Technology and Application Effect of 2DVSP and Surface Seismic Joint Exploration in Shale Gas

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Abstract. 2DVSP and surface seismic joint exploration technology is a seismic exploration method formed by the combination of surface seismic exploration and in-well VSP logging technology. It realizes the combination of surface seismic and in-well VSP logging. Through simultaneous acquisition and processing, the advantages of these two technologies can be brought into play. This method can improve the interpretation accuracy of seismic profile and provide the basis for the implementation of the structure and reservoir characteristics. The method has been applied to demonstrate the trajectory of shale gas directly into horizontal well and good geological results have been obtained.

1. Introduction

The 2DVSP and surface seismic joint exploration technology deploys geophones simultaneously on the surface and in large drilling. According to the design of the shot line, the seismic source is moved on the surface, the surface is excited, and the geophones in the surface and large drilling wells are simultaneously received. By synchronizing the signals received on the surface and in large drilling, a joint imaging profile is obtained, which improves the interpretation accuracy of the target area. [1].

At present, shale gas is a hot spot in the field of unconventional oil and gas resources in China, and Sichuan Basin is the main battlefield.

Horizontal well technology is one of the key technologies in shale gas development. It is very important for shale gas production to do well trajectory design and optimization of horizontal well. The trajectory design of horizontal well of shale gas requires fine seismic structure imaging and accurate formation tendency, dip angle, fault, etc. Reservoir information is used to improve the success rate of exploration.

The exploration and development of shale gas reservoirs in Sichuan gradually developed into deep layers. Most areas lack 3D surface seismic exploration data. 2D surface seismic data is mainly arranged perpendicular to the structure. The trajectory of shale gas horizontal wells is mainly along the direction of the minimum principal stress. Therefore, the existing 2D surface seismic data cannot meet the requirements of horizontal well trajectory design and optimization. By combining 2DVSP and surface seismic exploration technology, high-quality seismic profiles in the direction of the horizontal well trajectory can be obtained. Satisfactory geological results have been achieved in the application, which supports the optimization of shale gas well vertical well development programs.
2. Method

2.1. Acquisition and observation system
In order to meet the geological task and ensure the integrity of the observation data of the target layer, it is necessary to carry out forward simulation work. First, based on geological information, well data, and fault information, a geological model is established. Then, the forward modeling of 2DVSP and surface seismic are carried out respectively to design and optimize the acquisition parameters. 2DVSP and surface seismic acquisition observation system are designed independently.

The 2DVSP imaging range and coverage times are determined according to the horizontal well length and geological target reflection characteristics. Through the forward demonstration of the geological model, when the 2DVSP imaging range and coverage times are met, the maximum offset, shot spacing, detector sinking position and detector spacing are required. The design of the surface seismic observation system includes offset, coverage, receiving interval, receiving arrangement length, etc. Finally, the integrated 2DVSP and surface seismic acquisition parameters are used to construct a well-surface joint exploration and acquisition observation system.

2.2. Matching of collected records
Both surface seismic and in-well 2DVSP have relatively mature acquisition instruments and techniques. However, as a combination of borehole and surface exploration, it is necessary to combine the two sets of acquisition, and the two sets of acquisition can be better matched and used [2]. The key points are as follows:

First, the problem of signal synchronization is solved. Before officially collecting the data, please test the explosive device to show whether the receiving time of the two devices on the surface and the well are inconsistent. If there is a discrepancy, calibration is required to ensure synchronous reception.

2.3. Technical processes
Combined with the main processing steps of surface seismic and 2DVSP data processing, a joint processing flow was established. As shown in Fig. 1.

Fig. 1. Joint processing flow chart.
2.4. Surface seismic data processing
Surface seismic profile processing includes field static correction, noise attenuation, amplitude compensation, deconvolution, velocity field establishment, residual static correction, migration imaging, high resolution processing, etc.

Combining with in-well VSP data, the true amplitude compensation factor (VSP) wavelet and anisotropic parameter Q quality factor are used to process surface seismic data in order to improve the resolution of surface seismic data [3].

2.5. 2DVSP data processing
The data processing of 2DVSP mainly includes amplitude compensation, static correction, vector synthesis, wave field separation, establishment and optimization of velocity model, imaging, etc. [4]. Among them, wave field separation, velocity modeling and imaging are the most important. The 2DVSP imaging is embedded in the surface seismic profile to obtain a joint profile. The results of 2DVSP imaging provide a lot of geological information around the well. And combine with the surface seismic data to expand the spatial description of the target layer and provide a means to improve the accuracy of seismic exploration and development [1].

3. Case study
The work area is located in the southern Sichuan Basin. The surface of the well area is flat, the height fluctuation is small, and the maximum height difference is about 150 m. The bare lithology on the surface is mainly composed of Jurassic sand and mudstone and Triassic sandstone.

3.1. Exploration demand
The well area has complex ventral structures and develops faults. The burial depth of the shale gas target layer varies greatly. The existing seismic data in the well area cannot meet the needs of horizontal well design.

Using 2DVSP and surface seismic exploration technology, the depth, dip and fracture characteristics of the horizontal well trajectory design direction are described. Provides support for horizontal well design.

3.2. Data collection
According to the drilling requirements for supporting horizontal wells, the azimuth of the 2DVSP logging line is 51 degrees. The imaging range of the target layer trajectory direction is greater than 1.8 km, and the number of full coverage is 45. The acquisition and observation system in the well is shown in Fig. 2.

And a seismic survey line is designed on the surface to carry out the joint exploration of wells and surface, and the acquisition and construction parameters are shown in Table 1.
Fig. 2. Acquisition observation system diagram.

### Table 1. Collect construction parameter list.

| Parameters name | Value | Parameters name | Value |
|-----------------|-------|-----------------|-------|
| Line azimuth    | 51°   | Receiving point spacing(m) | 30    |
| Excitation line length | 108Hz (NE1, 654Hz, SW1, 54Hz) | Receiving point number | 240   |
| Seismic gun spacing (m) | 60   | Vertical arrangement | 15585-15-3585 |
| Number of physical points | 236  | Coverage | 120   |
| Number of shots | 236   | Number of shots | 236   |
| Receiver sinking range (m) | 790-3175 | Excitation(m) | 30    |
| Detector-level spacing (m) | 15m  | The smallest gun spacing(m) | 15    |
| Sampling Rate(ms) | 1     | The maximum gun spacing(m) | 3585  |
| Record length (s) | 5     | Sampling Rate(ms) | 1     |
|                  |       | Record length (s) | 5     |

### 3.3. Data Processing

Interpretation and Effect Analysis 2DVSP data have high resolution, clear wave group features and reliable imaging. Fig. 3 is a comparative map of surface seismic profile and 2DVSP section.

It can be seen from the figure that the waveform characteristics of the two sections of 1800-2000ms at the main purpose layer are in good agreement with each other.

The vertical and horizontal resolution of 2DVSP data is obviously higher than that of surface seismic section.

The frequency of the target layer of the 2DVSP profile is 45 Hz, and the bandwidth is 5 to 80 Hz. The 2DVSP profile has clear wave resistance characteristics and high-resolution breakpoints. Compared with conventional surface seismic profiles, the 2DVSP profile has obvious advantages in the description of small faults and the characterization of thin reservoirs [6].
The 2DVSP data can be used to obtain the ideal wavelet and improve the resolution of seismic data. Downward direct wave data received by the downhole geophone during 2DVSP acquisition is closer to the true subsurface reflection coefficient wavelet sequence. It can be used as the source wavelet.

Using this wavelet to convolve the seismic reflection signal on the surface can enhance the weak signal and obviously improve the recording resolution. Fig. 4 is a comparison chart between conventional deconvolution and wavelet deconvolution, from the figure it can be seen that the recording frequency is broadened and the phase sidelobe compression is better, Fig. 5 is a comparison of surface data before and after deconvolution, as can be seen from the figure, the 2DVSP wavelet information collected on the surface seismic simultaneously can effectively improve the data frequency of 8-10Hz, and the effect is very remarkable.
Fig. 6 (a) is the combined depth profile of 2DVSP and surface seismic. The bottom boundary of the target layer slopes upward in the northeast direction. Within 1000m from the wellhead, the stratum is inclined upwards, and the dip angle is about 3-6 degrees. 1000 to 1800m from the wellhead, the formation dip angle is 6-10 degrees. There are fault features at 2800m and 3870m from the wellhead, and the fault distance is 25m and 120m.

Fig. 6 (b) shows the coherency profile. There is high coherence anomalies exit in the target interval. As shown by the location of red line marking below the destination in the figure. In the paper, the logging data is used to perform attribute inversion on the joint profile to predict reservoir distribution characteristics. As can be seen from the TOC inversion profile of Figure6(c), a thicker set of high TOC strata are developed in the target zone. In the target layer 1845- 2190 meters away from the well TOC worse, as shown by the oval box in the figure. Considering the formation dip, fault and reservoir information, suggest that horizontal section length is controlled within 1800m. The actual drilling of horizontal wells is in good agreement with the prediction results, confirming the reliability of the data.

4. Conclusions
The exploration practice of combine 2DVSP and surface seismic shows that this technique can obtain high SNR and resolution acquisition data and the acquisition technology is mature.

2DVSP and surface seismic joint exploration can obtain high-precision imaging profile, accurately calibrate the horizon, and improve the interpretation accuracy of seismic data. And it can implement detailed information such as dip angle, fault, etc. It guides the trajectory design and optimization of horizontal wells and provides the basis for oil and gas exploration and development evaluation.

Joint exploration technology is a very significant issue, access to higher economic and social benefits. The application example shows that this technology has good application value in shale gas exploration and development. Therefore, worth more people deserve research.

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