

The Neogene of Portugal

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ABSTRACT

Key words: Neogene; Portugal.

After a brief historical introduction, this paper deals with the main concerned geotectonic units: the Lower Tagus and Alvalade basins, the Western and Southern borders, and their infillings. Most of the Neogene events and record concern areas South of the Iberian Central Chain, a nearly inverse situation as that of Paleogene times.

In the most important of these units, the Lower Tagus basin, there are quite thick detrital series, mostly marine in its distal part near Lisboa (albeit with several continental intercalations), and mainly continental in its inner part. Sedimentological record is almost complete since Lowermost to Upper Miocene. The richness of data (paleontology, isotope chronology, paleoclimate, etc.) it gives and the possibility of direct marine-continental correlations render this basin one of the more interesting ones in Western Europe.

Alvalade basin is separated from the previous one by a barrier of Paleozoic rocks. Two transgressions events (Upper Tortonian and Messinian in age) are recorded. Active sedimentation may be correlated to Late Miocene tectonics events.

In Algarve, chiefly marine units from Lower to Upper Miocene are well developed. The Lower unit (Lagos-Portimão Formation) is best exposed in Western Algarve, but disappears eastwards. Middle Miocene is not as well known, whereas Upper Miocene main outcrops are in Eastern Algarve. Cacula Formation is remarkable for its beautiful fossils. Sedimentation as a whole reflects the tectonic activity and in special the evolution of the Algarve flexures. There is scant evidence of post-Lower Miocene volcanism, the latest known in Portugal. Pliocene has not been recognized there beyond doubt.

Miocene sediments are much less important to the North of the Central Iberian Chain. Continental beds near Leiria that yielded the well-known "*Hispanotherium* fauna" are lower Middle Miocene.

Pliocene corresponds to dramatic changes in paleogeography. At Setúbal Peninsula there is some evidence of a minor Lower Pliocene transgression. Continental detrital sediments, often coarse, occupy rather large areas. In Western Portugal between the Setúbal Peninsula and Pombal there is good evidence of a marine Upper Pliocene transgression, followed up by dune sands overlain by marsh clays, diatomites, lignites and boghead levels that can be partly Pleistocene in age.

FOREWORD

After years of research dedicated to the Mediterranean Neogene (Project Nº 25, IUGS-UNESCO), there has been a considerable development in activities concerning the Atlantic Neogene.

Within this framework, the hinge-like situation of Portugal is quite interesting, considering the fact that the Neogene units here are well represented and complete. This is particularly true for the Tagus basin, that has a very rich record.

At the beginning of the XIX century, research has been conducted by the remarkable mineralogist (and politician) José Bonifácio de Andrada e Silva (1763-1838). Towards the 30's and 40's, the contributions due to Baron Von

Eschwege, Alexandre Vandelli, Daniel Sharpe and a few others followed. Meanwhile, there was a considerable development in investigations with the second Geological Commission (1857-1867), mainly due to the field works of Carlos Ribeiro and the important contributions of Francisco Pereira da Costa.

After being abandoned for a while, the studies were vigorously restarted at the Geological Survey with Jorge Cândido Berkeley Cotter, towards the end of the century. Lithostratigraphic classification, now considered classical but still used in the Lisboa Miocene, is due to him.

Some of the most remarkable paleontologists at the time, such as Oswald Heer, F. Fontannes, Perceval de Loriol, Frédéric Roman and Gustave Dollfus gave important contributions.

After a long eclipse, there was a remarkable resumption of Neogene studies due to Portuguese geologists or foreign geologists at the service of Portugal. G. Zbyszewski deserves a special reference for his work.

Finally, we have tried to develop and coordinate efforts to reach the knowledge that, in spite of the amount of data already obtained, is far from being complete. This justifies the follow-up of researches that are frequently done with the collaboration of colleagues from other countries.

THE NEOGENE

The Neogene is widely represented in Portugal. However, its geographical distribution is not homogeneous. Generally

speaking, the Miocene formations are particularly important to the South of the Central Mountain Range and the Nazaré fault in the continent as well as in the continental shelf as far as Algarve. Special reference is made to the Miocene of the terminal part of the Lower Tagus basin due to its remarkable importance in the frame of Western Europe. It will be followed up by references to the Miocene in the inner (Ribatejo) part of the same basin; to the southern basins where Miocene units are better developed; and finally to Miocene or supposedly Miocene units to the North of the Iberian Central Chain.

The Pliocene, whose paleogeography is quite different, mainly corresponds to a band that basically stretches along the shore line. The importance of the inland Pliocene deposits is quite limited.

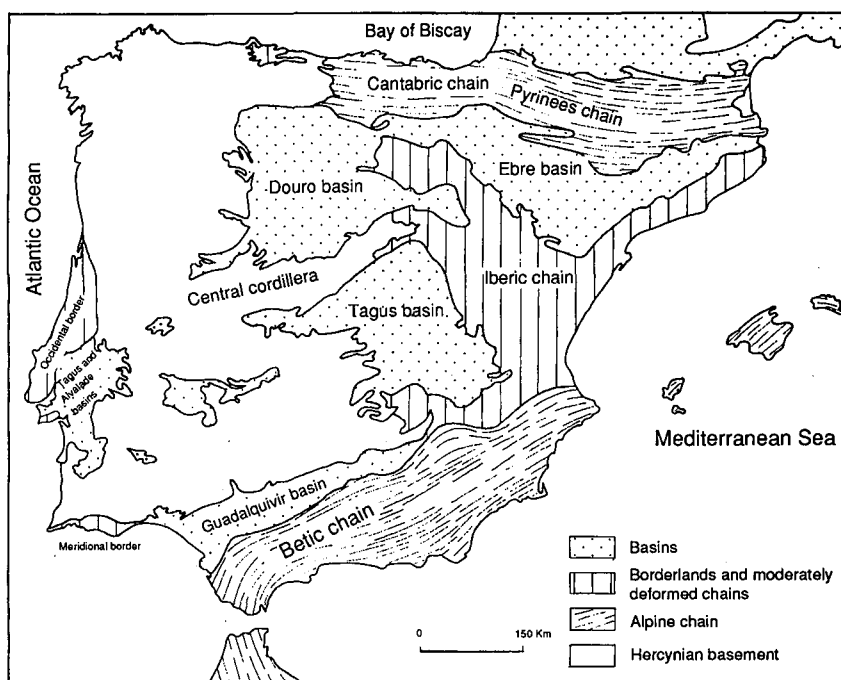


Fig. 1 — Morphostructural units of the Iberian Peninsula (Lautensach in Ribeiro *et al.*, 1979, modified).

THE MIOCENE OF THE TAGUS BASIN

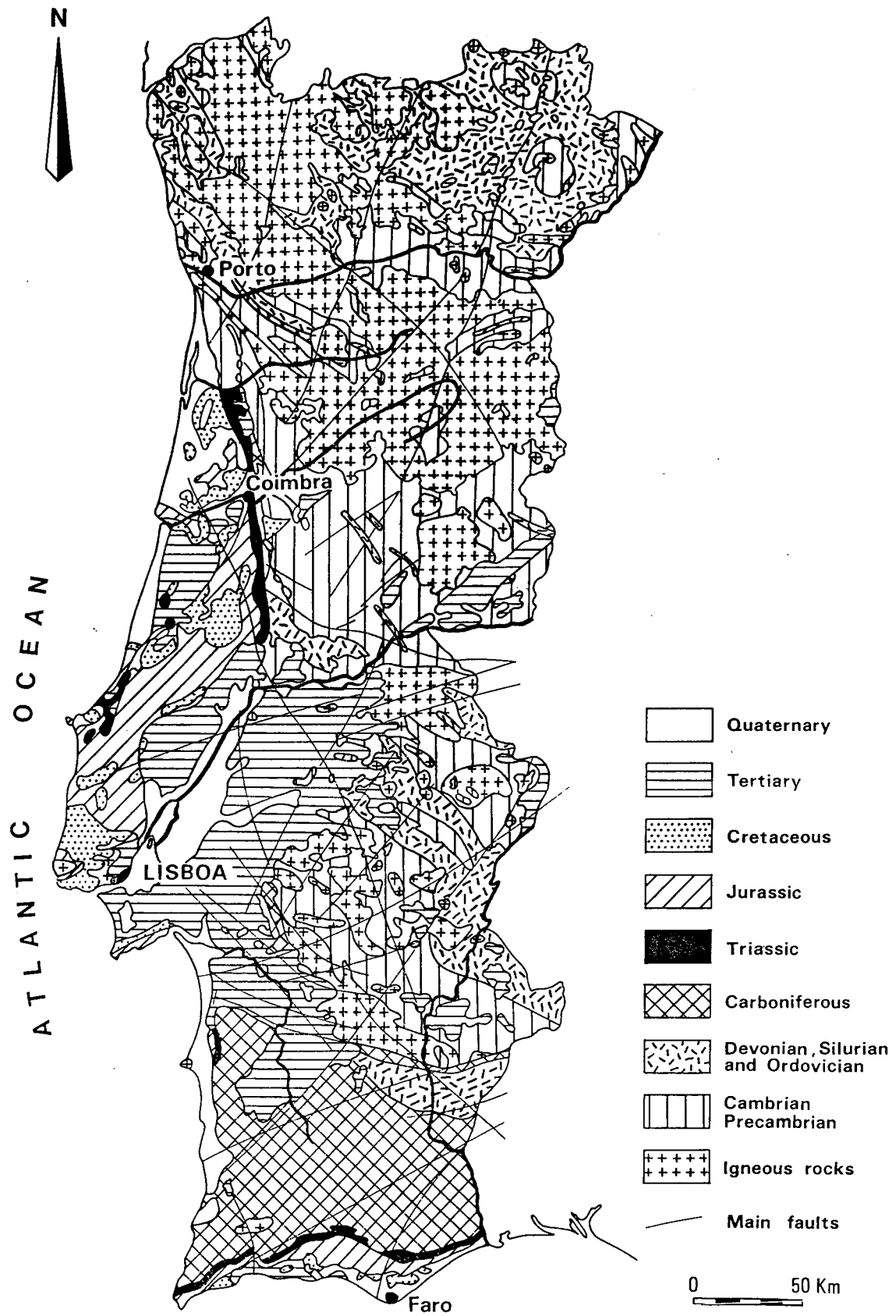
The Neogene of the lower Tagus basin is remarkable in several ways: its geographical position, in the limits of the Mediterranean and Atlantic domains; the very complete representations of nearly all stages, from the Lower Aquitanian up to the Pliocene; the richness of the data provided; the possibilities of geological correlations and their economical importance.

In Lisboa, the thickness of the Miocene does not exceed 300 meters, and the Pliocene is hardly represented; to the South, the thickness of the whole Neogene increases to about 1200 meters (results obtained from deep boreholes) whereas the outcropping Pliocene reaches the thickness of 50 meters or more.

Generally, several marine ingressions and the same amount of intercalated regressions were situated at the terminal region of the basin; one may enumerate several sedimentary cycles framed by transgression and the following regression, seven for the Miocene and one or two for the Pliocene. Subsidence was intensive and was compensated by active sedimentation. The continental debris arrived in large quantities mainly during the orogenic movements which reactivated old hercynian faults.

The Miocene in the western region of the Tagus basin

The Oligocene-Miocene boundary is a problem in the Tagus basin as well as in other basins where the



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Fig. 2 - Simplified geological map of Portugal.

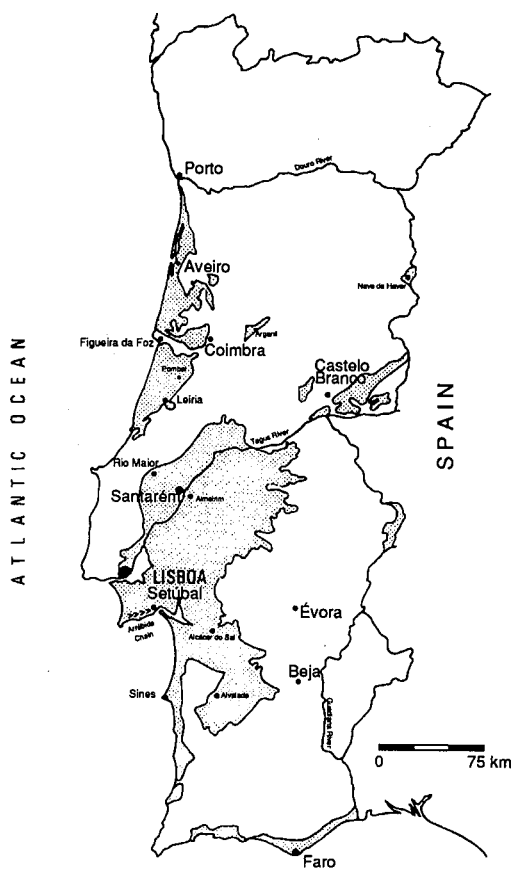


Fig. 3 - Main Tertiary deposits of Portugal.

Aquitanian does not grade down to a marine Chattian. Thus, the lower layers which correspond to the first sedimentary cycle, have supplied apparently archaic fossils (certain ostracods, pollens, etc.), suggesting an Oligocene age. Another important fact is the presence of glauconite dated by K-Ar to 24 ± 1 Ma and $21,1 \pm 0,5$ Ma. As far as accuracy is concerned, the method used is subject to errors that are not always controllable. The date in question seems to overtake the 22.5 Ma limit accepted by some authors. Other authors, in fact, place the Oligocene-Miocene limit at 24 or even 25 Ma.

In some places, the Aquitanian overlays unconformably older units. Elsewhere, there is a continuous passage evidencing the development of the first miocene transgression.

The region between Lisbon and the Arrábida chain is important. In the present state of knowledge, seven miocene cycles (marked T0 to T6) and at least a cycle belonging to the Pliocene (Fig. 5) have been identified. One has to note the considerable wealth of these facies as well as paleontological information. The positions of the levels containing mammals are easily referred in relation to the marine formations. These allow the possibility of doing direct correlations of the first order between marine and continental horizons, at least for the lower Miocene and the first stages of the Middle Miocene. One may also recognize

climate changes. Changes are important in marine fauna: tropical conditions were predominant, at least since the genesis of the coralline barrier reefs of the Aquitanian; maximum sea temperatures, comparable to the present day Gulf of Guinea, were reached at the Upper Burdigalian and Langhian. Later, the prevailing conditions were closer to those existing at the present day in the moroccan coast with a slight increase in Middle Tortonian; however temperature never reached again the earlier maximum.

The fauna and vegetation of the continent indicate humid periods alternating with relatively dry ones, leading to forestal environments rather than savannah or steppe.

Transgressions and regressions also had palaeogeographical consequences (Fig. 5; Fig. 6): limited ingressions forming a narrow gulf (T0); aquitanian gulf spread out to the hinterland up to the region of Almeirim (T1); similar circumstances for (T2) in the great Aquitanian transgression and for the Burdigalian; at the late Burdigalian-early Langhian two brief oscillations (T3 and T4) gave rise to important changes with the submergence of the Sado basin and the coast North of the Serra de Sintra; at the apogee of the Serravallian transgression (T5) the Serra de Sintra-Caneças anticline probably became an island while the maximal progression inland was responsible for the establishment of the Tejo/Sado basin beyond Santarém (these indications allow one to correlate the continental deposits of Ribatejo with the marine formations); lastly, the gulf has clearly shrunk during the Lower Tortonian.

The fundamental lithological characteristics are indicated as a whole in the given scheme (Fig. 4).

The Pliocene formations, or supposed as such, are more reduced and not as well known. Firstly, a series of feldspathic sediments, mostly coarse and of continental facies, have never been properly dated. They overlie the marine lower Upper Miocene. However, as the last well dated layers are not later than Lower Tortonian, there is a considerable poorly defined gap (Messinian or Zanclean?). These sediments show the setting up or the renewal of an important hydrographic network. The mouth could be situated further to the South, near Fonte da Telha.

The preceding series is overlaid by marine layers that are more or less coarse, mostly sandy, with a mollusc fauna reported to the Piazencian, and some plants (dealt with later in this paper).

The Pliocene gulf was not well developed to the East. On the other hand, the deposits related to the Pliocene transgression stretch from the North of Portugal to the Algarve. This is limited to the costal region that is more or less reached by marine erosion.

The Miocene of Ribatejo

On the contrary to the region of Lisbon, the Miocene of Ribatejo is essentially continental. However a few intercalated brackish or even marine beds are known.

The oldest formations are as follows:

— the Serra de Almerim Aquitanian, the only outcropping marine formation of this age. It is equivalent to part of the layers with *Venus ribeiroi*, occurring in Lisboa and its surroundings;

— poorly known marine layers, drilled to a certain depth by boreholes (Tagus right bank, Coruche map);

— detrital assemblage of Arneiro and Ota, comprising intercalations of oysters in its upper part.

This heterogeneous last unit is poorly defined. It is often admitted that it may comprise palaeogene layers, exceeding a burdigalian age (up to an "helvetian" one).

However, one may recognize that the majority of the outcrops are more modern. On the right bank of the Tagus, one may have a precise view of the stratigraphy and age of most of the series, which corresponds mainly to the upper part of the Middle Miocene and to the lower part of Upper Miocene (continental stages: Astaracian and Vallesian). This is due to the recent discovery and reinterpretation of a certain number of mammalian localities. There is initially a predominance of sands and clays with carbonate levels as well as lignites; above this there are some important limestone layers, specially at Cartaxo-Almoster-Santarém, with some intercalated sandy beds. We are now able to date these limestones as Upper Vallesian and can consequently recognize that its deposition occurred during a quite short time span and does not seem to attain Uppermost Miocene (Turolian).

The lack or paucity of available information has made difficult the whole interpretation for the Miocene of the left bank of the Tagus, where the upper limestone horizons are absent.

On the other hand, the argillaceous layers outcrop in large outspreading extensions (mainly in the valleys) and stretch to the Sado basin. Their age corresponds more or less to the second half of the Middle Miocene and/or to the lower part of Upper Miocene. In places, these deposits overlie oyster deposits, which seem to represent the apogee of the Serravallian transgression. The argillaceous layers are covered by arkosic sands with beds with gravel and pebbles, probably of Pliocene age.

The Neogene infilling of the Tagus basin corresponds, with minute variations, to the mean-water bed and the flood plain of a river and its tributaries, carrying materials from the "Hesperic Massif" or from the limestone massif to the West. Later on, in an environment characterized by advanced relief leveling, with extensive zones subject to a lacustrine regime and a certain aridity, the carbonate sedimentation was predominant.

At Ribatejo, the last Miocene layers are overlain, with a clear contrast, by generally coarse-grained detrital deposits which correspond to a fluvial sedimentation. These deposits cover erosion surfaces. The most important layers ascribed to the Pliocene are the ones that made up the infilling of the Rio Maior graben basin (and also to a lesser degree that of Vale de Santarém graben). These consist of a rather thick succession of industrially exploited white sands, overlain by diatomites and important layers of lignite and some boghead coal.

The Miocene of the Alvalade basin

To the South of the Tagus basin, in an area corresponding to the present day hydrographic Sado basin, another basin (the Alvalade basin) was formed. This basin is separated from the Tagus basin by a horst of paleozoic rocks (Senhor das Chagas-Valverde), and was only crossed by the River Sado in Quaternary times. Formerly, its identity was not recognized; all the corresponding area and the geologic units of its infilling were regarded as a part of one Tagus-Sado basin. Indeed the Senhor das Chagas-Valverde horst acts as a barrier. Shallow marine, mainly sandy beds were deposited at both sides of this barrier. No one clearly doubted that the corresponding transgressive events were correlative; they were instead treated together. However accurate dating was possible on the basis of small mammals; marine beds to the North and West of Senhor das Chagas - Valverde dated from Late Serravallian and perhaps Lower Tortonian were, for the first time, recognized as certainly not correlative of the much later southern ones, recognized as Upper Tortonian and Messinian (Antunes *et al.*, 1986). Hence both sides of the barrier had independent geologic histories and must be regarded as distinct entities — the northern part being just a part of the Tagus basin, the southern part an independent basin, that we named Alvalade basin. Its shallow marine sediments filled in a SW-NE through (then a gulf) between Paleozoic blocks, a western one more or less corresponding to the extant Cercal and Grândola serras, and eastwards the "Sul Portuguesa" zone of the Hesperic massif. Evidence points to a marine ingression from the Southwest through the Odemira — S. Teotónio region. Recent hydrogeologic data concerning subsurface draining pattern show that it corresponds to the dual basin former situation; it thus corroborates our viewpoints about it (Ribeiro & Costa, 1992).

THE MIOCENE OF ALGARVE

Most Neogene in Algarve is of Miocene age.

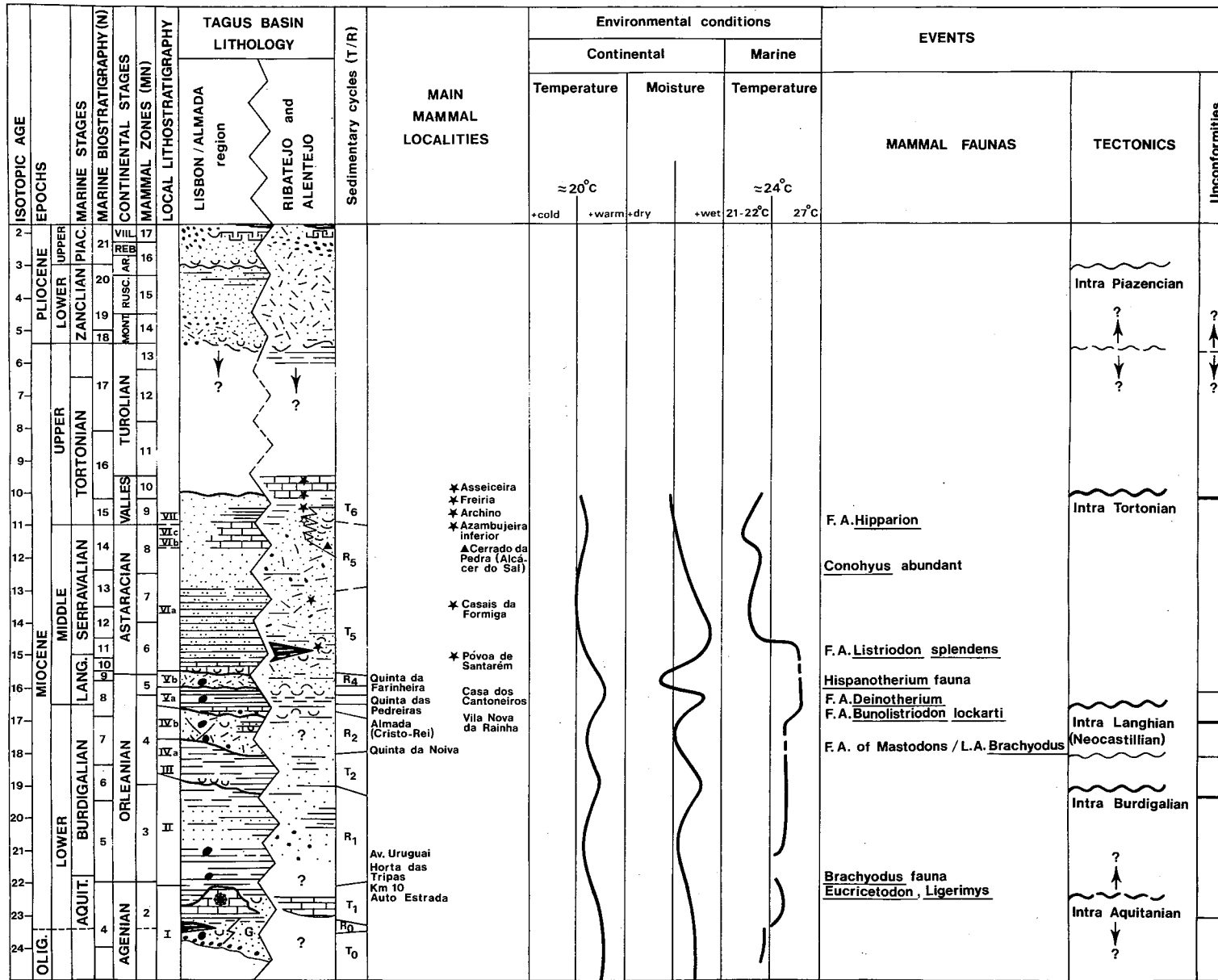
No unit was ascribed to or dated as Pliocene, which does not mean that deposits of this age do not occur. Those of Morgadinho (Antunes *et al.*, 1986b) are probably (at least in part) Pliocene in age.

The Cenozoic units of Algarve are shown in the fig. 6, and will be discussed by age order from the earliest one.

Lagos - Portimão Formation

This unit overlies Carboniferous, Jurassic, Cretaceous and possibly Paleogene units. In some places a very clear angular unconformity can be observed, whereas in other places stratigraphical hiatuses or paraconformities are recognizable.

This unit comprises yellow or pink massive and very fossiliferous biocalcarenes. At its lower part Molluscs



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Fig. 4 - Lithological, chronostratigraphical, environmental conditions and main events table from Tagus basin.

are abundant. An Aquitanian age cannot be excluded for it. As for the top, there are many sea-urchins, Bryozoa, pectinids and fishes. Foraminifera point out to a Burdigalian or Lower Langhian age (Antunes *et al.*, 1981).

This Formation is the most spectacular Miocene unit in western Algarve. It makes up a considerable portion of the coastal sea cliffs.

Calcareous sandstones with pebbles

This is an assemblage of poorly exposed carbonate rocks rich in detrital material. It was formed after the Lagos - Portimão Formation, which it overlies with a distinct erosion surface (Praia da Rocha).

The lower part of this unit consists of sandy limestones with sand-wave type structures (Olhos de Água). These are followed by very fossiliferous limestones rich in quartz pebbles. Pectinids are most frequent among the fossils. Oyster banks are also known.

These deposits correspond to a shore line facies.

Orbulina indicates a post Lower Miocene age. Relative position shows that this unit is older than the glauconite silts at Praia da Galé, K-Ar dated (10.1±0.25 Ma). The best outcrops are the highest part of Praia da Rocha cliffs (near Albufeira) and the beach near Olhos de Água.

Olhos de Água sands

Near Olhos de Água, there is an outcrop of a thick sand series between the calcareous sandstones with pebbles unit and the Faro-Quarteira sands.

This succession starts by alternating sandy and pelitic layers (flaser facies) overlain by cross-bedded brownish sands and followed by feldspathic white sands. Over these sands there are beach sands and conglomerates with oysters, pectinids and remnants of abraded aquatic Vertebrata. Mollusks indicate estuarine environments and brackish waters.

The majority of the fishes are marine, frequently of very large size (*Carcharocles megalodon*, *Isurus hastalis*). The degree of abrasion of the vertebrate remnants suggests that they were rolled by waves in shallow, sandy bottoms at a beach. The Sirenians point out to shallow seashore environments, rich in aquatic vegetation. The presence of fish like *Lates*, as well as that of feldspathic sands seems to show the existence of a large river whose mouth was close by. The presence of large crocodilians as *Tomistoma cf. lusitanica* corroborates these views and indicates sub-tropical conditions.

Mollusks do not seem time characteristic enough. Vertebrata are compatible with a post-Langhian age but are certainly pre-Pliocene.

Mem Moniz spongoliths

Overlying the Cretaceous of inner Algarve there are white spongoliths.

These deposits are unknown elsewhere in Portugal, but closely similar ones are widespread in the Mediterranean periphery. They were accumulated in a trough related to tectonic events.

The rock is essentially composed of sponge spicules. It contains many Foraminifera, calcareous nannoplankton, diatoms and fish remnants.

Planktic Foraminifera allow the reporting of these deposits to *Globorotalia acostaensis*, N16 Blow zone, Tortonian. The calcareous nannoplankton show the arrival of cold waters by upwelling (Antunes *et al.*, 1981)

Glauconitic silts

At Praia da Galé, this unit is separated through an erosion surface from the Lagos-Portimão Formation.

Glauconite-rich silts allowed K-Ar dating: at Praia da Galé, near the base, 10.1±0.25 Ma, lower Tortonian; at Galvanas, near the top, 6.91±0.81 Ma, uppermost Tortonian (Antunes *et al.*, 1984). This unit may be more or less correlative to the Mem Moniz spongoliths.

Cacela Formation

The upper and uppermost Miocene deposits are well represented in eastern Algarve but they also outcrop in the Lagos region. At Cacela, the type locality, these deposits lie directly over the Triassic; at Galvanas, over the glauconiferous silts at Campina de Faro.

This unit comprises mainly yellow, orange, or green silts (the latter being rich in glauconite). One exception is the spectacular Galvanas conglomerate, with blocks exceeding one meter interbedded in the glauconiferous silts (K-Ar age, 6.72±0.17 Ma) (Antunes *et al.*, 1984). Conglomerates are related to strong tectonic instability and were probably formed in the sub-marine slopes associated to the southern Algarve flexure.

The lower conglomerates at Cacela and overlying silts yielded the richest mollusk fauna of the Portuguese Miocene. This fauna was described by F. A. Pereira da Costa (1866, 1867) and by Dollfus *et al.* (1903, 1904), and revised by Chavan (1940). Planktic Foraminifera indicate N16 - 17 of Blow, *Globorotalia humerosa* zone, Upper Tortonian.

The middle and upper members of the Cacela Formation, also silty, correspond to confined marine facies with a scarce and poorly preserved impoverished mollusk fauna and a few plant remnants.

These sub-units are related to the Messinian crisis.

Volcanism

Although evidence of older volcanism is plentiful in Algarve, there are only scant data about Miocene igneous activity. Some earlier references to it could not be verified;

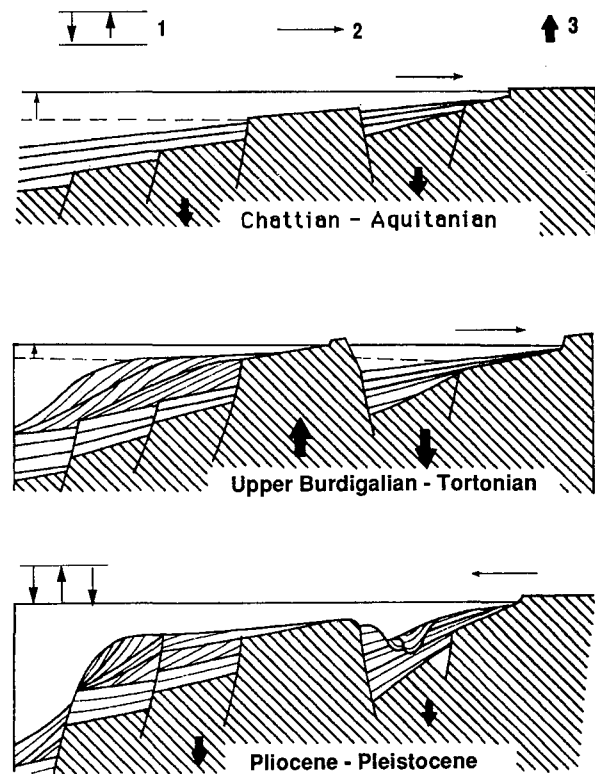
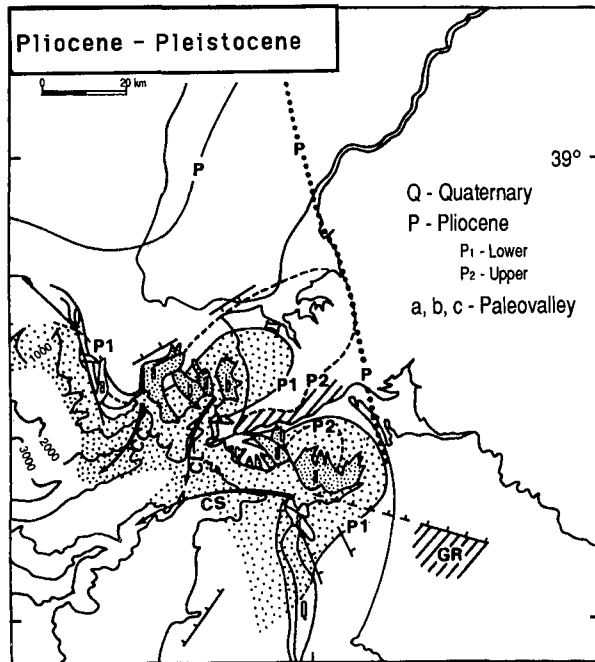
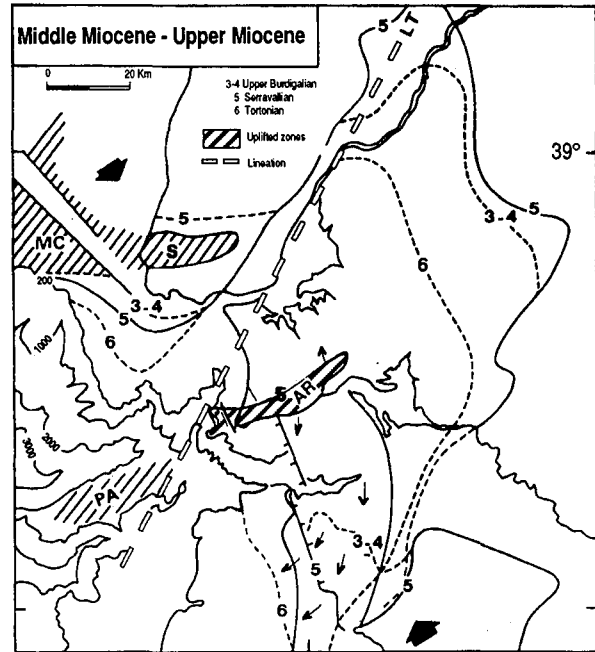
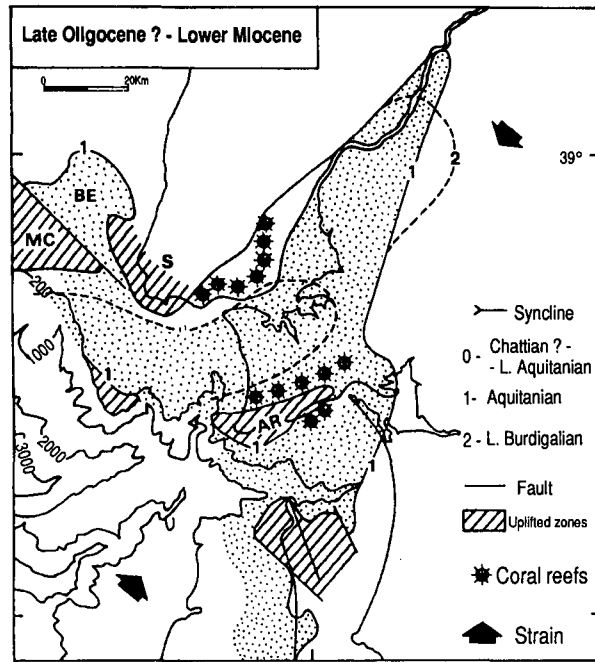


Fig. 5 — The three main phases of the paleogeographic evolution of the Lisboa region (Tagus basin) (Coppier & Mougénot, 1982, modified). Maps: inland transgressions borders after Antunes (1979, modified); offshore: AR - Arrábida chain; BE - Ericeira basin; CC - Cascais canyon; CL - Lisboa canyon; CS - Setúbal canyon; GR - Grândola massif; Tagus lineation; MC - Camões mountain; PA - Albuquerque platform; S - Sintra massif. Schematic geological sections corresponding to the three paleogeographical phases; 1 - relative sea level change; 2 - transgressions or regressions; 3 - tectonic movement.

the only occurrence which could be recognized is that of a basanite outcrop that cuts and contact metamorphoses Lower Miocene, Lagos-Portimão Formation at Figueira (Mexilhoeira Grande). Alteration did not allow reliable K-Ar dating. This is the last volcanic event so far known in Portugal.

MIOCENE (?) AND OTHER NEOGENE TO THE NORTH OF THE CENTRAL MOUNTAIN CHAIN

The Neogene deposits to the North of the Central Mountain Chain and their extensions to the Nazaré great fractures are poorly known or absent. The only exceptions are marine Pliocene sandy deposits well represented at S. Pedro de Muel, Monte Real, Leiria and Pombal, as well as the continental beds with lignites, clays and diatomites which overlie them. We will return to this point in the chapter about Pliocene.

The Miocene around Alcobaça, Leiria and Coimbra

In this rather extensive area there are outcrops of sandy-argillaceous sediments which, according to their stratigraphic position, were ascribed (according to Choffat) either to the Oligocene or to the Miocene. In fact, to the West of Pombal they are covered by well dated marine Pliocene formations; on the other hand, they clearly overlie late Cretaceous and Eocene detrital continental series. Dating was, however, uncertain, or at least not accurate, until the discovery of fossil mammals at Amor; this partly cleared the situation.

However, the well dated part is limited to the region westward of the Leiria diapir; elsewhere, the interpretation of these deposits, mostly of fluvial facies (sometimes marshy or swampy), is problematic due to the absence of any direct proof of age.

However, there are some indications of marine deposits, even if their characterization is rather uncertain:

— at Casal Verde, 2 Km to the North-East of Paião, Figueira da Foz, siliceous rocks surprisingly contain Foraminifera such as *Globigerina* and Miliolids; there has been intensive diagenetic, secondary silification, probably after limestones with clastic elements deposited in marine environments, their age being uncertain;

— boreholes drilled in the region of Marinha Grande, West of Leiria, cut through clays and greenish grey marls with Foraminifera (*Ammobaculites*, etc.), Ostracoda, Characeae and Pelecypoda ascribed to the Miocene; no outcrops are known.

The deposits at Amor are most interesting, for they are the only ones to the North of the Nazaré fault that allow accurate dating. An initial survey at three points yielded large and small mammals, reptiles, amphibians and fish, as well as gastropods. It is interesting to note the existence

of two different biotopes, although contemporary. One of them corresponds to fluvial sedimentation, the other to a marsh with many amphibian and freshwater fish remnants. The mammalian fauna indicates the beginning of Middle Miocene, Langhian MN5 mammal unit of Mein like the V-b of Lisboa with "*Hispanotherium* fauna". The fossiliferous horizon seems to correspond to a very limited time span although the area where the formation outcrops is rather extensive, reaching Monte Real (clays with *Helix*, *Planorbis*, Unionids and some rodents as Cricetodonts) and further more northwards; at Carvide, layers which could be more or less correlative have produced, besides *Helix* and *Chara*, *Cerithium* and *Gobius* (teleost fish) which may indicate slightly brackish waters maybe communicating with the sea. The supply of detrital material, namely bipyramidal quartz issued from Lower Lias marls, show that the nearby diapir was moved during the neo-castilian phase. This miocene series seems to be represented northwards till Pombal region. However it is poorly exposed there among outcrops from earlier units.

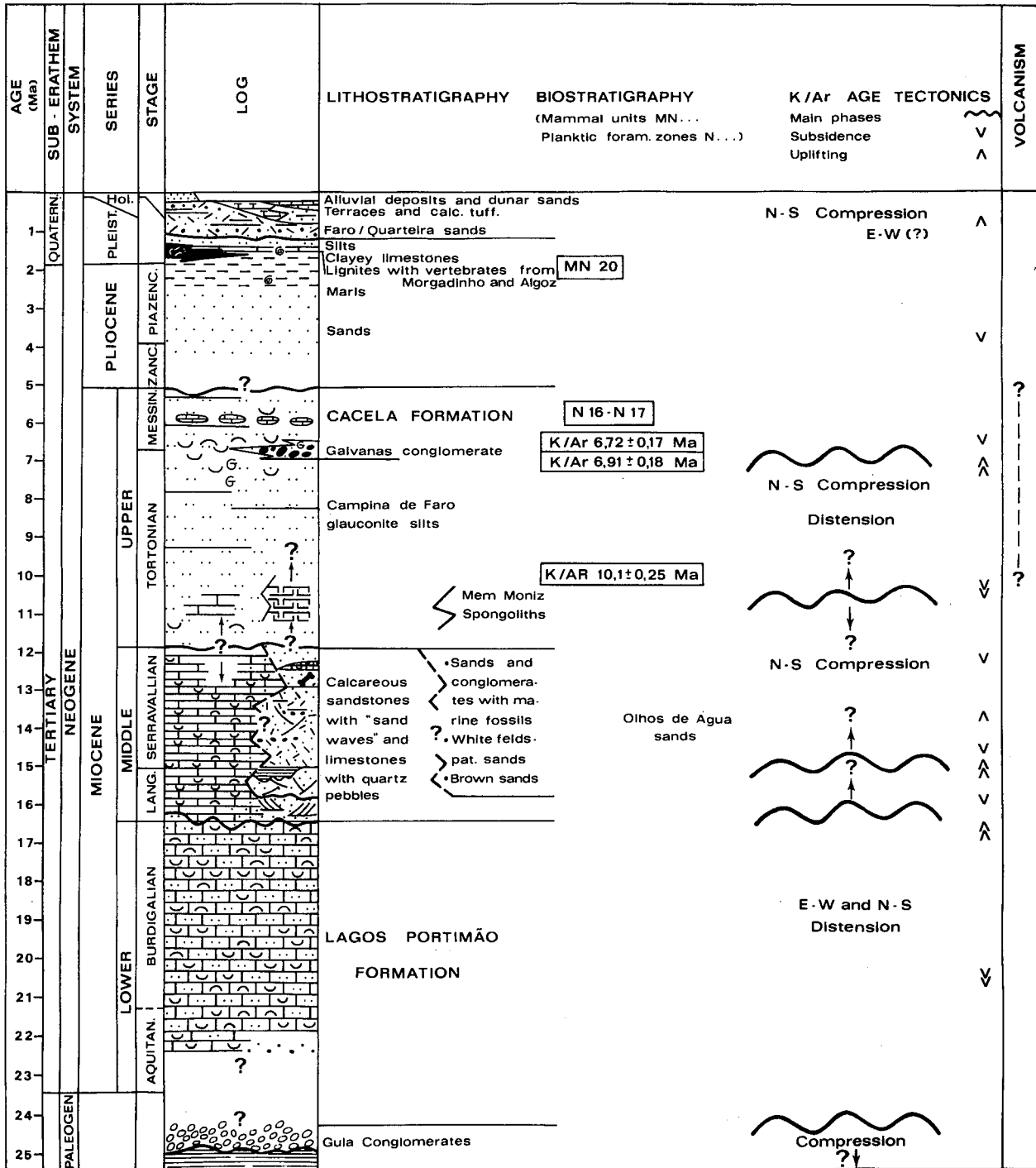
There are other deposits (sands and clays with some lignite layers) in the region of Leiria-Alencarce and Fonte da Moura, from where plant macroremains, the only fossils collected so far, do not allow any accurate dating even if they have been regarded as Miocene.

Possible Miocene in Beira Alta

Among the units that overlie the Beira Alta basement, there are essentially argillaceous sediments derived from the Beira pre-ordovician slates and graywackes. Shale clasts of variable sizes form the bulk of these sediments which generally evolve to greenish and often reddish clays. Other important components are cobbles of vein quartz, whereas the contribution from granites is rather limited. Several small outcrops spared by erosion witness their former vast extension. Their origin is certainly related to rejuvenation of the shale and granite relief. It is known that such deposits are later than the Ludian (Upper Eocene) arkoses from Coja. On the other hand, they are covered by blocks and other coarse grained sediments, more or less equivalent to the rañas described in Spain and elsewhere in Portugal, possibly of Villafranchian age. These occur to the South-East of the Caramulo Mountain, at Arganil, Folques, and elsewhere.

Hence, a Miocene age is possible but far from being proved. In Spain, always North of the Central Chain in the Douro basin, the Miocene is largely represented to the East of Toro. Remarkable deposits at Palencia, Valladolid, etc., are ascribed to the Middle Miocene; others are reported to the Upper Miocene.

Older Miocene deposits are not known; the "*Hispanotherium* fauna" has never been found. These facts could suggest the upper part of the Middle Miocene as a possible age for certain sedimentary mantles of Beira. Without decisive evidence, the problem remains open to discussion.



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Fig. 6 — The Cenozoic of Algarve.

PLIOCENE

According to current ideas, during the Pliocene there was a succession of events comprising a marine transgression followed by a regressive phase and finally a new transgression. The latter has been ascribed to the Calabrian; the Calabrian stage, being included in the Pleistocene, is not dealt with in this text. Also avoided, are formations as interesting as the highest raised terrace covers (about 120 to 190 meters). Their remnants in the coastal morphology are evident from the northern coasts down to Algarve.

In the present state of our knowledge, Pliocene deposits comprise: a) - fossiliferous sands and conglomerates between the Arrábida chain in the South and the region of Pombal; b) - arkosic sands developed mainly to the South of the Tagus river: non marine gravels, sands and clays in depressions such as in Rio Maior and Vale de Santarém, the Tagus basin at Cartaxo, Serra de Almerim, etc. and maybe even further North at Pampilhosa; c) - clay deposits with diatomite and lignite, particularly important near Leiria, Óbidos, Rio Maior and Vale de Santarém.

Summing up, the study of the Portuguese Pliocene is in part rather restricted by the lack of updated stratigraphy as well as the lack of accurate dating.

The Pliocene in the Tagus basin

Setúbal Peninsula

Pliocene layers are well represented to the South of the Miocene outcrops between Cacilhas and Trafaria, in the left bank of the Tagus River. They follow the axial part of a syncline, limited southwards by the Arrábida Chain and by the costal cliffs of Fonte da Telha and Adiça and further inland towards Pinhal Novo and Montijo.

Over the last Miocene layers, one can see coarse layers of conglomerates and arkosic sands. These correspond to a sedimentation that proceeded under the double influence of high energy sea and rivers. Some rather poorly preserved molluscs were collected in this series at Alfeite. Other known fossils are land plants which provide ecological information but are not useful for age determination. Indirect reasons lead to the assumption that they may represent the Tabianian (Lower Pliocene) with a modest transgression followed by a regression shown by layers with plant fossils.

High above them are sands and gravels with clay intercalations that have produced a varied malacological fauna with a costal marine character regarded as Astian. They may be ascribed to the Upper Pliocene (Piazencian), according to earlier interpretations (Piazencian according to Dollfus & Cotter, 1909; Piazencian - Astian according to Zbyszewski, 1959) corroborated by the interpretation of Brébion (1971) after his detailed revision of the gastropods. No doubt there was a new sea ingression, more important than that of the Lower Pliocene, even if its inland progression did not exceed about 25Km from the present coast.

Uppermost units regarded as Pliocene comprise fine sands with rounded pebble layers, clays and diatomites.

The sands no doubt show eolian transport representing the progression of coastal dunes further inland. A stratigraphic revision has to be done, for the relationships between certain clay layers, gypsum, diatomites and lignites are still not clear. As for their age, different authors, lacking decisive proofs, tentatively ascribed them to the Pliocene, but a Pleistocene age was also possible. On account of the Upper Pliocene age of the underlying layers and the importance of this series, it can be entirely Quaternary or nearly so.

The assemblage of lignites, as well as the levels with marine fossils that follow them, are overlain in some localities by the Belverde conglomerates and yielded archaic lithic industries.

Inland detrital residual soil related to the Pliocene

On the right bank of the Tagus river, a few remnants of sands and clays (sometimes with lignites) are preserved at Azambuja, Cruz do Campo, the surroundings of Santarém, etc.

On the other hand, to the South of the river Tagus there are far more extensive outcrops of arkosic sands with pebble bands (mainly towards the top): these are fluvial deposits corresponding to a predominantly south-southwest drainage pattern.

The sands of Rio Maior should be referred for its economic importance. These may represent the progression of dunes further inland between the Candeeiros and Montejunto Hills, starting from a broad littoral abrasion platform which is today at about a 200 metres level. They seem to be correlated to the fine sands of Coia in the Setúbal Peninsula; if this is so, those sands were formed after the marine levels of Alfeite and Fonte da Telha with an Upper Pliocene fauna. Hence the diatomites and lignites that at Rio Maior and Óbidos overlie those sands may be Quaternary, at least in part.

Pliocene in Estremadura

In the region of the Caldas da Rainha diapir and further to the North until Leiria and Pombal, a well characterized Pliocene transgression is responsible for the deposition of fossiliferous conglomerates and sands on Miocene or older formations. These sediments are overlain by continental diatomites and lignites (Óbidos, Barracão, etc.) and these ones by marine or fluviomarine deposits without fossils that may be Calabrian in age.

Most authors ascribed a Lower Pliocene age for the earlier marine beds, mainly because Piazencian was formerly regarded as Lower (and not Upper) Pliocene. This seems contradictory to the acknowledged correlation with the Alfeite deposits (upper layers), Fonte da Telha, etc. considered as Astian; however this is a matter of

CHRONOST.	TEJO BASIN (Lisboa/Almada region)	ALVALADE BASIN	ALGARVE	
PLEIST.	Clays, sands, conglomerates lignites and diatomites	Sands, sandstones and conglomerates	Faro-Quarteira sands Morgadinho deposits	
	PLIOCENE	Alfeite beds	Marateca Formation	?
Zanclean				
MIOCENE	Messinian	?	Esbarrondadoiro Formation Galvanas conglomerate Cacela Formation	
	Tortonian	?	Mem Moniz spongolithes Glaucinitic silts from Campina de Faro	
	Serravallian		Olhos de Água sands	
	Langhian		Calcareous sandstones and limestones with pebbles	
	Burdigalian		Lagos-Portimão Formation	
	Aquitanian		Vale de Guizo Formation	?
	EOC.- -OLIG.		"Benfica Complex"	

Fig. 7 — Main neogene lithological units from Tejo and Alvalade basins, and from Algarve (southern Portugal).

different facies, not a chronologic one. Brébion, also correlated the gastropod fauna to the Upper Pliocene. Recent data on calcareous nannoplankton assemblages may indicate Martini's NN16, or Okada & Burky CN12a correlated to the Lower Piazencian and thus compatible with former dating. Furthermore, all other available data indicates an Upper Pliocene age. Taking into account the small span of the Pliocene (about 3Ma), this practically means that at least part of the diatom and lignite beds must be Pleistocene in age, although the chronological limits are still not accurate enough.

For stronger reason the transgression which follows it, well marked in the geomorphology of coastal regions from the extreme North down to the Algarve, has to be treated as Pleistocene.

As elsewhere in Europe, the Pliocene palaeogeographies are rather different from the Miocene ones — the so-called "Pliocene revolution". Even if the data concerning Pliocene are incomplete and not always accurate, we may suppose that in the Setúbal Peninsula there was a very limited marine incursion followed by another regression (Fig. 5; Fig. 6). This small transgression corresponds to the lower layers of Alfeite. Its age has been regarded as Lower Pliocene (Zanclean) according to its position and without good direct dating evidence.

Later on, a new and more important transgression much enlarged the small former gulf at the Setúbal Peninsula. The region between Pombal and Caldas da Rainha has

been flooded then. A larger abrasion platform was developed. It may be related to the Calabrian transgression in several places. Further inland this platform is limited by beautiful fossil cliffs. Its surfaces are frequently covered by rather thin detrital, quaternary layers where no fossils have been found.

Pliocene (?) and/or Pleistocene in Algarve

Morgadinho and Algoz deposits

This unit comprises thick sandy deposits in association (towards the top) with marls, lignite clays, lacustrine limestone and a silty calcareous crust.

At Morgadinho and Luz de Tavira these sands overlie the Cacela Formation and are overlain by the Faro-Quarteira sands, as at Algoz (where the substratum is not known).

At Morgadinho, the lignite clays yielded a few small mammals, fish, gastropods, fresh water Ostracoda, pollens and spores (Antunes *et al.*, 1986b). The mammalian fauna indicates an age span between the Upper Pliocene and the lower Middle Pleistocene, MN 17 to MN 20 mammal units.

In the present state of knowledge, we may think that Morgadinho and Algoz deposits are correlated. The Algoz mammalian fauna is dated from about 1 Ma (Antunes *et al.*, 1986a).

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