Application of VSP well drive data in the prediction of complex carbonate reservoirs

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Abstract. The qixia formation carbonate rocks in the northwest of sichuan are of great buried depth, thin reservoir thickness and strong heterogeneity. Therefore, VSP data are used to control the seismic data on the surface, VSP well drive data lay a good foundation for interpretation. Then, through waveform clustering analysis, favorable facies zones were developed. Secondly, natural faults are predicted based on maximum likelihood attribute technique. Finally, the reservoir quantitative prediction is carried out by using phase control inversion technique. The drilling well location is optimized based on reservoir and fracture prediction information, and the drilling effect is good, which provides strong technical support for subsequent exploration and development in this area.

1. Introduction
The research area is located in the northwest of sichuan basin, and qixia formation has great potential for oil and gas exploration and development. For example, well A was drilled in qixia formation and obtained a high-yielding gas flow of 876,000 m$^3$ per day [1]. Qixia formation in this area has large buried depth, thin reservoir thickness and strong heterogeneity. Due to the limitation of resolution of conventional seismic data, it is very difficult to identify reservoirs. Therefore, the well flooding research of seismic data VSP with improved resolution was carried out, and reservoir prediction was carried out on this basis, which improved interpretation accuracy and achieved good drilling results.

Qixia formation is carbonate platform deposit in the basin. In the carbonate deep slope environment during the first habitat period, a set of thick deep limestone and biogenic (clastic) micritic limestone was mainly accumulated. Except for the coral reef limestone with partial deep water deposition, there was no large biological beach. Its reservoir performance was poor, but it had good oil generation ability. During qi-ii period, affected by the decline of sea level and the reactivation of the ancient fault in longmenshan, the study area is generally a carbonate gentle slope sedimentary environment, which is conducive to the development of high-energy beach reservoirs.

Qixia formation is relatively stable in the area. The thickness of the first habitat member is about 50 ~ 60m, and the lithology is argillaceous limestone and micritic limestone. The second qi formation is about 60 The application of seismic exploration technology has developed from geological structure to formation lithology. In order to meet the needs of fine structural interpretation and reservoir prediction in the study area, and to improve the accuracy of lithology interpretation, the research on 3d seismic data processing technology of VSP well drive in this area was carried out 70m thick and is lithologically composed of fine-mesocrystalline dolomite, micritic biogenic (clastic) limestone and cloud-like "leopard spot" limestone. The reservoir is mainly controlled by sedimentary facies and dolomitization. Reservoir thickness (phi >2%) lateral variation is large, in 1.25 ~ 13.5m, reservoir velocity in 5200 ~ 5800m/s, mainly gas layer and poor gas layer.
2. Method

2.1. VSP well control treatment

The application of seismic exploration technology has developed from geological structure to formation lithology. In order to meet the needs of fine structural interpretation and reservoir prediction in the study area, and to improve the accuracy of lithology interpretation, the research on 3D seismic data processing technology of VSP well drive in this area was carried out.

VSP well flooding is to fully analyze, combine and constrain high-quality well point data and low-resolution ground seismic data, conduct quantitative analysis and optimize processing parameters, and improve data resolution without reducing signal to noise ratio. The key parameters of VSP well flooding include true amplitude compensation factor, seismic wavelet extraction of target layer, quality factor Q, etc.

![Figure 1. Comparison of well flooding profile and Conventional treatment profile.](image)

From the perspective of the imaging section (as shown in figure 1), the frequency of the well-flooding profile can be increased by about 8 ~ 10Hz compared with the conventional one, and the diffraction return position is reasonable. The breakpoint is clear and crisp.

2.2. VSP logging horizon fine calibration technique

Seismic exploration and drilling in the working area are relatively low. Therefore, in order to ensure the accuracy and reliability of the geological horizon. The seismic reflection horizon of the target layer is precisely calibrated by combining the acoustic synthesis record and the migration time profile. It can be seen from FIG. 3 that the characteristics of the target layer wave formation relation, waveform, phase and time difference in the offset time profile are in good agreement with the acoustic synthesis records. Therefore, the reliability of horizon calibration is high.
2.3. Maximum likelihood attribute fracture prediction technique
In seismic exploration, coherence, curvature and maximum likelihood are used to detect faults, fractures and geological boundaries. The prediction effect of the maximum likelihood attribute is good. Maximum likelihood attribute is a property proposed by Hale [2]. In the study of section extraction and fault distance estimation in 2012, which is mainly used to enhance the seismic imaging effect of faults. This method highlights discontinuity, improves lateral resolution, and makes the planar characterization of faults clearer.

2.4. Seismic phase analysis technique
There are mainly three seismic phases reflected from qixia formation seismic profile. You can see from figure 3. Phase one is parallel or subparallel reflection. The second is messy or dome-like reflection; The third is the broad and slow trough reflection. Seismic facies three-dimensional space using neural network identification technology, seismic facies to qixia group division, can be seen from the figure 4 earthquake phase plane distribution, south of the study area are mainly composed of parallel or the parallel reflection, mainly rolling troughs reflection in northern area, in the central area, high structure parts for clutter or mounded reflection. Based on the analysis of rock facies and well logging facies, three points are known. Firstly, the low-energy facies zone under open platform tide shows parallel or subparallel reflection in seismic profile. Secondly, the high energy phase zones in the open platform show chaotic or dome-like reflections in the seismic profile. The third point is that the slope facies zone in the seismic profile is a broad moderate trough. According to the geological characteristics, the chaotic or dome-like and broad and moderate trough seismic facies are favorable areas for reservoir development.

Figure 2. Fine calibration diagram of layers.

Figure 3. Typical seismic phase characteristic map.
2.5. Phase-controlled inversion technique
The vertical and horizontal heterogeneity of qixia formation reservoir is very strong, and the conventional stratified difference method is not applicable to the carbonate platform reservoirs with massive and dam-like distribution, especially in the few Wells and low exploration areas, the contradiction is more prominent. Therefore, the seismic facies boundary information is integrated into seismic inversion, and the initial reservoir parameter model is established in the facies division zone. The inversion results are more consistent with the geological knowledge of the study area, which is conducive to improving the prediction accuracy.

3. Effect analysis

You can see from figure 5, fractures are relatively developed in the research area. Qixia formation Reservoir in the research area is characterized by thickness in the northwest, which is more than 30 meters. According to this rule, two drilling Wells are proposed within the zone.

4. Conclusion
Using VSP well drive data to carry out reservoir prediction of qixia formation in northwest sichuan, the following understanding is obtained:

Well flooding of seismic data using VSP logging data can improve the fidelity and resolution of seismic data and facilitate the subsequent fine interpretation of structures and reservoirs.

By scanning the entire data volume to calculate the similarity between the data sample points, the maximum likelihood attribute significantly improves the accuracy of fracture zone characterization, and provides a relatively clear description of the fracture zone interior, which also serves as an indicator for fracture density development zones.

Based on the seismic data of VSP well drive, the maximum likelihood attribute fracture prediction,
seismic phase analysis and phase control inversion were carried out, and the reservoir of qixia formation was qualitatively and quantitatively predicted, and the drilling well location was optimized, and good results were obtained. The process of this method has certain application value.

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