



# Evidence for long-term uplift on the Canary Islands from emergent Mio–Pliocene littoral deposits

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## Abstract

Several islands in the Canarian archipelago show marine deposits with identical fossil faunas, which are generally assigned to different glacioeustatic marine episodes: mainly Pleistocene episodes in Lanzarote and Fuerteventura, and Mio–Pliocene ones in Gran Canaria.

Three fossil species (*Saccostrea chili*, *Nerita emiliana* and *Strombus coronatus*) characterize all the marine deposits from southern Lanzarote, to the west and south of Fuerteventura and northeast of Gran Canaria. Three other species (*Ancilla glandiformis*, *Rothpletzia rudista* and *Siderastraea miocenica*) confirm the chronostratigraphic attribution of these deposits. Other more occasional fossils (as *Chlamys latissima*, *Isognomon soldanii* and *Clypeaster aegyptiacus*) fit an upper Miocene and lower Pliocene age. This agrees with new K/Ar ages obtained from pillow lavas emplaced into 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. 9.8 Ma in Lanzarote) lava flows.

The marine deposits are eroded but large continuous segments are preserved sloping gently towards the coast. Variations in the highest and the lowest elevations of the deposits asl (above present sea level) indicate post-depositional uplift movements. Glacioeustatic causes are unlikely to be responsible for these variations on the basis of the coastal location of the deposits and their equatorial fauna characteristic of Mio–Pliocene corals. Differential uplift of the deposits across the archipelago is argued to result from the progressive seaward tilting of the islands along the insular volcanic trail marking the westward migration of hot spot head since 20 Ma. Successive westward accretion of younger volcanic edifices resulted in increasing lithostatic load of the crust with progressive (diachronous) tilting of the older edifices and their palaeo-shorelines marked by past coastal deposits.

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## 1. Introduction

The marine deposits outcropping in most of the islands of the Canarian archipelago are potentially good candidates for past (Mio–Pliocene and Pleistocene) climate reconstitutions.

Nevertheless their ages and the mechanism(s) which raised them above the sea level are too imprecisely known to define unequivocally their climatic significance.

Most of these deposits have been attributed to Mio-Pliocene and Pleistocene marine transgressions and regressions of glacioeustatic origin (Hausen, 1958; Tinkler, 1966; Müller and Tietz, 1966; Croft, 1967; Lecointre et al., 1967; Klug, 1968; Hernández-Pacheco, 1969; Rona and Nalwalk, 1970; Zazo et al., 2002). Volcano-tectonic tilting is a mechanism which has not been fully

tested in this particular context as was invoked on the Cook (Woodroffe et al., 1991) and Hawaiian (Muhs and Szabo, 1994) Islands hot spot chains in the Pacific to explain the uplift of Quaternary reefs.

In this work, we propose to elucidate the origin and age of these particular beds and to test the volcano-tectonic hypothesis, using a multidisciplinary approach involving palaeontology, mapping, and radiometric dating.

Indeed, well preserved volcanic formations occur interfolded with these marine deposits, and can be precisely

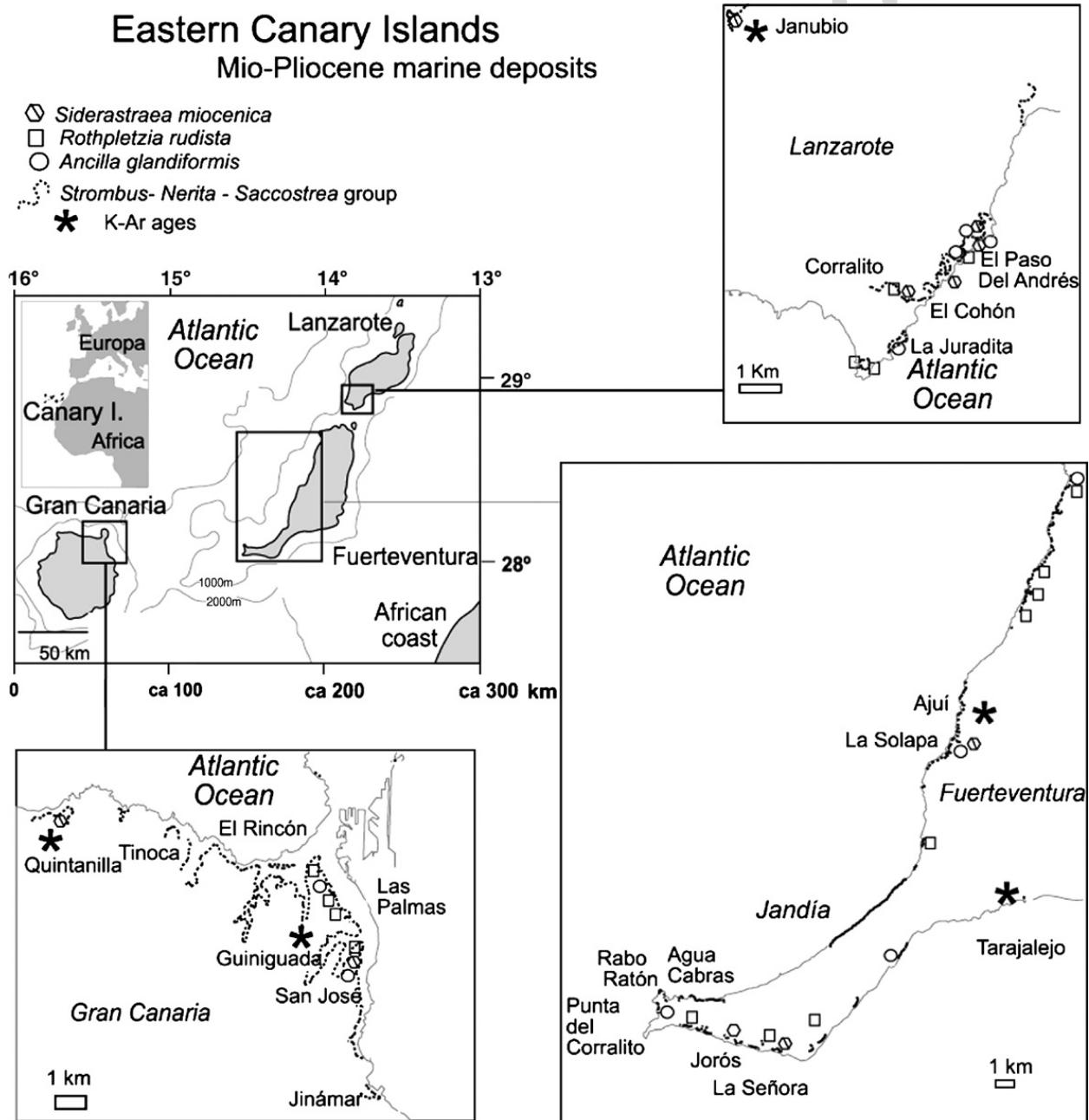


Fig. 1. Geological sites in the Canary Islands: the islands extend 500 km across the eastern Atlantic (a and b) off the African coast. The marine deposits bearing Mio–Pliocene fossil species appear in the eastern Canary Islands (c): southern Lanzarote (d), Jandía peninsula and western Fuerteventura (e) and northeastern Gran Canaria (f).

dated by the Unspiked K/Ar technique, which has proven particularly efficient in dating Miocene to Quaternary lavas of the Canarian archipelago (Guillou et al., 1996, 2001, 2004a,b). By applying this approach, critical time brackets are obtained which provide evidence for previously unreported uplift during the Neogene.

## 2. Regional setting and previous works

The Canarian archipelago comprises seven main volcanic islands and several islets that form a chain extending for ca. 500 km across the eastern Atlantic, with its eastern edge (Fig. 1) only 100 km from the northwestern African coast. The islands have had a very long volcanic history, with formations over 20 million years old cropping out in the eastern Canaries. Their origin has been closely related to African continental tectonics (Füster et al., 1968a,b,c,d; McFarlane and Ridley, 1969; Grunau et al., 1975; Anguita and Hernán, 1986). However, the timing of eruptive activity in the islands, their morphological and structural features, seismic signature and geochemical evolution (Schmincke, 1973; Carracedo, 1975; Schmincke, 1976, 1982; Hoernle et al., 1991; Hoernle and Schmincke, 1993; Carracedo, 1994; Hoernle et al., 1995; Carracedo et al., 1998, Carracedo, 1999; Carracedo et al., 2001, 2002) clearly support a slow-moving hot spot origin.

The first reported marine deposits on the Canary Islands were recognized in Lanzarote (Driscoll et al., 1965), Fuerteventura (Hartung, 1857), Gran Canaria (von Buch, 1825) and La Palma (von Fritsch, 1867). Studies of the two easternmost Canary Islands ascribed them to the Pleistocene or Quaternary (Hausen, 1958; Tinkler, 1966; Müller and Tietz, 1966; Croft, 1967; Lecointre et al., 1967; Klug, 1968; Hernández-Pacheco, 1969; Rona and Nalwalk, 1970; Zazo et al., 2002). However, in Gran Canaria, the central island of the archipelago, these have long been assigned to the Tertiary (upper Miocene: Lyell, 1865; Middle Miocene, Helvetian or Tortonian: Rothpletz and Simonelli, 1890; Vindobonian: Bourcart and Jérémie, 1937; Miocene or Pliocene: Anguita and Ramírez, 1974). The deposits are associated with contemporaneous lava flows originally dated as lower Pliocene (Bravo, 1960; Vuagnat, 1960; Navarro et al., 1969; Abdel-Monem et al., 1971; Lietz and Schmincke, 1975; Gimeno et al., 2000; Guillou et al., 2004a; Schneider et al., 2004).

Comparative palaeontological studies of deposits found at Fuerteventura, Lanzarote, and Gran Canaria reveal similar fossil associations of lower Pliocene age (Meco, 1977; Meco et al., 2003, 2005) corroborated by consistent K/Ar ages of the lavas associated with them

(Meco and Stearns, 1981; Coello et al., 1992). In Tenerife (Ibarrola et al., 1991) and La Palma (Staudigel and Schmincke, 1984) upper Pliocene pillow lavas were reported. As already mentioned, most of these deposits have been attributed to marine transgressions and regressions of glacioeustatic origin.

## 3. Methods

### 3.1. Palaeontological records

The deposits are characterized by the presence of three, combined or isolated, abundant species of fossil mollusks: *Saccostrea chili* (Simonelli), *Nerita emiliana* Mayer and *Strombus coronatus* Defrance. These three species became extinct during the lower Pliocene. Other species of the same genus occur in the Canarian Pleistocene: *Saccostrea cucullata* (Born), *Nerita senegalensis* Gmelin and *Strombus bubonius* Lamarck. They were studied in order to better constrain the chronostratigraphic framework of the deposits. These include the gastropod *Ancilla glandiformis* (Lamarck), *Rothpletzia rudista* Simonelli, and the anthozoan *Siderastraea*

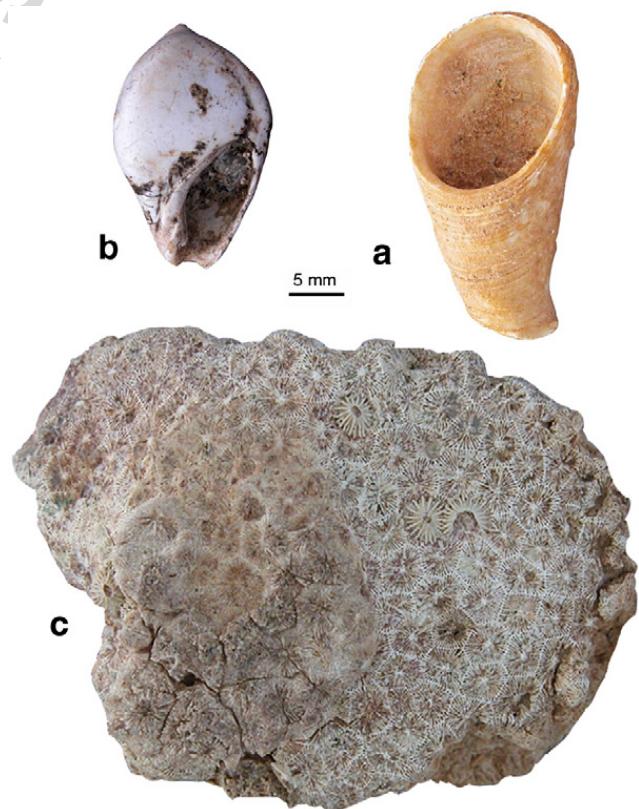


Fig. 2. The three most characteristic species in the Canarian Miocene-Pliocene marine deposits: (a) *Rothpletzia rudista* Simonelli in Rothpletz y Simonelli 1890, (b) *Ancilla glandiformis* (Lamarck 1822) and (c) *Siderastraea miocenica* Osasco 1897.

*miocenica* Osasco (Fig. 2). Other species of undisputed Mio–Pliocene age (Sacco, 1895; Palla, 1966; Raffi, 1970; Ben Moussa, 1994) are also found in these deposits: the mollusks *Chlamys latissima* (Brocchi), *Isognomon soldanii* (Deshayes), *Cerithium taurinum* Bellardi and Michelotti and the echinoderm *Clypeaster aegyptiacus* Wright.

### 3.2. Topographical records

A number of sites of Mio–Pliocene marine deposits have been geographically referenced based on a differential positioning method using U.T.M. (Universal Transversal Mercator) coordinates, G.P.S. (Global Position System) techniques and the W.G.S.84. reference ellipsoid.

The measurements of the sites (Fig. 3) have been performed through calculation of baselines between two receivers, with similar atmospheric conditions and observing the same group of satellites simultaneously. Baselines were always referred to Geodetic Vertices; and the distances between the points, measured by G.P.S., never exceeded 5 km. Observation durations of 5–10 min were needed during daylight, meanwhile a good satellite geometry (GDOP between 0 and 5) and signals from 5 or more satellites were checked. Calculation of Geographic and U.T.M. coordinates were done using SKI software.

We used a Leica G.P.S. System 530 device, with a double frequency satellite receiver and two channels for continuous searching. A static precision for the baseline of  $5\text{ mm} \pm 1\text{ ppm}$  was achieved for the Differential Phase and of 30 cm for the Differential Codex.

On Gran Canaria island, we used previously reported survey measurements (Báez and Melián, 2000; González and Moreno, 2002). Measurements and reference systems were checked carefully. The comparative level for heights has been referred to the maximal equinoctial low tide.

### 3.3. K/Ar dating

To provide independent age control on the deposits, lava samples devoid of traces of alteration were selected for K/Ar dating. Phenocrysts and xenocrysts, which are potential carriers of extraneous  $^{40}\text{Ar}$  (including excess and inherited components) were eliminated using magnetic, gravimetric, and visual hand picking separation (Guillou et al., 1996). The determination of K was carried out by atomic absorption, with a relative precision of 1%. The isotopic composition and concentration of Ar were determined using an Unspiked technique (Charbit et al., 1998) used previously with success to

date Miocene–Quaternary volcanic rocks of other Canarian islands (Guillou et al., 1996, 2001, 2004a,b). This technique differs from the conventional isotope dilution method in that the argon extracted from the sample is measured in sequence with purified aliquots of atmospheric argon (Air-1), at the same working gas pressure in the mass-spectrometer. This allows one to suppress mass discrimination effects between the atmospheric reference and the unknown (i.e. sample), and allows quantities of radiogenic  $^{40}\text{Ar}^*$  as small as 0.14% to be detected on a single-run basis (Scaillet and Guillou, 2004). This technique is not suitable to check if the trapped  $^{40}\text{Ar}/^{36}\text{Ar}$  ratio has a value equivalent to the modern atmospheric value. Consequently, errors given in the analytical tables are instrumental only and do not account for further errors due to possible improper (non-atmospheric) contamination correction, although past experience with similar samples in the Canarias shows this effect to be only marginally significant (Guillou et al., 1996, 1998, 2001).

The manometric calibration of the Air-2 reference is based on periodic, replicate determinations of international dating standards of known K/Ar age using the same procedure as for the unknowns (Charbit et al., 1998). This allows the total  $^{40}\text{Ar}$  content of the sample to be determined with a precision of about  $\pm 0.2\%$  ( $2\sigma$ ). Standards used include LP-6 ( $127.8 \pm 0.7$  Ma: Odin, 1982) and HD-B1 ( $24.21 \pm 0.32$  Ma: Fuhrmann et al., 1987; Hess and Lippolt, 1994; Hautmann and Lippolt, 2000). At the 95% confidence level, the values adopted here are consistent with those obtained for several  $^{40}\text{Ar}/^{39}\text{Ar}$  standards intercalibrated against biotite GA-1550 (Renne et al., 1998; Spell and McDougall, 2003).

## 4. Field observations and results

During the upper Miocene and the lower Pliocene, the number, morphology, and topography of the Canary Islands were different than today, as revealed by K/Ar ages of the subaerial volcanic rocks. Older shorelines are characterized by fossiliferous conglomerates and sandstones characteristic of high-wave-energy coastlines. Associated dunes and alluvial deposits were built by North Atlantic winds and strong tropical hurricanes. Some fossiliferous marine deposits are associated with dated lava flows, showing concordant radiometric and palaeontologic ages. These deposits have been faulted, eroded by the Pleistocene fluvial systems and the marine cliffs recession, and affected by rubefaction (Fe oxidation), partial solution and re-crystallization.

Marine deposits with Mio–Pliocene fossils are found along the coasts of southern Lanzarote, the western

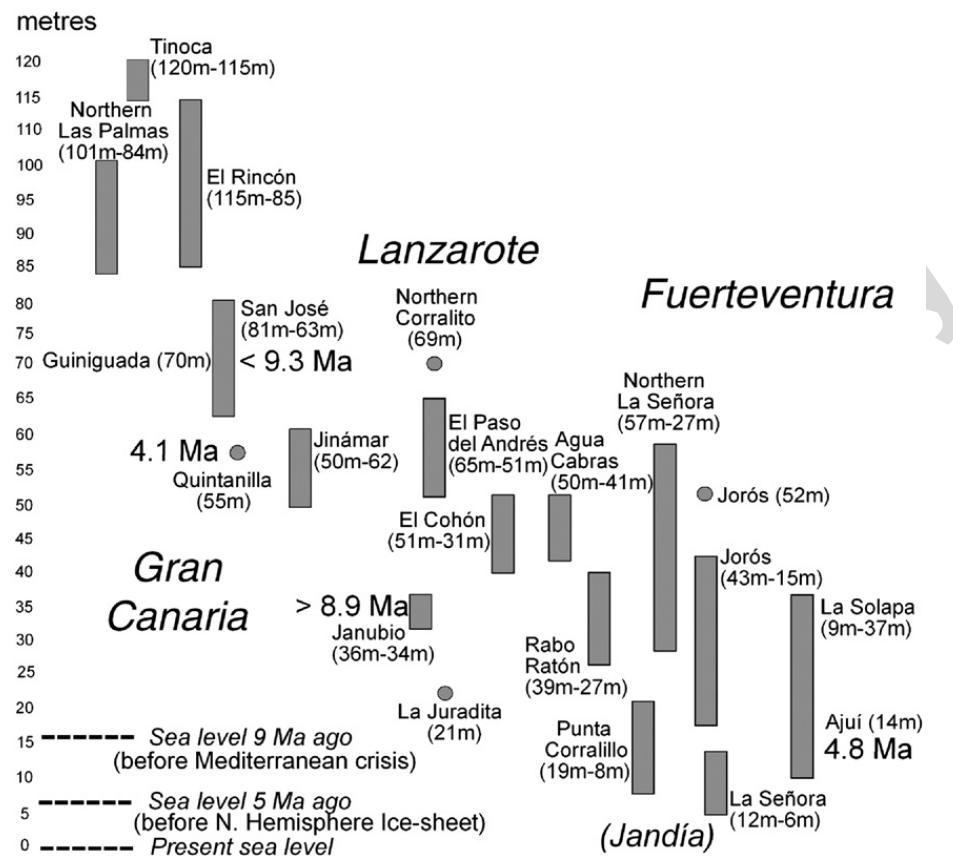


Fig. 3. Altitude over the present sea level of the Mio–Pliocene marine deposits and K/Ar ages from the lava flows located under, over or between them. From the lowest heights in Fuerteventura to the highest ones in Gran Canaria, some discontinuities are due to faults, besides several uplifts could have affected different islands.

coast of Fuerteventura (particularly the Jandía peninsula), and northeastern Gran Canaria (Fig. 1). Moreover, emergent Pliocene pillow lavas are found in San Juan de la Rambla (Tenerife) and, associated with fossil corals, in Barranco de las Angustias (La Palma).

#### 4.1. Fauna

On Lanzarote island, *R. rudista* is found in deposits 24 m apsl, as well as 51 m apsl. *Ancilla gladiformis* is found in deposits 21 m apsl, as well as 60 m apsl and *S. miocenica* is found in deposits 36 m apsl, as well as 70 m apsl. At El Paso del Andrés, these three species appear together in marine sediments at 50 m apsl (Fig. 1). Collectively these observations demonstrate that the Mio–Pliocene fauna (Fig. 2) is similar at different elevations. On the Jandía peninsula (Fuerteventura), *A. glandiformis* has been found at the lowest elevation, 8 m apsl, and *R. rudista* appears at 15 m apsl and 50 m apsl. These two species, and as well as *S. miocenica*, are found on the western coast of the island under Pliocene lava flows, and also on Gran Canaria where the elevations and faunas of the deposits differ from those of Pleistocene deposits.

#### 4.2. Palaeoclimatology

The Mio–Pliocene marine deposits imply an equatorial climate. Among the six fossil species characterizing the Canarian Mio–Pliocene marine deposits, only *Rothpletzia* is extinct. The other five genera are extant and live, at present, in warm seas (Fischer, 1887). It has long been known (Fischer, 1887) that species of the *Strombus* live strictly in shallow, warm waters. In addition, the two hundred species of the genus *Nerita* live along warm water coasts; as do about 50 species of *Ancilla*. The genus *Saccostrea* also lives only in warm waters of the Indian Ocean, Red Sea and Gulf of Guinea (Dautzenberg, 1912; Nicklès, 1950). Finally, the genus *Siderastraea* only lives in the West Indies, the western coast of Africa, the Red Sea and the Indian Ocean. These reefal madrepores form isolated colonies in sandy and muddy habitats (Chevalier, 1961). Hence, the occurrence of such species collectively and consistently points to coastal equatorial climatic conditions (Font Tullot, 1951; Crosnier, 1964), similar to present-day conditions prevailing along the coasts of the Gulf of Guinea and the Caribbean Sea.



Fig. 4. Janubio site, Lanzarote island. Marine deposits (b) interbedded between Los Ajaches mid-Miocene basalts (a) and Tias-Janubio group ones (c), dated 8.9 Ma (Tortonian).

#### 4.3. Elevations of the marine deposits

Along the western coast of Fuerteventura, the deposit at La Solapa displays the highest and lowest elevation (37 m to 9 m apsl) along this coast. On the Jandia peninsula, the elevations range between 57 m and 6 m apsl, with long, sloping fragments. On Lanzarote, the maximum elevation measured is 69 m apsl, and the lowest is 21 m apsl (Fig. 3). Segments of the marine deposits slope gently (about 2%) towards the

coast. Finally, elevations of Mio–Pliocene marine deposits on Gran Canaria range from 50 m apsl (Jinamar) to 120 m apsl (Tinoca, Fig. 3).

#### 4.4. K/Ar ages

On Lanzarote island, marine deposits overlie basalts of the Los Ajaches Formation, with K/Ar ages ranging between 14.5 Ma and 13.5 Ma (Carracedo et al., 2002). However, at Janubio (Fig. 4) marine deposits are below

Table 1

K/Ar ages of samples from eastern Canary Islands. Age calculation are based on the decay and abundance constants from Steiger and Jäger (1977). LZ: Lanzarote, FV: Fuerteventura, GC: Gran Canaria

Sample ID experiment no.	Weight molten (g)	K* (wt.%)	$^{40}\text{Ar}^*$ (%)	$^{40}\text{Ar}^*$ ( $10^{-11}$ mol/g)	$^{40}\text{Ar}^*$ weighted mean	Age $\pm 2\sigma$ Ma
<b>LZ-22</b>						
Salinas del Janubio						
6547	0.84531	1.353 $\pm$ 0.013	32.944	2.084		
6963	0.96794	1.353 $\pm$ 0.013	32.564	2.098	2.091 $\pm$ 0.008	8.89 $\pm$ 0.19
<b>FV-38</b>						
Ajuy (pillows)						
6567	1.05686	0.872 $\pm$ 0.009	18.632	7.349		
6983	1.14585	0.872 $\pm$ 0.009	21.759	7.277	7.311 $\pm$ 0.027	4.83 $\pm$ 0.10
<b>FV-A</b>						
Tarajalejo						
6935	1.60090	1.353 $\pm$ 0.014	64.039	3.962		
6947	0.69317	1.353 $\pm$ 0.014	51.785	3.920	3.941 $\pm$ 0.014	16.72 $\pm$ 0.35
<b>GC-A</b>						
Guiniguada						
6936	1.38917	3.462 $\pm$ 0.035	87.345	5.624		
6948	0.71346	3.462 $\pm$ 0.035	70.977	5.658	5.641 $\pm$ 0.020	9.37 $\pm$ 0.20

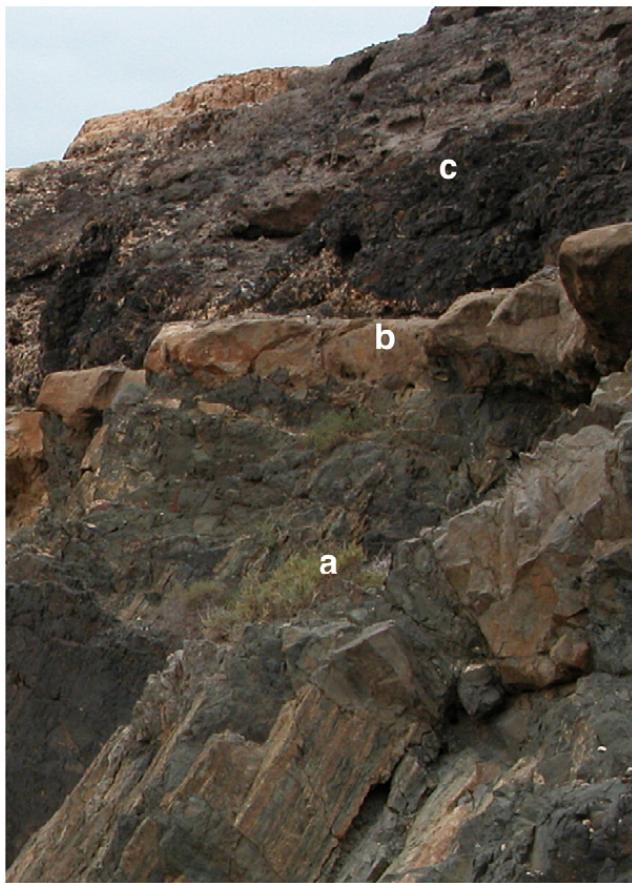


Fig. 5. Ajúi site, Fuerteventura island. Above pre-Miocene oceanic sediments crossed by many dykes (a) marine deposits (b) underlying a pillow lava dated 4.8 Ma (lower Pliocene).

lava flows of the Tías-Janubio Group that have a K/Ar age of  $8.89 \pm 0.19$  Ma (Tortonian, sample LZ-22, Table 1).

On Fuerteventura, marine deposits overlie the pre-Miocene shield in the central area of the western coast, and overlie Miocene basalts in Jandia, with K/Ar ages between 21 Ma and 14 Ma (Carracedo et al., 2002). In the northern part of the island, marine deposits overlie basalts dated between 17 Ma and 11.8 Ma (Abdel-Monem et al., 1971). These marine deposits are, in turn, below Pliocene basalts dated at 1.9 Ma, 2.4 Ma, 2.7 Ma, 2.9 Ma, and 4.4 Ma (Abdel-Monem et al., 1971; Meco and Stearns, 1981; Coello et al., 1992). Upon reaching the sea level, some flows were locally emplaced as pillow lavas indicating submarine quenching and sub-aerial to a submarine conditions contemporaneous with the marine deposits upon which they lie. At Ajúi (Fig. 5) a pillow lava has been dated at 5.8 Ma (Meco and Stearns, 1981) and 5.0 Ma (Coello et al., 1992). A new K/Ar age of  $4.83 \pm 0.10$  Ma (Table 1) confirms their lower Pliocene age. At Tarajalejo, a lava flow is K/Ar dated at  $16.7 \pm 0.35$  Ma (sample FV-A, Table 1). This lava overlies a pyroclastic layer containing Rhodophyceae remnants (Burdigalian).

On Gran Canaria island, the marine deposits overlie trachytes and phonolites dated at 13.3 Ma and 9.0 Ma (Carracedo et al., 2002). Fragments from Roque Nublo Volcano are included within these marine deposits. The volcanic rocks have ages ranging between 4.9 Ma and 2.9 Ma (Guillou et al., 2004a). Moreover, a phonolitic



Fig. 6. Tamaraceite site, Gran Canaria island. The sediments (a) bearing Mio–Pliocene marine fossil underlie the pillow lava flows (b) of the Quintanilla group, dated 4.1 Ma (Guillou et al., 2004a,b).

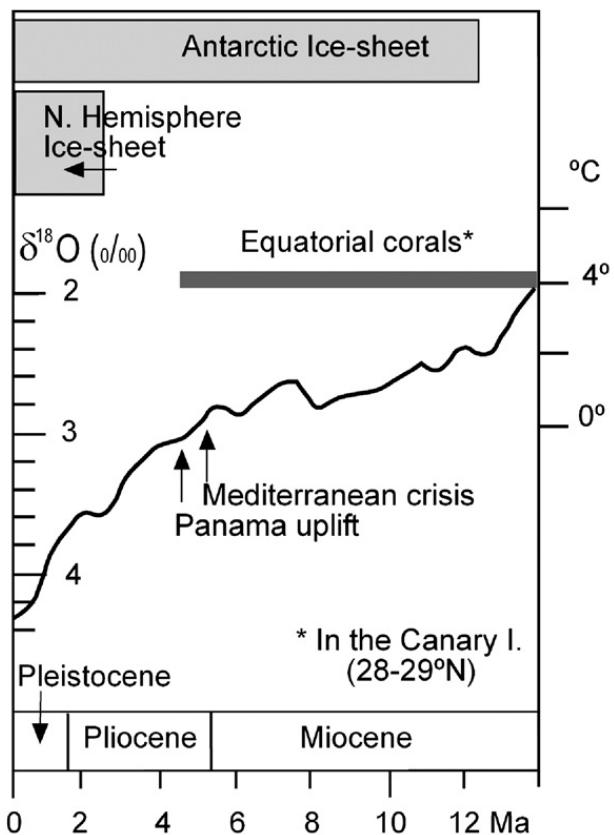


Fig. 7. Mio–Pliocene corals indicate a warm climate, the cooling begins after the Mediterranean crisis and the Panama uplift and it continues until the North Atlantic ice-sheet forms (Zachos et al., 2001 modified, and data of Haug et al., 2005).

lava flow, interbedded between phonolitic-derived alluvial deposits and the marine deposits, is dated at  $9.37 \pm 0.20$  Ma (Sample GC-A, Table 1). Lower Pliocene pillow lavas are dated at  $4.10 \pm 0.08$  Ma (Guillou et al., 2004a) at Barranco de Quintanilla (Fig. 6).

Field relationships at Tenerife and La Palma islands display different features. At San Juan de La Rambla, western Tenerife, pillow lavas dated at 2.6 Ma (Ibarrola et al., 1991) are contemporaneous with a raised beach 7–8 m a.s.l. At Barranco de las Angustias (La Palma), *Dendrophyllia cornigera* (Lamarck, 1816) outcrops in marine deposits at 150 m a.s.l. At this site, pillow lavas are palaeontologically dated using foraminifera as time marker (Staudigel and Schmincke, 1984) between 2.8 Ma and 3 Ma, during the upper Pliocene climatic change. This cool coral-type fauna presently lives in the Mediterranean and Eastern Atlantic Ocean, from Ireland to Cabo Verde islands, at circalittoral depths of 180 m.

Hence, K/Ar ages of associated lava flows indicate spatially variable emersion ages at different localities (Burdigalian and lower Pliocene on Fuerteventura, Tortonian on Lanzarote and lower Pliocene on Gran Canaria). An east-to-west trend is apparent with the K/Ar ages of subaerial basalts progressively decreasing from a given island to the next (Carracedo et al., 2002).

## 5. Discussion

In the Northern Hemisphere, the Mio–Pliocene climatic setting (Herbert and Schuffert, 1998) is characterized at middle latitudes by a cooling and a transition



Fig. 8. Morro Jable faulted site in the Jandía peninsula. Dykes are older than marine deposits with Mio–Pliocene fauna, dunes are younger.

from an equatorial climate, without seasonality, to an arid and desert one in Euroafrica (Aguirre, 2003) (Fig. 7). The Pliocene climate of the northeastern Atlantic Ocean region was conditioned by the closure of the Panama channel 4.6 Ma (Ravelo et al., 2004). This warm climatic regime continued until the cool climate that brought on the development of Pleistocene ice-sheets 2.7 Ma (Haug et al., 2005).

Due to the formation of Northern Hemisphere ice-sheets, the sea level dropped some 8 m (Berger, 1992; table IV.14) below the present-day level, which agrees with minimal heights apsl recorded by the Canarian Mio–Pliocene coastal marine deposits (Fig. 3). Moreover, by the end of the Mediterranean crisis and the post-Messinian marine transgression through the Strait of Gibraltar at about 5.4 Ma (Hsü et al., 1973), the sea level probably lowered another 10 m (Fig. 7). The Antarctic ice-sheet, known to have developed (Zachos et al., 2001) long before the Canarian archipelago (<25 Ma) must have played a minimal role, if any, in the Mio–Pliocene sea level changes recorded in the Canary Islands.

Due to their locally quite high magnitude, variations in elevations of the deposits hosting the Mio–Pliocene faunas are unlikely to be purely eustatic, and rather reflect a long-lived volcano-tectonics instability locally manifested by post-depositional faulting (mostly apparent in Gran Canaria and Jandia peninsula; Fig. 8).

The Canaries, originated from a continuous long-lived volcanic activity (>23 Ma subaerial volcanism), were generated by a localized mantle anomaly or hot-spot, interacting with a slow-moving plate (Carracedo, 1999; Carracedo et al., 2002). Several features of the Canarian and Hawaiian hotspots show interesting similarities (i.e.: shield and post-erosional rejuvenation stages of development, the presence of rifts and giant lateral collapses). Some differences are equally interesting, however, in particular the lack of significant subsidence in the Canaries that allowed the whole archipelago to remain emersed for very long periods — over more than 23 Ma (Carracedo et al., 2002), compared to about 6 Ma in the Hawaiian Islands (Walker, 1990). In the Canaries, more mature stages of development and magmatic differentiation can be reached that result in a wider range of volcanic rocks, features and processes, particularly large, felsic stratovolcanoes, conspicuously absent in the majority of intraplate oceanic islands (Carracedo et al., 2002).

Contrary to more common intraplate oceanic islands, field observations and geophysical data indicate that the Canarian archipelago is not the locus of large-scale upward and downward movements such as invoked in intraplate oceanic islands to explain raised beaches and

submersed marine abrasion platforms (Moore, 1987). Considering the peculiar location of the archipelago close to a passive continental margin over a very old and rigid oceanic crust (Carracedo et al., 1998) alternative explanations must be sought to explain the existence and the present-day distribution of raised marine deposits across the archipelago.

Local gravitational or tectonic–volcanic instabilities (regional faulting, folding, magma underplating, etc.) are unable to explain the observed regional pattern of upraised marine deposits across the whole archipelago. A more plausible explanation supported by existing geological and geophysical data is that progressive tilting of the oldest islands through large-scale lithostatic loading of the supporting crust by younger edifices resulted in apparent vertical movements responsible for the differential exhumation of the palaeo-shoreline and the associated deposits at different stages across the archipelago.

The best evidence for such a tilting in Gran Canaria comes from shallow pillow lavas of similar age (about 4 Ma) cropping out at different elevations today (Fig. 3) around the island. Another evidence comes from boreholes drilled in the northwestern part of Gran Canaria for ground water exploration which crossed Miocene airfall basaltic pyroclastic beds at about 100 m below present sea level (Araña and Carracedo, 1978), while the Miocene at the northeast part of Gran Canaria crops out at about 100 m at the same epoch (Fig. 9).

A similar model of far-field uplift (though operative on a much shorter timescales) due to lithospheric flexure on hot spot chain has also been proposed by Woodroffe et al. (1991) for the uplift of Quaternary reefs on the Cook Islands in the South Pacific, and by Muhs and Szabo (1994) for recent (Quaternary) upraised reefs on Hawaii.

## 6. Conclusions

Upraised Mio–Pliocene marine deposits containing diagnostic faunas (*S. chili*, *N. emiliana*, *S. coronatus*, *A. glandiformis*, *R. rudista*, *S. miocenica*, *C. latissima*, *I. soldanii*, *C. aegyptiacus*) of warm, shallow water conditions have been studied across the Canarian archipelago where they occur at different elevations relative to the present sea level. These marine deposits are eroded but large continuous segments are preserved sloping gently towards the coast. Variations in maximal and minimal elevations of the deposits apsl indicate post-depositional uplift movements. Combination of field data, K/Ar dating and high-precision topographical positioning indicates that glacioeustatic (sea-level) changes are unlikely to be responsible for these variations on the basis of the coastal location of the deposits

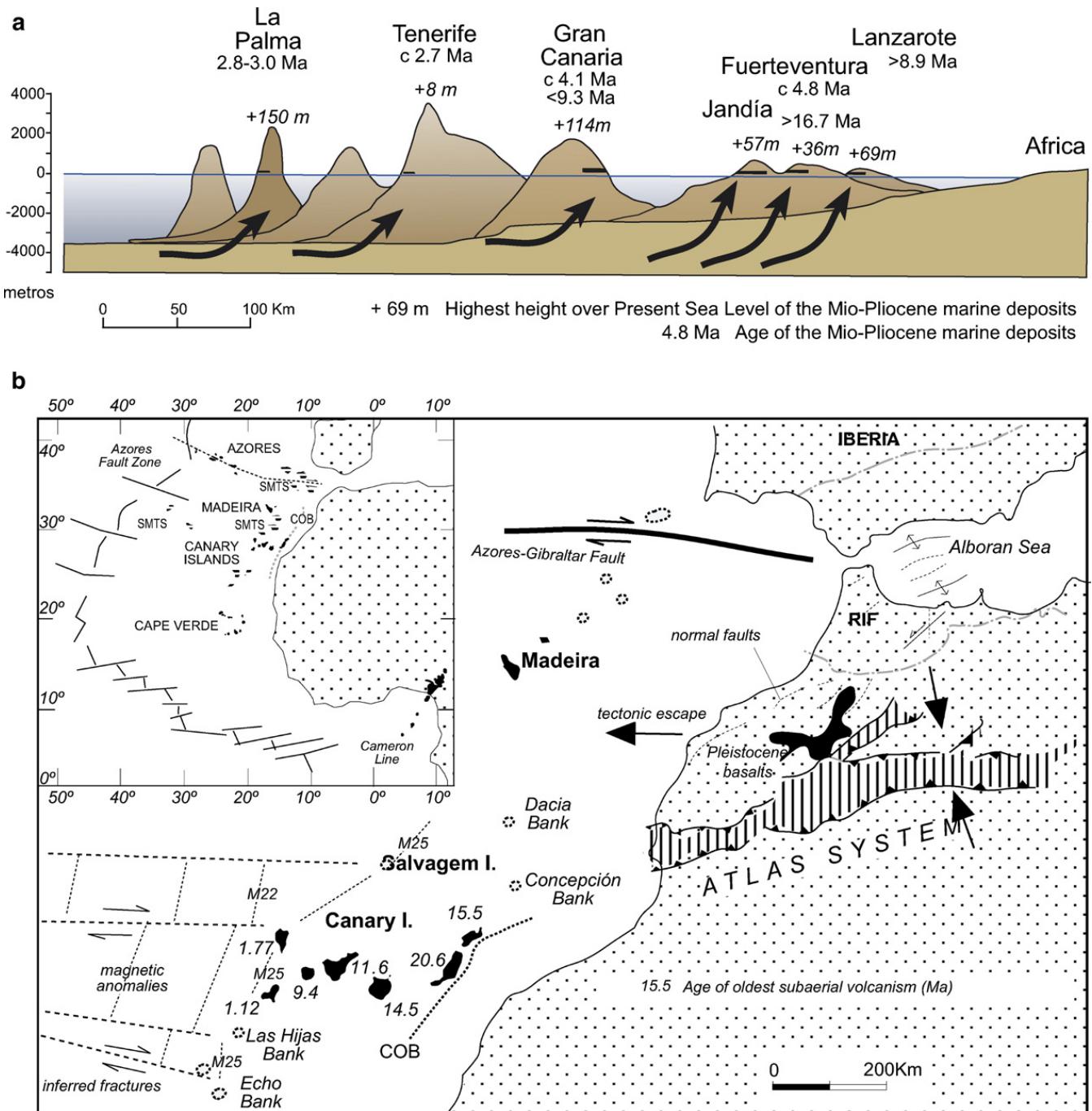


Fig. 9. (a) The probable cause of the uplift of marine deposits is a tilting of the islands by the weight of the other new islands (Carracedo et al., 2002 modified). (b) Geographical and geodynamical framework of the NW African continental margin volcanic groups (Carracedo et al., 2002 modified).

and their equatorial fauna characteristic of Mio-Pliocene corals. Differential uplift of the deposits across the archipelago is argued to result from the progressive seaward tilting of the islands along the insular volcanic trail marking the westward migration of the hot spot head since 20 Ma. Successive westward accretion of younger volcanic edifices resulted in increasing lithostatic load of the crust with progressive (diachronous)

tilting of the older edifices and their palaeo-shorelines marked by past coastal deposits.

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