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Spatial distribution and geochemistry of the nearshore gas seepages and their implications to natural gas migration in the Yinggehai Basin, offshore South China Sea

Baojia Huang [a,b,*], Xianming Xiao [a,*], Xushen Li [b], Dongshen Cai [b]

[a] State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
[b] CNOOC Ltd, Zhanjiang 524057, China

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ABSTRACT

About 120 gas seepage vents were documented along the west and southwest coast of the Hainan Island, South China Sea, in water depths usually less than 50 m. The principal seepage areas include the Lingtou Promontory, the Yinggehai Rivulet Mouth, Yazhou Bay, the Nanshan Promontory and the Tianya Promontory. They occur along three major zones, reflecting the control by faults and lateral conduits within the basement. It is estimated that the total gas emission from these seepage vents is 294–956 m^3/year. The seepage gases are characterized by a high CH_4 content (76%), heavy $\delta^{13}C_1$ values (−38 to −33‰) and high C_1/C_{1-5} ratios (0.95–1.0), resembling the thermogenic gases from the diapiric gas fields of the Yinggehai Basin. Hydrocarbon–source correlation shows that the hydrocarbons in the sediments from seepage areas can be correlated with the deeply buried Miocene source rocks and sandstone reservoirs in the central depression. The 2D basin modeling results based on a section from the source rock center to the gas seepage sites indicate that the gas-bearing fluids migrated from the source rocks upward through faults or weak zones encompassed by shale diapirism or in up-dip direction along the sandstone-rich strata of Huangliu Formation to arrive to seabed and form the nearshore gas seepages. It is suggested that the seepage gases are sourced from the Miocene source rocks in the central depression of the Yinggehai Basin. This migration model implies that the eastern slope zone between the gas source area of the central depression and the seepage zone is also favorable place for gas accumulation.

1. Introduction

Natural hydrocarbon seepages from sea bottom have been reported in quite a few offshore petroleum-bearing basins, such as North Sea of Netherlands (Hovland and Judd, 1988; Schroot and Schuttenhelm, 2003), Gulf of Mexico (Behrens, 1988), offshore California (Scott et al., 1999), Great Britain (Selley, 1992), the Torry Bay of Scotland (Judd et al., 2002), and southeast Asia (Macgregor, 1993). Because hydrocarbon seepages are proxies to migration pathways and/or deeper hydrocarbon reservoirs (Abrams, 2005), they are very important clues for petroleum exploration. The hydrocarbon seepages along the eastern margin of the Yinggehai Basin, South China Sea, have been known and recorded for more than 100 years (Zhang, 1965). However, little information has been reported on their geochemistry and origin. With increasing petroleum exploration activities in the Yinggehai Basin, it has been realized that the gas seepages may provide new information to trace the hydrocarbon sources and thus reduce the exploration risk in the basin. In this paper, we present the spatial distribution, gas flux rates and geochemical characteristics of the hydrocarbon seepages, and discuss their origins and migration models in the basin.

2. Geological setting

The Yinggehai Basin is one of the most gas-rich Cenozoic rift basins in China (Gong, 1997; Huang et al., 2003). It trends northwest–southeast, and is separated from the Hainan Island to the east by the No.1 fault (Fig. 1). The tectonic evolution of the basin can be divided into two stages: a Paleogene extensional rifting event and a Neogene post-rift thermal subsidence (Gong, 1997). The basin was filled with thick deposits of Cenozoic clastics on Paleozoic and Mesozoic basement rocks (Fig. 2). It was estimated that the maximum thickness of the Cenozoic deposits reaches 16 km at the basin center (Huang and Xiao, 2004).

* Corresponding authors. State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China. Tel.: +86 20 85290176.
E-mail addresses: huangbj@cnooc.com.cn (B. Huang), xmxiao@gig.ac.cn (X. Xiao).

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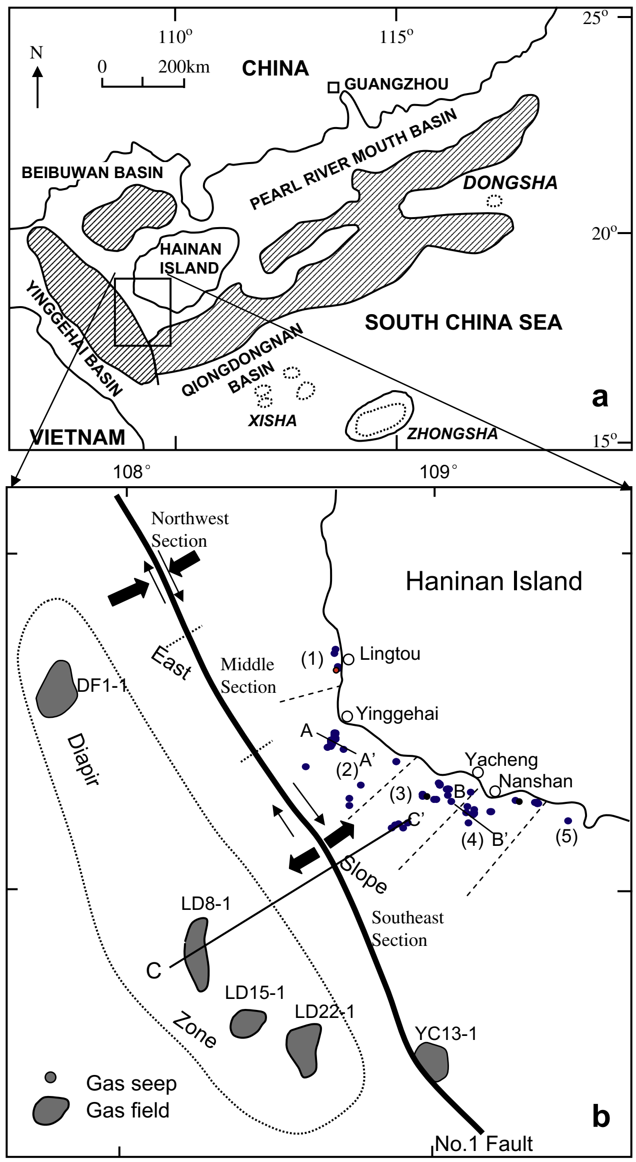

Fig. 1. (a) General map showing the location of the Yinggehai Basin and (b) the distribution of the Yinggehai nearshore gas seeps.

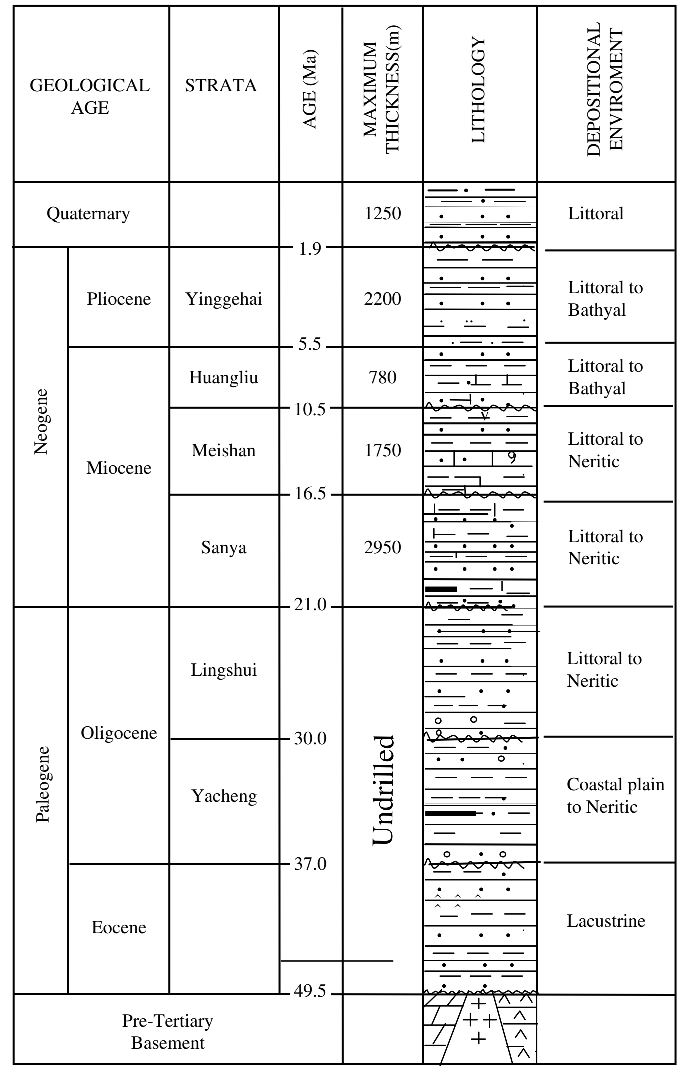

Fig. 2. Schematic stratigraphic column of the Yinggehai Basin.

The basin is characterized by a rapid subsidence rate, a high geothermal gradient and overpressure (Zhang et al., 1996; Huang et al., 2003; Huang and Xiao, 2004). It is evaluated that the maximum sedimentation rate was up to 1.2 mm/year. The geothermal gradient was as high as 4.25–4.56 °C/100 m during the Tertiary period (Huang et al., 2002, 2003). The maximum pressure coefficient reaches 2.0–2.3 (Zhang et al., 1996; Huang et al., 2003) with the major part of the basin being an overpressure system. The combination of overpressure and high palaeo-geothermal gradient had an important influence on the generation, migration and accumulation of natural gases in the basin. Available geological and geochemical data indicate that the main hydrocarbon–source rocks in the basin reside in the Meishan and Sanya Formations (Huang et al., 2003). These source rocks contain gas prone higher plant-derived organic matter (Huang et al., 2003).

Another important geological character of the basin is the widely developed diapiric structures in the basin center area. The diapiric faults act as preferential pathways for upward migration of natural gases from the deep sources into the Pliocene sandstone bodies and Quaternary strata, forming the major exploration targets in this basin. Several gas fields related to the diapiric structures have been discovered in the Yinngehai Basin in recent years (Dong and Huang, 1999; Huang et al., 2002, 2003).

The discovered natural gas pools principally occur in the Pliocene–Quaternary marine sandstones from the central diapir zone, with a burial depth of 390–2000 m. Most of them are of diapiric origin. The gases are believed to be derived from a set of Type II_2–III sources rocks in the Meishan and Sanya Formations occurring in the central depression of the Yinggehai Basin (Huang et al., 2003; Huang and Xiao, 2004). The gas seepages occur in the west and southwest coastal area of the Hainan Island, and cover the southeast part of the hanging wall of the No.1 fault in the Yinggehai Basin (Fig. 1), with water depths usually ranging from 10 to 50 m. Most of the seafloor topography appears to be relict and related to the erosion of older sedimentary strata. A thin layer of surfacial sediments consisting of silts, clays, and sands is deposited in this area. The basement rocks comprise inter-bedded deltaic sandstones, siltstones and shales of Pliocene and late Miocene age. Some of the gases derived from the deep buried source rock in the central basin migrate to the seabed through tortuous pathways and exit from the seafloor surfacial sediments, leading to the formation of the near-shore gas seepages in the Yinggehai Basin, which will be discussed in following sections.