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Characterization of Fault Opening for Hydrocarbon Migration

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SUMMARY

In order to characterize the sealing capacity of faults during hydrocarbon migration most studies use sealing indexes based on one or two parameters. However, these indexes, may successfully used in some areas but not in others, since fault sealing is the consequence of many geological processes that cannot be simply described by so few factors. We present an empirical method (termed fault-connectivity probability method) for assessing the long-term sealing capacity of a fault for hydrocarbon migration. This method is based on the observational evidence of the opening or closing behavior of the fault during the entire process of hydrocarbon migration. In practice, petroleum leakage through an element of fault is identified by the existence (or not) of hydrocarbon-bearing layers on both sides of this element. The data from the Wangjiagang Oil Field in the South Slope of the Dongying Depression in the Jiyang Sub-basin in Bohai Bay Basin, NE China, are used to develop this method. Fluid pressure in mud-rocks, normal stress perpendicular to fault plane, and clay smear are identified as the key factors representing fault seal capacity. They are combined to compose a non-dimensional Fault Opening Index, FOI. The values of FOI are calculated from the key factors measured on elements, and the relationship between FOI and fault-opening probability on any an element is established through a statistical analysis: when FOI is <1.0, the fault-opening probability is 0; when FOI is in the range (1-3.5), its relationship with fault-opening probability is quadratic polynomial; when FOI is > 3.5, the fault-opening probability is 1. Then, the values of fault-opening probability can be contoured on a fault plane, to characterize the variations of seal capacity on the fault plane.

A variety of approaches have been used to infer the sealing properties of faults in order to predict the impact of faulting on the migration processes of hydrocarbon that may result in industrial accumulations (Perkins,1961; Allen, 1989; Yielding et al., 1997; Kachi et al., 2005). The purpose of the present study is to present a new stochastic method (Zhang et al., 2007) aimed at characterizing the sealing-opening capacity of faults. The method is applied to the Wangjiagang Oil Field.

The Wangjiagang Oil Field is located in the South Slope of the Dongying Depression in the Jiyang Sub-basin in Bohai Bay Basin, NE China. This basin has experienced two rift episodes: an earlier Paleogene syn-rift period, and a later Neogene to Quatenary post-rift stage (Li et al., 1998). The tectonic evolution is related to strike-slip movements along Tanlu Fault and Qinling Structure Zone (Xu, 1980). The Cenozoic is composed of continental clastic deposits with a total thickness of 2000-5000m. Sediment units during the Paleogene syn-rift period include Shahejie and Dongying formations, and the Neogene to Quaternary post-rift system consists of the Guantao and Minghuazhen Formations. The Shahejie formation is separated into 4 units, downward from Sha-1 to Sha-4. The study area has experienced regional trans-tension since the end of the Mesozoic (Li et al., 1998), resulting in extensive syn-sedimentary faults which have played important roles in hydrocarbon migration and accumulation. Most hydrocarbons found in reservoirs of the Sha-2 and Sha-3 members were proved as originating from deeply buried source-rocks of the Sha-4 unit.

Our study concentrates on fault systems that have been drilled extensively on both their footwalls and hanging-walls and offer offer sufficient data to characterize the history of fault opening and closing. A gridded fault surface is constructed using 3-D seismic data, with local axes along strike and down-dip. Firstly, the connectivities of fault for migration at each grid node are identified from hydrocarbon migration-accumulation evidence established by geological studies. Then, the values of various parameters are determined at each grid node on the fault, obtaining a "Fault Opening Index" FOI. FOI is a dimensionless coefficient defined by FOI = P/ ($\delta \cdot SGR$), where P is the fluid pressure in mudrocks near to the fault, δ is the normal stress to the fault and SGR is the mudstone smear factor. FOI values (obtained on independent locations of faults) are divided into 13 intervals. For each interval of FOI, a Fault-Connectivity Probability $N_p = n/N$ is defined, where n is the number of nodes where the connectivity for hydrocarbon migration may be ascertained, and N is the total number of nodes within the interval. As shown on Figure 1, Fault- Connectivity Probability N_p is 0 for FOI values smaller than 1, and is 1 for FOI values larger than 3.5. The value $N_p = 1$ indicates that the fault area was open at least once as a migration pathway. For 1<FOI<3.5, the relation between FOI and Np can be gently fitted by a polynomial.

Figure 2 illustrates the distribution of N_p on one fault plane. This fault connectivity probability N_p varies over a wide range on the contour map of the fault plane. For example, the area west of H 12 Well, where the Shahejie Formation is present, has a probability generally greater than 0.6, except in between ZhC 1 Well and ZhH 6 Well, where the probability is low (<0.4), indicating low potential of fault opening. Hydrocarbon accumulations have been discovered in Guantao Formation and the Lower Minghuazhen Member, supporting the interpretation from fault connectivity probability.

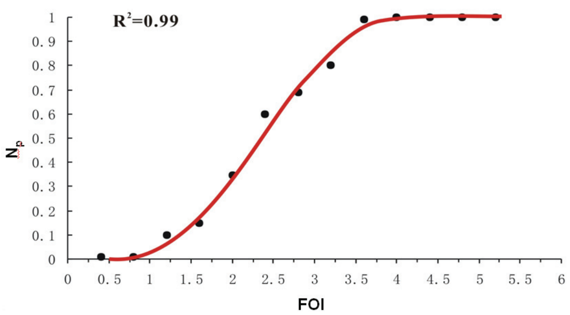

Figure 1 The relationship between N_p and FOI.

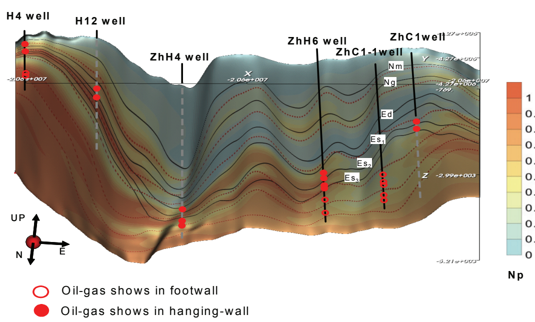

Figure 2 Distribution of N_p values on a fault surface.

Conclusions

The concept and model of fault connectivity probability proposed in this study incorporates fluid pressure, normal stress on the fault plane and mud content in rocks. It can be used to characterize quantitatively fault opening and closing. The method is effective in evaluating the history of fault opening and closing to hydrocarbon migration in the Wangjiagang Oil Field, Bohaiwan Basin. It improves the characterization of fault zones as potential hydrocarbon migration pathways, and is a step further in establishing the complete framework of hydrocarbon carrier systems in petroliferous basins.

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