

Early Pliocene fishes (Chondrichthyes, Osteichthyes) from Gran Canaria and Fuerteventura (Canary Islands, Spain)

Los peces (Chondrichthyes, Osteichthyes) del Plioceno inferior de Gran Canaria y Fuerteventura (Islas Canarias, España)

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ABSTRACT

Fossil fish teeth are contained in marine deposits dated at ca 4.8 Ma found on the islands of Gran Canaria and Fuerteventura (Canary Islands, Spain). These islands, situated in the North Atlantic Subtropical Gyre, can be considered a mid-way stopover point between the Caribbean Sea, with the Central American Seaway about to close in this epoch, and the Mediterranean, in the first stage of its post-Messinian Gibraltar Seaway period. Accordingly, there existed extensive pantropical communication, particularly for nektonic animals capable of travelling large distances. In this paper, we present a number of fossil fishes, most of which are identified for the first time on the basis of their teeth: the Chondrichthyes species *Carcharocles megalodon*, *Parotodus benedeni*, *Cosmopolitodus hastalis*, *Isurus oxyrinchus*, *Carcharias* cf. *acutissima*, *Carcharhinus* cf. *leucas*, *Carcharhinus* cf. *priscus*, *Galeocerdo* cf. *aduncus*, and the Osteichthyes species *Archosargus cinctus*, *Labrodon pavimentatum*, and *Diodon scillae*. Coincidences are observed between these ichthyofauna and specimens found in the Azores Islands, the Pacific coast of America and the Mediterranean Sea.

Keywords: Biogeography; Palaeoclimatology; Pillow-lavas dating; Subtropical North Atlantic; Central American Seaway; Mediterranean Flood.

RESUMEN

Los dientes fósiles de peces están contenidos en depósitos marinos datados en ca 4.8 Ma de las Islas de Gran Canaria y Fuerteventura (Islas Canarias, España). Estas islas, situadas en el Giro subtropical del Atlántico Norte, pueden considerarse una estación intermedia entre un Mar Caribe que estaba cercano al cierre del Paso de América Central, y el Mediterráneo en su primera etapa tras la apertura post-Mesiniense de Gibraltar. Ello permitía una comunicación pantropical para los animales del necton que eran capaces de desplazarse a grandes distancias. Se identifican por primera vez los peces Chondrichthyes *Carcharocles megalodon*, *Parotodus benedeni*, *Cosmopolitodus hastalis*, *Isurus oxyrinchus*, *Carcharias* cf. *acutissima*, *Carcharhinus* cf. *leucas*, *Carcharhinus* cf. *priscus*, *Galeocerdo* cf. *aduncus* y las especies de Osteichthyes *Archosargus cinctus*, *Labrodon pavimentatum* y

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Diodon scillae. Se ha observado coincidencia entre los ejemplares canarios y los encontrados en las Islas Azores, las costas pacíficas de América y el mar Mediterráneo.

Palabras clave: Biogeografía; Paleoclimatología; Datación de Pillow-lavas; Atlántico Norte Subtropical; Paso de América Central; Inundación del Mediterráneo.

Introduction

There is little documentation of Canary fossil fishes, with the exception of two publications from the 19th century: (1) the study carried out by Cocchi (1864) in which he created the genus *Pharyngodopilus* and its two species *Ph. canariensis* and *Ph. Africanus*, catalogued in 1857 by the British Museum of Natural History and which formed part of the collection of Charles Lyell; and (2) the study conducted by Rothpletz & Simonelli (1890), which includes *Oxyrhina plicatilis*, Ag., *Oxyrhina* sp., *Galeocerdo* cf. *egertoni*, Ag., *Chrysophrys* sp., *Nummopalatus africanus*, Cocchi and *Diodon sigma* Martin (Fig. 1). It should be noted that the age of the deposits which contained these fauna were ascribed to the Upper Miocene (Cocchi, 1864; Lyell, 1865) and were included in the Helvetian or Tortonian (Rothpletz & Simonelli, 1890).

The Canary Islands is a volcanic archipelago (Carracedo *et al.*, 2002) and the marine deposits occur intercalated between lava-flows. Pillow-lavas are structures that are formed during the interaction of lava and water. Accordingly, if a pillow-lava enters into contact with a marine deposit under formation, it indicates that they both have the same age. This is the case of the Canary marine deposits containing the fossil fishes studied in this paper that have a $^{40}\text{Ar}/^{39}\text{Ar}$ age of 4.80 ± 0.03 Ma in Gran Canaria (Meco *et al.*, 2015) and a K/Ar age of 4.83 ± 0.10 Ma in Fuerteventura (Meco *et al.*, 2007). This clearly places the marine deposits in the first half of the Early Pliocene which began 5.33 Ma ago and concluded around 3.60 Ma ago (Grandstein *et al.*, 2004; Walker & Geissman, 2009).

On the basis of this information, we propose: (a) to present the list of fossil fishes contained in these dated deposits, thereby contributing to the elaboration of a corrected biochronostratigraphy, and (b) to check if the fossil ichthyofauna that have been found is consistent with the palaeoceanographic scenario in the area for the Early Pliocene. This scenario is characterised principally by an open Central American

Seaway (CAS) (Schmidt, 2007; Montes *et al.*, 2012; Erkens, 2015; Meco *et al.*, 2015; 2016), an open Gibraltar Seaway after the so-called Messinian crisis (Garcia-Castellanos *et al.*, 2009) and warm pantropical waters (Meco *et al.*, 2015) in the Pacific, Subtropical North Atlantic (Ávila *et al.*, 2012) and Mediterranean (Pawellek *et al.*, 2012).

Geological, palaeontological and stratigraphic setting

The Canary Islands comprise seven main volcanic islands and several islets and are located in the Eastern Atlantic Ocean between N 27° and N 30° latitudes, forming a chain that extends latitudinally about 450 km; with the easternmost point just over 100 km off the north-western African coast (Fig. 2).



Fig. 1.—*Diodon sigma*, is one of the few remaining first fossil fishes from Las Palmas de Gran Canaria that were studied in 19th century. It remains in the Paläontologisches Museum München having survived two world wars. It was found at La Vista (Barranco Seco) by Rothpletz. This German geologist was visiting Las Palmas de Gran Canaria for health reasons according to an unpublished letter of his addressed to Dr. Chil who at the time (1879) was founding El Museo Canario. During his time on the island Rothpletz made an extensive collection of fossils (most of which have sadly been lost) which was studied by Simonelli and published by Rothpletz & Simonelli (1890). The deposits attributed to the Miocene have been recently dated at ca 4.80 Ma (Meco *et al.*, 2015). Scale bar: 10 mm.

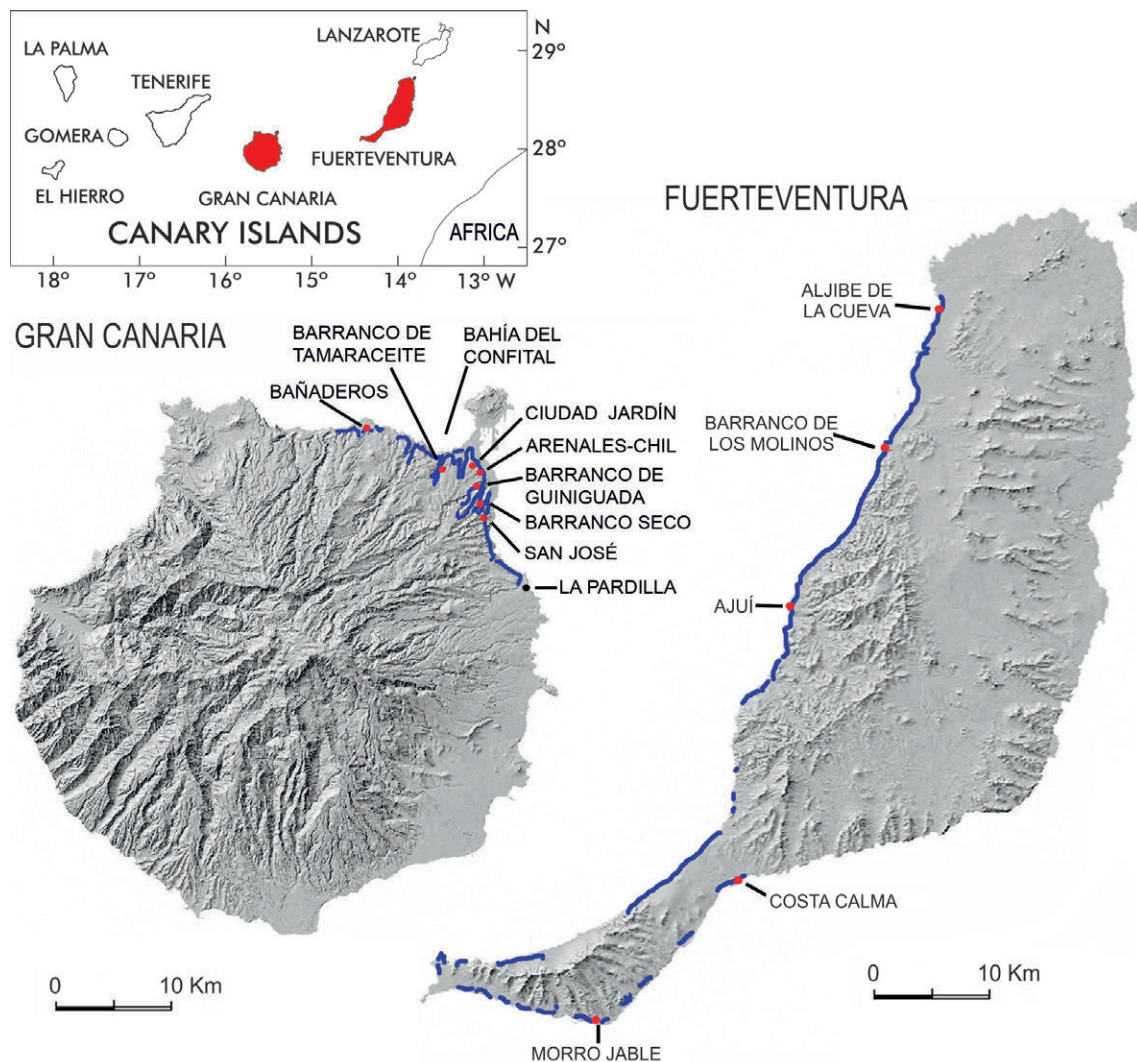


Fig. 2.—Early Pliocene sedimentary beds (lines in blue) with marine fossils of the Eastern Canary Islands (dated *ca* 4.80 Ma by Meco *et al.*, 2015 and *ca* 4.83 Ma by Meco *et al.*, 2007) and main sites (red dots) where the fossil marine fishes were found.

The islands have a complex geological history, with volcanic formations over 20 million years old (Carracedo *et al.*, 2002), but they also include extensive sedimentary deposits (Meco & Stearns, 1981).

They are composed of layers of two materials: (1) reddish conglomerate (rubefacted conglomerates as a result of Fe oxidation) consisting of coarse gravel, cobble and medium to coarse size sand, and (2) grey to white sands, medium to fine in size, with bioturbation structures, which constitute reference layers (or strata) in the local stratigraphy of each island. The original conglomerates, comprised of cobbles and sands with a wide variety of fossils, were deposited on wave-cut platforms tens of kilometres long.

Subsequent withdrawal of the sea resulted in oxidation of pebbles and fossil remains because of contact with freshwaters. These reddish sandy conglomerates as a whole are considered regional key layers, in both a stratigraphic and palaeontological sense (Fritsch, 1867; Lomoschitz *et al.*, 2011). All the fossil fish teeth that have been found in these deposits have a heavy layer of enamel with a dark orange colour.

The fauna which accompany the fossil fishes in Gran Canaria and Fuerteventura indicate ecological and climatic conditions very different to those of today. The first information about invertebrate fossils of the Canary Islands was provided by Lyell (1865)

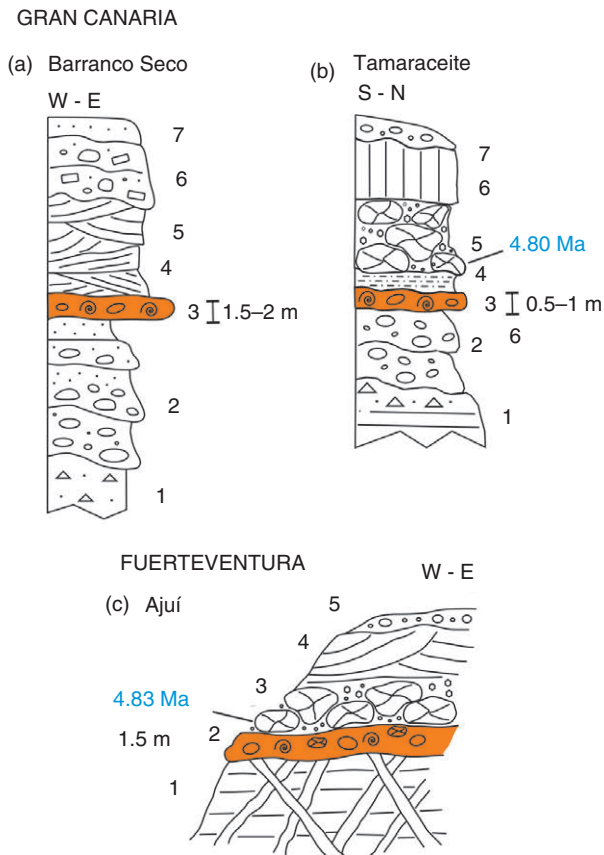


Fig. 3.—Schematic stratigraphic sections of sites on NE Gran Canaria and W Fuerteventura where the fossil marine fishes have been found. A) Barranco Seco: 1 - Miocene phonolitic ignimbrite; 2 - Miocene alluvial fan; 3 - Early Pliocene marine deposit (reddish conglomerate); 4 - Foreshore grey fine sand; 5 - Dune white sand; 6 - Pliocene alluvial fan; 7 - Colluvium. B) Tamaraceite (ravine mouth): 1 - Miocene phonolitic lava flow and ignimbrite; 2 - Miocene alluvial fan; 3 - Early Pliocene marine deposit (reddish conglomerate); 4 - White silty sand; 5 - Basaltic pillow lava $^{40}\text{Ar}/^{39}\text{Ar}$ dated *ca* 4.80 Ma (Meco *et al.*, 2015); 6 - Basaltic lava flow; 7 - Colluvium. C) Ajuí: 1 - Pre-Miocene basaltic lava flows and dykes; 2 - Early Pliocene marine deposit (reddish conglomerate); 3 - Basaltic pillow lava K/Ar dated *ca* 4.83 Ma (Meco *et al.*, 2007); 4 - Pliocene dune; 5 - Colluvium.

and Rothpletz & Simonelli (1890). Detailed studies were later conducted of foraminifera (Anguita Virella & Ramírez del Pozo, 1974), of genus *Strombus* (= *Perisitrombus*) (Meco, 1977), neogastropods (Meco, 1981), bivalves (Meco, 1982), bryozoans (Sendino & Taylor, 2014) and crustaceans (Betancort *et al.*, 2014). The presence of fossil species belonging to the gastropod genus *Persististrombus* and *Nerita*, and the coral genus *Siderastrea*, and others, suggest climate conditions equivalent to those of present day tropical

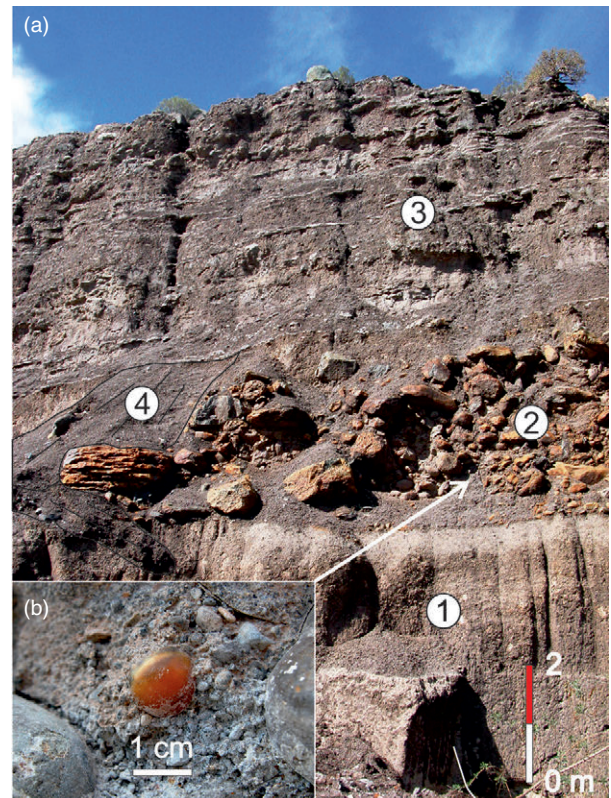


Fig. 4.—A. Outcrop at Barranco Seco site (NE Gran Canaria) where many fossil marine fishes have been collected: 1 - Phonolite non-welded ignimbrite; 2 - Early Pliocene reddish conglomerate with fossils; 3 - foreshore grey fine sand; 4 - colluvium. B. Tooth of *Archosargus cinctus*.

and sub-tropical regions, like the Caribbean Sea (West Atlantic) or the Gulf of Guinea (East Atlantic) (Meco, 1977; Meco *et al.*, 2007, 2015).

Stratigraphic sections

The fossil fish specimens were found in sedimentary layers consisting of old coastal and marine deposits which outcrop along over 130 km, if all the stretches are considered together (Fig. 2). As these layers show many lateral variations throughout the outcrops, three sections were chosen as representative of the whole area: Barranco Seco and Tamaraceite sections from NE Gran Canaria Is. (Figs. 3 and 4) and Ajuí section from W Fuerteventura Is. (Figs. 3 and 5). The Barranco Seco locality provided the most numerous and the largest variety of fossil fishes, while the Tamaraceite and Ajuí localities are characterised by the presence of lava flows which have allowed dating of the marine deposits at *ca* 4.8 Ma.



Fig. 5.—Outcrop at Ajuí site (W Fuerteventura): 1 - pre-Miocene volcanic and intrusive rocks; 2 - Early Pliocene marine deposit where some of the fossil specimens were found; 3a - basaltic pillow lava with a K/Ar age of *ca* 4.83 Ma (Meco *et al.*, 2007); 3b - basaltic lava flow; 4 - Late Pliocene dune.

Barranco Seco section

Location: NE Gran Canaria Is., slope on Barranco Seco ravine.

Latitude: 28° 05' 25.40", longitude: 15° 25' 40.25", height: 85 m (apsl).

This section comprises seven units which are (bottom to top):

- (1) Phonolitic non-welded ignimbrite (>15 m). Homogeneous in appearance, it is composed of thick layers of yellow to white rocks and corresponds to the Miocene of Gran Canaria.
- (2) Heterogeneous sandy conglomerate of phonolitic pebbles (20–25 m). This is a mixture of coarse gravel, pebbles and cobbles with a matrix of coarse sand and fine gravel. Their clasts are sub-angular to sub-round in shape. It corresponds to a Miocene alluvial fan.
- (3) Reddish conglomerate with fossils (1.5–2 m). The variable outcropping thickness of this layer is due to coastal erosion that occurred on an old phonolite cliff. A later exposure to fresh water caused the red colour, which is common in weathering processes.
- (4) Grey sand with bioturbation structures (3–8 m). It is a deposit of medium to fine sand which originated in a foreshore environment.
- (5) White sand dunes (5–10 m). Aeolianite composed of carbonate grains of fine to medium sand, with a characteristic cross-bedding internal structure.

- (6) Heterogeneous sandy conglomerate of phonolitic and basaltic pebbles (20–25 m).

This is a mixture of coarse gravel with sand, cobbles and boulders, angular to sub-round in shape and slightly horizontally layered. It is an alluvial fan of Pliocene age.

- (7) Colluvium.

Tamaraceite section

Location: NE Gran Canaria Is., slope on Tamaraceite ravine mouth.

Latitude: 28° 07' 12.99", longitude: 15° 27' 30.64", height: 97 m (apsl).

This section comprises seven units which are:

- (1) Phonolitic lava flows and non-welded ignimbrite (>15 m). Homogeneous in appearance, it is composed of thick layers of yellow to white rocks and corresponds to the Miocene of Gran Canaria.
- (2) Heterogeneous sandy conglomerate of phonolitic pebbles (20–25 m). This is a mixture of coarse gravel, pebbles and cobbles with a matrix of coarse sand and fine gravel. Their clasts are sub-angular to sub-round in shape. It corresponds to a Miocene alluvial fan.
- (3) Reddish conglomerate with fossils (0.5–1 m).
- (4) White silty sand with fine parallel lamination (0.3–2 m).
- (5) Basaltic pillow lavas and hyaloclastite (25 m) with a $^{40}\text{Ar}/^{39}\text{Ar}$ age of *ca* 4.8 Ma (Meco *et al.*, 2015).

- (6) Basaltic lava flows (15 m).
 (7) Colluvium.

Ajuí section

Location: W Fuerteventura Is., slope on Barranco de Ajuí ravine mouth.

Latitude: 28° 24' 03.86", longitude: 14° 09' 21.20", height: 7 m (apsl).

This section comprises five units which are:

- (1) Pre-Miocene volcanic, intrusive and sedimentary rocks.
- (2) Reddish conglomerate with fossils (1.5 m). It is mainly composed of basaltic sub-rounded pebbles, gravels and cobbles with a sandy matrix.
- (3) Basaltic pillow lavas and hyaloclastite (3 m). They come from olivine basaltic lava flows that erupted about 9 km inland. This lava-flow has a K/Ar age of *ca* 4.83 Ma (Meco *et al.*, 2007).
- (4) Pliocene white sand dunes (2 m). Aeolianite composed of carbonate grains of medium to fine sand, with a characteristic cross-bedding internal structure.
- (5) Colluvium.

Methodology - Canary Island fossil fishes

The specimens that have been studied form part of the collection belonging to the University of Las Palmas de Gran Canaria (Laboratory of Palaeontology) [ULPGC], with one specimen coming from the collection that belongs to El Museo Canario in Las Palmas de Gran Canaria. We were also able to consult the Rothpletz collection in the Paläontologisches Museum München. Systematics of the present publication for Chondrichthyes follows Cappetta (2012). The teeth terminology for Sparidae is in accordance with Day (2002).

As the Canary marine deposits containing fossil fishes have been isotopic dated in *ca* 4.8 Ma, we focused the search on bio-geographic and climatic data of the Early Pliocene, and sometimes on the more imprecise Mio-Pliocene information. We also selected one representative locality in the Mediterranean Sea (Lybia), two in the eastern

Atlantic (Morocco and Azores), one at the Atlantic entrance of the Mediterranean Sea and some in the Pacific coast of America just in order to show the dispersal of this fossil fishes at that time.

Systematic palaeontology

Class CHONDRICHTHYES Huxley, 1880
 Order LAMNIFORMES Berg, 1958
 Family OTODONTIDAE Glickman, 1964
Carcharocles megalodon (Agassiz, 1843)

Material:

4 teeth (Fig. 6: A1, El Museo Canario); ULPGC fishes n°: f61 to f63.

Localities:

Barranco Seco, La Pardilla (Figs. 2– 4).

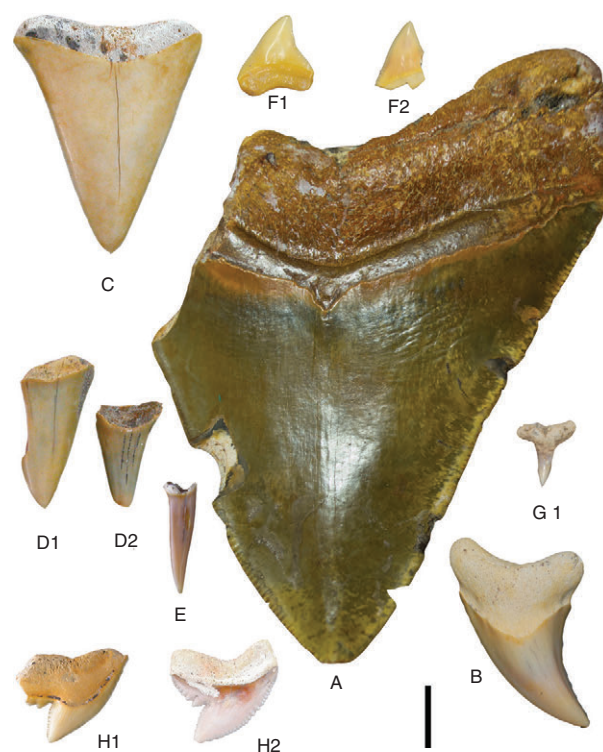


Fig. 6.—Chondrichthyes fossil fish teeth from Early Pliocene deposits of the Canary Islands. All from ULPGC-Pal collection, except A from El Museo Canario collection. Scale bar: 10 mm. *Carcharocles megalodon*: A – Lingual view of upper right tooth. *Parotodus benedeni*: B – Lingual view. *Cosmopolitodus hastalis*: C – Labial view. *Isurus oxyrinchus*: D1 and D2. Lingual view. *Carcharias cf. acutissima*: E – First upper anterior position Lingual view. Left side of the upper jaw. *Carcharhinus cf. leucas*: F1 – Labial view upper lateral tooth, F2 – Anterior tooth labial view. *Carcharhinus cf. priscus*: G – Lingual view. *Galeocerdo cf. aduncus*: H1 – Lingual view. H2 – Labial view.

Comparisons and systematic attribution:

The teeth are large, thick and robust with a curvature towards the labial commissures in relation to the central position. The *distal* curvature is more marked as the position of the tooth becomes more posterior. The anterior teeth are, if at all, only very slightly curved towards the internal (*lingual*) face. The upper teeth are wider, slightly inclined towards the posterior edge and vertical grooves or ridges can be observed on the external (*labial*) face. Contrastingly, the lower teeth are narrower and more symmetrical. The crown has an equilateral triangular shape with a uniform, strongly serrated edge. The root is bilobed and coarse. All the teeth that have been found correspond to adult specimens (Gottfried *et al.*, 1996; Pimiento *et al.*, 2010). Those found at La Pardilla site and kept at the Museo Canario are anterior and lateral upper teeth from the right jaw. *C. megalodon* is a very well known species and our specimens are identified with those studied by Menesini (1969).

Stratigraphic and geographic records:

Pan-oceanic except for the polar seas (Pimiento *et al.* 2016). Late Miocene of Panama (Pimiento *et al.*, 2013) Miocene and Pliocene of Morocco (Lecointre, 1952), Azores (Ávila *et al.*, 2012), Europe (Reinecke *et al.*, 2011), Africa (Antunes, 1978), American Atlantic and the Pacific, Ecuador (Carrillo-Briceño *et al.*, 2014; Yabe *et al.*, 2004).

Genus *Parotodus* Cappetta, 1980*Parotodus benedeni* (Le Hon, 1871)**Material:**

2 teeth; ULPGC n°: f71 (Fig. 6: B), f72.

Locality:

Barranco Seco (Figs. 2–4).

Comparisons and systematic attribution:

Robust, triangular crown, inclined towards the commissure. Flat labial face and markedly convex lingual face of the crown. The crown bends towards the commissure, increasing the curvature with the lateral position of the tooth. Smooth edge. Very thick root with two globular and separated lobules. Nutrient canal absent. Our specimens are identified with those from the Azores shown by Ávila *et al.* (2012).

Stratigraphic and geographic records:

Pliocene de North America, Australia, Japan, Angola, Belgium, Italy (Cappetta, 1987), Mio-Pliocene of the Balearic Islands (Mas, 2003) and the Azores, (Ávila *et al.*, 2012), Lower Pliocene of Huelva (García *et al.*, 2009).

Family LAMNIDAE Müller and Henle, 1838

Genus *Cosmopolitodus* Glikman, 1964*Cosmopolitodus hastalis* (Agassiz, 1843)**Material:**

41 teeth; ULPGC n°: f31 (Fig. 6: C) to f341.

Localities:

Barranco Seco, San José, Ciudad Jardín, Arenales-Chil, Bañaderos (Fig. 2–4).

Comparisons and systematic attribution:

The length from tip to base of the crown of the numerous teeth varies between 2.5 cm and 4.3 cm. The teeth are very similar to those of *C. carcharias*, differing in their smooth edge.

The teeth are triangular, thin and compressed. The external face of the crown is concave or flat, with vertical grooves observable on rare occasions. The root is short with strongly diverging lobes that are generally blunt and small. The teeth of the lower jaw are thicker than their upper counterparts, with a more dense and robust appearance though their crown is narrower and rises vertically describing a slight sigmoidal curve in the anterior teeth. The external face presents a slight concavity that is particularly noticeable in the anterior teeth. We attribute these specimens to *C. hastalis* given their strong resemblance to the material published by Ávila *et al.* (2012, Fig. 5) of Azores origin.

Stratigraphic and geographic records:

Cosmopolite Mio-Pliocene, Miocene of Peru (Klug & Kriwet, 2008), Pliocene of Belgium (Herman *et al.*, 1974) and North America (Purdy *et al.*, 2001). Pliocene Mediterranean (Marsili *et al.*, 2007), Late Miocene and Early Pliocene of the Azores (Ávila *et al.*, 2012), late Early Pliocene of Spain (García *et al.*, 2009).

Genus *Isurus* Rafinesque, 1810*Isurus cf. oxyrinchus* Rafinesque, 1810**Material:**

4 teeth; ULPGC n°: f41 (Fig. 6: D1), f42, (Fig. 6: D2) to f44.

Locality:

Barranco Seco (Figs. 2–4).

Comparisons and systematic attribution:

The teeth display different states of preservation: none retain the root and two retain the tip of the crown. The teeth have a narrow crown with a very sharp edge. The bulging external face is scored with longitudinal grooves and the internal face is convex and smooth. The teeth are labially inclined and present a slight sigmoidal curvature. The lingual face resembles that of the anterior teeth of *C. hastalis*, though differing in the thickness of the tooth and the bulging appearance of its external face. The narrowness of the crown and the bulging appearance of the external face from base to tip are characteristic features of this species, along with a slight depression at the base of the crown observable on both faces though more pronounced on the external face. Our specimens are very similar to those shown in Marsili *et al.* (2007).

Stratigraphic and geographic records:

Upper Miocene and Lower Pliocene of Chile (Long, 1993) Pliocene of the south and southeast of Spain (Malaga and Catalonia) (Marsili *et al.*, 2007). In the present day, it appears near shores with a temperate climate and tropical waters, and can migrate into warmer waters in winter (Dyldin, 2015).

Family ODONTASPIDIDAE Müller and Henle, 1839

Genus *Carcharias* Rafinesque, 1810*Carcharias cf. acutissima* (Agassiz, 1843)**Material:**

7 incomplete teeth; ULPGC n°: f11 (Fig. 6: E), to f17

Localities:

Barranco Seco, Aljibe de la Cueva and Barranco de los Molinos (Figs. 2–5).

Comparisons and systematic attribution:

The available material is considered scarce and fragmented. The most complete specimen (Fig. 6) is a long and vertical

crown 18 mm in length that is a first upper anterior tooth in the left side of the upper jaw. Even though dental morphology varies with the position on the jaw, the longer and vertical teeth of *C. acutissima*, and the most similar species *C. taurus*, correspond to the upper or lower anterior position (Cunningham, 2000).

For the purpose of making a roughly quantitative comparison with other similar teeth and given the longer teeth of *C. acutissima*, we calculated a slenderness index of the crown (width at midlength / length, on the lingual side). This index gave us a value of *ca* 0.17. We compared the value of this index with that of the single specimen of the Azores (Ávila *et al.*, 2012, Fig. 4; an upper anterior tooth) and found them to be practically identical (*ca* 0.16). Bauzá & Plans (1973) specimen (lám 4 Fig 28; Catalonia) is *ca* 0.16 as well. The corresponding slenderness index of the most similar teeth to these, those of *C. cuspidata*, is *ca* 0.25 (Bauzá & Plans, Lám 5, Fig. 36) and *C. taurus* is *ca* 0.23 measured in a identical dental piece (Cunningham, 2000).

Stratigraphic and geographic records:

Cosmopolite Mio-Pliocene species (Cappetta, 1987). Pliocene of Morocco (Lecointre, 1952), Pliocene of Majorca (Mas, 2000), Early Pliocene of North Carolina USA (Purdy *et al.*, 2001) and Pliocene of Ecuador (Cione *et al.*, 2007).

Order CARCHARHINIFORMES Compagno, 1977

Family Carcharhinidae Jordan and Evermann, 1896

Genus *Carcharhinus* Blainville, 1816

Carcharhinus cf. *leucas* (Valenciennes, 1839 in Müller and Henle, 1839–1841)

Material:

One tooth and 3 incomplete teeth; ULPGC n°: f21 (Fig. 6: F1), f22 (Fig. 6: F2), to f24.

Localities:

Barranco Seco, Ciudad Jardín, Bañaderos (Figs. 2–4).

Comparisons and systematic attribution:

Though found specimens are scarce, one of them is nearly complete (Fig. 6, F1) and corresponds to an upper anterior-lateral tooth comparable to those from the Italian Pliocene (Marsili, 2007).

The triangular shaped fragments correspond to a broad crown of small thickness. Inclination of the teeth is slightly towards the lingual face. The lingual face is flat and the labial face slightly convex. Grooves can be seen at the base of the crown that are more marked on the labial face. The lateral teeth have a marked curvature.

Stratigraphic and geographic records:

Miocene to Recent. They lived in warm oceans. Miocene Pacific coasts of South America (Lovejoy *et al.*, 2006), Pliocene of North Carolina (Purdy *et al.*, 2001) and California (Applegate, 1978) in the USA, Angola (Antunes, 1978) and Italy (Marsili, 2007).

Carcharhinus cf. *priscus* (Agassiz, 1843)

Material:

One tooth; ULPGC n°: f81 (Fig. 6: G1)

Locality:

Barranco Seco (Figs. 2–4).

Comparisons and systematic attribution:

A single lateral tooth from the lower jaw with complete root. Small-sized triangular crown (0.8 cm high), smooth internal and convex external faces. Smooth edge. Very open root. Our tooth is comparable with those from Hungary studied by Kocsis (2007).

Stratigraphic and geographic records:

Neogene de Peru y Ecuador (Carrillo-Briceño *et al.*, 2014), Miocene and Early Pliocene of the Mediterranean and Belgium (Menesini, 1969; Cappetta 1987). Early Pliocene of Huelva (García *et al.*, 2011).

Genus *Galeocerdo* Müller & Henle, 1837

Galeocerdo cf. *aduncus* Agassiz, 1843

Material:

11 teeth; ULPGC n°: f51 (Fig. 6: H1), f52 (Fig. 6: H2) to f511.

Locality:

Barranco Seco (Fig. 2–4).

Comparisons and systematic attribution:

The teeth are triangular, highly curved and in general more wide than long. The crown is markedly crenulated. A strongly serrated talon emerges from the posterior edge, with denticles or secondary cusps whose size decreases regularly in a backwards direction. The differences in size and inclination of the tooth become more pronounced as they are found in a more posterior position. The anterior edge of the crown is convex and the posterior edge is strongly inclined forming an angle close to 90° with the talon. The whole edge is heavily dentated. Crenulation is finer on the main cusp and more pronounced in the anterior region. Denticles or secondary cusps can be observed emerging from the talon. The root is slender and presents two very open lobes which form an angle of between 130° and 140°. It is separated from the crown by a small groove parallel to the base of the crown. The Miocene *Galeocerdo aduncus* disappears in the Pliocene, giving place to *G. cuvier* (Menesini, 1969). However, our specimens resemble those shown in Marsili *et al.*, (2007), while differing from those shown by Pawellek *et al.*, (2015) particularly with respect to the angle formed by the posterior edge and the talon, which is much bigger in *G. cuvier*. They also differs a lot to those *G. cuvier* shown by Carrillo-Briceño *et al.*, (2015; Table Fig. 3 OP Miocene and QR Early Pliocene), mainly because those are very small and long and, by contrast, the canary specimens are nearly the same in length and in thickness. Lobule aperture at the root is wider in *G. cuvier* (about 160°) than in our specimens.

Stratigraphic and geographic records:

Neogene of Ecuador (Carrillo-Briceño, 2014), Miocene of Europe, America, Asia (Marsili *et al.*, 2007), Early Pliocene of Huelva (García *et al.*, 2011).

Class OSTEICHTHYES Huxley, 1880

Order PERCIFORMES Johnson and Patterson, 1993

Family SPARIDAE Linné, 1758

Genus *Archosargus* Gill, 1865

Archosargus cinctus (Agassiz, 1843)

Material:

593 teeth; ULPGC n°: f91 (Fig. 7: A1), f92 (Fig. 7: A2), f93 (Fig. 7: A3), f94 (Fig. 7: A4), f95 (Fig. 7: A5), f96 (Fig. 7: A6), f97 (Fig. 7: A7) to f9593.

Localities:

A few specimens appear in all the localities (Fig. 2), but the largest collection comes from the Barranco Seco (Figs. 3–4) locality with a total of 469 teeth.

Comparisons and systematic attribution:

There are three dentition types: molariform, conical and incisiform. The largest sized teeth are molariform, ranging between 42 mm and 162 mm in diameter. These are circular, hemispherical shaped and have a central depression. Some of the molariform teeth are significantly smaller in size, ranging between 5 mm and 8 mm, while others have an oval contour and yet others a somewhat reniform contour. A neck-like root structure with radial grooves can be observed at the base of the crown. The size of the conical teeth is approximately half that of the molariforms. As for the incisiforms, the crown is quadrangular and slightly broader than the root, convex and concave respectively in the external and internal faces. The concave part of the internal face becomes wider from the base to the cutting edge where it extends along its full length.

The morphology of the Sparid fossil teeth allows us to assign them for the first time to the genus *Archosargus*. According to Day (2002, Fig. 13), the Sparidae which have molariform teeth belong to the genera: *Sparus*, *Argyrops*, *Calamus*, *Archosargus*, *Acacthopagrus*, *Diplodus*, *Crenidens*, *Stenotomus*, *Lithognatus* and *Pagrus*. If we eliminate the genera which possess caniniform as well as molariform teeth (*Sparus*, *Argyrops*, *Calamus*, *Acacthopagrus*, *Crenidens*, *Stenotomus*, *Lithognatus* and *Pagrus*) and the genus in which conical teeth are absent (*Diplodus*), the only genus that satisfies the condition of having only molariform, conical and incisiform teeth is *Archosargus*. In *Archosargus probatocephalus* (Walbaum, 1792; Worcester, 2012), a present day species of the Caribbean (Smith, 1997), the following features are observed: (a) some 120 – 130 teeth; (b) the lingual teeth are the largest with a spheroid shape that becomes more ellipsoidal towards the anterior part; (c) the labial series is comprised of conical teeth; and (d) there are central teeth in the maxilla of notably smaller size. There are 6 incisiforms in the upper maxilla and 8 in the lower. From the deposits of the Early Pliocene of the Canary Islands, we have examined 382 spheroidal molariform teeth, 154 oval-shaped molariforms, 55 conical teeth and 2 incisiform belonging to sparid fossils. The proportions and morphologies are roughly in agreement with, on the one hand, a dentition pertaining to the genus *Archosargus* and, on the other with fossils attributed before the work of Day (2002) to the species *Sparus cinctus* and subsequently to sparid morphotypes of undetermined genus (Marsili *et al.*, 2007). Accordingly, we consider we are justified in attributing the sparid fossils of the Canary Islands to a species of the genus *Archosargus*.

Stratigraphic and geographic records:

Miocene of Morocco (Lecointre, 1952). Miocene and Pliocene of Europe and the Mediterranean, in the Atlantic from the north coast of Africa to the coast of Angola and in

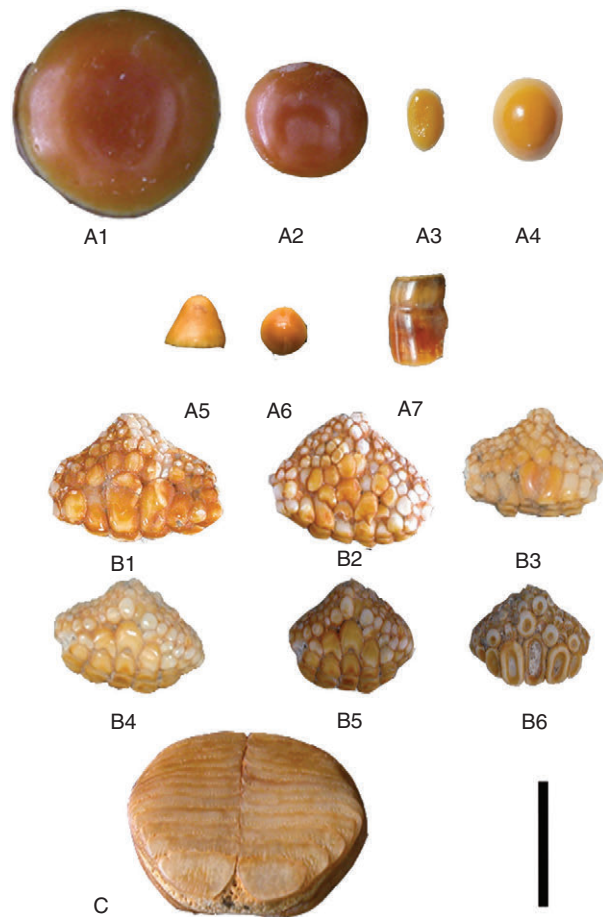


Fig. 7.—Osteichthyes fossil fish teeth from Early Pliocene deposits of Canary Islands. All from ULPGC-Pal collection. Scale bar: 10 mm. *Archosargus cincta*: A1 and A2 – Upper lingual hemispheroidal molariform with central depression; A3 and A4 – Upper ellipsoidal molariform of central position (between the labial and lingual series); A5 and A6 – conical teeth of the labial series A7 – 4th lower right incisiform; *Labrodon pavimentatum*: B1– Upper grinding face view of lower pharyngeal plate. B2 – Grinding face view of upper pharyngeal plate. B3 Lower side view of upper pharyngeal plate. B4 and B5 – Upper side view of lower pharyngeal plates. B6 – Grinding face view of upper right pharyngeal plate. *Diodon scillae*: C – Internal dental battery, ventral view.

the Caribbean (Menesini, 1968; Bauzà & Plans, 1973; Mas, 2000). A Lower Pliocene fossil fish found in Mediterranean Libya could be attributed to the genus *Archosargus* (Pawellek *et al.*, 2015).

Family LABRIDAE Cuvier, 1816**Genus *Labrodon* Gervais, 1857*****Labrodon pavimentatum* Gervais, 1857****Material:**

63 pharyngeal plates; ULPGC n°: f101 (Fig. 7: B1), f102 (Fig. 7: B2), f103 (Fig. 7: B3), f104 (Fig. 7: B4), f105 (Fig. 7: B5 and B6) to f1063.

Localities:

Barranco Seco, Ciudad Jardín (Figs. 2–4).

Comparisons and systematic attribution:

Among the numerous pharyngeal plates found in various states of conservation we have chosen for representation purposes: three lower pharyngeal plates, and one right and one left upper pharyngeal plates (Fig. 7, B). These plates were described in detail by Cocchi (1864), who based his species *Pharyngodopilus africanus* on material from the same Barranco Seco site on the island of Gran Canaria. In some of our specimens, there also appears a sigmoidal shape similar to that of *Pharyngodopilus crassus*. The Barranco Seco pharyngeal plates are very similar, if not identical, to *L. multide*, according to Sacco (1916), and to *L. pavimentatum*, according to Simonelli (1889). Moreover, according to Sacco (1916), *Pharyngodopilus crassus* is synonymous with *L. pavimentatum*.

Stratigraphic and geographic records:

Very abundant in Miocene deposits of the Mediterranean coasts (Cocchi, 1864). Miocene of France and Portugal (Sauvage, 1875). Miocene of Costa Rica (Laurito et al., 2014). Pliocene of Morocco (Lecointre, 1952).

Order TETRAODONTIFORMES Regan, 1929

Family DIODONTIDAE Bibron in Duméril, 1855

Genus *Diodon* Linné 1758

Diodon scillae Agassiz, 1843

Material:

2 complete dental plates and one fragment; (Fig. 1, Paläontologisches Museum München) and; UPLGC n°: f111 (Fig. 7: C1) to f113.

Localities:

Barranco de Guinguada, Barranco Seco (Fig. 2–4).

Comparisons and systematic attribution:

Complete upper dental plate, approximately 18 mm wide. Bilobed structure with heart-shaped contour and triangular-shaped lobes comprised of 14–16 fused blades or platelets. The uppermost pair of platelets are very thin and narrow whereas the two at the base are wider and ellipsoidal or trapezoidal in shape. The specimens are identical to that described by Rothpletz & Simonelli (1890) from Gran Canaria island, which is currently part of the PMM collection [Paläontologisches Museum München] (Fig. 1) and very similar to the specimen from the Miocene of Cuba in shape and dimensions. *D. scillae* is a senior synonym of *D. sigma* (Iturralde-Vinent & Case, 1998).

Stratigraphic and geographic records:

Miocene of France (Leriche, 1957), Italy (Menesini, 1969), Miocene of Cuba (Iturralde-Vinent & Case, 1998).

Discussion

The presence of pillow lavas in relation to the deposits (Meco et al., 2007, 2015) has allowed a dating (ca 4.8 Ma) for Canary fossil fishes, which - from the 19th through to the 21st century - have gone from

being attributed to the ‘Miocene’ (Fig. 1), ‘Mio-Pliocene’ or ‘Neogene’ to finally being assigned to the first half of the Early Pliocene.

The age of the Canary deposits allows a reconstruction of the palaeoceanographic scenario in which the fossil fishes considered in this paper lived. A means of communication was open at the time between the Atlantic and Pacific Oceans via the CAS (Erkens, 2015), while the Gibraltar Seaway was again connecting the Atlantic Ocean with the Mediterranean Sea (García-Castellanos et al., 2009). In addition to these circumstances, we need to consider the capacity of some of these fishes to travel large distances.

About 5 to 4 Ma ago, in the Early Pliocene, the earth had a warm, temperate climate (Fedorov et al., 2013). The marine waters of the Canary Islands between 4.8 and 4.2 Ma (Meco et al., 2015, 2016), as well as those of the Azores (Santa Maria Island), were subtropical to warm-temperate seas (Ávila et al., 2012). The presence in the Mediterranean (Lybia) of the genera *Galeocerdo*, *Carcharhinus*, *Archosargus* (?) and *Diodon* indicates a tropical to equatorial climate (Pawellek et al., 2012).

Among the Chondrichthyan fishes studied we find *Carcharocles megalodon* and *Isurus hastalis*, the largest marine predators of the Pliocene (Randall, 1987; Gottfried et al., 1996). It is thought that these were trophic migrators with a pan-oceanic distribution who sought out stable food sources. All of the above lived in all seas during the Early Pliocene. Notable among the Osteichthyes is the presence of the genus *Archosargus*. The few present day species of this genus live mainly in the western Atlantic, the Caribbean and the Galapagos islands (Smith, 1997). Their presence in the eastern Atlantic and the Mediterranean would be consonant with the palaeogeographic conditions described above (Meco et al., 2015) and related to the CAS. One possible *Archosargus* has been found in the Early Pliocene of Libya (Pawellek et al., 2012). *Diodon scillae* has been found in the Miocene of Cuba and the Mediterranean (Iturralde-Vinent & Case, 1998).

The coincidental circumstances of an open CAS and Gibraltar Seaway, along with the capacity of the Chondrichthyes to travel long distances, highlight the tropicopolitan nature of Canary fossil fishes in the Early Pliocene. This is a factor to be considered in the

explanation of the presence of numerous Indo-Pacific sharks in the Mediterranean (Pawellek *et al.*, 2012).

The teeth of the genus *Galeocerdo* found in Gran Canaria Island are comparable to *G. aduncus* which is a Miocene species (Marsili *et al.*, 2007). For Cigala-Fulgosi & Mori (1979), the main difference between this fossil species and the present-day species (*G. cuvier*) lies in the greater robustness of the teeth of *G. cuvier*. Nonetheless, many teeth attributed to *G. aduncus* due to their stratigraphic origin cannot be distinguished from those of young, small or immature specimens of *G. cuvier*. According to Cigala-Fulgosi & Mori (1979), the transition or evolution from *G. aduncus* to *G. cuvieri* was very rapid and possibly coincided with the start of the Early Pliocene (5.33 Ma); both are present in deposits of the Late Miocene whereas only *G. cuvier* has been found in Early Pliocene deposits. Consequently, the presence of *G. aduncus* in the Early Pliocene of Gran Canaria (*ca* 4.80 Ma) could be added to those from the Early Pliocene of Huelva (SW Spain) (Garcia *et al.*, 2011).

Conclusion

A total of 8 taxa of Chondrichthyes and 3 of Osteichthyes have been identified and classified: *Carcharocles megalodon*, *Parotodus benedeni*, *Cosmopolitodus hastalis*, *Isurus oxyrinchus*, *Carcharias cf. acutissima*, *Carcharhinus cf. leucas*,

Carcharhinus cf. priscus, *Galeocerdo cf. aduncus*, *Archosargus cinctus*, *Labrodon pavimentatum* and *Diodon scillae*.

Of seven fossil shark species found in the Azores and eight in the Canary Islands, six or seven are common to both archipelagos (*Carcharocles megalodon*, *Parotodus benedeni*, *Cosmopolitodus hastalis*, *Isurus oxyrinchus*, *Carcharias cf. acutissima*, *Carcharhinus cf. leucas*, and perhaps *Galeocerdo cf. aduncus* = *Carcharhinus egertoni*?) (Fig. 8).

In addition, we have also identified among the Osteichthyan fishes from the Canary Islands, thanks to the numerous teeth and dental fragments that have been found the tropical genera *Archosargus* and *Diodon*.

The fossil species found in the Early Pliocene of Libya that have also been found in Gran Canaria are: *Carcharocles megalodon*, *Cosmopolitodus hastalis*, *Isurus oxyrinchus*, genera *Archosargus cinctus* and *Diodon scillae*.

Carcharocles megalodon, *Cosmopolitodus hastalis*, *Isurus cf. oxyrinchus*, *Carcharias cf. acutissima*, *Carcharhinus cf. leucas*, *Carcharhinus cf. priscus*, *Galeocerdo cf. aduncus* were also present in the Pliocene Pacific coasts of South America. Consequently, their preference for warm waters suggests an open CAS between the Atlantic and Pacific oceans at that time.

Galeocerdo aduncus from the Canary Early Pliocene should be added to the reference from the same epoch in Huelva (SW mainland Spain).

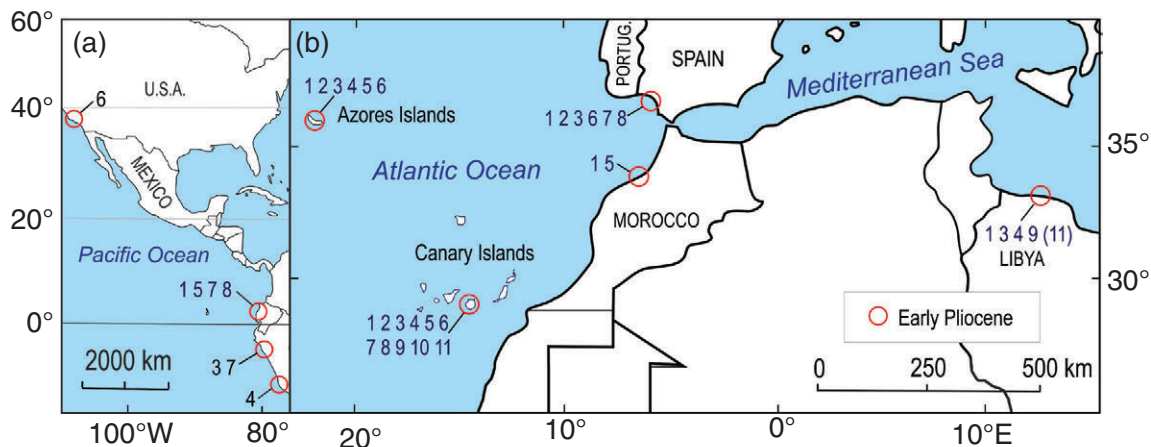


Fig. 8.—Maps of selected localities with palaeogeographic significance: (a) on the western Pacific coasts; (b) on the eastern Atlantic and Mediterranean coasts. Numbers refers to the fossil species of the present paper: 1 *Carcharocles megalodon*, 2 *Parotodus benedeni*, 3 *Cosmopolitodus hastalis*, 4 *Isurus oxyrinchus*, 5 *Carcharias cf. acutissima*, 6 *Carcharhinus cf. leucas*, 7 *Carcharhinus cf. priscus*, 8 *Galeocerdo cf. aduncus*, 9 *Diodon scillae*, 10 *Labrodon pavimentatum*, 11 *Archosargus cinctus*.

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