Carbonate Reservoir Prediction in Tarim Basin

Yang Ping[1,2], Liu Yonglei[2], Li Haiyin[2], Dan Guangjian[2], An Haiting[2] (1:China University of Petroleum, Beijing; 2: BGP, CNPC)*

Abstracts

Carbonate reservoir in Tarim basin has a special reflection feature on seismic section called strong beadlike reflection (SBR for short). Although SBR sometimes bring about good reservoir, but they not always mean good oil/gas pools. Therefore we must first understand what a SBR is corresponding to the geology, then study their distribution pattern, calculate their volumes, and evaluate their oil/gas bearing conditions. This paper tries to use the concept of fracture-cave body (FCB) and fracture-cave unit (FCU) to interpret this kind of carbonate reservoir. Enlightened by the modern karstology, people think that the tectonic movement as well as its geological result including fault system, paleo-landform and paleodrainage pattern are the most important control factors for reservoir development. Based on the iteration of acoustic inversion and forward modeling, we get the proper parameters for volume calculation. With both post and pre-stack hydrocarbon identification (HI) techniques combined with geological analyses, we understand the oil/gas bearing conditions of the target. The raising of successful drilling ratio shows that the new well design work flow and the techniques used are feasible and effective.

Introduction

Tarim basin is located in the western China and it is the largest Paleozoic marine facies craton basin in China with the total area of 560,000 sq km. There is about 70% of the basin has relationship with carbonate E&P, thus carbonate study is very important in this basin.

Most of the carbonate traps of the basin belong to stratigraphic traps, and the development degree of paleo-karst reservoir is the main control factor for these traps. Carbonates of Tarim basin have some significant features different form other carbonates in the world. First, they belong to Ordovician or Cambrian sediments, and most of them are buried more than 5500m. Because of these, the matrix porosities of these rocks are very small and most of them are less than 2%, and the secondary pores and fractures are the main storage spaces. As a result, the rocks become highly inhomogeneous and the reservoirs become difficult to be predicted.

After years of E&P, we have already recognized that the carbonate reservoirs of this kind will form very special reflection which makes them very obvious on both seismic sections and RMS amplitude maps, we call it strong beadlike reflection (SBR for short, Figure 1).

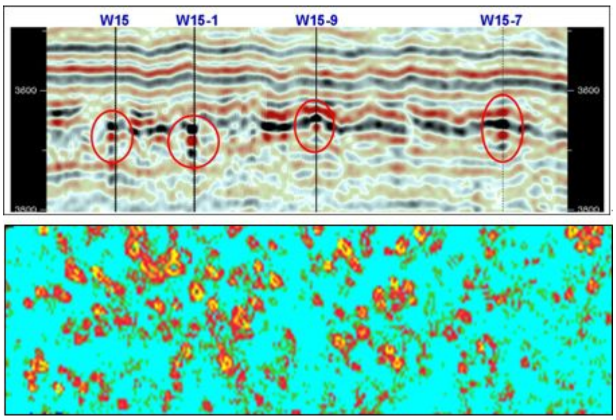

Fig. 1 Typical strong beadlike reflection on seismic section (above) and on RMS amplitude map (blow)

Although SBR sometimes bring about good reservoir, unfortunately, not all the SBRs give expectative drilling results. In fact, besides different amount of oil/gas, the SBRs can also mean mud, water, or just tight rock. Therefore, it is important to answer these questions: what on earth is a SBR corresponding to the geology? How is it distributed? How big is it? And how and what is it filled?

Geological model

Outcrop data, well data and seismic data are used to set up the schematic geological texture model of SBR (figure 2). Simply, a SBR is a seismic scale fracture –cave body (FCB) made of one cave or several caves as the main body and some fracture zones around or between them. There are 3 types of FCB models, they are big fractures and caves model, inter –phase fractures and caves model, and even distributed fractures and caves model. A FCB can be one of the 3 models or a combination of them. Usually, a FCB in seismic scale can range from 20m to 200m vertically and 50m to 500m or even longer horizontally.

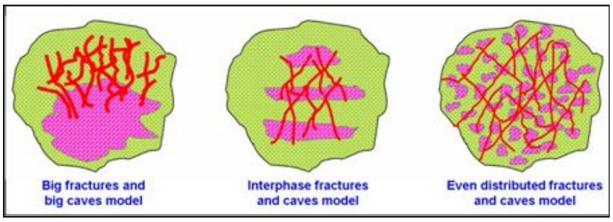

Fig.2 Classification of FCB

A SBR is the integrated response of both fractures and caves inside a FCB which is just the carbonate reservoir we want to drill. That means the inner structure as well as its caves and fractures of a SBR are unrecognizable. Still, there are some ways to qualitatively judge whether a SBR is good enough to be drilled. Among them, the most important rule is that according to some forward modeling experiments, the reflection strength of a SBR has a positive relationship with the total porosity of the FCB as well as the volume of it. It can even be deduced (not be proved) that the reflection strength of a SBR has a positive relationship with the total pore space (the product of total porosity and volume) of the FCB. That indicates, under the condition if the volume difference is not too big, the seismic responses of a small FCB with higher porosity and a big one with lower porosity may be the same. Hence, it can be concluded that the stronger the reflection of a SBR is, the better the reservoir of the corresponding FCB is.

If different FCBs are connected by fractures in seismic scale, we call it a FCU (figure 3). In this situation, FCBs in the FCU can be distinguished from each other in seismic. Attention must be paid that not all the fractures in a FCU are really contributed to the connectivity of FCBs as some of them are not open.

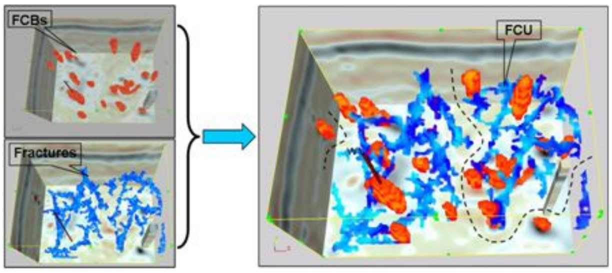

Fig. 3 Schematic model of FCU in seismic scale

The concept of FCB and FCU can be used to easily interpret the unpredictable drilling results such as a big SBR drilling meets only a 1m hole, a SBR yield such a huge amount of oil that it is obviously beyond the volumes of it, and so on.

Distribution pattern

According to the modern karstology we know that the forming of FCBs in a carbonate layer has close relationship with tectonic stress after sedimentation, current fault system, paleo-landform, and especially the palaeodrainage pattern. Many techniques such as 3D visualization and trend surface are used to characterize these geological features. In this step, we also know that whether a FCB is filled with mud or not depends on whether it is located under a surface channel or under a residual hill, and the shape of the residual hill may has important influence on the accumulation ability and production ability of the oil/gas pool. Then the reservoir development pattern becomes clear. Generally, regional tectonic stress and the faults formed under the stress are the basis for forming karst landform and palaeodrainage; paleo-landform and palaeodrainage react on each other through weathering, erosion, transportation, and sedimentation; during this process, the carbonate reservoir is formed along and around the channels, and FCBs appear in the places where the reservoir developed best. Usually, a FCB under a residual hill will be unfilled and if it is strong and big enough, it is worth drilling (figure 4).

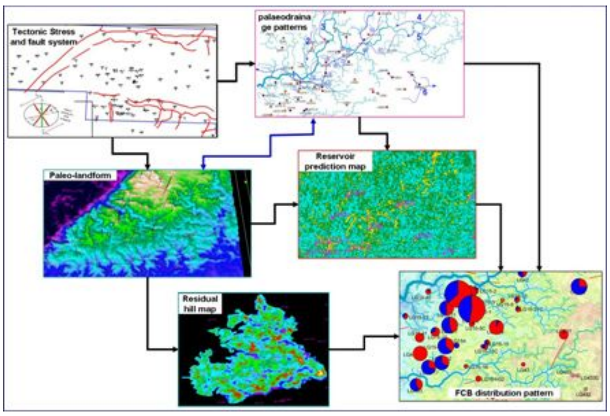

Fig. 4 Schematic diagram showing FCB developing mechanism

Volume calculation

Since the volume of a FCB cannot be calculated like what we do for an ordinary sand reservoir, we use an iteration of AI inversion and forward modeling bases on wave equation to get the proper parameters for FCB volume calculation (figure 5). If the forward modeling profile is very similar to the original seismic section, we can confirm that the AI inversion result is acceptable and the following parameters of velocity and porosity in geological model is relatively correct. The other important parameters include volume calibration factor, porosity calibration factor, and threshold of AI value. Among them, the volume calibration factor is got from a series of forward modeling and the other two parameters can be got from cross plot analyses of well data and seismic data. Using these parameters, following the steps of volume adjustment, porosity adjustment, time-to-depth conversion, and reservoir sculpture in 3DV, we can get the final volume of the FCB at last.

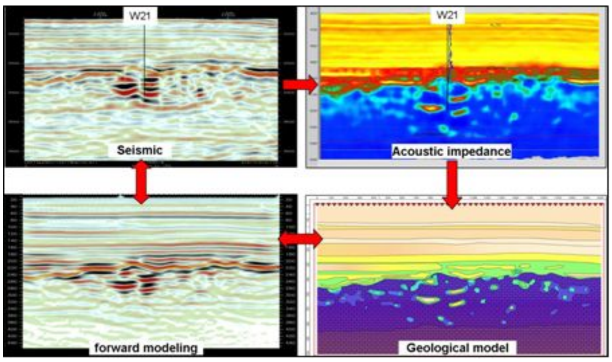

Fig. 5 Flow chart determining volume calculation parameters

Since the connection condition of different FCBs is important to oil/gas production, we have made effort to fracture prediction to judge whether some FCBs are connected together by fractures and form a fracture-cave unit (FCU, figure 3). The techniques employed in this step include qualitative methods such as enhanced coherence and curvature as well as quantitative method like anisotropy (figure 6). The oil/gas pool volume should be the total volume of all the FCBs in a FCU.

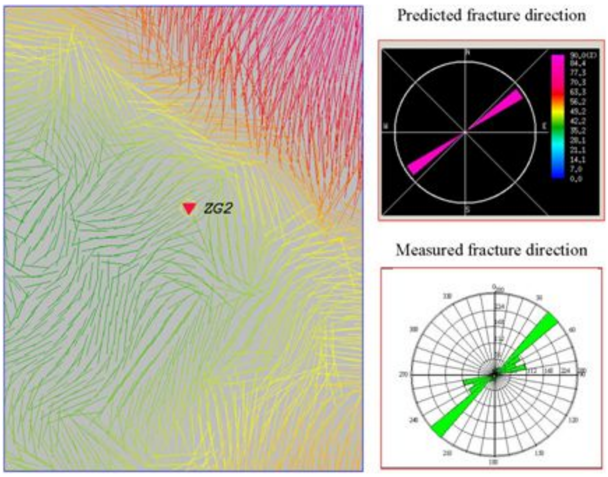

Fig. 6 Quantitative fracture prediction in ZG2 area

Hydrocarbon identification

To reduce the drilling risk, hydrocarbon identification (HI) is important before proposing well location. Both frequency anomalies in post-stack domain and AVO anomalies in pre-stack domain are employed to perform HI. Some sidetrack wells proved that these techniques are usually effective (figure 7).

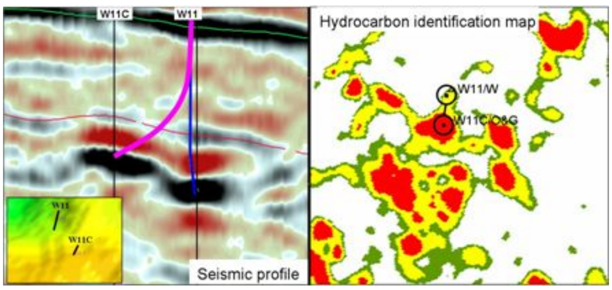

Fig. 7 W11C (Oil&gas) is the sidetrack well of W11 (water). Well tie seismic profile (left) and hydrocarbon identification map (right) in W11 area prove the HI result is reliable.

From the above picture we can see that the geological position has very important influence on petroleum acumination. Figure 8 shows that oil/gas acumination is not controlled by the reservoir alone like what was thought before, but also controlled by the basic rule of gravity differentiation. Therefore, geological analyses are essential for the final judgment of well drilling.

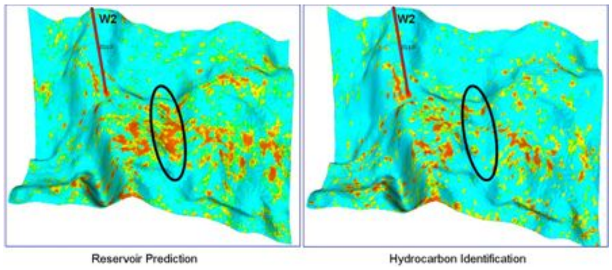

Fig. 8 Difference of reservoir prediction (left) and HI (right) in structural low

Application

After all the above studies are finished, the well location can be easily pointed out. The key points to well location selection includes: a relatively higher position, stronger reflection, more fractures, bigger volume, and clearer hydrocarbon response. By this way, the well drilling successful ratio raises from 40% in 2008 to 80% in 2009 (figure 9).

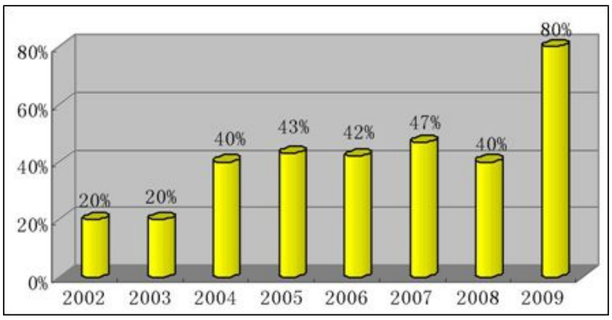

Fig. 9 Change of successful drilling ratio

Conclusions

Based on above analyses and application, we can have the following conclusions:

1. For the fracture –and –cave reservoir in Tarim basin, setting up the new concepts of FCB and FUC is necessary and effective.

2. Because the FCB is mainly caused by different kind of geological functions of water, studying the paleo –landform and palaeodrainage patterns is a proper way besides common reservoir prediction to understand the macro reservoir development rules.

3. With volume calculation and gas/oil bearing condition prediction of a FCB during well design, we can effectively reduce the drilling risk and increase the successful ratio.

Acknowledgments

The author would like to thank Tarim Oilfield Company for the permission to publish this work, and thank Mr. Zhao Jianxun, Zhang Xizhe, and Zhang Rujie for their help in preparing this manuscript.