (Unger) Saporta

PLATE 1


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PLATE 2

(Scale in millimeters)

Fig. 8 - *Sapindus falcifolius* (Braun) Braun
Figs. 9, 10 - *Populus serrulatus* (Heer) Pais
Fig. 11 - Cf. *Engelhardtia orsbergensis* (Wessel & Weber) Jahnichen, Mai & Walther
Figs. 12, 13 - Undetermined taxa

PLATE 2

8

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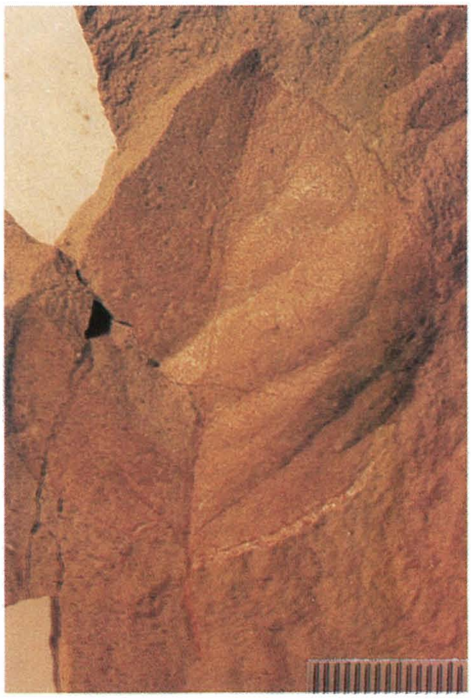

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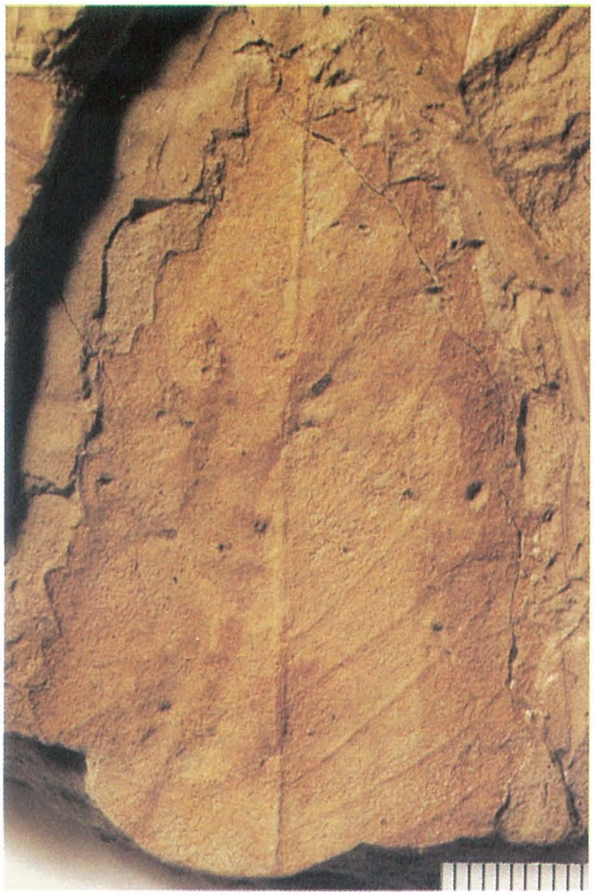
PLATE 3

(Scale in millimeters)

Figs. 14, 15 - *Ulmus bronnii* Unge
Fig. 16 - *Daphnogene polymorpha* (Braun) Knobloch & Kvacek
Figs. 17, 18 - *Podogonium oeningense* (Koenig) Kirchheimer
Fig. 19 - *Gleditschia knorrii* (Heer) Gregor
Figs. 20, 21 - Undetermined taxa

PLATE 3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