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Comprehensive Analysis on the Oil-Water Interface Distribution Characteristics in Tight Oil Reservoir

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INTRODUCTION

Gravity differentiation and the law of buoyancy indicate that when oil accumulates in a trap, the oil-water interface must be horizontal. If the distribution of oil-water interface is inferred from this, it will be very regular. As long as the oil-water interface of a few wells is determined, other wells' oil-water interface can be extended without research. This is true for sandstone reservoirs with good connectivity and simple structure (Zhang et al., 2017; Gao et al., 2007; Cai et al., 2019). However, due to the complexity of geological conditions, the true shape of the oil-water interface is not horizontal, and its shape and distribution characteristics change due to changes in geological conditions (Fu et al., 2017; Zhou et al., 2016; C.R.; Clarkson, 2013).

In terms of the distribution of oil-water interface, predecessors often encounter the situation which is contrary to the principle of gravity differentiation, and the situation that the formation has high porosity without oil. When studying these special situations, they generally use detailed research on the overall structure and the small-layer sand body adopts horizontal spreading and other means. After the studies on the reservoir of badaowan reservoir, it is found that the lower water production was caused by fracturing, which led to the breakthrough of oil and gas from other layers into the target layer, and lowered the oil production rate (Zhang, 2008; Miskimins, 2009; Zou et al., 2013). A fault block reservoir in the Subei Basin, the high part of the structure is the same layer of oil and water, and the low part of the structure is the oil layer. The reason is that the low part of the structure is located in an underwater distributary channel. The physical properties and pore structure of the rock are better than the physical properties of the channel edge at the high part of the structure, so the low part can produce oil. The high part has poor physical properties and high capillary pressure does not produce oil (Liu., 2011; Jia et al., 2012; Wang et al., 2014; Roberto et al., 2014).

The controlling factors of the oil-water interface mainly include structural characteristics, lithology, physical properties, tectonic stress, hydrodynamics, oil and gas charging, etc. The research of related literature is mostly found in structural lithological oil and gas reservoirs, and certain results have been obtained (Lin et al., 2007; Wang et al., 2020; Zhou et al., 2021; Zhou et al., 2021). The changes of oil-water interface in reservoirs less affected by hydrodynamic force are mainly affected by structural characteristics, lithology, pressure, physical properties and other factors. The structure controls the oil-water distribution macroscopically, and the local oil-water interface distribution is controlled by lithology. Under the combined influence of the above factors, the surface of the oil-water transition zone is a wavy cone shape with uneven thickness. The changes in physical properties and lithology are the main causes of local changes in the oil-water interface. The influence of hydrodynamics and oil and gas charging on the tilt of the oil-water interface is still controversial. Different scholars have put forward different views, which need to be further studied. The influence of changes in lithology and physical properties on the oil-water interface is not negligible. Sedimentary differentiation leads to regular changes in the grain size of clastic materials, resulting in regular changes in lithology and physical properties, and thus changes in the oil-water interface.

Basic Characteristics of Sangonghe Formation Reservoir

The Sangonghe Formation in the study area is a set of sedimentary strata dominated by braided river delta-lacustrine facies, the underlying strata is the Badaowan Formation, and the overlying strata is the Lower Jurassic Xishanyao Formation, with stable distribution in the work area. The main identification marks of sedimentary facies, subfaces and microfacies of the Upper Jurassic Sangonghe Formation in the study area are: rock color, rock structure, sedimentary structure, logging curve, etc. The rock color of sedimentary rocks firstly depends on its composition, and secondly, it is closely affected by its sedimentary environment. Therefore, the color of sedimentary rocks plays a key role in discerning the environment in which they were deposited. Especially through sedimentary rocks primary color, it is possible to visualize the climatic conditions and the aqueous oxidation-reduction conditions under which the formation was formed and to determine the quality of the hydrocarbon source rock. Different hydrodynamic sedimentary environments will develop sedimentary rocks with different structural characteristics, so the hydrodynamic conditions of the sedimentary environment are the prerequisites for the formation of various sedimentary rocks. In addition, the sedimentary structure of sediments is also affected by the sedimentation rate, the transformation of sediments after sedimentation, and the length of its transformation time.

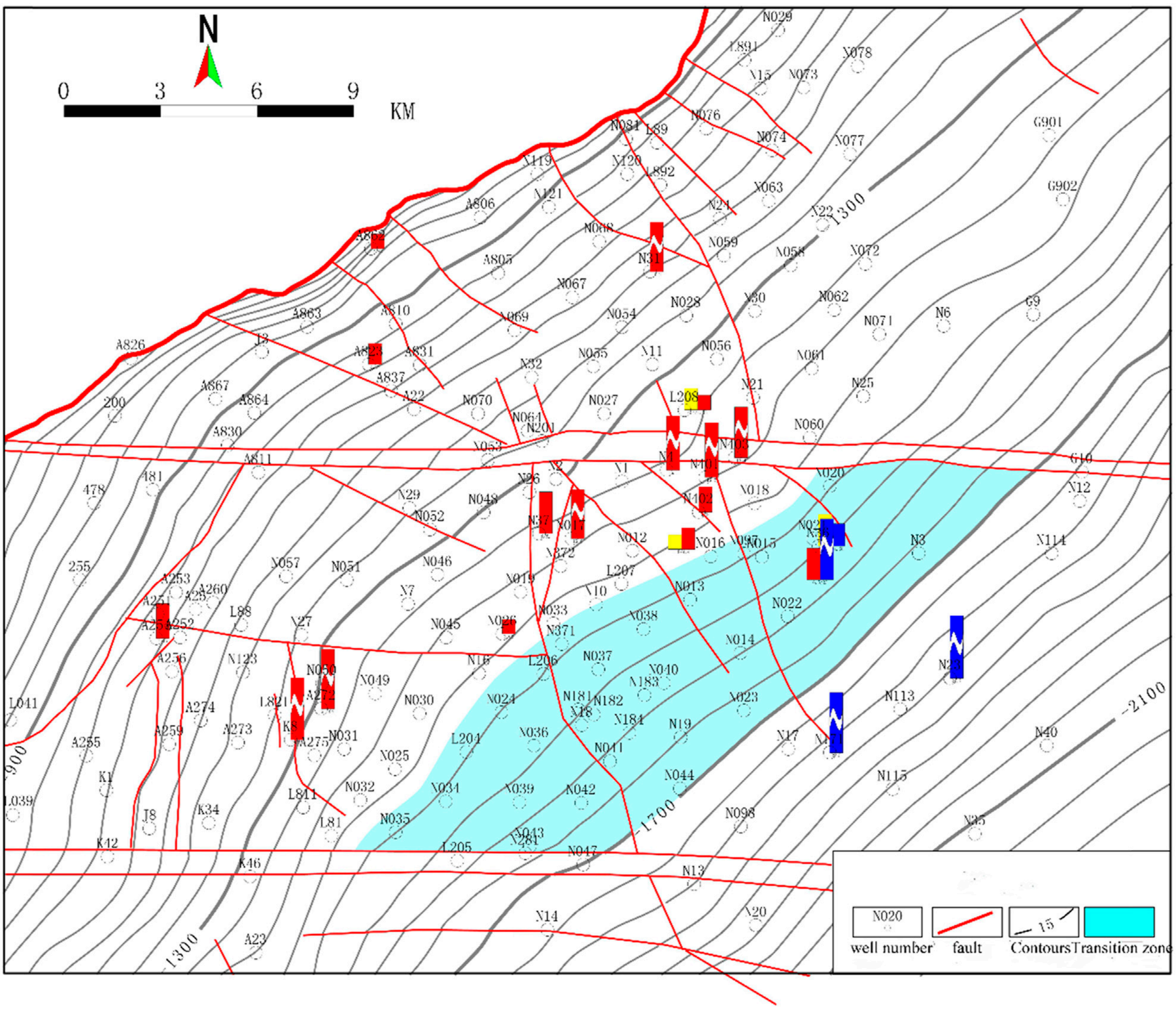

FIGURE 1 | Prediction map of the oil-water transition zone of the Sangonghe Formation reservoir in the Mahu 1 well area (Qiu et al., 2020).

In terms of sedimentary structure, scouring structure usually means that the sedimentary environment changes abruptly from low energy to high energy, and the sedimentary hydrodynamic conditions suddenly change from weak to strong. Typically, depositional environmental hydrodynamic conditions differ significantly below the scour surface, and the upper part is lower than the lower part. There is obvious enhancement, and the rock grain size is significantly different between the upper and lower scour surfaces, and the rock grain size on the upper part of the scour face is significantly higher than that on the lower part. In the stratum depositional system of the Sangonghe Formation in the study area, the bottom scour structure is mainly developed in the high-energy depositional environment such as distributary channels. The bedding structure can be revealed through mutations or gradual changes in mineral composition, structure, and color. In the study area, the Sangonghe Formation has developed sedimentary structures such as erosion surfaces, plate-like cross-bedding, and block-like bedding.

Control Factors of Oil-Water Interface

- **The influence of structural features on the oil-water interface**

There are not many references for research on the controlling factors of oil-water interface in oil reservoirs. Most experts and scholars believe that the main factors that control the changes of oil-water interface are: structure, lithology, physical properties, hydrodynamics, etc., and analyze on this basis the influence of these factors on the oil-water interface. At present, domestic research on controlling factors of oil-water interface mainly focuses on structural oil and gas reservoirs, which provides a reliable reference and basis for this research. The impact of structure on the oil-water distribution of the Sangonghe Formation reservoir in the Mahu 1 well area is obvious. The tectonic movement causes the formation tilt, which makes the reservoir sand body tilt, and the oil and gas migrate along the up dip direction of the formation. Accumulation in traps, the inclination of sand bodies accelerates the gravity differentiation of oil and water. After a long period of time, the oil-water distribution pattern of oil layer-oil-water layer-water layer is finally formed. Good positive correlation. As the depth of the formation increases, the oil bottom and the oil-water interface in the study area also decrease.

- **The influence of lithology and physical properties on the oil-water interface**

Generally speaking, blocks with thicker sand bodies and relatively stable sand bodies overlap laterally and vertically, with good connectivity, weak heterogeneity, little difference in oil-water distribution, and differences in oil bottom and oil-water layers in the same layer. Not big, the difference in the oil-water interface between single wells is small, and the oil-water interface is almost a flat surface. The Sangonghe Formation is mainly composed of braided river delta front deposits. The provenance comes from the north and part of the provenance comes from the west. The distribution of sand bodies appears to be gradually thinning from northwest to southeast. The physical properties of the reservoir are mainly porosity, permeability and pore structure, among which porosity and permeability are a macroscopic manifestation of pore structure. The effect of physical properties on the oil-water interface is mainly realized as an effect on the thickness of the same layer of oil and water, which in turn affects the oil-water interface.

- **Forecast of oil-water transition zone**

The formation of the oil-water interface of a reservoir is inseparable from the oil-water distribution of the reservoir. The former is controlled by the latter, and the oil-water distribution is closely related to the lithology and physical properties of the reservoir. Through studying the distribution law of reservoir lithology and physical properties, Study on its influence on oil-water distribution and finally reveal its influence on the oil-water interface. The oil-water distribution of the Sangonghe Formation reservoir in the Mahu 1 well area is obviously controlled by the structure. From the high part of the structure to the low part of the structure, there is a changing trend of oil layer-oil-water layer-water layer (**Figure 1**).

CONCLUSION

The oil-water interface is the basis for determining the oil-bearing boundary and calculating reserves. It is an important basis for well deployment, potential tapping, and edge expansion in oilfields. It is of great significance to study the enhanced oil recovery by CO_2 injection. The Sangonghe Formation reservoir in the Mahu 1 well area has a relatively low structural range, the reservoir is of medium porosity and low permeability, with complex pore structure, which has an important influence on the distribution of oil and water. Based on the core analysis and laboratory data, combined with lithology, physical properties, structure, sedimentation and diagenetic evolution and other factors, a comprehensive study shows that structure is the main controlling factor that causes the difference of oil and water in the study area and the existence of oil-water transition zone. The rock structure complexity and poor physical properties also weaken the degree of hydrocarbon differentiation to a certain extent. The comprehensive single-well oil test characteristics predict the plane distribution of the oil-water transition zone of the Sangonghe Formation reservoir. The transition zone is located between the oil and water layers and spreads in the northeast-southwest direction along the structure. The comprehensive interpretation of the newly completed Sangonghe Formation in the middle of the predicted oil-water transition zone is that the oil and water are in the same layer, and the oil and water production is tested at the same time, which confirms the accuracy of the prediction of the oil-water transition zone.

AUTHOR CONTRIBUTIONS

WH, LC, HH, ME, and YC contributed equally to this work.

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