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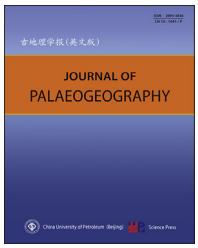

Lithofacies palaeogeography and sedimentology

Growth characteristics and sedimentary mode of Permian reefs, Lengwu, Tonglu, Zhejiang Province, southern China

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Abstract Organic reefs are favourable accumulation spaces for hydrocarbons and various mineral resources. A complete Permian organic reef profile about 44 m thick with distribution area no more than 1 km^2 is exposed near Lengwu, Tonglu, Zhejiang Province. Examination of outcrops and thin sections revealed that the main reef-building organisms are calcisponges, with inozoans as dominant type. Five types of rocks have been recognized in the reef, and they are calcisponge framestone, calcisponge bafflestone, bindstone, rudstone and bioclastic wackestone. The profile was constructed in three reef-building stages. The thickness of the second stage is largest, followed by the first stage and the third stage is smallest. Each stage started with a framestone or bafflestone, ended as the reef grew near the sea-level, and died because of influx of terrigenous sediments. The development of the Lengwu reef is controlled by biological factors and sea-level changes. Based on the study a reef sedimentary model is established.

Keywords Reef, Rock types, Calcisponges, Sedimentary model, Permian, Lengwu, Southern China

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1. Introduction

Reefs are favourable enrichment sites for varieties of mineral resources, and are regarded as a unique "paradise" for hydrocarbon reservoirs (Cai, 2009; Fan, 1996; Michel *et al.*, 1970; Liu, 2007; Lu and Gong, 2007; Xu, 1992; Yang *et al.*, 2002). At the beginning of the last century (1916), the crude oil production of Well Azul 4 in Mexico prime belt was up to 35 620 t, stimulating people's enthusiasm for reefs research (Song, 2012). The last century was the fastest developing period for reefs research (Zhong *et al.*, 2005).

Changes in environmental factors, coupled with the evolution stage of the main reef building organisms, as well as a series of extinction events have

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controlled the types of ancient reefs (Kiessling *et al.*, 1999; Webb, 1996; Wood, 1995). The diversity and complexity makes the reefs very appealing, but also makes it very difficult to establish widely accepted concepts and classification of reefs (Heckel, 1974). Wood, Dickson, and Kirklandgeoge (1994) made a new appraisal for the ecology of the Permian Capitan Reef, Guadalupe Mountains, Texas and New Mexico, suggesting a detailed ecological reappraisal of the ecology and role of cavities within all parts of the reef, within a well defined stratigraphic and palaeodepth framework.

During the Devonian, Permian and Neogene periods, reefs were well developed in China (Liu *et al.*, 2007). In China most studies are regarding the Paleozoic reefs, especially the Permian reefs, and secondly is the Cenozoic reef, since reefs were better developed in the Paleozoic, and less developed in the Cenozoic.

The study of Permian reefs in China began in the late 1970s (Wang *et al.*, 1998), with a few formal publications. In the 1980s, Fan (1982, 1996), Fan and Zhang (1987) and Fan and Qi (1990) conducted some detailed studies on the reefs in Lichuan, Hubei Province and other areas in Yunnan, Guizhou, and Guangxi. Their work described the types, petrography, palaeogeography and evolution of the reefs. In addition, Qiang *et al.* (1985), and Chen *et al.* (1985) carried out researches on the Permian reefs in Sichuan Basin and eastern Sichuan, focussing mainly on the diagenesis and hydrocarbon reservoir properties of the reefs. In the 1990s, more and more new reefs were discovered, and researches on them involved more aspects of the reefs. Yang and Li (1995) and Xu *et al.* (1996) made a detailed study on the reef in Cili, Hunan Province, which was constructed not only by calcisponges but also by corals. Subsequently, more Permian reefs or bioherms were found along the mid Yangtze River section, such as Chongyang in Hubei Province, Xiushui in Jiangxi Province, Wuxi in Jiangsu Province and Tonglu in Zhejiang Province.

The reef studied in this paper is located at Lengwu, a small village in Yao Lin town, Tonglu County, Zhejiang Province. Since the 1960s, many researchers have studied this reef, such as the Regional Geological Survey of Zhejiang Province, Institute of Geology and Mineral Resources of Zhejiang Province, Petroleum Geology Bureau of East China, Hangzhou Institute of Petroleum Geology, Institute of Geology and Palaeontology CAS, Nanjing University, Tongji University, Zhongshan University, Chinese Academy of Sciences, Petroleum Exploration and Development Research Institute, China National Petroleum Corporation and some other organizations, but there is still much controversy on the nature of the reef. Some researchers regarded the reef to have developed on a shelf (Wang, 1987); some believed that it was not a reef, but a biostrome or biological bank (Institute of Geology and Mineral Resources of Zhejiang Province, 1989). Wu (1998) found rudstone mainly consisting of lying skeletons of reef-builders such as calcisponges in the reef, and proposed a reef-developing mode characterized by cycles ended with rudstone formed as the reef grew to the sea-level. Based on recent observations on outcrops and studies of thin sections, this paper deals with the rock types and sedimentary background, and proposes a sedimentary model for the reef development.

2. Geological background

The studied organic reef is located at Lengwu, Tonglu County, Zhejiang Province (Fig. 1). It is a reef built by calcisponges, and occurred in the Middle Permian Maokouan Lengwu Formation (Table 1). The outcrops of the Lengwu Formation extend in a northeast-southwest direction, for about 1.5 km (Yang, 1995). The base of the formation underlying the reef is gray-black argillite with thin layers of siltstone belonging to the Maokouan Dingjiashan Formation, which contains brachiopods and ammonoid fossils representing continental shelf environment. The strata overlying the reef is the Upper Permian Longtan Formation sandstones and siltstones containing coal seams.

The reef has a total thickness of 44 m with distribution area no more than 1 km^2. Based on lithology and palaeontological features, the reef profile has been divided into 23 layers from the bottom to the top (Fig. 2).

3. Reef composition and rock types

The reef is a calcisponge reef. The main reef-building organisms are calcisponges, with a small amount of bryozoans and Hydrozoans. The main encrusting organisms are blue-green *cyanophytes*, *Archaeolithophyllum* and *Tubiphytes*. The organisms dwelling in the reef include echinoderms (Echinoidea, crinoids), brachiopods, foraminifers, gastropods, bivalves, and red algae.

3.1. Reef composition

3.1.1. Reef-building organisms

The reef-building organisms of the Lengwu reef are mainly the following groups:

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