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MIO-PLIOCENE CRUSTACEANS FROM THE CANARY ISLANDS, SPAIN

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Abstract. There are few previous references to fossil crustaceans for the Neogene marine layers of the Canary Islands (Spain). The Mio-Pliocene marine sedimentary layers in the eastern islands (Gran Canaria, Fuerteventura and Lanzarote) were previously characterised by the presence of numerous fossil fauna, mainly anthozoans and molluscs, which correspond to an equatorial-type palaeoclimate, warmer than the present climate. This Mio-Pliocene transition dated between 9.3 and 4.1 Ma. In this paper, 12 fossil crustacean taxa are identified and classified, including decapods and barnacles: *Balanus concavus* Bronn, 1831, *Balanus spongicola* Brown, 1827, *Balanus perforatus* Bruguière, 1789, *Chenolobia testudinaria* Linnè, 1767, *Tetraclita* cf. *rubescens* Darwin, 1854, *Callianassa matsoni* Rathbun, 1935, *Callianassa* sp., *Upogebia* sp, *Eriphia* aff. *verrucosa* (Forskal, 1775), *Maja* sp., *Scylla michelini* Milne-Edwards, 1861 and *Ocypode* sp. Some of these taxa mean new references for the Atlantic islands and the North African Atlantic and definitely enlarge the palaeographic distribution of Neogene crustaceans beyond the Mediterranean region, extending it to the North Atlantic. Particularly significant are the presence of *Tetraclita* cf. *rubescens*, this being the first reported fossil occurrence of this barnacle outside the North America Pacific coasts, and *Chenolobia testudinaria*, indicating for the first time the existence of marine turtles in these islands during the Neogene. These results are coherent with previous research hypothesising the existence of a flow of surface water between the Pacific and Atlantic in the Mio-Pliocene transition (Central American Seaway, CAS) which explains the arrival of organisms, in larval stage, from Central America to the Canary Islands.

Introduction

Fossil fauna from the Canary Islands of the Mio-Pliocene age plays an important role in understanding climate evolution in the North African Atlantic. The very few crustacean fossil records for the Canaries come from the XIX century (Rothpletz & Simonelli 1890) [PMM collection: Paläontologisches Museum München, Germany] and the ULPGC-Pal collection [Palaeontology Laboratory of the Universidad de Las Palmas de Gran Canaria, Spain]. However, other fossil fauna groups of Mio-Pliocene sedimentary layers in the Canaries have been studied by Buch (1825), Lyell (1865), Rothpletz & Simonelli (1890) and more recently by Meco (1975). These layers appear in the eastern Canary Islands (NE of Gran Canaria, S and W of Fuerteventura and S of Lanzarote) at varying elevations above more than 140 km of the present-day coastline (Fig. 1).

The chronostratigraphic position of the fossiliferous sedimentary layers corresponds to the Late Miocene and Early Pliocene and was determined by Lietz & Schmincke (1975), Meco & Stearns (1981), and Meco et al. (2007) from K/Ar radiometric dating of lava flows and submarine pillow lavas.

Recently, a Mio-Pliocene fauna association was determined from a study of the ULPGC-Pal collection by Meco et al. (2005, 2007). They established a group of three main fossils and a group of three accompanying fossils (all anthozoans and molluscs) to characterise the Mio-Pliocene layers of the eastern Canary Islands from a chronostratigraphic perspective. In palaeoclimatic terms, these layers importantly indicate temperatures typical of tropical-type warm waters, which are higher than those of the present day are.

The new findings and systematic classification of fossil crustaceans in the sedimentary strata of the Neogene in the Canary Islands contribute to augmenting the palaeontological record and to a better understanding of

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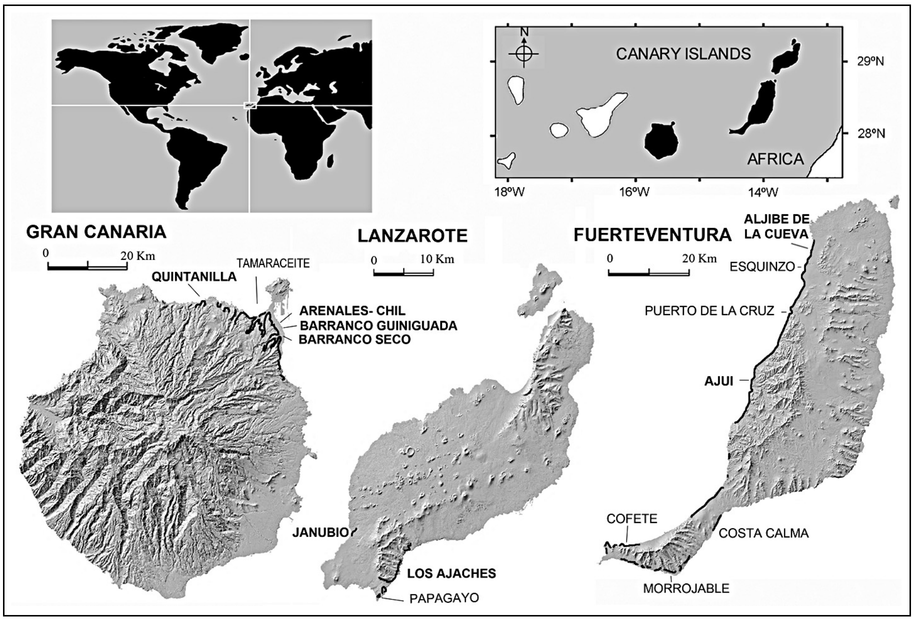


Fig. 1 - Sedimentary layers (black lines) with Mio-Pliocene marine fossils and main sites from the eastern Canary Islands. Selected sites where the stratigraphical sections were made (in bold).

palaeoecological conditions during this period in the North African Atlantic region.

There are very few previous references to fossil crustaceans for these marine layers in the Canaries. Rothpletz & Simonelli (1890) mentioned the presence of *Balanus perforatus* Bruguière, 1789 and defined the new species *Chenolobia hemisphaerica*.

As for accompanying fauna, Meco et al. (2005) defined a group of species of stratigraphic and palaeoclimatic interest, divided into an first triad that characterises these layers in the Canaries (*Gryphaea virleti* Deshayes, 1832, *Nerita emiliana* Mayer, 1872 and *Strombus coronatus* Defrance, 1827) and a second triad of chronostratigraphic confirmation (*Ancilla glandiformis* Lamarck, 1822, *Rothpletzia rudista* Simonelli, 1890 and *Siderastraea miocenica* Osasco, 1897). This fauna not only provides stratigraphic contextual information corresponding to the Miocene-Pliocene transition, consistent with the different existing radiometric dating, but also additionally informs us of climate conditions different to those of the present day.

Geological and stratigraphic setting

The Canary Islands comprise seven main volcanic islands and several islets and are located in the Eastern Atlantic Ocean between N 27º and N 30º 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. 1). The islands have a complex geological history, with volcanic formations over 20 million years old, but they also include extensive sedimentary deposits.

Fossil marine fauna of the Mio-Pliocene are found in coastal deposits on the eastern Canary Islands (NE of Gran Canaria, S and W of Fuerteventura and S of Lanzarote) at varying elevations above the present-day coastline (Fig. 1). They are always 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 (anthozoans, brachiopods, molluscs, crustaceans, echinoderms, fishes, etc.), were deposited on wave-cut platforms tens of kilometres long. Subsequently, withdrawal of the sea saw 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 (Lomoschitz et al. 2011).

In order to establish a general time interval, the fossil specimens previously studied from these deposits dated to a Late Miocene and Early Pliocene age (Fig. 2). This agrees with K/Ar ages obtained from pillow lavas emplaced in the marine deposits (ca 4.1 Ma in Gran Canaria, ca 4.8 Ma in Fuerteventura) and from underlying (ca 9.3 Ma in Gran Canaria) or overlying (ca 8.9 Ma in Lanzarote) lava flows (Meco et al. 2007). Consequently, it is consistent to consider a time interval between 9.3 and 4.1 Ma for Neogene marine deposits in the eastern Canary Islands as a whole.

Another important aspect of the fossiliferous sedimentary layers is the varying height above present sea level (apsl) of the different outcrops in the Canaries. These range from 9 to 57 m apsl in Fuerteventura, from 21 to 69 m apsl in Lanzarote and from 50 to 120 m apsl in Gran Canaria. These variations in height have been

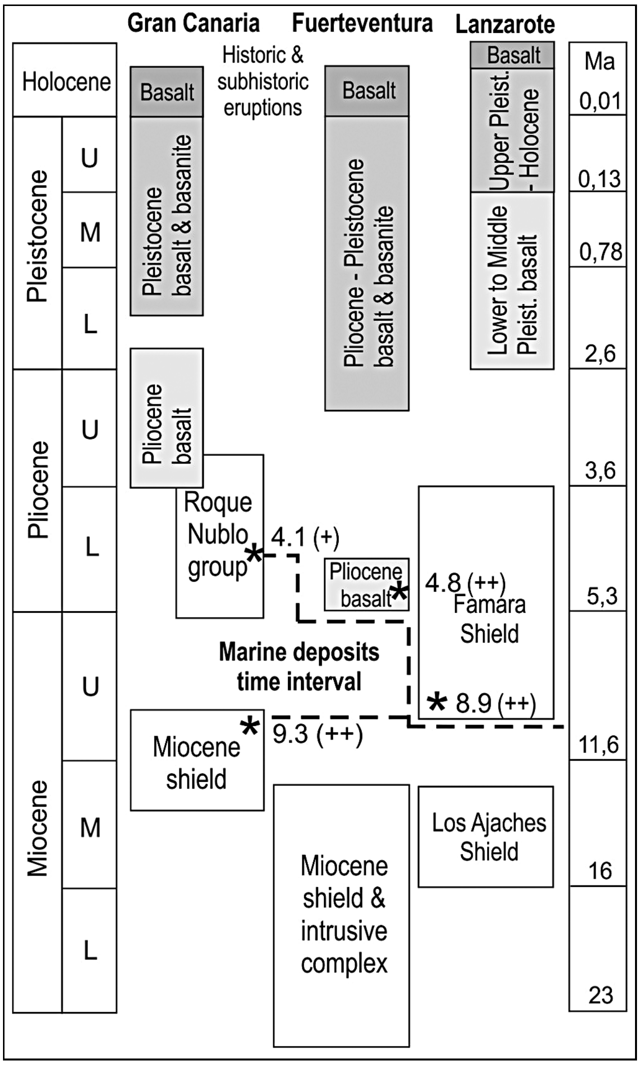


Fig. 2 - Volcanic chronostratigraphy of the eastern Canary Islands and K/Ar ages (*) Ma of Mio-Pliocene marine deposits from underlying and overlying lava flows. Datings from (+) Guillou et al. (2004) and (++) Meco et al. (2007).

interpreted as being related to tectonic readjustments in the different island edifices (Meco et al. 2007). In addition, from a palaeoclimatic perspective these raised marine deposits in the eastern Canary Islands have been interpreted as warming episodes within Plio-Quaternary climate variations.

Stratigraphic sections

The fossil crustacean specimens were found in the sedimentary layers, consisting of old coastal and marine deposits which outcrop along more than a hundred kilometres, if all the different stretches are considered together. As these layers show many lateral variations along the outcrops, eight sections have been selected to be representative of the whole area: Janubio and Los Ajaches from S. Lanzarote Is., Aljibe de la Cueva and Ajuí from W Fuerteventura Is. (Fig. 3), and Guiniguada, Barranco Seco, Arenales-Chil and Quintanilla from NE Gran Canaria Island (Fig. 4, Fig. 5A).

1 - Janubio section

Location: SW Lanzarote Is.

Latitude: 28°55'57.48", longitude: 13°49'17.72", height: 36 m (apsl)

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

3) Basaltic lava flows (3 m). These are thin layers of rock with intercalations of pyroclasts, horizontally displayed and slightly weathered. They are of Early Pleistocene age according to IGME (2005) and Meco et al. (2007).

2) Reddish conglomerate with fossils (0.5 m). This is composed of sub-rounded basaltic pebbles and cobbles with a matrix of fine gravel and sand, partially cemented by calcite.

1) Basaltic lava flows (20-30 m). These are a succession of predominant lava flows and beds of scoria and buried tephra cones, which are densely crossed by dykes. All these materials are intensely weathered. They are of Middle to Late Miocene age, according to IGME (2005).

2 - Los Ajaches section

Location: SE Lanzarote Is.

Latitude: 28°50'32.04", longitude: 13°47'16.63", height: 21 m (apsl).

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

4) Sandy gravel colluvium (0.5 m) of Holocene age.

3) White dune sand (3 m). Aeolianite composed of carbonate grains of medium to fine sand, with a characteristic cross-bedding internal structure.

2) Reddish conglomerate with fossils (1.5 m). This is composed of rounded to sub-angular basaltic pebbles, cobbles and some boulders with a matrix of fine gravel and sand, partially cemented by calcite.

1) Basaltic lava flows (35 m). These are massive and very thick layers of basalts, with columnar jointing. They are composed of dark basalt of aphanite matrix, with weathered olivine (iddingsite) and pyroxene crystals. They are of Late Miocene age, according to IGME (2005).

3 - Aljibe de la Cueva section

Location: NW Fuerteventura Is.

Latitude 28°39'56.39", longitude: 14°00'43.22", height: 17 m (apsl).

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

4) White sand dunes (2 m). Aeolianite composed of carbonate grains of fine sand.

3) Basaltic lava flows and tephra (2 m). These are part of a succession of thin layers of olivine basalt, rather weathered, with some intercalated layers of pyroclasts. They are of Late Pliocene age, according to IGME (2006).

2) Reddish conglomerate with fossils (0.5-2 m). As a whole, it is composed of conglomerate and sand layers. The conglomerate layer has sub-rounded basaltic pebbles and cobbles with a matrix of gravel and sand, partially cemented by calcite. The sand layer is comprised of grey coarse sands with slightly defined planar lamination. They correspond to the Pliocene coast platform described in IGME (2006).

1) Basaltic lava flows and dykes (5 m). These are highly weathered rocks with olivine and pyroxene crystals and secondary filling of calcite and zeolite. Basaltic and trachytic dykes also densely cross them. This formation is of Early Miocene age, according to IGME (2006).

4 - Ajuí section

Location: W Fuerteventura Is.

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

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

5) Sandy gravel colluvium (1 m) of Holocene age.

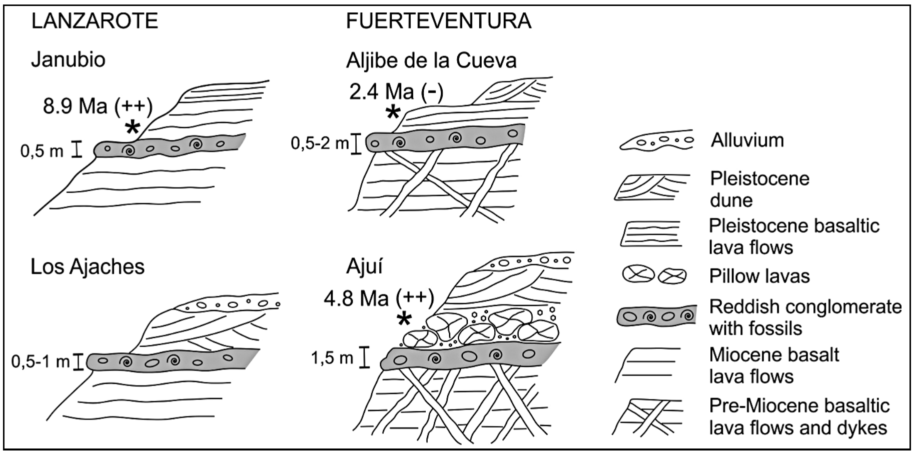


Fig. 3 - Stratigraphical sections on Lanzarote and Fuerteventura islands where the fossil crustaceans have been found. K/Ar dating ages (*) from (-) Coello et al. (1992) and (++) Meco et al. (2007).

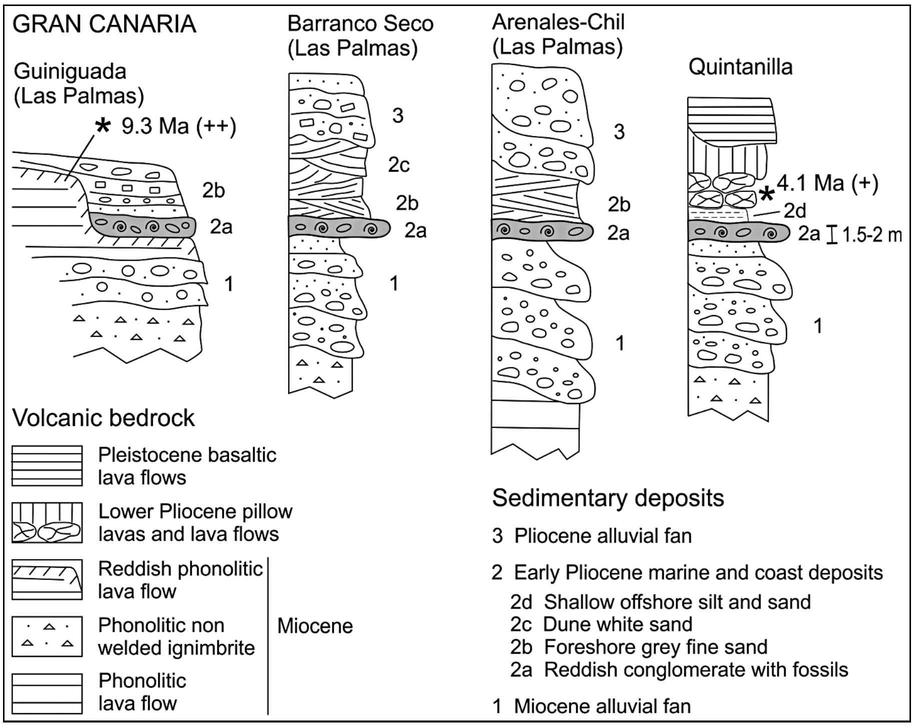


Fig. 4 - Stratigraphical sections on NE Gran Canaria where the fossil crustaceans have been found. Modified from Gabaldón et al. (1989) and Meco et al. (2005). K/Ar dating ages (*) from (+) Guillou et al. (2004) and (++) Meco et al. (2007).

4) White sand dunes (2 m). Aeolianite composed of carbonate grains of medium to fine sand, with a characteristic cross-bedding internal structure.

3) Basaltic pillow lavas and hyaloclastites (3 m). These come from olivine basaltic lava flows that erupted about 9 km inland. This formation is of Early Pliocene age, according to IGME (2006) and Meco et al. (2007).

2) Reddish conglomerate with fossils (1.5 m). This is mainly composed of basaltic sub-rounded pebbles, gravels and cobbles with sandy matrix. It is part of the Pliocene marine platform described in IGME (2006).

1) Basaltic lava flows and dykes (8 m). These are badly defined layers of basaltic materials: lava flows, breccias, tuffs and hyaloclastites. They are highly weathered rocks and densely crossed by dykes. As a whole, they are part of the "basal complex" of Fuerteventura that is of Oligocene age, according to IGME (2006).

5 - Guiniguada section (Las Palmas)

Location: NE Gran Canaria Is.

Latitude: 28°06′03.91", longitude: 15°25′54.96", height: 92 m (apsl).

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

5) Heterogeneous sandy conglomerate of phonolitic and basaltic pebbles (> 15 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 deposit of Pliocene age.

4) Reddish conglomerate with fossils (1.5 m). This is composed of sub-rounded phonolitic pebbles and cobbles with a matrix of fine gravel and sand, partially cemented by calcite. It is a Lower Pliocene deposit and was formed in a tidal environment of a coastal platform.

3) Reddish phonolitic lava flow (1-12 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.

2) Heterogeneous sandy conglomerate of phonolitic pebbles (5-10 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.

1) Phonolitic non-welded ignimbrite (> 15 m). This has a homogeneous appearance and is composed of thick layers of yellow to white rocks. It corresponds to the Miocene of Gran Canaria.

6 - Barranco Seco section (Las Palmas)

Location: NE Gran Canaria Is.

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

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

6) Heterogeneous sandy conglomerate of phonolitic and basaltic pebbles (20-25 m). It is similar to unit 5 of the Guiniguada section, described above.

5) White sand dunes (5-10 m). Aeolianite composed of carbonate grains of fine to medium sand, with a characteristic cross-bedding internal structure.

4) Grey sand with bioturbation structures (3-8 m). This is a deposit of medium to fine sand, which originated in a foreshore environment.

3) Reddish conglomerate with fossils (2 m). It is similar to unit 3 of the Guiniguada section, described above.

2) Heterogeneous sandy conglomerate of phonolitic pebbles (20-25 m). It is similar to unit 2 of the Guiniguada section, described above.

1) Phonolitic non-welded ignimbrite (>15 m). It is similar to unit 1 of the Guiniguada section, described above.

7 - Arenales-Chil section (Las Palmas)

Location: NE Gran Canaria Is.

Latitude: 28°06′43.63”, longitude: 15°25′35.62”, height: 47 m (apsl).

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

5) Heterogeneous sandy conglomerate of phonolitic and basaltic pebbles (20-25 m). It is similar to unit 5 of the Guiniguada section and unit 6 of the Barranco Seco section, described above.

4) Grey sand with bioturbation structures (5 m). This is a deposit of medium to fine sand, which originated in a foreshore environment.

3) Reddish conglomerate with fossils (2-3 m). It is similar to unit 3 of the Guiniguada and Barranco Seco sections, described above.

2) Heterogeneous sandy conglomerate of phonolitic pebbles (20-25 m). It is similar to units 2 of the Guiniguada and Barranco Seco sections, described above.

1) Phonolitic lava flow (>12 m). This is composed of a hard rock, dark green in color and with homogeneous appearance. It corresponds to the Miocene of Gran Canaria, which are of Late Miocene age.

8 - Quintanilla section

Location: NE Gran Canaria Is.

Latitude: 28°07’12.84”, longitude: 15°27′30.75”, height: 97 m (apsl).

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

6) Basaltic lava flows (25 m). These are horizontally displayed layers, with scoriaceous layers at their top. They are of Early Pleistocene age according to ITGE (1990).

5) Basanitic lava flows and pillow lavas (40 m). These form a monotonous layer, about 25 m thick, that is only disturbed at their bottom, where lava flows (originally aerial) turn to pillow lavas and hyaloclastites (submarine) with an average thickness of 15 m. They are of Early Pliocene age according to ITGE (1992) and Meco et al. (2007).

4) White silt and sand (0.5-1.5 m). This is an easily distinguishable layer because of its light colour. In detail, it is composed of 2-3 thin layers, which correspond to specific sedimentary facies: white silt with planar lamination; grey coarse sand with undulated lamination and grey coarse to fine sand with planar lamination. It most probably originated in a quiet and shallow offshore environment, e.g. a small bay.

3) Reddish conglomerate with fossils (0.5-2 m). This is similar to unit 3 of the other Las Palmas sections, described above.

2) Heterogeneous sandy conglomerate of phonolitic pebbles (12-15 m). This is similar to unit 2 of the other Las Palmas sections, described above.

1) Phonolitic non-welded ignimbrite (15-20 m). This is similar to unit 1 of the Guiniguada and Barranco Seco sections, described above.

Canary Island Neogene Crustaceans

Twelve taxa have been identified in the different outcrops of the deposits in the islands, corresponding to both decapod and cirriped crustaceans. These Neogene fossil crustaceans are shown in the following list:

1. *Balanus concavus* Bronn, 1831
2. *Balanus spongicola* Brown, 1827
3. *Balanus perforatus* Bruguière, 1789
4. *Chenolobia testudinaria* Linnè, 1767
5. *Tetraclita cf. rubescens* Darwin, 1854
6. *Callianassa matsoni* Rathbun, 1935
7. *Callianassa* sp.
8. *Upogebia* sp.
9. *Eriphia aff. verrucossa* (Forskal, 1775)
10. *Maja* sp.
11. *Scylla michelini* Milne-Edwards, 1861
12. *Ocypode* sp.

Systematic Palaeontology

Phylum **Arthropoda** Latreille, 1829

Subphylum **Crustacea** Pennat, 1777

Class **Maxillopoda** Dahl, 1956

Infraclass **Cirripedia** Burmeister, 1834

Superorder **Thoracica** Darwin, 1854

Order **Sessilia** Lamarck, 1818

Suborder **Balanomorpha** Pilsbry, 1916

Superfamily Balanoidea Leach, 1817

Family Balanidae Leach, 1817

Genus *Balanus* Da Costa, 1778

Balanus concavus Bronn, 1831

Pl. 1, figs A1, A2, A3

1854 *Balanus concavus* Darwin, p. 235, pl. 4, fig. 4a-e.

1906 *Balanus concavus* - Alessandri, p. 295, pl. XVI, figs 21-25; pl. XVII, figs 1-4.

1952 *Balanus concavus* - Davadie, p. 17, pl. I, figs 1-2; pl. II, figs 1-2; pl. III, figs 1-2, pl. IV, figs 1-2; pl. V, figs 1-2.

1963 *Balanus (Balanus) concavus* – Davadie, p. 52, pl. XXIV, figs 8-9.

Balanus concavus - Menesini, p. 110, pl. IV, figs 2-6; pl. VI, figs 1-4; pl. X, figs 7-8; pl. XI, figs 1-2; pl. XVII, figs 3-8; pl. XIX, figs 1-3.

Balanus concavus - Cuerda and Sacares, p. 115, pl, II, fig. 1a-b; fig. 2.

1979 *Balanus concavus concavus* - D'Alessandro et al., p. 94, pl. 18, figs 4-5; pl. 19, figs 1-3.

Material: Many free *scutum* and a few shells attached to bivalves (*Chama* sp.)
Locality: Fuerteventura: Jandía (Costa Calma) (Fig.1), Costa de Barlovento. Gran Canaria: Barranco de Mata, Las Rehoyas-El Polvorín, San José, Bañaderos.

Remarks. Reported for the Oligocene of Hungary and Algeria. Found at sites of Miocene age in Germany, Austria, France, Italy, Algeria, Portugal and even the Atlantic coasts of North America. During the Pliocene, it is very abundant in Italy, Algeria, Spain and England. Currently found in the Caribbean, Panama, Peru, the Philippine archipelago and Australia (Darwin 1854; Menesini 1964), but extinct in the Mediterranean (D'Alessandro et al. 1979). Displays a high degree of polymorphism, with a slender and angular *scutum*, the design of which has grooves, or vertical and horizontal lines, which criss-cross in a highly characteristic pattern.

Balanus perforatus Bruguière, 1789

Pl. 1, fig. B1

1873 *Balanus perforatus* – Seguenza, p. 28, pl. I, fig. 2-2a.
1906 *Balanus perforatus* – Alessandri, p. 294, pl. XVI, figs 17-20.
1952 *Balanus perforates* - Davadie, p. 20, pl. III, fig. 3; pl. IV, fig. 1.
1963 *Balanus (Balanus) perforates* - Davadie, p. 38, pl. XI, figs 5-8.
1964 *Balanus perforatus perforatus* – Menesini, p. 95, pl. I, figs 10, 12, 13; pl. II, figs 1-6; pl. VIII, figs 5-8; pl. XII, fig. 8; pl. XIV, figs 1-5.
1976 *Balanus (Balanus) perforatus angustus* - Pajaud, p. 483, fig. 1a-b; fig. 2.

Material: Large number of specimens forming aggregates.
Locality: Fuerteventura: Cofete (Cofete, Risco del Moro).

Remarks. Reported in the Miocene and Pliocene levels of the Indian Ocean and Mediterranean Seas. Found today in the Mediterranean and Atlantic, along the French coast, England and west coast of Africa (Menesini 1964).

Balanus spongicola Brown, 1827

Pl. 1, fig. C1, C2

1854 *Balanus spongicola* – Darwin, p. 225, pl. 4, fig. 1a-d.
1873 *Balanus spongicola* var. *pliocenica* Seguenza, pl. IX, fig 9-17.
1906 *Balanus spongicola* – Alessandri, p. 290, pl. XVI, figs 6-13.
1963 *Balanus (Balanus) spongicola* - Davadie, p. 49, pl. XXIV, figs 1-7.
1965 *Balanus spongicola* – Menesini, p. 106, pl. III, figs 2-14; pl. IV, fig. 1-1a; pl. X, figs 1-6; pl. XVII, figs 1-2.

Material: Fragments of various large-sized *scuta*.
Localitiy: Fuerteventura: Costa de Barlovento (Barranco de la Cruz). Gran Canaria: Arenales (Fig. 1).

Remarks. Reported in the Miocene of England, Italy, Sardinia, France, Spain, Algeria, Tunisia, and Egypt. Very common during the Pliocene and Pleistocene of Italy, Portugal and Algeria. Currently found in the Mediterranean, Cape of Good Hope and south of England. It is characterised by its large-sized *scuta* with grooved or parallel line decoration.

Genus *Chelonibia* (*Chenolobia*) Leach, 1817

Chelonibia testudinaria Linnè, 1758

Pl. 1, fig. D1, D2

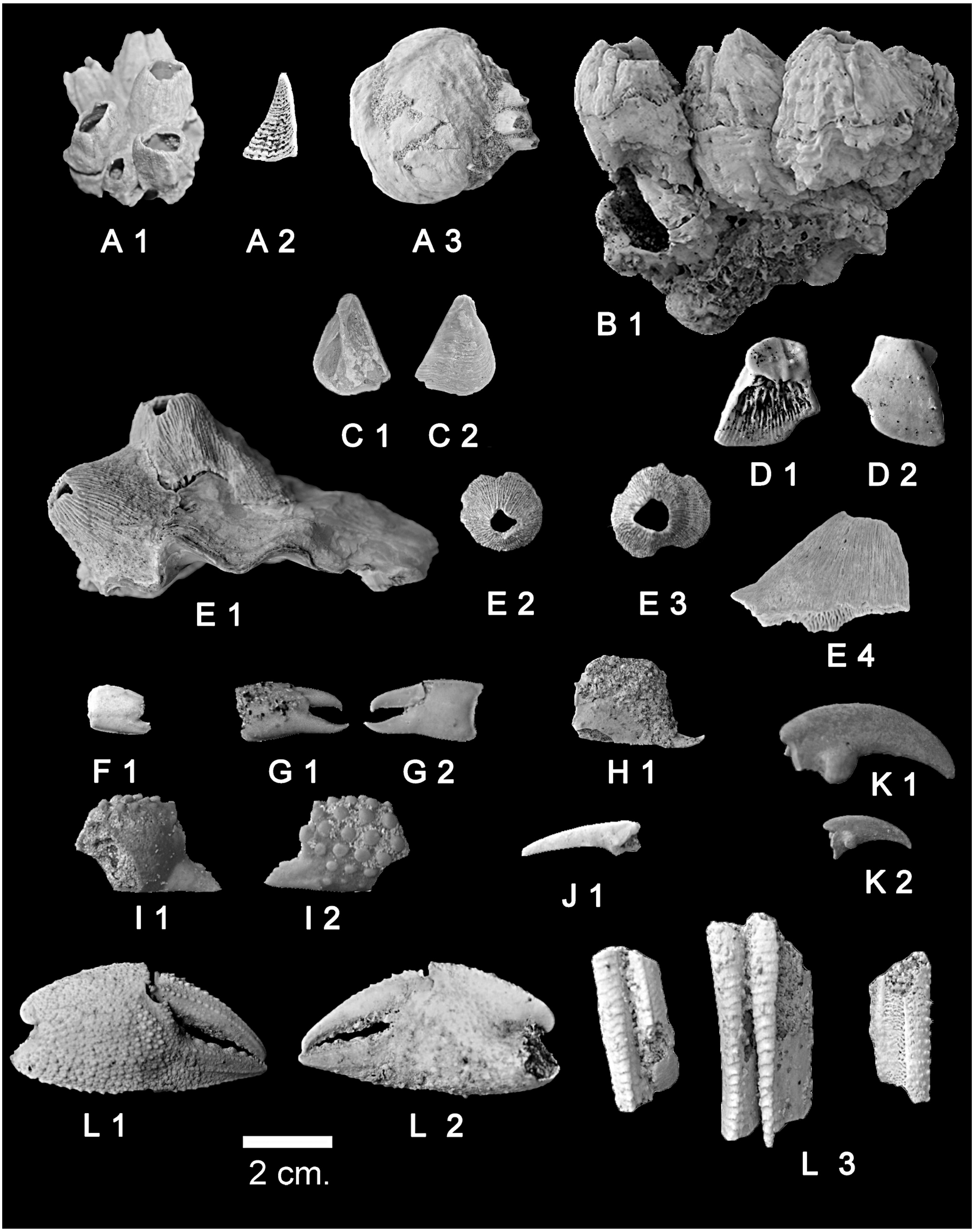
1854 *Chelonobia testudinaria* - Darwin, pl. 14, fig. 1 a-d, fig. 5; pl. 15, fig. 1.
1906 *Chelonibia testudinaria* - Alessandri, p. 314, pl. XVIII, figs 6-7.
1980 *Chelonibia testudinaria* (Linnaeus, 1758). Morris et al., p. 516, fig. 149.

Material: A single fragment of *rostrum*.
Locality: Gran Canaria: Mata ravine.

PLATE 1

Fossil crustaceans remains of the Mio-Pliocene transition in the eastern Canary Islands.

A - *Balanus concavus* Bronn, 1831. A1) Specimen from Costa Calma, Fuerteventura. A2) *Scutum,* Costa Calma, Fuerteventura. A3) Specimens attached to the upper valve of *Chama* sp.
B - *Balanus perforatus* Bruguière, 1789. B1) Cofete, Fuerteventura.
C - *Balanus spongicola* Brown, 1827. C1 & C2) *Scutum*. Barlovento coast, Fuerteventura.
D - *Chenolobia testudinaria* Linnè, 1767. D1) interior view and D2) exterior view. Las Rehoyas-El Polvorín, Gran Canaria.
E - *Tetraclita* cf. *rubescens* Darwin 1854. E1) *T.* cf. *rubescens* Darwin, 1854 attached to an upper valve of *Gryphaea virleti* Deshayes, 1832. Aljibe de la Cueva, Fuerteventura. E2) & E3) Top view. E4) Side view. Aljibe de la Cueva, Fuerteventura.
F - *Callianassa matsoni* Rathbun, 1935. F1) Right chela. Aljibe de la Cueva, Fuerteventura.
G - *Callianassa* sp. G1) Right chela, exterior view, G2) Interior view. Barranco de Esquinzo, Fuerteventura.
H - *Upogebia* sp. H1) Left Chela. Las Rehoyas-El Polvorín, Gran Canaria.
I - *Scylla michelini* Milne-Edwards, 1861. I1) & I2) Dactylus. Aljibe de la Cueva, Fuerteventura.
J - *Maja* sp. J1) Dactylus. Aljibe de la Cueva, Fuerteventura.
K - *Eriphia* aff. *verrucossa* (Forskal, 1775). K1) interior view, K2) exterior view. Papagayo cliff, Lanzarote.
L - *Ocypode* sp. L1 Right chela, exterior view, L2) interior view, L3) meropodite fragments. Cofete, Fuerteventura.


A 1
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K 1
I 1
I 2
J 1
K 2
L 1
L 2
2 cm.
L 3

Remarks. Reported in the Pliocene of the Mediterranean (Italy) and currently found in the Mediterranean, Atlantic and Pacific (Mexico and northern Australia), it is always associated with the presence of marine turtles. Epibiont barnacle on turtle shells. Reaches a maximum diameter of 8 cm (Morris et al. 1980), low height, smooth shell on the outside with only slight inclination. *Rostrum* consisting of three fused plates.

Superfamily Tetraclitoidea Gruvel, 1903
Family Tetraclitidae Gruvel, 1903
Subfamily Tetraclitinae Gruvel, 1903
Genus *Tetraclita* Schumacher, 1817

Tetraclita aff. **rubescens** Darwin, 1854
Pl. 1, fig. E1, E2, E3, E4

1854 *Tetraclita porosa var. rubescens* Darwin, p. 382, pl. 10, fig. 1b.
1916 *Tetraclita squamosa rubescens* – Pilsbry, p. 250, pl. 61, fig. 1a-c.
1980 *Tetraclita rubescens* - Morris et al., p. 157, pl. 150.

Material: Very abundant. Large-sized complete specimens and fragments of specimens found attached to bivalves (*Gryphaea virleti* Deshayes, 1832).

Locality: Lanzarote: Papagayo, Costa de Los Ajaches (Punta Gorda, La Colorada). Fuerteventura: Costa de Barlovento (between Los Molinos and Santa Inés), Jandía (Costa Calma – Costa Esmeralda), Aljibe de la Cueva. Gran Canaria: Ciudad Jardín, Guiniguada (Fig. 1).

Remarks. Limited in both its fossil (Pliocene and Pleistocene) and present-day form from Cape San Lucas, Baja California, Mexico, to San Francisco Bay (Pilsbry 1916). Exterior decorated with very marked grooves. The region of the orifice of these barnacles tends to be eroded and so is seen enlarged. They grow in intertidal habitats, in exposed and quite wave-beaten areas. They occasionally appear in the subtidal region, in this case attached to shells, mainly to *Haliotis* (Morris et al. 1980).

Subphylum **Crustracea** Brünnich, 1772
Class **Malacostracea** Latreille, 1803
Subclass **Eumalacostraca** Grobben, 1892
Order **Decapoda** Latreille, 1803
Suborder **Pleocyemata** Burkenroad, 1963
Infraorder **Thalassinidae** Latreille, 1831
Superfamily Thalassnoidea Latreille, 1831
Family Callianassidae Dana, 1852
Genus *Callianassa* Leach, 1814

Callianassa cf. **matsoni** Rathbun, 1935
Pl. 1, fig. F1

1935 *Callianassa matsoni* Rathbun, p. 24, figs 23-28.

Material: Two chelas without dactylopodites with different degrees of preservation. One corresponds to a right pincer with a fragment of finger and the other to a left pincer with the two ends broken.

Locality: Fuerteventura: Aljibe de la Cueva (Fig.1, Fig.3). Gran Canaria: Chil (Fig. 1).

Remarks. Present in Florida Miocene deposits. Pincer of subrectangular form with smooth edges and convex appearance, which has a narrow fixed finger. The distal edge of the pincer where the dactylopodite is inserted is oblique or perpendicular. The outer surface is convex in a vertical direction. A deep, highly characteristic U-shaped sinus is observed at the base of the lower finger.

Callianassa sp.
Pl. 1, fig. G1, G2

Material: Two right chelas, one complete but with dactylopodite insertion point broken and eroded, the other in bad condition with complete fixed finger.

Locality: Costa de Barlovento (Barranco de Esquinzo) and Jandía (Costa Calma), Fuerteventura (Fig.1).

Remarks. Two chelas (manus and dactylus*)* with similar taxonomic features to those seen in the genus *Callianassa* Leach, 1814. These two chelas have the following characteristics: rectangular shaped, slender and narrow, slightly bulging. Concave interior and convex exterior. Long and inward-curving fingers. Very pronounced beak-like curvature of the fingertips. In the interior region of both the movable and fixed finger, a fine keel-like ridge (carina) extends over the finger from virtually the tip to the end giving it a blade-like appearance. This fine carina follows both the upper and lower edges of the chela and appears much more pronounced at the distal vertices, with a slight continuation noticeable towards the joint. A slight semi-circular depression is observed in the mid-interior region of the chela at the distal end where the joint is situated.

C. candida (Olivi, 1792), presently found in the Mediterranean, has the interior or cutting edges of the two fingers serrated, whereas they are smooth in *Callianassa* sp. The upper finger is notably more robust in the present day species and displays a series of tubercles on the interior edge which are absent in the Mio-Pliocene species.

Family Upogebiidae Borradaile, 1903
Genus *Upogebia* Leach, 1814

Upogebia sp.
Pl. 1, fig. H1

Material: Partially broken left pincer.
Locality: Gran Canaria: Las Rehoyas - El Polvorín.

Remarks. Rectangular left chela, slightly concave interior and markedly convex exterior. Smooth external surface. Fine lower margin, finely and evenly serrated, with very small and flat, triangular shaped spines. Superior and anterior edge encrusted with sand. Superior or movable finger absent, as is its insertion. Fixed finger well preserved, small in size, very curved and interior edge with a carina that runs along its length.

Infraorder **Brachyura** Latreille, 1802
Section **Eubrachyura** Saint Laurent, 1980
Subsection **Heterotremata** Guinot, 1977
Superfamily Eriphioidea MacLeay, 1838
Family Eriphiidae MacLeay, 1838
Genus *Eriphia* Latreille, 1817

Eriphia aff. **verrucosa** (Forskal, 1775)
Pl. 1, fig. K1, K2

Material: Fragment of left pincer, broken at both joints and with encrustation of fine sands on both the interior and surface.
Locality: Papagayo coast, Lanzarote (Fig. 1, Fig. 5C).

Remarks. Small squared chela with fixed finger and cusps. Smooth interior face, exterior face covered with rounded tubercles, moderately aligned longitudinally, that extend to the upper edge and slightly beyond to the interior face. They are of a larger size in the upper half. Fixed finger with a slight rectangular depression in the exterior surface.

There is a strong resemblance between this chela and that shown by Varola (1981) and classified as *Eriphia verrucosa* (Forskal, 1775) for the Neogene deposits (Miocene and Pliocene) of Sicily. Baldanza et al. (2013) quote this genus in the deposits of the lower Pleistocene of Siena Basin, Tuscany, Italy.

This crab is presently found in the Mediterranean Sea, West Africa and Canary Islands coasts (González Pérez, 1995).

Superfamily Majoidea Samouelle, 1819
Family Majidae Samouelle, 1819
Genus *Maja* Lamarck, 1801

Maja sp.
Pl. 1, fig. J1

Material: Two dactylopodite fragments of different length and different states of preservation.
Locality: Fuerteventura: Aljibe de la Cueva (Fig 1, Fig. 3).

Remarks. Reported for the levels of the Lower Pliocene of England, Upper Pliocene of Italy and the Pleistocene of Italy and Sicily (Varola 1981). Slender, curved cone-shaped dactylopodites with smooth surface. The fragments are very similar to the dactylopodite of *Maja squinado* (Herbst, 1788) of the Neogene of southern Italy (Varola 1981).

Superfamily Portunoidea Rafinesque, 1815
Family Portunidae Rafinesque, 1815
Subfamily Portuninae Rafinesque, 1815
Genus *Scylla* de Hann, 1833

Scylla michelini Milne-Edwards, 1861
Pl. 1, fig. K1, K2

1861 *Scylla michelini* Milne-Edwards, p. 262, pl. 3, fig. 3.

Material: Numerous pincer fragments (dactylopodites and propodites), varying in size from 0.9 to 3.85 cm.
Locality: Fuerteventura: Aljibe de la Cueva. Gran Canaria: Chil (Fig. 1, Fig. 3).

Remarks. Reported for the Miocene of Ajou, France. According to Milne-Edwards (1861) the difference in pincers between the *S. michelini* Milne-Edwards, 1861 and the *Scylla serrata* (Forskal, 1775) is minimal. Complete carapaces need to be examined for a full classification.

Section **Thoracotremata** Guinot, 1977
Superfamily Ocypodoidea Rafinesque, 1815
Family Ocypodidae Rafinesque, 1815
Subfamily Ocypodinae Rafinesque, 1815
Genus *Ocypode* Weber, 1795

Ocypode sp.
Pl. 1, fig. L1, L2, L3

Material: Numerous stray fragments in compacted sands, fragments of legs, carapace and pincers, attributable to several individuals.
Locality: Cofete, Fuerteventura (Fig. 1, Fig. 5B).

Remarks. Robust and quadrangular-oval pincer with convex exterior and concave interior. Surface covered with granules, more pronounced in the distal region and the region near the fixed finger. In the interior side there is a rounded and prominent insertion point for the joint, with a well-defined sinus which tapers the chela to the insertion point in a highly characteristic form. Both upper and lower edges have a row of short spines, more marked on the lower edge, which extend as far as the respective fingers. Triangular-shaped lower finger with dentate internal edge and 7-8 teeth, more pronounced in the central region. The tip of the pincer terminates in a hook-like tooth. The upper edge has a series of short spines. Both interior and exterior surfaces are adorned with two slightly raised lines comprising an alignment of granules which are more separated at the distal region of the fixed finger. The interior edge of the movable finger has 8-10 teeth of slight prominence. The exterior side has an alignment of well-defined spines in addition to a single ornamental line similar to that present in the fixed finger.

The remains found in the Canary islands and classified as *Ocypode* sp. do not allow a conclusive classification. The available remains display a certain resemblance to *Ocypode italica* Garassino, 2010 (Garassino et al. 2010) described for the Pliocene deposits of Tuscany, Italy. In terms of general appearance, there is a strong resemblance in the decoration of the *merus, carpus,* and *propodus* of the walking legs, in terms of overlapping grooves, and in the chelipeds, covered in fine granules. The main difference observed between *O. italica* and the *Ocypode* found in the Canary Mio-Pliocene lies in the shape of the chelipeds.

It also differs from other species of the genus *Ocypode*, both fossil and present day specimens, as for example *O. africana* De Man, 1881 in the general shape of the pincers and the decoration of the walking legs.

Biogeography

The species above have an extensive and variable bio-geographical distribution, both fossil and current (Tab. 1). They have been found in areas of the Atlantic, Pacific and Indian oceans and of the Mediterranean Sea. Three quarters of the Neogene species still exist now. However, in the Canary Islands, only half of the fossil species have been identified in present times. This is further evidence of the tropical-type climate which occurred in the Mio-Pliocene stage, different to today's subtropical-type climate.

Conclusions

This paper offers a review and systematic classification of the crustacean fossils of the Canary Neogene, a group of fossils which to date has not been the subject of a specific study.

These fossils were found in marine sedimentary deposits of the eastern Canary Islands (NE of Gran Canaria, S and W of Fuerteventura and S of Lanzarote) along more than 100 km of coast (if the different

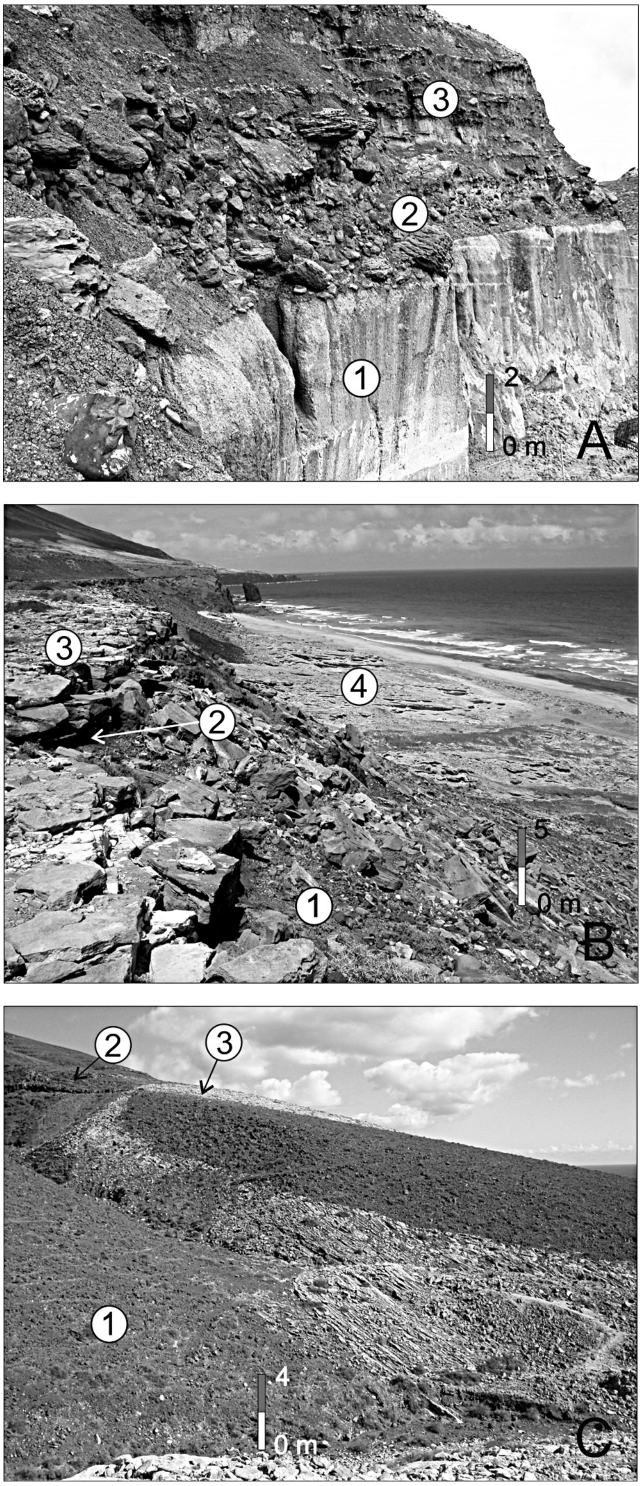

Fig. 5 - Examples of outcrops where the fossil crustaceans have been collected: A) Barranco Seco (NE Gran Canaria): 1 - phonolite non-welded ignimbrite; 2 - reddish conglomerate with fossils; 3 - foreshore grey fine sand (2 and 3 correspond to the middle member of the Las Palmas Detritic Formation). B) Cofete (SW Fuerteventura): 1 - basaltic lava flows and tephra cones; 2 - reddish conglomerate; 3 – white marine sandstone. 4 - Pleistocene dunes. C) Papagayo cliff (S Lanzarote): 1 - basaltic lava flows and pyroclasts; 2 - reddish conglomerate; 3 - Pleistocene aeolianite sandstone.

Taxa	Global biogeography		Global chronostratigraphy			Canary Islands	
	Fossil	Current	Mio-Pliocene	Pleistocene	Holocene	Fossil	Current
Balanus concavus Bronn, 1831	Miocene Tethys coasts of Germany, France, Austria and Italy. Upper Neogene Atlantic and Mediterranean Basin (Italy, Algeria, Spain). England	Caribbean Sea, Panama, Peru, Philippines, Australia	X	X	X	X	
Balanus spongicola Brown, 1827	England,Tethys and Mediterranean Basin (Italy, France, Spain, Algeria, Tunisia, Egypt)	Widespread along the Mediterranean and Atlantic coasts (from the south of England to Cape of Good Hope)	X	X	X	X	X
Balanus perforatus Bruguière, 1789	Miocene Tethys and Mediterranean Basin	Widespread along the Mediterranean and Atlantic coasts.	X	X	X	X	X
Chelonibia testudinaria Linnè, 1767	Pliocene of Italy	Widespread around the Mediterranean, Gulf of Mexico and North Atlantic.	X			X	X
Tetraclita cf. *rubescens* Darwin, 1854	Pacific coast of North America, from Cape San Lucas to San Francisco Bay	Pacific coast of North America, from Cape San Lucas to San Francisco Bay	X	X	X	X	
Callianassa cf. *matsoni* Rathbun, 1935	Miocene of Florida, east coast of North America		X			X	
Callianassa sp.	Widespread in the Miocene and Pliocene in the Tethys and Mediterranean Basin and Atlantic European Coast.	Widespread	X	X	X	X	
Upogebia sp.	Miocene and Pliocene in the Mediterranean Basin	Widespread	X	X	X	X	
Eriphia aff. *verrucosa* (Forskal, 1775)	Neogene Sicily. Pleistocene Sicily	Widespread along the Mediterranean, Atlantic coasts of Portugal, Morocco, Azores and Canary Islands				X	X
Maja sp.	Widespread in the Miocene and Pliocene in the Tethys and Mediterranean Basin and Atlantic European Coast.	Widespread	X	X	X	X	X
Scylla michelini Milne-Edwards, 1861	Miocene Of Tethys and Mediterranean		X			X	
Ocypode sp.	Miocene and Pliocene in the Mediterranean Basin (Italy, Hungary, Spain, Morocco) and Atlantic (Florida and Argentina)	Widespread	X	X	X	X	

Tab. 1 - Global biogeography and chronostratigraphy of the crustaceans in the Mio-Pliocene marine deposits from the Canary Islands. Comparison between fossil and current species.

stretches of coast are considered as a whole) and at varying elevations above the present-day coastline (Fig. 1).

Their assignment to the Mio-Pliocene transition has been possible by verifying their chronostratigraphic position with respect to lava flows for which there are previously published K/Ar datings (Meco et al. 2005, 2007). These allow establishing a range of ages for the marine deposits of between 8.9 and 4.1 Ma (Fig. 2).

Eight stratigraphic sections have been selected along the coasts of Gran Canaria, Fuerteventura and Lanzarote, representative of the marine sedimentary strata of this period in the Canary Islands (Figs 3-5).

The marine deposits are generally composed of two materials: 1) reddish conglomerate of gravel, cobble and sand, and 2) grey to white sands with bioturbation structures, which constitute a guide layer in the local geology of each island.

A total of 12 taxa have been identified and classified (Pl. 1): *Balanus concavus* Bronn, 1831, *Balanus spongicola* Brown, 1827, *Balanus perforatus* Bruguière, 1789, *Chenolobia testudinaria* Linnè, 1767, *Tetraclita* cf. *rubescens* Darwin, 1854, *Callianassa matsoni* Rathbun, 1935, *Callianassa* sp., *Upogebia* sp., *Eriphia* aff. *verrucossa* (Forskal, 1775), *Maja* sp., *Scylla michelini* Milne-Edwards, 1861 and *Ocypode* sp.

The studied fossil fauna, including cirripeds and decapods, provides new localities of their Neogene distribution and allow their presence to be extended beyond the Mediterranean region to the North Atlantic (Tab. 1).

It is notable that the observation of *Tetraclita* cf. *rubescens* Darwin, 1854 in the fossiliferous marine deposits of the Canary Neogene supposes the first fossil report of this barnacle outside the Pacific coasts of North America. This allows its palaeogeological setting to be extended beyond the strictly defined region of the coasts of North America to the Canary Islands. Additionally, the appearance of *Chenolobia testudinaria* Linnè, 1767 indicates the existence, sporadic or otherwise, of sea turtles in the Canary Islands during the Neogene.

The Mio-Pliocene fauna which accompany the Canary crustacean fossils indicate ecological and climatic conditions very different to those of today. The presence of fossil species belonging to the genera *Strombus* Linné, 1758 (*Strombus coronatus* Defrance, 1827), *Ancilla* Lamarck, 1799 (*Ancilla glandiformis* Lamarck, 1810) and others, as well as the presence of the coral *Siderastraea miocenica* Osasco, 1987, suggest climate conditions equivalent to those of present day tropical and sub-tropical regions, like the Caribbean Sea (West Atlantic) or the Gulf of Guinea (East Atlantic).

The results of this study are coherent with previous researches (e.g. Sumata et al. 2004) which hypothesise the existence of a flow of surface water between the Pacific and the Atlantic in the Mio-Pliocene transition (Central American Seaway, CAS). This Pacific-Atlantic connection explains how organisms arrived in larval stage from Central America to the Canary Islands in the Mio-Pliocene transition.

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