Journal of China University of Geosciences, Vol. 19, No. 5, p. 471–480, October 2008 *ISSN 1002-0705*
Printed in China

Molecular Records of Primary Producers and Sedimentary Environmental Conditions of Late Permian Rocks in Northeast Sichuan, China

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ABSTRACT: A series of biomarkers were identified in the aliphatic and aromatic fractions of the extracts from Late Permian Dalong (大隆) and Wujiaping (吴家坪) formations in Shangsi (上寺) Section, Northeast Sichuan (四川), South China, on the basis of the analysis of gas chromatography-mass spectrometry (GC-MC). The dominance of lower-molecular-weight *n*-alkanes throughout the profile suggests the dominant contribution of algae and bacteria to the organics preserved in the marine section. Wujiaping Formation is characterized by the elevated contribution from algae as well as other photoautotrophs such as photosynthetic bacteria as shown by the molecular ratios of hopanes to steranes or tricyclic terpanes as well as the ratio of pristane (Pr) and phytane (Ph) to C_{17} and C_{18} *n*-alkanes. This is in accord with the data from the microscopic measurement on the calcareous algae. In contrast, Dalong Formation is featured by enhanced contribution from bacteria and probably terrestrial organics indicated by the enhanced C_{24} tetracyclic terpanes relative to tricyclic terpanes. The two formations also show a distinct discrimination in sedimentary environmental conditions including redox condition and salinity. The anoxic condition was only found in the middle of the Dalong Formation as shown by the ratios of Pr/Ph and

This study was supported by the National Natural Science Foundation of China (No. 40730209) and the SINOPEC project (G0800-06-ZS-319).
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Manuscript received May 20, 2008.
Manuscript accepted July 1, 2008.

dibenzothiophene to phenanthrene, consistent with the reported data of Mo and U. An enhanced salinity indicated by the homohopane index is observed at the shallow Wujiaping Formation. On the basis of the composition of primary productivity and the redox condition, Dalong Formation is proposed, herein, to be potential hydrocarbon source rocks in the study site. It is notable that the topmost end-Permian is characterized by a large perturbance in both the redox condition and salinity, with oxic conditions being frequently interrupted by short-term anoxia, likely showing a causal relationship with the episodic biotic crisis across the Permian–Triassic boundary.

KEY WORDS: molecular fossil, lipid biomarker, Late Permian, mass extinction, geobiology, hydrocarbon source rock.

INTRODUCTION

Biomarkers are demonstrated to be indicative of the organic origins and types, sedimentary environmental conditions, thermal evolution history, and the alteration of the organics (Peters et al., 2005; Peters and Moldowan, 1993; Johns, 1986; Philp, 1985). Recent achievements in the biomarker diagnostics of some specific organisms allow the wide application on the biological and environmental events in association with the early life, biotic crisis, and extreme life (Xie et al., 2007a, 2005; Brocks et al., 2005, 1999; Grice et al., 2005; Zhang et al., 2004; Schouten et al., 2000; Summons et al., 1999). Identification of biomarkers derived from anaerogenic microbes favors exploring the microbial degradation of crude oils (Greenwood and Summons, 2003; Barber et al., 2001; Hinrichs et al., 1999).

Reconstruction of the composition of the primary productivity on the basis of the biomarker records was widely used in sedimentary rocks after Mesozoic. For example, Meyers and Takeuchi (1981) documented a progressive increase in the ratio of phytol to dihydrophytol that they interpret to represent greater contributions of algal organic matter. Their conclusion was on the basis of the work of Schultz and Quinn (1974), who showed that phytol concentrations correlate with chlorophyll and hence, with algal biomass. Sachs and Anderson (2005) reconstructed the algae productivity for the past 70 ka in the Subantarctic Ocean on the basis of the analyses of C_{37} methyl ketones diagnostic of coccolithophorid algae and brassicasterol (24-methylcholesta-5, 22E-dien-3β-ol) indicative of diatoms.

The organic matter of marine source rocks before Proterozoic in China was proposed to be dominated by bacteria, algae, and macrophytes (Qin, 2005; Zhang et al., 2005; Liang et al., 2000). However, because of the difficulty in the identification of algae, and in particular bacteria, in the ancient rocks, it is hard to evaluate their contribution to the primary productivity. Biomarkers are capable of offering such kind of information, particularly, in the Precambrian rocks without any identifiable microfossil or macrofossil (Wang T G et al., 2008; Olcott et al., 2005). It is notable that biomarkers would be thermally decomposed because of the increased maturation, and thus, care should be taken in the rocks that have experienced a high thermal history. Xie et al. (2007b) summarized some specific origins of the biomarkers compiled from the literatures, which provides a guide for the application of the biomarkers.

Shangsi Section in Guangyuan, Northeast Sichuan, was one of the candidate sections of the Permian–Triassic boundary. A series of events including volcanisms, uplift of the crust, biotic replacement and crisis, were believed to occur in this area (Peng and Yin, 2002; Yin et al., 1989; Fu and Zhang, 1988; Gao et al., 1987). Meanwhile, the study site was demonstrated to be the sedimentary center of the Guangyuan-Wangcang marine in Late Permian to Early Triassic, characterized by the widely spread Upper Permian strata including Wujiaping and Dalong formations with several layers of hydrocarbon source rocks. These source rocks are believed to contribute to several large gas reservoirs of Late Permian and Early Triassic in Northeast Sichuan, such as Puguang Gas Field and Maoba gas reservoirs, and the study area is a target for the current exploration of oil and gas (He et al., 2008; Wang Y G et al., 2008; Ma and Cai, 2006). Furthermore, the maturation of organic matter from the Upper Permian is measured to be relatively low, falling within the range of oil window. This makes the