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Research paper

The effect of river-delta system on the formation of the source rocks in the Baiyun Sag, Pearl River Mouth Basin

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ABSTRACT

Source rock formation influenced by river-delta system, especially in continental margin basins, is still poorly understood. This article aimed to reveal the effect of river-delta system on the formation of the source rock by taking the Baiyun Sag of the Pearl River Mouth Basin for example. Paleo-Pearl River began to develop since the Enping Formation, providing abundant organic matter beneficial for the formation of the source rocks in the Baiyun Sag. The main controlling factor of source rock formation in the Baiyun Sag is terrestrial organic matter supply rather than the paleoproductivity or redox conditions. Low Al/Ti and P/Ti ratios suggest low marine productivity, which may be associated with a large number of terrigenous detritus input, occupying about 43.04%–94.91%. There is a positive correlation between the oleanane/C_{30}hopane ratio and the TOC value, showing that terrigenous organic matter controls the source rock formation. The size of the delta below Pearl River estuary determines the extent of terrestrial organic matter supply. Source rocks with high organic matter abundance mainly formed in delta environment, and those in neritic environment in Enping and Zhuhai Formations also have high TOC values as a result of adequate terrestrial organic matter supply.

1. Introduction

The debate on whether high organic matter abundance in marine sedimentary stratum is dependent on preservation conditions or production has already existed since the 1980s (Tyson, 1987; Tyson and Pearson, 1991; Calvert and Pedersen, 1992). It is believed recently that organic matter supply, organic matter preservation and sedimentation rate all contribute to the formation of marine source rocks, among which, paleoproductivity and redox conditions are the main factors (Stow et al., 2001; Chen et al., 2006). However, in continental margin basins, terrestrial organic matter input is also a significant factor affecting marine source rock formation (Li et al., 2013a,b). Many rift basins where high quality marine source rocks formed are mainly located below the estuary of big rivers, which provides abundant terrigenous organic matter (Evamy et al., 1978; Stephenson and Cadman, 1994; Peters et al., 2000; Longly et al., 2003; Samuel et al., 2009; Akinlua and Torto, 2011).

The river-delta system affects the formation of source rocks. Firstly, nutrients transported by rivers give rise to surface plankton boom, leading to high biological productivity, which is beneficial to the formation of high quality source rocks (Hao et al., 2011). However, marine productivity can also be diluted by detrital materials transported by rivers. Secondly, terrigenous plants debris can be carried into lakes or the sea attributed to fluvial transportation. A large scale delta is likely to form below the estuary of a large scale river, which can provide abundant terrestrial organic matter to form high quality source rocks. For example, the famous Niger Delta Basin and the Congo Basin are both affected by the inflow of fresh water and develop certain scale of delta (Tong, 2002; Hou et al., 2005; Bentahila et al., 2006; Zhou et al., 2007; Deng, 2010).

The crude oil and natural gas discovered in the deep water area of northern South China Sea are mainly from coal-measure source rocks in Yacheng and Enping Formations of transitional facies (Fu and Yu, 2000; Fu et al., 2007, 2010; Zhu et al., 2009, 2012; Li et al., 2010; Li et al., 2013a,b), and the formation and distribution of the source rocks are closely related to delta. Although the marine source rocks in Zhuhai Formation partly contribute to the oil and gas in the Baiyun Sag of the Pearl River Mouth Basin (Zhu et al.,

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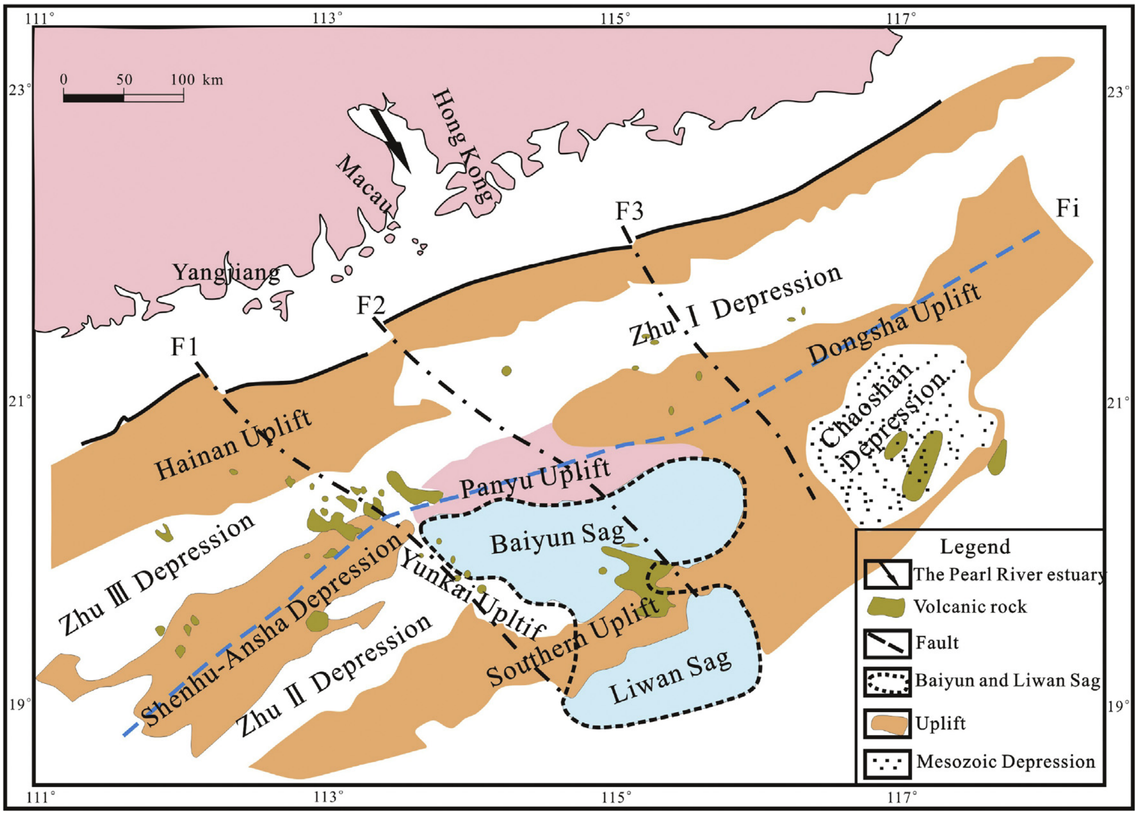

Fig. 1. The structural location of the Pearl River Mouth Basin.

2005, 2008), these source rocks are significantly influenced by the delta (Wu et al., 2010). The formation of the source rocks in the Baiyun Sag are controlled by the ancient Pearl River, which can even affect south of the Baiyun Sag in the sedimentary period of Zhuhai Formation (Xu et al., 2010). As a result, terrestrial organic matter largely contributed to the formation of the source rocks in Zhuhai Formation (Li et al., 2011). It is of great significance to understand the effect of river-delta system on the formation of the source rocks in the Baiyun Sag, which can provide some reference for the oil and gas exploration in deep water area of the northern South China Sea.

This paper mainly discussed the effect of paleoproductivity, terrestrial organic matter and redox conditions to the formation of source rocks affected by river-delta system in the Baiyun Sag using trace elements and biomarker data. The controlling factor and the developmental model of the source rocks were proposed through the analysis of the effect of ancient Pearl River and delta on the formation of the source rocks.

2. Analytical samples and methods

A total of 40 samples were collected in the Baiyun Sag, Pearl River Mouth Basin. The samples were ground in an agate mortar and pestle to 200 mesh size. For TOC analyses, a 0.10 g sample was treated in a sterilized crucible with 12.5% HCl to remove carbonates, then washed with distilled water at intervals of about half an hour for three days. The samples were eventually oven-dried and residual organic carbon was measured using a Leco CS230 analyzer.

Samples for analysis of GC-MS were crushed into 80 meshes and extracted in a Soxhlet apparatus with dichloromethane (CH_2Cl_2) for 24 h. The extracts were evaporated, deasphaltened with n-hexane, and then separated through column chromatography using silica gel and alumina (3: 1) into the saturated, aromatic and polar fractions by n-hexane, dischloromethane: n-hexane (2:1, v: v) and chloroform: ethanol (1: 1, v: v) as elution solvents, respectively. The saturated and aromatic fractions were analyzed by gas chromatography-mass spectrometry (GC-MS). GC-MS analyses were performed on a Thermo-Finnigan Trace-DSQ equipped with an HP-5MS (60 m × 0.25 mm × 0.25 μm) fused silica capillary column, operating in full scan modes. GC-MS conditions were split injection at 300 °C; helium (99.999% purity) as carrier gas; and oven temperature initially at 50 °C for 1 min, programmed at 20 °C/min to 120 °C, then at 3 °C/min to 310 °C and held at this temperature for 25 min. The mass spectrometer was operated in the electron impact (EI) mode at 70 eV with a total scan range.

The samples were prepared for trace and major elements analyses using about 25 mg of powdered and homogenized sample loaded in polytetrafluoroethylene (PTFE) vessels and heated to 190 °C for 72 h in PTFE autoclaves with 1 ml HF (40%) and 1 ml

Table 1
Stratigraphic evolution of the Pearl River Mouth Basin.

System	Series	Formation	Tectonic evolution	Bottom stratigraphic age (Ma)
Q			Depression stage	2.6
N	N_2	Wanshan Formation		5.3
	N_1	Yuehai Formation		10.5
		Hanjiang Formation		16
		Zhujaing Formation		23.3
E	E_3	Zhuhai Formation	Transitional Stage	28
		Enping Formation	Rapid Rifting Stage	32
	E_2	Wenchang Formation	Early Rifting Stage	56.5
	E_1	Shenhu Formation		65