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A 400-year record of black carbon flux in the Xisha archipelago, South China Sea and its implication

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ABSTRACT

We reconstructed the first long-term (~400 years) records of black carbon (BC) deposition flux from three ornithogenic sediment profiles, which were collected from three remote, isolated islets of the Xisha archipelago, South China Sea. The significant correlations between black carbon, organic matter and excess ^{210}Pb suggested that black carbon was mainly derived from atmospheric deposition, and further enriched by plant-derived organic matter in sediments. During the past 400 years, the BC flux remained relatively low before the onset of 20th century; it started to increase from approximately 1900 AD, and peaked around the 1970s. In the recent 30 years, the BC flux seemed to display decreasing trend, very likely due to the change of energy structure and development of pollution control techniques. In comparison with marginal sea regions that are greatly impacted by anthropogenic activities, these pristine Xisha islands were not significantly influenced by black carbon of anthropogenic origin.

1. Introduction

Black carbon (BC) is a chemically heterogeneous class of carbon compounds formed during incomplete combustion of biomass or fossil fuels (Masiello, 2004). It is widely distributed in a variety of environmental mediums, such as air, soil, sediment, water and snow, and can be well-preserved for quite a long time (Goldberg, 1985; Verardo and Ruddiman, 1996; Kuhlbusch, 1998; Masiello and Druffel, 1998; Schmidt and Noack, 2000; Gelinas et al., 2001; Jacobson, 2002; Muri et al., 2002, 2006; Fernandes et al., 2003; Shrestha et al., 2010). BC in sediments is resistant to microorganisms and thus a robust marker for environmental changes. It has been used to study the history of forest exploitation and forest fire and the shift of historical energy structure (Verardo and Ruddiman, 1996; Marlon et al., 2008; Sun et al., 2008). Furthermore, BC adsorbs persistent organic matter and plays a substantial role in biogeochemical cycles of some elements, such as carbon and oxygen (Kuhlbusch and Crutzen, 1995; Menon et al., 2002; Bucheli et al., 2004; Sánchez-García et al., 2010). Consequently, the study of BC in sediments has drawn increasing attention in recent years.

A great quantity of BC has been emitted into the atmosphere with the growth of human civilization, i.e. the Industrial Revolution, and this led to a notable increase in its background level. With the continuous growth of economy in recent times, especially over the past decades, East and Southeast Asia has gradually become the foremost source of anthropogenic pollutants (Streets et al., 2003; Pacyna et al., 2010). Anthropogenic BC emitted into atmosphere, reached remote area via a long-range atmospheric transport, deposited on the earth surface by dry or wet precipitation, and then ultimately entered sediments. A number of studies have investigated BC records in marine sediments, and the results suggested that both human activities and river transportation had significant impacts on distribution of BC in such sediments (Middelburg et al., 1999; Jia et al., 2000; Wang and Li, 2007; Sun et al., 2008; Ribeiro et al., 2008; Kang et al., 2009; González-Vila et al., 2009). However, the majority of previous studies focused on marine sediments, and little attention has been paid to BC distribution and its biogeochemical cycle in ocean or coral islands, which are isolated from mainland and are not influenced by river transportation.

South China Sea has some of the highest biodiversity in the world and is very sensitive to environmental changes. The Xisha archipelago is located in the central South China Sea, and is in a relatively pristine condition due to its long distance from Mainland China and restrictions imposed by the Chinese military on travel to this area. It is covered by thriving vegetation and used to be inhabited by a large number of seabirds, but the seabirds have left most of the small islands (Hainan Ocean Administration, 1999). The impact on the Xisha Islands from drastic anthropogenic activities has drawn increasing attention in recent years (Morton and

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Blackmore, 2001; Liu et al., 2008). Our previous investigations have shown that the ornithogenic sediments in the Xisha archipelago were ideal materials to study regional environmental changes in response to global climate change and human civilization (Xie et al., 2005; Liu et al., 2006a,b, 2008; Yan et al., 2010). In the present study, we collected three sediment profiles from three isolated islets of the Xisha archipelago (Guangjin, Jinqing and Jinyin islands) and analyzed their BC contents. Our main aims are to identify the main source and distribution characteristics of BC in the ornithogenic sediment profiles, to reconstruct BC flux over the past 400 years in the Xisha archipelago and to examine BC's possible environmental implication.

Table 1
Parameters of the studied islands and sediment cores.

Island	Location	Elevation (m)	Length × width (m × m)	Area (km^2)	Core No.	Core length (cm)
Jinyin Island	16°26′57″N, 111°30′24″E	0.2	1020 × 350	0.36	JY2	55
Guangjin Island	16°27′07″N, 111°42′5″E	6–8	320 × 200	0.06	GJ3	95
Jinqing Island	16°27′50″N, 111°44′27″E	6.0	880 × 230	0.20	JQ	55

Note: the data listed in table are cited from Hainan Ocean Administration (1999).

2. Study area

The Xisha archipelago (15°47′–17°08′N, 110°10′–112°55′E) consists of more than 40 islets, coral reefs and sandbanks. According to observations from Yongxing meteorological station, annual mean air temperature and annual rainfall of the Xisha Islands were 26–27 °C and 1500 mm, respectively. From June to November, the Xisha Islands are subject to the effects of the southwest monsoons, tropical cyclones of high frequency from intense convergent convection, and heavy precipitation; about 87% of the total annual precipitation occurs in these months (Hainan Ocean Administration, 1999). The typical plant community in most of the Xisha Islands has circular-zonary growth around the islets; this is the characteristic landscape in the Xisha archipelago (Xu et al., 2010). Flourishing vegetation provides habitats for seabirds and this gives rise to the accumulation of abundant guano fertilizer (Gong and Huang, 1995; Hainan Ocean Administration, 1999).

The sediment profiles used in the present study were collected from Jinyin (JY2), Jinqing (JQ), and Guangjin (GJ3) islands (Fig. 1). Jinyin Island, Jinqing Island, and Guangjin Island are developed on Yongle atoll, and were formed in mid-late Holocene, the primary formation period of the Xisha Islands (Lu et al., 1979; Hainan Ocean Administration, 1999). They are typical cays with common landform. The basic features of these three coral islets were summarized in Table 1. The trees *Pissonia grandis*, *Guettarda speciosa* and shrubs *Scaevola sericea*, *Messerschamidia argentea* are widely distributed on these islands. We did not observe any seabirds on these islands during field investigations. However, a large number

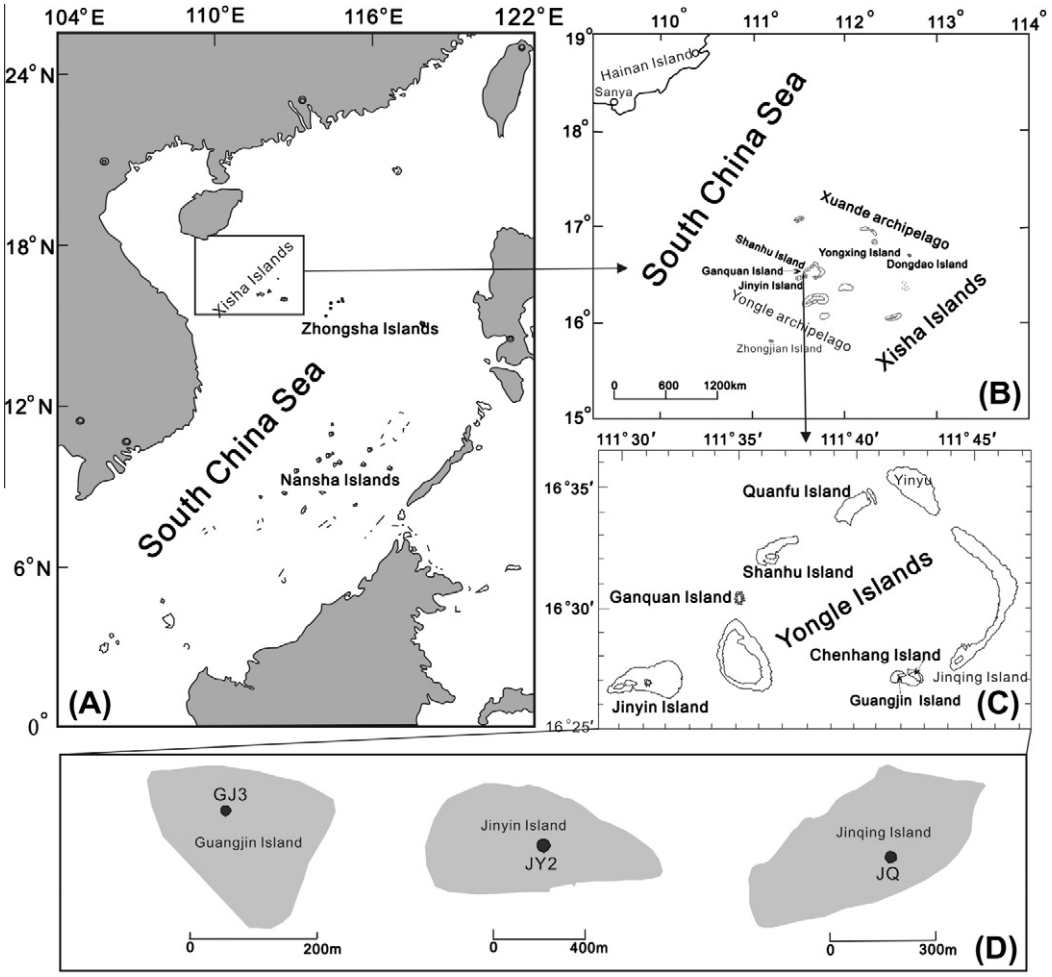

Fig. 1. Map of the study area showing three sampling sites.