Isolated carbonate platform reservoir multiple grouped discrete fracture network modelling

Xing Zeng¹, Heng Song¹, Anzhu Xu¹, Xiuguang Liang¹, Congge He¹, Yunyang Liu¹, Changhai Li², Erhui Luo¹, and Song Chen¹

¹ PetroChina Research Institute of Petroleum Exploration & Development, Beijing 100083, China
² School of Earth and Space Sciences, Peking University, Beijing 100871, China
*Corresponding author’s e-mail: zengxing678@petrochina.com.cn

Abstract. The fracture distribution on isolated carbonate platform is complicate congregation, it is necessary to accurately characterize fracture for oilfield development purpose. Based on the imaging logging fracture interpretation, this study analyzed the fracture grouping condition by sedimentary facies belt, also evaluated corresponding fracture intensity and orientation parameters; the fracture orientation trend for azimuth continuously changes fracture group can be established using the fracture group azimuth parameter; the intensity property calculation of each fracture group was carried out by Sequential Gaussian Simulation method under the seismic curvature volume control; each group’s discrete fracture network calculated from fracture intensity property and the analyzed fracture parameters accurately described the fracture distribution and orientation, the all groups together upscaled fracture property model shows permeability which consistent with with geological concept. This study shows: fracture features significant differentiated in each sedimentary facies belt on isolated carbonate platform, reservoir fracture can be characterized reasonably and accurately by azimuth trend control, thus lay the foundation for the reservoir simulation.

1. Introduction

The carbonate reservoir fracture distribution and quantitative prediction are difficult problems in oil and gas exploration and development. Fractures are the key seepage channels of fracture-cavity reservoirs, and are also secondary storage spaces, which are of great significance to the development and production of reservoirs [1]. Fracture model with precise characterization of reservoir fracture groups is quite meaningful for new well deployment and reservoir development plan.

In the 1980s, thanks to the research of Jane Long, Bill Dershowitz, DFN (Discrete Fracture Network)-officially appeared and widely spread. The DFN model displays fracture of different scales and shapes through a three-dimensional window to describe the overall network of fractures [2].

Under the impact of complicated geological stress, reservoir develops multiple sets of fractures. Normally, each set of fractures has its own fixed orientation characteristics, and the orientation of each group of fracture can be described by azimuth, dip angle and other parameters [3]. However, for isolated carbonate platform reservoir, fractures are mainly developed in the platform rim area. The high dip angle fracture group orientation continuously changes along the rim area and cannot be accurately describe by fixed parameters.

Taking the isolated carbonate platform oil reservoir in the M oilfield as an example, this paper compared fracture characteristics between the platform interior and platform rim area, analysed
orientation trend of fracture group. By the integration of three-dimensional seismic attribute selection and fracture orientation trend controlment techniques, the obtained DFN model accurately described the fracture groups characteristics in each sedimentary facies belt.

2. Oilfield background
The Devonian system in the M oilfield is a local structural uplift formed by tectonic process. This structural uplift developed into an isolated carbonate platform in the Carboniferous period (Figure 1). The oilfield pay zone is the Middle Carboniferous carbonate reservoir. Reservoir’s sedimentary facies distributed in a ring shape, and is divided into platform interior, rim area, and slope from inside to outside (Figure 2). The platform interior area thickness is 100-120 meters, surface is relatively flat; the rim area thickness can reach 300 meters, and 200m higher than that of the platform interior; the slope area is mostly collapse sediments from the higher rim area. Reservoir lithology is mainly limestone, with an average porosity of 6.5% and an average permeability of 2.3md. The platform interior is mostly oolitic limestone and bioclastic limestone; the rim area are mostly oolitic limestone, boundstone, and breccia limestone.

3. Fracture description
The M oilfield platform rim area developed reefs, which frequently exposed out of water surface during the deposition process, formed karst caves by weathering and leaching. Affected by the gravity collapse from the slope belt, at rim area developed fractures significantly, and large-scale fracture (fault) obviously developed parallel to the rim direction (Figure 1).

Wells M3, M5, M8, and M5-2 are located in the platform interior (Figure 2), fractures sporadically distributed, at well M3 no fracture identified; well M4 located in the south-east rim area, fractures are densely developed, fracture intensity (number of fractures on every meter interval along well bore) can reach up to 3.7.

3.1. Platform interior
Fracture orientation stereonet map of 4 platform interior wells M3, M5, M8, and M5-2 showed fractures divided into NE group (red area) and SW group (blue area) (Figure 3), all dip angle less than 35°, the average azimuth of the NE group is 60° and the average dip angle is 22°; the average azimuth of the SW group is 235° and the average dip angle is 25°. Fracture aperture of two groups in the platform is distributed in the interval of 10um-70um.
3.2. Rim area
Fracture orientation stereonet of the rim area M4 well shows that fractures can be divided into three groups (Figure 4). The first group is the low dip angle (less than 35°) fracture group with a mean azimuth of 300° and a mean dip of 13°, aperture is distributed in the interval of 32um-60um; followed by high dip angle (greater than 35°) fracture group with an average dip angle of 67°, divided into north azimuth group (red region-average azimuth 10°) and south azimuth group (blue region-average azimuth 175°). Aperture is distributed in the interval of 25um-63um. Since the development of fracture zones is usually closely related to faults [4], the fracture groups and adjacent faults has obvious direction consistency [5], so the high dip angle fractures of rim area and the large fractures (faults) have the same direction, that means is consistent with the platform rim direction, which is controlled by structural contours, and two high dip angle fracture groups have opposite azimuth. Well M4 located in the south of the rim area (Figure 2), where the structural contours are generally east-west strikes. Therefore, the azimuth parameters of high dip angle fracture groups are southward and northward respectively.

4. Discreet Fracture Network calculation
Discrete fracture simulation method uses fracture parameters (orientation, aperture, etc.) and the spatial distribution (fracture intensity volume) to control the stochastic calculation.

Fracture’s characteristics between rim area and platform interior are significantly different, fracture parameters of each group can be obtained through imaging log interpretation and core analysis. In the
case of insufficient well data, in order to obtain the fracture intensity space property, well fracture intensity log should be interpolated under constraint of seismic curvature volume. DFN calculation performed respectively for each fracture groups, after then fracture networks of each group were upscaled together into three-dimensional model grid.

4.1. Azimuth continuous controlment
The direction of high dip angle fracture groups continuously changes along rim area. In this study, two sets of dip angle parameters: Dip A and Dip B were used to control the two sets of high dip angle fracture respectively. The process is as follows:

Select a representative contour line of the rim area, extract its azimuth value, and make an azimuth (Dip A) map (Figure 5). Value distributes in the range of 0 to 180°, as shown at point P in Figure 5, has a Dip A value of 135°, which means azimuth direction to be south-east. Add the Dip A azimuth map by 180°, obtain the other group of fractures with the opposite azimuth, as Dip B (Figure 6), azimuth of which distributes in the range of 180° to 360°, providing another set of fracture with azimuth of 315° for point P.

4.2. Fracture intensity body
The seismic curvature attribute is one of the seismic geometric attributes, which are mostly used to describe the geometric changes of geological bodies. Due to its sensitivity to fractures [7], it reflects the degree of deformation of the interpretation plane. The greater the curvature of the structure, the greater the fracture development degree. The seismic curvature reflects the fracture intensity, orientation, aperture to a certain extent [8], which can be used for quantitative analysis of fractures. According to the fracture grouping analysis, extract the fracture body density curve P32 (fracture surface total area per unit volume) of each fracture group, under the spatial control of the seismic curvature value, and obtain each Density attribute of fracture group by Sequential Gaussian Simulation method.

4.3. Discrete Fracture network calculation and upscale
Perform discrete fracture network calculation by integration of fracture orientation parameters and intensity attributes. The NE group and SW group fractures were generated in the area of the platform, and the high dip angle fractures were generated on the platform rim area. Fracture groups orientation control is successful, results is consistent with the original orientation parameters (Figure 7&8).
Figure 7. Discrete fracture network and orientation stereonet for Dip A group.

Figure 8. Discrete fracture network and orientation stereonet for Dip B group.

A three-dimensional model grid was established for discrete fracture network upscale process, set the grid I, J, K directions as northeast, southwest, and vertical, respectively.

There are three main upscale algorithms for discrete fracture networks: Oda, OdaC and FBSA (based on fluid). The difference among them is mainly the definition of effective fracture slices in a given model grid. Normally, the fracture permeability obtained by Oda method is the highest, and the method has the lowest sensitivity with respect to model grid size [9]. For the M oilfield, the Oda algorithm is used to complete the upscale calculation. The upscaled fracture properties show significant difference between platform interior and rim area (Figure 9).

Figure 9. Fracture permeability Ki and histogram distribution.

| Facies  | Ki(mD) Ave | Ki(mD) Max | Kj(mD) Ave | Kj(mD) Max | Kk(mD) Ave | Kk(mD) Max |
|---------|------------|------------|------------|------------|------------|------------|
| Interior| 0.127      | 3.289      | 0.121      | 3.567      | 0.082      | 2.568      |
| Rim     | 395        | 896        | 320        | 815        | 393        | 758        |

5. Conclusions

(1) The fracture characteristics in different sedimentary facies belts on isolated carbonate platform are significantly different. The fracture intensity at rim area is higher than that of platform interior.

(2) On isolated carbonate platform direction of reservoir fractures can continuously change along rim area. Fracture azimuth trend control is an effective orientation describing technique which can be used in DFN calculation.
(3) It is recommended that carry out fracture grouping analysis before Discrete Fracture Network calculation, and calculation should be performed separately for each fracture group. The generated discrete fracture networks of each fracture group should be upscaled together in to model grid.

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