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Quaternary sea-level history and the origin of the northernmost coastal aeolianites in the Americas: Channel Islands National Park, California, USA

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ABSTRACT

Along most of the Pacific Coast of North America, sand dunes are dominantly silicate-rich. On the California Channel Islands, however, dunes are carbonate-rich, due to high productivity offshore and a lack of dilution by silicate minerals. Older sands on the Channel Islands contain enough carbonate to be cemented into aeolianite. Several generations of carbonate aeolianites are present on the California Channel Islands and represent the northernmost Quaternary coastal aeolianites on the Pacific Coast of North America. The oldest aeolianites on the islands may date to the early Pleistocene and thus far have only been found on Santa Cruz Island. Aeolianites with well-developed soils are found on both San Miguel Island and Santa Rosa Island and likely date to the middle Pleistocene. The youngest and best-dated aeolianites are located on San Miguel Island and Santa Rosa Island. These sediments were deposited during the late Pleistocene following the emergence of marine terraces that date to the last interglacial complex (~120,000 yr to ~80,000 yr). Based on radiocarbon and luminescence dating, the ages of these units correspond in time with marine isotope stages [MIS] 4, 3, and 2. Sea level was significantly lower than present during all three time periods. Reconstruction of insular paleogeography indicates that large areas to the north and northwest of the islands would have been exposed at these times, providing a ready source of carbonate-rich skeletal sands. These findings differ from a previously held concept that carbonate aeolianites are dominantly an interglacial phenomenon forming during high stands of sea. In contrast, our results are consistent with the findings of other investigators of the past decade who have reported evidence of glacial-age and interstadial-age aeolianites on coastlines of Australia and South Africa. They are also consistent with observations made by Darwin regarding the origin of aeolianites on the island of St. Helena, in the South Atlantic Ocean, more than a century and a half ago.

1. Introduction

"Aeolianite" is a term that originated with Sayles (1931), based on his studies on Bermuda, where such deposits make up the bulk of the island's subaerially exposed parts. Sayles (1931) defined aeolianite as any wind-deposited sediment that is cemented into rock. Thus, in principle, pre-Quaternary, continental-interior, silica-cemented, quartzose sandstones with an aeolian origin could be considered "aeolianite." In practice, however, the term has been restricted to precisely the kind of sediments that Sayles (1931) studied on Bermuda, namely carbonate-cemented aeolian sand of Quaternary age along coastlines. Such deposits are not extensive over large areas except in Australia (see Playford et al. 2013; Brooke et al. 2014, and Bourman et al. 2016), nor are they on a par volumetrically with silicate-rich dune fields or sand seas (Fig. 1). However, they have a widespread occurrence globally and are found at multiple localities, primarily in subtropical to temperate latitudes (between about 15° and 40°, both north and south of the equator; Brooke 2001), and they occur in some tropical latitudes as well.

Darwin observed and described aeolianites in southwestern Australia, South Africa, St. Helena, and Ascension Island on his voyage on HMS *Beagle* in the 1830s (see discussion in Fairbridge 1995). Since then, many researchers have studied aeolianites worldwide, resulting in a large number of publications summarized in reviews by Fairbridge and Johnson (1978), Gardner (1983), McKee and Ward (1983), Fairbridge (1995), Brooke (2001), Loope and Abegg (2001), Bird (2005), McLaren (2007), Playford et al. (2013), Brooke et al. (2014), and Bourman et al. (2016). Authors in the present study have examined

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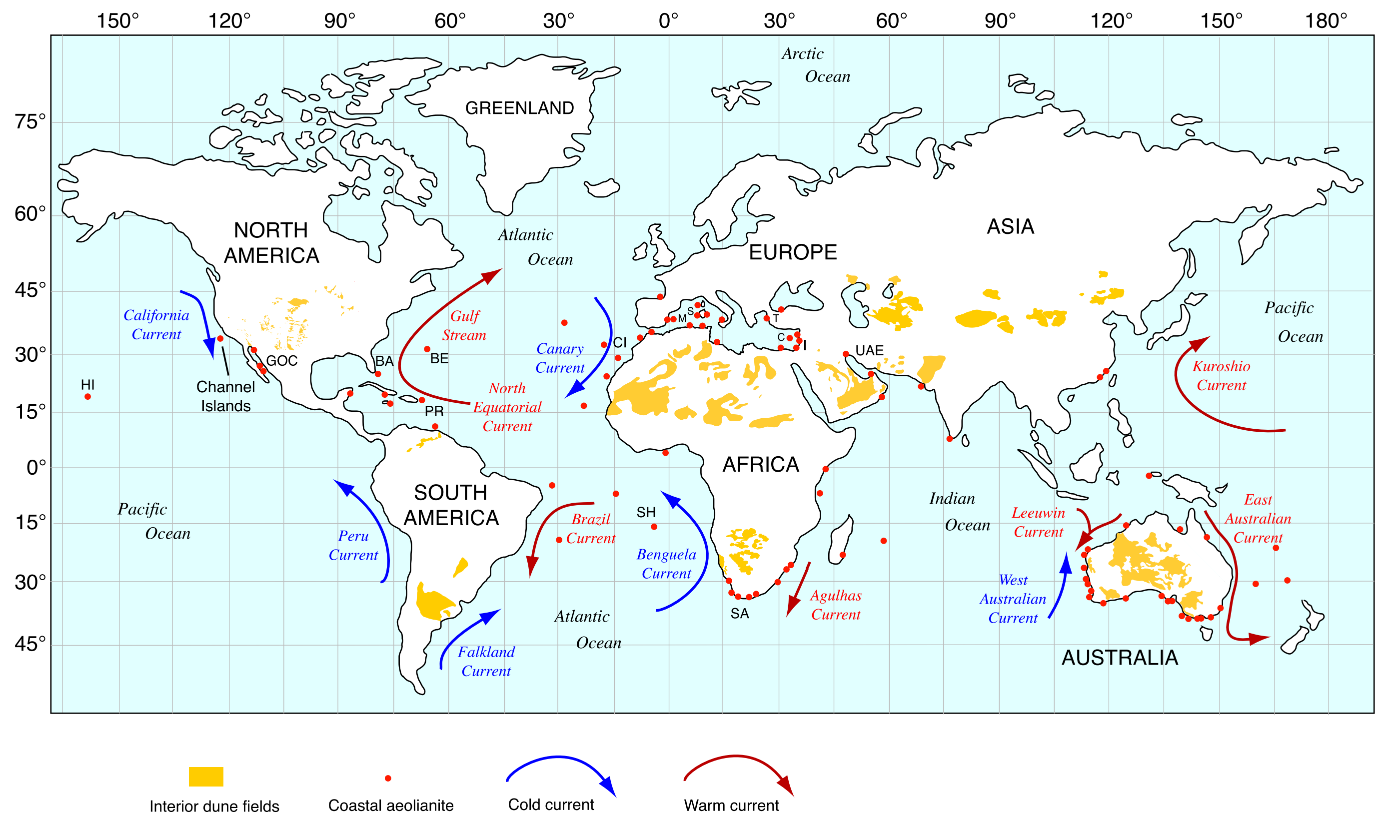

Fig. 1. Map showing the global distribution of aeolian sand, whether active or stabilized (gold pattern) and coastal carbonate aeolianite (filled red circles). Also shown are major cool and warm currents along continental margins. Currents around Australia taken from Murray-Wallace et al. (2000; their Fig. 3). Abbreviations of selected aeolianite localities referred to in text: HI, Hawaii; GOC, Gulf of California, Mexico (Johnson and Backus 2009); BA, Bahamas; PR, Puerto Rico; BE, Bermuda; SH, St. Helena; SA, South Africa; CI, Canary Islands; M, Mallorca; S, Sardinia; I, Israel; UAE, United Arab Emirates; C, Cyprus (Milàn et al. 2015); T, Turkey (Kiyak and Erginal 2010; Erginal et al. 2013). Distribution of aeolianite from Fairbridge and Johnson (1978), Brooke (2001) and sources therein, as well as personal observations of the authors. Distribution of interior dune fields from the following sources: northern Africa, Wilson (1973); southern Africa, Lancaster (1989) and Thomas and Shaw (1991); Sinai-Negev, Muhs et al. (2013); Arabian Peninsula and India, Wilson (1973); Central Asia, Maman et al. (2011); the Americas and China, Sun and Muhs (2007) and sources therein; Australia, Bowler et al. (2001). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

aeolianites on Bermuda, the Bahamas, Puerto Rico, the Canary Islands, Mallorca, Sardinia, Israel, the United Arab Emirates, South Africa, Hawaii, around the Gulf of California, Mexico, and on the California Channel Islands, the focus of the current study.

Aeolianites are common on islands, where bank or shelf sediments are characterized by high biological productivity and detrital carbonate grains are not diluted by continental siliceous sediment (Fig. 1). This explains the extensive aeolianites on Bermuda, the Bahamas, Caribbean islands, the Canary Islands, and Mediterranean islands, among others. An important exception to this is Australia, where aeolianites are extensive, but also where streams provide very little silicate sand to beaches and continental shelves, which are rich in biogenic carbonate particles (Collins 1988; James and Bone 2011; Brooke et al. 2014; Murray-Wallace 2014; Short 2014; Bourman et al. 2016).

Common to all aeolianites is a relatively high carbonate content compared to typical silicate-mineral-dominated aeolian sands. In Australia, aeolianites of the Bridgewater Formation have carbonate contents (by volume) of 66–99% (Blakemore et al. 2015). Aeolianites on Mallorca have carbonate contents as high as 90–95% (Muhs et al. 2010) and those on Bermuda range from 94 to 99% (Muhs et al. 2012a). On the Bahamas, aeolianites we have studied are 100% calcium carbonate. Clastic skeletal aragonite and calcite particles comprise much of the carbonate component of aeolianites worldwide, but in addition, secondary, low-Mg calcite is the main cementing agent. Skeletal carbonate grains can be derived from mollusks, echinoderms, corals, algae, or foraminifera, but in some places (notably the Bahamas), they are composed of inorganically precipitated aragonite ooids or peloids. In other environments, such as on Mallorca, they are composed of both skeletal carbonate grains and detrital sands derived from pre-Quaternary limestones. In still other environments, although well cemented, aeolianites are low in carbonate content. For example, some aeolianites on the Mediterranean coast of Israel have as little as 15–30% carbonate content (Porat et al. 2004), although others in that region have 42–54% carbonate (Yaalon 1967).

Geomorphically, aeolianites are often expressed as transverse or parabolic dunes (e.g., Murray-Wallace et al. 2010; Nichol and Brooke 2011; Playford et al. 2013; Bourman et al. 2016; Brooke et al. 2017), as is the case with many other coastal dunes. Because of early carbonate cementation, primary sedimentary structures, such as crossbeds, often show spectacular preservation, and thus allow for easy reconstruction of paleowinds, based on foreset bed dip azimuths. Secondary structures are also common in aeolianites, and consist of carbonate root casts (rhizoliths), carbonate fracture-fills, and paleosols. As with other aeolian sands, paleosols mark periods of land-surface stability and vegetation cover, during times when aeolian deposition had ceased or was at least minimal. Similar to calcareous loess deposits, land snails are commonly found in aeolianites, and are often well preserved in the carbonate-dominated host sediment.

The relation between aeolianite formation and sea level has been controversial (see reviews in Fairbridge and Johnson 1978; Gardner 1983; Fairbridge 1995; Brooke 2001; McLaren 2007; Brooke et al. 2014), and concepts have evolved considerably over time. The idea that at least some aeolianites could have formed during periods of lower sea level (i.e., glacial periods) can be found in studies dating as far back as the 19th century. Darwin (1844) studied these deposits on the island of St. Helena in the southern Atlantic Ocean, on the return voyage of