Dust accumulation and loess formation under the oceanic semiarid climate of Tenerife, Canary Islands

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Abstract

Sediments formed by mixing dust of Saharan origin with local weathered pyroclastic rocks were investigated using granulometric analyses for environmental reconstruction. For this purpose traditional sedimentological parameters were applied together with indices such as FG (fineness grade) and K_d (degree of weathering). It could be established that surface deposits are loess or loess-like sediments reworked by colluvial processes. It was also concluded that soils formed on alkalic basalt lava are semipedolites i.e. sediments that have undergone pedogenesis of limited extent, whereas on the phonolite genuine paleosols formed. The stratification of sediments show half-year variation instead of annual one due to the alternating dry and wet seasons (parent material being transported by north-eastern and Sahara trade winds). With the exception of the soil developed on the phonolite lava all the deposits studied are younger than 1 Ma.

Keywords: Saharan dust, pyroclastic rocks, grain size analysis, sedimentological indices, trade winds

Introduction

In the section at Bandas del Sur, on the south-eastern part of Tenerife (*photos 1* and *2*), Canary Islands (*Figure 1*) loess-like deposits and sediments affected by pedogenesis were investigated using grain size parameters. Based on the parameter values this method is aimed to characterize these deposits and to identify the environmental conditions that prevailed during their formation.

The deposits have developed on volcanic pyroclastic rocks as a result of the weathering of the latter and a concurrent admixture of the falling dust of African origin. Dust accumulation and formation of loess-like deposits is going on even nowadays (*Photo 3*). Nevertheless this so-called African dust is not uniform either; partly it was blown out from sand deserts of Sahara and from the western areas of Atlas Mountains, partly derives from "perisaharan loess" of Africa. On the Western Canary Islands airborne material of sand

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Photo 1. The island of Tenerife, with the highest peak of the stratovolcano (Pico del Teide, 3718 m). (http://upload.wikimedia.org/wikipedia/commons/8/8c/Tenerife_LANDSAT-Canary_Islands.png)

Photo 2. Volcanic rocks and sediments building up Tenerife (Photo by Schweitzer, F.)

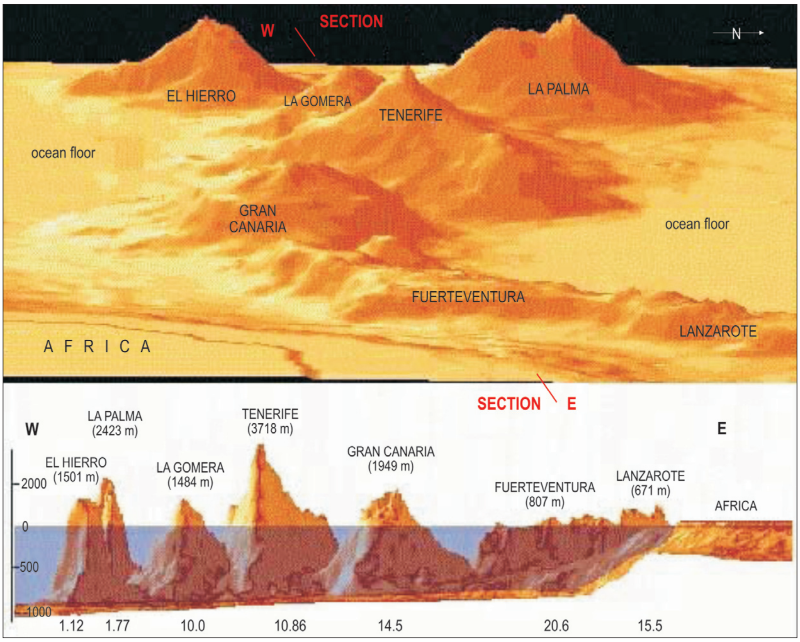

Fig. 1. The Canary Islands hot spot. Carracedo, J.C. *et al*. 2002.
http://www.mantleplumes.org/Canary.html

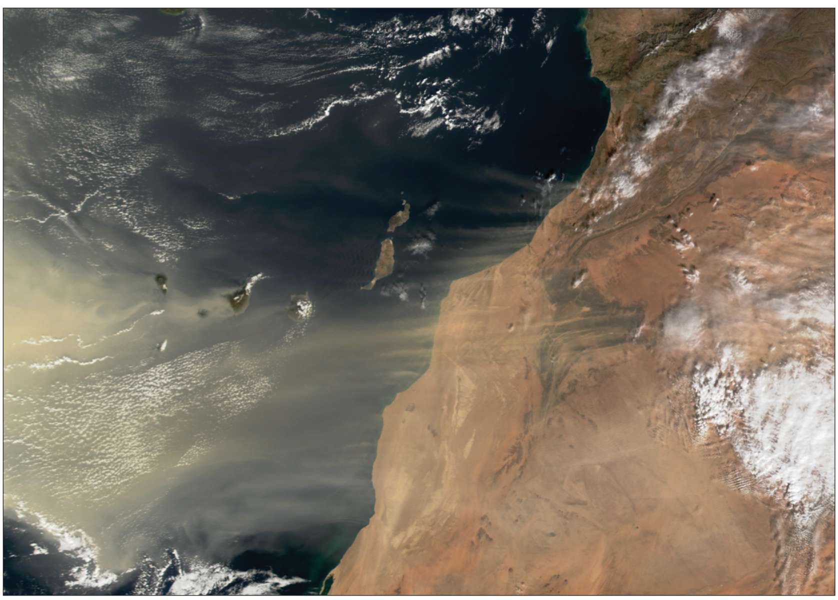

Photo 3. Satellite image showing African dust blown towards the Canary Islands (http://earthobservatory.nasa.gov/IOTD/view.php?id=1169)

dunes and loessial sediments redeposited from the Eastern Canary Islands (Lanzarote, Fuerteventura) to Tenerife or Gran Canaria, sometimes reworked several times was also added.

The climate on Tenerife is oceanic semiarid, thus periodicity i.e. alternating dry and humid half-years are reflected by the stratification of geological sequences. Half-year periods stem from the differences in warming of the ocean and land and expressed by dry trade winds of north-eastern direction in summer and humid trade winds blowing from the Sahara in winter. Half-year periods of deposition are manifest on Canary Islands similar to China, where they are the consequence of summer and winter monsoons due to differences of warming.

Von Suchodoletz, H. *et al.* (2009) described and analysed reddish clays and loess-like yellowish sediments on the Isle of Lanzarote. He identified paleosols, loessial colluvial layers and sediments/colluvia with traces of pedogenesis.

Fluvio-lacustric loessial sediment was described on Gran Canaria by Menéndez, I. *et al.* (2009). Fluvial action was responsible here for the redeposition of sediments. In his opinion calcareous sheets were formed in the humid seasons, whereas desiccation and formation of "dry" soils (with carbonate precipitation) characterized the arid phases.

The method applied

A unified method of comparative grain size analysis has been elaborated for the analysis of Quaternary sediments and there were laid foundations of an exact characterization and comparability of these deposits by the classification of loess regions. This method was tested in Hungary and applied exclusively by our research team for the investigation into Quaternary deposits (loess and loess-like sequences).

Through the evaluation of the results an opportunity has opened to acquire much more information in a rapid way about the history of evolution of the studied area:

– palaeoenvironmental conditions during the deposition of the loess material;

– changes taking place in the geographical environment;

– climate fluctuations during the past 2 million years, including the ice ages;

– warming maxima and cooling minima of temperature during the Quaternary;

– differences between the profiles of various loess regions based on the above research methods.

Values of each parameter (index) as environmental indicator are gained by the application of analogous methods, so they are to be considered a highly correct and reliable source for a comparative analysis of profiles within a given region and between different regions, and for drawing conclusions on their palaeogeography.

Quaternary sediments are characterized using the above method and an attempt is made to draw conclusions about changes of the dynamics of rate of sedimentation and to establish local correlation between horizons with similar characteristics. Traditional sedimentological parameters (So, K, S_k, M_d) were applied together with two indices introduced in Hungary recently: FG (fineness grade) and K_d (degree of weathering), and with $CaCO_3$ content and percentage share of clay, silt, loess and sand fractions.

The role of parameters as environmental indicators could be established. Their values point to changes in granulometry and in turn can also be instrumental in demarcation of basic lithological units and identification of phases of sedimentation and gaps in the process. Variations can be recognized inside seemingly homogeneous horizons as differences might be detected as well between layers of apparently identical genesis in order to make comparisons, correlations, to draw conclusions about palaeogeography of the given region.

Table 1 contains two new indices. Fineness grade (FG) serves for an exact separation of horizons from each other, reconstruction of palaeotopography. Increasing or decreasing values of FG are indicative about the source area of the parent material of loess, about wind direction and velocity during transport. K_d index can be used to determine the degree of weathering, to point out extreme warming and cooling events. Traditional parameters provide additional information such as sorting (So) on the origin of the sediment material, kurtosis (K) is instructive for the sharp separation between loess and sand, asymmetry (S_k) gives orientation to separate between regions of accumulation and denudation.

Of the newly adopted indices fineness grade shows maximum values in soils and minima in sands. Knowing these values soil horizons become recognizable while those finer than the average represent young loesses and considerably finer ones indicate old loesses. Minimum values indicate sands, while somewhat higher ones represent silt interbeddings. FG values are used for an exact denomination of sediments, delimitation of the boundary of layers, their trend to increase or decrease refer to grain size to refine or coarsen so it can be used for distinguishing between old and young loesses, revealing alterations within paleosols, correlation between loess and paleosol horizons.

K_d index is represented by minimum values in soils and maxima in loesses (and by figures slightly above minimum in sands). Apart from being useful for the identification and demarcation of sediments, its maxima is suitable for pointing out extreme cooling within loess sequences (their exact depth can be identified within a given loess layer) and minimum values refer to warming maxima inside

Table 1. *Values of FG, K_d, M_d, So, K and S_k in the section at Bandas del Sur*

Denomination	FG (fineness grade)	K_d (degree of weathering)	M_d mm (median)	So (sorting)	K (kurtosis)	S_k (asymmetry)
Paleosol (formed on phonolite lava)	73.12–85.84	1.14–1.17	0.016–0.023	3.16–3.72	0.15–0.23	0.24–0.27
Sediment (formed on alkali basalt) affected by pedogenesis	64.28–70.23	1.74–1.83	0.041–0.140	6.73–6.84	0.46–0.51	0.81–1.37
Loess sediment (formed on a sequence affected by pedogenesis)	56.21–64.89	1.12–4.49	0.023–0.057	2.26–3.15	0.23–0.28	0.12–0.18
Loess-like deposit I (on weathered pumice stone as parent rock)	58.09–60.02	2.45–4.47	0.027–0.187	5.66–5.82	0.36–0.38	0.42–0.47
Loess-like deposit II (on weathered lapilli as parent rock, with an admixture of Saharan dust)	60.02–62.40	2.72–3.15	0.027–0.028	2.59–2.78	0.39–0.42	0.17–0.22 0.41–0.49
Loess-like deposit III (on weathered breccia as parent rock, with an admixture of Saharan dust)	57.13–63.09	2.49–3.33	0.027–0.085	1.37–1.48	0.36–0.43	0.32–0.57
Sediment (formed on upper alkali basalt) affected by pedogenesis	63.32–71.14	1.68–1.73	0.04–0.06	6.01–6.11	0.49–0.55	0.34–0.38

soils (exact depth within the soil horizon).

Sorting (So) has its peaks of maximum in soils, minima in sands and average values are typical of loesses. According to Trask, P.D. (1932) So index values less than around 2.5 represent poorly sorted sediments, normal sorting is around 3 and well sorted deposits are above 4.5. In the sequences the highest figures represent loess sand, stratified sand, clays and incipient soils. Minimum values appear in unstratified sand, fine grained sand loess and in young loess. By this classification most of the deposits are poorly or normally sorted sediment.

S_k indicates *asymmetry* of sediments. They allow to distinguish between sands and loess on the one hand and clays and silt on the other, and to separate areas of accumulation from those of denudation. Using this parameter more phases of sedimentation can be identified than using other methods.

Kurtosis (K) values are low in soils, with minimum peaks in sands and medium figures in loesses. Its extremes indicate mixing loess with soil, referring to boundaries of loess and soils sharply.

Geographical setting

Canary Islands are situated between 27°37′ and 29°23′ of northern latitude and 13°20′ és 18°16′ of western longitude. The largest isles are Tenerife, Fuerteventura, Gran Canaria, Lanzarote, La Palma, Gomera and Hierro (*Figure 1*) and there are numerous islets. The archipelago is located along the margin of the African litosphere plate. Tenerife is in the central part of Canary Islands (*photos 1* and *2*), 300 km off the coasts of mainland Africa. It is ca 97 km long, and 16 to 48 km wide. Pico del Teide is the highest mountain on Tenerife ("snow covered mountain") and on the islands, raising to 3,718 m.

Origin of the islands

The latest results of investigations confirm basalt rocks becoming younger from the west to the east. Figures of absolute dating seem to fit in the theory by Hess, P.C. (1992) based on Schmincke, H.-U. (1976) that the islands emerged from the plate formed by sea-floor spreading from the Mid-Atlantic Ridge.

Along the boundary of continental/oceanic plates sediments have accumulated in a thickness of ca 10 km, and "oceanized" subsequently. There is a considerable difference between the age of oceanic crust (ca 180 Ma, Jurassic) and that of the majority of the volcanites (ca 20 Ma, Miocene). Transversal faults run perpendicular to the ridge and might continue on the continental plate. Canary volcanism is presumably the continuation of the fault running from South Atlas. The emergence of the islands is due to the Canary hotspot, associated with convection upwelling of melted rock from great depth of the mantle (intraplate volcanism).

According to Viñuela, J.M. (http://www.mantleplumes.org/Canary.html) Canary Islands formed at the margin of Jurassic oceanic plate and of African continental plate. Material of the mountain chain on the rise originated from the upper mantle and *settled in a vertical sequence*.

The first alkali magmatic activity of this *hotspot* started with the emergence of the isle of Fuerteventura in Upper Cretaceous (~70 Ma), and continued with submarine volcanism through Eocene and Oligocene (~39 Ma) into surface volcanism in Miocene (~20.6 Ma).

The development of submarine and surface volcanism associated with hotspots include the following phases (Walker, G.P.L. 1990).

Submarine volcanism

Volcanism on the Canary Islands has included submarine stages and emergent stages. The latter are shield building stage, declining stage, erosional stage, and rejuvenated stage. Four isles: Fuerteventura, Lanzarote, Gran Canaria and Tenerife are currently in the stage of rejuvenation, La Gomera is in erosional stage, La Palma and El Hierro are in declining stage. It is widely accepted that the material of oceanic "hotspot" volcanism is molten rock upwelling from the mantle. The age of volcanism on the Canary Islands (Carracedo, J.C. *et al.* 2002): Fuerteventura 20.6 Ma (rejuvenated stage), Lanzarote 15.5 Ma (rejuvenated stage), Tenerife 11.6 Ma (rejuvenated stage), Gran Canaria 14.5 Ma (rejuvenated stage), La Gomera 12.0 Ma (erosional stage), El Hierro 1.12 Ma (shield building stage) és La Palma 1.77 (shield building stage).

Surface volcanism

According to Ancochea, E. *et al.* (1990) surface volcanism on the Canary Islands can be classed into four main groups: 1. *"old basalt sequence" (11.6–3.3 Ma),* presumably separated volcanic ensembles: Teno in the north-west, Anaga in the north-east, and Roque del Conde in the south, have K/Ar age of Late Miocene and Early Pliocene; 2. interruption of volcanic activity until *1.9 Ma* with the dissection of the initial structure of the central Cañadas Volcano, emergence of Cañada sequence I and II as a result of trachyte, phonolite and basalt extrusions between *1.89* and *0.13 Ma*; 3. minor eruptions of basalt *from 0.9 Ma to historic times*, minor basaltic eruptions on the ridge between Cañadas és Anaga stretching in south-west–north-east direction; 4. emergence of the caldera and disappearance of part of Cañadas Volcano between *0.17* and *0.13 Ma;* subsequent building up of a volcano with the centre at Teide–Pico Viejo (basalt, trachyte, phonolite).

According to the actually accepted geochronological data *in the vicinity of Cañadas,* i.e. within the study area, *four pyroclastic phases* could be distinguished *during the past 2 million years:* 1. *San Juan de la Rambla phase (~2 Ma*) towards North Tenerife (Ancochea, E. *et al.* 1990); 2. *Adeje phase* (*1.5–1.8 Ma*); 3. *Las Amérocas phase* (*1.1–0.9 Ma*) with all the pyroclastic clays between La Bentrana and Arico ignimbrites; 4. *Bandas del Sur phase (0.7–0.15 Ma)* in the south-east of Tenerife.

Relief

Landforms on the Canary Islands are characterized by heterogeneity within a small area. Surface features are the result of volcanism, wind and fluvial erosion and marine abrasion. The main rocks to build up the islands are the *basalts, phonolites* and *rhyolites.* Volcanism is still active on Tenerife, Lanzarote and La Palma. The most typical landforms of volcanic origin are the cones with calderas of different size, the lava fields and basaltic plateaus. A basic type of *valleys* is represented by deeply cut *barranco*s running partly on a radial pattern. Also there are wide troughs (*walle*s) and trench-like valleys dissected by a dense network of gullies.

Sea coasts are mostly high. In the west of the island 100 m high coasts are not exceptions. In contrast, low coasts are infrequent, they rather occur in the south.

The most ancient regions on Tenerife are the mountains of *Teno, Anaga* and (partly) those of *Adeje–Lorenzo*. There are walls built of basalt with a length of several hundred metres. Due to heavy rainfalls and a long erosional period lasting since the Tertiary barrancos are the most characteristic landforms. The considerable relief intensity between Teide peak and the sea coast strengthens the *impact of erosion*.

Mountains of Anaga

In the lack of plateaus, volcanic cones and walls of craters several elongated ridges stretching northwards and southwards were formed by barrancos cutting in deeply. Part of them resembles alpine relief.

Teide and Las Cañadas

Pico de Teide elevates to 3717 m, over timber line and is visible from all over the Canary Islands. In winter time the summit remains snow covered for weeks. This is a regular cone of a stratovolcano descending northward abruptly. On its south-western side Pico Viejo rises to 3,102 m. Pico de Teide is half-circled at 20 km length by a curious piedmont called Las Cañadas del Teide. The landscape is dominated by extensive lava fields.

At *Bandas del Sur* erosional gaps could be recognized which separate three cycles of landform evolution (Bryan, S.E. *et al.* 1998; Brown, R.J. *et al.* 2003). Altogether they make up 15 pyroclastic units (paleosols, other sediments, erosional gaps and "fallout" deposits originated from volcanic ash clouds).

The ignimbrite of Arico is a product of Plinian eruptions of limited scale composed of falling dust and ash flows. The former deposited within a small area. The material of deposited pyroclastic flows can easily be separated. In this area no lava flows occur, only pyroclastic sediments can be found. The latter are of phonolite or trachyphonolite (Rodehorst, U. *et al.* 1998) and originate from the volcano Las Cañadas, active for 3.3 million years (Bryan, S.E. *et al.* 1998). The ignimbrite of Arico is labelled as "welded" one by Fritsch, K.

and Reiss, W. (1868). It was them who recognized that this type of ignimbrites unites the features of tuffs and lava flows. The ignimbrite was also investigated by Schmincke, H.-U. and Swanson, D.A. (1967), Ridley, W.I. (1971) and Alonso, J.J. *et al.* (1988). This viewpoint was opposed by Brown, J.R. *et al.* (2003).

The studied section

In the exposure (*Photo 4*, *Figure 2*) soils formed on phonolites and alkalic basalt, loess interbeddings, and loess-like deposits formed by the mixture of weathered pyroclastic matter with an admixture of dust from Sahara were studied in the south-eastern part of Tenerife, in the surroundings of Arico. The oldest deposit is the lowermost phonolite with an age of 3.3–2 Ma (Martí, J. *et al.* 1994), followed upward by Arico ignimbrite: by K/Ar dating it is 0.65±0.03 Ma (Ancochea, E. *et al.* 1999) and by $^{40}Ar/^{39}Ar$: 0.61±0.09 (Bryan, S.E. *et al.* 1998). The oldest ignimbrite in the environs is La Brentana with $^{40}Ar/^{39}Ar$: 1.44±0.12 Ma and isochron age: 1.50±0.17 Ma (Alonso, J.J. 1989). Most of the layers in the section goes back to Bandas del Sur phase (0.7–0.15 Ma) and are associated with pyroclastic processes of Las Cañadas volcano (Huertas, M.J. *et al.* 2002).

Photo 4. The studied section in the environs of Bandas del Sur (Photo by Kis, É.)

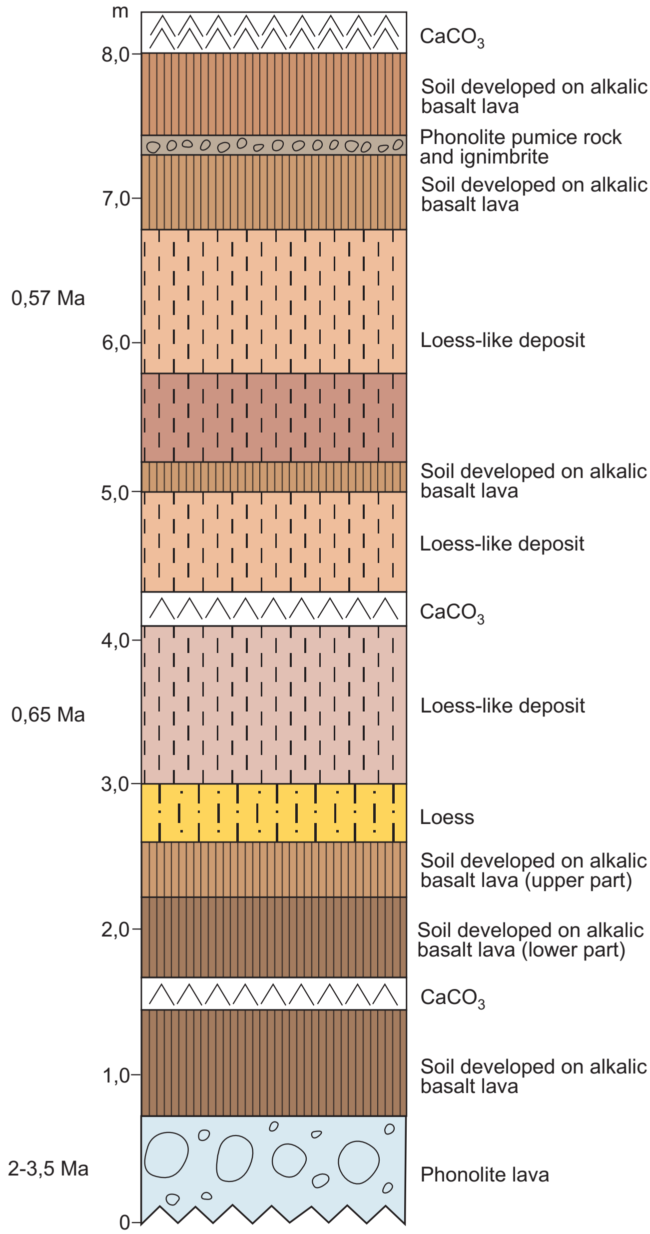

Fig. 2. The section at Bandas del Sur (Schweitzer, F. and Kis, É. 2010)

In the lowermost part of the section the phonolite lava of Las Cañadas volcano is found dated 3.5–2 Ma (Martí, J. *et al.* 1994, *Photo 4, Figure 2*). There is an erosional hiatus above it overlain by a paleosol (*Photo 5*), which is separated from the superimposing layer formed on alkalic basalt undergoing double soil formation by two tuff horizons (*photos 6* and *7*, one of them is a phonolite pumice lapilli). Upwards the profile there is a loess horizon *(Photo 8).*

Further up above the loess and a layer with the traces of pedogenesis the *first loess-like sediment sequence* contain two well-sorted ash layers and two weathered pumice horizons originated from fallout deposits (i.e. from ash clouds) with an admixture of Sahara dust (*Photo 9*). There is a strong erosional hiatus above this layer.

Parent material of the *second loess-like sediment sequence* with yellowish sandy colour is lapilli. Its characteristic feature is the occurrence of light green pumice rock pieces that could reach 40 cm

Photo 5. The lowermost soil developed on phonolite (Photo by Poór, I.)

Photo 6. Soil developed on alkalic basalt lava (Photo by Poór, I.)

Photo 7. Upper soil with the underlying tuff and breccia (Photo by Schweitzer, F.)

Photo 8. Loess-like deposit upon alkalic basalt affected by pedogenesis (Photo by Poór, I.)

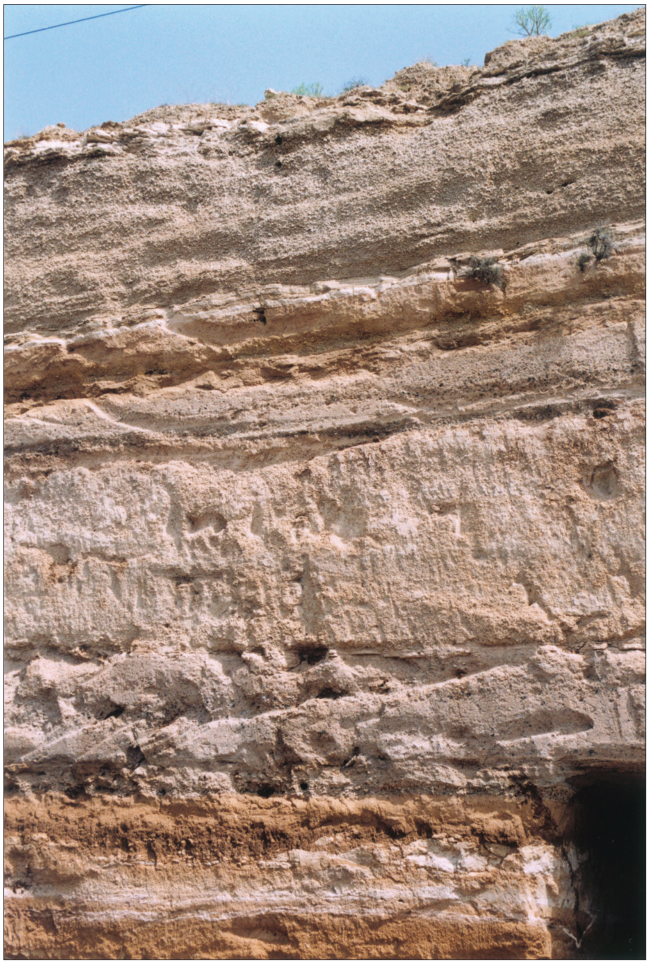

Photo 9. Loess-like deposit formed by weathering of pumice rock and its mixing with Saharan dust above the lower double soil (Photo by Schweitzer, F.)

in size. The smaller they are the more they are zeolitized. There are voids i.e. places of large pumices having fallen out. This layer of zeolitized lapilli has been eroded intensely by the overlying breccia. Here at the boundary of two phases of sedimentation a long gap can be recognized (*Photo 10*).

The *third loess-like sediment sequence* starts with breccia composed by black and green pumice stones above layers containing water (*Photo 9*: sediments over lapilli). Upon this ash layer there is an embryonic soil developed on a pyroclastic flow. Further up a layer containing pumice follows and an embryonic soil developed on a pyroclastic flow can be detected that is overlain by two ash layers, with a thickness of ca 30 cm each (*photos 8* and *9*).

Photo 10. Loess-like deposit formed by weathering of lapilli and its mixing with Saharan dust in the lower part of the photo (Photo by Kɪs, É.)

Climate

The climate on the Canary Islands is determined by their position within the strip separating North- and South Atlantic with temperate and tropical climate, respectively and where the Sahara and the longitudinal Atlantic climatic zone meet. Decisive role belongs to three types of air currents: 1. oceanic tropical, 2. oceanic polar and 3. Saharan continental. The climate is rhythmic with alternating half-year periods (summer and winter half-years). Oceanic tropical climate dominates the summer half-year, whereas Sahara and oceanic polar prevail in the winter one. North-west off the island is situated the area of high pressure all year long (Azores high/anticyclon). Its position is varied during the year but basically remains within the Azores–Madeira–Canary strip. In the summer this Azores high is predominant with north-estern trade winds. In the winter however its position and strength change and oceanic polar or humid tropical air masses intrude and the latter cause intense rainfalls. If Azores high moves eastbound the Canary Islands would fall under the influence of African continental climate.

Climate on the islands shows periodicity, under the influence of monsoon. *In the dry summer half-year* Azores high dominates up to 30° of northern latitude with north-eastern trade winds of a 90–95% frequency. Trade winds generally are dry and do not bring rains. However, they do to the islands, because they take up moisture over the ocean and near-surface air is lifted upwards by mountains which in turn condense water vapour in the rising and cooling air, and clouding over starts. During the humid winter half-year polar oceanic or humid tropical air masses might invade. At this time monsoon is less significant and winds blowing from the Sahara and transporting humid subtropical air masses turn northward along the western margin of the African continent (Ortiz, J.E. *et al.* 2006 based on Nicolson, S.E. 1996 and Moreno, A. *et al.* 2001).

Half-year climate periods similar to the Canary Islands can be identified in China as well (summer and winter Asian monsoon). Consequently, in both areas, e.g. on the Loess Plateau too stratification of sediments displays half-year variations.

Climate change, the amount of dust transported from Africa and the character of transport bear importance in our case because dust as parent material of loess and loess-like deposits at Tenerife have been blown out (and still are) by north-eastern trade winds, polar oceanic and continental Saharan winds.

Dust blown out from the Sahara can reach places several thousand kilometres away, e.g. coral reefs of the Caribbean *(Photo 11).* Saharan dust accumulates on the oceanic floor and it is detectable in deep cores. Part of the deposited dust might be redeposited repeatedly, because due to the sea level subsidence during the glacial epochs it appears on the surface of the shelf surrounding the isles. This is why we should have some idea about the past sea level oscillations.

Dust transport

In the summer Saharan dust is transported by north-eastern trade winds (*Photo 11*) and in winter this is done by the Saharan air masses. *In the summer* the northern portion of Saharan air masses flows north of the Canary Island *at a height of 1,500–5,500 m*. The material is moving horizontally in the lower part of the troposphere towards the islands (Koopmann, B. 1981; Bozzano, G. *et al.* 2002). Eventually dust is deposited upon dry or wet surface (Criado, C. and Dorta, P. 2003; Menéndez, I. *et al.* 2007). In winter dust is transported at *0–1500 m height* during Calima event. Calima winds are continental African trade winds (*harmattan*) deflecting Atlantic cyclons westward, to Canary Islands (Criado, C. and Dorta, P. 2003).

As dust is being deposited both on the ocean floor and land surface, particles sedimented over three years in deep sea were studied at European

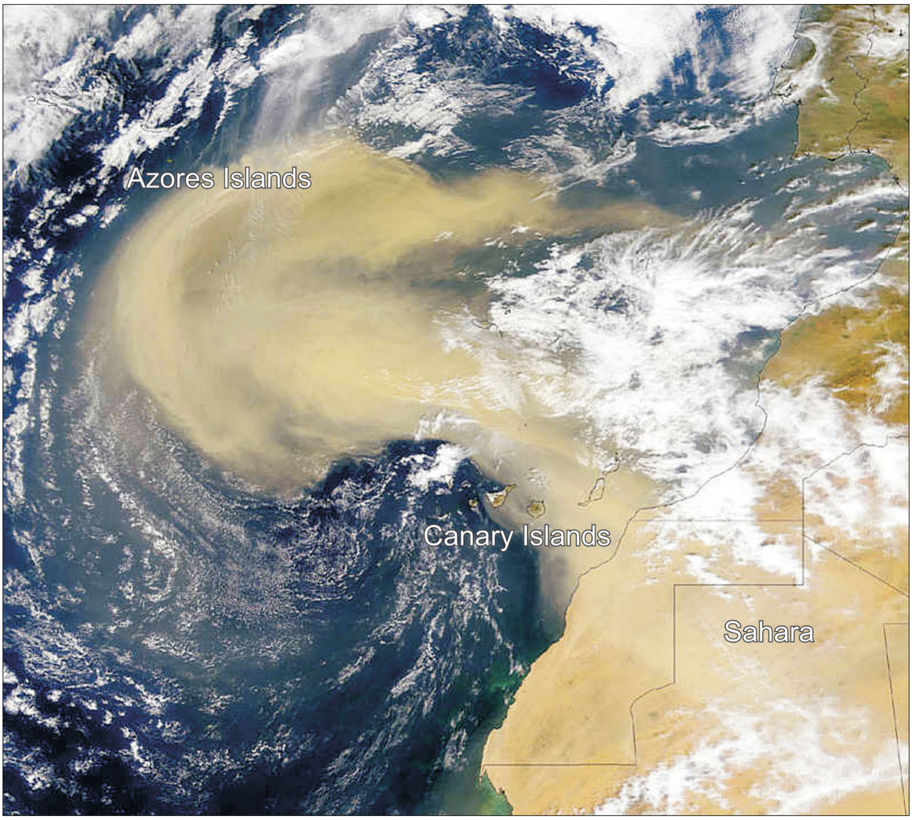

Photo 11. North-eastern trade winds transporting Saharan dust (http://www.phys.unsw.edu.au/~jbailey/planets/dust.html)

Station for Time-series in the Ocean, off Canary Island. By Neuer, S. *et al.* 1997 sedimentation has a highly seasonal character, its maximum falls to late winter, early spring. Most of the particles consist of basalt, various minerals and carbonates and a large amount of organic matter. Minerals make up *eolian deposits of African origin*. Comparing sediment at depths of 1 and 3 km it was found that the amount of sedimented particles increases gradually with depth. Annual deposition of organic carbon was 0.6 gm^{-2} at 1 km and raised up to 0.8 gm^{-2} at 3 km depth.

On the Canary Islands in the warm and *wet time intervals* marine terraces and fossil soils (with warm fauna) developed, whereas in dry intervals calcareous crusts and poligonal evaporite soils and eolian deposits (including dunes) (Petit, J.R. *et al.* 1999) formed. Of the sediment studied those having undergone pedogenesis formed in humid periods and loess and loess-like sediments formed during dry intervals.

Photo 12. Traces of sea level oscillations in the northern part of the Mountains of Anaga (Photo by Schweitzer, F.)

Sea level oscillations and the age of marine terraces

Dating of terraces is a serious challenge for researchers as the islands are situated in a highly tectonic area with a sizeable annual uplift. Zazo, C. *et al.* (2003) compared the highest sea levels during interglacials and interstadials with marine isotope stages (OIS 5a [5c, 5e, 7, 11 or older]). During OIS 5e (135–117 ka) three sea level maxima occurred. At the highest of them sediments contained the so called Senegal Fauna. The rate of uplift was 0.011 mm/yr, which suggests 2 m sea level rising during OIS 5e. Terrace formation was triggered by intense tectonic movement. Most of the terraces emerged in the Middle and Late Pleistocene. *Strombus bubonius* warm fauna found in a layer of *Cladocora caespitosa* coral has OIS 7 age; Hillaire-Marcel, C. *et al.* 1986; Goy, J.L. *et al*. 1986; Zazo, C. and Goy, J.L. 1989; Chappell, J. and Shackleton, N.J. 1986 established 15 m rise in sea level, whereas Roy, P.S. and Boyd, R. (1996) came to 2–4 m in stable South Australia. This oscillation was determined by Hearty, P.J. and Kindler, P. (1995) in 2.5 m (OIS 7a) and ≤ 0 m (OIS 7c) on the Bahamas.

The following warm faunas of high sea level stages dated OIS 9 or OIS 11. OIS 11 was the longest (420–360 ka) and warmest interglacial over the past half of a million years (Droxler, A.W. and Farrell, J.W. 2000). Its warm fauna was described in Chile (Ortlieb, L. *et al.*, 1996). During this interval sea level rising presumably was 17 m in South Australia with tectonic stability (Murray-Wallace, C.V. *et al.* 2001) and on the Bahamas (Hearty, P.J. *et al.* 1999)

On Tenerife (Igueste, 97–13 m a.s.l.) warm marine fauna (*Strombus bubonius*) is dated OIS 5e (Zazo, C. *et al.*, 2003, change in sea level: 0 m).

In the Mountains of Anaga the fossil sea coast has an age of OIS 5e (≈130 ka), at Igueste de San Andrés OIS 5e (~131 ka). On the Canary Islands *Strombus bubonius* was dated last interglacial i.e. OIS 5e (Meco, J. *et al.* 2002). Talavera, F.G. *et al*. 1989; Zazo, C. *et al.* 2003 describe fossil coasts as of OIS 5 age and indicate sea level rise of 1–2 m (e.g. Poque de las Bodegas).

The degree of uplift (sea level curve compared with present-day values): El Medano 1.5 m, North Anaga 10.5 m (*Photo 12*, OIS 5e), Igueste de San Andrés 2.8 m, Playa de Gordejuela 18.5 m (540–690 ka), Montana Pelada 35 m, <778 ka.

Results

In the sections studied and their surroundings there were investigated sediments formed by a mixture of weathered surface pyroclastic deposits with Saharan dust. The analyses were aimed to determine the character of these sediments and the circumstances of their formation. For sediment analysis (*Table 1, Photo 3, Figure 3*) a new method was applied by our research team with the involvement of the values of sedimentological parameters for the indication of environmental conditions for the first time in Europe.

With the applied method of environmental evaluation loessial materials and layers affected by pedogenesis were identified in the studied surroundings, hitherto largely neglected by researchers.

Similar loessial sediments had not been described on Tenerife. There were determined parameter values for the sediments identified as weathered pyroclastic surface deposits formed in the course of colluvial processes and subsequently mixed with Saharan dust. Environmental conditions, past climate change and character of sea level oscillations had also been studied.

Along with the traditional parameter values fineness grade (FG) were determined used so far only in American and German literature, and K_d, applied by Chinese researchers. This way the deposits on Tenerife became characterized and new denominations for the layers were introduced. Of the other isles fluvio-lacustric deposits have been identified on Gran Canaria and colluvial loess on Lanzarote.

Parameter values were used to characterize: a paleosol developed upon phonolite lava dated 2–3.5 Ma, the overlying ignimbrite sequence, upward

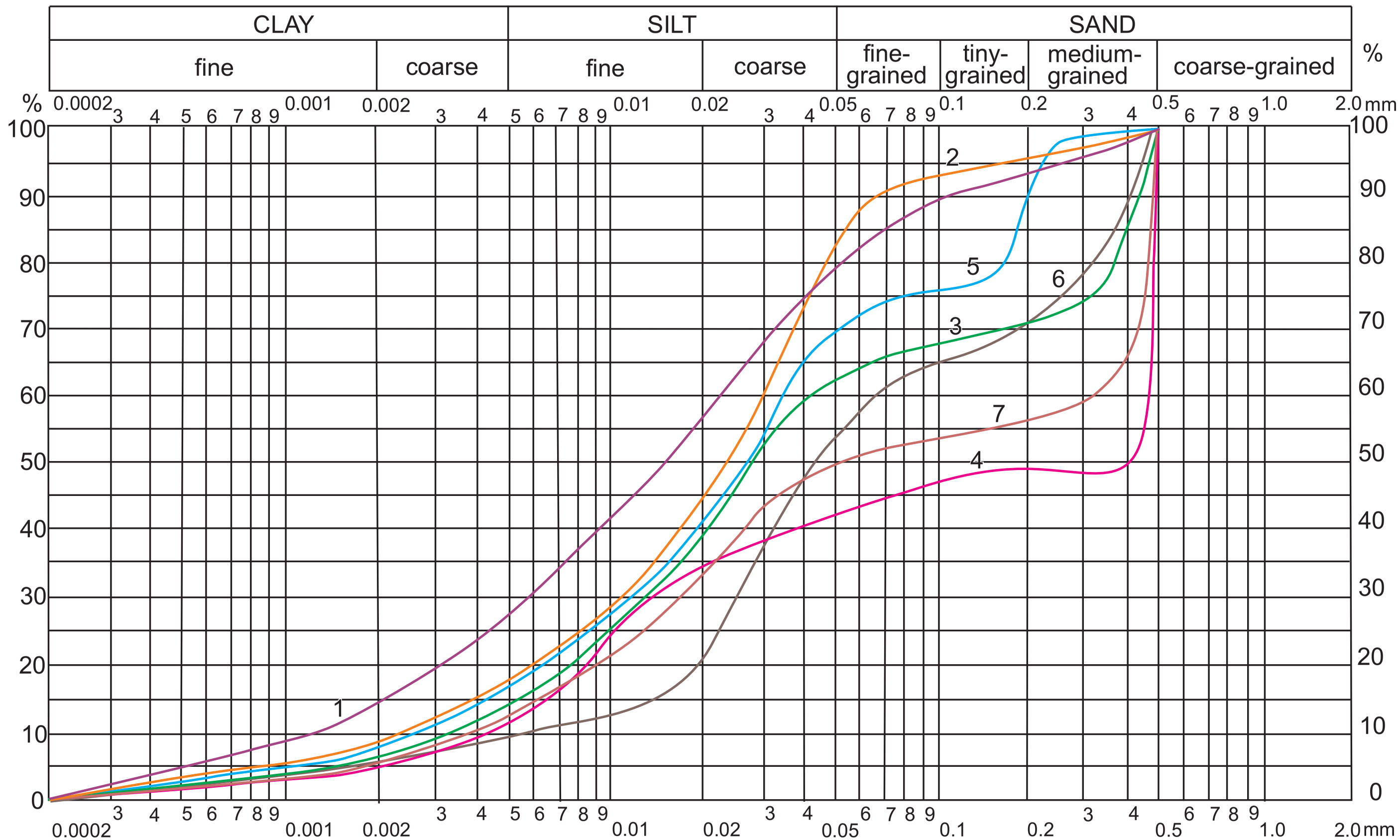

Fig. 3. Grain size curve of the section at Bandas del Sur on the basic of nine sediment size classes (Kis, É., Schweitzer, F. and di Gléria, M. 2010)

sediments affected by pedogenesis upon alkalic basalt lava, a series of sediments formed upon parent rock formed on three ignimbrites and cover sediments containing two alkalic basalt lavas affected by pedogenesis with tuff and breccia interbeddings.

Apart from the soil and sediments there is a loess horizon superimposing the deposit affected by pedogenesis over the lowermost alkalic basalt and three loessified sediments on weathered surfaces with an admixture of Saharan dust. Sediment upon pumice stone as its parent material above the loess was described as the first loessified layer, that overlying lapilli as the second and the sediment affected by pedogenesis situated upon breccia parent rock as the third deposit. It was established that most of the loessial sediments are slope deposits, affected by colluvial processes, so their appropriate denomination is colluvial loess-like sediments. A marked erosional gap could be identified above the lower phonolite lava (*Photo 4*), above the loess horizon, first loessial sediment and sediment formed on the upper alkalic basalt and affected by pedogenesis. Also there is a sharp boundary between the two fine tuff layers within the first loess-like sediment. Calcareous crusts and dry poligonal soils formed during interglacials, and terraces and paleosols were described. Of the calcareous crusts formed during arid stages the thickest are those underlying second and third loess-like deposits. The sequence above the paleosol is younger than 1 Ma.

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