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Late Holocene cliff-top dune evolution in the Hengchun Peninsula of Taiwan: Implications for palaeoenvironmental reconstruction

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ABSTRACT

The Fung-Chuei-Sha (FCS) cliff-top dunes, the only coastal cliff-top dunes known in Taiwan, are situated on a 70 m high, tectonically uplifted Quaternary marine terrace surface in the Hengchun Peninsula of southern Taiwan. The development of the FCS dune and its relationship with palaeoenvironmental changes are still unknown. The optically stimulated luminescence (OSL) dating approach utilizing a pIRIR150 (post infrared, infrared stimulated luminescence at 150 °C) single aliquot regenerative (SAR) dose protocol for K-rich feldspar, in combination with radiocarbon dates and high resolution sedimentological analyzes, have proven to be a powerful tool for reconstructing the depositional history of the FCS dune and the related palaeoenvironmental conditions during the late Holocene. This study identified three major aeolian sediment accumulation periods at ~4 ka to ~2.3 ka, ~1.8 ka to ~1.1 ka, and ~0.7 ka to ~0.4 ka, which are consistent with the cold/cooling periods identified from the palaeoclimate record of the Dongyuan Lake in southern Taiwan. Two palaeosurfaces and two short interruptions of sand accumulation indicate periods of surface stabilization at the FCS site. The OSL ages and radiocarbon ages from the dune, and the palaeoclimate data from Dongyuan Lake suggest that these surfaces developed at ~4.3 ka, ~2 ka, ~1 ka and ~0.3 ka. The palaeoclimatic conditions inferred from the FCS dunes are largely consistent with those reconstructed for the coastal dunes of the Fulong Beach area in northeastern Taiwan. This may indicate an over-regional pattern of dune formation primarily driven by strong winds of the Asian Winter Monsoon as the primary forcing factor for coastal dune development in Taiwan during the late Holocene.

1. Introduction

The term cliff-top dune (also called bluff-top dune or perched dune) describes a type of dune sitting on top of a scarp. Such dunes develop as a consequence of cliffs interfering with airflow that leads aeolian sediment to be transported upward, and to be accumulated on the top of coastal or lake cliffs (Tsoar, 2001). Cliff-top dunes have been described to occur in different environmental settings worldwide. Previous studies indicate that relative sea-level change (Jennings, 1967; Pye and Tsoar, 1990; Blumer et al., 2012), sediment source and supply (Jennings, 1967; Saye et al., 2006; Haslett et al., 2000), wind regime changes (Clemmensen et al., 2001; Germain et al., 2009), and cliff morphology (Tsoar, 1983; Tsoar et al., 1996) are the main factors that control the formation of cliff-top dunes.

The aim of this study is to reconstruct the palaeoenvironmental conditions that led to the formation of the Fung-Chuei-Sha (namely "wind-blown sand" in Chinese) dune, which is the only coastal cliff-top dune known in Taiwan (Fig. 1), and to correlate the palaeoenvironmental record with relevant archives throughout Taiwan. The cliff-top dune is situated on a 70 m-high, tectonically uplifted Quaternary marine terrace surface in the Hengchun Peninsula of southern Taiwan (Fig. 2). It is a famous geomorphological site in the Kenting National Park. The understanding of the landscape evolution of the Fung-Chuei-Sha cliff-top dune and the surrounding area is still poor. In a guidebook of the Kenting National Park, Wang (2009) cited several of Jennings' development models of cliff-top dunes, but did not clearly indicate which model could reasonably explain the development of the FCS cliff-top dunes. The palaeoenvironmental conditions as well as the timing of the dune development are still unknown.

For the reconstruction of past climatic and environmental conditions, terrestrial gastropod assemblages were analyzed. Compared with other coastal dunes in the nearby areas, a unique feature of the Fung-Chuei-Sha cliff-top dune is that the cliff-top aeolian deposits contain relatively large amounts of small terrestrial gastropod shells exposed in

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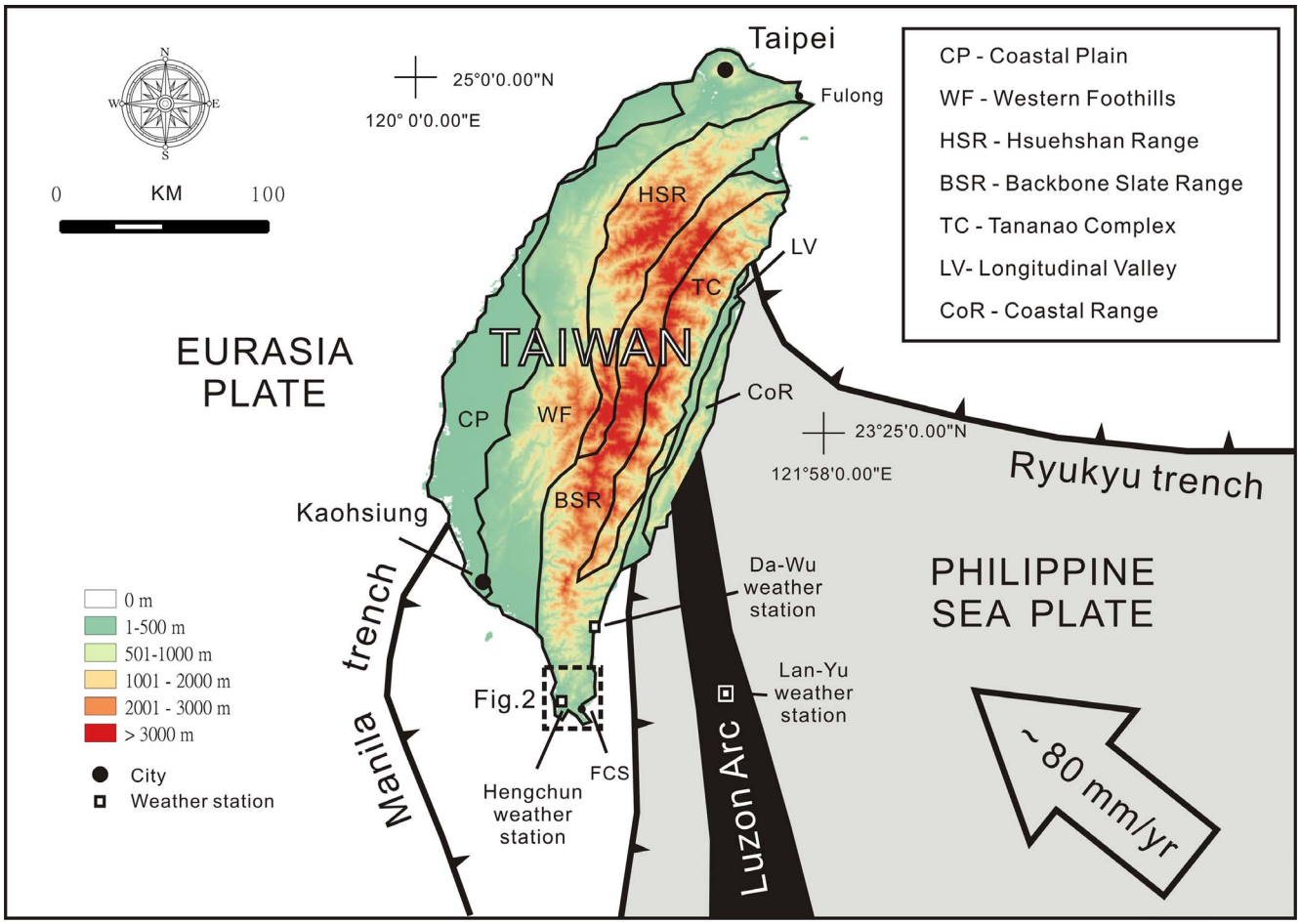

Fig. 1. Geographic locations, tectonic setting and major geological areas of Taiwan. Hengchun Peninsula is marked by black dotted box in the diagram.

a 6-m excavated profile. The terrestrial gastropod shells not only provide important environmental information of the past (Lauriol et al., 2002), but can also be used for radiocarbon dating to establish a chronological framework of the cliff-top dune development. However, as radiocarbon ages from terrestrial gastropod shells may be problematic (Goodfriend et al., 1999; Mastronuzzi and Romaniello, 2008; Pigati et al., 2010), we also applied optically stimulated luminescence dating using feldspar as a chronometer in order to establish an independent chronology and to cross check the reliability of the radiocarbon ages determined from the land snail shells.

This paper describes the analytic results of cliff morphology, stratigraphic observation of the excavated profile, grain-size and carbonate content of the aeolian deposits, terrestrial gastropod assemblages, and numerical ages from ^{14}C and OSL analyzes. We use these results to derive a late Holocene landscape evolution model of the Fung-Cheui-Sha cliff-top dune, and discuss the palaeoenvironmental implications on a local and over-regional scale.

1.1. Geological and geomorphological settings of the research area

The island of Taiwan, crossed by the Tropic of Cancer, is located off southeastern China (Fig. 1). The convergence between the continental margin of the Eurasian plate and the Luzon arc, a part of the oceanic Philippine Sea plate, led to the Taiwan arc–continent collision that created the island (Fig. 1). The collision started around 6.5 Ma ago, and the emergence of the Central Mountain belts and coupling with surface processes became efficient after 5 Ma in northern Taiwan and not before 3.5 Ma in southern Taiwan (Mesalles et al., 2014). The southward-propagating mountain-building makes the Hengchun Peninsula the most recently emerged region in Taiwan (Chang et al., 2003; Giletycz et al., 2015).

The southernmost part of the Central Range is the backbone of the Hengchun Peninsula (Fig. 2a) and mainly consists of rocks of the Mutan formation and the Kenting formation (Fig. 2b). Well-developed Pleistocene and Holocene marine terraces can be found along the southern coast of the peninsula (Fig. 2c). These marine terraces are built up by rocks of the Kenting formation and the Plio-Pleistocene Kenting Limestone. They are widely found to be covered with late Pleistocene gravels in which typical red soil developed. The topmost sediments consist of the most recent Holocene aeolian deposit (Fig. 2b). Uplift rates of around 3–4 mm/year during the late Pleistocene and 1.8–3.5 mm/yr during the Holocene were reconstructed from the uplifted marine terraces by previous authors (Cheng and Huang, 1975; Hsu, 1986; Liew and Lin, 1987; Chen and Lee, 1990; Chen and Liu, 1993; Wang and Burnett, 1990).

The Fung-Chuei-Sha cliff-top dunes are sitting on top of a tectonically uplifted Pleistocene marine terrace (Fig. 2c and e). Shown in a 1976 aerial photo, two cliff-top dunes extended from the eastern edge of the cliff toward southwest for almost 1.5 km (Fig. 2c). According to the survey of Shih et al. (1994), the movement of these cliff-top dunes was disrupted by the highway constructed along the cliff edge (disrupting the sand supply) and the planting of vegetation for dune stabilization. Today, the Fung-Cheui-Sha cliff-top dunes are mostly covered by dense vegetation except those parts at the edge of the cliff top. In winter, strong NNE winds have been observed to still blow sand from the climbing dunes at the bottom of the cliff to the roadside area, with sand sometimes even accumulating on the cliff top and blocking the highway.