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RESEARCH PAPER

Subsalt high steep structure imaging technique: A case study of Keshen area in Kuqa depression, Tarim Basin, NW China

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Abstract: The seismic imaging has three difficulties in the Keshen area of the Kuqa depression in Tarim Basin: difficult static correction, poor original data, difficult velocity modeling and pre-stack depth migration. A dual-scale tomography inversion approach based on BP neural network and LSQR was developed to obtain the accurate near-surface velocity of the complex near-surface structure, to address the static correction of subsalt high steep structure imaging. On the basis of applying high-precision static correction and root-mean-square (RMS) velocity to the seismic data, three dimensional cone filtering and spherical spreading amplitude compensation were used to enhance the signal to noise ratio and restore the deep effective signals to cope with the poor quality of original seismic data. Under the constraints of geologic, well logging and drilling data, the dual-scale velocity modeling technology based on model-based velocity updating and grid-based tomography was adopted to obtain the precise velocity model of the complex substructure, and then the pre-stack depth migration was taken to improve the imaging effect of structure with complex surface conditions, to solve the problem of subsalt high steep structure velocity modeling and pre-stack depth migration. By applying these three techniques, the high-quality imaging achievements of subsalt high steep structure were obtained. The results of seismic imaging prediction are in good agreement with drilling results and three ultra-deep wells have been drilled successfully.

Key words: Tarim Basin; Keshen area; seismic imaging; high steep structure; static correction; velocity modeling; pre-stack depth migration

1. Overview of the study area and challenges in seismic imaging

The Keshen area is located in the south of the Kelasu structural belt in the Kuqa depression of the Tarim Basin, where the main target layers are the Paleogene Kumugeliemu Group sandstone underlying the Paleogene Kumugeliemu Group gypseous-salt rock and the Mesozoic Cretaceous Bashijiqike Formation sandstone. The study area has good oil and gas geological conditions, including good cap rocks, reservoirs and accumulation conditions[1–4].

Seismic imaging is difficult in the study area due to complex surface conditions and high steep subsurface structures. The unclear seismic imaging with lower accuracy results in inaccurate interpretation of the structural heights in the substrate layers of interest and trap geometry, and also the inconsistency between prediction results and the actual drilling data. Therefore, it is of great significance to find seismic imaging technology suitable for the subsalt high steep structures in the Keshen area.

Seismic imaging in the Keshen area is mainly faced with the following three challenges.

(1) Highlighted static correction problem. The Keshen area has drastic surface elevation differences (1 142 m–2 192 m above the sea level), with a maximum elevation difference of nearly 1 000 m. As shown in the satellite image (Fig. 1a), the northern surface of the study area is mainly the outcropped mountain of older strata, with higher and steeper terrain, and more precipitous cliffs; the southern surface is mainly the Quaternary alluvial fan and Gobi gravel zone[5], with a low-lying terrain; a series of large gullies in nearly south-north direction are developed in the eastern and western parts of the study area. The surface survey data has proved that the velocity and lateral thickness of the low velocity zone vary greatly in the study area; super-thick low velocity zones are developed locally; and the refracting layer has wide variation in lateral velocity, and no stable refracting interface. The raw single shot profile reveals poor continuity of the first break in this area (Fig. 1b). The near-surface velocity structure of the Keshen area is very complex, and consequently, the accurate inversion of the near-surface velocity structure is very diffi-

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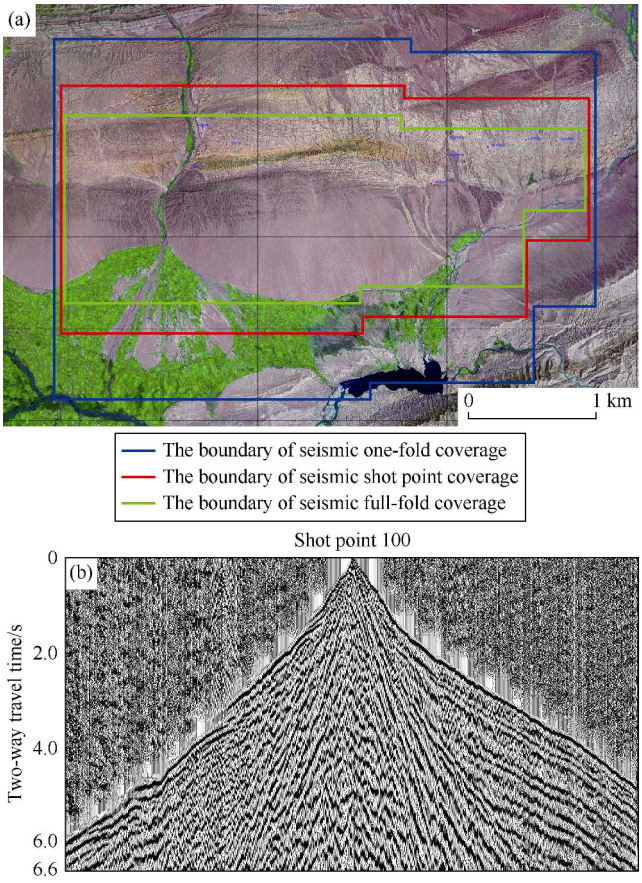

Fig. 1. Satellite image of the Keshen area (a) and raw single shot profile (b).

cult, which makes the static correction challenging. This is a major bottleneck restricting the seismic imaging of this area.

(2) Low-quality raw data. The raw single shot records collected under the complex surface conditions of the Keshen area have strong surface waves and linear interferences, and the SNR (signal-to-noise ratio) of seismic data is low. With deep burial depth (about 5 s of two-way travel time), the target layer has weak energy of effective reflection signals, seriously affecting the data quality of seismic imaging. The raw single shot profile (Fig. 2) shows that the raw seismic data has strong surface waves and linear interferences, and effective reflection waves of the deep target interval are almost invisible.

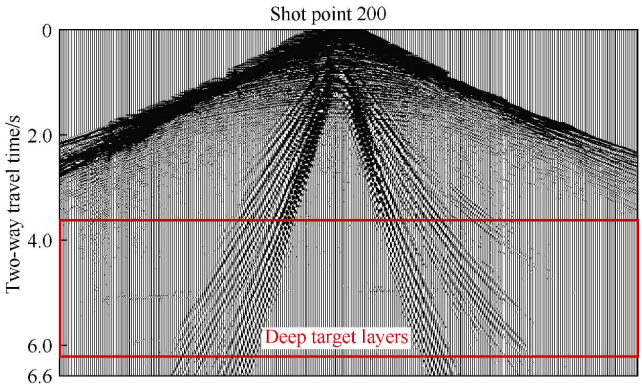

Fig. 2. The raw single shot profile.

(3) High difficulty in velocity modeling and pre-stack depth migration. The geological structure profile of the Keshen area shows that there is a set of the plastic deformation layer of low-velocity gypseous-salt rock (Fig. 3) in the Paleogene Kumugeliemu Group ($E_{1\text{-}2}$km) with the thickness ranging from tens of meters to over one thousand meters and the velocity ranging from 4 200 m/s to 4 400 m/s. The layers above the gypseous-salt rock have velocities from 2 000 m/s to 5 600 m/s with the growing depth. Below the gypseous-salt rock, the target layer, highly steep and broken, with developed thrust fault system, has the velocity of about 4 500 to 4 800 m/s. The high-steep structure, complex thrust fault system and drastic lateral change in velocity bring about the extremely complicated seismic wave field[6]. Hence the velocity modeling and pre-stack depth migration are faced with great difficulties, which is another major bottleneck restricting the seismic imaging of this area.

2. Seismic imaging technique

According to the above analysis, there are three major problems in the seismic imaging processing of the Keshen area, the static correction, poor quality of the raw seismic data, and velocity modeling and pre-stack depth migration. To address the problem of static correction, the dual-scale tomography inversion technique for static correction based on Back Propagation Neural Network (BP Neural Network) and Least Squares QR Decomposition (LSQR) was adopted to improve the inversion accuracy of the near-surface velocity model. On the basis of the high-precision static correction and root-mean-square velocity, fine pre-stack preprocessing technique of cone filtering in the frequency-wave number domain and spherical spreading compensation were applied to solve the problem of poor quality of the raw seismic data. As for velocity modeling and pre-stack depth migration, the multi-information-constrained dual-scale velocity modeling and true-

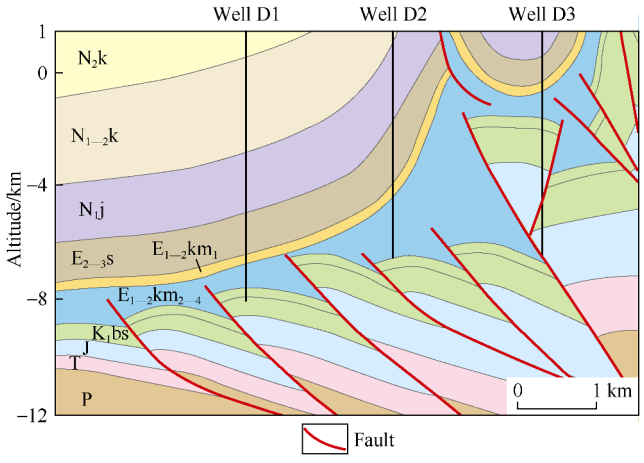

Fig. 3. Geological structure profile of the Keshen area. (N_2k—Neogene Kuqa Formation; $N_{1-2}k$—Neogene Kangcun Formation; N_1j—Neogene Jidike Formation; $E_{2-3}s$—Paleogene Suweiyi Formation; $E_{1-2}km_1$—Paleogene Kumugeliemu Group Mudstone Section; $E_{1-2}km_{2-4}$—Paleogene Kumugeliemu Group Gypseous-salt Rock Section; K_1bs—Cretaceous Bashijiqike Formation; J—Jurassic System; T—Triassic System; P—Permian System).