Reservoir Bodies Geometry Shape Modeling Method of Carbonate Fracture-cavity Reservoir: Taking the Ordovician Carbonate Reservoirs in Tahe Oilfield Area 4 as An Example

Bin Zhao1,2, Jiagen Hou3
1 School of Geophysics and Oil Resources, Yangtze University, Wuhan Hubei, China
2 Key Laboratory of Exploration Technologies for Oil and Gas Resources, Ministry of Education, Yangtze University, Wuhan Hubei, China
3 School of Geosciences, China University of Petroleum, Beijing, China
*Corresponding author(E-mail: zhaobin@yangtezu.edu.cn)

Abstract
Because of the tectonic reconstructions, weathering, denudation and eluviations, the carbonate fracture-cavity reservoir space types are diverse, reservoir body geometries are quite irregular, spatial distribution is stochastic, and reservoir 3D space distribution is difficult. Research on carbonate fracture-cavity reservoir bodies geometry shape modeling method will be necessary for depicting reservoir bodies spatial distribution, quantitatively characterizing fracture-cavity reservoir heterogeneity, and accurately calculating oil and gas reserves. This paper proposed the basic research approach of “cave and fracture reservoir bodies classification modeling” according to the characteristics of carbonate fracture-cavity reservoir. For cave reservoir body, we proposed the modeling idea of "vertical and horizontal zoning, karst facies controlled" according to origin modeling principle, regarding well cave data as main data, and cave development probabilistic data from wave impedance analysis as auxiliary data, building cave reservoir body model by the sequence indication modeling method. For fracture reservoir body, we proposed the modeling idea of "multi-scale discrete fracture network" according to hierarchy modeling principle, using deterministic modeling methods to build the large scale fracture model, using an object-based marked point process simulation to build the middle scale fracture model, under the constraint of fracture occurrence data and fracture density distribution model. Finally we use above modeling methods, taking the Ordovician carbonate reservoirs in Tahe oilfield area 4 as the example to build the geometry model of cave and fracture reservoir bodies respectively. These models reproduce the 3D geometry of fracture-cavity reservoir bodies.

Keywords: Tahe Oilfield, carbonate, fracture-cavity reservoir, cave reservoir body, fracture reservoir body, reservoir modeling

1. INTRODUCTION

Carbonate fracture-cavity reservoir has experienced many tectonic movements and strong weathering, denudation and eluviations, which leads to the various types of reservoir space, irregular shapes of reservoir bodies with random distribution and serious reservoir heterogeneity. So it's hard to describe the spatial distribution of reservoir bodies. To research the method of carbonate fracture-cavity reservoir bodies shape modeling can objectively describe the spatial distribution of the reservoir bodies. It's the base of quantitatively characterizing of reservoir heterogeneity and reservoir parameters characteristics in 3D space. What's more, for accurate calculation of oil and gas reserves, reasonable evaluation and exploitation management in such reservoirs, it also has important practical significance.

Since the overseas carbonate reservoir is mostly pore-type carbonate reservoir, study on carbonate fracture-cavity reservoir modeling is less. Domestic carbonate reservoir modeling research started in the beginning of this century, and was originally using the data interpolation to establish the reservoir property model. Then vertical formations “karst facies-controlling modeling”, reservoir space “various types modeling”, ”cave type modeling” and “under the constraint of waveform data volume” modeling principle, “under the constraint of RMS attributes volume” modeling method were put forward as a guidance to establish reservoir model, mainly focusing on a single cave reservoir model. For the carbonate fracture-cavity reservoir bodies shape modeling, there hasn't formed a set of corresponding ideas and methods at home and abroad, the methods that have been proposed include a multi-dimensional data integration modeling approach that takes genetic relationships into account(Hou,2012;Hu,2013), “vertical and horizontal zoning, fracture priority” three-dimensional distribution modeling method for Paleocene Karst Reservoir(Liu, 2012; Li,2016; Bin,2011). In this paper, based on Tahe oilfield 4 area Ordovician reservoir as an example, we will discuss the ideas and methods of carbonate fracture-cavity reservoir bodies shape modeling.

2. CHARACTERISTICS OF CARBONATE FRacture-CAVITY RESERVOIR BODIES
Tahe Oilfield lies in Kuqa County and Luntai County of Xinjiang Uygur autonomous region, on Akekule arch slope of Shaya uplift in the north of Tarim basin. It’s on the east of Halahatang depression and the west of Caohu depression, between the Manjua depression in the south and Yakela-Luntai Broken convex in the north, which is the first huge-scale Paleozoic Marine carbonate oilfield, with the main oil layer in the Ordovician carbonate fracture-cavity reservoir.

Being different from the clastic reservoir and general fractured carbonate reservoir, the Ordovician carbonate reservoir in Tahe Oilfield belongs to reconstruction reservoir, which experienced many tectonic movements and karstifications, etc. So it’s with the characteristics of deep burial, large thickness and complex reservoir distribution, strong heterogeneity, changeable fluid properties. Reservoir space is dominated by pore, cave and fracture, which were formed by tectonic fractures and karstification(Yang .2013). Based on geometric shape, size and the cause of reservoir spaces, it can be divided into matrix pore, fracture and cave (table 1). Matrix pore has no ability of porosity and permeability. Fracture is divided into structural fracture and non-structural fractures by formation cause, which has little contribution to oil-gas accumulation and plays the main role of flow channel. Cave is the most important reservoir space of carbonate reservoir, and almost 99% of oil output in Tahe oilfield come from cave reservoir. Cave reservoir bodies are classified into solution pores and large caves according to the size of reservoir space. The diameter of some smaller pores are less than 10 cm, while some large caves are high up to 72 m (TK409 Well 5586 m ~ 5658 m).

Table 1. Classification of Ordovician carbonate reservoir space in Tahe Oilfield (statistics according to outcrops, core, logging data)

<table>
<thead>
<tr>
<th>Reservoir space type</th>
<th>Category</th>
<th>Size (diameter or width) μm</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cave</td>
<td>large cave</td>
<td>&gt;100×10³</td>
<td>weathering karstification</td>
</tr>
<tr>
<td></td>
<td>solution pores</td>
<td>hundreds of to100×10³</td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>structural fractures</td>
<td>a few to dozens of</td>
<td>tectonic movement</td>
</tr>
<tr>
<td></td>
<td>pressure soluble fractures</td>
<td>a few to dozens of</td>
<td>diagenesis</td>
</tr>
<tr>
<td></td>
<td>dissolution fractures</td>
<td>a few to dozens of</td>
<td>diagenesis</td>
</tr>
<tr>
<td>Matrix pore</td>
<td>intercrystal (dissolved) pore,</td>
<td>dozens of to hundreds of</td>
<td>dissolution, sedimentary and diagenesis</td>
</tr>
<tr>
<td></td>
<td>intergranular (dissolved) pore</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

During the process of drilling, when drilling into cave section (especially in unfilled large cave section), the mud is seriously lost and the drill is unloading, which leads to coring and logging lost. What’s more, the Ordovician reservoir buried deeply (> 5300m), with low quality of seismic data, it is difficult to in identifying and predicting of fracture-cavity reservoir bodies. The characteristics of various types of reservoir space, complex shape, different size, random distribution also causes the difficulty of description in carbonate fracture-cavity reservoir space.

3. FRACTURE-CAVITY RESERVOIR BODIES SHAPE MODELING METHOD

3.1. Applicability analysis of modeling principles

Reservoir modeling should follow three modeling principles, which are isochronal modeling, origin modeling principle and hierarchy modeling principle (Wu,2007). Similar to the sedimentary facies and architecture element in clastic reservoirs, cave reservoir body and fracture reservoir body are discrete variables, can be regarded as generalized reservoir facies. Combining with the characteristics of Ordovician carbonate fracture-cavity reservoir in Tahe Oilfield, the applicability of the three modeling principles are analyzed.

(1) Cave and fracture reservoir bodies are formed by post-depositional process, don’t have the concept of isochronous interface, therefore, the isochronous modeling principle is not suitable for fracture-cavity reservoir modeling. (2) The development and spatial distribution trends of fracture-cavity reservoir bodies have some original relation with Paleo drainage systems, paleo geomorphology, Paleo structure and so on. In order to establish fracture-cavity reservoir models accord with reality geology condition, we should use these original relationships and origin modeling principle. (3) Faults and fractures have obvious hierarchy in reservoir, and fault distribution obviously controls fracture development, so we can use hierarchy modeling principle, build faults and fractures models by hierarchical control.

To sum up, origin and hierarchy modeling principle can be adopted in carbonate fracture-cavity reservoir bodies geometry shape modeling, while the isochronous modeling is not suitable.

3.2. The ideas of reservoir bodies classification modeling
Based on the analysis of fracture-cavity reservoir bodies origin, Ordovician carbonate reservoirs in Tahe Oilfield are Weathing Crust Karstic Reservoirs. The formation of solution pores and large caves are closely related with weathering crust karstification(Cao,2012), and their development are controlled by the Karst palaeogeomorphy, palaeo drainage systems, and paleo structure(Qi,2013). The key factors of fracture formation of Ordovician carbonate reservoirs in Tahe Oilfield includes tectonic movements, lithology, anticipate fractures, rock strata structures, and the most important is early hercynian tectonic movement(Yuan,2016). The origin between cave and fracture reservoir body is different.

The shape of fracture-cavity reservoir bodies is extremely complex. The shape, size and spatial distribution of fracture-cavity reservoir bodies are obviously different, even for cave and fracture reservoir body themselves, they are not the same. For example, cave reservoir bodies can be divided into the type of the hall and the pipe according to the shape, solution pores and large caves according to the size. Discrete distribution, single pipe distribution, dendritic distribution and mesh distribution according to the spatial distribution.

If the cave and fracture reservoir body models are established together, the origin modeling principle can’t reflect the internal rules of the two kinds of reservoir body development because of different origin. Moreover, the differences among the shape, size and spatial distribution of cave and fracture reservoir bodies are too large, it is hard to use hierarchy modeling principle to build fracture-cavity reservoir body models uniformly. Therefore, in order to reflect the actual geological conditions of different reservoir body, we should build cave and fracture reservoir body model respectively.

3.3. The modeling method of cave reservoir bodies
3.3.1. Cave development control factors and development rules

In vertical direction, under the control of water table's depth and groundwater movement, single period karstification of the Ordovician reservoirs in Tahe Oilfield can be divided into surface karst zone, seepage karst zone and subsurface flow karst zone from up to down vertically. Surface karst zone is controlled by surface water seepage and shallow formation runoff, can formed a series of small-scale cave, but most of them are filled or half-filled with surface residual deposits and wall colluvial content. Groundwater permeates down along the faults or fractures in seepage karst zone, leaches and corrodes carbonate reservoirs, and form a series of vertical or high-angle caves, especially in the middle of seepage karst zone, large-scale caves are developed because of strong denudation. Because upper leaching water gather into subsurface flow karst zone and form stronger underground horizontal runoff. Subsurface flow karst zone can easily form large-scale horizontal cave, with collapse accumulation and chemical deposition filling.

In surface direction, because of strong weathering and erosion, landforms of Ordovician reservoirs in Tahe Oilfield is irregular, and can be divided into karst upland, karst slope and karst depression. Karst upland is the recharge area of karst atmospheric water, with vertical seepage underground dynamic and isolated caves development. Karst slope is the transition zone between karst upland and karst depression, groundwater dynamic has the characteristics of both vertical seepage and horizontal subsurface flow, subsurface runoff development, and cave reservoirs has obvious stratiform character. Groundwater dynamic of karst depression decrease obviously, so karst cave reservoirs are less developed.

From here we can see that cave reservoir body development is controlled by paleo drainage systems and palaeo geomorphology, and spatial distribution trend of cave reservoir bodies has original relationship with paleo drainage systems and palaeo geomorphology, although cave reservoir bodies distributed randomly in 3D formation.

3.3.2. The modeling idea of "vertical and horizontal zoning, karst facies controlled"

Through the above analysis we can see that cave reservoir body development has obvious zonation in vertical different karst zone, regionalization in horizontal different geomorphic unit. Therefore, in the cave reservoir body modeling process, followed the origin modeling principle, we proposed the modeling idea of "vertical and horizontal zoning, karst facies controlled", established paleokarst zone model and palaeogeomorphic model, then built the cave reservoir bodies model under the control of paleokarst zone model and palaeogeomorphic model.

Paleokarst zone model is similar to the strata model of conventional clastic reservoir modeling, regarding karst zone as layer, interface of karst zone as stratigraphic interfaces. To identify the boundaries of the different karst zone in those wells which drilling encountered cave, establish zoning interface by interwell data interpolation, and obtain paleokarst zone model. Before Carboniferous Bachu formation bimodal limestone deposition, the stratigraphic evolution of karst developmental zone mostly are entirety fluctuation in early Hercynian period, bimodal limestone and the underlying mudstone deposition were filling-up under its former palaeogeomorphic evolution, the thickness of Bachu formation mudstone and bimodal limestone can approximately reflect the karst palaeogeomorphic fluctuation in early Hercynian. Through filling-up palaeogeomorphic restoring method, restore palaeogeomorphic form approximately, establish palaeogeomorphic model.

Cave reservoir bodies are discrete variables. Some stochastic simulation methods are suitable for discrete variables, which included the marked point process simulation method based on object, truncated Gaussian...
simulation and sequential indicator simulation methods based on pixel. Cave reservoir body shapes are complicate, distributions are random, geometry shapes and distribution rules are hard to be represented, so the marked point process simulation method and truncated gaussian simulation method are not applicable to cave reservoir bodies. For cave reservoir bodies of different karst zone and palaeogeomorphology units, sequential indicator simulation method can give different variogram that reflects different environmental effects on the controlling of cave development. In the classical sequential indicator simulation method, the proportion of every discrete variables is for all the grid, that is to say, the ratio of each discrete variable is unchanged while simulated different grid nodes, this is clearly inconsistent with the actual geological, so we adopt the sequence indication with a trend method, establish discrete variables probability trends by importing seismic data to constrain stochastic simulation. In this way, we can offer a local discrete variable proportion for every simulation nodes, its simulation process is not only faithful to the hard data but also to the soft data.

Seismic inversion wave impedance attributes and cave reservoir bodies have a good response relationship in Tahe oilfield when analysing various seismic attributes. Carbonate has characteristics of high-speed, high-density and high-wave impedance because carbonate is hard and dense itself. When the caves are highly developed in carbonate rocks, it will cause the decrease of speed and density, which means the decrease of wave impedance, and the cave developed section shows the "low wave impedance" characteristic. But the wave impedance character is a comprehensive response of reservoir lithology, physical properties and fluid properties, it lacked the definite relations with cave reservoir bodies, so we need find probability correlation between the wave impedance and cave reservoir bodies in different karst zone and different palaeogeomorphic during the modeling process, and take this correlation as an interwell constraint on the random simulation cave reservoir bodies.

During the actual modeling process, regarding cave data from well as hardware data, using the sequence indication method, analysing probability correlation between wave impedance data and single-well cave development level. Using this correlation to transfer the wave impedance data into cave development probability trend data, and it is used as a modeling soft data to establish a cave reservoir model.

3.4. Fracture reservoir body modeling method

The tectonic fracture in Ordovician reservoirs of Tahe oilfield can be divided into large-scale, middle-scale and small-scale fractures according to the scale. Large-scale fractures are faults that can be interpreted directly by the seismic data, mddl-scale fractures can be identified by logging data and had the response in seismic data, but small-scale fractures can only be recognized in core thin sections. Large-scale and middle-scale fractures are the main effective fractures in reservoir. Therefore, only large-scale and middle-scale fractures are considered in fracture reservoir body modeling.

3.4.1. The modeling idea of "multi-scale discrete fracture network"

Because fractures in study area are obvious divided, and large-scale fractures (faults) have obvious controlling effect to middle-scale fractures(Partha,2001). Therefore, we follow the hierarchy modeling principle, put forward “Multi-scale discrete fracture network” modeling idea, we first build large scale fractures model, and then build middle-scale fractures model, show reservoir fractures distribution by lots of discrete fracture slices with different direction, length, shape, dip, and azimuth.

Large-scale fracture models (fault model) consists of a series of 3D fault planes which can characterize the faults spatial location, orientation and cutting relations. According to seismic faults interpretation data such as fault-point data, through the section interpolation, the model is established by the deterministic modeling method.

The middle-scale fractures are the main part of reservoir fracture network, their information are difficult to obtain directly. Therefore, middle-scale fractures model is not established by deterministic modeling method. For middle-scale fractures, we use an object-based stochastic simulation method and the marked point process simulation method to build fracture network model, the principle and steps of which is similar to the object-based sedimentary facies modeling method. Taking middle-scale fractures as "object bodies", and taking stratus as "background facies", the simulation process is to put middle-scale fractures object body into stratum background facies randomly, but the randomly fracture object bodies is difficult to reflect the real trend of the fracture distribution. In order to make the model more in line with actual geological reality, the prior geological knowledge on middle-scale fractures must be established before simulation, then under the restriction of this knowledge to establish middle-scale fractures model.

Prior geological knowledge of middle-scale fractures include statistical data of fracture occurrence and fracture density distribution model. Fracture occurrence information includes fracture groups, length, azimuth angle, dip, etc, which can be obtained from the core observation and statistics of imaging logging. Fracture density distribution model is obtained by single-well fracture density interpolation which is acquired from imaging logging data, the model reflects the distribution trends of middle-scale fractures in background faces, taking fracture density distribution model as the objective function of the simulated annealing, generating fracture pieces randomly according to fracture occurrence statistical data until generated fracture density achieve
the given fracture density distribution model. The progress of middle-scale fracture modeling is similar to "two steps modeling", the fracture density distribution modeling should be completed firstly, and then establish the middle-scale fractures model under the restriction of the facture occurrence statistical data and facture density distribution model.

3.4.2. Cross-well restriction of fracture reservoir bodies modeling

Large scale fracture model (fault model) can be obtained by deterministic modeling method. The location and the shape of faults are identified, without the problem of cross-well stochastic simulation. Previously stated, the middle-scale fractures model was built with an object-based stochastic simulation method under the restriction of the facture occurrence statistical data and facture density distribution model. The facture occurrence statistical data is obtained from well information, and it can not reflect cross-well facture information, so cross-well facture stochastic simulation is controlled by the facture density distribution model. The reliability of fracture density distribution model is the key of accuracy of the medium scale fracture modeling.

Facture density distribution model can be built by single-well facture density interpolation which is obtained from imaging logging data. Under the situation of limited imaging logging data and few single-well facture density data, fracture density distribution models simply built through cross-well interpolation are with poor reliability. Carbonate reservoir in Tahe Oilfield are buried deep and of poor quality seismic data, single seismic attribute has little obvious response of cross-well fracture development degree. For achieving effective constraint of seismic data to cross-well fracture density, it is needed to pre-process seismic data to enhance the boundary feature of fracture, highlight stratum discontinuity caused by fracture, then to extract seismic properties that can reflecting fracture distribution density. Both of variance cube technique and ant-tracking technology (Randolph,2005) are effective methods in identifying faults, fractures and stratum discontinuity, through variance cube analysising in seismic facies adjacent channel and samples, which can highlight the location of abnormal points of seismic event, enhance spatial discontinuity in seismic data. We adopt ant tracking technology to find discontinuous traces in accordance with default fracture conditions, then track this traces, eventually obtain the ant attributes body that has the characteristics of low noise, showing clear faults and fractures trace. So the ant attributes body can reflect cross-well fractures development degree, therefore, using ant attributes body data restrain single-well facture density interpolation can ensure the reliability of fracture density distribution model.

3.5. Summary

According to the characteristics of Ordovician carbonate fracture-cavity reservoir in Tahe oilfield, this paper proposed the basic research approach of "cave and fracture reservoir bodies classification modeling", followed origin modeling principle, proposed the modeling idea of "vertical and horizontal zoning, karst facies controlled". Taking cave data from well as main data, cave development probabilistic data from wave impedance analysis as auxiliary data, built cave reservoir bodies model by the sequence indication with a trend method, followed hierarchy modeling principle, proposed the modeling idea of "multiscale discrete fracture network", using deterministic modeling methods to build the large scale fracture model, obtaining the facture occurrence statistical data from well information, and obtaining fracture density distribution model under the restraint of ant attributes body data. Under fracture occurrence statistics and fracture density distribution model constraints, using an object-based marked point process simulation to build the middle scale fracture model.

4. CASE STUDY

Follow the above research ideas and methods, taking Tahe oilfield 4 area for example, the models of cave and fracture reservoir bodies were established for further expounding of the carbonate fracture-cavity reservoir modeling method. Tahe oilfield 4 area is located in the northeast of Tahe oilfield, which is high place in the main part and the earlier block to be developed. There are a total of 100 wells in the area, with 57.4 km², being divided into 21 fracture-cavity units. The reservoir is lower Ordovician Yingshan group, lacking of middle-upper Ordovician formation. Taking the top unconformity(T74) of Yingshan group as the top surface of formation model in Tahe 4 area. Due to the lack of bottom information of Yingshan group, and reservoir mainly developed in 0~240 m formation of below T74, we take the surface that is 240m under away from the T74 as the undersurface of formation model, and grid design accuracy of formation model in X, Y, Z direction is 30×30×2m.

4.1. Cave reservoir bodies modeling of Tahe oilfield 4 area

4.1.1. Paleokarst zone model and palaeogeomorphic model

The paleokarst reservoirs in Tahe 4 area mainly developed in superimposition and reformation places of multi-stage vertical seepage karst zone and horizontal subsurface flow karst zone. From top to bottom, the karstification weaken while the reservoirs development became poor gradually. The top unconformity of
Yingshan group was flattened using the layer flattening technique and profile correlation was carried on after identifying single-well caves in this area. The results show that caves in the profile are characterized by layered distribution and three karst zones can be divided with the distances of 0 m-60 m, 60 m-150 m and 150 m-245 m from the top of cave to T74, respectively, of which the caves in 0 m-60 m karst zone is best developed. Based on all of these above, the karst zone model in the Tahe 4 area was built (Figure 1).

Tahe 4 area missed karst valley landform, and karst palaeogeomorphology is mainly karst upland and karst slope. Relatively low-lying part of Karst slopes can be separately set aside and called karst depression. Karst upland groundwater hydrodynamic are mainly vertical seepage, and horizontal subsurface flow is less developed, as well as the cave reservoir bodies. Karst slope is the transition zone of karst upland and karst valley. Groundwater hydrodynamic is including vertical seepage and horizontal subsurface flow, underground runoff is developed well, and cave reservoir bodies are developed better. Based on cave reservoir bodies plane development rules, the distribution of the palaeogeomorphology plane is established, and put it into Tahe oilfield 4 area 3D model to obtain palaeogeomorphology model (Figure 2).

![Figure 1. Paleokarst zone of Tahe Oilfield area 4](image1)

![Figure 2. Palaeogeomorphic zone of Tahe Oilfield area 4](image2)

**4.1.2. Correlation between the wave impedance and cave reservoir bodies development probability**

The caves identified in 45 wells in area 4 were analyzed and compared with the wave impedance re-sampling data, the results have indicated a high consistent rate of caves developed section and the wave impedance, which is over 70%, therefore, wave impedance data can be used as the basis of three-dimensional shape characterization of cave reservoir bodies.

For the three-dimensional seismic data of karst developed layers in the study area, the logging-constrained inversion was carried on to obtain high-resolution three-dimensional seismic wave impedance data, and different karst zones and palaeogeomorphic units were analyzed to prove the correlation between the wave impedance data and the probability of cave reservoir bodies development. The results have showed that the wave impedance data of different palaeogeomorphic units corresponds well to the borehole data of cave reservoir bodies. Take 0 m-60 m karst zone for example, in this karst zone, the karst upland caves are mainly distributed in the region where wave impedance value is higher than 9500 and cave probability is generally less than 0.3. Karst slope caves are mainly distributed in the region where wave impedance is greater than 9000. caves are
most likely to distribute in the region where wave impedance value is around 10500, caves development probability gradually decreasing after 11000. Karst depression caves are mainly distributed in the region where wave impedance is greater than 8500; And wave impedance in the vicinity of 10000 and 13000, there are two high development probability area. Overall there is high probability of development in karst slope and depression, low probability in karst upland, which is in line with the discipline of cave reservoir bodies development in Tahe area 4, we analyzed the relationship between the wave impedance data and cave development probability in different palaeogeomorphology units, and established cave development probability trend data of different palaeogeomorphology units.

### 4.1.3. Cave reservoir bodies model

According to the modeling idea of "vertical and horizontal zoning, karst facies controlled", on the basis of paleokarst zone model and palaeogeomorphic model in Tahe oilfield area 4, taking 66 caves which are identified from 45 wells in area 4 as hardware data, 9 groups of cave development probability trend data of different paleokarst zones and palaeogeomorphic units as cross-well constraint data, we built cave reservoir bodies model(Figure 3) by the sequence indication with a trend method, realized the modeling process origin controlling of cave reservoir bodies in 3D space.

![Figure 3. Cave reservoir bodies geometry model of Tahe area 4 (Hollow out)](image)

### 4.2. Fracture reservoir bodies modeling of Tahe area 4

#### 4.2.1. Large scale fracture model

According to structure interpretation results, 309 faults are found on the top surface of the Ordovician (T74) in Tahe oilfield area 4, the main characteristics of which are small fault throw and short extension. The maximum fault throw of seismic data interpretation is 60 m, and the minimum fault throw is 5 m, extending length are usually 110 m to 1500 m, the maximum can reach 3300 m. Faults mainly divides into three groups: NE, NW, and near EW direction. Using deterministic modeling methods to build matched large scale fracture model according to structure interpretation results (Figure 4).
4.2.2. Middle scale fracture model

After analyzing 10 cored wells and 4 imaging logging wells data, we concluded that fractures and faults have the same trend. Fractures are largely divided into three NE, NW, EW trending, and mainly are high dip angles. Extended length ranges from 0.3m to 110m, where NE trending fractures extended length are relatively larger. Statistical analysis azimuth, dip, length attributes of middle scale fracture (Table 2) by group, to build middle scale fracture occurrence statistics data.

Table 2. Middle scale fracture occurrence parameters of Tahe area 4

<table>
<thead>
<tr>
<th>Groups</th>
<th>Azimuth angle (°)</th>
<th>Dip angle (°)</th>
<th>Extended length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>average value</td>
<td>range</td>
<td>average value</td>
</tr>
<tr>
<td>NE</td>
<td>138</td>
<td>105~168</td>
<td>79.73</td>
</tr>
<tr>
<td>NW</td>
<td>45</td>
<td>22~79</td>
<td>79.63</td>
</tr>
<tr>
<td>EW</td>
<td>180</td>
<td>151~208</td>
<td>79.46</td>
</tr>
</tbody>
</table>

Calculating single-well fracture density of four well by imaging logging data, using ant tracking technology to build ants attribute model (Figure 5) on the basis of variance analysis, regarding single-well fracture density as hardware data, ants attribute model as cross-well constrained software data, we build fracture density distributing model of Tahe area 4 (Figure 6) by cross-well interpolation.
Under the restriction of middle scale fracture occurrence statistics and fracture density distributing model, using a target-based marked point process simulation to produce fracture plane network of each fractured groups until fracture density reach the fracture density distributing model. Finally, different groups of fracture plane network are combined to form the middle scale fracture model of Tahe area 4(Figure 7).

5. CONCLUSION

(1) Origin and hierarchy modeling principle can be adopted in carbonate fracture-cavity reservoir bodies geometry shape modeling, isochronal modeling principle is not suitable for fracture-cavity reservoir.

(2) Cave and fracture reservoir bodies have different origins so that they have very different scale, shape and distributing. In order to reflect their real geologic conditions objectively, we should build cave and fracture reservoir bodies model respectively.

(3) Cave reservoir bodies exists conspicuous zoning not only in different paleokarst zone, but also in different geomorphic unit. This article followed origin modeling principle, proposed the modeling idea of "vertical and horizontal zoning, karst facies controlled", according to the modeling process of "paleokarst zone model→ palaeogeomorphic model→ cave reservoir bodies model". Regarding cave data from well as hardware data, cave development probabilistic data from wave impedance analysis as software data, building cave reservoir bodies geometry model by the sequence indication with a trend method.

(4) Faults and fractures have obviously hierarchy. This article followed hierarchy modeling principle, proposed the modeling idea of "multiscale discrete fracture network". Using deterministic modeling methods to build the large scale fracture model. Obtaining fracture occurrence statistical data from well data, fracture density distributing model from single-well data interpolation under Ants attribute volume control. Under fracture occurrence statistical data and fracture density distributing model constraints, using an object-based marked point process simulation to build the middle scale fracture model.

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