ANAS Transactions **Earth Sciences** **Special Issue / 2023**

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ESTIMATION OF UNCONVENTIONAL TIGHT OIL RESERVOIR POTENTIAL USING GEOCHEMICAL, MINERALOGICAL AND PETROGRAPHICAL CHARACTERISTICS OF THE DOMANIK FORMATION FROM NORTH SAMARA REGION IN THE VOLGA-URAL BASIN, RUSSIA

Saeed Sh.A.[1], Al-Muntaser A.A.[1], Hakimi M.H.[2], Zhou. X.[1], Varfolomeev M.A.[1]

[1]Department of Petroleum Engineering, Kazan Federal University, Kazan, 420008, Russia: shad.saeed@ya.ru

[2]Geology Department, Faculty of Applied Science, Taiz University, Taiz 6803, Yemen

Keywords: *Domanik Formation, organic-rich rocks, kinetic modeling, unconventional tight oil, Volga-Ural Basin (Russia)*

Summary. This work presents a comprehensive analysis of the geochemical, mineralogical, and petrographical properties combined with bulk kinetics modeling of Domanik rocks from various depths of the Kuzminovsky oilfield in the Volga-Ural Basin, Russia. The study reveals that the Domanik samples have a high content of total organic matter (TOC) of up to 13.31 wt %, and mainly contain Type II kerogen with a slight II/III kerogen type, which indicates very good to excellent oil generation potential. The hydrogen-rich kerogen in the samples is expected to generate paraffin, naphthene, and aromatic (P–N-A) oil with low wax content. The maturity indicators demonstrate that most of the studied Domanik samples have generally reached low thermal maturity stages, defining an immature to moderate-mature oil generation window. The results of the kinetic models suggested that Domanik rocks with vitrinite reflectance (VRo) values in the range of 0.60–0.71% have reached relatively low kerogen transformation ratio, indicating low probability of oil generation. The Domanik samples are characterized by low porosity (up to 3.29%) with a wide range of pore sizes, including interparticle, cavities, cracks, and organic matter pores. The development of these pore types and their quality is mainly controlled by high mineralogical brittleness, i.e., carbonate and quartz, together with high organic matter inputs. Based on the obtained results and observations, the Domanik Formation has a high potential for commercial oil production, which typically requires hydraulic fracturing followed by an in-situ retort, mainly by thermal methods such as steam injection and in-situ combustion processes.

1. Introduction

Undoubtedly, global unconventional oil resources, such as shale oil, natural bitumen, and extra-heavy oil, can be a future of the petroleum industries. Oil shales, as unconventional hydrocarbon resources, are the most promising sources of hydrocarbons in terms of their reserves (30% of the proved global reserves (Meyer, Attanasi, 2003). Generally, fractured, tight, shale oil as well as oil shale plays, are considered as exploitable self-contained source and reservoir rocks (Romero-Sarmiento et al., 2016). Tight reservoirs are characterized by low porosity averaging 3 to 6% and poor permeability from µD to less than < 0.1 mD (Kunar, Shandilya, 2013). The lithology of tight reservoirs is typically shale and carbonate rocks with large thickness (Kunar, Shandilya, 2013). Tight oil reservoirs are also known as intractable rocks with low permeability which containing fluids such as shale-hosted oil (shale oil) with little or no water (Mills, 2008). Consequently, hydrocarbons can be produced from such reservoirs using special recovery techniques and technologies including hydraulic fracturing, thermal-based recovery methods, etc.

Present research aims to evaluate the Domanik Formation in the Kuzminovsky oilfield, Samara region, Volga-Ural Basin, Russia, as a potential unconventional tight reservoir to exploit these types of reservoir rocks for development and high probability production.

Methods

A total of 18 samples of Domanik Formation, with geological ages ranging from Upper Devonian (Frasnian) to Lower Carboniferous (Tournaisian), were collected from different depths (from 1726.5 m to

1784.9 m) in Kuzminovsky oilfield (well № 26R), north of Samara region, Volga-Ural basin, Russia. These samples were subjected to multi geochemical, petrographical, and petrophysical analyses.

2. Results and discussion

2.1. Organofacies characteristics under microscopic examinations

The analyzed samples are composed of carbonate minerals, liptinite, and vitrinite macerals. The liptinite macerals appear light brown to brown under reflected white light and show yellow to greenish-yellow fluorescence under ultraviolet (UV) light (Fig. 1). Structured and unstructured hydrogen-rich kerogens, including alginite, amorphous organic matter (AOM), and bituminite, are present in the liptinite assemblages. *Telalginite and lamalginite* forms of structured alginite were observed in most of the liptinite macerals, indicating an oxygen-depleted benthic environment. Unstructured AOM exhibited greenish-yellow to yellow fluorescence, and a small portion of structureless bituminite II was also observed. These findings suggest that the samples could be a potential oil source rock with low waxy characteristics.

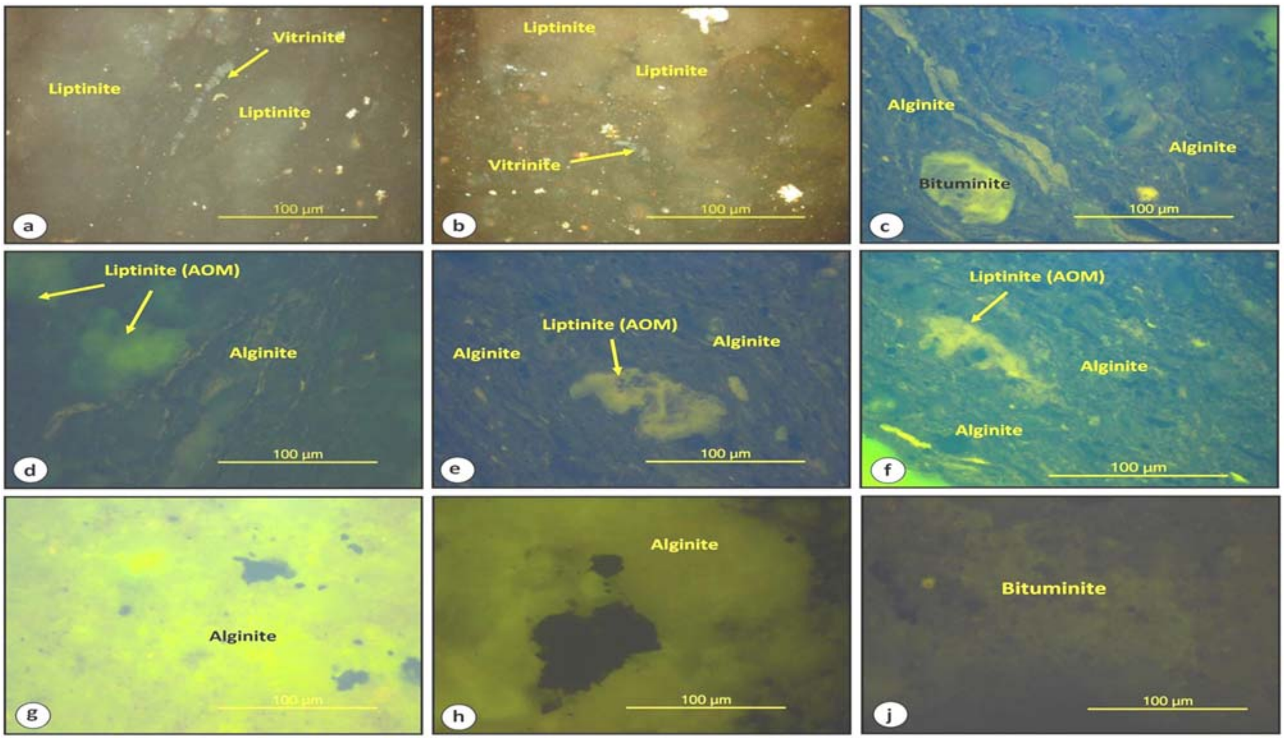

Fig. 1. Photomicrographs of the analyzed, under reflected white and UV lights.

2.2. Geochemical characteristics

The Domanik samples exhibit a significant quantity of OM, with a range of 0.72% to 13.31%. This suggests that the majority of the samples analyzed contain substantial amounts of OM, making them promising source rocks for producing large amounts of petroleum. Moreover, the correlation between the Total Organic Carbon (TOC) and the yields of petroleum produced through thermal cracking of kerogen (S2) indicated a high potential for generating hydrocarbons. This potential ranges from good to excellent, with the ability to produce substantial quantities of hydrocarbons at optimal thermal maturity levels (Bissada, 1982). The Domanik rocks are mainly characterized by Types II and II/III kerogen, suggesting that the organic matter input is in the immature to moderate mature stage of the oil-window. This implies a strong potential for oil generation.

2.3. Bulk kinetics modeling

In this research, the bulk kinetics analysis was conducted on three spent samples collected from the Domanik Formation. Depending on the kinetic model, the VRo values of the examined samples were measured and plotted against the computed transformation ratios (Fig. 2). The findings revealed that the current thermal maturity of the analyzed samples, equivalent to 0.61 to 0.71% VRo, had reached approximately 11-20% TR ratio at geological temperatures ranging from 110-125°C. As a result, the studied intervals of the Domanik Formation have not generated commercial amounts of oil.

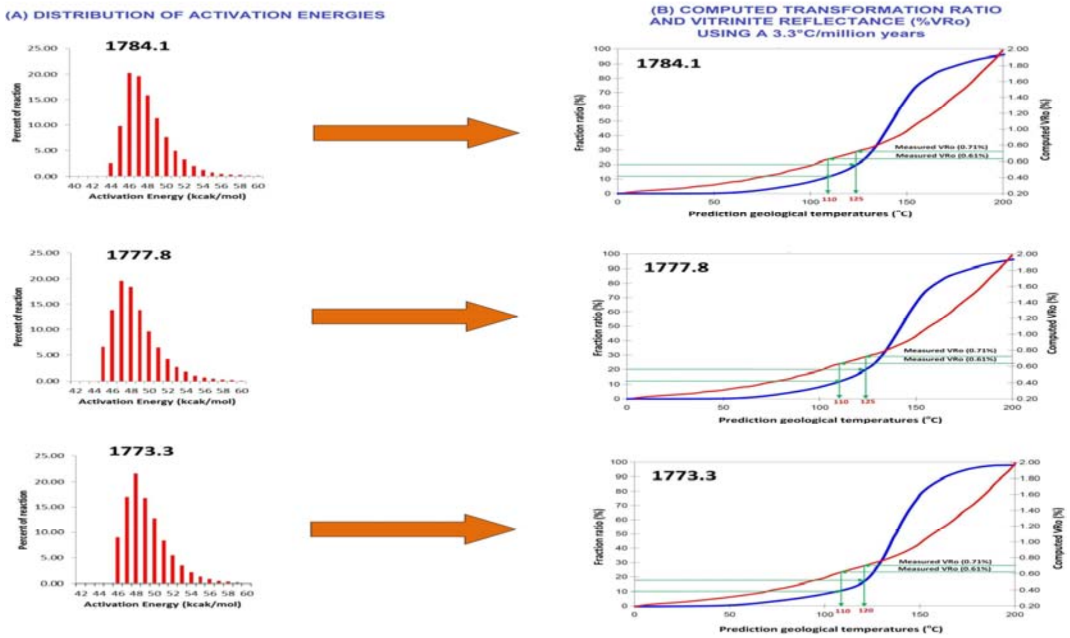

Fig. 2. Bulk kinetic parameters in terms of (A) activation energy distribution (Ea) and computed temperature (°C), and (B) TR (TR %) and vitrinite reflectance (%Ro).

2.4. Mineralogical characteristics and their contribution for brittleness

In this study, the analyzed Domanik rock samples consist higher carbonate and quartz brittle minerals compared to clay mineral, with high brittleness index (BI) of up to 0.99%. Based on this mineral constituent, the analyzed Domanik rocks are likely to be high brittle rocks for fracability and development of natural and artificial fractures. This interpretation was supported by the presence of the fractures in the analyzed Domanik rocks (Fig. 15a and b).

2.5. Petrophysical characteristics (porosity)

The microscopic examinations conducted in this study have revealed the presence of secondary porosity in the form of micro-fractures (Fig. 3c). These fractures in the Domanik rocks are observed to be filled with oil, as observed under reflected UV light (Fig. 3d). Additionally, thin section microscopy has shown the partial dissolution of unstable shell grains (foraminifers) in some of the analyzed samples (Fig. 3e-h). This partial to complete acidic alteration of the foraminifer's grains has enhanced and developed the total porosity of the Domanik rocks. Microscopic examinations conducted under transmitted light have further revealed that the oil (brown color) mainly fills the entire pore spaces of the foraminifer's grains (Fig. 3g and h).

In addition to thin section, the nano-focus X-ray control system (micro-CT) also revealed the presence of fractures in the analyzed Domanik rocks (Fig. 4). This suggests that the high content of brittle minerals in the Domanik rocks, which have high BI values, is the primary factor contributing to the fractures observed in the study area.

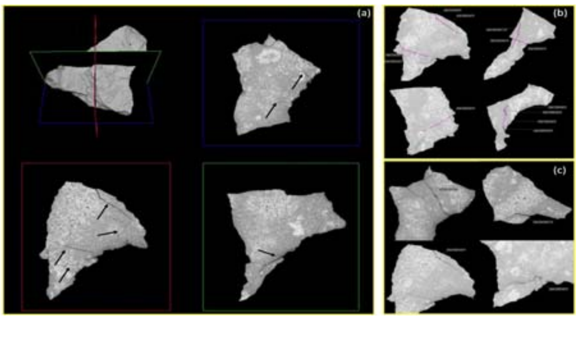

Fig. 3. Micro-CT imaging of the analyzed samples.

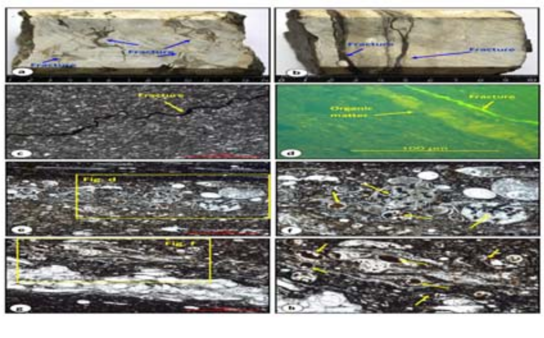

Fig. 4. Photomicrographs of cores, thin sections of the analyzed samples.

Moreover, micro- and nano-focus X-ray control systems (micro-CT) were employed to study the structure of the porous space in the Domanik rocks, as shown in Fig. 5. Accordingly, the porous space of Domanik rocks could be divided into three types based on grain diameter (µm). The first type consists of interparticle pores, with sizes ranging from 10 µm to 100 µm (Fig. 5a). The second type comprises cracks and cavities with a grain diameter of more than 0.1 mm (100 µm) (Fig. 5a), which are believed to have formed during the diagenesis process. The final type of pores is mainly found in OM pores, with sizes of 10 µm or less (Fig. 5b). The total volume of these pores is likely to increase with higher OM input into the Domanik rocks. SEM analysis also confirms the presence of these pore types, including interparticle, cavities, cracks, and OM pores (Fig. 6).

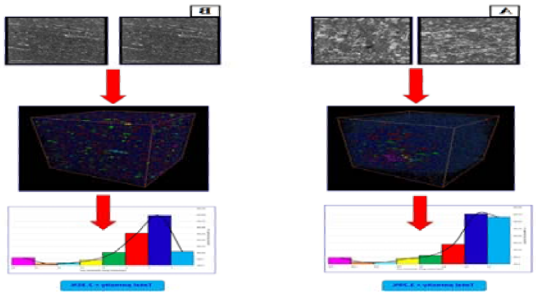

Fig. 5. The orthoslices in different projection of region of interest (ROI), 3D visualization of the region of interest (ROI).

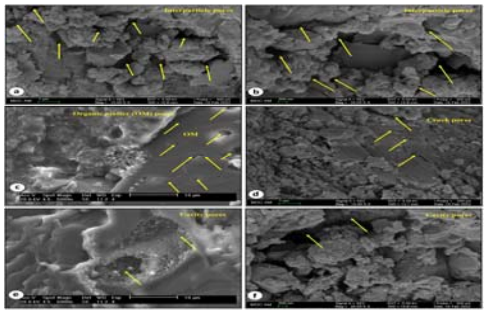

Fig. 6. Photomicrographs of the SEM for the analyzed samples.

3. Conclusions

Based on the obtained results, the following major conclusions can be drawn:

- The studied samples have a high TOC content of up to 13.31 wt. %, and a petroleum potential of up to 32.86 mg hydrocarbon/g rock, indicating that they are highly prospective source rocks.
- The OM input in the studied samples is mainly composed of Types II and II/III kerogen, which suggests that the samples are in the immature to moderately mature stage of the oil window and have a high potential for oil generation.
- The presence of hydrogen-rich kerogen and high oil generation potential also confirms the results of the Py-GC investigation, as well as the abundance of fluorescent oil-prone liptinitic assemblage.
- Bulk kinetic modeling indicates that the analyzed samples in the studied well have generated low amounts of oil at geological temperatures ranging from110 to 125°C, which correspond to relatively low vitrinite reflectance (VR) values and transformation (TR) ratios of 0.60–0.71% Ro and 10–20%, respectively.
- The studied samples are primarily characterized by brittle minerals such as carbonate and quartz with a high brittleness index of up to 0.99 and low porosities (up to 3.29%). This indicates the presence of unconventional tight oil reservoir rocks that could be suitable for conducting hydraulic fracturing for commercial oil production.

Generally, the above characteristics of the Domanik rocks can be used as a foundation for further unconventional tight oil exploration in the Volga-Ural Basin, particularly in the deeper burial depths, where these rocks of the Domanik Formation are anticipated the high maturity levels and resulted in retinted of more oil that could be released.

Acknowledgement

This work was supported by the Ministry of Science and Higher Education of the Russian Federation under agreement No. 075-15-2022-299 within the framework of the development program for a world-class Research Center "Efficient development of the global liquid hydrocarbon reserves".

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