MULTI-SCALE ANALYSIS OF ALKALINE LACUSTRINE SHALE OIL CHARGING CHANNELS IN FENGCHENG FORMATION, JUNGGAR BASIN*

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Fengcheng Formation with the feature of giant shale oil resource potential is a typical dolomitic source rock of alkaline-lacustrine deposition. Based on study of drilling cores, image logs, thin sections, confocal microscopy, fluorescence observation and scanning electron microscopy (SEM), it is shown that Fengcheng Formation develops multiple reservoir storage space types, such as rock fractures, kerogen networks, stylolites, and micro-nano pore-throat systems. This paper reports on a study on the shale oil charging channel system according to logging, core and micro pore-throat scales. The macro-charging channels identified by drilling core and FMI images include all of the following, tectonic, induced, bedding and dissolution expansion fractures. The micro-charging channel types identified by laser confocal microscopy, thin section inspection and SEM include kerogen networks, micro-fractures, stylolites and micro-nano pore-throat systems, with a large number of stylolite structures in the studied source rocks. The reservoir pore types are mainly secondary dissolution and inter-crystalline pores, and the fractures are mainly tectonic and bedding fractures. Channels with different types of genesis and scales interconnect to form a complex pore-fracture network system. The research shows that the Fengcheng Formation has two types of source-reservoir channel combination models: tectonic fracture-pore systems (tectonic fracture-type reservoirs) and stylolite-matrix pore-tectonic micro-fracture systems (shale oil reservoirs), forming the shale oil preponderant charging channel network. Charging channel type and its spatial distribution are the main factors for shale oil charging in the Fengnan area of the Mahu Sag.

Key words: shale oil, charging channels, multi-scale analysis, Junggar Basin.

INTRODUCTION

Fengcheng Formation with the feature of giant shale oil resource potential is a typical dolomitic source rock of alkaline-lacustrine deposition (Gao *et al.*, 2018; Yu *et al.*, 2018a; Yu *et al.*, 2018b; Ma *et al.*, 2019; Zhang *et al.*, 2019). Mahu Sag experienced humid-semiarid climate during Fengcheng deposition stage (Zhang *et al.*, 2018). The lacustrine transgression period occurred from the late stage of the first member of Permian Fengcheng Formation (P1F1) to the early stage of the second member of Permian Fengcheng Formation (P1F2), then the lake retreated gradually, and wide distribution high potential source rocks were developed. Within this sedimentary framework, the Fengcheng Formation with its two types of unconventional oil and gas reservoirs developed the lithological sequence from shale rich in organic matter to tight volcanic rocks. The third member of Permian Fengcheng Formation (P1F3) and P1F2 are typical shale oil reservoirs of source-reservoir integration type. The P1F1 is tight volcanic reservoir of adjacent source type. This paper discusses a study on the charging channel of shale oil (P1F2+P1F3) according to logging, core and micro pore-throat scales. The results show that charging channel type and its spatial distribution are the main factors for shale oil charging in the Fengnan area of the Mahu Sag.

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METHODS

The macro-charging channels identified by drilling core and FMI images in Fengcheng Formation include of the following, tectonic, induced, bedding and dissolution expansion fracture types (Fig. 1).

① **Tectonic fractures.** Under the regional tectonic compression or shear strike-slip condition, Fengcheng Formation produced ruptures and deformation, forming high-angle fractures, medium-low angle fractures, fracture networks and other complex tectonic fracture systems. High-angle fractures and fracture networks are mostly filled with calcite, quartz, carbon and mud. Among them, sheared fractures are relatively straight, the fracture aperture is large, mostly open or partially-filled, with the characteristics of good connectivity, long distance extension and concentrated distribution in local places.

② **Induced fractures.** Induced fractures in the Fengnan area are formed by the interaction of wellbore pressure with rock formations during the drilling process. The fractures are often distributed in the middle of the core. Drilling induced fractures are symmetrically distributed on the FMI image as two black bands, which are parallel to the well axis, have stable orientation, and extend for a long distance.

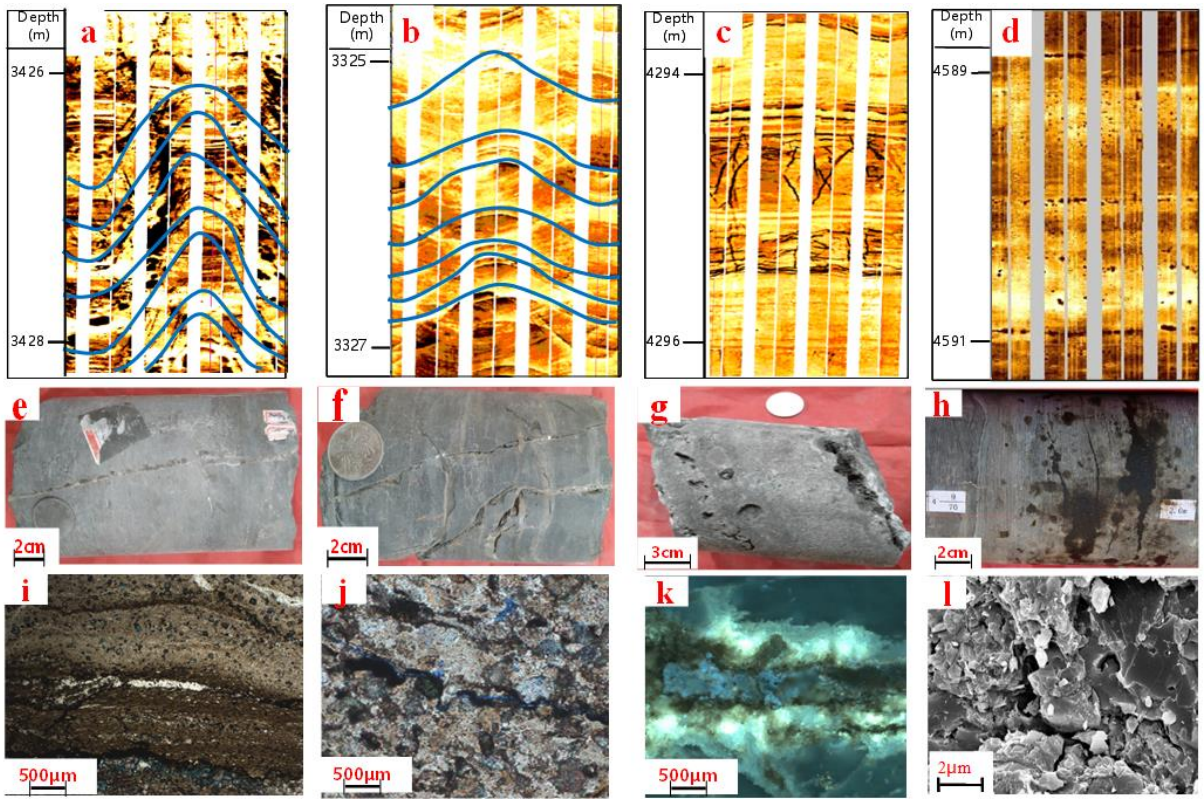

Fig. 1 – Photographs showing channel type on multiple scales in Fengcheng Formation of Mahu Sag in Junggar Basin: (a) Well Wu5, P1F3, 3426 m, high-angle fracture, FMI; (b) Well FN5, P1F2, 3325 m, middle-angle fracture, FMI; (c) Well FN4, P1F3, 4294 m, net fracture, FMI; (d) Well MY1, P1F3, 4589 m, dissolved pore and bedding fracture, FMI; (e) Well FN1, P1F2, 4183.1 m, dolomitic mudstone with oil spot, micro tectonic fracture, CP; (f) Well F5, P1F2 , 3231.2 m, fluorescent dolomitic mudstone, net fracture, CP; (g) Well FN3, P1F2, 4128.2 m, argillaceous dolomite containing oil spot, dissolved fracture, CP; (h) Well MY1, P1F3, 4607.1 m, dolomitic mudstone, bedding fracture, CP; (i) Well F8, P1F2, 3167.9 m, fluorescent dolomite, fracture crossing particle, PPL; (j) Well FN3, P1F3, 3959.47 m, dissolution expansion fracture along stylolite, CTS; (k) Well FN5, P1F2, 4066.07 m, stylolite, FTS; (l) Well Wu35, P1F2, 3508.62 m, fracture along particle margin, SEM. (FMI = fullbore formation micro-imager, CP = core photo, PPL = plane-polarized light, CTS = casting thin section, FTS = fluorescence thin section, SEM = scanning electron microscope, P1F = Permian Fengcheng Formation, P1F3 = the third member of Permian Fengcheng Formation, P1F2 = the second member of Permian Fengcheng Formation).

③ **Bedding fractures.** Compared with macro tectonic fractures, the length and scale of bedding fractures in Fengcheng Formation are both, smaller and mostly horizontal, which not only increase the pore network connectivity, but also promotes the development of secondary pores. It is also an effective reservoir storage space, which is favorable for horizontal drainage and shale oil local accumulation.

④ **Dissolution-expansion fractures.** Tectonic fractures developed in the early stage or zones of secondary dissolution pores have become important drainage channels for geological dissolution fluids in the later stage and promote the development of dissolution fractures. The tectonic dissolution fractures of the Fengcheng Formation are mostly developed in the muddy and sandy dolomites, with fracture widths ranging from 1~12 mm, either open or partially-filled. The shape of dissolution fractures at the core scale is irregular, and the fracture surfaces are often uneven, with appearance of dissolution pores and dissolution caves. FMI images show pinhole-shaped pores formed by dissolution and the distribution of dissolution pores presents a certain layered structure, the thickness is generally several meters, and resistivity logging curves commonly feature low values.

The micro-charging channel types identified by laser confocal microscopy, thin section and SEM include kerogen networks, micro-fractures and stylolites, and micro-nano pore-throat systems (Fig. 2).

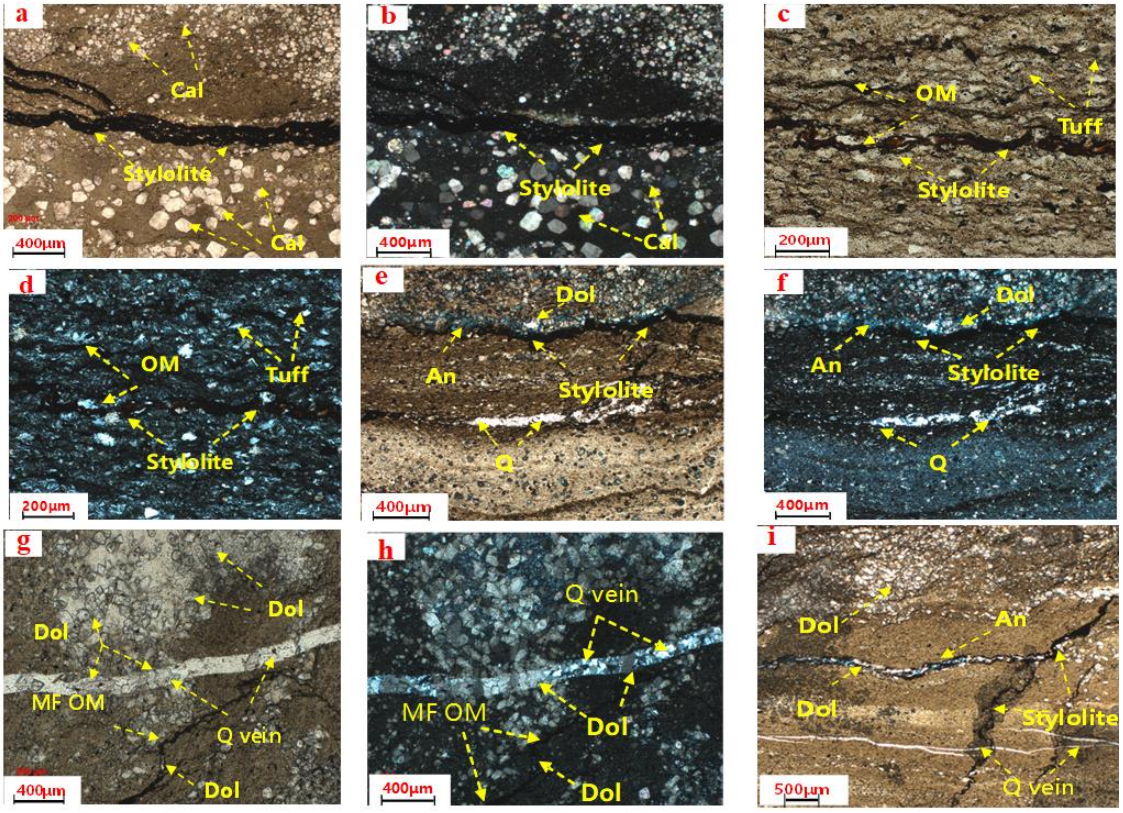

Fig. 2 – Photographs showing stylolite and micro structural fracturing in Fengcheng Formation of Mahu Sag in Junggar Basin: (a) Well F8, P1F2, 3065.4 m, stylolite, PPL; (b) Well F8, P1F2, 3065.4 m, stylolit, XPL; (c) Well F8, P1F2, 3068.2 m, OM, PPL; (d) Well F8, P1F2, 3068.2 m, OM, XPL; (e) Well F8, P1F2, 3226.81 m, stylolite, PPL; (f) Well F8, P1F2, 3226.81 m, stylolite, XPL; (g) Well F5, P1F2, 3226.81 m, micro-fracture, PPL; (h) Well F5, P1F2, 3226.81 m, micro-fracture, XPL; (i) Well F5, P1F2, 3231.45 m, stylolite and micro-fracture, XPL. (PPL = plane-polarized light, XPL = cross polarized light, OM = organic matter, Q = quartz, Dol = dolomite, Cal = calcite, An = ankerite, MF OM = micro-fracture with organic matter, P1F = Permian Fengcheng Formation, P1F2= the second member of Fengcheng Formation).

① **The kerogen network.** The organic kerogen network is an important channel system for oil and gas charging and migration. If the hydrocarbon generated by the kerogen reaches a specific concentration, it can be migrated along the kerogen vein into the reservoir. The source rocks of the Fengcheng Formation are rich in organic matter. Among them, I-III type kerogens are distributed in the P1F3, and the main type in P1F2 are II and II1, providing a favorable channel network for shale oil.

② **The micro-fractures and stylolites.** Thin sections and SEM showed that the Fengcheng Formation developed three types of micro-channels: transgranular micro-fractures, dissolution fractures and pressure-solution stylolites. Among them, the transgranular micro-fractures are tectonic fractures, which are mostly developed in brittle rocks such as dolomite and dolomitic siltstone. They often cut through multiple mineral particles, and the fracture widths range from 20~80μm, with dendritic shape and long distance extension. On the microscopic scale, the surfaces of dissolution fractures are mostly curved or irregular, with a short extension distance, and mostly connect the dissolution pores and inter-crystalline pores of mineral particles, forming a three-dimensional pore-fracture drainage system for shale oil. The stylolites in the Fengcheng Formation often experienced multi-stage dissolution or were filled with minerals such as dolomite and ankerite. The stylolites are rich in residual organic matter with blue and blue-white fluorescence.

③ **Micro-nano pore-throat system.** In Fengcheng Formation without fractures, the reservoir space is dominated by mineral matrix pores such as inter-granular, intra-granular and inter-crystalline pores. Oil bearing grade of such cored intervals is from oil trace to oil spot, and the fluorescence is light yellow and yellow. This is evidence that the micro-nano pore-throat system is also an important channel type for shale oil charging.

CONCLUSION

Shale oil charging is a complex geological process, and charging and micro-migration rarely occur along a single channel (Saif *et al*., 2017). There is a large number of stylolite structures in the source rocks of the Fengcheng Formation. The reservoir pore types are mainly secondary dissolution pores and inter-crystalline pores, and the fractures are mainly tectonic fractures (logging, core, and micro pore-throat scales) and bedding fractures (Fig. 3). Channels with different types of genesis and scales interconnect to form a complex pore-fracture network system. This study shows that the Fengcheng Formation has two types of source-reservoir channel combination models: tectonic fracture-pore systems (tectonic fracture-type reservoirs) and stylolite-matrix pore-tectonic micro-fracture systems (shale oil reservoirs), forming the shale oil preponderant charging channel network (Fig. 4). Hydrocarbons generated at an early stage were charged into the micro-nano pore-throat system, which promoted the change of the wettability of the rock particles from water wet to oil wet, and resulting in an increase in free oil content.

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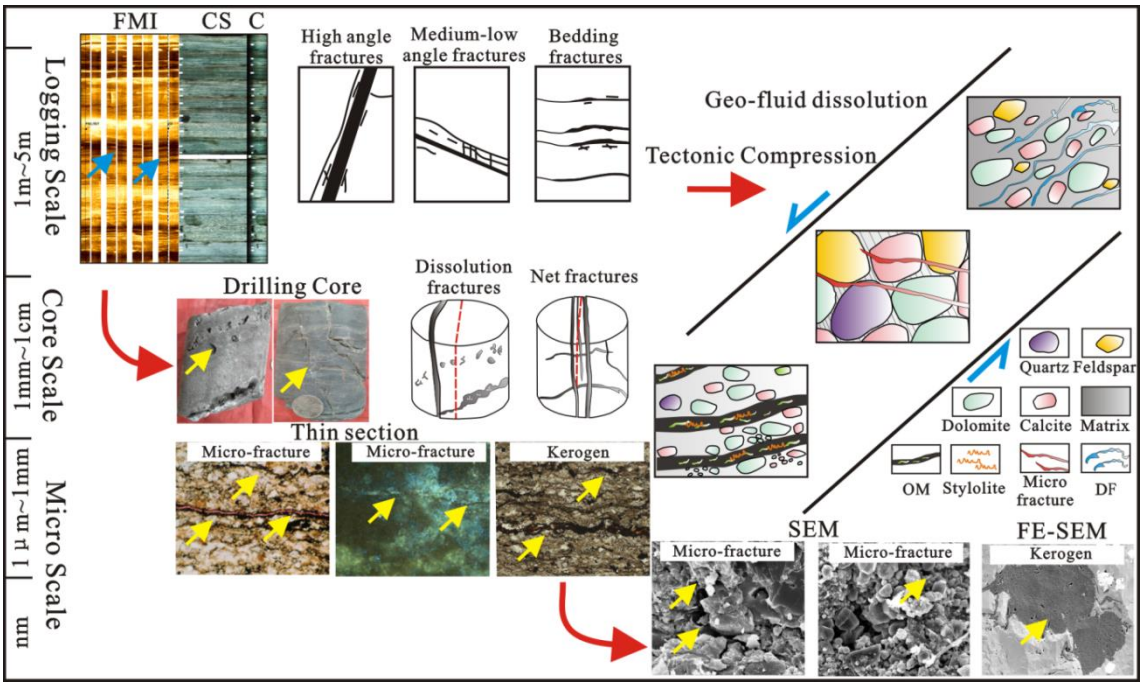

Fig. 3 – Images showing multi-scale charging channel in Fengcheng Formation of Mahu Sag in Junggar Basin. FMI = fullbore formation micro-imager, CS = core scanning, C = core, SEM = scanning electron microscope, OM = organic matter, DF = dissolution fracture, FE-SEM = field emission scanning electron microscope.

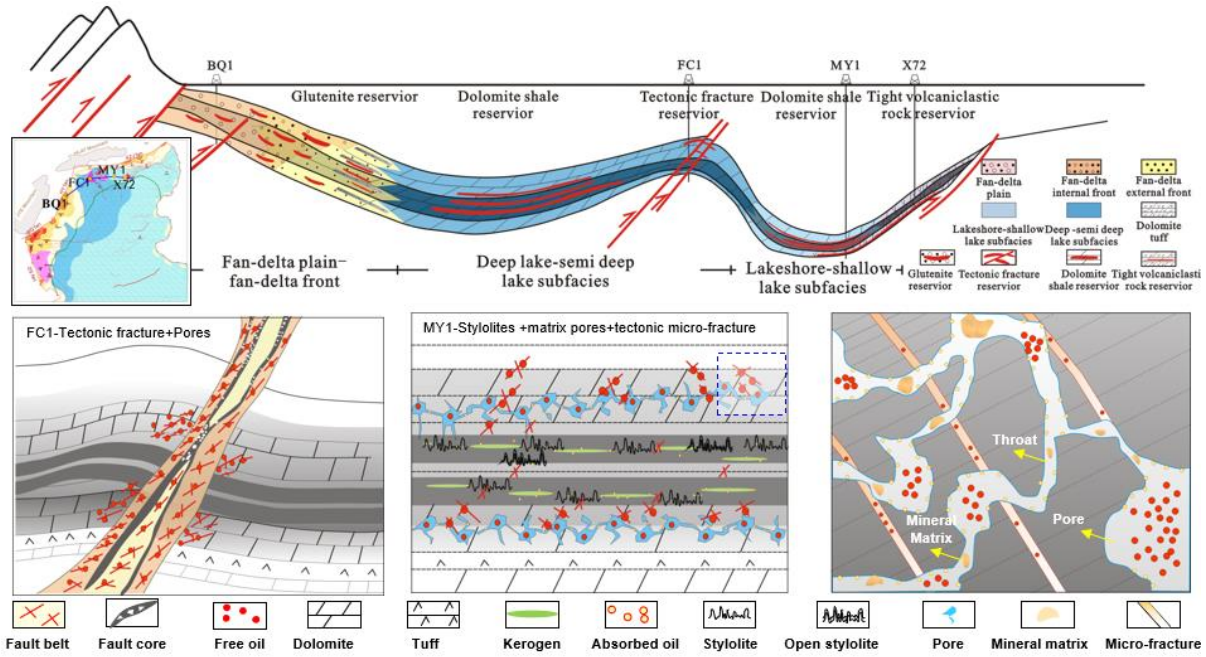

Fig. 4 – Section showing source-reservoir channel combination model in Fengcheng Formation of Mahu Sag in Junggar Basin.

REFERENCES

GAO, G., YANG, S., REN, J., ZHANG, W., XIANG, B. (2018), *Geochemistry and depositional conditions of the carbonate-bearing lacustrine source rocks: A case study from the Early Permian Fengcheng Formation of Well FN7 in the northwestern Junggar Basin.* Journal of Petroleum Science and Geology, 162, pp. 407–418.

MA, L., ZHANG, Y., ZHANG, Z., ZHANG, G., WANG, S. (2020), *The geochemical characteristics of the Fengcheng Formation source rocks from the Halaalate area, Junggar Basin, China*. Journal of Petroleum Science and Engineering, 184, 1–14.

SAIF, T., LIN, Q., BUTCHER, A.R., BIJELJIC, B., BLUNT, M.J. (2017), *Multi-scale multi-dimensional microstructure imaging of oil shale pyrolysis using X-ray micro-tomography, automated ultra-high resolution SEM, MAPS Mineralogy and FIB-SEM.* Applied Energy, 202, 628–647.

ZHANG, G., WANG, Z., GUO, X., SUN, Y., SUN, LE., PAN, LU (2019), *Characteristics of lacustrine dolomitic rock reservoir and accumulation of tight oil in the Permian Fengcheng Formation, the western slope of the Mahu Sag, Junggar Basin, NW China.* Journal of Asian Earth Sciences, 178, pp. 64–80.

ZHANG, Z., YUAN, X., WANG, M., ZHOU, C., TANG, Y., CHEN, X., LIN, M., CHENG, D. (2018), *Alkaline-lacustrine deposition and paleoenvironmental evolution in Permian Fengcheng Formation at the Mahu sag, Junggar Basin, NW China.* Petroleum Exploration and Development, 45(6), 1036–1049.

YU, K., CAO, Y., QIU, L., SUN, P. (2018), *The hydrocarbon generation potential and migration in an alkaline evaporite basin: The Early Permian Fengcheng Formation in the Junggar Basin, northwestern China*. Marine and Petroleum Geology, 98, pp. 12–32.

YU, K., CAO, Y., QIU, L., SUN, P., JIA, X., WAN, M. (2018), *Geochemical characteristics and origin of sodium carbonates in a closed alkaline basin: The Lower Permian Fengcheng Formation in the Mahu Sag, northwestern Junggar Basin, China*. Palaeogeography, Palaeoclimatology, Palaeoecology, 511, pp. 506–531.

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