Fuel 222 (2018) 207–231

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Hydrocarbon distribution pattern and logging identification in lacustrine fine-grained sedimentary rocks of the Permian Lucaogou Formation from the Santanghu basin

Guoheng Liu[a,b,1], Bo Liu[c,1,*], Zhilong Huang[a,b,1,*], Zhiyuan Chen[a,d,1], Zhenxue Jiang[a,d], Xiaobo Guo[e], Tingwei Li[d], Lei Chen[d]

[a] State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing 102249, China
[b] College of Geosciences, China University of Petroleum, Beijing 102249, China
[c] Accumulation and Development of Unconventional Oil and Gas, State Key Laboratory Cultivation Base Jointly-constructed by Heilongjiang Province and Ministry of Science and Technology, Northeast Petroleum University, Daqing 163318, China
[d] Unconventional Natural Gas Institute, China University of Petroleum, Beijing 102249, China
[e] School of Earth Sciences and Engineering, XI'AN University of Petroleum, Xi'An 710065, China

ARTICLE INFO

Funding: The National Natural Science Foundation of China (41272156 and 41472125).

Keywords:
Lithofacies identification
Tuffaceous shale
Hydrocarbon distribution
Lucaogou Formation

ABSTRACT

A series of qualitative descriptions and quantitative analyses was used to determine the lithofacies characteristics and hydrocarbon distribution pattern of Lucaogou Formation fine-grained sedimentary rocks in the Santanghu Basin. The qualitative descriptions include core description, petrographic thin section observation, fluorescence observation, cathode luminescence observation and scanning electron microscope (SEM) observation. The quantitative analyses include X-ray diffraction, total organic content analysis, programmed pyrolysis, Soxhlet extraction, vitrinite reflectance, maceral composition, porosity and permeability analysis, and oil saturation analysis.

Three main types of lithofacies were identified in this study area: organic-rich massive tuffaceous shale lithofacies (RMTSL), organic-rich laminated and cloddy diamictite lithofacies (RLCDL) and organic-lean massive dolomite lithofacies (LMDL). RMTSL mainly includes massive shale and tuffaceous shale. Quartz and clay minerals are the major components of rocks from this lithofacies. RLCDL develop lamina and a cloddy structure. Rocks from this lithofacies chiefly consist of dolomite and quartz. LMDL mainly contains massive bedding fine-grained carbonate rocks. Dolomite accounts for the main portion of these rocks. RMTSL contains the highest content of free hydrocarbon and solid organic matter. Moreover, higher porosity was observed in RMTSL. LMDL contains the lowest solid organic matter content and develops the least pores. RLCDL develop the largest number of cracks and fractures.

Resistivity logging (RD) combined with tri-porosity logging suites were finally selected to differentiate the three lithofacies. The response characteristics of RMTSL should be high acoustic time (AC), low density (DEN), high compensated neutron logging (CN) and high resistivity logging (RD). On the contrary, the response characteristics of LMDL are low acoustic time (AC), high density (DEN), low compensated neutron logging (CN) and low resistivity logging (RD).

Commercial oil production mainly appears in RMTSL. Uplift belts that are away from erosion areas and develop thick RMTSL will be the area with the most potential. Hence, the Mazhong uplift belt is the most favourable area for the accumulation of hydrocarbon on a large scale.

1. Introduction

Over a decade, the successful development of unconventional resources via horizontal drilling and hydraulic fracturing from marine shales such as Barnett shale, Marcellus shale, Eagle Ford shale, Wufeng-Longmaxi shale and Niutitang shale has rapidly increased [1–12]. In recent years, although major breakthroughs have also been made in transitional and lacustrine shale exploration, such as the Upper

---

* Corresponding authors at: State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing 102249, China (Z. Huang).
E-mail addresses: Liubo6869@163.com (B. Liu), huang5288@163.com (Z. Huang).

[1] Equal contributors.

https://doi.org/10.1016/j.fuel.2018.02.123
Received 16 November 2017; Received in revised form 14 February 2018; Accepted 20 February 2018

Carboniferous Benxi shale, the Lower Permian Shanxi shale, the Triassic Yanchang formation shale and the Cretaceous Qingshankou Formation shale, the overall oil and gas production is far behind that from marine shale [8,13–20]. So far, only some wells have produced shale gas at a commercial scale from lacustrine shale in the Chang 7 Member of the Yanchang Formation after fracturing. Taking Sichuan Basin as another example, Sichuan Basin develops shale formed under various depositional settings, ranging from Middle Permian marine shale and Upper Permian transitional setting shale, to Triassic and Jurassic lacustrine shale. Many shale gas blocks in the Sichuan Basin had good production test results after hydraulic fracturing, but only marine shale has produced at a commercial scale [17,20–23].

The accumulation of organic matter in fine-grained sediments is one of the main carbon fixation processes in the global carbon cycle, and these organic-rich fine-grained sediments comprise the primary source of hydrocarbons [24–27]. There are three main factors controlling hydrocarbon enrichment and distribution in fine-grained sedimentary rocks, which are the geological structure, depositional environment and diagenesis [19,28–31].

The slopes and subsidence depositional centres of basins are favourable areas for the generation and distribution of hydrocarbon in fine-grained sedimentary rocks of the Qingshankou Formation in Songliao Basin [19]. Structural faults set up close oil-source correlations between oil reservoirs in the tuffaceous Tiaohu Formation and the source rocks underlying Lucaogou Formation in Santanghu Basin [30–31].

Another factor that controls the hydrocarbon enrichment and distribution in fine-grained reservoirs is lithofacies, which is an important property of rock formed under certain depositional environments [2,32–36]. Fine-grained sedimentary rocks, such as shale, formed under different sedimentary conditions display great particularity and distinctiveness. Hence, lithofacies identification of reservoirs is the base and key to oil exploration. Han et al. (2016) classified the Upper Ordovician and Lower Silurian black shale in the Sichuan Basin into three lithofacies and proved that the low calcareous mixed mudstone was the most favourable type of lithofacies [35]. Paleogene fine-grained sedimentary rocks in Dongying Sag, Bohai Bay Basin was classified into five types of lithofacies, and organic-rich laminated limestone facies was identified as the most advantageous lithofacies for oil enrichment [34]. There are many parameters that have been used in the definition of lithofacies, including total organic carbon (TOC), mineral composition, colour, structure, genesis, fossil, texture, lamination characteristics, geochemical parameters and 3D seismic data [2,6,7,37–67].

Moreover, other factors that can be used to predict hydrocarbon

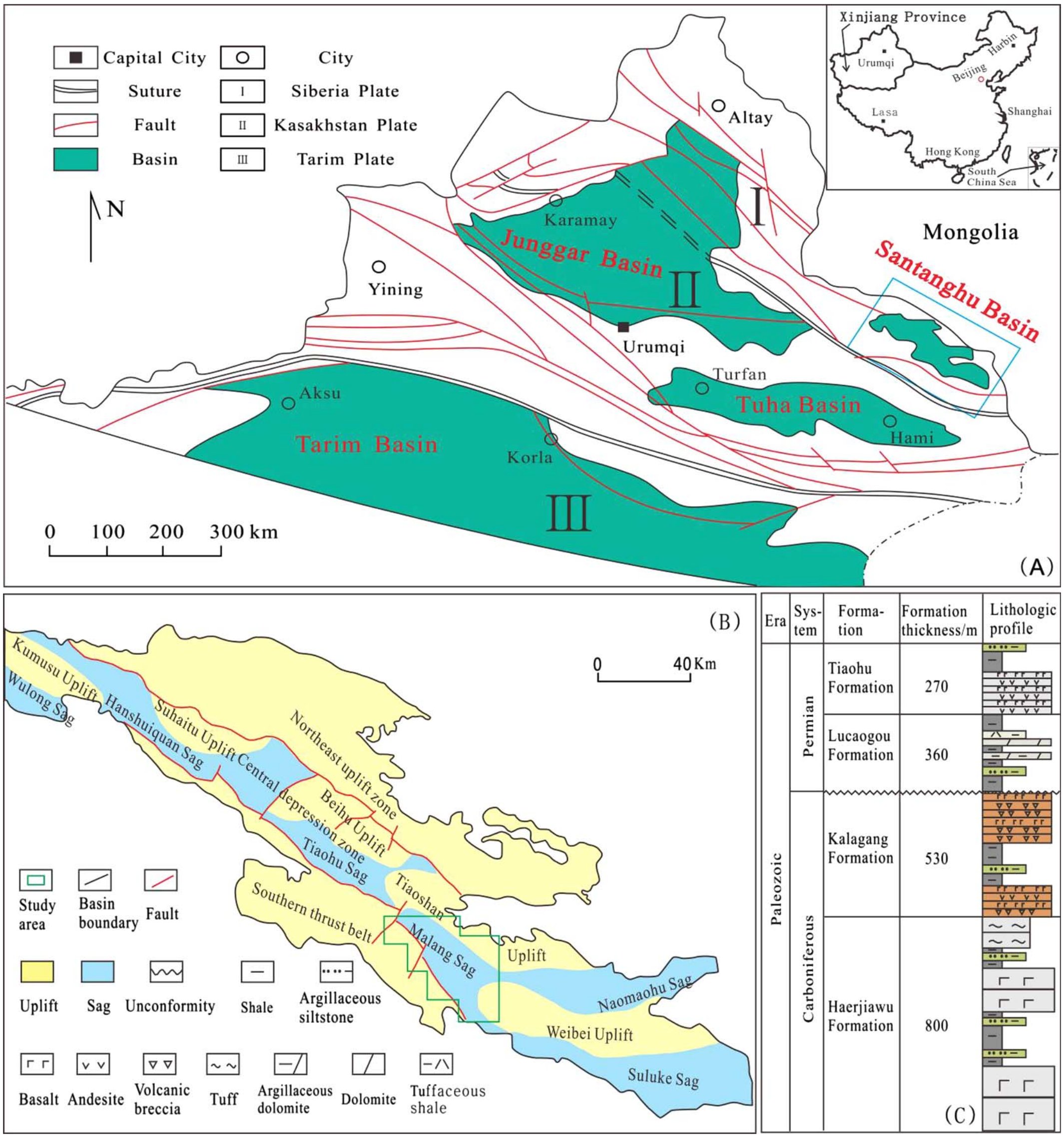

Fig. 1. Location of the Santanghu Basin (A) and the study area (B). Lithological sketch of Upper Permian and Carboniferous strata (C) (Fig. 1 (B, C) modified from [91]).