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Research paper

Geochemical characterization and depositional environment of source rocks of small fault basin in Erlian Basin, northern China

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A B S T R A C T

A combined investigation of molecular geochemistry, elements and carbon isotopic composition of carbonate distribution was carried out on the Early Cretaceous mudstones of the Tengger Formation in the Erlian Basin, northern China, to define source rock geochemical characteristics, depositional environment and tectonic setting of small faulted basin. The biomarkers of mudstone extracts are characterized by short to middle chain n-alkanes, high CPI values (>1.12), a wide range of Pr/Ph (0.4–1.94), relatively high concentrations of C_{29} sterane and the presence of relatively low tricyclic terpanes and low gammacerane index values (0.01–0.25), which is consistent with a relatively oxic to anoxic depositional environment of fresh to brackish water conditions, with a major contribution of terrigenous organic matter input and a low contribution of aquatic algal-bacterial organic matter. The oxic to anoxic depositional environment of small fault basins and a fresh and brackish water conditions are also confirmed by reduced sulphur/organic carbon ratio and element distribution. In these small fault basins, the cross-plots of $\delta^{13}C_{carb}$ and TOC show that productivity has an obvious control on source rock development. The differences in tectonic settings cause variations in productivity, redox conditions and terrigenous organic matter input, which account for the distinctly different geochemical characteristics and depositional environment of source rocks in small fault basins.

1. Introduction

Erlian Basin is an Early Cretaceous rift basin group and comprises more than 40 small fault basins with individual area ranging from 150 to 4200 km^2 (Dou et al., 1998). It is one of the most petroliferous basins with great proven oil reserves and undiscovered resources in the northern china. To date, potential oil resources are estimated at 1, 170 million tons (8, 564 million barrels), in which 234 million tons (1, 713 million barrels) are proved in fifteen oil fields. The oil resources in Erlian Basin Group show strong vertical and horizontal variations. The hydrocarbon potential of a basin depends on the presence of favorable petroleum source rocks, while previous studies on the characterization of organic matter and depositional environment of these small fault basins were limited and not known (Fang et al., 1998; Tian, 2008). Moreover, most of the previous studies of these small fault basins were based primarily on pyrolysis methods, without significant input from biomarkers and inorganic geochemistry.

Biomarkers distributions have been used effectively in characterization of the environmental conditions and source input of organic matter during the deposition (Peters et al., 2005). Likewise, elemental analysis of trace elements can provide essential information of the depositional environment (Sinninghe Damsté et al., 1999; Meinhold et al., 2013; Tripathy et al., 2014). The integration of biomarkers and elements distribution can give more detailed information of the source rock characteristics and depositional environment.

We have conducted a comprehensive investigation of molecular geochemistry, elements and carbon isotopic composition on the

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Early Cretaceous mudstones of the Tengger Formation in the Erlian Basin Group to (1) investigate the origin and type of the organic matter, maturity and depositional environment conditions of the source rock in the small fault basins, (2) define the controlling factor on source rock development in the small fault basins, (3) reveal that differences in tectonic setting of small fault basins can cause variations in productivity, redox conditions, clastic influx input and lead to systematic changes in source rock quality and depositional environment.

2. Geologic setting

Erlian Basin is an Early Cretaceous rift basin group developed on Hercynian folded basement and comprises more than 40 north-northeast trending small fault basins, with an area smaller than 5000 km^2 (Fig. 1, Fig. 2). These small fault basins are formed by extension during the Jurassic and Cretaceous and dominated by half-grabens or asymmetric grabens, and display similar tectonic evolution and clear basin boundary (Dou, 1997; Dou et al., 1998; Dou and Chang, 2003).

The Erlian Basin Group experienced three main stages of evolution (Fig. 3). The first synrift stage, formed in the Jurassic, is only developed in some small basins, such as the Wuli. The main phase of rifting took place during the Early Cretaceous, when a series of lacustrine sediments were deposited as a transgressive–regressive cycle.

The first synrift sediments include the Alatanheli Formation ($J_{1-2}a$) and the Xingan Formation (J_3x), composed of alluvial and lacustrine deposits with coal seams (Fig. 3). The second synrift stage was from 135 to 112 Ma (basin stage), with the post rift stage from 112 Ma to the present. The Lower Cretaceous sequence includes the Aershan (K_1a), Tengger (K_1t) and Saihantala (K_1s) formation, which are composed of alluvial, fan deltas and lacustrine sediments. The Tengger Formation is made up of dark grey-black mudstones interbedded with sandstones and siltstones, with a thickness of 500–2100 m, and can be further subdivided into the lower Tengger member (K_1t^1) and the upper Tengger member (K_1t^2) based on its lithology and fossil assemblages (Huang et al., 2003). Possible source rock horizons exist mainly in the K_1a and K_1t^1 formations. The K_1t^2 formation is excluded as a possible source rock mainly due to its shallow burial depth and low maturity. The hydrocarbons associated within the Erlian Basin are mainly normal oils accumulated in the K_1a and K_1t^1 formations along with some heavy oils in the K_1t^2 formation.

3. Samples and methods

A total of 48 mudstone samples of the first member of Tengger formation (K_1t^1) were collected from oil exploration drill core in Aer, Wuli, Jier, Hongte, Naoer and Saihan basins of the Erlian Basin Group (Fig. 1). Locations of the sampling basins are shown in Fig. 1. All of the samples were selected for total organic carbon and total reduced sulphur measurements, pyrolysis analysis, gas chromatography–mass spectrometry (GC–MS) analysis, carbon isotope of carbonates. Thirty-nine of these samples were selected for trace element measurements.

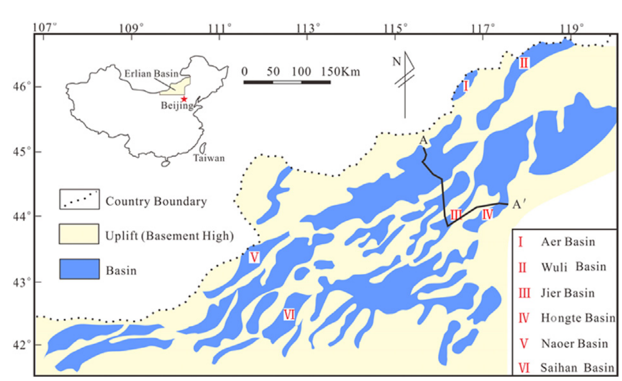

Fig. 1. Map of the Erlian Basin Group, showing location of each study small fault basin: Aer, Wuli, Jier, Hongte, Naoer and Saihan.

The samples were pulverized to 100 mesh in preparation for total organic carbon content (TOC) and total reduced sulfur (TRS) measurement Rock-Eval pyrolysis. The TOC of the mudstones were measured using a LECO CS-230 analyser. The method for determining abundances of inorganic TRS is after Zhabina and Volkov (1978), as modified by Canfield et al. (1986). A Rock-Eval instrument is used to perform the pyrolysis analysis, which provides the parameters of T_{max}, S_1 and S_2. The results are listed in Table 1.

The rock samples were cleaned prior to powdering. Soxhlet extraction was conducted using chloroform/methanol (87:13) for 72 h and the isolated extractable organic matter was separated into saturated hydrocarbons, aromatic hydrocarbons and polars. Saturated fractions were dissolved in hexane and analyzed by a GC instrument (HP-5MS column, temperature programmed from 40 to 300 °C at a rate of 4°C/min, and then held for 30 min at 300 °C). GC–mass spectrometry (GC–MS) analyses of the saturate fractions were performed with a HP6890GC/5973MSD instrument equipped with a HP-5MS fused silica column (30 m × 0.25 mm i.d., film thickness 0.25 μm). The GC oven temperature for analysis of the saturate fractions was initially held at 50 °C for 2 min, then programmed to 100 °C at 20 °C/min and to 310 °C at 3 °C/min, and held at 310 °C for 16.5 min. The selected ion monitoring capabilities of the data acquisition system permitted specific ions to be monitored, such as tricyclic terpanes and hopanes (m/z 191), and steranes (m/z 217). Relative abundances of triterpanes and steranes were calculated by measuring peak areas in the m/z 191 and m/z 217 fragmentograms, respectively. The results are listed in Table 2.

Carbon isotopic compositions of carbonate in the mudstone samples were determined by a traditional acid-release method. Powdered samples were treated with anhydrous H_3PO_4 at 25 °C for 24 h to liberate CO_2, and the liberated CO_2 was collected and sealed for carbon isotope analysis. The carbon isotopic ratio was analyzed on a Finnigan MAT 252 mass spectrometer. Results were reported in standard per mil δ-notation relative to the V-PDB standard. Analytical error of these analyses is less than 0.1‰. The results are listed in Table 1.

Concentrations of trace elements were determined using an Agilent Technologies 7500 Series Inductively-coupled plasma mass spectrometer (ICP-MS). About 250 mg of the ground samples were prepared for the analysis in duplicate by digestion with HNO_3, HCl and HF in an Anton 3000 microwave oven. Boric acid was used for complexation after digestion and then diluted up to 100 times with ultimate pure water (UPW). Standard solutions of the elements with an analyte concentration of 10 ppm were used for calibration. The stock solutions were diluted with deionized distilled water to prepare each working solution for calibration. The minimum detection limit of the equipment is less than 1 ppb. The results are listed in Table 3.

4. Results and discussion

4.1. Source rock characteristics

TOC is the main index to evaluate the organic matter abundance of source rock. In the Erlian Basin Group, the TOC contents of mudstone samples show wide range of 0.08%–3.6%. The source rocks in the eastern basins have higher TOC than the western