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A last glacial and deglacial pollen record from the northern South China Sea: New insight into coastal-shelf paleoenvironment

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ABSTRACT

This study presents a marine palynological record of the Asian summer monsoon and sea level change in the Last Glacial Maximum (LGM) and the deglacial period in the northern South China Sea (SCS). A fossil core STD 235 (855 cm in length) and 273 surface sediment samples from the northern SCS were pollen analysed to reconstruct the paleoenvironment of the continental shelf during the last glacial period. Results from fossil pollen show that the main pollen source region fundamentally changed from the LGM to the deglacial period as sea level rapidly rose. The modern marine surface samples show that pollen concentrations in the estuary of the Pearl River are extremely high, and modern pollen assemblages are in good agreement with the regional vegetation. However, wind transport becomes more important in the deeper ocean as the percentages of *Pinus*, a taxon with very high pollen production and dispersal capacity, is highest in these sediments, which otherwise have very low pollen concentrations. The concentration of total pollen between surface and fossil pollen samples is compared in order to determine the possible vegetation sources areas for the marine core. Pollen concentration as high as >100 grains/g at the LGM suggested that the paleo-shoreline was located within 80 km of the core. Consequently, pollen would mostly have derived from the exposed continental shelf in the northern SCS. By contrast, pollen concentrations were very low due to a much greater transport distance (318 km at present, core STD 235) under higher sea levels, and windblown pollen played a more important role because of the limitation of riverine input into the deep ocean during this highstand period. Such alternation of pollen flux and source distance should be repeated during all glacial-interglacial cycles, reflecting closely sea level and climate dynamics. According to fossil pollen assemblages from Core STD 235, we conclude that wetland and/or grassland communities with sparse subtropical trees dominated most of the exposed shelf during the LGM rather than forest that characterizes the region today. The existence of a predominantly open landscape on the exposed continental shelf suggests lower precipitation during the LGM, which in turn indicates a weaker Asian summer monsoon. This finding is supported by other records from the Okinawa Trough and the East China Sea, suggesting that a weaker summer monsoon was a key characteristic of the LGM in East Asia.

1. Introduction

Vegetation distribution in south China is controlled by variations in the Asia monsoon, which is sensitive to climate variability over a range of temporal scales (An, 2000; Seddon et al., 2016). Most past vegetation records for the south China region are based

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on terrestrial peat bogs or lakes from the southern mountains of this region, with results suggesting that forests still dominated during glacial periods, and temperature rather than precipitation played the key role during glacial periods (Lee and Liew, 2010; Liew et al., 2013; Xiao et al., 2007; Yue et al., 2012). However, palynological records from maar lake core TY1 in the coastal area of south China (Zheng and Lei, 1999) and deep ocean sediments from core ODP 1144 in the northern SCS (Sun et al., 2003) have demonstrated that herbaceous taxa dramatically increased during glacial periods, suggesting that precipitation changes may have also been important in vegetation representation during these periods. Additionally a record from Taiwan Island indicates that high non-arboreal pollen (NAP) values in MIS 2 might represent a forest-steppe environment existing under precipitation levels as low as half those of today (Liew et al., 2006). Nevertheless, recently, a core MD05-2906 taken from the northern SCS indicates that the exposed continental shelf was still dominated by subtropical and tropical forest at this time (Dai and Weng, 2015; Dai et al., 2015) suggesting that a southern subtropical climate prevailed under high precipitation in the South China during the LGM. This disagreement has focused on the source of pollen (especially herbs) to marine sediments in the northern SCS (Sun et al., 2003; Dai et al., 2015) as well as to terrestrial cores from maar lakes in the coastal area of south China (Wang et al., 2012; Zheng and Lei, 1999), and whether the high abundance of herbs in south China during glacial periods is sufficient to explain the vegetation representation as well as the strength of precipitation change. Therefore, new palynological records in the subtropical-tropical area of south China are needed to further investigate the relative role of temperature and precipitation in vegetation distribution and whether climate alterations are sensitive to variations in the Asian summer monsoon.

The SCS is in a subtropical to tropical monsoon area, which is situated close to the Eurasian continent and the Pacific Ocean, with one of the largest marginal seas (~3.6 million km^2) and widest continental shelf areas in the world. It connects with the Pacific Ocean through the Luzon Strait and the East China Sea through the Taiwan Strait, and the whole of Taiwan Strait was exposed during the LGM when sea level was around 130–140 m lower than present (Barrows and Juggins, 2005; Wang et al., 1995; Yokoyama et al., 2000). As the most recent ice-sheet maximum period (Clark et al., 2009; Mix et al., 2001), the LGM is well recorded in deep ocean sediments in the SCS by a range of proxies including foraminifera, geochemical elements and biomarkers (Huang and Tian, 2012; Shintani et al., 2011; Steinke et al., 2010; Tian et al., 2010). However marine pollen in this area has been poorly represented due to confusion about pollen source areas especially with the herbs, making interpretation of marine pollen records problematic.

Here we present a novel, empirical approach to assess pollen source area for the northern SCS, through analysis of 273 surface seafloor samples, which are then linked to the last glacial to deglacial pollen record from deep ocean core STD 235 (8.55 m in length). This paper provides insight into the pollen transport mechanisms and their terrigenous source areas that greatly assists in reconstructing the paleovegetation of the exposed continental shelf during the LGM. In addition, it provides insight into the strength of the Asian summer monsoon and the impact that sea-level variation and deglacial warming had on East Asian coastal environments.

2. Regional setting

The study area is located in the northeast SCS, which is dominated by subtropical and tropical climates, with mean annual temperatures between 18 and 24 °C and high annual precipitation (>1000 mm). Precipitation is controlled by shifts in the inter-tropical convergence zone (ITCZ) and summer monsoon winds (Turney et al., 2004; Wang et al., 2004). In summer, southwesterly winds gather large amounts of moisture and blow towards the Eurasian continent as the ITCZ moves northward. In winter, dry and cold air moves from the interior of the Eurasian continent to the SCS as the ITCZ moves southward.

The general surface circulation of the SCS changes seasonally with the monsoon winds and is also heavily impacted by the Kuroshio Current intrusion (Zhang et al., 2006) (Fig. 1). In winter, the Loop Current and SCS Branch of the Kuroshio Current are distributed along the continental slope from the southwest of Taiwan to the west of the Dongsha Islands, which are warmed by the Kuroshio Current. The SCS Warm Current is a northeastward flow separated from the SCS Branch of the Kuroshio Current. The Guangdong Coastal Current flows northwest and is largely controlled by the winter monsoon. In summer, the SCS Branch of the Kuroshio Current also shifts southeast and the Guangdong Coastal Current is reversed, while the SCS Warm Current becomes the prevailing northeasterly surface current forced by summer monsoon winds. Besides, there exists a deep water current (2000–2500 m) that turns southwest along the continental margin off the southeast China coast called the SCS Contour Current (Qu et al., 2009).

The topography of much of south China is characterized by widespread hills (mainly between 200 and 2000 m) except for the Yushan Mountains in Taiwan, which reach an elevation of 3952 m and the peak of Fujian coastal mountain that have a height of 2158 m. The submarine topography of the northern SCS consists of a broad continental shelf, that transitions to a continental slope and then into a deep ocean (Wang et al., 1995).

There are several large rivers in southeast China, including the Pearl River in Guangdong Province and the Han and Min Rivers in Fujian Province. The Pearl River is the largest and flows into northeastern SCS with a substantial amount of terrestrial sediment. It delivers $3.5*10^{11}$ m^3/yr of freshwater and 85 $*10^6$ tons/yr of sediment load into the SCS (Bai et al., 2015). The catchment of these river systems is located in an area directly influenced by the East Asian Monsoon. Nearly 80% of the discharge occurs during the wet season from April–September and only 20% during the dry season of October–March (Yin et al., 2004).

The vegetation in southeast China is dominated by subtropical evergreen broadleaf forest in the hills, with tropical semi-evergreen broadleaf forest along the coast, as well as tropical evergreen broadleaf forest on Hainan and Luzon islands (Olson et al., 2001; Zheng et al., 2014). The native forests in this area, especially along the coastal plain, have been mostly destroyed by anthropogenic activities and are now dominated by tropical and subtropical grasslands. Extensive areas of plantation forests (*Pinus massoniana*, *Cunninghamia lanceolata* and *Eucalyptus*) also occur within the catchment and were planted in the 1960s and 1970s. Tropical evergreen broadleaf forests are rare and are now only found in the lowlands of southern Hainan Island and southern Taiwan at elevations below 600 m, and consist mainly of taxa such as Dipterocarpaceae, *Pterospermum*, *Heritiera*, *Sterulia*, *Aglaia*, Moraceae and Sapindaceae (Whitmore, 1989). Natural subtropical evergreen broadleaved forests are scarce and mostly located on the low hills (elevation 600–1500 m) of Jiangxi and Fujian provinces and consist mainly of *Castanopsis*, *Cyclobalanopsis*, *Laurance*, *Ilex*, Hamamelidiaceae and Magnoliaceae (Wu, 1980). The vegetation of this region tends to be controlled by latitude, although mountains above 1500 m support temperate deciduous broad-leaved forest with, for example, *Carpinus*, *Betula*, *Alnus*, *Acer*, *Liquidambar* and *Tsuga*. In addition, the Yushan Mountains, the highest range in the region (elevation peak of 3925 m), supports cold-temperate coniferous (*Abies* and *Picea*) forest.