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Research Article

Geological conditions for lateral sealing of active faults and relevant research methods ☆

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Abstract

Many researchers worked a lot on geologic conditions for lateral sealing of faults, but none of their studies took the effect of internal structures of fault zones on the lateral sealing capacity of faults. Therefore, the lateral sealing of active faults has rarely been discussed. In this paper, based on the analysis of the composition and structure characteristics of fault fillings, the geological conditions for lateral sealing of active faults and relevant research method were discussed in reference to the lateral sealing mechanisms of inactive fault rocks. It is shown that, in order to satisfy geologically the lateral sealing of active faults, the faults should be antithetic and the faulted strata should be mainly composed of mudstone, so that the displacement pressure of fault fillings is higher than or equal to that of reservoir rocks in oil and gas migration block. Then, a research method for the lateral sealing of active faults was established by comparing the displacement pressure of fillings in the fault with that of reservoir rocks in oil and gas migration block. This method was applied to three antithetic faults (F1, F2 and F3) in No. 1 structure of the Nanpu Sag, Bohai Bay Basin. As revealed, the fillings of these three active faults were mostly argillaceous at the stage of natural gas accumulation (the late stage of Neogene Minghuazhen Fm sedimentation), and their displacement pressures were higher than that of reservoir rocks in the first member of Paleogene Dongying Fm (F1 and F3) and the Neogene Guantao Fm (F2). Accordingly, they are laterally sealed for natural gas, which is conducive to the accumulation and preservation of natural gas. Industrial gas flow has been produced from the first member of Paleogene Dongying Fm in Well Np101, the Guantao Fm in Well Np1-2 and the first member of Paleogene Dongying Fm in Well Np1, which is in agreement with the analysis result. It is verified that this method is feasible for investigating the lateral sealing of active faults.

Keywords: Active fault; Lateral sealing; Geological conditions; Research method; Fault filling; Reservoir; Displacement pressure; Bohai Bay Basin; Nanpu Sag

Oil and gas exploration practices indicate that there are a large number of faults developed in petroliferous basins or sags. These faults play a pivotal role in the accumulation and distribution of hydrocarbons, acting as the pathways for the migration of oil and gas and providing lateral blocking conditions for oil and gas to accumulate and distribute near them [1–6]. However, as a lateral blocker of hydrocarbon accumulation, a fault manifests it sealing capacity not only in its inactive stage, but also in its active stage. Is the geological condition for lateral blocking in the inactive stage consistent with that in the active stage? Are their study methods identical to each other? The above-mentioned questions are one of the key to oil and gas exploration in fault developmental zones of the sag. There have been a lot of research and discussion on the geological conditions and research methods for the lateral blocking of faults. And it is considered that the geological conditions for lateral blocking of faults in the stationary stage is that fault rocks contain a displacement pressure greater than or equal to that of reservoir rocks in the oil and gas migration wall. Once the displacement pressure of fault rocks and that of the reservoir rocks in the migration wall are confirmed, the

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lateral sealing capacity of fault rocks can be quantitatively studied [7–13]. But these studies were mainly conducted by analyzing the composition of the fault rocks without considering the influence of the internal structural characteristics on the lateral sealing capacity of fault. It was considered that faults in the active stage show no lateral sealing capacity, causing the rare mention of the lateral sealing of faults in the active stage. Therefore, there is a lack of research methods aiming at the lateral sealing of faults in the active stage.

In fact, not all the faults and positions in the same fault are open laterally. Due to the influence of compositions and structures of the filling materials in the fault belt, the lateral oil and gas sealing capacity is not as strong as that of fault rocks experiencing diagenesis of compaction, but there is still some sealing capacity for a certain amount of oil and gas, thus affecting the accumulation and distribution law of oil and gas [14–18]. Whether the problem can be correctly understood is the key to oil and gas exploration in the fault developmental zone of the sag. Therefore, to conduct study on the geological conditions and their research methods for lateral sealing of faults in the active stage is of great significance to correctly understanding the distribution law of oil and gas and guiding oil and gas exploration in the fault developmental zone.

1. Geological conditions for lateral sealing of faults in the active stage

During the activity of faults, the opening is formed by associated fractures and induced fractures. And the vertical opening of faults is the migration channel for the vertical migration of oil and gas and the infeasibility of vertical sealing has been an uncontroversial fact. However, whether an active fault plays a role in sealing the migration of oil and gas mainly depends on the compositions of the filling materials. Only with the fault zone filling materials with shaly compositions being the lateral migration blockers, the displacement pressure will be greater than or equal to that of the reservoir rock in the migration wall, thus there is fault lateral sealing, otherwise there is none (Fig. 1). However, the condition for this kind of sealing is that the fault should be in a reverse direction and the faulted strata are dominated by mudstone. Due to the dominance of mudstone in faulted strata, the filling materials in the fault zone after fracturing can also be dominated by shaly compositions; otherwise it will be dominated by argillaceous composition. Only when there was no development of induced fracture zone in the footwall of reverse faults [19], the fault zone filling materials with shaly compositions will act as the direct blocking materials, forming lateral sealing; otherwise the induced fracture zone will act as the blocking materials and there is no formation of lateral sealing.

2. Research methods for the lateral sealing of faults in the active period

As can be seen from the above, once the displacement pressure of fault rock and that of the reservoir rock in the oil and gas migration wall are confirmed, the lateral sealing of faults in the active stage can be studied based on the above two kinds of pressure.

2.1. Determination of the displacement pressure of filling materials in fault zones

As a fault zone in the active stage was in its open state, its filling materials were not compacted in diagenesis, they are equivalent to sediments. Their lateral sealing capacity to oil and gas migration is significantly weaker than that of the compacted fault rocks which experienced diagenesis. Because the magnitude of their displacement pressure is not only mainly affected by the shaly content like the displacement pressure of fault rocks, although they can be compacted by the weight load of overlying sediments, they were not diagenetic yet. They resulted in a displacement pressure significantly lower than that of fault rocks [20–22]. According to the perspective [23] that the displacement pressure of fault rocks is proportional to the diagenetic depth of compaction and the shaly content, the empirical relationship between the displacement pressure of filling materials in the fault zone and shaly content and depth (Equation (1)) can be derived as follows.

$$pd_{\mathrm{f}} = \mathrm{c}\mathrm{e}^{\mathrm{d}R_{\mathrm{f}}Z_{\mathrm{f}}} \tag{1}$$

where pd_{f} indicates the displacement pressure of filling materials in the fault zone, MPa; c, d indicates the constants varying with areas; R_{f} represents the shaly content of filling materials in the fault zone; and Z_{f} is the burial depth of filling materials, m.

As can be seen from Equation (1), the depth of filling materials in the fault zone can be obtained from the direct reading of drilling wells and seismic sections, and the shaly content of filling materials in the fault zone can be calculated from the faulted distance, thickness of faulted strata, and shaly content in Equation (2) [24].

$$R_{\mathrm{f}} = \frac{\sum_{i=1}^{n} H_i R_i}{L} \tag{2}$$

where n is the number of faulted strata; H_i is the thickness of strata i in the faulted strata, m; R_i is the shaly content of strata i in the faulted strata; L represents faulted distance, m.

Once the empirical relationship between the displacement pressure of filling materials in the fault zone and their burial depths and shaly content are determined (Equation (1)), the displacement pressure of filling materials in the fault zone can be derived. Due to the restriction of drilling and coring, the displacement pressure of filling materials in the fault zone can't be tested directly; however, the empirical formula of Equation (1) can only be indirectly obtained by means of physical simulation experiment.

Clay and siltstone were mixed respectively in accordance with the ratios of 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100 to simulate the fault zone filling materials with different shaly content. Then they were mixed in the stirrer, and the mixture obtained was wetted with an atomizer before it was poured