CLIMATE CHANGE PERSPECTIVES FROM THE ATLANTIC:
PAST, PRESENT AND FUTURE

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LATE HOLOCENE WOOD REMAINS FROM ALLUVIAL/COLLUVIAL DEPOSITS IN THE CALDERA DE TABURIENTE NATIONAL PARK (LA PALMA, CANARY ISLANDS)

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Abstract

The geomorphological dynamics of the Barranco de Taburiente gorge, in La Palma (Canary Islands), has exposed sub-fossil organic layers in its riverbanks and margins, in which a large number of woody remains have been recovered. Samples have been located along ~3 km of the river and are clustered in three sites. Radiocarbon dating of the remains indicates that the recovered samples date from the late Holocene and have been identified as *Pinus canariensis*, a pine species that may have long been dominant and stable in the landscapes of the Caldera. The deposition of the remains could be explained by a single geomorphic event related to a humid (and probably torrential) episode. The factors that would explain the persistence of these pinewoods are discussed.

Keywords: Caldera de Taburiente, geomorphic events, Holocene, *Pinus canariensis*, sub-fossil wood.

INTRODUCTION

La Palma, the most north-westerly of the Canary Islands, is also one of the youngest islands of the archipelago. Recent volcanic activity is very important on this island and has made it a key place of interest for scientists during the last decades. Since the latest subaerial volcanic eruption in Spain (emergence of the Teneguía volcano) during 1971, this island has been the subject of many, diverse geological studies, including ones on sedimentological features, gravitational collapses or eruptions (e.g. Day *et al.*, 1999; Vegas *et al.*, 1999; Klügel *et al.*, 2000; Ward and Day, 2001).

However, little is known about the Quaternary history of vegetation on the island. The vegetal remains found at the archaeological site of the cave of El Tendal (San Andrés y Sauces), at 150 m a.s.l. on the northeast of the island, is to date, the only one that has been investigated using carpological and anthracological studies (Machado, 1995; Morales Mateos, 2004). At this site, charcoals from layers corresponding to ~2200 cal. years BP and ~1000 cal. years BP show the dominance of laurel forests during this period. On other islands of the Canarian archipelago, studies on macrofossils have been developed mainly from charcoal recovered from archaeological sites. On the nearby island of El Hierro, the archaeobotanical evidence from the site of Guinea (80 m above sea level – a.s.l.) records the existence of *Pinus* and *Juniperus*, as well as other species of laurel forests and the *fayal-brezal* (Machado, 2002). Late-Holocene anthracological records have also been studied in Tenerife, La Gomera, Gran Canaria and Fuerteventura (e.g. Machado, 1996; Machado *et al.*, 1997; Machado and Galván, 1998; Navarro *et al.*, 2000; Navarro, 2003; Mireles *et al.*, 2005). However, non-archaeological sites with plant macrofossils are rare in the Canary Islands, and only Miocene–Pliocene sites have been studied (García-Talavera *et al.*, 1995; Vegas *et al.*, 1999; Anderson *et al.*, 2009 and references therein). In the Caldera de Taburiente, pollen and megafossil assemblages corresponding to the Upper Miocene–Middle Pleistocene show the existence of helophytes and point to the presence of marshes in that period (Vegas *et al.*, 1998; Álvarez Ramis *et al.*, 2000). Recent findings in these deposits suggest the existence of a former lake in the basin of La Caldera and evidenced the presence of Lauraceae trees in the site ca. 200,000 years ago (see news in http://www.diariodeavisos.com/caldera-taburiente-fue-gran-lago-hace-200-000-anos/).

Geomorphological processes have been used as indicators of palaeoclimatic events in the Canary Islands. The work of Lomoschitz *et al.* (2002) on Gran Canaria suggests that the timing of landslide events corresponds to the wet episodes of the interglacials, and such relationships can be also found in debris-avalanches and erosive episodes (Lomoschitz *et al.*, 2008). More recent events have also been investigated, such as the cold period of the Little Ice Age that has been linked with the occurrence of periglacial landforms in the Teide volcano on Tenerife (Quirantes *et al.*, 1994; Marín Moreno, 2010).

The aim of this work is to interpret the presence of woody macrofossils that were detected during the geomorphological mapping of the eroded shores of the Barranco de Taburiente, in an area of great biological interest: the Caldera de Taburiente National Park. Despite the fact that macro- and megafossil assemblages found at this type of site rarely provide sequential records, this material is interesting because precise taxonomic identifications are frequently achieved and the dispersion of the remains is much more restricted when compared to pollen analysis. Until the finding described in this work, no palaeobotanical studies had been published on the area's Holocene woody macrofossil remains from natural contexts and in the interior of the island of La Palma.

MATERIAL AND METHODS

Study area

The Caldera de Taburiente is a massive depression located in the central part of La Palma Island. It is approximately 8.5 km wide and was declared a National Park in 1954. It is surrounded by a semicircular ridge that reaches 2426 m a.s.l.

at the highest point of the island, the Roque de los Muchachos. The altitudinal range is wide, as erosion has intensely modelled the depression and slopes are steep. The lower altitude of the National Park, at the bottom of the Barranco de Las Angustias is 430 m a.s.l.

Geologically, this landform is not strictly a volcanic caldera (which is a subsidence near the crater following a large and explosive eruption) but a majestic volcano derived from several overlaying volcanoes that were shaped by giant landslides and intense erosion. Lithology is mainly composed of basalt and volcanoclastic rocks (Carracedo *et al.*, 1999; Vegas *et al.*, 1999).

Sub-fossils were found in a stretch of approximately three kilometres in the Barranco de Taburiente, whose northern part is called Playa de Taburiente (800 m a.s.l.). This part is an alluvial braided bar plain with large boulders, cobbles and gravels where two (sometimes three) shallow streams flow through the bottom terrace, with a high riverbank of ~2.3 m on average. To the south, the stream is narrowly entrenched and meanders among boulders and cobbles.

The climate is Mediterranean with little to moderate annual precipitations (~900 mm) and intense summer drought. The influence of the Atlantic currents makes seasonal variations in temperature relatively small, with mean annual temperatures of approximately 15 °C. However the big difference in altitudes make climatic parameters (precipitations and temperatures) vary greatly on the island. Moist trade winds that often generate cloud banks at mid to high altitudes on the northeastern side of the island do not affect the Caldera (Mestre Barceló and Filipe Nunes, 2012).

The vegetation is dominated by forests of *Pinus canariensis* often accompanied by shrubs, such as *Cistus symphytifolius* and *Lotus hillebrandii*, and *Erica arborea* at humid locations. At high altitudes (higher than ~1800 m a.s.l.), *Adenocarpus viscosus* occurs and dominates the landscape in the summit areas. At lower altitudes (under ~1000 m a.s.l.) other shrubs are present such as *Spartocytisus filipes* or *Cistus monspeliensis* (Fuertes Díaz, 1995; Arco *et al.*, 2006). At the Playa de Taburiente, near the sites studied in this work, stands of *Salix canariensis* dominate locally along the riverbanks. This buffer forest of willows is of natural origin but most of its current area is the result of recent afforestations.

MATERIALS AND METHODS

The detailed search for woody samples was conducted by a careful screening of the exposed profiles of the Barranco de Taburiente. Subfossils were located at three different sites, separated by approximately 1 km along the stream (Figs. 1 and 2). In all, 39 woody samples were recovered, one of them from a large tree that was found buried and laying horizontally in the bank sediments as represented in Fig. 3 (site 2, Fig. 2b).

Woody remains were prepared for wood anatomical (thin sections) or anthracological observation (manual fracture) depending of on their preservation

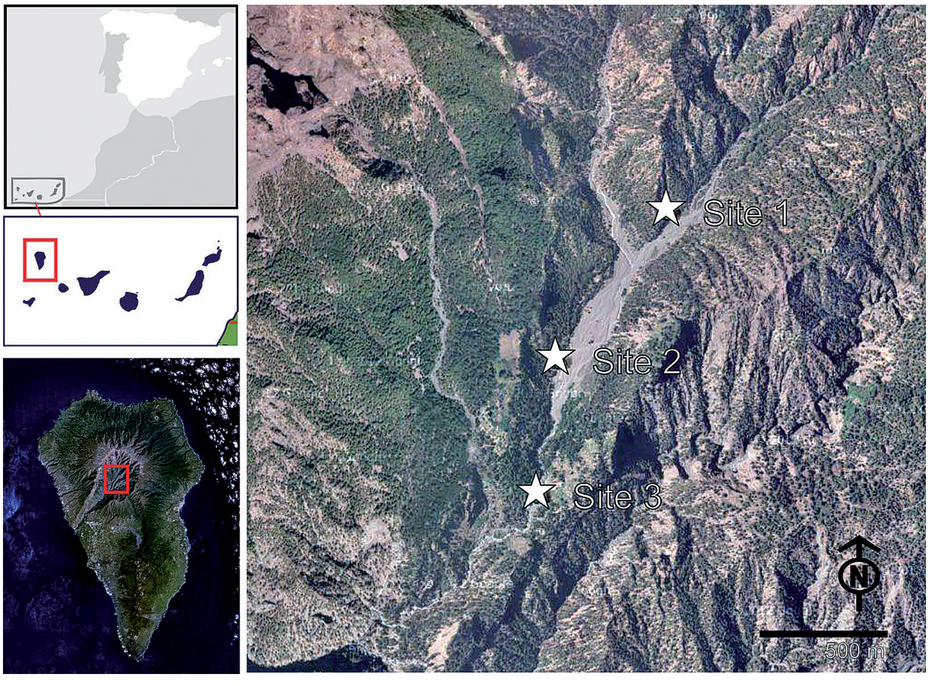

Figure 1. Location of the sites in Caldera de Taburiente. Map sources: Wikimedia commons, Ginkgo maps and Google Maps.

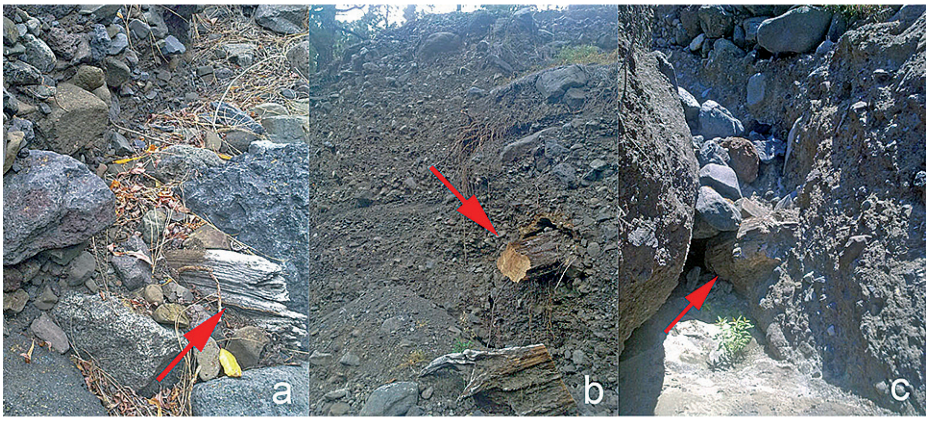

Figure 2. Pictures of the sites where woody remains were recovered, a: site 1, b: site 2, c: site 3.

Fig 3. Sedimentological sketch of the vertical section revealed at site 2. Legend: 1) Coarse gravels, grain supported in discontinuous layers with cobbles; 2) Medium gravels, matrix-supported in sandy clay dark brown matrix, presenting interlensing with gray matrix; 3) Decreasing grain-size sequence of coarse gravels, sand and clay; 4) Alternation of layers of coarse gravel–grain supported gravel with layers of fine gravel matrix-supported with a dark clay matrix; 5) Layer of grain supported cobbles with a palaeochannel in a lateral, intercalated with finer gravels with dark matrix. The log was found into a lag or bar; 6) Alternation of grain supported cobbles and coarse gravel layers with more matrix.

state. Thin sections (approximately 15 to 20 µm thick) of non carbonised specimens were obtained using a sliding microtome. Slices were stained with safranin and dehydrated with alcohol and *Histoclear*. Radial and tangential sections were successfully obtained but no appropriate cross sections were obtained due to poor preservation. Sections were then mounted, coverslipped with a hardening epoxy (*Eukit*) and dried. Furthermore, charcoals and carbonised wood were fractured manually to obtain transversally, radially and tangentially aligned surfaces, and then examined under reflected-light microscopy at different magnifications (50x, 100x and 200x). Wood identification was achieved using keys to wood anatomy, including those of Peraza and López de Roma (1967), García Esteban and Guindeo (1988), and Vernet *et al.* (2001).

Three samples (one from each site) were selected for AMS radiocarbon dating that was carried out at the ^{14}Chrono Centre (Queens University Belfast, UK) and the Centro Nacional de Aceleradores (Seville, Spain). Date calibration was conducted with the *CALIB 6.0.1* software (Stuiver and Reimer, 1993) with the

TABLE 1. SITE LOCATION AND RADIOCARBON DATES FOR SELECTED SAMPLES OF EACH SITE.

Site	Lat degrees N)	Long (degrees W)	Altitude (m a.s.l.)	Sample ID	Radiocarbon age (yr BP)	2 sigma (cal. yr BP)
Site 1	28.7315	-17.8706	850	UBA 18436	3256 ± 24	3405–3559
Site 2	28.7257	-17.8761	770	CNA 1368	3550 ± 35	3720–3961
Site 3	28.7189	-17.8798	700	UBA 18435	3086 ± 42	3170–3390

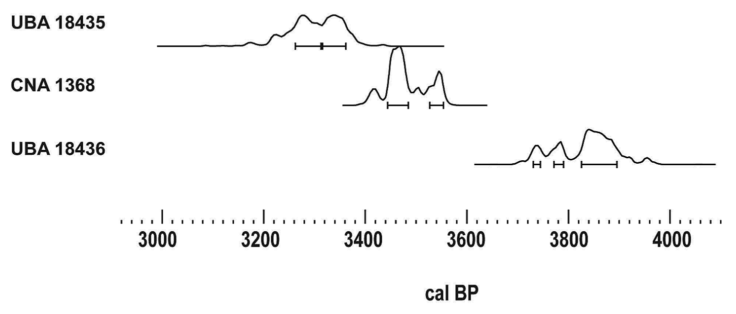

Figure 4. ~~Location of the sites in Caldera de Taburiente. Map sources: Wikimedia commons, Ginkgo maps and Google Maps.~~

last dataset available (INTCAL 09, Reimer *et al.*, 2009). The dates were expressed as 2 sigma calibrated years BP (Table 1, Fig. 4).

RESULTS

Wood anatomical analysis allowed the identification of all the samples. The 39 woody remains correspond to *Pinus canariensis* and present the following features, previously reported for this species in Peraza and López de Roma (1967), García Esteban and Guindeo (1988), García Esteban *et al.*, (2005): In the cross section, growth rings are clearly defined with tracheids of irregular to square shape that often present intercellular spaces in the earlywood. Resin ducts are frequent, with an average size of ~200 microns of diameter; epithelial cells are thin-walled and are surrounded by parenchyma cells. In the radial section, tracheids show uniseriate rows of areolate pits and cross fields pits (area of contact between radial parenchyma–axial tracheid) are of pinoide type, generally with one or two per field. Ray tracheids are located in a marginal position or in the interior of the ray and have irregular thickenings, without extensive marked dentations. However, some dentations are present in the latewood of some ring growths. In the tangential section, two types of rays appear: uniseriate rays, of about 10 to 15 cells and multiseriate, with horizontal resin ducts.

The deposits of sites 1 and 2 are coarse gravel layers in the river banks and lower terraces, showing different depositional events corresponding to flooding events of different magnitudes in layers higher up to that where the subfossils were retrieved (Figs. 2a and 2b; Fig. 3). The deposit at site 3 is a chaotic matrix-supported conglomerate (Fig. 2c).

Three AMS radiocarbon dates were obtained yielding an age of 3960 to 3170 cal. years BP for the samples (Table 1, Fig. 3).

DISCUSSION

The fact that the sedimentary context is similar for the three sites may indicate that all the specimens could have been deposited at the same period. The differences in radiocarbon dates could be explained by an *old wood effect*, as the method does not date the moment at which the sample dies (or it is deposited), but the moment when the tissue was created. So, although it could be possible that three (or two) different events may have occurred during this period, or that relocated subfossils may have been deposited by a single event, what seems more reasonable is that the differences correspond to differences in longevity between specimens. While at site 1 rings that were dated may have been created more than 350 years before the moment when the tree died and was drowned by the flood, at sites 2 and 3, the trees died at a younger date. Age estimates for the specimen dated at site 2 (Fig. 2b, the biggest specimen retrieved) are over ~290 years, but longevity of pines on the island may exceed 800 years, as reported for the species by Génova and Santana (2006). Thus, all the specimens may have been deposited at the same time (somewhere around 3200 cal. years BP).

This event could correspond to a large lateral landslide or debris-flow (site 3) probably triggered by a wet episode. The landslide may have been followed by a river blockage which provoked a progressive alluvial filling of the valley bottom upstream (sites 2 and 1). After this event, several minor but more frequent flooding episodes were needed to open the drainage. These kinds of large landslides and debris-flows have been described in the literature (see Vegas *et al.*, 1999), and can be still observed nowadays together with flash flood events, albeit with lower magnitudes (see Díez Herrero *et al.*, 2012). To date there is no evidence that the floods have significantly affected the shape of the Barranco bed due to the incised valley morphology or that a blockage was involved in the formation of a lagoon at the Playa de Taburiente. However, lagoon deposits, if existed, may have already disappeared by intense erosion events.

The Barranco de Taburiente is to date, the only site in La Palma at which Holocene megafossils have been found. *Pinus canariensis* subfossil data suggest the persistence of the species in this area throughout the end of the Holocene. Nowadays, La Palma is the island that hosts the best conserved forests of Canarian pine and, relative to its surface area, is the island with the largest part of its territory covered by forests of this species (Arévalo and Fernández-Palacios, 2009). In the Canary Islands, *Pinus canariensis* appeared during the Miocene, around 13 Myr ago (García Talavera *et al.,* 1995) in the site of Macizo de Inagua, Gran Canaria. Palaeoecological and genetic evidence from other sites from the archipelago indicate that the distribution area of *Pinus canariensis* responds, over the Quaternary, to processes of expansion and extinction related to volcanism (Navascués *et al.*, 2006). Shifts of pine demise are recorded in the second half of the Holocene (de Nascimento *et al.*, 2009), which could be linked to climatic variation. The pollen records from La Gomera and Tenerife, however, show a continuous signal of *Pinus* throughout the Holocene (de Nascimento *et al.*, 2009; Nogué *et al.*, 2013) even though forest cover of Canarian pine have suffered a severe reduction over the last millennium primarily due to the intensification of human activities on the islands (e.g. Machado, 1996; Machado and Galván, 1998). Thus, pine may be a key species sensitive to environmental changes over time, such as volcanism, climate or human activity.

Evidence of recent extinctions of *Pinus canariensis* is found in some marginal populations. In Fuerteventura, anthracological data indicate intense deforestation as a consequence of both the use of wood as fuel, and land clearing for agriculture and pastoralism. Archaeological charcoals document the extinction of pines on the island between 1400 and 900 cal. years BP (Machado, 1996). This pattern is repeated on La Gomera (Navarro *et al.*, 2000; Navarro, 2003; Morales Mateos *et al.*, 2007), although, natural pines still persist on this island. The signal of *Pinus* in the Laguna Grande is relatively small but continuous from ~9600 cal. years BP, although it is higher during the mid Holocene (~6000 to ~3000 cal. years BP). From 3000 cal. years BP onwards, *Pinus* percentages have decreased, while *Cistus* (characteristic of the pine forest understory and disturbed sites) has increased progressively since 5500 cal. years BP (Nogué *et al.*, 2013). In Gran Canaria, the genetic and demographic study of the marginal population of Arguineguín, below the standard elevational range of the pine belt, also shows the severe recent contraction of this pine population (López de Heredia *et al.*, 2010).

Several factors may account for the long-term presence of pinewoods in the Caldera de Taburiente. First, the geographical configuration of the Caldera, with unstable slopes and numerous ridges, makes access very difficult compared to the other regions of the island. This would have discouraged humans from using this space for wood extraction or intense pastoralism, which would have drastically transformed the vegetation (e.g. Garzón-Machado *et al.*, 2012). Despite the fact that goats were introduced by the *auaritas* (La Palma aborigines) about 2500 cal. years BP and have grazed in the park since then (Pais, 1995), this space has remained protected from intense management. Instead of livestock or wood resources, water has been the main source of incomes for the owners of this area, at least since the Hispanic stage (Palomares, 2005). Second, extremely steep slopes also influence negatively the processes of soil formation in the interior of the Caldera, and when heavy torrential rains occur, soil denudation stops the process of soil development. If erosion is not dramatic, pine recruitment is however possible in poor soils (López de Heredia, 2010) and may benefit from a great advantage over other potential tree competitors under different climate conditions. Finally, disturbances such as fire or other geomorphic events (i.e. landslides, flows) may serve to rejuvenate the system, which can be also favourable for *Pinus canariensis*, allowing recolonisation or controlling the establishment of other woody species.

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