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HOLOCENE COASTAL PALAEOENVIRONMENTS IN LAS CANTERAS BEACH, GRAN CANARIA (CANARY ISLANDS, SPAIN)

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the Interuniversity Master in Oceanography

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Paleoambientes costeros del Holoceno en la Playa de Las Canteras, Gran Canaria (Islas Canarias, España)

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Abstract

Las Canteras beach outcrops correspond to vestiges of Holocene palaeoenvironments that represent changes in the sea-level and climate conditions. Under detailed stratigraphic, sedimentological, mineralogical, petrographic, geochemical and dating studies it has been possible to identify and characterise a variety of facies from Las Canteras palaeoenvironments. The basal level is a beachrock (several calcarenite layers, dipping 8 to 15 degrees seawards and with isopaque LMC cement around sand grains of marine origin) formed through a rising sea level during the Present Interglacial stage (lower Holocene >6.6 ka). Afterwards, during middle Holocene (about 6.6 ka, ^{14}C dating), coastal progradation phase or lower sea level (or both) could lead land emersion and formation of soil, with well-developed weathering and accumulation horizons and the presence of abundant terrestrial gastropods. Overhead, but only observed in the Central Arc of the beach, eolianite facies from cemented palaeocoastal dunes were identified (calcarenite levels, dipping around 20 degrees landward, and with phreatic LMC and vadose aragonite cement) formed in the upper Holocene (<6.6 ka). This eolian deposit represents the highest coast progradation or the end of low-stand sea level, with a more recent time than the palaeosol, whereas its cementation can be interpreted as the beginning of the sea level rise towards the current highstand sea level situation.

1. Introduction

The study of coastal palaeoenvironments has been a useful tool, helping to survey local response to global changes. The evolution of such environments is changing within spatial and temporal scales, being affected by from daily tidal shifts to millennial eustatic processes, biological, climatic and oceanic influences, tectonic events and, moreover, the increasing pressure due to human occupation. Accordingly, earlier coastal landscapes and their components have been studied around the world, dealing with all aspects of understanding and reconstructing past environments, including integrated studies, linking diverse geological and biotic records (i.e. Dickinson, 2001; Murray-Wallace, 2002; de Carvalho et al., 2006). In the Canarian archipelago, palaeocoastlines and sedimentary formations such as beachrock, palaeosol and eolianite, has been risen due to the action of geological agents, being widely studied and related with environmental changes since the early 60s until present (Zeuner, 1958; Lecointre et al., 1967; Meco et al., 1997, 2002, 2011, 2018, Zazo et al., 2002, 2003; Calvet et al., 2003; Hernández-Calvento and Mangas, 2004; Ortiz et al., 2006; J. Mangas, Cabrera, et al., 2008; J. Mangas, Menendez, et al., 2008; Kröchert et al., 2008; Menéndez et al., 2009; Fernandez-Palacios et al., 2011; José Mangas et al., 2012; Martín-González et al., 2016; Calvento et al., 2017).

In the north-eastern coast of Gran Canaria, there is one of the most touristic attractions on the island, Las Canteras beach, with a significant economic, social and environmental value (Santana-Cordero et al., 2017). This consist of several sedimentary deposits including a particular calcarenitic barrier, locally known as "La Barra" and calcarenitic outcrops (Pérez-Torrado and Alonso, 1992; Pérez-Torrado and Mangas, 1992; Alonso, 1993; Pérez-Torrado et al., 2000). The most studied deposit here is the offshore rocky bar, which confers a distinctive wave dynamic to the beach (Martínez-Martínez et al., 1990; Alonso, 1993, 1994, 2005; Alonso and Vilas, 1996). This have been reported as a calcarenitic sedimentary setting presumably from the Jandian geological time, about 110 ka (thousands of years ago) (Balcells et al., 1990; Pérez-Torrado and Mangas, 1992) constructed by the formation of sand dunes during Riss Glaciation (more than 130 ka) (Alonso, 1993) and accepted as an ancient coastline (Alonso and Vilas, 1996). Pérez-Torrado and Mangas (1992) described it in detail (lithology and petrography) surveying especially the geologic origin. Afterwards, Pérez-Torrado et al. (2000) studied its mineralogy carefully, discriminating between offshore and nearshore deposits, concluding that its formation was into a foreshore environment. This calcarenitic setting has experienced about 29% destruction by human exploitation (Ferrer-Valero et al., 2017).

Another solid substrate emerges on the lower part of the foreshore covered by sediments during accretionary conditions and appearing during erosive situations (Alonso, 1994) as a set of parallel layers, between 10 to 15 cm, dipping 8 to 15 degrees seawards (Pérez-Torrado et al., 2000). This visible outcropping emerges because of the local wave dynamics (Alonso and Vilas, 1994) but its horizontal extension is unknown. This deposit has been considered as an extension of La Barra with the same geologic origin and settling within the same stratigraphic level except by Pérez-Torrado et al. (2000) who divide and interpret their particular petrological characteristics. Due to the similarities of both deposits, the offshore and foreshore calcarenitic, they have been acknowledged as beachrocks (Alonso, 2005). Nevertheless, in this work, for clarifying purposes, we consider separately La Barra and the intertidal calcarenitic formation which is addressed as the Beachrock.

Adjacent to the beachrock, a silty-clayey deposit has been reported due to its specifics characteristics, with incrusted terrestrial gastropods, pinkish tone colours (Pérez-Torrado and Mangas, 1992; Alonso, 1993) and vegetal bioturbation (Pérez-Torrado et al., 2000). It was found in different topographic levels, with distinct compaction degrees (Alonso, 1993), probably originated from earlier palaeosol (Alonso, 1993), on the previously mentioned beachrock, or under lagoon conditions (Pérez-Torrado et al., 2000). Finally, the less mentioned deposit in bibliography appears at the southern and landward part of the central arc. It was described as a laminated unit dipping around 20 degrees landward, formed in backshore conditions (Pérez-Torrado et al., 2000), according to Alonso (1993) possibly during the Flandrian period (10 Ka) after dunes immersion, generating the material known as eolianite.

The objective of this research is the study of the mineralogy, petrography, geochemistry, geochronology and stratigraphy of the different sedimentary deposits that emerge on Las Canteras beach, comparing the results with previous descriptions and providing new information to interpret the coastal palaeoenvironments.

Geological background

The Canary Islands is an archipelago located 100–700 km off Western Sahara, on the oceanic crust of Jurassic age (165–176 Ma (millions years ago)) (Schmincke and Sumita, 2010). The accepted theory about the archipelago origin is the hotspot model, like the Hawaiian (Schmincke and Freundt, 1990; Walker, 1990; Carracedo et al., 1998) or, the Cape Verde Islands (Kissel et al., 2015). Thus, successive sub-marine volcanic eruptions are generated progressing vertically until turned to sub-aerial volcanism. Submarine magmatism took place on the Jurassic oceanic crust and begin in the Late Cretaceous Age (around 60 Ma), but it is just 34 Ma (Oligocene) when has been dated submarine lava flows in Fuerteventura island (Schmincke and Freundt, 1990; Carracedo et al., 2002; Schmincke and Sumita, 2010).

Gran Canaria is a representative example of volcanic island-building on oceanic intraplate. Therefore, there is a lack of information about the submarine volcanism, despite the vast volume of the volcanic and sedimentary materials emitted, representing about 97% of the whole island (Menéndez et al., 2008). However, there are numerous studies about subaerial geological materials which show the main three magmatic cycles. The first one is characterised by the shield build stage with emission about 1000 km^3 of ultramafic and mafic materials (lava flows, fall pyroclastic deposits and dykes) and later an alkaline declining stage with formations of intermediate and felsic deposits (lava flows, ignimbrites, dykes and stocks) with, again, about 1000 km^3 of emitted volume. The shield building stage occurred during Miocene from 14.5 to 14.1 Ma (effusive vulcanism forming basanites, basalts and intermediate rocks) while the alkaline declining stage took place from 14.1 to 7.3 Ma (effusive and explosive vulcanism forming intermediate and acid rocks), all of them associated to Tejeda Caldera. Later there is a volcanic inactivity period, and alluvial sedimentary deposits were formed at the main island ravine between 7.3 and 5.3 Ma, which now is part of Las Palmas Detritic Formation (LPDF).

Afterwards, processes of rejuvenation and recent volcanism (Plio-Quaternary, less than 5.3 Ma) formed the younger northeast portion, and the emitted volume was 210 km^3 of ultramafic and mafic materials (lava flows, pyroclastic fall deposits and domes). In this period, the Roque Nublo stratovolcano was active in the centre of the island (5.3–2.8 Ma), and mafic and felsic materials were formed (Roque Nublo magmatic cycle). Also, fissural, platform and individual volcanism (ultramafic,

mafic and intermediate rocks) were active between 3.7 Ma to 1.9 Ka (Post Roque Nublo magmatic cycle). Into the Plio-Quaternary period, the external geological processes (rivers, wind, ocean, gravity and weathering) had been active in the island, and numerous sedimentary deposits were formed (alluvial, colluvial, palaeosol, eolianites, marine terraces, among others). Part of these sedimentary deposits conform the middle and upper members of LPDF with individual sedimentary rocks and sediments (Fuster et al., 1968; Balcells et al., 1990; Schmincke and Sumita, 1998, 2010; Carracedo et al., 2002; Schneider et al., 2004).

The sedimentary and volcanic materials outcropping in the surrounding area of Las Canteras beach, are associated with alkaline declining (phonolite lava flows and ignimbrites) and rejuvenation stages (basaltic lava flows and pyroclastic deposits), the LPDF (sandstones and conglomerates), quaternary marine terraces, alluvial deposits and recent sediments (Pérez-Torrado and Mangas, 1992; Pérez-Torrado et al., 2000).

2. Materials and methods

2.1. Study area

Las Canteras is an approximately 3 km long sandy beach, located on the north-eastern coast of Gran Canaria, within the Confital Bay, on the east side of Guanarteme isthmus, which connects the central city of Las Palmas de Gran Canaria with La Isleta headland (Figure 1). Indicating the position of a palaeo-coastline appears La Barra, approximately 1600 m long and 50-100 m width, whose elevation is similar to the mean sea level (MSL), therefore during low tide it generates a calm water zone where the wave action is practically null (Pérez-Torrado and Mangas, 1992; Alonso, 2005). This particular natural barrier, running parallel to the coast, separated about 200 to 250 m from the shoreline, have significant impact in this specific beach sedimentary dynamics (Martínez-Martínez et al., 1990; Alonso, 1993, 1994, 2005; Alonso and Vilas, 1994), formerly an extended beach-dune system partially disappeared through resource exploitation and urbanisation (Santana-Cordero et al., 2017).

There are three different sectors on this semi-enclosed beach: the Southern arc, from 28°7'56''N/15°26'56''W to 28°8'8''N/15°26'24''W, where there are substantial losses of sediment through erosion during winter, especially in storms, due to the direct wave action (Alonso, 1993; Alonso and Vilas, 1994). The central arc located between the southern arc to 28°8'26''N/15°26'9''W, about 750 meters long, is partially sheltered by the bar, presenting accumulation of sediments, mostly in summer, from the currents towards the NE at high tide periods. The sedimentary budget variations in this part of the beach are fewer in comparison to the south and north ones (Casanova, 2015). And finally, the northern arc, from the end of the central one until the end of the beach (28°8'54''N/15°25'54''W) known by locals as La Puntilla, is almost entirely sheltered, presenting higher accumulation of sand from submerged bars and southern arc erosion (Alonso, 1993; Alonso and Vilas, 1994; Casanova, 2015). This study includes the sedimentary deposits located in the central arc, in which there are sets of materials with clearly differentiable layers.

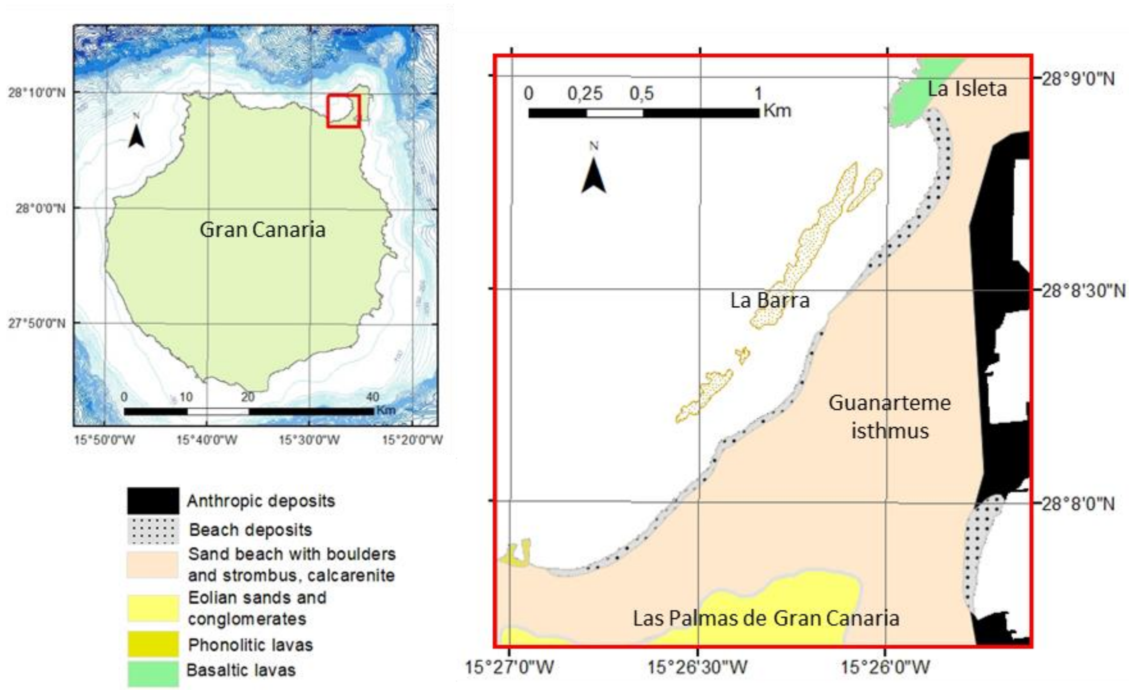


Figure 1. Location map of Las Canteras Beach in the city of Las Palmas de Gran Canaria. To the right: enlargement of the study area showing the lithologies (see legend below on the left). Modified from Barrera-Morate and Balcells (1987).

2.2. Methods

Sampling procedure

Based on the description of the main materials present on the beach, the sample selection seeks to have a representation of the reported palaeoenvironments of interest. Three sections were chosen for sampling: Playa Chica (PC), a transition section (TS) and Central Arc (CA) (Figure 2). The PC section is a semi-enclosed beach environment, whereas the CA is at the southward end of the central arc connecting the northern extreme of the Cicer beach and it is more exposed to wave action. The campaign was synchronised with one of the lowest neap tides of the year, on September 17th 2017 at 8:00 hours, and thus maximise the intertidal exposure.

Sediment blocks samples and uncemented sediments exposed during the low tides of September were removed using a rock pick. GPS coordinates were taken at each sample point (Table 1). The amount of sampled rock was around 0.5 to 1 Kg in the case of hard coastal sedimentary formations. Moreover, around 0.1 to 0.5 Kg of uncemented sediment was collected in plastic bags. Current beach sands information and additional samples (A7 and A9) were provided as a collaboration by Ignacio Alonso Bilbao PhD.

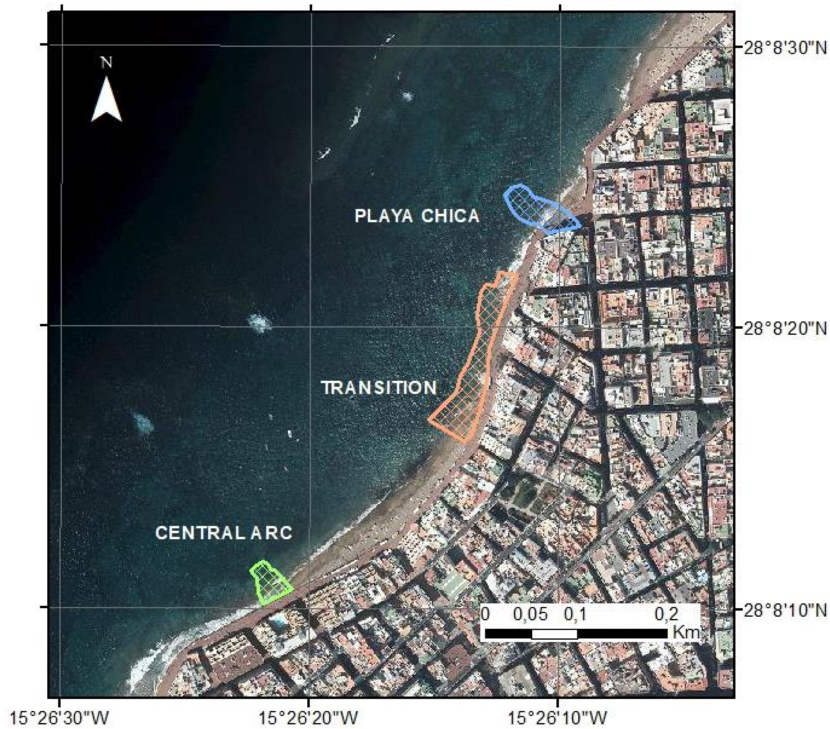


Figure 2. Las Canteras beach middle section map. Showing the three studied sectors, Playa Chica section in blue (11 sample points), Transition Section in orange (3 sample points) and Central Arc section in green (6 sample points). Modified from OrtoExpress (IDE Canarias). Updated for Gran Canaria in July-October 2017.

Grain size distribution

Grain size analyses of three uncemented samples were made (PAC11, PAC11b and PAC17, Table 1). The measurement of the grain size distribution was conducted using a sieve analysis test, with sieves ranging between 2 and 0.045 mm. GradiStat V8® free software (Blott and Pye, 2001) was used to analyse the results obtained after sieving. The results were arithmetically and geometrically studied through the method of moments; the distribution, mean and sorting were considered. Linear interpolation was also used to calculate statistical parameters.

Calcimetry

The calcium carbonate content was determined by the volumetric method of the Bernard calcimeter by the acid leaching method. This technique consists of measuring the volume difference of a liquid indicator displaced by the CO_2, before and after the reaction takes place, in which the carbonate reacts with the hydrochloric acid (diluted to 10%), producing a salt ($CaCl_2$), H_2O and CO_2. For the development of this analysis, it was necessary to carry out a preliminary calibration line with a standard sample of pure calcium carbonate, since this method has the disadvantage that the reaction produced is influenced by temperature and environmental pressure. Three replicates of each sample were made to obtain the average percentage.

Sample ID	Latitude	Longitude	Section	Material
PAC1	15°26'11''N	28°8'23''W	Playa Chica	Beachrock
PAC 2	15°26'11''N	28°8'22''W	Playa Chica	Beachrock
PAC 3	15°26'10''N	28°8'22''W	Playa Chica	Beachrock
PAC 4	15°26'10''N	28°8'22''W	Playa Chica	Beachrock
PAC 5	15°26'10''N	28°8'22''W	Playa Chica	Palaeosol
PAC 6	15°26'10''N	28°8'22''W	Playa Chica	Palaeosol
PAC 7	15°26'10''N	28°8'22''W	Playa Chica	Palaeosol
PAC 8	15°26'10''N	28°8'22''W	Playa Chica	Gastropod shells
PAC 9	15°26'10''N	28°8'22''W	Playa Chica	Palaeosol
PAC 10	15°26'10''N	28°8'22''W	Playa Chica	Palaeosol
PAC 11	15°26'10''N	28°8'22''W	Playa Chica	Palaeosol
PAC 11B	15°26'10''N	28°8'22''W	Playa Chica	Palaeosol
PAC 12	15°26'11''N	28°8'20''W	Transition	Palaeosol
PAC 13	15°26'13''N	28°8'16''W	Transition	Beachrock
PAC 14	15°26'13''N	28°8'14''W	Transition	Palaeosol
A_7	-	-	PC and TS	Current sands
PAC 15	15°26'21''N	28°8'10''W	Central Arc	Beachrock
PAC 16	15°26'21''N	28°8'9''W	Central Arc	Palaeosol
PAC 17	15°26'21''N	28°8'9''W	Central Arc	Palaeosol
PAC 18	15°26'21''N	28°8'9''W	Central Arc	Palaeosol
PAC 19	15°26'21''N	28°8'9''W	Central Arc	Palaeosol
PAC 20	15°26'21''N	28°8'9''W	Central Arc	Eolianites
A_9	-	-	Southern CA	Current sands

Table 1. Identification, coordinates, location and geological material of the Samples from the palaeoenvironment study of Las Canteras beach.

Petrography

In order to identify the nature of the grains and its relative abundance of bioclastic and lithoclastic particles, 19 thin sections were prepared from this study besides five thin sections from a morphodynamical study at Las Canteras by Alonso (1993), in order to compare the past and current materials. The samples were dried at 50C˚ for at least 24 hours. The cemented ones were sliced with a wet tile saw (Diamant Boart TS 350), producing 17 block samples with 10 x1 cm size. Thin sections were made in the General services of Geology Faculty of the Universidad de Salamanca. The petrographic study was made under a geologic microscope (Ortoplan-Leitz) with a pointer counter stage (PETROG). The percentages of each component have been quantified and classified into subcategories for their interpretation. These are (i) bioclastic grains (seaweed meshes, foraminifera, molluscs, echinoderms and other bioclasts), (ii) lithoclastic grains (mafic rocks, felsic rocks, intraclasts, olivine, pyroxene, opaques, feldspar, amphybole and others lithoclasts), (iii) carbonate cements (sparite and micrite) and (iv) soil features (palaeosol matrix and cutans). Finally, the porosity of the rocks is quantified as the void surface (holes).

XR Diffraction

Due to the scarce information in the bibliography and the apparent diversity of the found palaeosol, additional studies were carried out on uncemented palaeosol samples. Uncemented subsamples of the palaeosol (PAC 11, PAC11b and PAC17) were dried after washing them with distilled water and subsequently, in order to reduce flocculation of fine material and separate the clay, a 'Calgon' solution (sodium hexametaphosphate) was used. It was prepared by mixing 5g ($Na_6O_{18}P_6$) (Sperazza et al., 2004) in 1000 ml of distilled water. The dispersion was conducted by adding the solution in a 2:1 proportion related to the weight of the subsample and the substance was manually stirred, in periods of 20 minutes during work hours, until 48 hours of reaction was completed. Finally, the decantation of the particles took place for 8 hours to extract and dry the clays in suspension and the obtained sands. The resultant subsamples were sent to the Geology Laboratory of La Laguna University where the samples were analysed by X-ray diffraction.

EMPA and SEM

In order to precise and accurate chemical analyses, Electron Microprobe Analysis (EMPA) was used for analysing six representative samples for their elemental geochemistry, at the Scientific and Technological Centre of the University of Barcelona (CCiTUB). The $MgCO_3$ and Sr contents of the different types of cement were determined. The scanning electron microscope (SEM) equipped with an energy-dispersive spectrometer (EDS), was used to specific microanalysis, obtaining direct images. This technique allowed us to observe the grains morphology of the sedimentary rocks and its cement, petrographic textures, and the chemical semi-quantitative composition of these materials, using the CAMECA SX-50 microprobe, equipped with four vertical wavelength dispersive spectrometers and an EDS of the Silicon Drift Detector type

Carbon dating

In order to calculate the age of palaeosol facies, some gastropods (*Helix* sp.) were previously collected during 2013 in the upper part of Playa Chica Section for ^{14}C radiocarbon dating by Beta Analytic Radiocarbon Dating Laboratory (Florida, USA). Dates were reported as RCYBP (radiocarbon years before present, "present" = AD 1950). By international convention, the modern reference standard was 95% the ^{14}C activity of the National Institute of Standards and Technology (NIST) Oxalic Acid (SRM 4990C) and calculated using the Libby ^{14}C half-life of 5568 years. Calibrations were calculated using the 2009 calibration database (Talma and Voguel, 1993) within the mathematics used for calibration scenario by Stuiver and Braziunas (1993).

Stratigraphy

Stratigraphic columns were built to obtain a relation of superposition of the materials in each section, interpret and reconstruct their geological history. All the information of the previous analyses was incorporated for integration purposes.

3. Results and discussion

3.1. Facies definition

After examination of 20 samples along with the field data collected the following facies were identified: (1) the oldest one is the beachrock, on which (2) the palaeosol facies was developed, showing different characteristics that there will be detailed below. On the top of this palaeosol and only in the AC Section, (3) a dune deposit was found. Covering and surrounding all the outcrops are the (4) current sands (Figure 3).

(1) Beachrock	This facies can be observed in the three sections. Mainly consists of 5 to 20 cm bands of intertidal calcarenites with dips ranging from 5 (Central Arc) to 15 degrees (Playa Chica).
(2) Palaeosol	It can be subdivided into two subfacies: A stratum formed by tabular calcareous bands subhorizontal, which represent the weathering horizon (CH) and a discontinuous bed of silty sands, which represent the accumulation horizon (BH) with abundant terrestrial gastropods (Helix sp.) and observable rhizo bioturbation (rhizoliths).
(3) Eolianite	Structures of calcarenites with wide angle (20 degrees approx.) stratifications, dipping towards land associated with backshore dunes
(4) Current sands	Coarse to medium light-coloured sands with good to moderate sorting*.

*Figure 3. Identified facies in Las Canteras beach. A) Laminar beachrock (PC). B) Tabular palaeosol (PC). C) Silty palaeosol (PC). D) Eolianites exposed after an erosive event (CA). E) Current sands in the central arc. *Information about current sands was taken from Alonso (1993) as the correspondent thin sections studied belongs to that survey.*

The vertical distribution of the facies in each section is similar, appearing the beachrocks between the subtidal and intertidal zone, the palaeosol in the intertidal environment and the eolianites in the Backshore or Swash Zone (Figure 4). On Playa Chica, the tabular section of the palaeosol is much more developed than in the other two zones and in the silty conglomerate section greater volume of buried terrestrial gastropods and greater bioturbation are observed. Transition Section presents more erosion and fractures in all deposits, and it is more difficult to distinguish between the start and end of facies. In the Central Arc section, punctual deposits are outcropping most of the time, not a visible transition, except for specific erosive conditions (Figure 4F). We also found a chain of Eolianites dipping towards the shore (Figure 4E), which do not appear under the same conditions of high tide as the rest of the deposits.

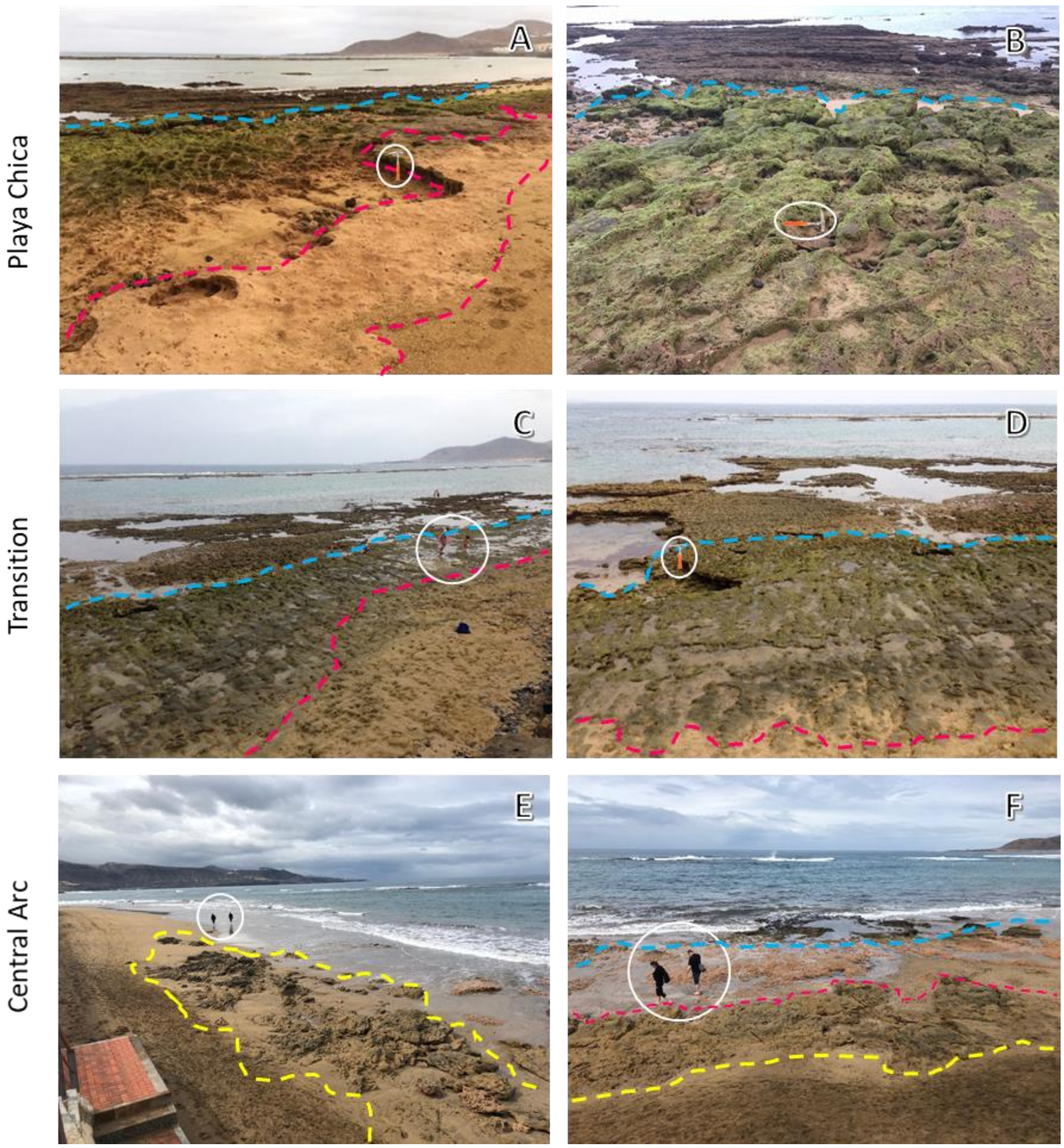


Figure 4. Sedimentary outcrops studied in three different sections along Las Cantera beach. Dotted lines: Beachrock limits (blue), Palaeosol limits (magenta) and Eolianites limits (yellow). A) Playa Chica S-N view. B) Playa Chica E-W view. C) Transition S-N view. D) Transition E-W view. E) Central Arc N-S view. F) Central Arc E-W view.

3.2. Grain size distribution

The analysis of uncemented samples of the palaeosol (PAC11, PAC11b and PAC17) present a grain size geometric mean of 465µm, 532µm and 551µm, respectively, with slightly gravelly sand to gravelly sand texture and is poorly sorted (between 2.4 and 3.5). Additionally, there are differences between the samples, particularly between the uncemented palaeosol level in PC (PAC11) and a sub superficial palaeosol level in the CA (PAC 17), having very fine skewed and very leptokurtic and a fine-skewed platykurtic distribution respectively (Figure 5 and Table 2).

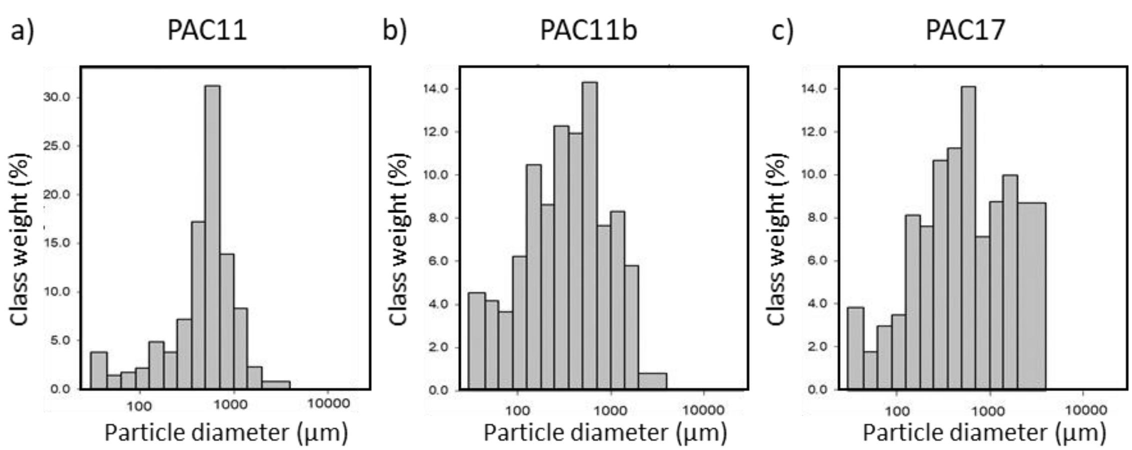


Figure 5. Particle size distribution of uncemented palaeosol samples from Las Canteras Beach: a) Silty uncemented sample of PC section, b) Sandy grey coloured sample incrusted into PAC11 and c) Soil sample in sub superficial layer into a pond in CA.

	Playa chica		Central arc
	PAC11	PAC11b	PAC17
Sample type	Bimodal, poorly sorted	Polymodal, Poorly Sorted	Polymodal, poorly sorted
Textural group	Slightly Gravelly Sand	Slightly Gravelly Sand	Gravelly Sand
Sediment name	Slightly Very Fine Gravelly Coarse Sand	Slightly Very Fine Gravelly Medium Sand	Very Fine Gravelly Medium Sand
Geometric mean particle size	465 µm	532 µm	551 µm

Table 2. Main results from the particle size distribution analyses of three uncemented palaeosol samples of Las Canteras beach.

The samples were not unimodal thus the sorting, skewness and kurtosis statistics are therefore unreliable, notwithstanding, textural triangle let us notice differences between samples (Figure 6). It is observable how the sample PAC11b, which is an intrusion into sample PAC11 present different textural characteristics.

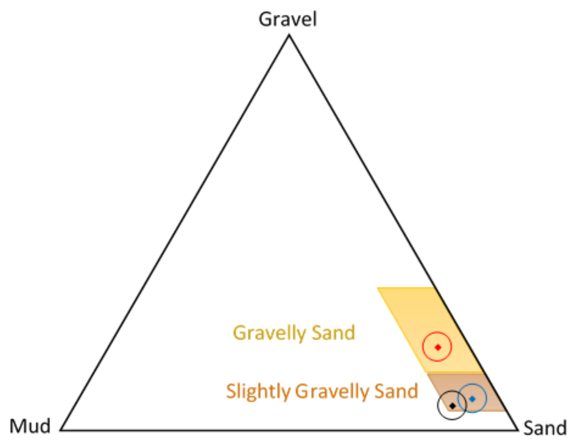


Figure 6. Gravel, sand, mud diagram of uncemented palaeosol samples from Las Canteras beach. Represented samples: PAC11 (blue), PAC11b (black) and PAC17 (Red).

3.3. Calcimetry

The calcimetry analysis indicates a high content of carbonates, with values around 70%. It is, therefore, highly biogenic materials, with $CaCO_3$ maximum of about 88% in PC and a minimum of about 45% in CA. These values indicate a low content of terrigenous fragments in PC, contributing poorly to the sedimentary rocks. Regarding the distribution of carbonate content in the study area, a variation trend was observed between the different environments (Figure 7).

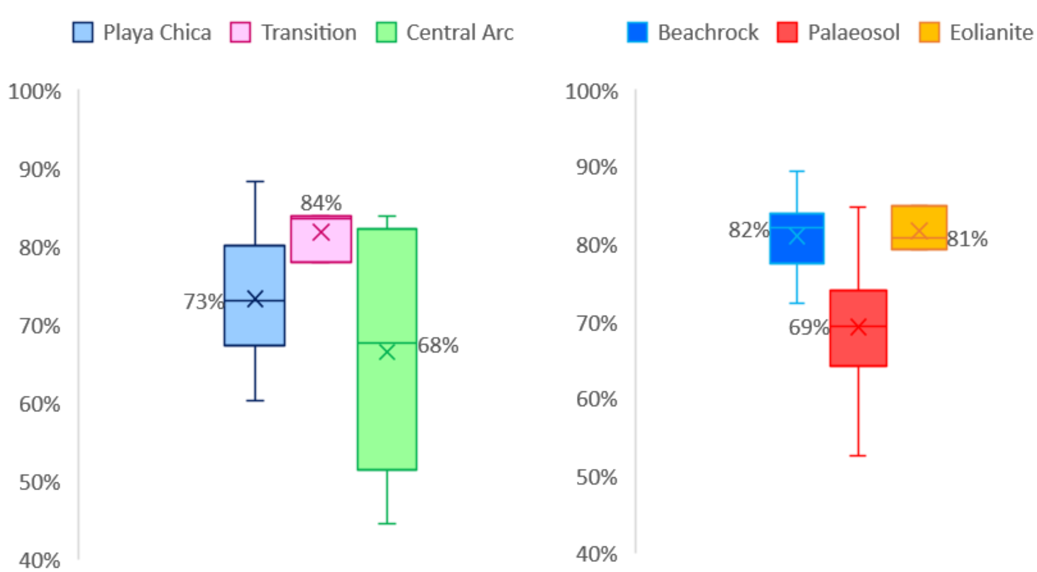


Figure 7. Box-and-whisker plot of carbonate content of the materials outcropping in Las Canteras beach. Left: differences between sections. Right: differences between materials in the intertidal area. Box spans the interquartile range, whiskers extend to the highest and lowest observations. Vertical line inside for the median and x-marker for mean value.

The minimum $CaCO_3$ content values in the central arc correspond to the samples located into and next to a rocky pool outcrop, with 45%, 54% and 63% to the sub-superficial, superficial and surrounding area respectively. The rest of the analysed samples indicate values of carbonate content quite homogeneous. In PC, the highest values were found in the beachrock, and the lowest into and nearby the fossilised terrestrial snails, with an average of 65% of $CaCO_3$.

In summary regarding facies criteria, the highest carbonate content is for beachrock and eolianite (82 and 81% respectively) being a marked reduction in palaeosol (69%). It can be interpreted as an increase in fine silicate fractions in palaeosol. It can be said that the highest proportion in carbonate is for the Transition area (84%) followed by PC and CA (73 and 68% respectively). It could reflect the beachrock predominance in the TS.

3.4. Petrography

After studying thin sections of the different materials of the column, the proportions of lithoclasts, bioclasts and soil features were analysed. Despite de differences between facies, in general, petrographic results show that bioclasts are constituted mainly by algae meshes and molluscs (63% and 26%, respectively). Lithoclasts are mainly constituted by sedimentary intraclasts and felsic rocks (38% and 27%, respectively), and although the degree of alteration varies from one sample to another, phenocrysts of olivine and feldspar can be distinguished with or without alteration. The intraclasts are aggregates of carbonated composition, formed mainly by grains of bioclasts and lithic fragments included in a silty matrix in the palaeosol, or by carbonated cement in the eolianites and beachrock. See Figure 8 and Table 3 to identify relevant petrographic channels quantified in thin sections of each material.

The configuration of the calcarenitic beachrock is very similar to the current sandy sediments that cover the beach, which is due to the higher presence of intraclasts in the beachrock (47%) while in the sands there is not such weathering (17%). The eolianite deposits seem to have an intermediate composition between these two materials; however, as having a single sample, it is not possible to reach any conclusion about it. In this calcarenitic formation, the rounded shape of the grains stands out in comparison to the other thin sections.

More than half of the samples stand out for their high percentage of edaphic features, characterising them as Palaeosol. It is observable in Figure 9 the wide variation of petrographic configurations, which coincides with the variety of colours, textures and structure of the materials collected in the field. Some samples were initially mistaken as other materials, therefore, after petrographic results, a reclassification of the samples took place in concordance with their characteristics.

The cement appears forming a band around the grains and filling the intragranular porosity. By counting points, it was determined that the porosity in the study area vary widely between 0.5% and 66%. The petrographic study also shows variations in the abundance of cementing materials; with sparite representing the 42%, mainly present in beachrock, and palaeosol matrix with the 30%. This matrix is a characteristical protosoil and defines the facies considered as palaeosol in this coastal environment. Micrite and cutans are included in these cementing compounds, being the first the less abundant in the samples while cutans, considered as another soil feature, is abundant mainly in the PAC10, a solid sample from PC section and PAC17, an uncemented sample from AC section.

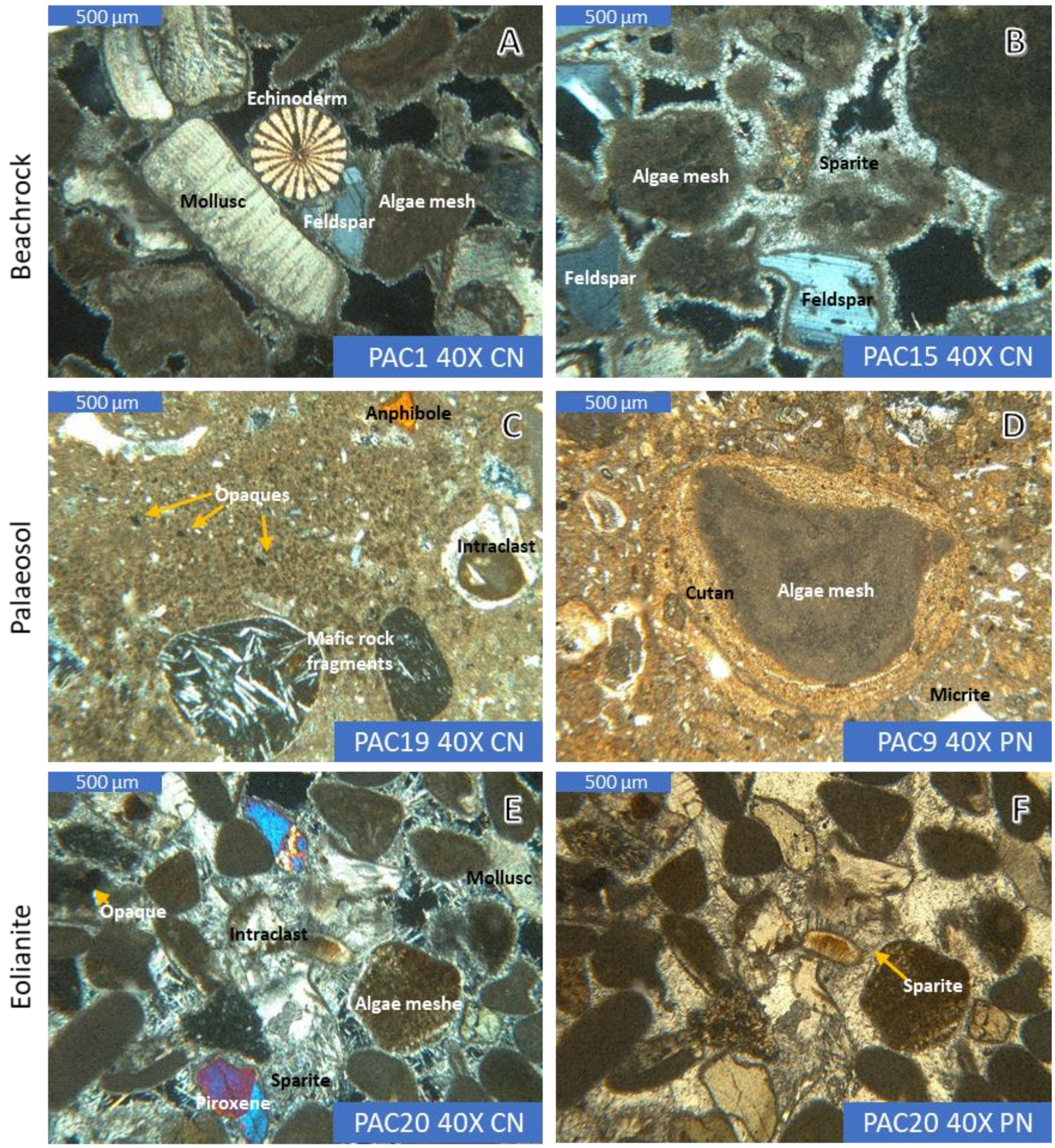


Figure 8. Images from petrographic microscopy of identified facies showing some biogenic and lithogenic components. A and B: sparite is isopaque calcite cement; C and D: micrite is clay and silt particles with microcalcite cement; E and F: sparite is isopaque calcite and prismatic aragonite cement. CN: Crossed Nicols. PN: Parallel Nicols.

	Content (average percentage)							
		Beachrock			Palaeosol		Eolianite	Current sands
Section	AC	PC	TP	AC	PC	TP	AC	AC
Echinoderms	1.00	0.75	1.00	0.55	0.75	1.60	1.50	1.20
Foraminifera	1.00		0.50		1.50		1.50	0.87
Molluscs	8.15	8.70	8.80	4.17	6.01	5.70	5.00	8.54
Others Bioclasts	18.95				0.50			2.50
Seaweed meshes	16.95	30.03	22.10	5.07	13.69	2.60	23.50	19.48
Micrite	0.50		0.50	42.20		1.00	0.50	
Sparite	18.25	11.87	21.85	8.00	10.42	9.30	36.00	3.10
Amphibole	0.50			0.80	0.75	0.50		1.50
Feldspar (Anorthoclase)					0.50			0.50
Feldspar (Plagioclase)	3.55	2.55	1.25	2.80	3.07	2.10	5.00	5.32
Felsic rock fragment	4.80	7.00	6.50	3.67	5.73	6.20	9.00	12.54
Intraclasts	10.65	14.57	13.30	2.30	15.04	9.80	4.50	6.64
Mafic rock fragment	1.50	0.50	3.00	2.93	2.25	3.10	0.50	3.20
Olivine	0.75		0.50	1.10	0.82	2.60	1.50	2.70
Opaques	1.00		0.50	2.07	1.42	1.00	1.00	4.00
Other lithoclasts		1.25		1.10	2.00			
Pyroxene	0.50		1.75	1.60	0.87	0.50	2.00	3.40
Cutans			9.00	26.40	32.77			
Palaeosol matrix	14.10		0.75	11.00	27.73	22.80	0.50	0.50
Porosity	4.40	24.43	13.85	18.40	16.03	4.15	7.50	21.07

Table 3. Content (average percentage) of quantified components in the petrographic study (thin sections) of Las Canteras beach sedimentary deposits.

Identifying petrographic evolution between materials (Figure 10) is possible. First, we see how, as we ascend, the content of bioclasts decreases and the percentage of lithoclasts increases, possibly due to the formation of sedimentary intraclasts. It draws attention above all, the appearance of edaphic features in an increasing way, together with an apparent decrease of porosity, which makes sense when we observe its lithology in the field. This progressive change is less evident into the Central Arc Section, as result probably of the sampling methods which did not attempt to lead a straight line and as was explain formerly, in the central arc the outcrops are less delimited making more difficult differentiate the Facies.

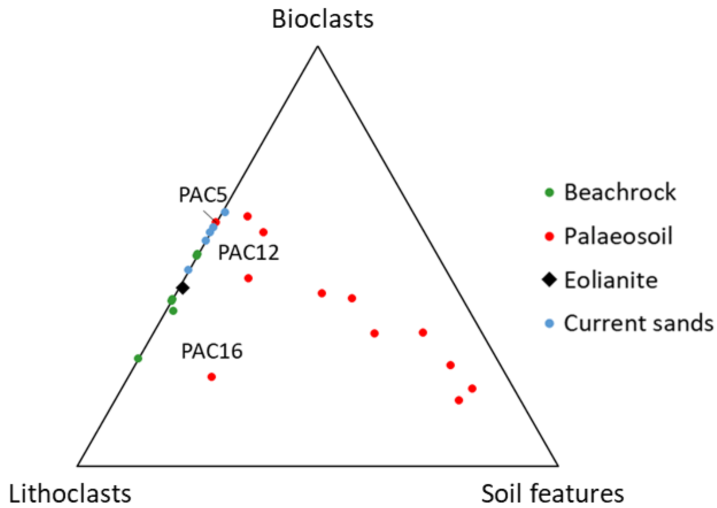


Figure 9. Triangular diagram with abundance data in percentage of bioclasts, lithoclasts and soil features (cutans and micritic silt) for each considered facies. Labelled red plots represent the CH samples from the palaeosol.

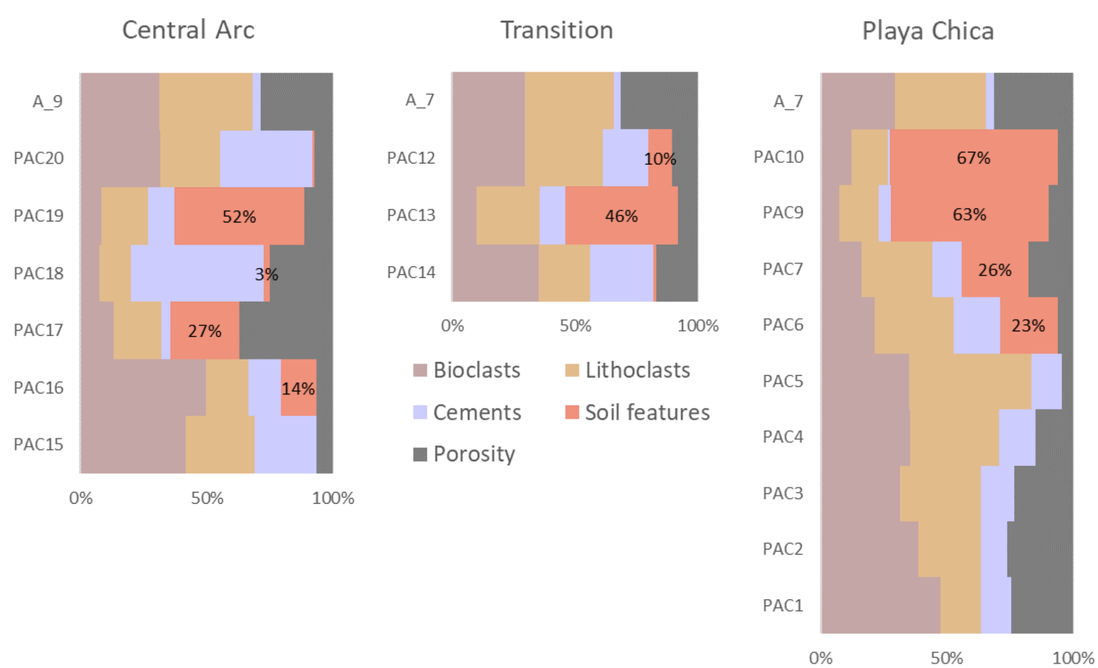


Figure 10. Graphic representation of the content (percentage) of petrographic features in three sampled sections of Las Canteras beach. Include current sands (A_7 and A_9). Sample identification in Table 1.

3.5. XR Diffraction

The XR-diffraction semi-quantitative analysis made to the uncemented samples (PAC11, 11B and 17) identified as main minerals calcite, with the presence of quartz on all of them and minor amounts of clay minerals (illite, kaolinite and traces of smectite) (Figure 11).

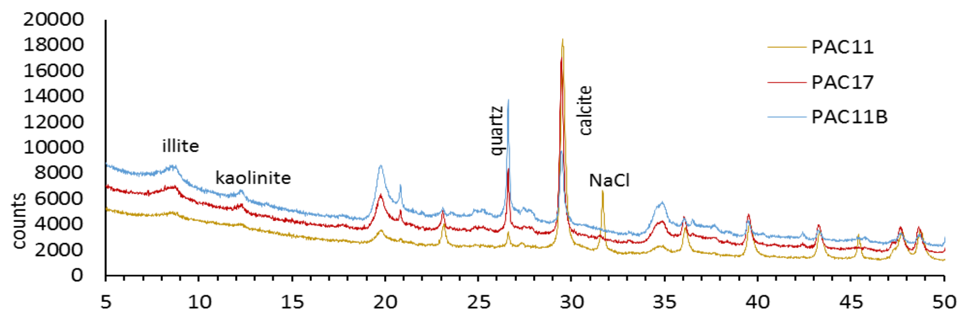


Figure 11. Diffractogram showing the mineralogical composition of uncemented palaeosol samples of Las Canteras beach.

No significant composition differences could be detected by X-ray diffraction on these samples. Minor NaCl peak in PAC11b occurs because the presence of sea salt, despite that, the sediment is quartz-rich with a pick well above the sandier samples and present a lower qualitative percentage of calcite. In all three samples, we found a proportional presence of illite and kaolinite (Table 4). The presence of quartz in this palaeosol reflects the occurrence of Saharan dust events during the formation of this palaeosol (Menéndez et al., 2007). The mean quartz concentration of the new soils of Gran Canaria is about 38% (Menéndez et al., 2007) similar to the mean quartz value of Las Canteras Palaeosol (32%) and remarkably different from Pleistocene palaeosols (25%; Menéndez et al., 2018)

	Playa Chica PAC11	PAC11b	Central Arc PAC17
Illite	6	3	3
Kaolinite	0	3	0
Smectite	0	0	3
Quartz	9	61	27
Calcite	85	33	67
Carbonate*	67	-	45

*Table 4. Mineral composition (percentage) from XR diffraction analysis of uncemented palaeosol samples of Las Canteras beach. *Calcimetry values.*

3.6. SEM and EMPA

The beachrock was identified as a calcarenite with interangular porosity, and sand grains are covered initially with microsparitic and micritic magnesian calcite (<10μm). Afterwards, the grains are joined by isopaque cement bands (>10µm) with the subsequent presence of sparitic magnesian calcite crystals in the shape of trigonal scalenohedral (>10µm) known as dogtooth pattern (Figure 12A and 12B). Sporadic and irregular groups of microcrystals of zeolites and rhombohedral forms (possibly heulandite or chabazite), accompanied by salts (chlorides and sulphates) and micrite are observed sporadically and irregularly. The precipitation of the beachrock cement was under phreatic conditions, showing a low content of Mg (LMC, low-Mg calcite) and Sr and a minor measure of Na, Fe and Mn (Figures 13A and 13B).

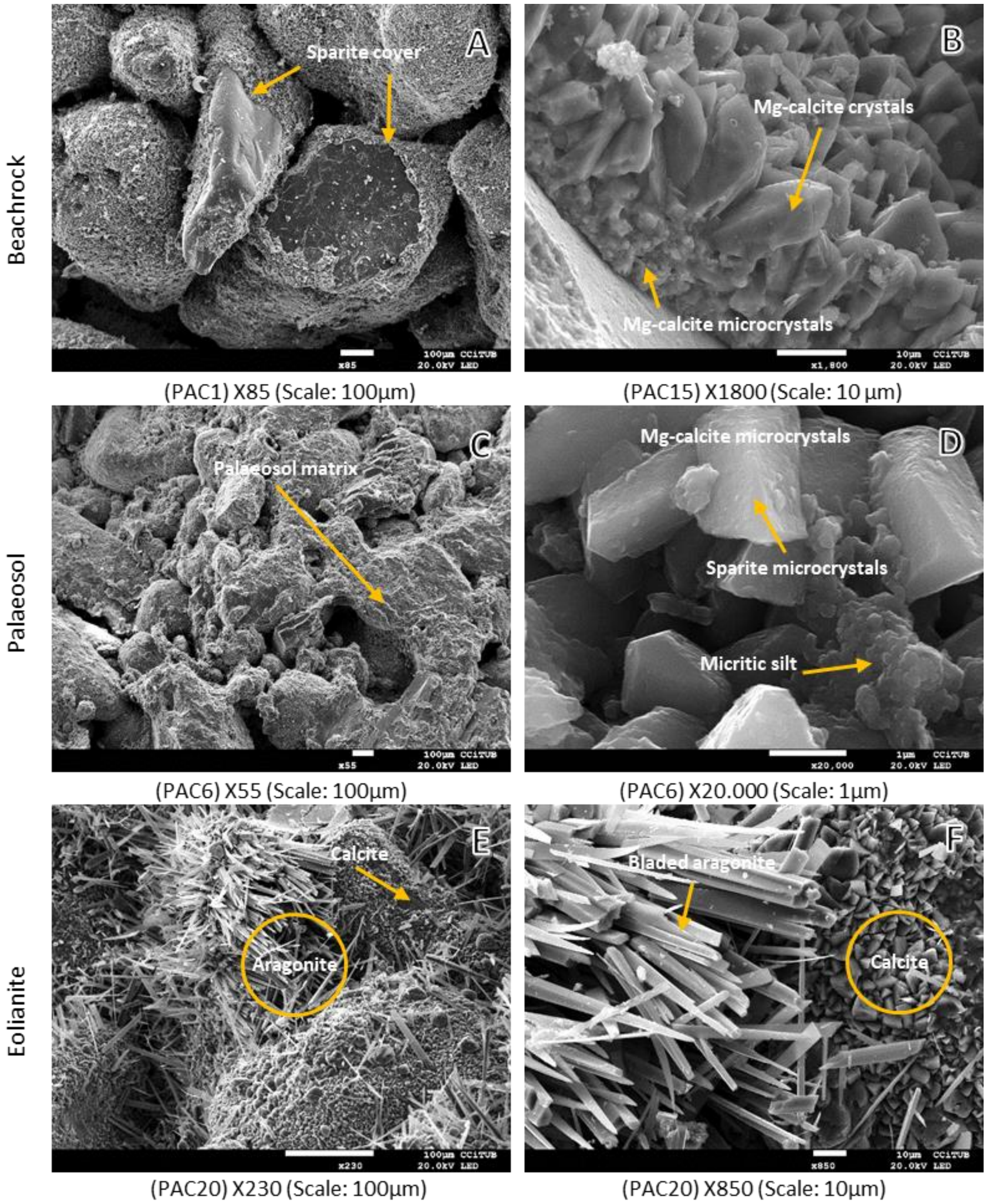
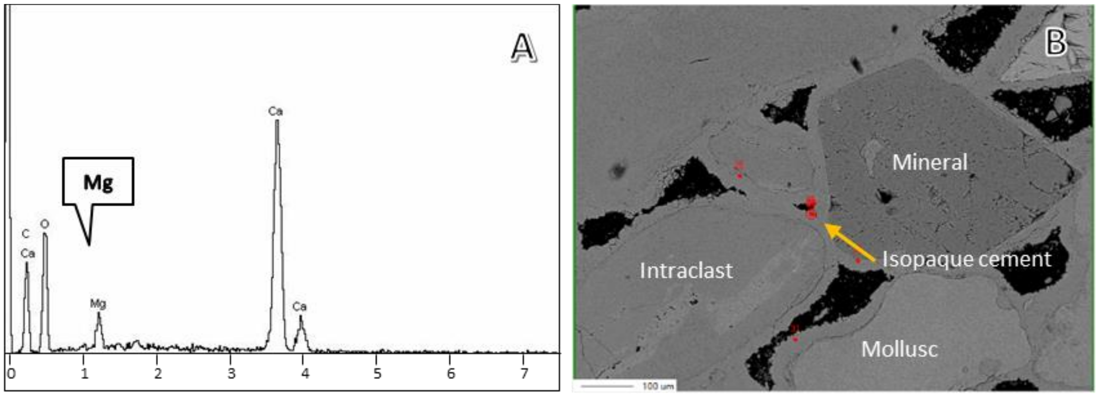
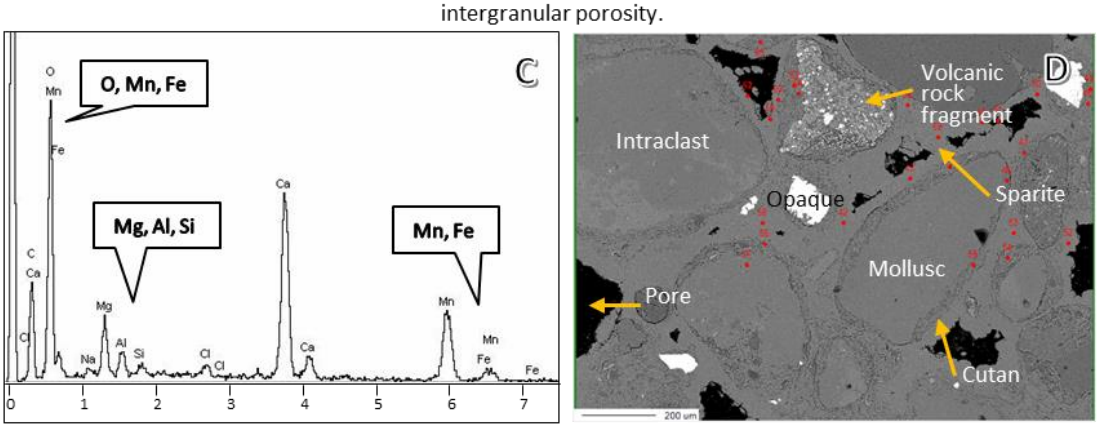


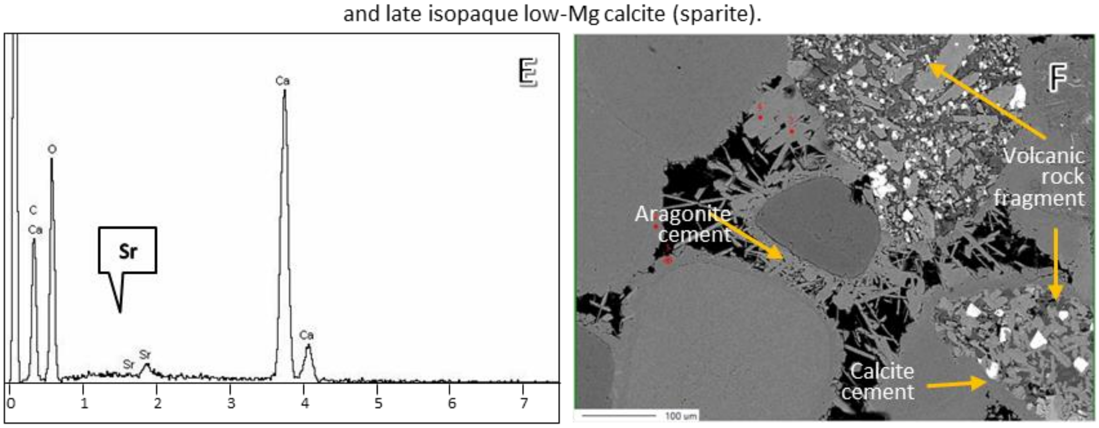
Figure 12. General (left) and detailed (right) view from Scanning Electron Microscope (SEM) of representative samples of A and B: beachrock; C and D: palaeosol; E and F: eolianite, from Las Canteras beach. Labels and pointers showing relevant elements.



Beachrock: LMC (low-Mg calcite) spectrum. View of isopaque bands of LMC around sand grains and intergranular porosity.



Palaeosol: cutan spectrum with carbonates, zeolites, oxides and salts. View of early cutan around the grains and late isopaque low-Mg calcite (sparite).



Eolianite: Spectrum of an aragonite crystal with Sr. View of early isopaque low-Mg calcite around grains and late prismatic aragonite crystals (discontinuous fibres).

Figure 13. Electron Micro Probe Analysis (EMPA) mineral spectrum showing relative content of selected points (red markers into right images) of representative samples of A and B: beachrock; C and D: palaeosol; E and F: eolianite, from Las Canteras beach. Labels and pointers showing relevant elements.

The palaeosol is a sandstone with a silty matrix with most of the grains covered by cutans with accumulation bands of silicates, oxides, salts and carbonates microcrystals (<5µm). Later isopaque carbonated cement up to 100µm thickness is observed (Figures 12C, 12D, 13C and 13D) and, occasionally, iron oxides or hydroxides (hematite or gethite) in bands (>30µm) were observed. Finally, as the beachrock, the eolianite is defined as a calcarenite with (LMC) calcium carbonate isopaque bands in dogtooth shape, but with later delayed cementation of rhombic aragonite (discontinuous and irregular) observed as acicular prismatic crystals up to 70µm in length (Figures 8E, 8F, 12E, 12F, 13E and 13F). These aragonite crystals do not have Mg and are rich in Sr (Figure 13E, 13F and Table 5). In some grains, the second generation of acicular aragonite (length until 100µm) grouped with zeolites, salts and calcite is observed. The precipitation of cement in eolianites shows two generations of calcium carbonate, the first is LMC isopaque around the grains and the second is with aragonite crystals, late and discontinuous.

	CO3Mg (%)		[Sr] (ppm)		[Na] (ppm)		[Fe] (ppm)		[Mn] (ppm)	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
CC Beachrock	5.2	0.5	1410.7	509.1	1149.7	476.2	220.8	144.3	126.6	240
CC Palaeosol	4.2	0.7	499.8	231.3	594.9	500.2	339.3	261.5	70.1	146.8
CC Eolianite	4.7	1.2	797.8	806.3	201.3	206.7	285	223.8	57.9	90.4
Cutan	4.1	1.4	1377.6	972.3	972.4	565	486.2	597.1	51.6	73
Aragonite	0	0	14129.1	2635.4	407	362.9	106.3	64.5	45.4	104.8

Table 5. Magnesian carbonate and element concentration (% and ppm, respectively) arithmetic mean and standard deviation in selected samples of representative materials of Las Canteras beach palaeoenvironments. (CC: Calcium carbonate).

Since mineralogical, petrographic and geochemical characteristics, carbonate cementation in the beachrock (isopaque LMC) is associated with marine waters in intertidal zones and with phreatic conditions. The palaeosol have first the formation of cutan around the sand grains due to meteoric waters with clay and silt materials in vadose conditions, and later or micritic mud cementation associated with meteoric vadose waters (Figure 8C, 8D, 12C, 12D and13D) or isopaque bands of LMC related to marine phreatic waters (Figure 13D). The eolianites have two carbonate generation, firstly isopaque LMC due marine phreatic conditions and secondly discontinuous aragonite cementation of meteoric vadose waters (Figures 8E, 8F, 12E, 12F, 13E and 13F).

3.7. Carbon dating on palaeosol facies

Terrestrial gastropods were collected in the palaeosol facies during this study (Figure 14). However the carbon dating here published corresponds to samples collected in the same area (PC) in September 2013. An AMS-Standard delivery analysis was performed after an acid pre-treatment obtaining a radiocarbon age of **6.6 ± 0.03 ka.** With this dating it was expected to assign a possible age to the silty palaeosol of Playa Chica, assuming these gastropods were, in somehow, living in this palaeosol. It is also important to keep in mind that the age of the beachrock has been assumed in the past as equivalent or close to La Barra and the Terraza Baja de Las Palmas (The Last Interglacial MIS 5e, around 126 ka) and that the age of the eolianites is unknown. Therefore, the formation of Las Canteras beachrock was before 6.6 ka and the eolianites after this age. On the other hand, a similar date of the palaeosol deposit was reported for terrestrial gastropods from alluvial materials of La Ballena Gully (6.2 ka, Hansen and Criado-Hernández, 1996) and they had estimated a littoral lagoon near of Las Canteras beach with the precipitation of clay and silt strata, and brief torrential facies.

Figure 14. Palaeosol facies in Las Canteras beach (Playa Chica) presenting subvertical rhizoliths and encrusted terrestrial gastropods.

3.8. Stratigraphy

Three sections have been identified in this work from northeast to southwest: Playa Chica (PC), Transition (TS) and Central Arc (CA). PC section in composed, from bottom to top, of about 2 m of beachrock facies with 79% mean carbonate content. On top of this, it was found a 50 cm of CH facies and about 2m of BH facies, in which some levels of abundant gastropods appeared (PAC8). Finally, covering the palaeosol facies a 50 cm of current sands were deposited (Figure 15A). TS section corresponds to 50cm of beachrock, about 60cm of CH facies and 40cm of BH facies. Covering the palaeosol facies is 40 cm of current sands (Figure 15B). It is noticeable in this section the lack of terrestrial gastropods in this palaeosol facies. The CA section is composed of about 60 cm of beachrock, 60cm of CH facies, 2m of BH facies, 30 cm of eolianites and covering all 40 cm of current sands (Figure 15C). As it can be seen in the stratigraphic correlation (Figure 16), the thickest beachrock outcrop was found in PC. Meanwhile, the highest development of palaeosol was in CA, being in this later the only place where eolianites were present.

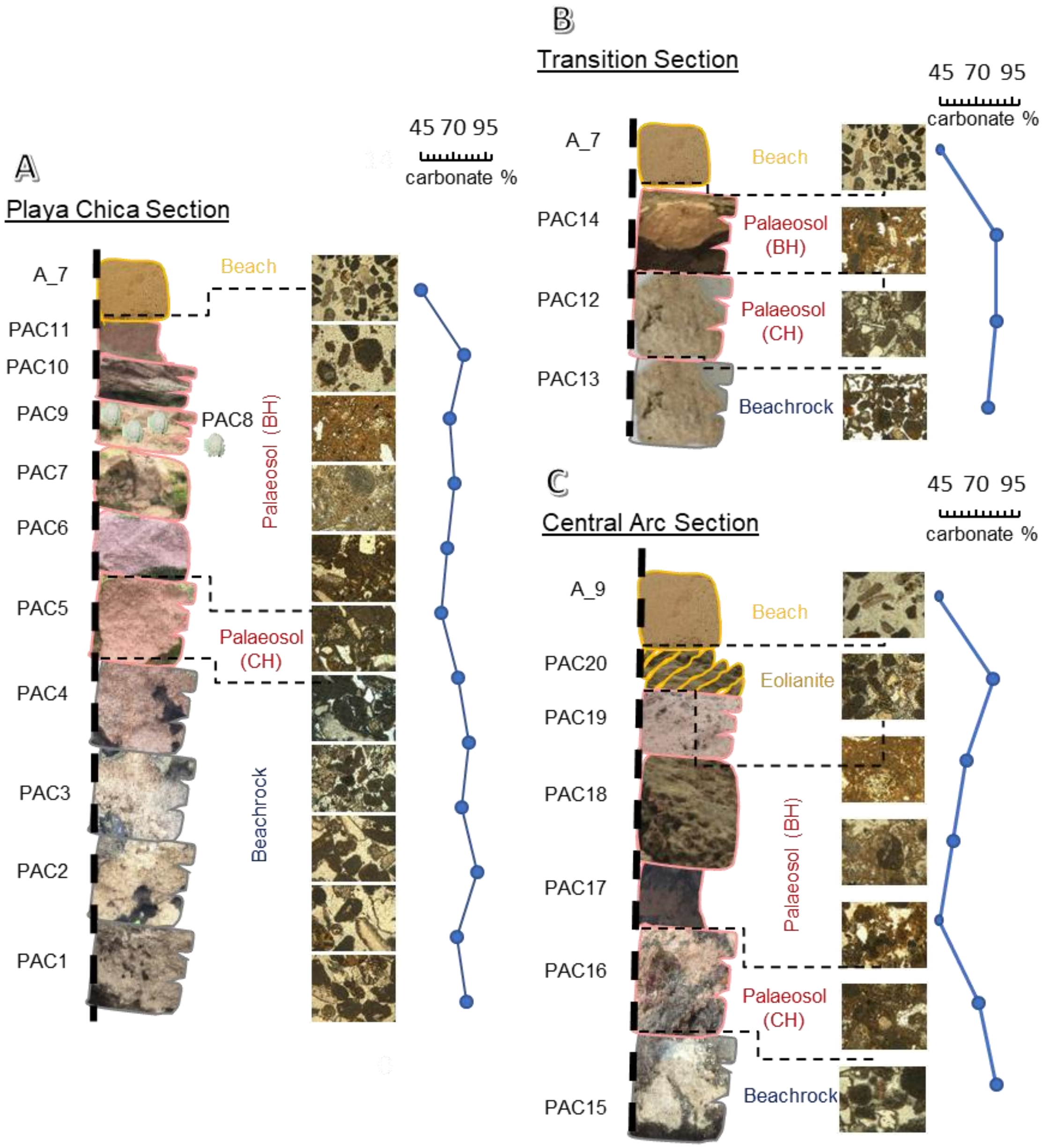


Figure 15. Stratigraphic columns for sampling sections in Las Canteras Beach A) Playa Chica B) Transition and C) Central Arc. At the right the petrographic microscopy image of each sample. Calcimetry curve at right in percentage.

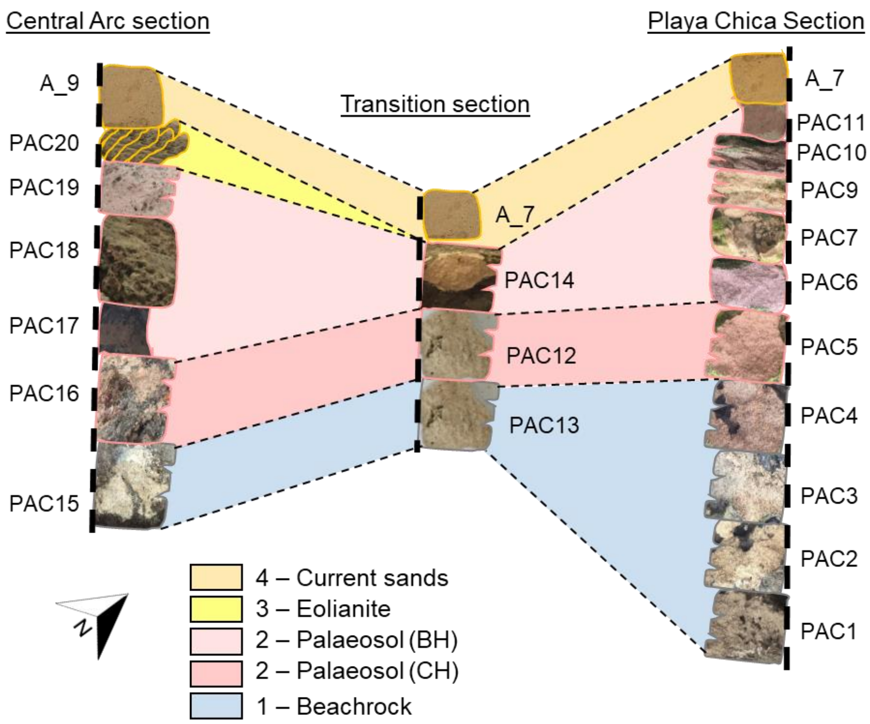


Figure 16. Stratigraphic correlation between three studied sections in Las Canteras beach, from Southwest to Northeast: CA, TS and PC sections.

3.9. Palaeoclimatic reconstruction

The palaeoclimatic reconstruction of Las Canteras starts with the beachrock information. The distinctive carbonate cementation formed this beachrock in intertidal environments of subtropical regions (28° latitude). Warmer marine waters mixed with fresh waters and physicochemical variations in these sandy materials (temperature, gases pressure, pH, composition, concentration) are the significant factors of beachrock formation, controlling its thickness by tidal level fluctuations (Vousdoukas et al., 2007; Meco et al., 2018) attributing Las Canteras beachrock to the warmer climate period of Jandian (110 ka). This age is close to the cited in previous works (Balcells et al., 1990; Pérez-Torrado and Mangas, 1992; Alonso, 1993), where it is assumed that the Las Canteras beachrock belongs to "La Barra", dated the latter to 126 ka, corresponding with the Last Interglacial -MIS 5e- (Terraza Baja de Las Palmas). However, the mineralogical, petrographic and stratigraphic characteristics besides the characteristic fauna and flora lack from Las Canteras beachrock do not correspond to the warm fossils of the MIS 5e deposits studied in many marine terraces of Eastern Canary Islands (Fuerteventura, Lanzarote and Gran Canaria, Balcells et al., 1990; Meco et al., 2002; Zazo et al., 2002). Superficial beachrock on coastlines have been rarely dated because of the absence of fossils, the small carbonated crystals and the chronostratigraphic differences in the beachrock layers (Friedman, 2004). The hypothesis is that Las Canteras beachrock would correspond to a younger period of Lower Holocene (complete absence of MIS 5e fossils, simple LMC cementation, sandy grain nature is similar to the composition of Las Canteras current sands, and the Middle Holocene date of upper palaeosol level). Also, this is not uncommon as there are numerous beachrocks reported in the bibliography with Holocene ages in the Canary Islands and many parts of the world (Vousdoukas et al., 2007).

The age of the palaeosol was dated about 6.6 ka, based on the living time of the analysed terrestrial snails. This age corresponds to a climatic optimum into a high stand sea level. Therefore, it is not simple to explain the presence of land conditions in the location, but several possible scenarios can be explored. One of them is related to the Holocene volcanic and tectonic activity of the island (isostatic movements). In the same way, the progradation of the alluvial middle Holocene fan of La Ballena gully and the coastal torrential and volcanic activity (Hansen and Criado-Hernández, 1996) could explain the required coastal progradation in Las Canteras area. Another aspect to take in consideration could be the progressive and continuous isostatic uplift of the coast area, due to the fluvial erosion of the island (Menéndez et al., 2008). Other possible explanation could be that this palaeosol corresponds to the first stages of the climatic optimum, with still low sea level, or low stand fluctuation levels of this period. The age of the eolianites was estimated by Alonso (1993) during the Flandrian period (10 Ka) after these coastal dunes immersion but according to our results should be of upper Holocene (less 6,6 ka). Other Eolianites have been reported in Maspalomas coastal dune field (Hernández-Calvento, 2002) interpreted as well as ancient dunes.

A common limitation in the study of coastal sedimentary deposits is the preservation of stratigraphic units (Meco et al., 2018). In consequence, it is vital to reconstructing the history of these environments before erosion erases relevant traces. Regarding exact dating, unfortunately, no method has been developed to measure absolute ages in carbonate sands without fossils (Rowe and Bristow, 2015). Technologies such as the use of pXRF (Portable X-ray Fluorescence) have been used to stratigraphy and sediment weathering studies during quaternary, dating with stimulated luminescence of Palaeoenvironments (Suchodoletz et al., 2009; Athanassas and Wagner, 2016) and dating of terrestrial deposits with AAR method (Amino Acid Racemization) (García-Alonso et al., 1996; Zazo et al., 2003; Ortiz et al., 2006) in the Canary Islands but with poor results at the moment. In summary, a palaeoenvironmental reconstruction of Las Canteras beach was illustrated in Figures 17 and 18.

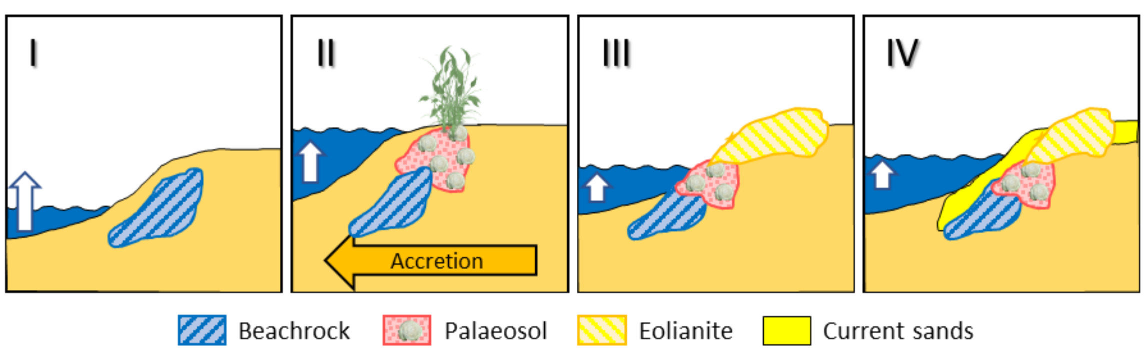


Figure 17. Las Canteras beach palaeoenvironments interpretation through recent geological history.

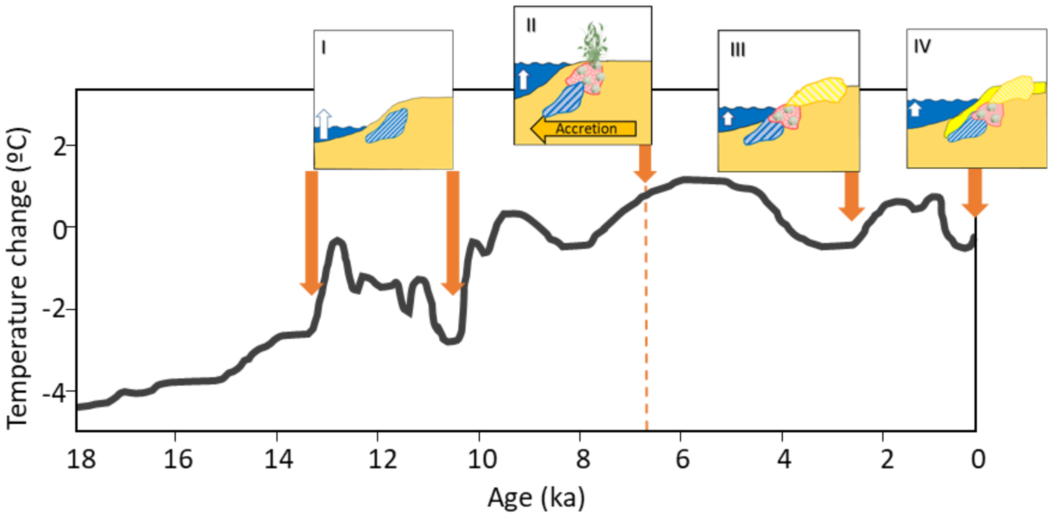


Figure 18. Las Canteras beach palaeoenvironments interpretation indicating the proposed position in geological timeline to each stage. Orange pointed line indicating around 6.6 ka (terrestrial snails dated from palaeosol). Temperature change curve modified from Brooke et al. (2010).

4. Conclusions

The present work is a multidisciplinary study of the Las Canteras beach outcrops that permit to gather essential information to understand the palaeoenvironmental changes of this coastal area. The main results obtained in this research are:

- ∴ Four facies have been identified. Their chronological order is 1) lower Holocene beachrock (>6,6 ka), 2) middle Holocene palaeosol (~6.6 ka), 3), upper Holocene eolianites (<6.6 ka), 4) current sands.
- ∴ The textual analysis of the palaeosols samples (BH) defined this material as poorly sorted gravely coarse sand to medium sand, with 10% of silt and clay fractions.
- ∴ The carbonate content of the facies varies from 82-81% from beachrock and eolianites respectively to 69% in the palaeosol.
- ∴ Petrographic studies show that the carbonate fraction is composed of bioclasts (mainly algae meshes and mollusc, 63% and 26%, respectively), The lithoclasts are mainly constituted by sedimentary intraclasts and felsic rocks (38% and 27%, respectively). The carbonate cement around the sand grains are crystals of sparite, microsparite and micrite. The beachrock and eolianites petrographic configuration are similar (% abundance of bioclasts, lithoclasts and cement), nor the palaeosols high percentage of edaphic features (14-30%).
- ∴ LMC (lower magnesian calcite) crystals with Sr, Na and Fe traces appear in beachrock, palaeosol and eolianite strata, as an isopaque carbonate cement formed by phreatic marine waters. Also, the palaeosols have micritic cement (cutan) around the grains associated with meteoric waters rich in fine particles (clays and silts) and sometimes a later isopaque LMC

cementation (phreatic waters) or micritic muds. Also, the eolianite level contains a generation second of calcium carbonate of dispersing aragonite crystals, very rich in Sr and without Mg, related with vadose waters.

∴ The presence of quartz in the soil samples (32%) evidence the Saharan dust accumulation during this middle Holocene period in a similar range that nowadays (38%).

∴ Las Canteras beachrock was formed in intertidal zone due to variations of physicochemical of marine/fresh waters (phreatic conditions) during the Present Interglacial stage (lower Holocene). The palaeosol developed on the beachrock correspond to an emersion or low-stand sea level period of Las Canteras beach about 6.6ka, after that the developed of coastal dunes and consequently, cementation might be conditioned by the upper Holocene transgression period (vadose environments), that ended in the present beach.

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The development of this work would never be possible without the collaboration of the technical staff and researchers of the Instituto de Oceanografía y Cambio Global, IOCAG and the Grupo de Investigación Geología Aplicada y Regional (GEOGAR). Moreover, the work and efficiency of the Geology Faculty of the Universidad de Salamanca, the Geology Laboratory of La Laguna University, the Scientific and Technological Centre of the University of Barcelona, the Beta Analytic Radiocarbon Dating Laboratory. The electron microscopy and microprobe analyses, X-ray diffraction and radiocarbon dating were financed by the research projects of the Ministerio de Educación y Ciencia CSO2016-79673-R and CSO2010-18150, respectively, with Luis F. Hernández Calvento PhD. as main researcher.

My academic supervisors, Pepe Mangas and Inma Menendez, who give me the inspiration and confidence to finish this work. All those members of the Geology team who have been teachers, counsellors and colleagues. I will always be grateful. "... people will forget what you said, but people will never forget how you made them feel." Maya Angelou.

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Personal assessment

Valoración final TFM

i. Descripción detallada de las actividades desarrolladas durante la realización del TFM con su temporalización

En primer lugar, establecimos la hipótesis científica de partida y la estructura general del trabajo a realizar en agosto de 2017. Por ello, llevé a cabo dos campañas de campo de reconocimiento del área de estudio (afloramientos rocosos de la parte central de la Playa de Las Canteras) desde el punto de vista geológico y en bajamar, para poder observar mejor las formaciones geológicas que aparecen en el intermareal y planificación y preparación de la tercera visita, coincidiendo con las mareas del Pino. Esta tercera campaña de campo fue la más completa pues se recogieron las muestras, se tomó su geolocalización, se levantaron esquemas geológicos de cada zona, se tomaron datos característicos de las rocas a visu y fotografías de los puntos de muestreo (septiembre 2017). Posteriormente, preparé las muestras rocosas y realicé estudios de calcimetría y granulometría en el Laboratorio de Geología (GEOGAR-IOCAG) de la Facultad de Ciencias del Mar (FCM) en octubre 2017. Simultáneamente, las muestras de rocas sedimentarias fueron cortadas en el Taller de Geología, para enviar los tacos individuales a los Servicios Generales de la Facultad de Geología de la Universidad de Salamanca, donde se prepararon láminas delgadas necesarias para estudio petrográfico. Dicho estudio microscópico lo ejecuté posteriormente, si bien necesité de entrenamiento en el método de identificación geológica de los granos de arena, cementos que unen las partículas detríticas y texturas petrográficas características por parte de mis tutores (noviembre 2017). Por otro lado, las muestras de suelo también fueron procesadas para extraer la fracción fina y enviar al Laboratorio de Geología de la Universidad de La Laguna, donde se realizó difracción de rayos X. Igualmente, fueron seccionadas las muestras de rocas sedimentarias originales nuevamente, para extraer submuestras y ser utilizadas con microscopía electrónica de barrido (SEM) y análisis por sonda de electrones (EMPA) en el Centro Científico y Tecnológico de la Universidad de Barcelona (mayo 2018). En el estudio también se incluyeron los resultados de datación de carbono 14 de caracoles terrestres de la zona de interés, estudiados en septiembre de 2013 (Beta Analytic Radiocarbon Dating Laboratory, Florida, USA), información que fue aportada por el Dr. José Mangas (Tutor) y se estudiaron petrográficamente láminas delgadas de arenas actuales, colectadas en 2013 y facilitadas por el Dr. Ignacio Alonso (Departamento de Geología, FCM). Durante todo el tiempo transcurrido realicé diversas búsquedas bibliográficas cubriendo los temas abordados en el TFM, interpreté los resultados obtenidos, tanto en el campo como en el laboratorio con los tutores. Finalmente, redacté el documento con la confección de tablas y figuras, recibiendo correcciones y retroalimentación de los tutores continuamente a lo largo de varias semanas.

ii. Formación recibida (cursos, programas informáticos, etc.)

El trabajo requirió que recibiera formación académica, teórica y práctica de forma amplia en el campo de la Geología Marina en general y de la Estratigrafía, Mineralogía, Petrología y Geoquímica en particular. En primer lugar, recibí dos cursos del Máster Interuniversitario en Oceanografía correspondientes a esta área de conocimiento: Oceanografía geológica (3 créditos) y Procesos geológicos en márgenes y cuencas oceánicas (5 créditos). Participé en dos campañas oceanográficas, primero la correspondiente al Máster (2 días), con componente geológico y su correspondiente tratamiento en laboratorio y procesamiento de datos geológicos (GradiStat, MatLab® y ArcMap (ArcGIS)) y la segunda, como visitante en la Campaña Zona Económica Exclusiva 2018 (15 días) alrededor de la isla de Gran Canaria. También participé en 2 excursiones de campo a lugares de interés geológico (con el Dr. José Mangas, tutor y profesor del Departamento de Geología de FCM) tanto por mar al sur de Gran Canaria como por tierra al noreste de La ciudad de Las Palmas de Gran Canaria. En el campo obtuve entrenamiento fundamental para un estudio geológico marino de esta naturaleza y recibí inducción del tema y el conocimiento previo por los tutores y colaboradores del Departamento de Geología. En laboratorio recibí entrenamiento en petrología-mineralogía (microscopio petrográfico) y sedimentología con trabajos de granulometría (análisis por tamizado mecánico) y calcimetría (método de Bernard). Igualmente, me fueron impartidos los conocimientos esenciales de estudio e interpretación de resultados de difracción de rayos X, microscopía electrónica SEM y análisis por sonda de electrones EMPA, estratigrafía (levantamiento de columnas y correlación) y datación de carbono 14 por parte de mis tutores.

iii. Nivel de integración e implicación dentro del departamento y relaciones con el personal.

He tenido la oportunidad de conocer de forma personal a los integrantes del departamento y la mayoría de ellos en uno u otro momento me han colaborado académicamente. Mis relaciones con el personal han sido de respeto y colaboración. Me he integrado fácilmente e implicado en tantas actividades de aprendizaje como he podido. Por otro lado, he conocido la constitución de un grupo de investigación (en este caso GEOGAR), sus componentes, sus instalaciones y su instrumentación científica.

iv. Aspectos positivos y negativos más significativos relacionados con el desarrollo del TFM

Destacaría los aspectos positivos, ya que esta experiencia ha sido totalmente gratificante para mí en varios aspectos. Primero, la elaboración del TFM me ha brindado la oportunidad de conocer más de cerca el trabajo de investigación, un espacio donde trabajar de forma autónoma y organizada, pero al mismo tiempo recibir la guía y conocimientos de personas excepcionales, tanto en la academia como en lo personal. En segundo lugar, aprender el manejo de técnicas analíticas nuevas que no se enseñan ni se utilizan durante la realización del máster, así como obtener datos científicos nuevos y originales, y su interpretación relacionándolas con otros trabajos anteriores sobre esta temática, para sacar conclusiones novedosas y publicables en un futura. En pocas palabras, es conocer el trabajo de un científico sobre un tema en particular como ha sido mi TFM. Como un componente nuevo en mi experiencia de vida, fue positivo el esfuerzo extra que conlleva el sintetizar todos los resultados obtenidos en esta investigación, y desarrollada en varios meses de trabajo de campo, laboratorio y gabinete, en 30 páginas y en un idioma extranjero.

Como aspecto negativo, a pesar de que no tuve prácticamente ninguna contrariedad en el proceso, este fue un trabajo que tomó más tiempo de lo esperado, en parte por condiciones personales y, en parte, por mejorar las interpretaciones y conclusiones de esta investigación. Indico que, lastimosamente, se espera que se ejecuten estos TFM por parte de los alumnos y profesores en muy poco tiempo y, por ello, tuve que extender mi matricula más de lo esperado y hacer el pago de las correspondientes tasas.

v. Valoración personal del aprendizaje conseguido a lo largo del TFM.

En grandes rasgos valoro de forma positiva el aprendizaje obtenido en investigaciones en Geología Marina y en el desarrollo de competencias y habilidades;

- Conocimientos generales del área de conocimiento (bases teóricas y prácticas).
- Técnicas y métodos de laboratorio y de gabinete en esta línea de investigación.
- Herramientas y software especializado para exposición e interpretaciones de resultados científicos.
- Trabajo independiente y autónomo, y al mismo tiempo trabajo en equipo con guía y acompañamiento de los tutores y otros colaboradores científicos.
- Búsqueda y análisis de fuentes bibliográficas sobre el objeto de estudio, necesarios para una buena interpretación de resultados y obtener conclusiones originales y novedosas.
- Estructuración y redacción de un documento de investigación que es este TFM y que puede ser publicado en revistas de índice de impacto y presentado en congresos nacionales e internacionales de la especialidad.