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An unusual 'blood rain' over the Canary Islands (Spain). The storm of January 1999

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Abstract

An intense storm, including strong winds, a dust storm, 'blood rain' and heavy rains affected the Canary Archipelago between 5 and 10 January 1999, producing damage valued at 156 million euros. The present paper analyses the weather conditions and sedimentological features of the dust. The resulting data provide a possible explanation of palaeoclimatic conditions essential for the stabilization of sand dunes in the eastern parts of the Canary Islands.

Keywords: Blood rain; Dust storm; Heavy rain; Canary Islands

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1. Introduction

During the first fortnight of January 1999, the Canary Archipelago (Fig. 1) was affected by two different types of stormy weather. The first caused serious economic damage mainly to roads, harbours and banana crops. Indeed, the massive arrival of dust reduced visibility significantly and ended with a dramatic blood rain[1]. The second type of weather had few consequences for the economy and communications, being a normal winter weather type.

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[1] Blood rain—in Spanish called *lluvia de barro, lluvia de sangre o lluvia coloreada* (Quereda Sala and Olcina Cantos, 1994)—could be defined as rain—occasionally snowfall—which while falling washes down fine dust particles to the ground. Its characteristics depend on the amount of dust in the atmosphere, grain size of aerosols, deposition ratio and chemical composition (MartínVide and Llasat, 1991).

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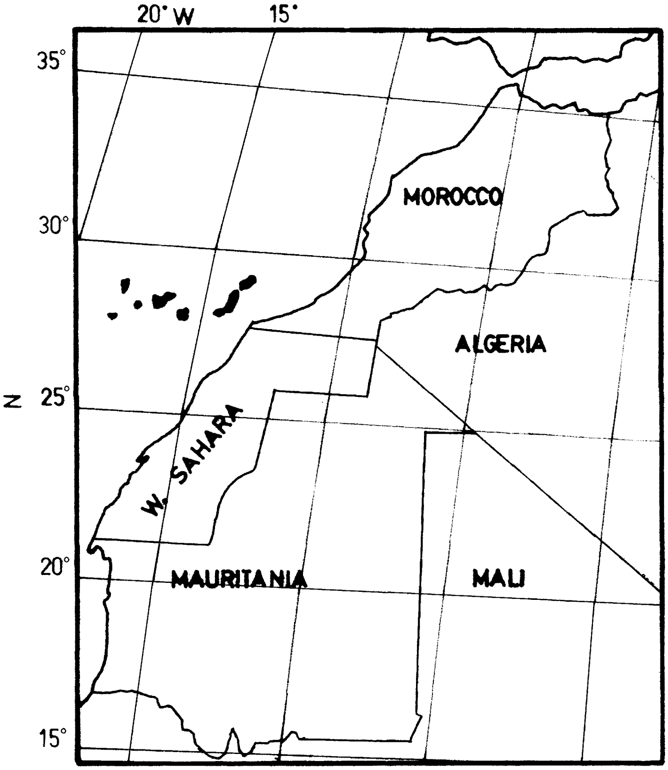

Fig. 1. The Canary Islands and North-west Africa.

The arrival of air from the Sahara is a common phenomenon in the Canaries, mainly during the winter. Often this type of weather prevails 30% of this season (Dorta, 1999). Its most striking features are an increase in temperature, a substantial decrease in humidity and poor visibility—sometimes less than 200 m—because of the presence of a massive amount of airborne Saharan dust. Other features of this weather type are defined by atmospheric stability and normally a drought period caused by the dry easterly winds (Scott, 1900; Huetz de Lemps, 1966; Marzol, 1993; Dorta, 1999), though it may occasionally produce some gentle showers (Huetz de Lemps, 1966).

In January 1999, however, this event also involved a very dense Saharan dust cloud preceding heavy rains. This combination is unusual in the Canary Islands, but there are references to similar atmospheric conditions in the meteorological literature, for instance, in February 1989 (Dávila and Torres, 1992) and earlier (February 1920: Bannerman, 1922). On the other hand, blood rain is a very well-known phenomenon in Northern and Central areas of Europe (Franzén, 1989; Littmann, 1991), but especially in the Mediterranean countries (Nihlén and Mattsson, 1989; Rapp and Nihlén, 1991). It is very frequent on the South-east coast of Spain occurring for an average of 3 days a year (MartínVide and Llasat, 1991; Quereda Sala and Olcina Cantos, 1994). However, because of problems associated with recording this kind of precipitation, the number of events could well be greater (Quereda Sala and Olcina Cantos, 1994).[2]

The second type of weather involved a storm coming from northern latitudes, a very common event during the winter (Marzol, 1988, 1993), with a very steep pressure gradient in the highest layers of the troposphere, like the one that developed between 10 and 14 January 1999. Only the first weather disturbance, which took place between 5 and 8 January, with its unusual frequency and origin, will be considered here.

While, dust storms produce problems by reducing visibility that may impede both surface and air traffic, the deposited dust is an important source of lithogenic material in the oceans (Torres Padron, 2000). Indeed, they provide a poorly evaluated supply of exogenic minerals, whose effects on Canary soils are already known (Fernández-Caldas et al., 1982; Mizota and Matsuhisa, 1995). Although dust storms are, and have been of global importance with respect to climatic change and geomorphological evolution (Goudie, 1978, 1983; Coudé-Gaussen, 1983), they have local importance in the eastern Canary Islands (Chamley et al., 1987; Coudé-Gaussen et al., 1987; Coudé-Gaussen and Rognon, 1988, 1993; Criado and Hansen, 2000).

The study of the dynamic behaviour of this dust storm and its sedimentological features, including particle size, chemical and mineralogical composition, provide a key to understanding palaeoclimates typified by heavy rain and dust deposition. Recent research in the eastern Canary Islands has shown that this type of palaeoclimates led to the stabilization of coastal sand dunes at least four times during the last 30 ka (Criado and Hansen, 2000), through a process described by other researchers in many parts of the world (Pye, 1987).

2. Materials and methods

Two different approaches to the dust storm of January 1999 are adopted here. The first analysis is based on a careful study of the synoptic evolution of the weather using the daily weather charts published by the Instituto Nacional de Meteorología (Boletines Meteorológicos Diarios) and the European Meteorological Bulletin. These include the near-surface situation as well as maps showing the form of the 850 hPa and the 500 hPa barometric surfaces and temperature.

We also use meteorological records from the main weather stations (including airports) in the Canary Islands (provided by the Instituto Nacional de Meteorología), especially atmospheric pressure, wind direction, wind speed, visibility, temperature, humidity and rainfall. Of course, a more complete picture would have been provided by inclusion of the detailed weather situation in the western parts of

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[2] These authors note an average of about 27 days a year between 1988 and 1993 (Quereda Sala and Olcina Cantos, 1994).

Sahara (the dust source region), but attempts to obtain such records for the airports of Agadir (Morocco), Laouine and Dakhla (Western Sahara) were unsuccessful. Nevertheless, this gap is partly filled by the weather data for Nouadibhou airport (Islamic Republic of Mauritania) and those provided by the European Meteorological Bulletin.

The second part of this paper focuses on the sedimentological analysis of the dust. The unusual and unexpected character of this storm rendered impossible to obtain an adequate number of samples using standard devices (Livingstone and Warren, 1996). Only two samples are available, collected in china bowls on the flat roof of two houses on the island of Tenerife, one located in Guamasa village (at 620 m a.s.l.), very close to Los Rodeos (TFN) Airport and the other in Tegueste (390 m a.s.l.). Good environmental sampling conditions were provided by the fact that the soils were saturated by the heavy rains of 5 and 6 January, so that contamination of the dust samples with particles of local volcanic soils is unlikely to have occurred. Thus, the samples collected represent only the Saharan dust deposited by the rain on the evening of 7 January 1999.

The particle-size was measured using a Coulter Laser Granulometer at the Postgraduate Institute for Sedimentology at Reading University (UK). In order to determine the geochemical characteristics as a guide to the possible source area of the dust, a part of the Guamasa sample was analysed at ACTLABS (Ancaster, Canada), together with two samples of the finer dust fraction ($<63\,\mu m$) from sandy surfaces close to Tindouf (Algeria) and *S*outhern Tiris (Mauritania). The mineralogical composition of these three samples was obtained by X-ray diffraction in the SIDIX in the University of La Laguna. Finally, the dust sample was examined under SEM in the University of La Laguna (Fig. 2).

The source and the pathway of the dust cloud were established using the meteorological, geochemical and mineralogical data and also satellite images provided by the SeaWIFS satellite. Also we have used the map of Total Ozone Mapping Spectrometer (TOMS) for the 7 January 1999, a powerful tool to study the dust (Goudie and Middleton, 2001; Middleton and Goudie, 2001).

3. Results

3.1. Weather patterns

January 1999 started with stable weather because of the presence of a high-pressure centred west of the Canary Islands, producing winds from the NW. On 4 January, a little change was noted; although conditions continued to be stable, the oceanic air mass was replaced by a the Saharan air mass with the habitual drop in humidity and presence of dust haze (Fig. 3). On 5 January, an upper-air trough appeared over the Canaries, a cold front passing trough at the surface with SW winds and heavy rains in the western Canary Islands (Fig. 4). The SeaWIFS satellite image shows this cold front moving across the archipelago towards the coast of the Sahara, with a dust plume drawn from the desert and into the Atlantic, crossing the

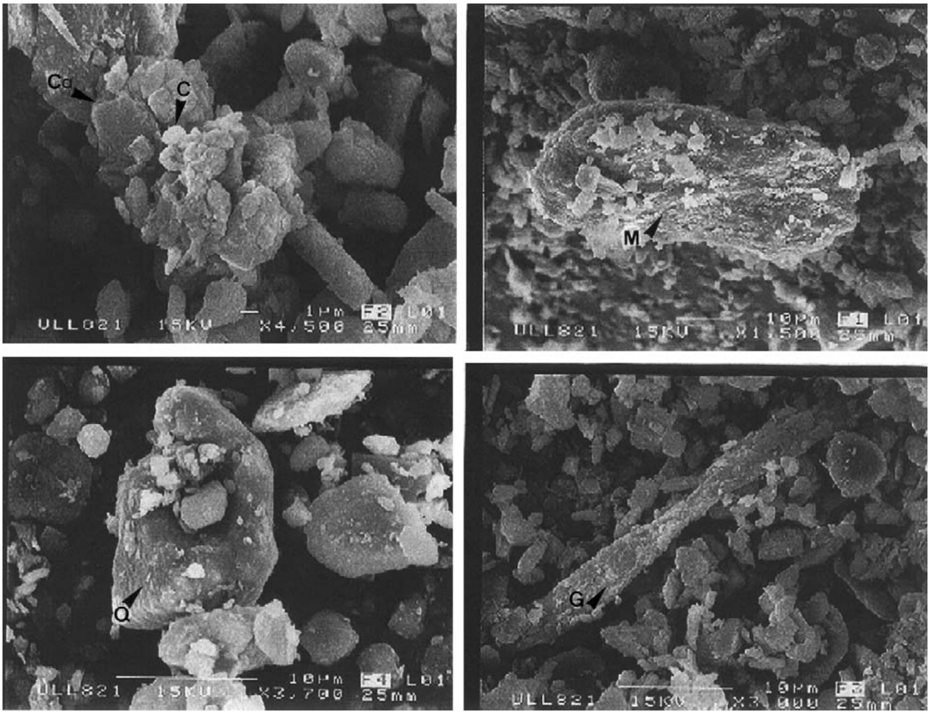

Fig. 2. SEM pictures of the Guamasa sample: F1, Mica (coarse fragment, M); F2, calcite and clays (Ca and C); F3, quartz (Q); F4, gypsum (G).

eastern Canary Islands (Fig. 5). Such situations are very common in the Western Sahara with the passage of a cold front (Font Tullot, 1955).

On 7 January, the weather changed dramatically. A low-pressure area appeared over the islands, with a core of cold air at around −20°C at the 500 hPa level. This situation produced winds from the SE (Fig. 6). This atmospheric situation is clearly reflected in the records of atmospheric pressure at Santa Cruz Weather Station between 1 and 20 January (Fig. 7). Such low-pressure systems are a common cause of such conditions over the islands and Western Sahara, and transport a substantial amount of Saharan dust. The low pressure reduced the visibility to values of less than 1 km, mainly during the afternoon of 7 January, the minimum visibility at Guacimeta airport (Lanzarote) of 500 m occurred at 13.00 p.m. The dust storm appeared very quickly, reaching its maximum density between the afternoon and evening of 7 January, when the whole archipelago recorded very low visibility (Table 1). The image from the SeaWIFS Satellite shows a dust plume elongated towards the NW and, behind, it a very dense cloud mass (Fig. 8). The aerosol data recorded by NASA (TOMS) clearly show the dust input over the Canary Islands (Fig. 9).

Everywhere the wind was also very strong, but always below the maximum recorded at different weather stations (Table 1). These winds, reaching over

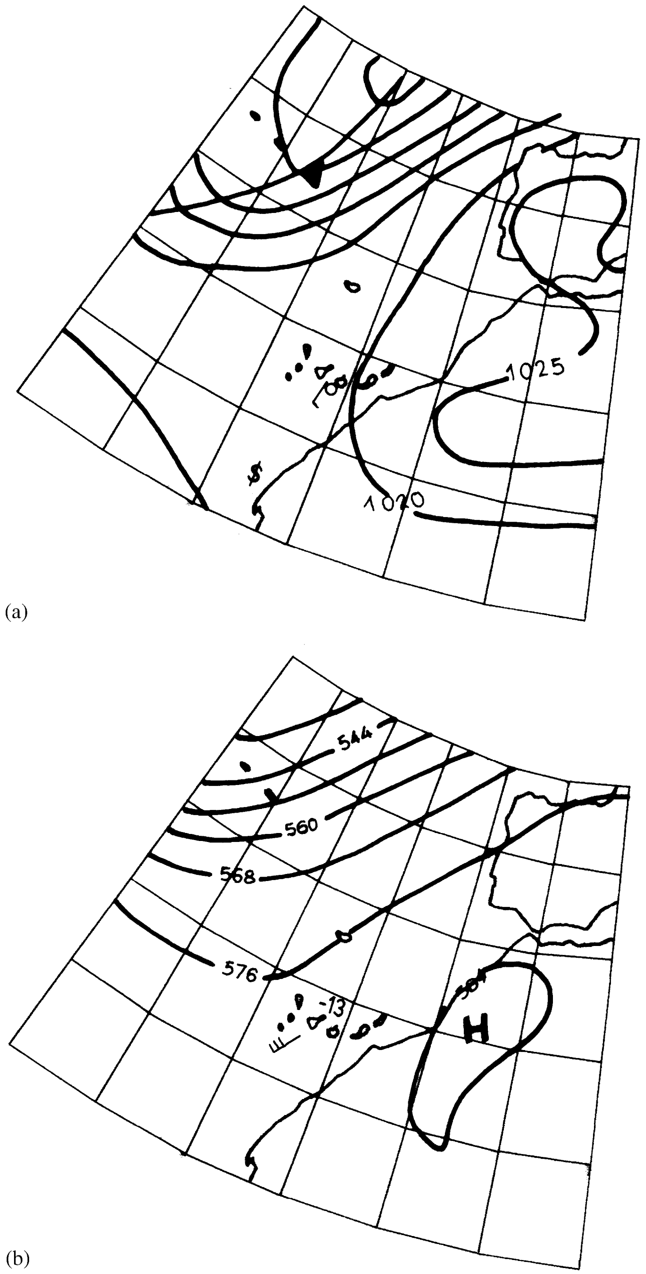

Fig. 3. (a) Meteorological chart showing the surface conditions on 4 January 1999 in the Canary Islands area (12 UTC). (b) Topography of the 500 hPa isobar surface (12 UTC).

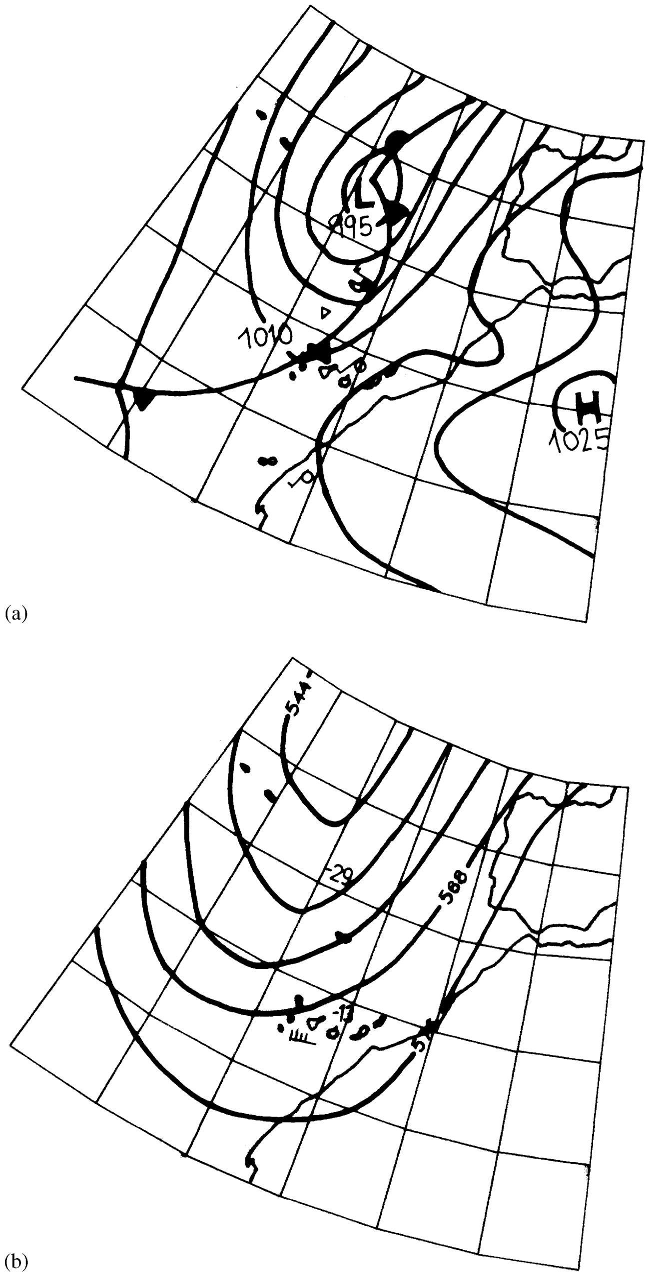

Fig. 4. (a) Meteorological chart showing the surface condition on 5 January 1999 in the Canary Islands area (12 UTC). (b) Topography of the 500 hPa isobar surface (12 UTC).

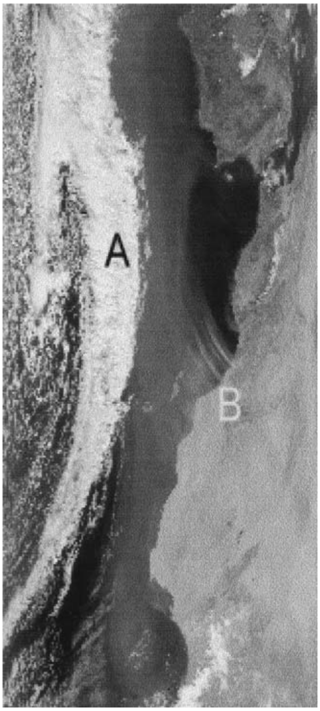

Fig. 5. Image obtained by SeaWIFS Satellite on 5 January 1999. The cold front can be seen travelling to the East (A) and inducing movement of Saharan dust to NNW (B).

$22\,\mathrm{ms}^{-1}$ from an unusual direction (SE) had catastrophic effects. The harbours, some open to the SE, were seriously affected, so that sea traffic was halted. Air traffic was also affected, airports were closed and a considerable number of scheduled flights cancelled. Fortunately, no casualties were directly attributable to the storm.

Some authors note how the presence of dust within a bout of stormy weather favours condensation in the clouds, so after the first precipitation (a 'blood rain') may follow an event of heavy rain or hail (Quereda Sala and Olcina Cantos, 1994). Thus, most but not all weather stations recorded intense rains (Table 1). For instance, there was no rain recorded at Reina Sofia Airport (South Tenerife), and Tafira (Gran Canaria). However, the airports of Guacimeta (Lanzarote) and Matorral (Fuerteventura), located only a few metres above sea level, recorded 32 and 49 mm, respectively. These impressive precipitation amounts to when compared with the annual mean ($125\,\mathrm{mm\,year}^{-1}$ at Guacimeta and $78\,\mathrm{mm\,year}^{-1}$ at Matorral), 25.6% and 62.8%, respectively.

On the afternoon of 7 January 1999, the dust storm caused reduced visibility, falling to 750 m at Guamasa, situated 1 km from Los Rodeos Airport (Fig. 10).

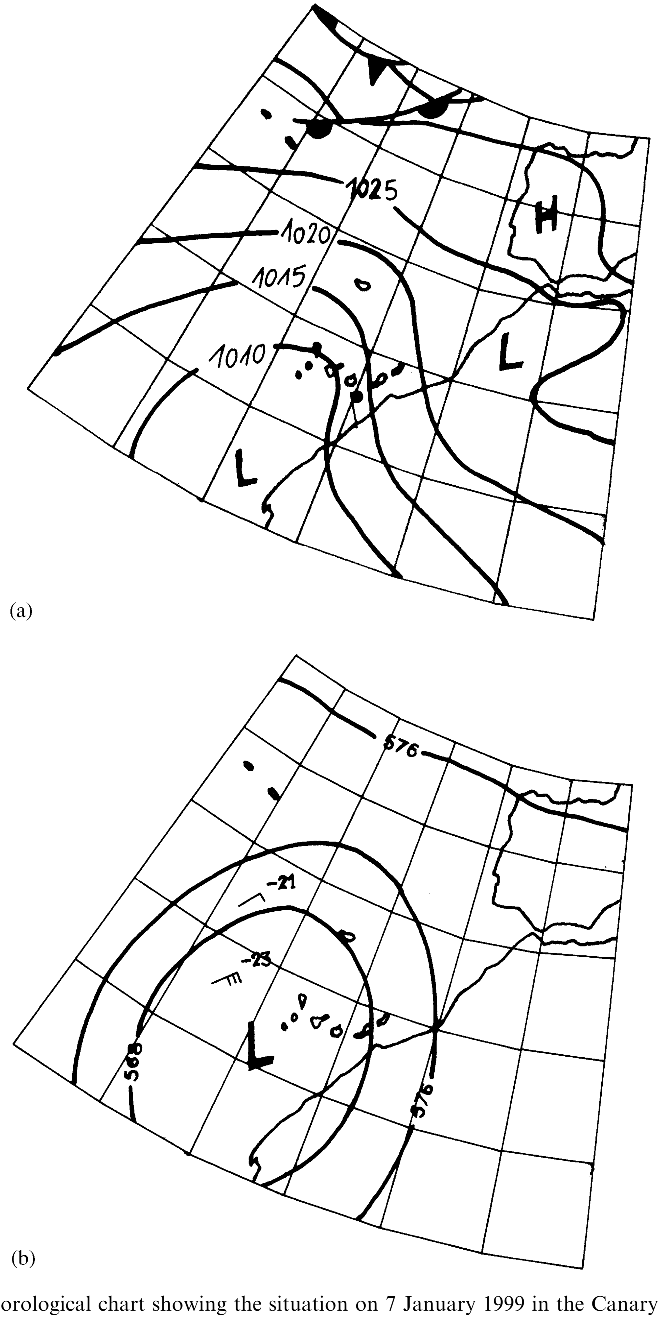

Fig. 6. (a) Meteorological chart showing the situation on 7 January 1999 in the Canary Islands area (12 UTC). (b) Topography of the 500 hPa isobar surface (12 UTC).

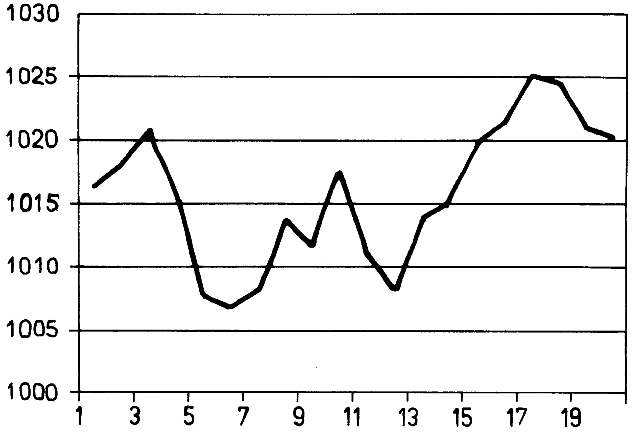

Fig. 7. Changes in the pressure registered at Santa Cruz de Tenerife weather station between 1 and 20 January 1999.

Table 1
Some records from the main weather stations in the Canary Archipelago for 7 January 1999

Weather station	Max. wind speed ($km\,h^{-1}$)	Direction	Visibility (m)	Rain	T (°C)
Reina Sofía (TF)	89	120	3500	0.0	18.4
Los Rodeos (TF)	89	120	1000	49.0	14.4
Santa Cruz (TF)	80	120	1500	11.0	20.3
Cangrejos (H)	89	130	15000	38.0	19.4
Guacimeta (L)	80	120	6000 (500)	32.0	17.9
Gando (GC)	81	110	3500 (1500)	4.0	19.0
Matorral (F)	67	130	4000	49.0	16.6
Tafira (GC)	81	110	5000	0.0	15.8

The lowest values of visibility are in parentheses.

3.2. Analysis of the dust samples

The samples, with a Munsell colour of 7.5 YR 6/6 (reddish yellow) were silt-like in appearance, lacking the very coarse grains found in the dust samples collected on Sal Island in the Cape Verde Archipelago some years ago (Glacum and Prospero, 1980). The particle size of the two dust samples are summarized in Table 2.

Both distribution curves are unimodal (Fig. 11) confirming the fact that there was no contamination of the dust by input from local soils by saltation (Pye, 1987). However, the Tegueste sample is slightly richer in the coarse silt fraction. Few particles are $<2\,\mu m$ (only 9.6% in the Guamasa sample and 7.2% in that from Tegueste) while the modal values are normal for samples derived from sources several hundred kilometres away (McTainsh and Walker, 1982; Middleton, 1997). The skewness values are highly positive and are evidence of transportation in

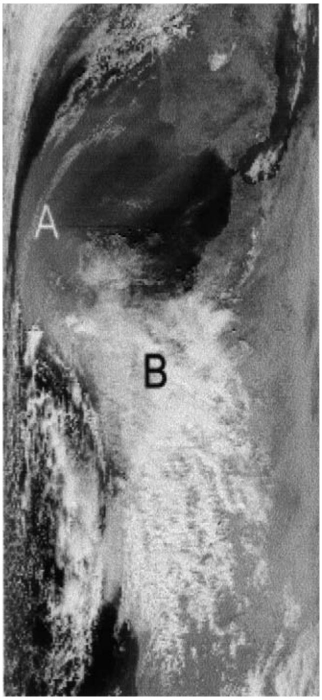

Fig. 8. Image obtained by SeaWIFS Satellite on 7 January 1999 showing the dusty plume coming from the Sahara Desert elongated to NW (a). It is followed by a very dense cloud formation (b) responsible for the massive dust deposition as 'blood rain'.

suspension (Nickling, 1983) with no local saltation input. Possibly due to its higher location in the profile of the dust storm, the Guamasa sample shows better sorting than that from Tegueste. The poorer sorting shown by the Tegueste sample may be related to the lower altitude of this sampling point, and its larger coarse fraction probably reflects its lower position in the dust cloud, in accordance with observation by several authors (Chepil and Woodruff, 1957; Gillete et al., 1974; Goosens, 1985). The differences between the January 1999 dust storm and others of a type that occurs more frequently, in which most particles are $<2\,\mu m$ (Chester and Johnson, 1971), is confirmed by these particle-size results.

The principal elements in the dust samples, expressed as total oxides, are shown in Table 3 together with comparative data (using the fraction $<63\,\mu m$) from Tindouf (Algeria) and Southern Tiris (Islamic Republic of Mauritania):

The main dust sample component is silicon dioxide, reaching more than 50%. Less important are aluminium oxide, iron oxide and calcium oxide. The relatively high proportion of this last component and the high value for loss on ignition (LOI) may indicate a relatively high calcium carbonate content. The determination of this latter by Bernard's method gave a value of around 25.8%. It is clear that the dust contains less CaO than the material collected in Tindouf a result to be expected because the Tindouf site is located on a *Hammada* formed by 100 m thick flaggy calcareous rocks

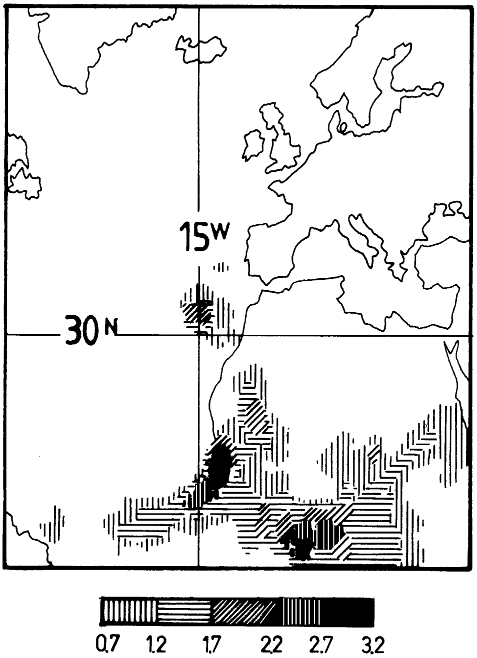

Fig. 9. Aerosol Index TOMS in West Africa on 7 January 1999 (after NASA).

belonging to the *Continental Terminal* (Furon, 1968). In contrast, the sample from Southern Tiris shows a very clear predominance of silica, as is to be expected given the presence in that area of Precambrian basement (called Dorsal Reguibat) very rich in granite (Bellion, 1991, pp. 17–24). Thus, the chemical composition of the dust that arrive in the Canaries on 7 January is consistent with a source on granite and limestone rocks (Fig. 12). Mineralogical analysis by X-ray diffraction provides further support for this view. Quartz and calcite are the dominant minerals, others of lesser importance including haematite, gypsum and apatite (Fig. 13). Peaks at 7.14 and 10 Å, indicate the possible presence of illite and kaolinite, heating 400°C confirming the former. Treatment with ethylene glycol did not indicate smectite. X-ray diffraction of the Tindouf sample showed calcite to be the principal crystalline mineral, together with quartz. The same technique applied to a sample from Southern Tiris showed a clear predominance of quartz.

Examination of the Guamasa sample, using a SEM showed the presence of quartz grains, calcite, gypsum and some large fragments of mica (Fig. 2).

4. Discussion

The data from Nouadhibou airport (Mauritania) provides information on the southerly position of the storm. At 9.00 GMT, the wind blew across the airfield from

Fig. 10. Image of the dust storm taken in Guamasa on the afternoon of 7 January 1999. The hill located in the foreground, partially visible, is at distance 750 m.

Table 2
Grain-size parameters of dust samples collected on 7 January 1999

Sample	Guamasa	Tegueste
Mean	16.91 μm	20.67 μm
Median	12.04 μm	18.79 μm
Mode	18.00 μm	26.14 μm
Standard deviation	15.94	14.38
Skewness	1.68 right skewed	0.74 right skewed

100° N at 9 knot, but the situation changed with a turn in the wind direction to 200° N, but without a change in wind speed. The sky was cloudy but visibility was more than 10 km, indicating an absence of dust storms at latitudes south of 20°N.

Knowing the southernmost limit of the storm, the SeaWIFS image and the sedimentological data (mainly geochemistry and mineralogical information), together with the study of wind directions at the principal weather stations in the

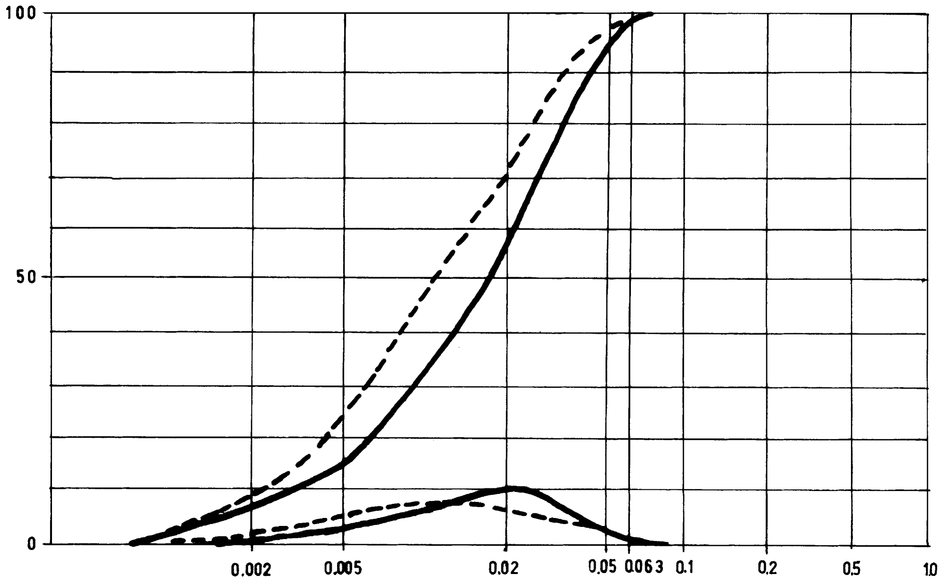

Fig. 11. Grain-size frequency curve and cumulative curve of the samples collected in Guamasa (black line) and Tegueste (dotted line).

Table 3
Total oxides from the dust samples collected in Guamasa and the Sahara Desert

Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI
Dust	50.41	11.80	5.00	0.08	3.47	9.62	0.90	1.95	0.87	0.38	15.40
Tindouf	27.89	5.26	2.59	0.03	4.43	25.42	1.82	1.14	0.53	0.07	30.45
Tiris	75.10	9.38	3.77	0.06	1.13	1.74	1.34	2.52	1.45	0.11	3.47
Average (Goudie)	59.99	14.13	6.85	—	2.60	3.94	—	2.35	—	—	16.99

The average values provided by Goudie (1978) are included for comparison.

Canary Islands, we conclude that the dust cloud was formed by very strong winds blowing over the Tiris area (granite outcrops in the South-east of the former Spanish Sahara) and, later, in sectors with limestone outcrops. The wind direction and SeaWIFS image support classification of this storm as a *haboob* (Pye and Tsoar, 1990). It took up most of the quartz in its path over the Tiris area, then blew over the Cretaceous *hammada* and Cainozoic formations on the Sahara coast (Alia, 1945) and finally crossed the sea to arrive over the Canary Islands (Fig. 12).

We have evidence of dust storms producing massive dust deposits associated with heavy rains on at least three occasions during the 20 century. The oldest was described by Bannerman (1922) in the following words: 'We are suffering here from a terrible so-called "sand-storm", the worst known for years. (The dust) appears

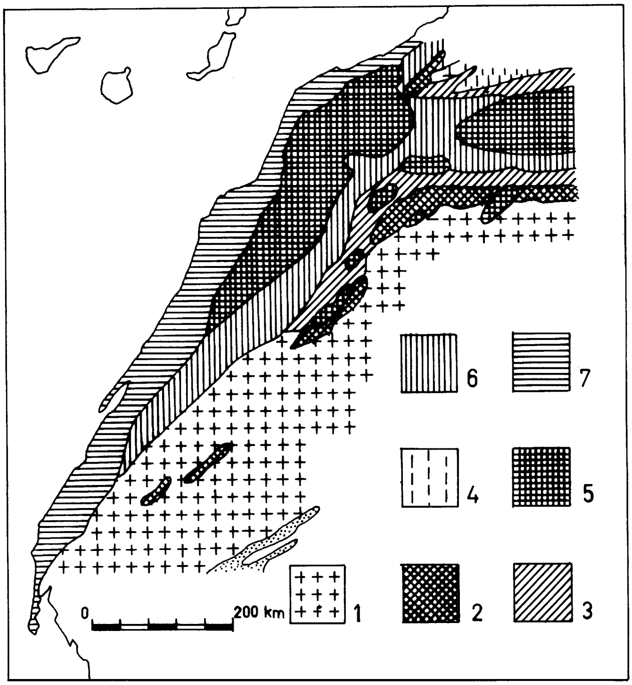

Fig. 12. Geological sketch of the Western Sahara (modified of Alia, 1945): 1. Pre-Cambrian areas; 2. Cambrian-Silurian; 3. Devonian; 4. carboniferous; 5. cretaceous *Hammadas*. 6. materials from degradation of *Hammadas* and Quaternary; 7. Cainozoic formations.

over the sea as thick mist, which gradually envelops everything. We can see about a quarter to half mile, but sometimes not 200 yards. Shipping is entirely disorganised, and many boats are lying outside apparently afraid to move. The dust finds its way into everything, through barred doors and windows, and is making life here very miserable. The storm commenced on the afternoon of the 8th with a very high southwesterly(sic) wind. The entire island is affected. It cleared slightly on the afternoon of 9th, but is worse than ever to-day (10th)'.

P.S.- 11/2/20. Pouring in torrents: dust-storm ended.

We compared our data with that obtained by W. Campbell Smith, assistant in the Department of Minerals of the British Museum (Natural History) who analysed a sample of dust collected in Tenerife by D. Bannerman. Quartz was found to be the main component, perhaps amounting to more than 67%. The sample reacted with dilute HCl (the carbonate content to 18.5%). We believe that the dust analysed by Smith could be of the same kind as that from the event on 7 January 1999.

The second of the three storm events was studied by Dávila and Torres (1992), and the third and last being this study. They appear to be broadly consistent so that, together, they increase our knowledge of dust storms associated with disturbed weather producing heavy rains in the Canary Archipelago.

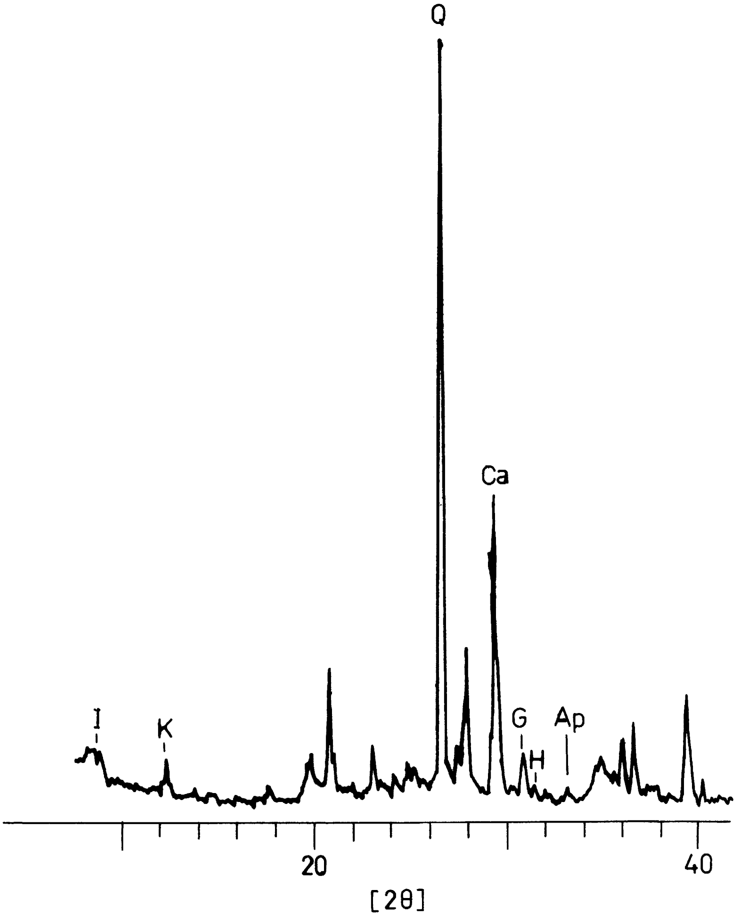

Fig. 13. X-ray diffractogram of the Guamasa sample.

5. Conclusion

The present paper provides a new evidence about strong dust invasions affecting the Canary Islands and Atlantic Ocean off North-west Africa related with a weather type still not noted in the literature (Middleton and Goudie, 2001). So, we must take account of these winter trajectories of the dust in this area of Atlantic Ocean linked with troubled weather.

On the one hand, we must watch carefully the role of North-west Mauritania and Western Sahara as a source of the dust travelling to the Canary Islands. Obviously it is a secondary source but, however, it is very important to understand the composition of the dust arriving massively to the Canary Archipelago and surrounding oceanic areas.

Any evaluation of the amount of dust deposited during a storm such as the one that occurred on 7 January is bound to be problematical as the basis is only one sample. Nevertheless, calculation yielded a figure of around 23 g^{-2}, yielding a total input to the island of Tenerife of ca. 47,311 tonne. Comparison of these data with literature provided a broad indication of the quantitative importance of these unusual events. Recent measurements in the Canary Islands show a mean annual dust input of about 20 g^{-2} in dry deposition, with the mean value of wet deposition representing only 10% of the annual total (Torres Padron, 2000). On this basis, the storm of January 1999 exceeded the annual mean value for both, dry and wet dust depositions.

The data in this paper also suggests ways in which this type of massive dust fall ('blood rain') may have played a role in the geomorphological evolution of the eastern Canary Islands during the Quaternary. It raises the possibility that, in palaeoclimatic periods much rainier than today, rain storms may have preceded massive dust falls and so stabilized coastal sand dunes in the eastern Canary Islands. These may have coincided with a stronger meridional moment in the jet stream such that very cold air was drawn into the upper layers of the atmosphere, and generated low pressure centres to the south of the Canaries. The wind blowing over the arid Western Sahara could have picked up the dust and carried it there in the storm. In a recent abstract (Criado & Hansen, 2000), we presented the results of a study of three cross-sections in Fuerteventura and Gran Canaria indicating sand-dune stabilization under wet conditions combined with massive dust deposition. Evidence for a wetter climatic period than the present is provided by the large number of insect nests and terrestrial snail shells. On the other hand the presence of quartz in the silt fraction is an evidence of a massive dust deposition. For the moment, we were able to distinguish four major events, occurring 30, 17, 14 and 9.5 ka before present. So the study of the actual unusual dust fall provides a key to understand the palaoeclimatical conditions in this area of North-west Africa.

Acknowledgements

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