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A New Method to Qualitatively Identify and Predict Fault-related Fracture (FRF)

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The effective identification and prediction of fault-related fractures (FRF), as an important type of structural fractures, has always been a concern for petroleum geologists, is also a worldwide problem. In recent years, with the rapid development of hydrocarbon exploration activities, it is more and more difficult to discover any large-scale underground fold-related fractures, the exploration activities are thus gradually moving from high point to the wing, monoclinic stratum and even broad gentle structure regions. It is well known that in broad gentle regions with compact carbonates and sandstones, due to the relatively weak folding, the FRF's traps would become the most important and the most realistic exploration targets. It has long been noted the associated relationship between faults and their related fractures, for example, the fault is the macroscopic expression of fracture, and they are always accompanying with and promoting each other, however, as the very high heterogeneity of fault development, different types of fault have different development law for FRF, even if the same fault, the FRF's development patterns may be quite different in segments of the fault. Therefore, the relationship between fault and their FRF, and their qualitative and quantitative identification and prediction are the problem in geology field. Recently, numerous studies have focused on qualitative analysis and quantitative characterization on fault and their FRF, and consequently lots of distinctive research methods, based on different data and from aspects, had been proposed and obtained certain application effect in their respective areas of research, in theory, these methods are feasible but their practicality, accuracy is different. As above-mentioned, due to the complexity of the FRF's development distribution, at present, there are no one method which can be used to completely solve the effective identification of FRF system. For this reason, to explore the qualitative and quantitative characterization of the FRF and their distribution law based on different ideas and from different angles, is still an inevitable choice for fracture researchers for a long period. In this paper, we put forward a new method, called Fault Detachment Method, to qualitatively identify and predict FRF. This method is based on the theory of fault detachment, which can be described as follows: when a layered competent stratum, located between the upper and lower weak layers, is compressed to form a fault-bend fold, if the bottom surface of the footwall remains level, whereas its top surface of the hanging wall deforms to an arc-shaped antiform, together with no any plastic deformation within the competent layer as well as no other outside material drag-in, there must be consequently a theoretical void space between the above-mentioned walls in accordance with the law of conservation of matter (balanced cross-section theory), we define this kind of void space as fault detachment space and establish a geological model between fault detachment void space and FRF. However, under the influence of overlying roof pressure and gravity, a huge underground theoretical model of void space formed by above-mentioned faulting process is hard to maintain, in other words, this void space is a theoretical space, their actual underground expression forms are those various kinds of fractures within the fault damage zone, including different sets of X-shaped conjugate joints, tension joints, feather joints etc., namely the total pore space of all kinds of fractures within the fault damage zone is equivalent to the fault detachment void space generated by the faulting. So, using the fault detachment theory, we can make a qualitative judgment on whether the FRFs are well-developed or not for one fault through observing the combination structural features among top and bottom surfaces of the fault and its fault surface. Further theoretical model and practices indicate that the

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use of the fault detachment theory to conduct qualitative identification on FRF can be summarized as follows: (1) if the bottom surface of footwall is level but the top surface of hanging wall is convex, or to the contrary the top surface is level but the bottom surface is concave, or the top surface is convex together with the bottom surface is concave, once the above three cases are observed, there may exist a theoretical void space between the hanging wall and footwall, indicating the FRF within the fault damage zone are well-developed, and their scale are determined by the deformation degree; (2) if both the bottom and top surfaces for one fault are level, or both the surfaces experience unanimously upward convex or concave deformations, and the stratigraphic thickness are basically the same for both the hanging wall and the footwall, in the circumstances, the fault surfaces for the hanging wall and footwall tightly closed just like two pieces of tiles overlayed in the same direction, there is consequently no generation of extra space, no theoretical detachment void space, suggesting the FRFs are poorly developed. Using this theory and method, we successively carried out qualitative identification and prediction on FRFs in the PermianYangxin limestons in Sichuan basin, the Upper Ordovician Lianglitage formation limestones in Tarim basin, and the Oligocene Qom formation limestons in Central Iran basin based on seismic interpretations in both vertical seismic profiles and in plane. A comparative study among results from drilling, logging inversion and seismic attribute analysis and from our fault detachment theory show that the profile predicted results are basically consistent with those revealed from logging inversion, and the plane predicted results are almost consistent with the overall characteristics obtained from RMS (root mean square), with difference in details, indicating that the fault detachment theory can be effectively used to qualitatively identify and predict the FRFs in broad gentle regions. The fault detachment theory, not only provides a new qualitative evaluation idea and method for the development distribution of FRF both ground and underground, but also provides an important theoretical basis for quantitative characterization of FRF.

Key words: fault-related fracture, fault detachment theory, qualitative identification and prediction, new method