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Rapid Accumulation and Dissipation of a Paleo-reservoir in the Bozhong Depression, China

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ABSTRACT

The Bozhong Depression, a proliferous petroleum area in China, is typical of a central generative kitchen surrounded by uplifts with a series of structural traps, most of which have been drilled with commercial discoveries, including the PL19-3, QHD32-6 and PL9-1 Oilfields. However, a structural trap in the southern Bodong Uplift is probably an exception, indicated by the occurrence of only a few hydrocarbon showings without commercial flows in the exploration well.

The structural trap in the southern Bodong Uplift seems prospective due to many favorable factors of favoring petroleum accumulation listed below. Firstly, two suites of siliciclastic reservoirs and cap rocks occur in the first and second members (30.3-24.6Ma) of the Dongying Formation and the Guantao Formation (24.6-12Ma). Secondly, it is located between the Bozhong and Bodong Sags in the west and east respectively, where the third member of the Shahejie Formation (42-38Ma) has been confirmed as the major high-quality hydrocarbon source by the known oil discoveries and both the first and second members (38-32.8Ma) of the Shahejie Formation and the third member (32.8-30.3Ma) of the Dongying Formation matured to be minor sources during the Neocene. Thirdly, boundary growth faults between the uplift and these two sags respectively serve as effective transformational pathways from the source rocks to the trap. Moreover, the modeling of preferential petroleum migration pathways (Hao et al., 2007) indicates that the trap is similar to the giant PL19-3 and QHD32-6 Oilfields (petroleum reserves greater than 1×10^8 ton) resulting from numerous “small petroleum streams” in a large area of the generative kitchens converging into a few preferential petroleum migration pathways for highly efficient hydrocarbon migration.
In fact, integration of 2D basin modeling with analysis of fluid inclusions (FIs), gas chromatogram-mass spectrometry (GC-MS) and apatite fission track (AFT) is performed to illustrate the whole process of petroleum accumulation and dissipation in the Dongying Formation in the trap (Figure 1), indicating that the trap is risky.

The analysis of grains containing oil inclusions (GOI) shows that two samples in the first member of the Dongying Formation between 3200 and 3210 m have high GOI values (>12%), which is obviously higher than 5% as an empirical threshold for oil layers proposed by Eadington et al. (1996) and Lisk et al. (1998). It means that the current water layers between 3200 and 3210 m were once oil-saturated reservoirs. Moreover, multiple periods of petroleum charges are indicated by further observation of inclusions, including oil inclusions occurring in both intragranular fractures and the dust rim of quartz overgrowths, two distinct hydrocarbon groups under ultraviolet fluorescence and two homogenization temperature intervals. Higher homogenization temperature than the current formation temperature indicates unsteady flow during the petroleum accumulation.

The oil in the second member of the Dongying Formation displays coexistence of integral n-alkanes distribution and 25-norhopane indicating at least two stages of petroleum charging. The ideal temperature for biodegradation is usually less than about 80 Celsius, which is below the observed homogenization temperatures of fluid inclusions, so the early hydrocarbon charging may not be recorded by inclusions.

The analysis result of apatite fission track of the first and second members of the Dongying Formation between 3198 and 3555 m indicates that apatite grains are partially annealed, although the current formational temperature is between 129 and 132℃. Besides the maximum temperature, the duration time is essential to the annealing level. According to the fanning model proposed by Laslett (1987), petroleum filling at higher homogenization temperature lasted for less than 0.2 million years for the first member of the Dongying Formation and less than 0.06 million years for the second member of the Dongying Formation, otherwise AFT would be totally annealed with AFT age equal to zero.

With these geological constraints, 2D basin modeling is well performed to illustrate the rapid formation and dissipation of the paleo-reservoir in the first member of the Dongying Formation. During the deposition of the Miocene Guantao Formation (24.6-12Ma), the source rock in the Bozhong Sag was buried more deeply to mature earlier, followed by that in the Bodong Sag due to differential subsidence. Hydrocarbon generated from these two kitchens passed through the boundary growth faults, and accumulated in the Dongying Formation of the trap during the first stage of low-matured oil charge. However, the reserves were reduced by strong biodegradation before the deposition of the upper member of the Minghuazhen Formation (5.1Ma). Since then, neotectonics had caused strong faulting in the Bozhong Depression, resulting in pervasive faults and episodic transformational hydrocarbon-bearing fluid flows. During this stage, high-matured oil was charged into the trap. Transient non-Darcy flow, proposed to explain the abnormally higher homogenization temperature of inclusions than the formation temperature, made limited contribution to the accumulation, because its minor thermal effect shows that the cumulative time of impulsive unsteady flow is less than 0.2My at the most. With the source rocks falling out of the oil window, the amount of the hydrocarbon charged into the trap was decreasing. Whereas, the boundary faults were a double-edged sword, served as pathways connecting the source rock and the trap as well as spoiling channels from the trap. If the hydrocarbon-charging rate is higher than the dissipation rate from traps, faulting will be constructive to petroleum accumulation, otherwise it will be destructive. Therefore, continual and intense faulting without sufficient hydrocarbon complement results in the dissipation of the paleo-reservoir, which is the critical weakness of the risky trap.