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Geoarchaeological and chronometrical evidence of early human occupation on Lanzarote (Canary Islands)

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Abstract

Two desert loess–paleosol sequences in sediment traps were investigated using (pedo-) stratigraphy, sedimentology, soil mineralogy and IRSL dating. So far we cannot recognise significant IRSL age-underestimates from the polymineral fine-grain fraction of our samples. We establish a first palaeoclimatic sequence spanning the past ca 200 ka which can be compared to data from other Canary Islands and surrounding areas, including terrestrial and deep sea records. More humid phases on Lanzarote are apparently triggered by Milankovich forcing, but the climate remained semi-arid to arid all over the past 200 ka. The onset of human occupation of the island during a slightly moister period is bracketed between 5 and 10 ka, based on the occurrence of archaeosediments containing bones of ovicaprid. This is the first proof of much earlier occupation than witnessed so far from archaeological records. The early subsidiary economy had a strong impact on soil stability and landscape shaping of the island.

1. Introduction

The volcanic island of Lanzarote (Canary Islands, Spain), situated in the North Atlantic trade wind belt, is the driest of the Canary Islands. The highest elevations (up to 670m a.s.l.) do not exceed the altitude of the trade wind dynamic inversion. Precipitation is therefore very low (100–250 mm/a) and falls almost entirely during winter when the island is occasionally influenced by the polar front (Jahn, 1988; Höllermann, 1991). Singular rainfall events may, however, be very intense with >20mm per day or even within an hour or less. Despite the maritime island climate with high (ca 70%) mean relative humidity, but almost permanent drying trade winds Lanzarote has a semi-desert to dry steppe climate actually not allowing natural forest growth and restricting agricultural use to limited areas. Several times per year easterly ‘‘levante’’ winds blowing from the Western Sahara desert transport considerable amounts of yellowish dust to the island. In buried and relict soils covering older plateau basalts the dust has accumulated to a considerable, or even to the main component ofthe soil’s parent material (Jahn, 1988, 1995). In sediment traps such as old craters or ancient valleys dammed by younger volcanic material the dust has accumulated to several meters thick loams and desert loess layers. The typology of buried soils argues for more humid weathering conditions during repeated past periods, but so far no sound chronology of the sediment–soil sequences has been established for Lanzarote.

The goal of our pilot project was to set up a complete stratigraphy of these sequences and to test luminescence (IRSL) dating ofthe fine-grained fraction originating mostly from Saharan dust. Our encouraging first results suggest a rough chronology for the past ca 200 ka and can be compared to data from neighbouring areas such as Fuerteventura island (e.g., Petit-Maire et al., 1986; Rognon and Coudé-Gaussen, 1987; Rognon et al., 1989, 1996) and the North Canary Basin (Moreno et al., 2001). Furthermore, we tried to find (geo-) archaeological evidence for the onset of human occupation (cf. Schmidt, 1996) during our fieldwork and to place this event into our chronometric framework of climate change in the area.

2. Geological overview

The beginning of alkaline volcanism (shield volcano phase) can be explained by the theory of a hot spot under the present day Canary Islands (Schmincke, 1998). Volcanism on Lanzarote started during the middle Miocene forming two separate islands in the north and in the south of present-day Lanzarote. The rejuvenation of volcanism during the Quaternary and even in historic time (1730–1736 AD, 1824 AD), however, requires a modification of the simple hot spot theory and is eventually linked to the activity of the North Canary transform fault (Rothe, 1996) or convection at the continental margin (King and Ritsema, 2000). The volcanic eruption history of Lanzarote is usually subdivided into four ‘‘series’’: Series I occurred during the Miocene and Pliocene. The volcanic landforms created during this series were subjected to strong erosion and pediplanation during rather long periods of volcanic and tectonic quiescence. Series II may have started during the upper Pliocene and was most active during the lower Pleistocene. The youngest published ^{40}Ar/^{39}Ar age is ca 0.98 Ma (Coello et al., 1992). The shape of volcanoes from this series have experienced rather strong erosion and flattening. Series III has been attributed to the normally magnetised Brunhes chrone but more recent ^{40}Ar/^{39}Ar dates suggest that series III started as early as 0.92 Ma and lasted until ca. 0.24 Ma ago (Coello et al., 1992). In contrast to volcanoes from series II, the morphology of craters from series III is well preserved, despite the apparently rather short period separating series II and III. Series IV is of Holocene age and can be subdivided into the older subseries IVa with volcanic activity in the Corona group in the north of Lanzarote (estimated 5–3 ka old, e.g. Jahn, 1988) and the historic eruptions (1730–1736 and 1824 AD) of subseries IVb in the west and southwest.

3. Study areas

For the purpose of this study it is most important that ancient valleys cut into the plateau basalts of series I and the extended lava flows ofseries II were dammed by younger lava flows and pyroclastic deposits of series II (younger part) and III. Some of these dammed ancient valleys are still small endorheic basins today and, thus, have served as sediment traps since their beginning.

Our fieldwork for the present study focuses on two of these dammed ancient valleys, the ‘‘Valle de Femés’’ in the southern part and a valley near the village of Guatiza in the northern part of Lanzarote (Fig. 1). The ‘‘Valle de Femés’’ was originally part of an ancient northeast directed drainage system in the ‘‘Los Ajaches’’ volcanic massif (series I). Near the small village ‘‘Las Casitas de Femés’’ at the northeast end of the ‘‘valle’’ the valley exit was dammed by repeated tephra falls and lava flows originating from the ‘‘Caldera Riscada’’. Careful geomorphologic and volcano-stratigraphic mapping suggests that the height of the dam is about 50 m. The lowest point of the present day bottom of ‘‘Valle de Femés’’ lies between 295 and 300 m a.s.l. We studied several exposures in the ‘‘valle’’, but samples for dating were only extracted from a quarry at the lowest point (Fig. 2) which contains almost no coarse detritus, close to Las Casitas de Femés. The ancient valley near Guatiza extends from SW to NE. It is cut in the eastern to southeastern slope of the ‘‘Famara’’ highland (series I) and is bordered by scoria cones and tephra layers from series III at its eastern side. A lava flow from the ‘‘Las Calderas’’ volcanic group east of Guatiza extended northeast into the valley and dammed it. Another lava flow from this group moved north and was briefly exposed in an aeolianite-paloesol sequence east of the village Mala. This sequence covers several marine terraces of unknown age up to 40 m a.s.l. and a small valley cut into the older terraces. Two intensively developed buried reddish-brown luvic calcisols (terrae calcis) and several buried weakly humic soils were found in the aeolianites overlying the lava flow. OSL dating from this sequence is in progress with M. Lamothe (Montreal, Canada). At its southwestern end the valley of Guatiza is locked by lava flows and ashes from the volcano ‘‘Montaña de Guenia’’ (series II) resting on lava flows from series II. The exposures ‘‘Guatiza I’’ and ‘‘Guatiza II’’ (Fig. 3) are located a few hundred meters southwest of Guatiza and about 1 km west of Guatiza at the foot of the Famara highlands, respectively. Stratigraphic correlation between the two sections was achieved by help of a basaltic tephra layer most probably originating from the Corona volcanic group (see below).

4. Sampling and laboratory procedures

Samples for IRSL dating were taken from the previously cleaned profiles in complete darkness immediately after removing the outermost few cm. Sample preparation according to the fine grain technique (4–11 µm) was performed under subdued green diode laboratory light. The multiple aliquot additive dose (MAAD) protocol was routinely applied, but for some samples we also used the multiple aliquot total bleach regeneration protocol (3 h bleach with the Dr. Hoenle SOL2 lamp). From one sample we also performed TL dating. We used calibrated ^{90}Sr (2.89 Gy/min) and ^{241}Am sources (2.60 Gy/min) for laboratory irradiations. Afterwards all aliquots were stored at 70°C for 1 week. Prior to IRSL readout on a Daybreak 1150 TL/OSL reader, they were preheated at 220°C for 120 s. IRSL shine-down curves were recorded for 100 s at 40 mW/cm^2 IR-stimulation energy (IR-LEDs with 880±80 nm), using a combination of BG39 and GG400 detection filters. For TL measurements the well-tried combination of a Corning 5-58 and a HA3 filter glass were used. For details see Mauz et al. (2002) and Lang et al. (1996). Data processing was performed with the Daybreak software TL Applic 4.26. Late light subtraction in addition to background subtraction was not performed because of very low IRSL intensities (see below).

For radioactivity analysis we used thick source alpha counting (conversion factors after Aitken, 1998), beta-counting (Risø GM-25, with reference to loess standard NUSSI presently submitted for certification; a factor of 0.385±0.005 was used to convert count per minute into beta dose-rates (Gy/ka)), and on-site measurements of the environmental dose-rate in the energy window 0.25–3MeV (Harwell 4-channel gammaspectrometer, modified). The small dose-rate contribution from cosmic radiation was estimated after Aitken (1985) assuming a more or less continuous sedimentation rate. Interstitial water content was measured from sealed samples, but as samples extracted from behind a removed detritus accumulation at the bottom of the profiles yielded much higher δ-values than samples from the dried-out exposure we calculated the ages with assumed higher δ -values (1.3 for samples >40% clay, 1.2 for other samples). The regenerative alpha dose of the oldest sample D213 was by far not high enough to regenerate the IRSL intensity of the natural signal. With respect to the onset of saturation of the beta-regenerated growth-curve we estimated the a-value to 0.028±0.009 and used this value for age calculation rather than the value of 0.022±0.004 determined from the quasi-linear part of the regeneration growth curve.

Tests for anomalous fading were performed as follows: five aliquots received the highest applied laboratory beta dose and their IRSL was measured on the next day. Their IRSL intensities were compared to IRSL intensities of those aliquots, which received the same dose but were stored at 70°C for 1 week. Sampling and laboratory procedures for sedimentological and pedological analyses and their detailed results will be described elsewhere.

5. Results

Analytical data and dating results are listed in Table 1. IRSL ages are also presented in stratigraphic order in Figs. 2 and 3. In general, a-values are low to extremely low (minimum value 0.022) which was also found by Pomel et al. (1985) for comparable parent material on Fuerteventura. Unusually low TL signals were also reported by Rögner et al. (1999) for desert loess from the Sinai Peninsula, Egypt. In both areas, however, the presence of feldspars in the silt accumulations was proved by XRD analysis. Despite the low IRSL intensities and resulting scatter in the EDs determined for the single channels (1 channel=1 s), ED shine-down plateaus did not show an increasing trend with shine-down time. Dose response curves and ED plateaus for a young (4.94±1.31 ka, Guatiza 250 cm) and the oldest sample (200±26 ka, Femés 670 cm) are plotted in Fig. 4. Most of the samples did not exhibit significant short-term anomalous fading, some others faded slightly (5–10%) or the IRSL intensity apparently increased slightly (5–10%) during storage after irradiation. Due to the very low IRSL intensities of the young samples the ‘‘inverse fading’’ may be an artefact from the low signal-to-noise ratios, as no obvious physical reason for signal increase can be given at this stage. It is important to note that no significant short-term anomalous fading was observed from the oldest dated samples. Only from one sample (D 222) the observed short-term fading exceeded 10%. The calculated age could therefore be a minimum age.

The Femés and Guatiza sections yielded very different but overlapping chronologies. The youngest sediments are poorly preserved in the sampled Femés section at the sampling site and probably due to anthropogenic removal of the uppermost few tens of cm of the parent soil. In neighboured exposures closer to the village of Femés, however, several meters thick young alluvial fan sediments from torrential ephemeral streams were preserved. They bracket the 1730–1736 basaltic ash (both air fall and fluvially reworked) from the Timanfaya (Montes del fuego) eruptions and contain ceramics from the colonial period (Hans-Martin Sommer, Maguez, Lanzarote, oral commun.). The IRSL ages obtained so far from the Femés section range from ca. 4.94±1.31 to ca 200±26 ka. A triple paleosol-complex consisting of luvisols (f1Bt, f2Bt) and a basal luvivertisol (f3Bt) is bracketed between ca. 4.94±1.31 ka and ca. 42.6±3.9 ka. Loess enriched with secondary carbonates in the f5Bvcc soil horizon is dated 101±14 ka. It overlies an intensively developed triple pedocomplex (f6Bvt, f7Bt and f8Bt) most probably including the last interglacial soil as suggested by clay contents and clay mineral composition. The oldest sample Femés 670 cm (200±26 ka) was extracted from the f9BtSd soil horizon which continues downward into the hand-augered part of the profile. The stacked profile at Guatiza contains many coarse alluvial fan deposits, and IRSL dating was restricted to layers with high aeolian (loess) content. No samples were dated from the lowermost exposed part (reddish brown soil sediments below 830 cm). The oldest dated sample here is from a loess-like layer containing lots of calcified nests of Anthophora, a hairy dry land bee requiring little more humidity than at present (Petit-Maire et al., 1986). The (minimum) age obtained from this layer is 18.5±2.2 ka which is coeval with the onset of the ‘‘Erg Ogolien’’ (maximum extent of large longitudinal dunes in the Sahel zone) shortly after the Last Glacial Maximum (LGM) (Reichelt et al., 1992, cf . Swezey, 2001). This layer is topped by a cambic soil horizon (fBvC) with mycelia-like secondary carbonate precipitation. The sedimentation age of the parent loesslike material is 10.2±1.4 ka providing a maximum age for the lower Holocene soil formation. The volcanic ash layer rests on a loess-like layer with some coarse scoria clasts dated 5.12±0.57 ka and is overlain by a probably aeolian loess layer without clasts dated 4.33±0.48 ka. These two ages strongly support the basaltic ash origins from the nearby (ca 12 km) Corona volcanic group. An ovicaprid bone found at a depth of 500 cm, 270 cm below the ash, could not be dated by radiocarbon due to very low collagen content and a very atypical δ^{13}C content (-26‰, Dr. B. Kromer, Heidelberg, Germany, pers. comm.), referred to typically -18‰ to -20‰ (Wagner, 1998). With respect to the stratigraphic consistence of our IRSL ages and - within error bars - identical ages for the youngest desert loess sedimentation pulse around 5–4 ka we consider our IRSL ages meaningful. This is supported by the agreement with other chronometric results and paleoclimatic records from neighbouring areas (see Section 6).

6. Discussion

A considerable number of ^{14}C ages and other geochronological data have been collected from aeolianite–paleosol sequences on the nearby island of Fuerteventura and in Morocco (Petit-Maire et al., 1986; Damnati et al., 1996; Rognon and Coudé-Gaussen, 1996), in the Sahara (Reichelt et al., 1992; Swezey, 2001) and in the North Canary Basin (Moreno et al., 2001). The well-established aridification of the Sahara after the lower to middle Holocene humid phase is reflected by the strong pulse of desert loess accumulation on Lanzarote since ca 5 ka, whereas the preceding more humid period is witnessed by the formation of a cambic soil between ca 10 and 5 ka. A rather humid phase preceding the ‘‘Erg Ogolien’’ known from the Sahara (e.g., Reichelt et al., 1992) is also recognised and further resolved on Fuerteventura and in Morocco, but its exact beginning and timing is limited by systematic errors and the range of radiocarbon dating. Our IRSL age from Femés (42.6±3.9 ka) as a maximum age for the beginning of‘‘middle Lake Period’’ (‘‘Mittlere Seenzeit’’, Reichelt et al., 1992) and related soil formations agrees considerably well with age estimates from Fuerteventura based on non-calibrated radiocarbon ages up to ca 37.7 ka BP (Damnati et al., 1996). More IRSL ages from the Femés section are needed to further resolve the environmental change documented in the triple pedocomplex. With respect to the results from Guatiza we believe that the uppermost paleosol of this complex represents the Late Glacial to Holocene and the middle paleosol the late MIS 3 to early MIS 2 pedogenesis, which are distinguished on Fuerteventura (Damnati et al., 1996). As far as the range of radiocarbon dating is concerned, we demonstrate that IRSL dating of the fine grain fraction of desert loess is a very helpful tool to decipher paleoclimate change in desert margin areas. Furthermore, we recognise that climate change in the western and southern Sahara (Sahel) is excellently recorded in the volcanogenic sediment traps on Lanzarote.

This leads to the question were the reasons for climate change the same in the Southern to Western Sahara and on Lanzarote? It is evident that the climate change in the Sahel was controlled by the strength ofthe paleomonsoon activity and, thus, by Milankovich forcing (precession). As so far we have no proof for significant IRSL age underestimates for our samples from Lanzarote, we used our geochronological and other sedimentological, pedological and mineralogical data to suggest a preliminary age model for the sediment-paleosol sequence beyond the present range of radiocarbon dating (Fig. 5). Assuming Milankovich forcing we find that our ages fit well with the 100 ka cycle. We recognise that stronger pulses of desert loess accumulation on Lanzarote (ca 5, 100 and 200 ka) occurred at the withdrawal of the northern hemisphere monsoon front towards the equator, shortly after an interglacial maximum with increased humidity (summer rainfall?) and soil formation. So far this makes an essential difference to the pulses of loess sedimentation in the middle latitudes (Antoine et al., 2001; Rousseau et al., 2002; Lang et al., 2003). The strong ca. 18 ka desert loess pulse on Lanzarote is, however, an outlier from this cycle and coincides with an apparently world-wide peak in mid-latitude loess sedimentation (Singhvi et al., 2001). For this period Rognon and Coudé-Gaussen (1996) reconstructed an atmospheric and oceanic circulation pattern for the Canaries and northwest Africa which allowed more Saharan dust to be transported to the Canary Islands. It must be considered that during maximum glacial advances the polar front over the North Atlantic had a much more southern position than at present and could therefore lead to more (winter) rainfall on the Canary Islands. Eventually the youngest humid phase with soil formation before the ‘‘Erg Ogolien’’ phase was triggered by increased activity of the polar front over the Canary Islands. A closer spacing of samples for IRSL dating between the ca 40 and 5 ka dated part of the Femés section is necessary to approach this question. The frequency of Anthophora nests in the ca 18 ka-loess at Guatiza argues for still slightly moister conditions than at present, despite the desert loess formation. It is stressed, however, that the occurrence of authigenic palygorskite in both, desert loess and paleosols, as well as the absence of lake sediments in the exposed sections, preclude semihumid or humid climates in the studied areas of Lanzarote during the past 200 ka (cf. Eitel, 1994).

The latest relatively humid period enabled the first intentional occupation of Lanzarote between 10 and 5 ka ago as witnessed by numerous bones of ovicaprids (probably the goat) embedded in alluvial fan (Guatiza) or mudflow sediments (Teguise, not described in detail in this work). The domestication of goats has been attested ca. 10,000 years ago in the Zagros

Mountains (Iran) by Zeder and Hesse (2000), and at the end of the 9th millennium calBC to the onset of the 8th millenium calBC humans deliberately brought goats onto the island of Cyprus, thereby causing early human impact on the landscape (Vigne et al., 1999). In both exposures (Guatiza and Teguise) a dramatic change in the sedimentology of the bone-bearing sediments, referred to the underlying ‘‘Anthophora’’-horizon and its terminating cambic soil, is striking (Fig. 3).

The hinterland of the sites with alluvial fan and mudflow sediments is intensively eroded by gullies, the larger ones being named ‘‘barrancos’’. At present we cannot decide if the age of the ‘geomorphological crisis’’ attributed to strong natural erosion on Fuerteventura at the end of the Late Glacial (Petit-Maire et al., 1986; Rognon and Coudé-Gaussen, 1996) is overestimated by the authors and they eventually describe the same erosion event we find on Lanzarote <10 ka. Alternatively, there is older, natural erosion in the area, which so far we could not distinguish on Lanzarote. In our opinion the poorly sorted bone-bearing sediments at Guatiza, Teguise, and elsewhere are clearly related to extensive goat husbandary by early humans on Lanzarote. The geomorphologic processes creating those sediments are most probably triggered by human impact on the semiarid ecosystem prevailing at that time on Lanzarote, and therefore we classify the sediments as archaoesediments sensu limitu. Together with the related geomorphologic forms of erosion, they reflect a strong anthropogenic reshaping of the island’s geomorphology, which may even have exceeded the geomorphologic impact of colonialism, but could actually be surpassed by the impacts of tourism. This will be subject to further investigations.

7. Note added in proof

During recent fieldwork (February, 2003) more ovicaprid bones were detected at the Guatiza I section at the bottom of the fBt horizon >5 ka old. In a nearby quarry a much more complete desert loess paleosol sequence than known so far was found. This new section will enable us to refine the chronology of the past 20–30 ka and to bracket the arrival of man in Lanzarote more precisely.

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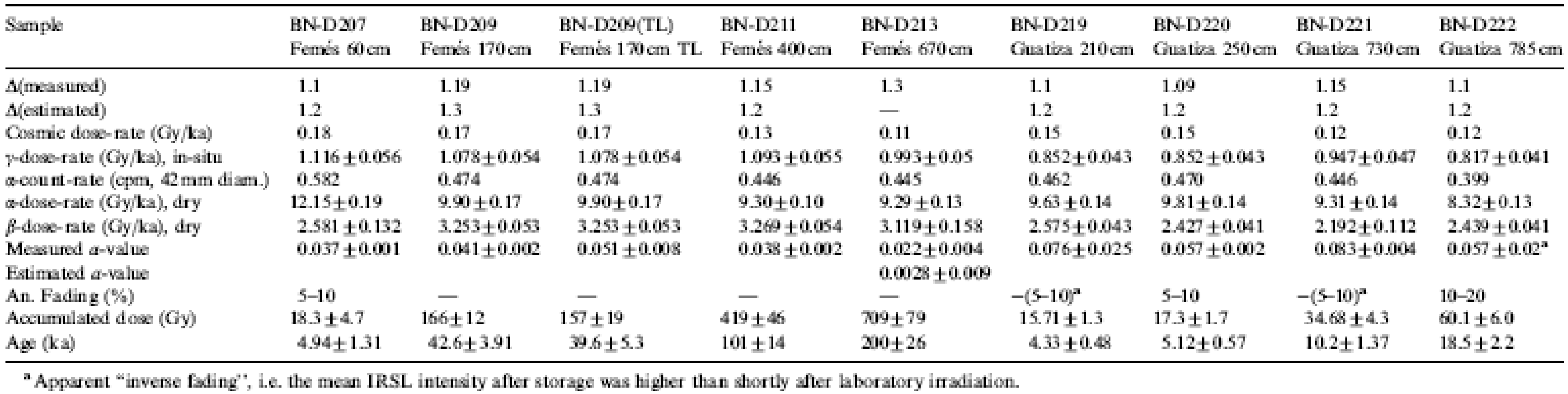
Tables

Table 1: Analytical data and luminescence dating results



Sample	BN-D207 Femés 60 cm	BN-D209 Femés 170 cm	BN-D209(TL) Femés 170 cm TL	BN-D211 Femés 400 cm	BN-D213 Femés 670 cm	BN-D219 Guatiza 210 cm	BN-D220 Guatiza 250 cm	BN-D221 Guatiza 730 cm	BN-D222 Guatiza 785 cm
Δ(measured)	1.1	1.19	1.19	1.15	1.3	1.1	1.09	1.15	1.1
Δ(estimated)	1.2	1.3	1.3	1.2	—	1.2	1.2	1.2	1.2
Cosmic dose-rate (Gy/ka)	0.18	0.17	0.17	0.13	0.11	0.15	0.15	0.12	0.12
γ-dose-rate (Gy/ka), in-situ	1.116 ± 0.056	1.078 ± 0.054	1.078 ± 0.054	1.093 ± 0.055	0.993 ± 0.05	0.852 ± 0.043	0.852 ± 0.043	0.947 ± 0.047	0.817 ± 0.041
α-count-rate (cpm, 42 mm diam.)	0.582	0.474	0.474	0.446	0.445	0.462	0.470	0.446	0.399
α-dose-rate (Gy/ka), dry	12.15 ± 0.19	9.90 ± 0.17	9.90 ± 0.17	9.30 ± 0.10	9.29 ± 0.13	9.63 ± 0.14	9.81 ± 0.14	9.31 ± 0.14	8.32 ± 0.13
β-dose-rate (Gy/ka), dry	2.581 ± 0.132	3.253 ± 0.053	3.253 ± 0.053	3.269 ± 0.054	3.119 ± 0.158	2.575 ± 0.043	2.427 ± 0.041	2.192 ± 0.112	2.439 ± 0.041
Measured a-value	0.037 ± 0.001	0.041 ± 0.002	0.051 ± 0.008	0.038 ± 0.002	0.022 ± 0.004	0.076 ± 0.025	0.057 ± 0.002	0.083 ± 0.004	0.057 ± 0.02[a]
Estimated a-value					0.0028 ± 0.009				
An. Fading (%)	5–10	—	—	—	—	−(5–10)[a]	5–10	−(5–10)[a]	10–20
Accumulated dose (Gy)	18.3 ± 4.7	166 ± 12	157 ± 19	419 ± 46	709 ± 79	15.71 ± 1.3	17.3 ± 1.7	34.68 ± 4.3	60.1 ± 6.0
Age (ka)	4.94 ± 1.31	42.6 ± 3.91	39.6 ± 5.3	101 ± 14	200 ± 26	4.33 ± 0.48	5.12 ± 0.57	10.2 ± 1.37	18.5 ± 2.2

[a] Apparent "inverse fading", i.e. the mean IRSL intensity after storage was higher than shortly after laboratory irradiation.

Figures

***Figure 1**:* Contour map of Lanzarote and locations of the investigated profiles.

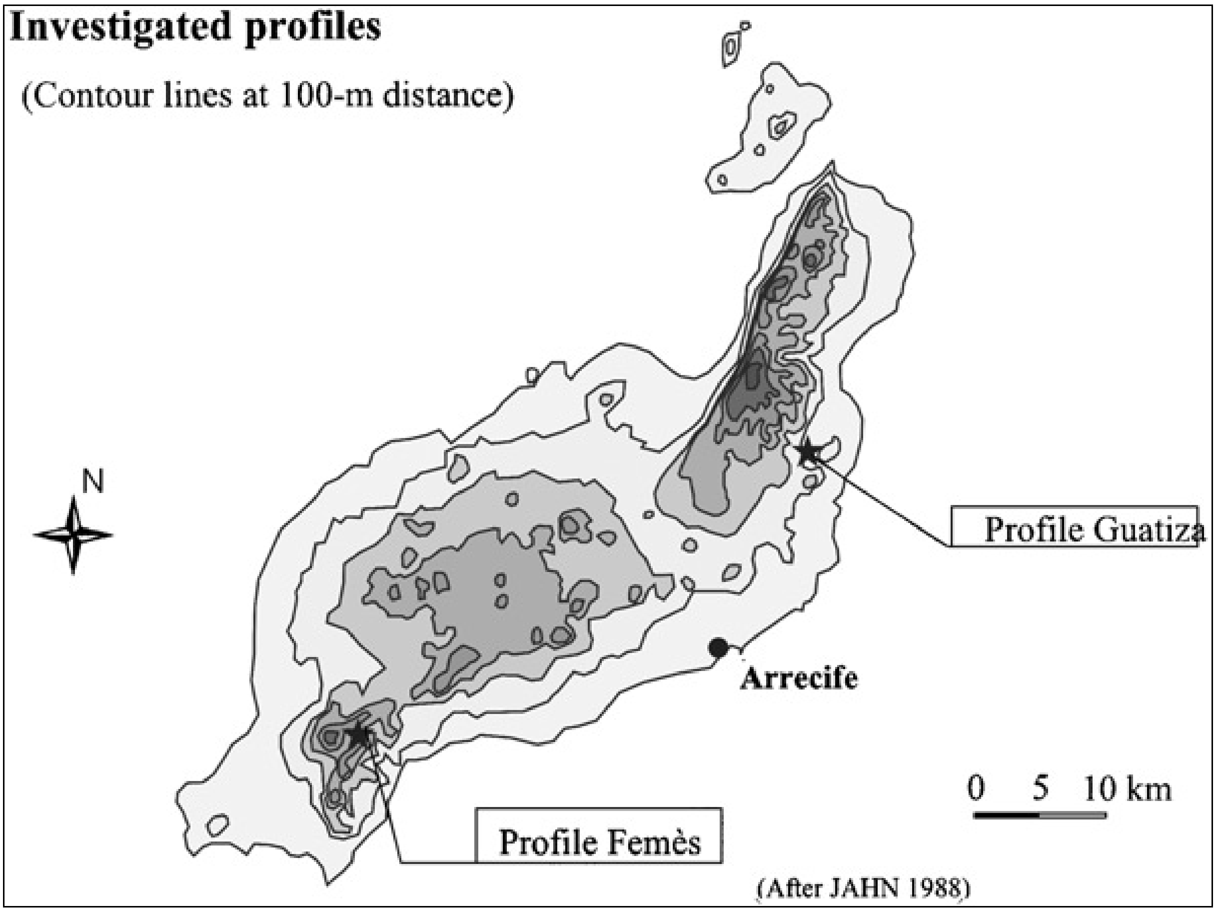


Figure 2: Stacked profile of the Femés section and luminescence ages (ka).

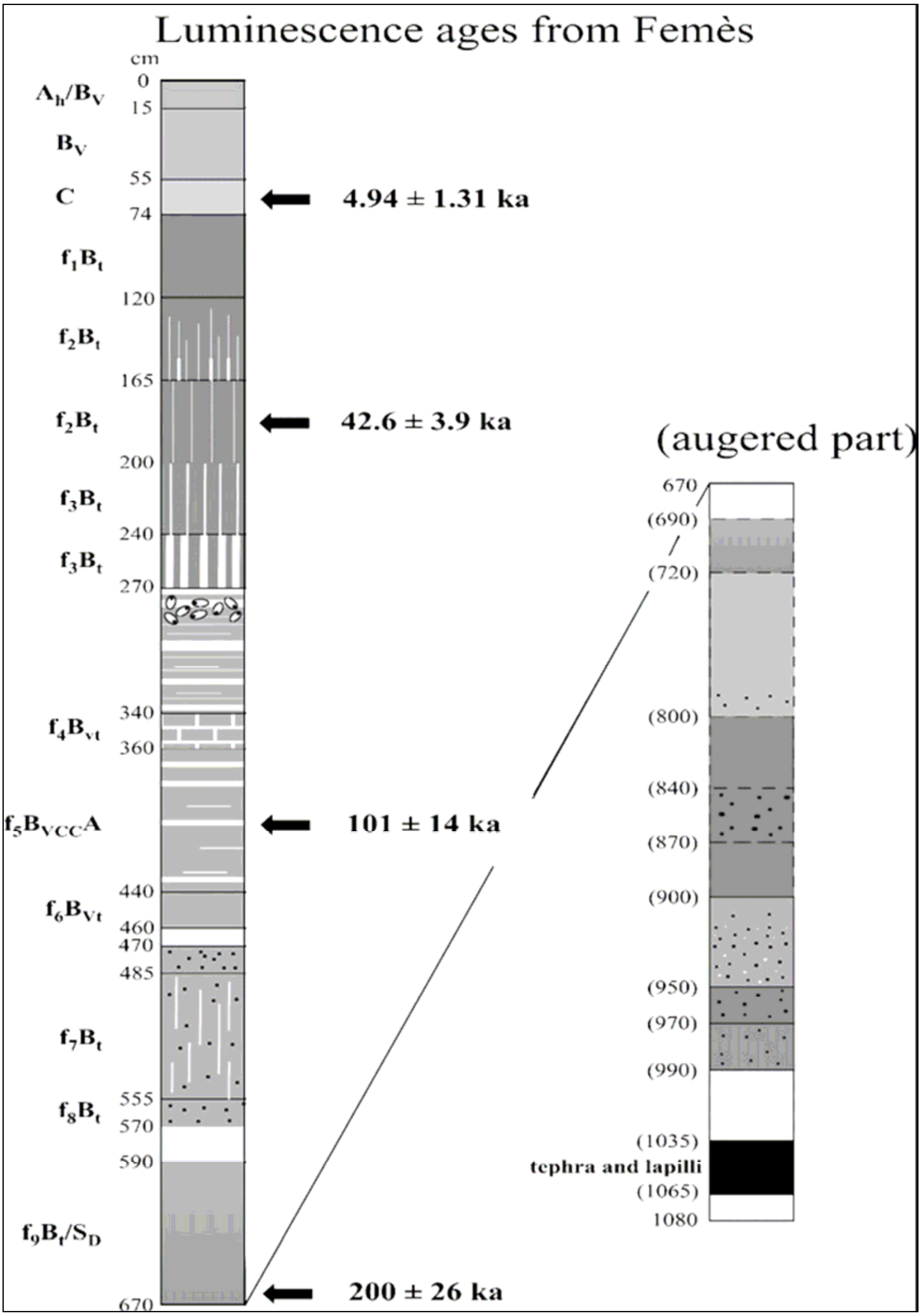


Figure 3: Stacked profile of the exposures at Guatiza and luminescence ages (ka).

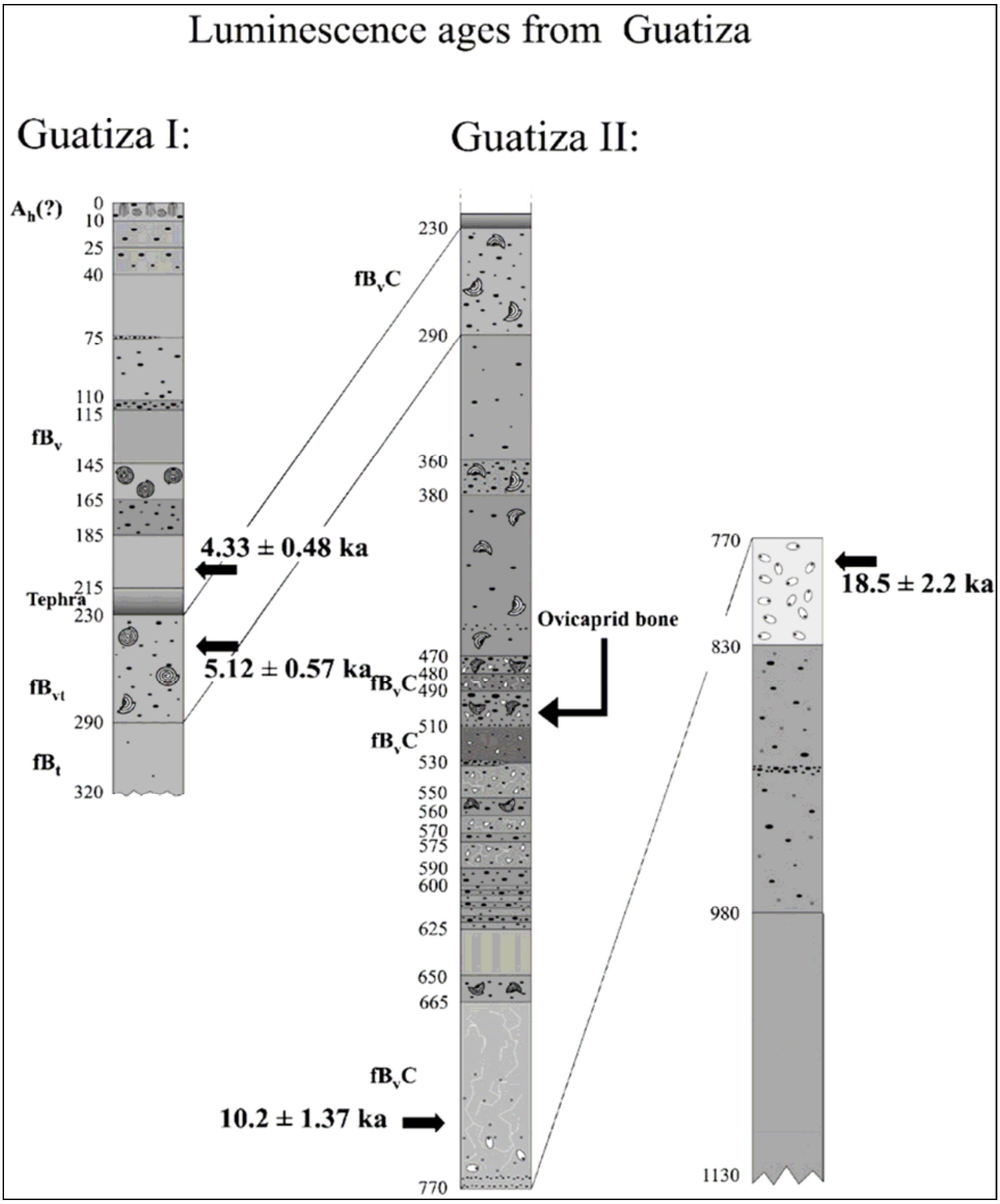


Figure 4: Shine-down plateaus and dose-response curves for samples BN-D 220 (a) and BN-D 213 (b).

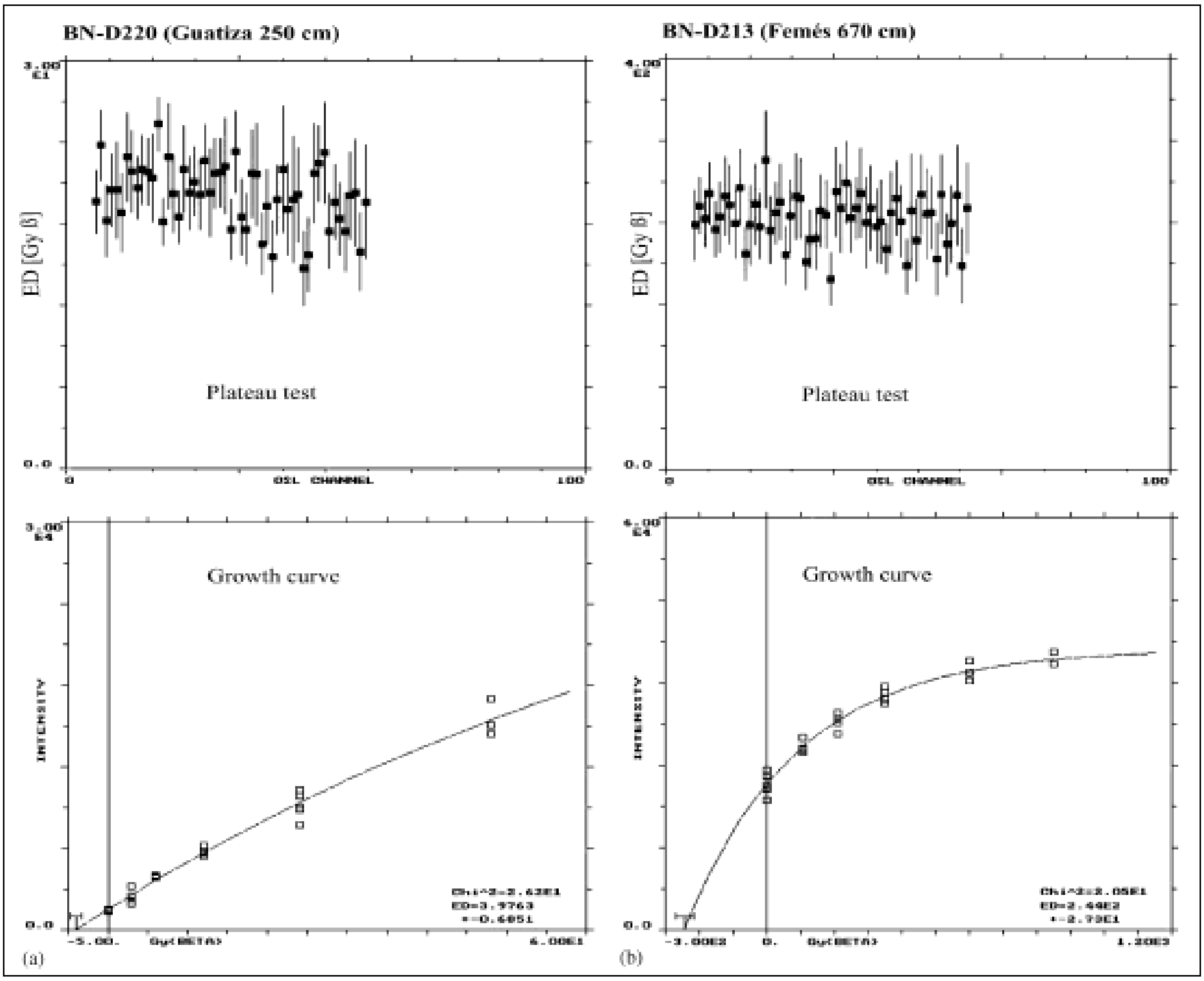


Figure 5: Tentative correlation of global climate data and data from the Femés section. Note the reversed intensity scale of dust input from the Arabian Peninsula. Mean IRSL ages from Femés are plotted along the time axis.