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ABSTRACT

Aeolian dunes are generally absent or poorly developed on oceanic islands. Yet, large-scale aeolian sedimentary systems characterize the oceanic islands of the Canary and Cape Verde archipelagos. These island-encapsulating sedimentary systems extend around or across entire islands and comprise upwind source areas, aeolian transport corridors and downwind sediment depocentres, each of which is characterised by distinctive dune forms. Upwind beaches are denuded of sand, while downwind locations exhibit progressive shoreline accretion. *Cross-island* transport corridors developed in topographic lows on the island surface are characterised by a variety of landforms including sandsheets, barchanoid dunes and transverse dunefields, depending on topography and local sediment volume and supply. *Circum-island* transport corridors develop when the island topography is high and sediment transport takes place on the island margins, alternating between headland-bypass dunes and longshore transport in the littoral zone in the intervening embayments. Depocentres comprise extensive aeolian dunefields, prograding

beaches or beach ridges depending on local topography. Recognition of the interconnected nature of the components of these contemporary systems has important management implications.

The presence of these sedimentary systems in the Canary and Cape Verde chains can be attributed to a particular combination of geological and geographical factors. The thick lithosphere in which the island chains occur slows subsidence rates and creates long-lived oceanic islands that are exposed to weathering and erosion for several million years during which terrestrial denudation and biogenic sediment production creates a sufficient volume of littoral sediment. From a geographical perspective, these islands are in arid or semi-arid environments with unidirectional or strongly asymmetrical transport-capable winds (i.e. Trade Winds).

INTRODUCTION

Although there are many large scale coastal aeolian dune accumulations in continental settings, a global review shows them to be rare on oceanic islands. The isolated nature of a volcanic island and surrounding very deep water means that littoral sand can only originate locally by (i) denudation and erosion of the islands themselves; and (ii) accumulation of biogenic sediment from the remains of marine organisms that inhabit the island margins.

Post-eruption subsidence means that most oceanic islands remain emerged for <5My (after their initial formation (Carracedo and Tilling, 2003). This limits the time available for sediment production. Islands in rigid oceanic lithosphere, however, have low subsidence rates and may remain emerged for >20 My. Long exposure to weathering and erosion promotes the development of marginal platforms, which retain terrigenous sand and provide an environment amenable to colonization by calcifying marine organisms. This sediment supply provides the potential for developing extensive littoral and aeolian deposits (Alonso et al., 2011; Criado et al., 2011).

In this paper we describe the large-scale coastal dune systems of the Canary and Cape Verde island chains. Uniquely among oceanic islands, active sedimentary systems traverse entire islands, moving sand from source to sink via distinctive transport pathways producing a hitherto undescribed type of dune system. Several examples are detailed below.

METHODS

A global review of the nature and distribution of coastal dunes on oceanic islands was conducted using historical and contemporary aerial photography, satellite images and published sources, as well as via fieldwork. Photos of the Canary and Cape Verde island chains were obtained from the governmental spatial data infrastructures (SDI) of the Canary Islands (www.idecanarias.es) and Cape Verde (http://www.idecv.gov.cv/), and from the ULPGC archives (Departamento de Geografía and Grupo de Geografía Física y Medio Ambiente). Together with Google Earth, these images (Table 1) were used to identify and classify aeolian landforms and track temporal changes. Fieldwork in the Canary Islands has been ongoing since 2002, whilst fieldwork campaigns were undertaken in Cape Verde in 2005 and 2009.

RESULTS

Cape Verde Islands

The Cape Verde Archipelago (14° - 18°N22° - 26°W (Figure 1) comprises two island chains generated by Neogene oceanic volcanism. The islands are between 20 million (eastern sector) and 8 million years old. The islands are located within the Sahelian arid belt with average annual rainfall <200 mm yr^{-1} (Ramalho, 2011). Winds are predominantly from the NNE (Figure 1 insert). The main aeolian sedimentary fields in the Canary Islands are shown in Figure 2 (Modified from Alonso *et al.*, 2011), which demonstrates the spatial variety and form differences found across the region.

Boa Vista

On Boa Vista large outcrops of Quaternary carbonate aeolianite form 100-m high, platforms. Contemporary aeolian processes rework these aeolianites plus contemporary carbonate sands into coastal and inland dunes. Sediment dynamics of Boa Vista are characterized by distinct transport pathways between the north and south of the island (Hernández-Calvento and Suárez, 2006). Sediment is transported by wind across low, unobstructed parts of the coast. Nebkha dunes (Figure 3A) in the source zone form around isolated vegetation patches immediately at the rear of the beach and individual hummocks are typically 1-2 m high and 2-3 m diameter. They often have a downwind 'tail' or 'shadow dune' form (Figure 3A). Cross-island transport occurs in sand sheets with occasional barchan dunes and barchanoid ridges (Figure 3B). Localized sediment accumulations within the transport corridor result in development of transverse ridges with linear crest lines (Figure 3C). Sediment transport occurs in a largely unbroken NE-SW direction with the sediment pathway dictated by local topography. These are noted as moving at rates between 9.11 m year^{-1} up to 27.69 m year^{-1} (1991-2015) (Figure 4 and table 2). At the coast, transport is observed to alternate between aeolian and nearshore wave-driven regimes (Figure. 5). On the downwind island margin sediment accumulates as a wide sandy beach backed by beachridges, indicating long-term progradation (see Figure 3D).

The Canary Islands

The Canary Islands Archipelago (27° 37'-29° 25' N, 13° 20'-18° 10' W) (figure 2A) is located on the African Plate, on oceanic crust of Jurassic age (165-176 My). The crust is among the oldest and most rigid on the planet, causing slow subsidence (Carracedo *et al*., 2002). The development of the island chain can be divided into several stages involving initial eruption and island formation, a resting phase when erosive processes dominate, a stage of rejuvenation, and a final stage of simultaneous volcanism and erosion, in which erosion gradually dominates to result in complete disappearance of the islands (Carracedo, 1999, Carracedo and Tilling, 2003).

The age of the islands increases eastward, with the oldest being Lanzarote and Fuerteventura (15-20 My), (Carracedo and Tilling, 2003). Fuerteventura and Lanzarote, share the same volcano. A wide shelf in the east promotes biogenic productivity on these islands. During phases of marine regression these sandy deposits are mobilised by NE Trade Winds (Figure 1 insert) and generate large dune fields in the prevailing arid conditions (Criado *et al*., 2011; Alonso *et al*., 2011). When the topography is low, coastal sand is blown inland as sand dunes or sandsheets. Dunefields migrate parallel to the direction of the trade winds, but can be modified by local topography (Cabrera Vega, 2010; Jackson *et al*, 2013$_{a,b,}$). Large aeolian deposits dominate in the eastern islands whereas in the western Islands, cliffs cause only isolated climbing-dunes to form (Criado *et al*. 2011).

Quaternary aeolian systems reached altitudes of around 200 m (Meco *et al*., 2002). These older deposits have since cemented to form aeolianites (Torres, 1995) some of which are being reworked by contemporary wind action to yield sediment for the modern aeolian system. Examples of these dune systems occur at Jandía (Fuerteventura) (Figure 2B) and El Jable (Lanzarote) (Figure 2C).

Jandia (Fuerteventura)

The Jandía aeolian field (Figure 2B) extends across the island of Fuerteventura. Its contemporary 55 km^2 dune system is developed by reworking of the surface of a Quaternary aeolianite that rests on a Miocene volcanic substrate. Two calcrete horizons within the aeolianite dated at 13.8 Ka and 9.8 Ka (Rognon *et al*., 1989) indicate emplacement during early Holocene low sea levels. The upwind margin of the aeolianite field and the underlying basalt has been wave-eroded to form a 30 m-high sea cliff. This precludes any significant contemporary sediment input from the littoral zone (Alcantara-Carrio, 2003). Contemporary aeolian deposits comprise sand sheets and reversing dunes in the upwind source area with shadow dunes in the interior of the dunefield. The terminus of aeolian activity is found on the SE (downwind) side of the island where a wide prograding sandy beach has developed.

El Jable (Lanzarote)

This 21 km-long aeolian system (Figure 2C) occupies a total area of 90 km^2. It is gently sloping but rises to 200 m in places. Aeolian phases occurred throughout the Quaternary (Meco *et al*., 2002). Contemporary aeolian activity is now restricted to only a small section at the NE part of the island at Playa de Famara. Here, nebkhas at the coastal fringe give way to a southward migrating sand sheet within which some barchan dunes are migrating at >20 m/year (Cabrera Vega, 2010). Agriculture, mining, and other human activities have inhibited aeolian transport (Cabrera Vega, 2010; Cabrera Vega et al., 2013).

Conceptual model

An oceanic island-encapsulating dune system is characterised by three main zones: source, transport corridor and sink (Figure 6). The source area on the upwind side of the island usually comprises a narrow sand beach backed by a zone of hummock dunes (also known as nebkhas or coppice dunes) and a sand sheet.

Sand that blows through the hummocky dune zone continues landward as sand sheets lacking in vegetation. Localized accumulations of sand in this inland zone form barchans that migrate as discrete forms and occasionally, large accumulations of wind-blown sand create fields of transverse dunes.

An alternative to cross-island sand transport occurs when the sand is blown around the margin of the island. In such instances, the transport corridor consists of alternating headland-bypass dunes and embayed beaches with littoral drift following the aeolian transport corridor. Aeolian sand passes from the dune to beach and back again several times as it circumnavigates the island.

At the downwind side of the island, dunes migrate seawards, returning the sand to the littoral zone (Short and Jackson, 2013) and creating prograding beaches (e.g. Fuerteventura), multiple beachridges (Boa Vista) or subtidal sediment accumulations (Lanzarote). Whether the dune system takes an overland or circum-coastal route depends on the local topography. Topography also induces variability in the source and depositional zones. If the depositional area consists of a cliff, sediment flows into the ocean and accumulates subtidally (e.g. Lanzarote) on the shoreface (Backstrom *et al.* 2009). If a low-lying area is present, the sand accumulates as a prograding beach.

Quaternary island-encapsulating dune systems are evidenced by aeolianite whose distribution sometimes mimics the contemporary aeolian landforms in the Canary and Cape Verde archipelagos. In many instances weathering of the upper surface of Quaternary aeolianites liberates formerly bound sand grains that re-enter the sedimentary system.

DISCUSSION

The aeolian systems described here involve the transport of large volumes of littoral sediment across and/or around entire hot spot volcanic oceanic islands in appropriate settings and stages of development. They require several conditions:

- Adequate sand supply (contemporary sources or wind-reworking of Quaternary sand)
- A uni-directional (or strongly asymmetrical) wind field (all occur in trade wind locations)
- Arid conditions (more humid conditions encourage vegetation growth and inhibit transgressive dune development)

The development of significant aeolian deposits on these oceanic islands requires prolonged periods of erosion with attendant biogenic productivity to create the necessary sediment. Encapsulating dune systems are thus restricted to mature volcanic islands that persist due to low subsidence rates. They represent a distinctive geological phase of evolution in such island systems. Our global review shows coastal dunes to be very poorly developed or absent on most contemporary oceanic islands. This, in turn points to the existence of globally unique conditions in the study sites considered here. Chief among these conditions is the longevity of the archipelagos - both are located in areas of thick and slowly subsiding crust. We suggest that this element is critical in providing sufficient time to develop an original sediment volume (though weathering, erosion and biogenic productivity) capable of subsequent transport and re-distribution by wind.

The systems described bear some similarity to headland-bypass dunes (Boeyinga *et al*., 2010), however, they encompass entire islands and may traverse several topographic highs or alternating aeolian and wave transport phases. Transport pathways are determined by local relief and they may cross or circumscribe the island.

Human activities can impact severely on interconnected aeolian systems, modifying the natural processes or inhibiting them. Land use changes, especially due to urban development, have played an important role in the geomorphological and functional changes in the dune fields of the Canary Islands. Santana Cordero et al. (2016a) show how traditional human activities remobilized the dunefield of La Graciosa. In contrast, the same authors explain how urban expansion of the city of Las Palmas de Gran Canaria, has destroyed the dunefield of Guanarteme (Santana Cordero et al., 2006b). García-Romero et al. (2016) relate changes in some aeolian sedimentary systems of the Canary Islands to urban-touristic development. Other authors have examined direct or indirect changes in aeolian sedimentary landforms, by mining or construction on parts of the dunefields themselves (Cabrera Vega, 2010; Alonso et al., 2011; Cabrera-Vega et al., 2013; Hernández-Calvento et al., 2014).

Taking into account the model presented in this paper, the alteration of any of these dune components can impact on those parts of the system located downwind, altering both beach and dune phases. This is especially relevant in those islands where touristic development is currently expanding such as in Cape Verde.

Conclusion

Development of substantial aeolian dunes is a distinctive evolutionary phase of some oceanic island chains. The dunes are transported in the direction of net aeolian drift and form sedimentary systems that encapsulate entire islands. Understanding the sedimentary system of an entire island as a single system has important implications for development.

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Figure Captions

Figure 1. Location of the Canary and Cape Verde Islands. Inserts show predominant wind directions at both sites.

Figure 2. A) location and classification of the main aeolian sedimentary fields in the Canary Islands (modified from Alonso *et al*., 2011). Red circles identify the dune fields of Jandía (Fuerteventura) and El Jable (Lanzarote), showed in 2B) and C) respectively. White arrows indicate the direction of the sedimentary transport. D) Playa de Jandía (SE): leaking dunes (falling dunes) and beach. E) Playa de Famara (N El Jable) accretionary dunes (hummock) and human interferences (by urban area).

Figure 3. Various dune types; A) Hummocks N shore Boa Vista; B) Barchans migrating across Boa Vista; C) Deserto de Viana, Boa Vista; D) sediment accumulation in the form of a wide sandy beach backed by beachridges, indicating long-term progradation.

Figure 4: Displacement rates of barchan dunes and barchanoid ridges at Chave (W Boa Vista), top row, and Santa Monica (SW Boa Vista), lower row, between 1991 and 2015, calculated following the method proposed by Gay (1999). Red lines (left) are the brinks in 1991, identified by photo-interpretation; blue lines (center) are the brinks in 2015. The red straight vectors (right) indicate the distance between brinks (in each dune). This distance, divided by the number of years, provides the rates (m $year^{-1}$)

Figure 5. Aeolian sand passes from the dune to beach and back again several times as it circumnavigates the island (Boa Vista)

Figure 6. Conceptual model of an island-encapsulating dune system showing the two possible routes that large sediment transport systems may take on encountering volcanic islands. The overland scenario (1) results in several dune types as the sediment migrates over the land surface from one side of the island to the next following a largely linear direction. The circum-island route (2) involves successive littoral and terrestrial transport phases to eventual encapsulate the island as it transfers sediment around the island.

REFERENCES

Alonso, I., Hernández, L., Alcántara-Carrió, J., Cabrera Vega, L.L., Yanes, A., 2011. Los grandes campos de dunas actuales de Canarias. In: Sanjaume, E. and Gracia, J. (eds), *Las dunas en España*, 467-496.

Backstrom, J.T., Jackson, D.W.T. and Cooper, J.A.G. 2009. Shoreface morphodynamics of a high-energy, steep and geologically constrained shoreline segment in Northern Ireland. *Marine Geology* 257 (1), 94-106.

Boeyinga, J., Dusseljee, D.W., Pool, A.D., Schoutens, P. Verduin, F., van Zwicht, B.N.M., and Klein, A.H.F. 2010. The effects of a bypass dunefield on the stability of a headland bay beach: A case study. *Coastal Engineering*, 57 (2), 152-159.

Cabrera Vega, L.L. 2010. Sedimentología, estratigrafía, dinámica sedimentaria y evolución de El Jable (Lanzarote). Propuesta de gestión. PhD Thesis. Facultad de Ciencias del Mar. ULPGC.

Cabrera-Vega, L.L., Cruz-Avero, N., Hernández-Calvento, L., Hernández-Cordero, A.I., Fernández-Cabrera, E., 2013. Morphological changes in dunes as indicator of anthropogenic interferences in arid dune fields. *Journal of Coastal Research* SI 65: 1271-1276.

Carracedo, J.C. 1999. Growths, structure, instability and collapse of Canarian volcanoes and comparisons with Hawaiian volcanoes. *Journal of Volcanology and Geothermal Research*, 94: 1-19.

Carracedo, J.C., Pérez, F.J., Ancochea, E., Meco J., Hernán, F., Cubas C.R., Casillas, R., Rodriguez, E., Ahijado, A., 2002. Cenozoic volcanism II: The Canary Islands. In Gibbons, W., Moreno, T. (eds.) *The Geology of Spain*. The Geological Society of London, London, 439-472.

Carracedo, J.C., Tilling, R.I. 2003. *Geología y volcanología de islas volcánicas oceánicas (Canarias-Hawaii)*. Servicio de Publicaciones de la Caja General de Ahorros de Canarias, 73 p.

Criado C., Yanes A., Hernández Calvento L., Alonso I., 2011. Origen y formación de los depósitos eólicos en Canarias. In Sanjaume E. and Gracia F.J (eds.): *Las dunas en España*. Sociedad Española de Geomorfología, Madrid, 447-465.

García-Romero, L., Hernández-Cordero, A.I., Fernández-Cabrera, E., Peña-Alonso, C., Hernández-Calvento, L., Pérez-Chacón, E., 2016. Urban-touristic impacts on the aeolian sedimentary systems of the Canary Islands: conflict between development and conservation. *Island Studies Journal* 11 (1): 91-112.

Gay, S.P., 1999. Observations regarding the movement of barchan sand dunes in the Nazca to Tanaca area of Southern Peru, Geomorphology 27: 279-293.

Hernández-Calvento, L., Suárez, C., 2006. Characterization of the contemporary aeolian sediment dynamics of Boa Vista (Cape Verde). *Journal of Coastal Research* SI 48, 64-68.

Hernández-Calvento, L., Jackson, D.W.T., Medina, R., Hernández-Cordero, A.I., Cruz, N.; Requejo, S., 2014. Downwind effects on an arid dune field from an evolving urbanised area. *Aeolian Research* 15: 301-309.

Jackson, D.W.T., Cruz-Avero, N., Smyth, T., Hernandez-Calvento, L. 2013$_{a}$. 3D airflow modelling and dune migration patterns in an arid coastal dune field. *Journal of Coastal Research*, SI 65. pp. 1301-1306.

Jackson, D.W.T., Beyers, M., Delgado-Fernandez, I. Baas, A.C.W., Cooper, J.A.G., Lynch, K. 2013$_{b}$. Airflow reversal and alternating corkscrew vortices in foredune wake zones during perpendicular and oblique offshore winds. *Geomorphology*, 187, 86-93.

Meco, J., Guillou, H., Carracedo, J.C., Lomoschitz, A., Ramos, A.J.G. and Rodriguez-Yánez, J.J. 2002. The maximum warmings' of the Pleistocene world climate recorded in the Canary Islands. *Palaeogeography, Palaeoclimatology,Palaeoecology*, 185 (1-2): 197-210.

Ramalho, R. A. S. 2011. Building the Cape Verde Islands, 1st ed., Springer, Berlin, Heidelberg.

Ramalho, R. A. S., Brum da Silveira, A., Fonseca, P. E., Madeira, J., Cosca, M. Cachao, M. Fonseca, M., Prada, S. N. 2015. The emergence of volcanic oceanic islands on a slow-moving plate: The example of Madeira Island, NE Atlantic, Geochem. Geophys. Geosyst., 16, doi:10.1002/2014GC005657.

Rognon, P., Coudé-Gaussen, G., Le Coustumer, M.N., Balouet, J.C., Occhietti, S. 1989. Le massif dunaire de Jandia (Fuerteventura, Canaries): Ëvolution des paléoenvironements de 20000 BP à l'actuel. *Bulletin de l'Assocation française pour l'étude du Quaternaire* 1, 31-37.

Santana-Cordero, A., Monteiro-Quintana, M.L., Hernández-Calvento, L.; Pérez-Chacón Espino, E.; García Romero, L., 2016a. Long-term human impacts on the coast of La Graciosa, Canary Islands. *Land Degradation & Development* 27: 479-489.

Santana-Cordero, A.M., Monteiro-Quintana, M.L., Hernández-Calvento, L., 2016b. Reconstruction of the land uses that led to the termination of an aridcoastal dune system: The case of the Guanarteme dune system (Canary Islands, Spain), 1834-2012. *Land Use Policy* 55: 73-85.

Short A.D., and Jackson D.W.T. 2013. Beach Morphodynamics. In: John F. Shroder (ed.) *Treatise on Geomorphology*, Volume 10, 106-129. San Diego: Academic Press.

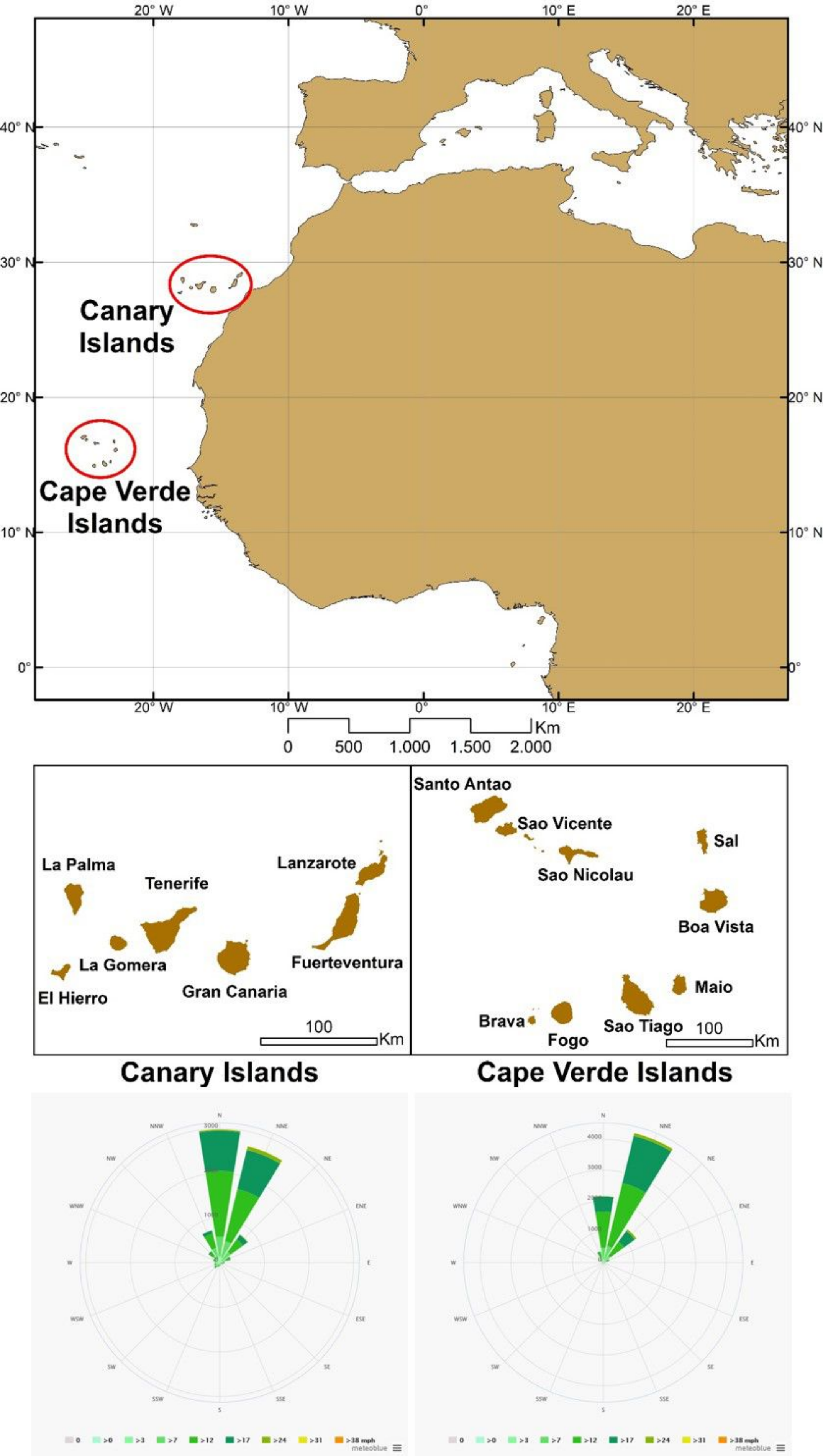
Torres J.M. 1995. *El suelo como recurso natural: Procesos de degradación y su incidencia en la desertificación de la isla de Fuerteventura.* PhD Thesis. Departamento de Edafología y Geología de la Universidad de La Laguna.

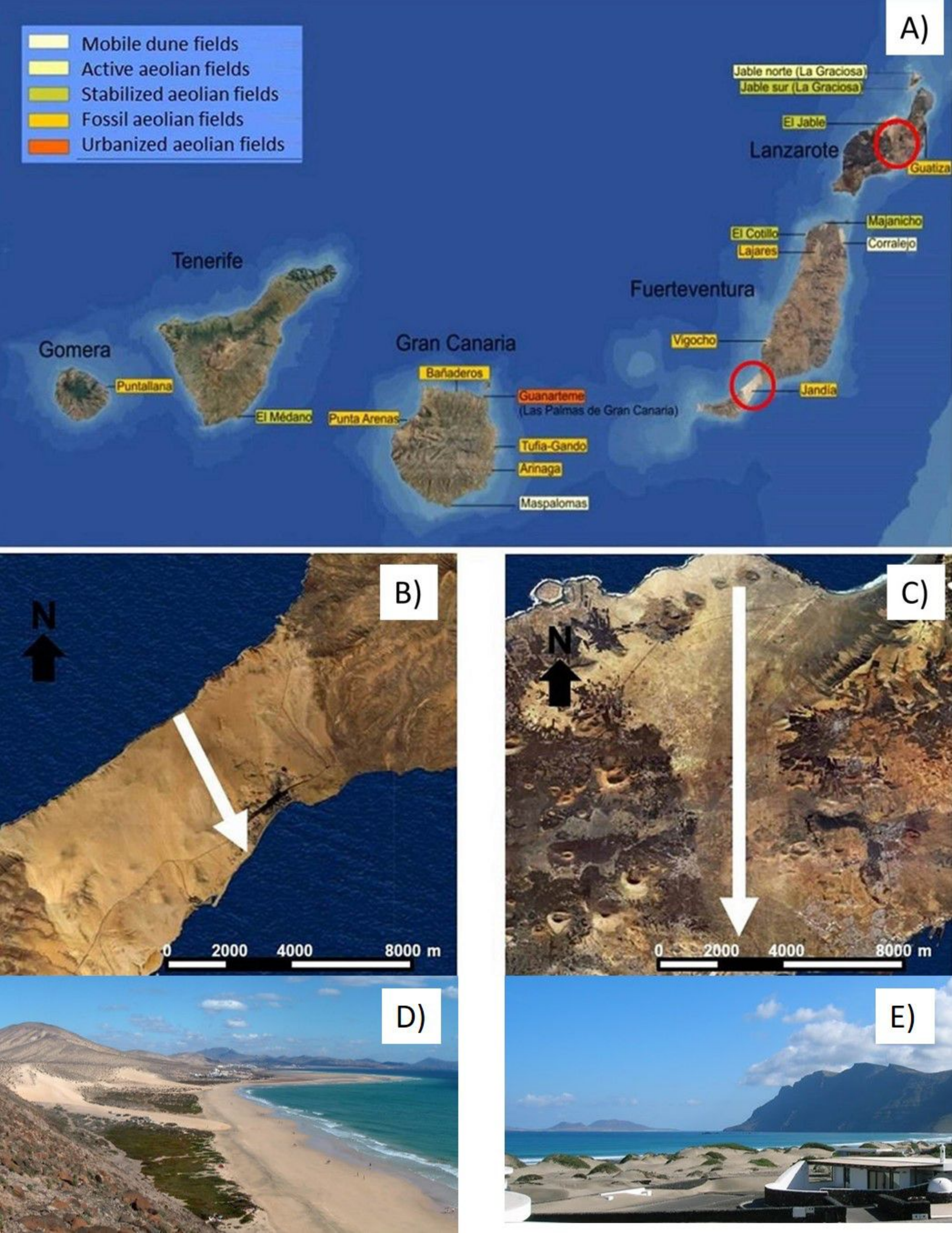
Table 1. Photos and images used

Place	Date	Source	Class	Scale / spatial resolution
Canary Islands (Fuerteventura and Lanzarote)	1977, 1987	ULPGC	Aerial photos	1/18.000
	1998, 2002, 2004, 2008, 2009, 2011, 2012, 2013, 2014, 2015	SDI Canary Islands	Orthophotos	1/5.000 – 1/18.000 (original aerial photos)
	2000, 2003, 2006, 2007, 2015	Google Earth	Satellite images and orthophotos	1 m/pixel – 0.6 m/pixel
Cape Verde Islands (Boa Vista)	1991	ULPGC	Aerial photos	1/15.000
	2003	SDI Cape Verde	Orthophoto	1/28.000 (original aerial photos)
	2005, 2010, 2011, 2012, 2013, 2015, 2016	Google Earth	Satellite images and orthophotos	1 m/pixel – 0.6 m/pixel

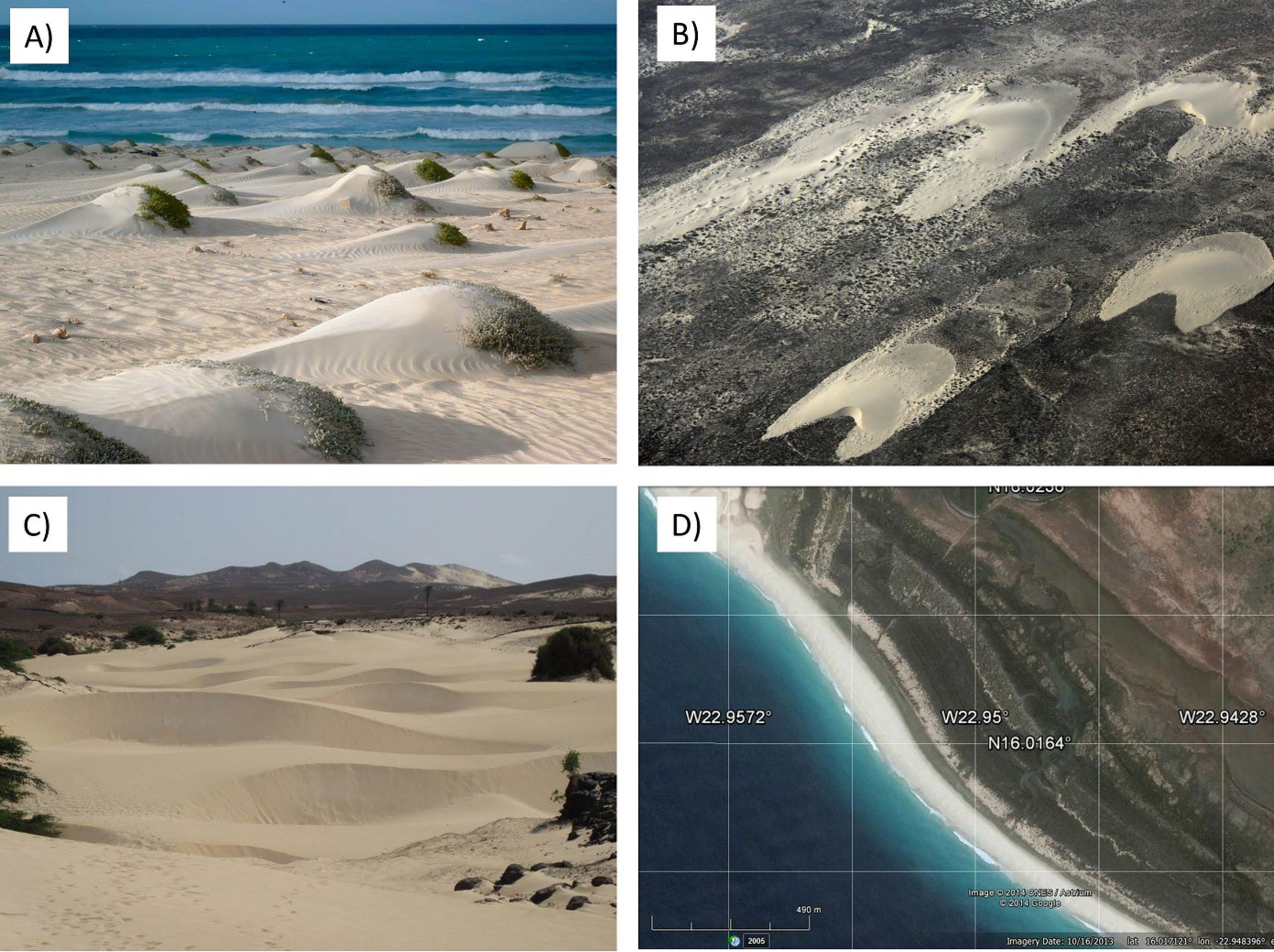
Table 2: Maxima, minima and average displacement rates of the dunes of Boa Vista.

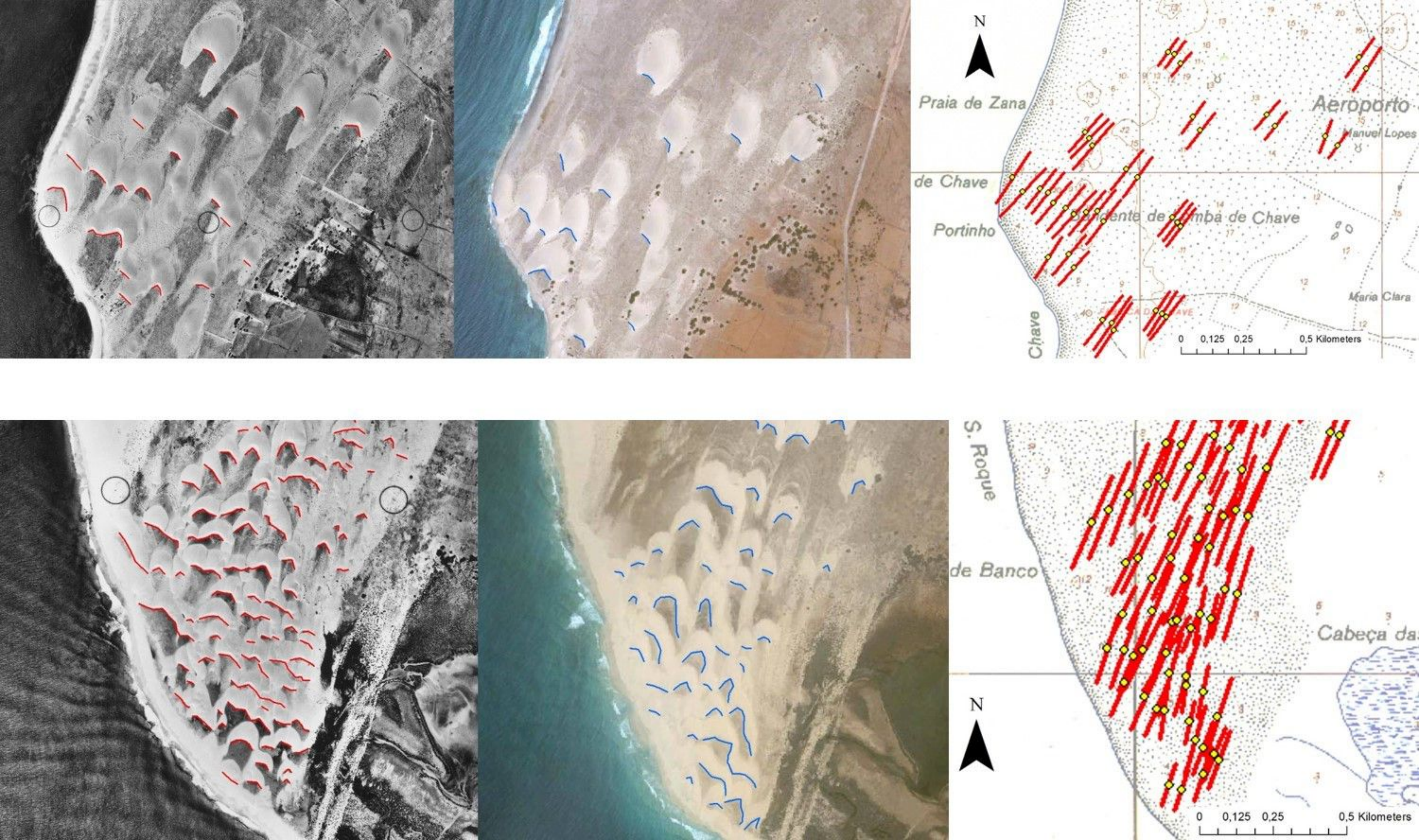
Place	**Rate (m/year)**		
	Max	Min	Average
Chave (W)	19.56	9.11	14.68
Santa Mónica (SW)	27.69	10.30	19.73


20° W
10° W
0°
10° E
20° E
40° N
30° N
20° N
10° N
0°
Canary Islands
Cape Verde Islands
Km
0
500
1.000
1.500
2.000
La Palma
Tenerife
Lanzarote
La Gomera
El Hierro
Gran Canaria
Fuerteventura
100
Km
Santo Antao
Sao Vicente
Sal
Sao Nicolau
Boa Vista
Maio
Brava
Fogo
Sao Tiago
100
Km
Canary Islands
Cape Verde Islands
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
>0
>3
>7
>12
>17
>24
>31
>38 mph
meteoblue



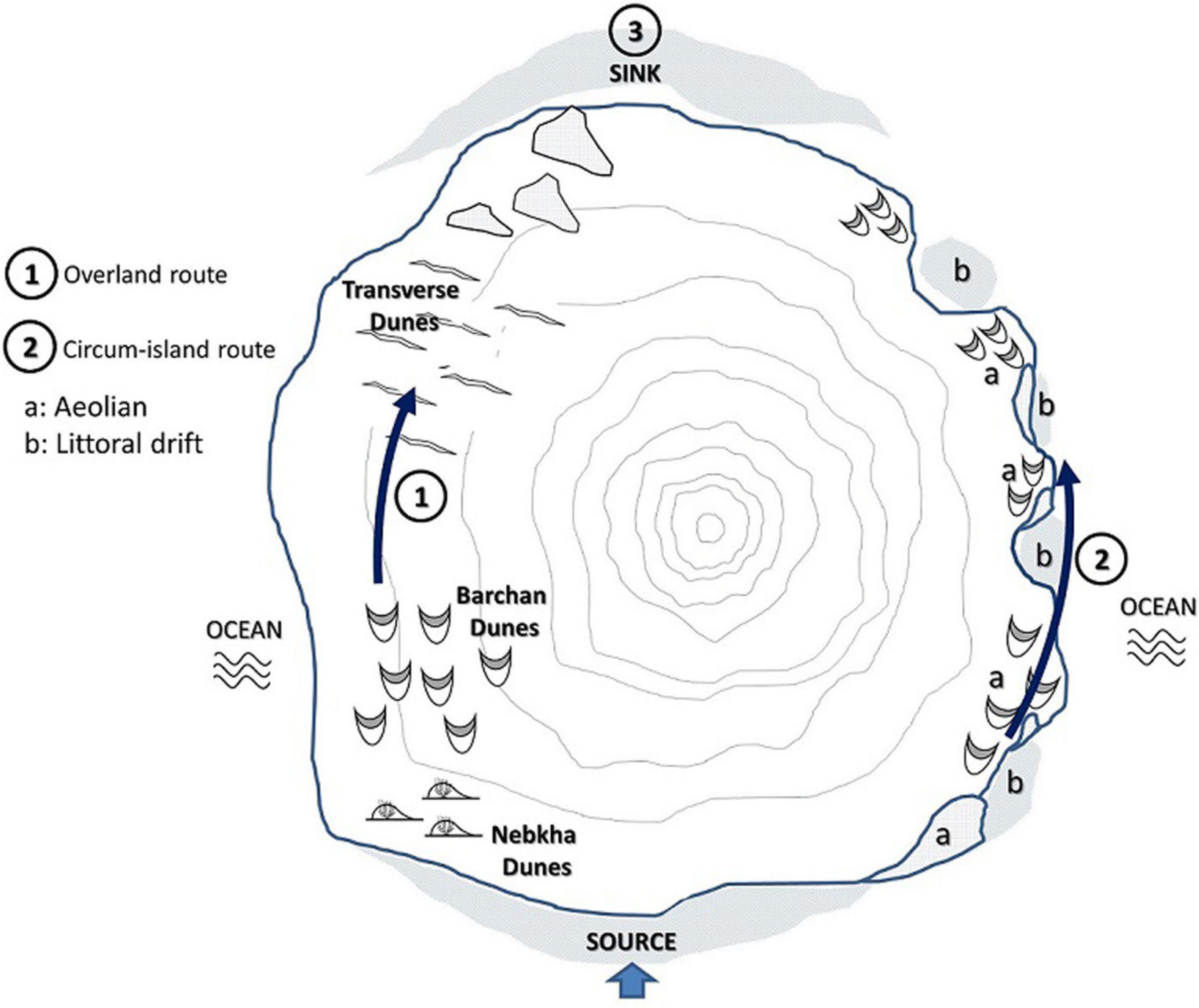
A)
Mobile dune fields
Active aeolian fields
Stabilized aeolian fields
Fossil aeolian fields
Urbanized aeolian fields
Jable norte (La Graciosa)
Jable sur (La Graciosa)
El Jable
Lanzarote
Guatiza
Majanicho
El Cotillo
Corralejo
Lajares
Fuerteventura
Tenerife
Vigocho
Gran Canaria
Gomera
Bañaderos
Jandía
Puntallana
Guanarteme
(Las Palmas de Gran Canaria)
El Médano
Punta Arenas
Tufia-Gando
Arinaga
Maspalomas
B)
N
0 2000 4000 8000 m
C)
N
0 2000 4000 8000 m
D)
E)


A)
B)
C)
D)
W22.9572°
W22.95°
W22.9428°
N16.0164°
Image © 2014 CNES / Astrium
© 2014 Google
490 m
2005
Imagery Date: 10/16/2013 lat 16.017121° lon -22.948396°



N
Praia de Zana
Aeroporto
Manuel Lopes
de Chave
Portinho
Chave
Maria Clara
0 0,125 0,25 0,5 Kilometers
S. Roque
de Banco
N
0 0,125 0,25 0,5 Kilometers


N
Beach phase
Sal Rei
Dune phase
Beach phase
Dune phase
A
Rabil
Beach phase
Dune phase
B
0
1.25
2.5
5 Kilometers



3
SINK
1 Overland route
2 Circum-island route
a: Aeolian
b: Littoral drift
Transverse Dunes
Barchan Dunes
Nebkha Dunes
OCEAN
OCEAN
1
2
a
b
SOURCE