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Natural and human controls of the Holocene evolution of the beach, aeolian sand and dunes of Caesarea (Israel)

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A B S T R A C T

The study focuses on the Holocene appearance, chronology and drivers of beach sand deposition and inland aeolian sand transport around the Roman–Byzantine ruins of Caesarea, Israel. Beach sand, sand sheets, nebkha, linear and transverse dunes as well as parabolic and transverse interdunes along two transects were sampled in the current study down to their substrate.

Sixteen new optically stimulated luminescence ages cluster at ~5.9–3.3 ka, ~1.2–1.1 ka (800–900 AD) and ~190–120 years ago (1825–1895 AD) indicating times of middle and late Holocene sand sheet depositions and historical dune stabilization. The first age cluster indicates that beach sand accumulated when rates of global sea level rise declined around 6–5 ka. Until ~4 ka sand sheets encroached up to 2.5 km inland. Historical and archaeological evidence points to sand mobilization since the first century AD. Sand sheets dating to 1.2–1.1 ka, coevally found throughout the dunefield represent sand stabilization due to vegetation reestablishment attributed to gradual and fluctuating decline in human activity from the middle Early Islamic period until the 10th century. Historical and chronological evidence of the existence of transverse and coppice dunes from the 19th century suggest that dunes only formed in the last few centuries.

The study illustrates the initial role of natural processes, in this case decline in global sea level rise and the primary and later role of fluctuating human activity upon coastal sand mobility. The study distinguishes between sand sheets and dunes and portrays them as sensors of environmental changes.

1. Introduction

1.1. Forcing factors of coastal dune evolution

There is a growing recognition of the contribution of the study of dunes for palaeoenvironmental and palaeoclimatic reconstructions (González-Villanueva et al., 2013; Telfer and Hesse, 2013; Long, 2014). Understanding the timing of the development of sandy beaches and spreading and stabilization of coastal dunefields is crucial for interpreting past coastal environments and climates, important for ecological management, and beneficial for interpreting coastal archaeology (Parker and Goudie, 2008; Davis et al., 2009; Bar, 2013).

Where topography is flat to undulating, the triggers of the timing and rates of sand and dune encroachment inland from lake and sea beaches include sea level change, sand supply, climate forcing, such as seasonal windiness and storminess, and devegetation due to drought or human activity. In general, sea level change is a primary control on the timing of coastal dune-field construction.

Determining a connection between coastal sand and dune growth and glacial sea level change, climatic cycles, anthropogenic disturbances and consequent sand supply is complex. Attempts to establish relationships between the accumulation of Holocene dunes in Europe with either marine transgressions or regressions have met with controversy (Bakker et al., 1990). Rowe and Bristow (2015) suggested low-order oscillating sea levels as a main driver for Pleistocene coastal dune construction in Bermuda.

In some regions the relationship between time and climate forcing affecting coastal dune development is evident. European coastal dunes offer abundant stratigraphic evidence for century- to millennial-scale climate forcing (Clemmensen et al., 2009;

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Costas et al., 2012; French and Burningham, 2009). In other settings, such as Israeli (Almagor and Perath, 2012) and Australian coastal dunefields (Lees, 2006), interpretations of dune mobilization and stabilization are difficult, as they are controlled by various drivers. Shifts in vegetation cover are suggested as facilitating transgressive dune dissection and inland sand migration beyond foredunes (Tsoar, 1990; Danielsen et al., 2012). Altogether, the hierarchy of dune driving triggers is not always fully understood, and may differ according to setting and dune type (Lees, 2006).

1.2. The southeastern Mediterranean Sea coastal zone and dunefields

The coastal zone of Israel is an ideal location for studying coastal dune system responses since the late Quaternary, due to its quite uniform geological, sedimentological and climatic setting (Fig. 1a and b). The Israeli coast is considered tectonically relatively stable (Tibor and Ben-Avraham, 1992; Galili and Sharvit, 1999; Sivan et al., 2001, 2004, 2010; Steinberg et al., 2011), it is a microtidal, high wave-energy coast (Emery and Neev, 1960) and Holocene sea levels track global eustatic sea-level changes. Since 6 ka sea levels have not substantially oscillated let alone Byzantine and Middle Age oscillations of up to several tens of centimeters (Sivan et al., 2001, 2004; Toker et al., 2012). The position of the shoreline along the coast of Israel is in a state of dynamic stability since the early 20th century (Klein et al., 2014) although offshore sedimentological disturbance due to the Nile River damming, Nile Delta destruction and coastal land cover change has been identified at the deeper continental shelf (Bookman et al., 2015).

The sediments of the exposed and submerged coastal zone of Israel since the Pliocene have largely been supplied by a single dominant source, the River Nile, leading to the formation of a broad and shallow marine shelf (Emery and Neev, 1960). Sand availability of the coastal zone of Israel is attributed to longshore current transport along the southeastern Mediterranean (SE-Med) coast (Nir, 1989) (Fig. 1b). Sediment flux by longshore transport gradually decreases from south to north, ending in Haifa Bay (Almagor et al., 2000).

The SE-Med coast has accumulated broad and thick Nilotic sand sequences in the form of aeolianites, sand units and dunes (Picard, 1943; Gvirtzman and Wieder, 2001; Almagor and Perath, 2012). The sand of all of these units is medium to fine-grained and quartz-rich (Almagor and Perath, 2012), and heavy mineral distributions are dominated by plutonic minerals (Greenberg, 1976). Nilotic sand blowing inland developed into dunes, which fossilized into a series of aeolianite (locally known as *kurkar*) ridges. Up to 18 exposed and submerged ridges run parallel to the current coastline, and are the main relief feature of the coast (Almagor et al., 2000; Mauz et al., 2013 and references within). Aeolianite ridges near the current shore line are dated to the Middle and Late Pleistocene (Porat et al., 2004; Sivan and Porat, 2004; Mauz et al., 2013). Upon and within the aeolianites are thick red sandy loam soils (Chromic Luvisol (WRB) (USDA: Rhodoxeralts) locally known as *hamra* (Dan et al., 1964; Tsatskin et al., 2008).

The coastal dunes extending 3–6 km inland from the SE-Med coast are the most dynamic landforms of the modern Israeli coast (Fig. 1c). The dunes unconformably overlay the aeolianite ridges

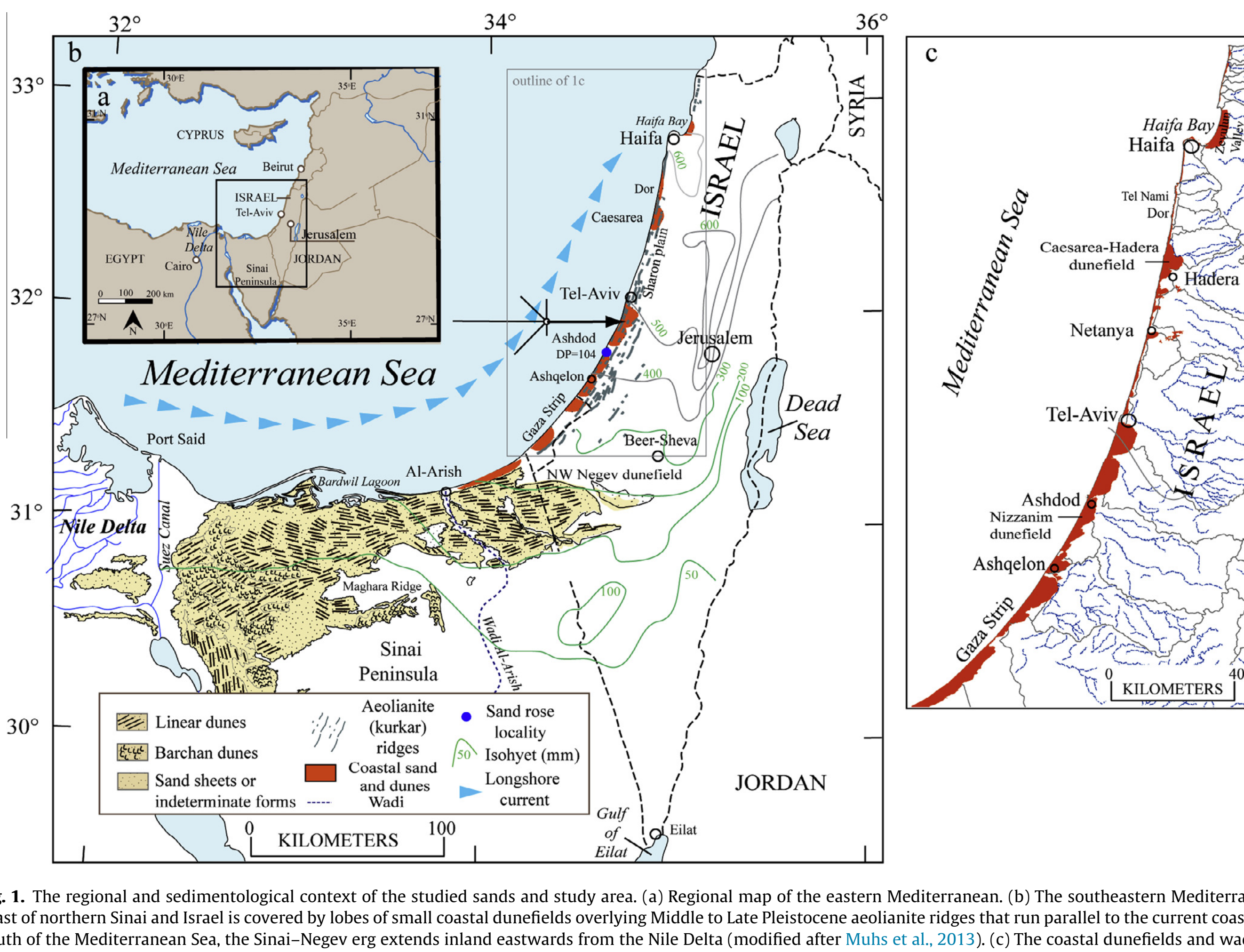

Fig. 1. The regional and sedimentological context of the studied sands and study area. (a) Regional map of the eastern Mediterranean. (b) The southeastern Mediterranean coast of northern Sinai and Israel is covered by lobes of small coastal dunefields overlying Middle to Late Pleistocene aeolianite ridges that run parallel to the current coastline. South of the Mediterranean Sea, the Sinai–Negev erg extends inland eastwards from the Nile Delta (modified after Muhs et al., 2013). (c) The coastal dunefields and wadis of western Israel based on the digitized GIS soil map of Israel (1:50,000 scale) (after Dan et al., 1972).