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Research paper

Key to mangrove pollen and spores of southern China: an aid to palynological interpretation of Quaternary deposits in the South China Sea

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ABSTRACT

Illustrations of, and keys to, mangrove pollen and spores from extant taxa are essential to studies of tropical Quaternary palynology and palaeoecology of estuarine and marine deposits. In this paper we present a pollen morphological "atlas" and identification keys for most of the mangrove flora of the coastal areas of south China, including an interspecific key to the major mangrove elements *Rhizophora* and *Sonneratia*. The morphology of the pollen and spores of 38 species of living mangrove and associated plants is described and illustrated by transmitted light photographs and scanning electron micrographs. These descriptions and illustrations, and the identification keys are presented at an achievable taxonomic level. The keys are open for future development so that pollen of other mangrove and associated plants can be accommodated when available. In their present state they should, nevertheless, aid palynological analyses of Quaternary mangrove and associated estuarine and marine deposits, particularly in the South China Sea and surrounding regions, but also elsewhere in tropical and subtropical regions.

1. Introduction

"As cogently noted by Alfred Russel Wallace during his equatorial travels, mangrove forests are crucial occupiers of the boundary between land and sea, being key ecosystems along many tropical and subtropical coastlines" (Alongi, 2009, p. 1). "Mangrove" is an ecological term that refers to a taxonomically diverse assemblage of trees and shrubs that forms dominant plant communities in tidal, saline wetlands along sheltered tropical and subtropical coasts (Blasco et al., 1996). Mangroves prosper mostly in tropical regions as a result of their adaptation strategies, their ecological dynamics being closely linked to changes in sea level. Pollen analysis of mangroves is important for both palaeoecological reconstructions of coastal vegetation and determinations of palaeoenvironment in tropical and subtropical regions (Muller, 1964, 1968; Muller and Caratini, 1977; Woodroffe, 1981; Semeniuk, 1983; Thanikaimoni, 1987; Grindrod, 1988; Baldibeke and Baldi, 1991; Larcombe and Carter, 1998; Chateauneuf et al., 2006; Farooqui and Achyuthan, 2006; Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008; Berkeley et al., 2009; Limaye and Kumaran, in press). Many papers on the succession of coastal vegetation, ecosystem dynamics and sea-level changes in these regions have been published (Woodroffe, 1988; Mildenhall, 1994; Parkinson et al., 1994; Blasco et al., 1996; Grindrod et al., 1999, 2002; Rull et al., 1999; Jaramillo and Bayona, 2000; Behling et al., 2001; Behling, 2002; Berdin et al., 2003; Behling and da Costa, 2004; van Campo and Bengo, 2004; Yulianto et al., 2004; Ellison, 2005; Kumaran et al., 2005; Scourse et al., 2005; Engelhart et al., 2007; Cohen et al., 2009; Hait and Behling, 2009; Jarzen and Dilcher, 2009; Monacci et al., 2009, 2011; Gonzalez et al., 2010; Barui, 2011; Bian et al., 2011).

Specifically in connection with the South China Sea (SCS) and the coastal areas of south China and central Japan, there are a few reports on Neogene and Quaternary mangrove pollen- and spore-bearing deposits (Yamanoi, 1984; Zhou, 1988; Sun, 1991; Zheng and Zhou, 1995; Lei, 1998; Wang and Zhang, 1998), and a mangrove vegetation landscape through Marine Isotope Stage 3 and the Last Glacial Maximum has been reconstructed, based particularly on frequently occurring pollen of the major components of mangroves, *Rhizophora* and *Sonneratia* (Zheng, 1991; Sun et al., 2000, 2002; Wang et al., 2008, 2009; Zhang et al., 2011). As for other parts of the world, recent studies based on mangrove pollen data from surface sediments and Quaternary deposits have highlighted their importance for palaeoenvironmental interpretation (Yulianto et al., 2004, 2005; Kumaran et al., 2005; Mao et al., 2006; Li et al., 2008; Urrego et al., 2009, 2010; Proske et al., 2010; Barui, 2011; Bian et al., 2011).

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Effective reconstructions based on palynological analysis depend upon accurate identifications of pollen and spores, and in this respect keys to the products of the extant flora are very valuable (Jimenez-B and Rangel-C, 1997; Chester and Rains, 2001; Rangel-C et al., 2001; Rull, 2003; Willard et al., 2004; Bauermann et al., 2009). Morphological studies have been carried out previously on mangrove pollen from both sides of the Atlantic Ocean (Vezey et al., 1988; Silva and Santos, 2009), the Indian subcontinent, south-east Asia and the western Pacific (Muller, 1969, 1978; Muller and Caratini, 1977; Liu and Tang, 1989; Yamanoi, 2003; Yao et al., 2006; Fujiki and Ozawa, 2007; Mao et al., 2008, 2009; Chumchim, 2010, 2011), but keys to the identification of the palynological products of a wide range of mangrove taxa are not generally available. Hitherto, there has been no effective key to the identification of the pollen and spores of the mangroves of the northern SCS upon which to rely for determinations of specimens preserved in the sediments of the region.

The family Rhizophoraceae and *Sonneratia* dominate tropical mangroves. The Rhizophoraceae, otherwise known as the "mangrove family", consists of 16 genera and around 120 species of trees and shrubs. Only about 20 species of four genera, the conspicuously viviparous *Bruguiera, Ceriops, Kandelia* and *Rhizophora*, are found exclusively in mangroves. *Rhizophora* is a pantropical genus and a key member of *Rhizophoraceae* (Duke, 2006). It occurs widely along tropical and subtropical coasts from East Africa across to Asia, the Malay Peninsula, the Philippines, the western Pacific Islands and northern Australia. *Rhizophora apiculata* is distributed from India and Sri Lanka across Asia to the western Pacific and northern Australia. It often dominates in mid intertidal, intermediate estuarine situations (Duke, 2006). The distribution of *R. mucronata* extends from East Africa and India through Asia and Indonesia and again to the western Pacific and northern Australia. It is also commonly dominant in similar conditions (Duke, 2006). Rather less widespread, *R. stylosa* ranges from the Malay Peninsula and the Ryukyu Islands through Indonesia and Asia to Micronesia, Samoa and northern Australia, and always dominates in mid to low intertidal, downstream estuarine situations (Duke, 2006).

Sonneratia occurs throughout the Indo-West Pacific region, i.e., from East Africa to China, through Asia and Indonesia, to New Guinea, the western Pacific and northern Australia (Duke, 2006). The most widespread of all species of this genus is *S. alba*. Its distribution ranges from East Africa to India and through south-east Asia (including southern China and Indonesia) to the western islands of the Pacific Ocean including New Caledonia, the Solomon Islands and northern Australia. The trees are found mostly at low tidal contours within frontal stands of downstream, lower reaches of estuaries and offshore island enclaves in regions of moderate to high rainfall where tidal ranges exceed 1 m (Duke, 2006). *Sonneratia caseolaris* occurs frequently in frontal stands in upstream estuarine situations subjected to high levels of freshwater runoff. It ranges from the west coast of India to southern China and again through the western islands of the Pacific Ocean, including New Guinea and northern Australia (Duke, 2006). Interestingly, the habitat distribution of *S.* × *gulngai*, which is a hybrid of *S. alba* and *S. caseolaris*, overlaps those of the parent species in that it is found in mid intertidal,

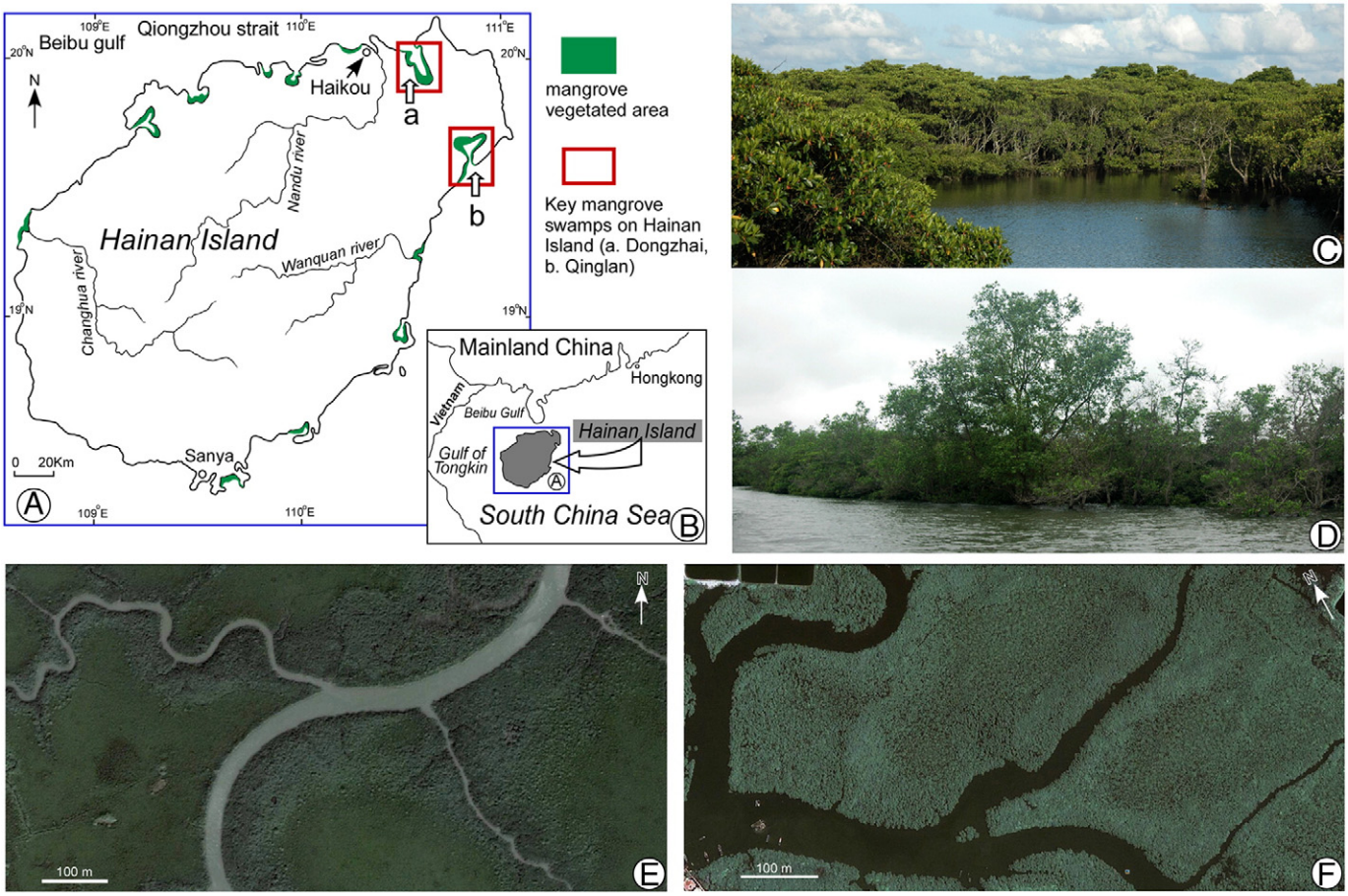

Fig. 1. A, B, maps showing the location of the research area and the mangrove swamps Dongzhai (a) and Qinglan (b) investigated. C, landscape of the *Bruguiera–Aegiceras corniculatum* community in Dongzhai. D, landscape of the *Sonneratia* community in Qinglan. E, F, aerial views (from Google Earth) of parts of the Dongzhai and Qinglan swamps respectively from where pollen material was collected.