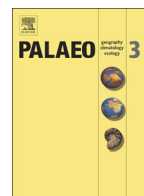




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Carbonate sedimentary characteristics of the beach rocks around Qilian Islets and Cays, Xisha Islands: Implication for coral reef development and decline

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ABSTRACT

Beach rocks, developed on the coast of Qilian Islets and Cays, Xisha Islands, China, represent carbonate sedimentary formation on a typical biogenic coast adjacent to coral reef areas. The subaerial and submarine distribution and natural outcrop sections of beach rocks around three islets were surveyed, traced, measured and mapped to determine their development and depositional successions. Carbonate sedimentary characteristics of the beach rocks show that more than 95% of sediments are sourced from adjacent reef flat and reef crest, and are dominated by reef-building coral skeletal fragments and detritus, calcareous algae, and other skeletal grains of reef dwellers. Bioclastic content, algal and microbial content, sorting and roundness of skeletal grains and porosity in depositional successions change with sediment source, sediment accumulation rate, grain characteristics and textures of sediments, hydrodynamic intensity and cementation features. Cementation of the beach rocks is characterized by the binding action of algae and microbes, the micritization caused by boring of endolithic algae and microbes, the early marine cementation, and the early meteoric cementation. Algal and microbial activity played a major role in micritization of skeletal grains of beach rocks. The beach rock formation is mainly affected by the algal and microbial content in beach sediments, the sediment supply from reef flat, the grain characteristics of beach sediments, cementation and diagenesis process, the hydrodynamic intensity driven by wind and monsoons, and sea-level changes. The developmental dimensions and spatial extent of coral reef architecture, the flourishing and extinction of reef-building organisms in reef ecosystem, the abundance of algae and microbes and the diversity of reef dwellers may influence wave energy dissipation and sediment transport patterns in reef flat, thus alter the carbonate sediment budget of the coastal environment.

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1. Introduction

Beach rocks are well developed on many reefal islands and islets in Xisha Islands (Huang et al., 1978; Zhang et al., 1989) (Fig. 1). However, with increased human activities and the acceleration of island development, the beach rock formations are being destroyed and will gradually disappear. There are continuous and discontinuous beach rock formations developed on the coast of Zhaoshu Islet, North Islet, Medium Islet and South Islet of the Qilian Islets and Cays (Fig. 1). Different from those beach rocks developed on the mainland shores or on the coastal island shores, the beach rocks on the Xisha Islands' coastlines are typical of a coral-sourced coast and reef islands. Almost no terrigenous clastics and lithic fractions sourced from bedrock erosion occur in these particular beach rocks. Therefore, they differ distinctly from those developed on the mainland shores or coastal island shores in

source composition, hydrodynamic conditions, and cementation and diagenesis. Beach rock successions around the Qilian Islets and Cays generally consist of 5–8 beds, with each bed being about ten to several tens of centimeters in thickness. AMS¹⁴C dating shows that the age of the beach rocks is 500–520 cal yr. B.P. Beach rock is a consolidated or semi-consolidated coastal sedimentary deposit formed by beach sediments and cemented by carbonate cements (Bricker, 1971; Voudoukas et al., 2007). Lithification usually takes place in the intertidal zone and may involve a variety of sediments, such as sands and gravels of both clastic and biogenic origin (e.g. Vieira and De Ros, 2007). Beach rock development is a global and diachronic phenomenon, and the great majority of beach rocks is found in tropical/subtropical and low temperate latitude, microtidal coasts (Goudie, 1969; Alexandersson, 1972; Voudoukas et al., 2007); some researchers also considered that beach rocks are formed in the wave-splash zone (surf zone) (Ginsburg, 1953; Zeng, 1980; Li, 1988; Viviane and Daniel, 1999).

During the 1980s to 1990s Chinese researchers have completed much work on beach rocks deposited on the mainland shores or coastal

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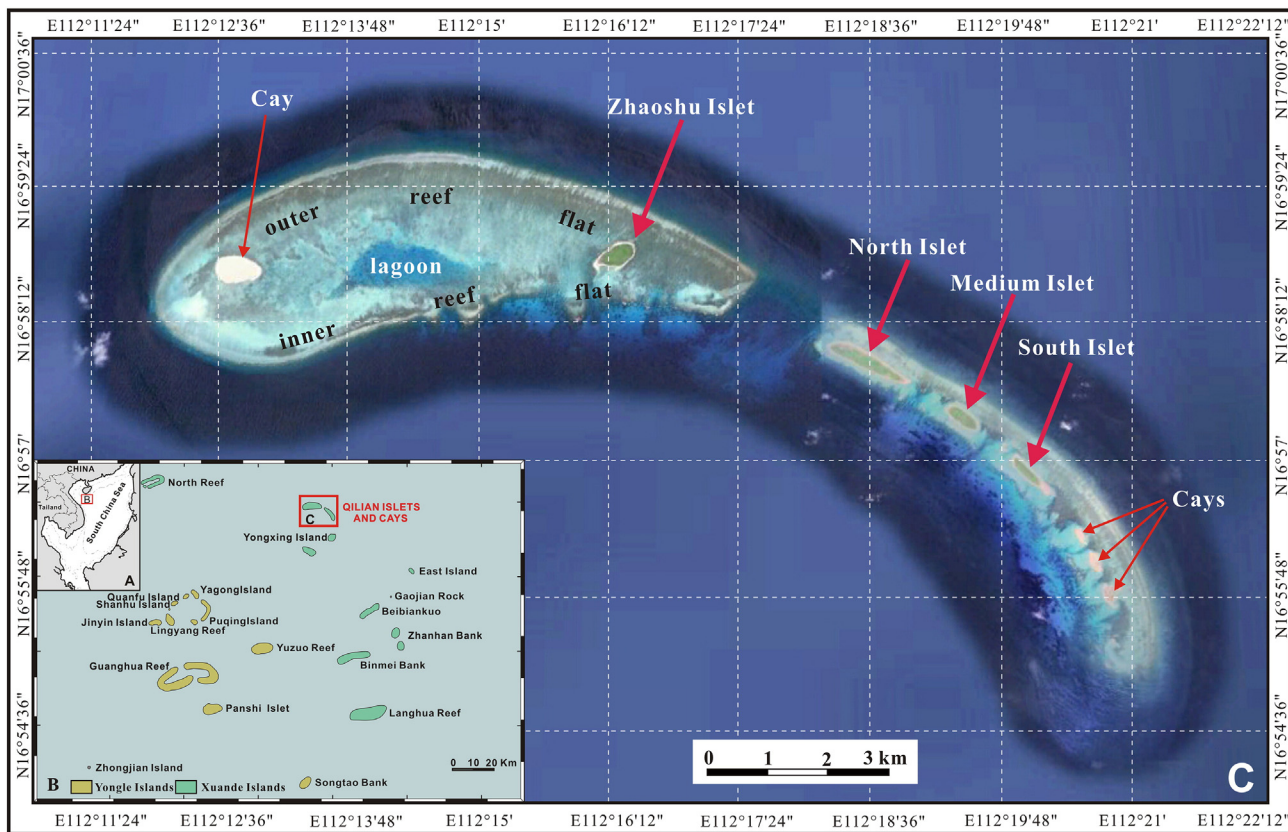


Fig. 1. Schematic diagram of the study area, the locations of Zhaoshu Islet, North Islet, Medium Islet, South Islet, and several Cays of the Qilian Islets and Cays, Xisha Islands.

island shores (Wang, 1992, 1997), but studies on beach rocks developed along the coast of offshore coral reef islands are lacking. Huang et al. (1978) studied the preliminary petrologic characteristics, cements and cementation types of Xisha beach rocks. Zeng and Qiu (1985) introduced the beach rocks of Chenhang and Puqing Islands. Sun et al. (2010) classified the beach rocks of the Xisha Islands, and discussed the relationships between beach rocks and petroleum reservoirs. During the last 15 to 20 years, little work has been done on beach rocks near coral reefs, especially those in the Xisha and Nansha Islands (Sun et al., 2010), and this topic has received little attention. In addition to the lack of work on subaerial beach rocks, there is also a lack of research on submarine residual and submerged beach rocks. In the past 20 years, the microbial deposition and cementation in beach rocks and the impacts of microbes and associated microbial carbonates on Holocene coral reef development have produced great interest and concern in the geosciences (Webb et al., 1999; Khadkikar and Rajshckhar, 2003; Kendall and Alsharhan, 2011). There is very little research on microbes and microbial carbonates in coral reefs and their associated beach rocks of the South China Sea. Previous studies lack systematic research on beach rocks through the multidisciplinary approach. Also, little previous work has examined the effects of microbial activities on beach rock cementation and microbial cement types caused by microbial media.

The purpose of this research was to document the sedimentary characteristics and cementation mechanism of beach rocks formed on a typical biologic coast in the offshore coral reef area, and what relations between the variations in depositional successions of beach rocks and the formation and development of different sedimentary and ecological zonation of coral reefs. The roles of endolithic algae and microbes in the depositional and cementational process of beach rocks received special attention. This paper reports on data collected from the beach rock

outcrops and its underwater extension and from the development of beach rocks in different wind directions, different hydrodynamic conditions and different geomorphologic positions of Zhaoshu Islet, North Islet and Medium Islet (Fig. 2). In addition, sedimentary component, grain forms, grain sorting, ratio of algae and microbial carbonate, sedimentary texture, depositional successions and cementation of beach rocks were studied, and the possible relationships between beach rock development and coral reef growth were discussed. The controlling factors on beach rock formation in coral reef areas, including algal and microbial content in beach sediments, sediment supply from reef flat and reef crest, grain characteristics of beach sediments, cementation features, leeward and windward positions, hydrodynamics driven by winds and monsoons, and sea-level changes, were evaluated.

2. Hydrological and meteorological conditions

Xisha Island is located in the northwest part of the South China Sea, which belongs to a tropical and monsoonal island climate (Fig. 1). Qilian Islets and Cays occur in an arced reef flat extended in NW–SE direction and curved to NNE direction (Fig. 1). The arc-extended reef flat is separated by a gap that divides it into northwest part and southeast part, and the former is much wider than the latter. The maximum width of northwest reef flat reaches 3 km, and Zhaoshu Islet and West Cay occur on it. The southeast reef flat is narrow and less than 1 km in the narrowest part, and North Islet, Medium Islet, South Islet and some cays are on it. The outer reef flat is wider than the inner reef flat in the northwest part, and an elongate and shallow water lagoon occur on the inner side in the medium of it (Fig. 1). The lagoon is 3 to 6 m in water depth, 2625 m long and 700 m wide.

Annual solar-radiation is high in the area of Qilian Islets and Cays; sunny weather is common. According to the data from the Xisha

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