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RESEARCH PAPER

Petrologic characteristics and genetic model of lacustrine lamellar fine-grained rock and its significance for shale oil exploration: A case study of Permian Lucaogou Formation in Malang sag, Santanghu Basin, NW China

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Abstract: Taking the Permian Lucaogou Formation in the Malang sag, Santanghu Basin as an example, by using petrological methods such as high resolution core image scanning, conventional thin section, scanning electron microscope and energy spectrum analysis and geochemical tests such as trace elements and biomarker compounds, the petrologic features and sedimentary origin of the lamellar organic rich fine-grained rocks of lake facies were investigated, and its significance for shale oil and tight oil exploration was analyzed. The results of the study show that there are four types of laminae, siliciclastic enrichment laminae, carbonate enrichment laminae, tuffaceous enrichment laminae and organic matter enrichment laminae, which can form three kinds of layer combinations. Organic matter is laminar enrichment or dispersed in the carbonate laminae and tuff laminae. Stratification of ancient lake water was formed in the closed saline lake sedimentary systems with insufficient continental clast supply, and the activity of warm water at the lake bottom and the monsoon climate worked jointly to control enrichment of organic matter and formation of lacustrine lamina fine-grained rocks. This kind of fine-grained rocks have higher potential of hydrocarbon generation due to high abundance of organic matter, are rich in reservoir space due to the existence of micro-pores in carbonate laminae and micro-cracks between the laminae, and suitable for fracturing because of high brittle mineral content. They have favorable conditions for shale oil and tight oil accumulation, and are significant for exploration.

Key words: lamellar fine-grained rock; laminae combination; organic matter enrichment mode; petrologic characteristics; genetic model; shale oil and gas; tight oil and gas

1. Concept and characteristics

Fine-grained rock refers to sedimentary rocks composed mainly of clay and silt less than 62 μm in grain size[1]. They contain not only clay minerals, but also silt, carbonates, organic matter etc[2]. Laminae are the thinnest and the smallest unit of original sedimentary layers recognizable from sediments or sedimentary rocks. There are many types of laminae, such as lacustrine varves[3], marine varves[4] etc. In recent years, more and more researchers found out that shale with alternating dark and light laminae had richer organic matter and thus higher hydrocarbon generation potential than shale with dispersed organic matter[5], for example, the third member of the Palaeogene Shahejie Formation in Dongying sag in Bohai Bay Basin, northern China, the laminated and organic-rich shale at the lower part of the member has better hydrocarbon-generation capacity than the central part of the member with scattered organic matter[6]. In addition, when meeting certain geological conditions, laminated mud shale can form oil shales with industrial value, for example, the Jurassic tasmanite comprising of marine algae in Alaska[7] and the Ordovician kukersite consisting almost entirely of telalginite derived from Gloeocapsomorpha in Estonia[7]. Other examples

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include the dark lamellar oil shales made up of dead red algea in Qingbaikou system of the Neoproterozoic in Hebei Province (TOC: 21.41%–22.91%, oil content: 5.29%–10.57%)[8], and Shehejie Formation oil shales with organic laminae of algae, clay, and carbonates in Dongying sag of Bohai Bay Basin (TOC: 2%–8%)[9]. The two oil shales in China share the following features: (1) They contain laminae of less than millimeter in thickness and of various types, including terrigenous clastics, crystal fragment, tuffaceous, and organic laminae; (2) Organic-rich laminae alternate with organic–lean laminae, and the two kinds of laminae differ greatly in TOC value, sometimes, as high as 10 to 30 times[10]; and (3) Dark organic laminae give off strong yellow fluorescence under microscope, and are held in between mud, silt and carbonate laminae with weak fluorescence. In this study, we performed systematic petrology study on fine-grained rock samples from the Permian Luocaogou Formation in Malang sag of Santanghu Basin through high-resolution imaging scanning, thin section observation, cathode luminescence, SEM and energy spectrum analysis to reveal its genesis and significance to oil and gas exploration in shale or other tight rocks (Fig. 1).

2. Petrological characteristics of lacustrine lamellar fine-grained rock

Variable in lithofacies, complicated in mineral composition, and strong in heterogeity, lacustrine fine-grained rocks are generally formed in shallow lake or semi-deep lake – deep lake where water power is weak. Laminae are the basic units of fine-grained rocks and appear as silt, carbonate, organic ones depending on specific sedimentary environment and climate. Lacustrine fine-grained rocks usually consist of interbedded and cycled laminae of different minerals. Generally 0.01 mm and 0.50 mm thick, laminae are different in color, mineral composition, grain size, structure and genesis (Fig. 2).

2.1. Basic laminae types

Analysis shows that there are four major types of laminae in the study area: siliciclastic, carbonate, tuffaceous and organic-rich ones.

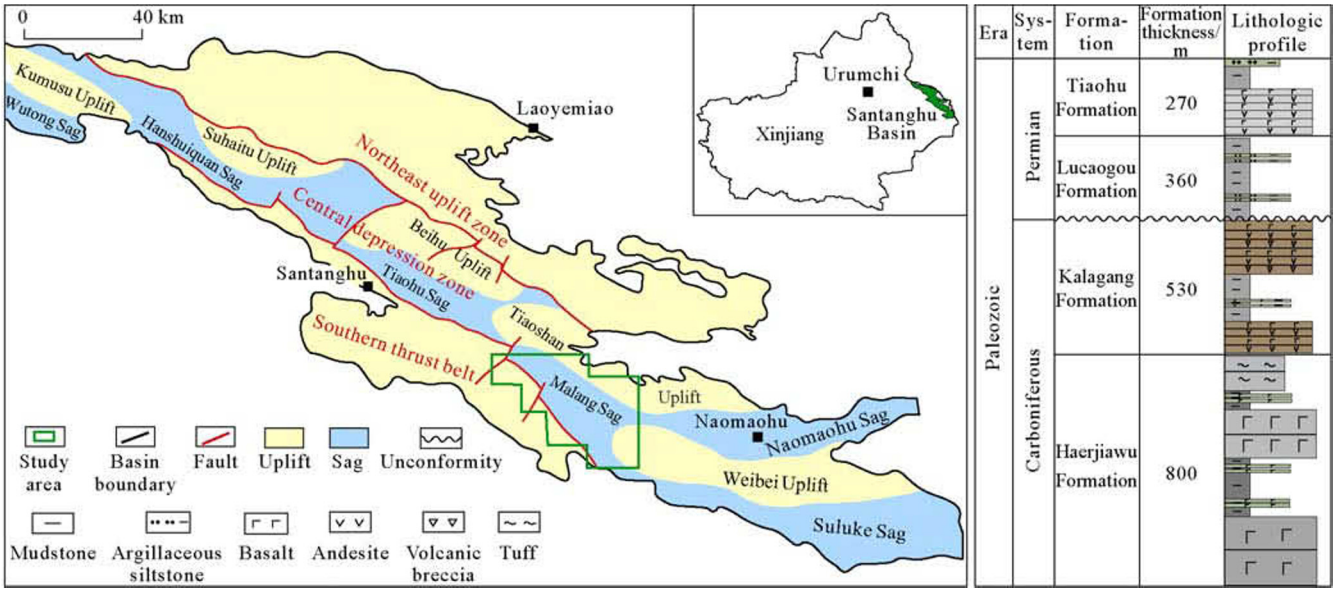

Fig. 1. Schematics of structures in Santanghu Basin and the location of the study area.

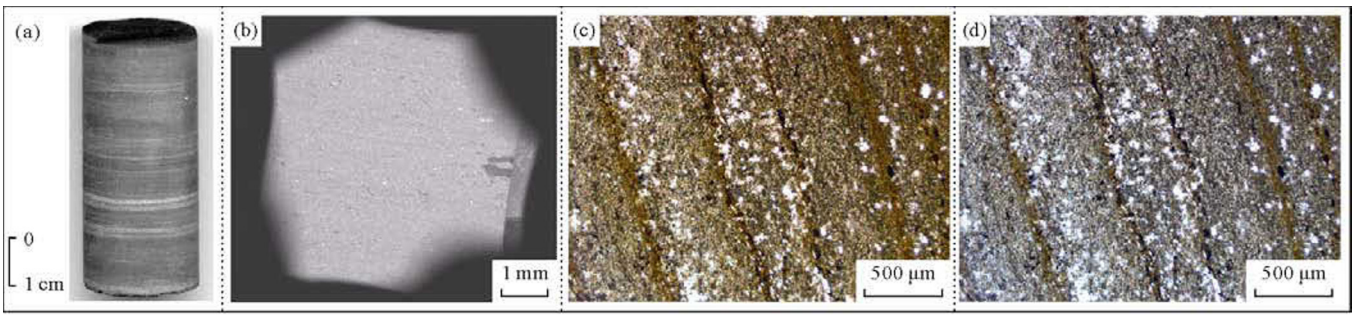

Fig. 2. High-resolution scanning and microscopic images of lacustrine lamellar fine-grained rocks in Lucaogou Formation of Malang sag. (a) Core scanning image showing alternative dark and bright laminae, Well N-122, 2 589.58–2 589.63 m; (b) SEI image showing minerals and organic matter of different colors in directional arrangement in laminae, Well N122, 2 589.60 m; (c) Photo taken with plane-polarizers showing vitrinite and inertinite strips lined up along bedding, Well N122, 2 589.00 m; (d) Photo taken with cross-polarizers showing micrite calcite/dolomite with white interference color, some recrystallized into fine grains and formed couplets with siliciclastics, Well N122, 2 589.60 m.