Palaeogeography, Palaeoclimatology, Palaeoecology 461 (2016) 12–28

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Characteristics of pollen in surface sediments from the southern South China Sea and its paleoclimatic significance

Chuanxiu Luo [a,*,1], Gang Lin [b], Muhong Chen [a], Rong Xiang [a], Lanlan Zhang [a], Jianguo Liu [a], Anding Pan [b], Shixiong Yang [c], Mingxi Yang [d,**,1]

[a] CAS Key Laboratory of Marginal Sea Geology, South China Sea Institute of Oceanology, Chinese Academy of Sciences, 164 Xingang Xilu, Guangzhou 510301, China
[b] School of Geographical Sciences, Guangzhou University, 230 Waihuan Xilu Xiaoguwei, Guangzhou Universities Town Campus, Guangzhou 510006, China
[c] Qingdao Institute of Marine Geology, Qingdao 266071, PR China
[d] College of Biological Sciences, University of California Davis, Davis, One Shields Avenue, CA 95616, USA

ARTICLE INFO

Article history:
Received 25 August 2015
Received in revised form 19 July 2016
Accepted 1 August 2016
Available online 4 August 2016

Keywords:
Pollen
Nansha Islands
Surface sediments
Ocean currents
Rivers
Paleoclimate

ABSTRACT

We investigated pollen distributions in surface sediments of the southern South China Sea (SCS) and their relation to seabed topography and the environment of the terrigenous sources. In this study, we analyzed 62 surface sediment samples collected from the SCS through modern pollen analysis methods. The results of our study can be summarized as follows. (1) trilete spores dominate the pollen and spore spectrum, which reflects the dominance of ferns in the Nansha Island vegetation. Similar pollen characteristics were found for different periods of high sea level and global warming after 12 Ma in ODP site 1143 and site 18287 in the southern South China Sea. Most pollen and spores on the Kalimantan Island coast are produced by herbaceous plants and trees, while few trilete spores produced by ferns are present. Furthermore, similar pollen characteristics were found for different periods of low sea level and global cooling in ODP site 1143 and site 18287. (2) Through an analysis of pollen samples from a transect line extending from the northwest to the southeast, the complex terrain of the Nansha Islands was observed to be unsuitable for pollen migration through ocean currents. Pollen counts in samples collected near the southern Nansha Islands decreased gradually from the east and west continental shelf areas to the central basin area. However, the same analysis confirmed that the Nansha Trough facilitates the entry, dispersal, and storage of pollen from external sources. (3) Principal component analysis (PCA) of samples collected from two different water depths in the southern SCS demonstrates that trilete spores and monolete spores in 4 samples near the Mekong River with water depths of <200 m are transported primarily by river flow. Conversely, pollen and spores mainly transported by rivers near Kalimantan Island were found at water depths of >200 m. However, analysis of samples from the northern SCS in a previous study obtained different results.

1. Introduction

The South China Sea (SCS) is one of the largest marginal seas in the western Pacific, and it forms a vast archive of paleoenvironmental information from tropical and subtropical ocean settings. Deep-sea sediments in the southern SCS contain comprehensive information about the environmental evolution of typical tropical marginal seas, the East Asian monsoon, and the western Pacific warm pool. Pollen in surface sediments in the southern SCS is a valuable tool for paleoenvironmental and paleoclimatic reconstructions. Pollen in the ocean is derived from terrestrial vegetation on surrounding land, and it can reflect the distribution and evolution of the terrestrial vegetation. Previous pollen studies near Western Australia (van der Kaars and De Deckker, 2003) and near southeastern Indonesia (van der Kaars, 2001), and NW Africa (Hooghiemstra et al., 2006) revealed a good correlation between the marine pollen signal and vegetation (Heusser, 1988; Sun et al., 1999). However in other places, such as the Gulf of Lions (western Mediterranean Sea), the relationship between inland vegetation and the pollen signal is uncertain (Beaudouin et al., 2007). Pollen in the ocean can be used as a reference for reconstructing the environmental evolution of the surrounding land, and it also reflects regional flow patterns of air and ocean currents to some extent. This is because changes in wind strength/direction and vegetation patterns (Hooghiemstra et al., 1987; Mudie and McCarthy, 1994; Dupont and Wyputta, 2003; Vincent Montade et al., 2011), ocean circulation patterns, and fluvial discharge (Chmura and Liu, 1990; Vincent Montade et al., 2011) have been established as important factors in pollen dispersal in the ocean.

* Correspondence to: C. Luo, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China.
** Correspondence to: M. Yang, University of California Davis, Davis, CA 95616, USA.
E-mail addresses: xiu104@scsio.ac.cn (C. Luo), alexymxily@gmail.com (M. Yang).
[1] These authors contributed equally.

http://dx.doi.org/10.1016/j.palaeo.2016.08.001
0031-0182/

Understanding pollen dissemination mechanisms forms the basis for correctly interpreting data on ancient pollen from an environmental perspective. This issue is especially important for pollen studies of marine sediments because the controlling factors of pollen distribution in the marine sedimentary environment are more complex (Heusser, 1978). For example, pollen distribution is affected by atmospheric circulation, ocean currents, and seabed topography, and other factors. Many researchers have previously conducted regional pollen studies of surface sediments from a large area of the SCS, particularly the continental shelf, continental slope, and basins of the northern SCS, and various achievements have been made in studies of pollen distribution and transport mechanisms (Wang et al., 1990; Sun et al., 1999; Y. Zhang et al., 2002; Sun et al., 2003; Chen et al., 2004; Zhang et al., 2011; Dai et al., 2012; Luo et al., 2013; Luo et al., 2014; Luo et al., 2015). Based on an analysis of pollen distributions in surface sediments of the northern SCS as recorded in 74 samples from the area 12.00–23.72°N, 108.57–120.00°E, an earlier study found that the characteristics of pollen grain abundances of percentage were influenced mainly by seafloor geomorphology (Luo et al., 2013). Pollen percentages from sample sites on the continental shelves or near islands can differ from those in sea basins. For example, the percentages of trilete spores are higher at continental shelf or island sites than at sea basin sites (Luo et al., 2013). Luo et al. (2015) collected 74 samples from surface sediments in the northern part of the SCS during autumn and 33 samples from surface sediments in the southern part of the SCS during winter, and found that pollen concentrations in the north were nearly 10 times higher than those in the south.

Nevertheless, due to difficulties in sample collection, research pertaining to the distribution patterns of pollen in modern sediments in the southern SCS remains sparse. In particular, only a few systematic studies of modern pollen have been conducted near the Nansha Islands in the SCS, on the continental shelf and continental slope near Kalimantan Island, and in other areas of the SCS. Therefore, by studying the relationship between pollen sources on land with pollen distributions in surface sediments in the southern tropical SCS at low-latitudes can provide important contributions to basic knowledge of the ancient marine environment and climatic evolution since the late Quaternary.

To elucidate the response of surface sediment pollen in the southern SCS to changes in the environment of the surrounding land, this study further explores the influence of seabed topography and other factors on pollen distribution and examines the relationship between the pollen distribution and its source on land.

2. Environmental setting

2.1. Geographical location

With a latitude range from 4° N in the south to 21° N in the north, the SCS is a marginal sea adjacent to the southern part of China. The northern part of the SCS is bounded by mainland China, the western part is adjacent to Vietnam, the southern part is near Kalimantan Island and the Natuna Islands, and the eastern part is bounded by Luzon and Palawan islands. The northeastern part of the sea is connected with the Pacific Ocean through the Bashi Channel and the Taiwan Strait, and the southwestern part is connected with the Indian Ocean through the Strait of Malacca and the Strait of Sunda. The entire ocean area is approximately 3.5 million km^2. The Xisha, Zhongsha, Dongsha, Nansha, and other islands and reefs are distributed in the internal part of the SCS (Fig. 1).

2.2. Topography and rivers

The outer edge of the SCS consists of broad continental shelf. The depth from the outer edge to the middle of the sea increases rapidly because the continental shelf with a depth of 100–200 m deepens to a narrow northeast–southwest-trending diamond-shaped central basin with depth > 3000 m through a sudden steep continental slope.

At Kalimantan Island and at Sarawak and Sabah, many rivers, for example the Rejang and Kinabatangan rivers, input to the southern SCS. Although the rivers that enter the SCS are short and small, because the rivers flow rapidly (Wang, 1995), the rivers can carry large amounts of terrigenous material and pollen into the southern SCS (Sun and Li, 1997). Thus, these rivers of the southern SCS play a significant role in terrigenous material input.

2.3. Climate and ocean circulation

The SCS crosses a great range of latitude; it has obvious subtropical climate in the north, but significant tropical climate in the south. Controlled by the equatorial low-pressure zone, high temperature (average annual temperature of 28–30 °C) and high humidity characterize the southern SCS. The annual precipitation is >2800 mm, and rainfall is abundant. From November to March, the prevailing wind is the northeast monsoon, and from June to October, the prevailing wind is the southwest monsoon, with more frequent typhoons (Chao et al., 1995). Fig. 2 shows the mean winter and summer wind and wind stress curl fields derived from 5 years of Quik SCAT data. The northeast winter monsoon produces a strong seasonal directionality of the wind. The southwest summer monsoon has generally weak wind stress and uniform wind stress curl. The northeast winter monsoon has higher, generally uniform wind speed and generally uniform wind direction along with significant wind stress curl. The wind stress curl pattern exemplifies the need for high spatial resolution. The mountainous coastal regions produce a distinct pattern of alternating positive and negative curl that is not well resolved in numerical wind products (Caruso et al., 2006; Luo et al., 2013) (Fig. 2).

The SCS is located between two global climate "drivers," the western Pacific warm pool and the Tibetan Plateau. The climate is affected mainly by the East Asian monsoon climate system. In summer, the southwest monsoon with warm moist wind that blows from ocean to continent prevails; in winter, the dry and cold northeast monsoon that blows from the Asian continent to the ocean prevails (Edition Board of Physical Geography of China, 1979). In summer, due to the impact of the East Asian monsoon and the western tributaries of the Kuroshio Current, driven by the southwest monsoon, the surface currents become a coastal current of southwest-to-northeast direction on the edge of the land, while an anticyclonic vortex, affected mainly by the summer monsoon, forms at the center of the southern SCS. In winter, driven by the northeast monsoon, currents with northeast-to-southwest direction form along the shore of the land, and a cyclonic vortex, also driven mainly by the winter monsoon, forms in the center of the southern SCS. On the east side of this vortex, there is a relatively weak anticyclonic circulation; along the middle of these two circulations, there is a flow away from the shelf of the Natuna Islands and extending to the north, which is opposite the wind direction (Luo et al., 2013) (Fig. 3).

2.4. Types of vegetation

Kalimantan Island, one of the largest islands near the southern SCS, has a tropical rainforest climate, hot, rainy, and humid all year, which makes for rich and diverse plant species of mainly tropical rainforest vegetation. Because the highest peak in the central part of Kalimantan Island is 4102 m and the terrain elevation decreases gradually from the center of the island to the surrounding areas, a vertical zonation exists; thus, the tropical rainforest vegetation on Kalimantan Island is divided into tropical rainforest, tropical monsoon forest, mountain rainforest, and mangroves. As the area has a tropical rainforest climate, tall trees are dominantly distributed. This flora is composed mainly by Dipterocarpaceae (including *Dipterocarpus*, *Hopea*, *Vitia*, and *Shorea*), *Pterospermum*, *Heritiera*, *Sterculia*, *Dysoxylum*, and *Aglaia*, along with some genera of Moraceae, Sapindaceae, and Sapotaceae (Luo and Sun, 2003), but lianas and epiphytes, rich, strangling plants, and the phenomenon of old stem flower are common. Lush lianas, collectively