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CASE STUDY- HIGH RESOLUTION VELOCITY MODEL BUILDING TO IMPROVE CARBONATE REEFS IMAGE IN TZ AREA

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ABSTRACT

The study area was a transition zone, located in middle Indonesia, and its near surface is soft weathered layer with many lower velocity anomalies. The seismic data acquired ten years ago has only limited offset of 3000 meters, which is very difficult for the imaging research of the target layer of carbonate reefs with a burial depth of 3600-4200 meters. Legacy stack presents strange image of formation, especially no image of carbonate reefs below shallow velocity abnormal. How to build a high resolution velocity model is the key for pre-stack depth migration to improve the carbonate reefs image. This paper focuses on the high-resolution velocity model building techniques according to the actual situation of the study area, including accurate ultra-shallow velocity model by nonlinear tomography of first break time which is helpful to the application of FWI to avoid cycle skipping due to inaccurate initial velocity model and relative narrow frequency band conventional vintage seismic data, geology targeted Initial velocity model building with sonic and RMS, FWI, and high density hybrid grid tomography are necessary to improve image quality. The more precision of velocity model, the higher image of PSDM such as sharpen faults and more details of carbonate reefs in our study area.

EXTENDED ABSTRACT

Introduction

The study area is a shallow water project and was acquired as narrow azimuth acquisition ten years ago, consisting of 48 receiver lines, each being acquired in S/N orientation, with orthogonal split spread, 4 receiver lines and 90 live channels per line, receiver line interval 300m, receiver interval 50m, with limited 2.3km offset, air-gun source depth 4 or 2 m varying with water depth, Data was acquired on grid of 25m x 25m.

This survey is composed of north faulted-step & trough unit and south platform. The structural trend of the southern carbonate platform with patch reefs is nearly East-West direction, which is consistent with the trend of the southern large faults system, and the carbonate platform is complicated by a series of NE strike-slip faults.

The geology characteristic of study area is very complex, there are velocity reverse layers in the shallow zones, the main targets are carbonate low relief reefs, faults are developed. On the other hand, seismic data is acquired with narrow wide, limited offsets. It is more important to apply scientific and reasonable technologies to get accurate velocity model for high-quality imaging. This paper presents a comprehensive velocity modeling incorporating FWI to improve carbonate reefs image, including seabed and water velocity confirmation, good initial velocity model merging sonic interval velocity and RMS, FWI, global grid tomography, which result in a high precision velocity model for PSDM and shorten the processing cycle.

High resolution velocity model building techniques

Diving wave tomography for near surface low velocity layer model building

Ultra shallow layer or near surface, which is normally not deeper than 200m, velocity was built with first break based diving wave tomographic inversion in acquired shallow water seismic data. Accurate first break pick give positive input of inversion, small and hybrid grid tomographic with multiple iterations shows stable decay of convergence curve, mild smoothing of 500m x500m reduces the local variations and provides smooth shallow velocity in the whole work area, which is very consistent with geological conditions (Fig.1). This method makes up for the inaccuracy of ulta shallow velocity calculated with reflection events due to the shortage of near offset in the seismic data (H. Du, H. Zhang, Y. Chen Et al, 2022).

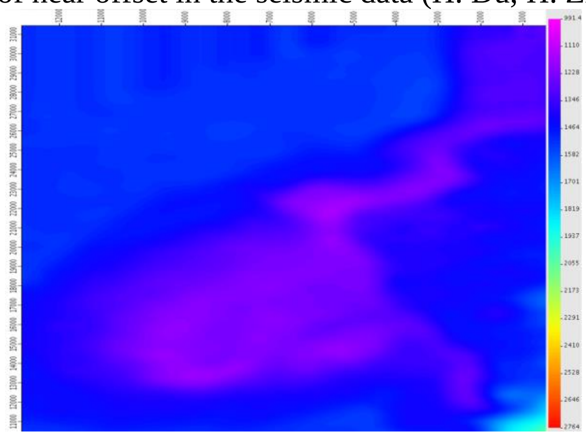

Figure 1 Depth slide at 93m of velocity model from diving wave tomographic inversion

Geology targeted Initial velocity model building with sonic and RMS

Initial velocity model is built by using RMS velocity in accordance with the well information (Fig.2 up left). Firstly, sonic logs are carefully analyzed, such as log normalization, anomalies edit, tendency curving and so on (Fig.2 down left). Then, target line PSDM are run with interval velocity model from well sonic (A) (Fig.2 up right) and the one (B) (Fig.2 middle right) from RMS converts and sonic constraint respectively. The depth horizon is conformed after compare the above two PSDM to merge A and B. Finally, a good initial velocity model is built by B and A merged at the horizon, which the model B is the main model and the shallower than the horizon is the A (Fig.2 down right). This solution combines the advantages of RMS velocity good tendency and high precision of sonic in the ultra-shallow depth. The initial velocity model is following the geology of the area reasonably. This will further improved in next few updates of the velocity model building.

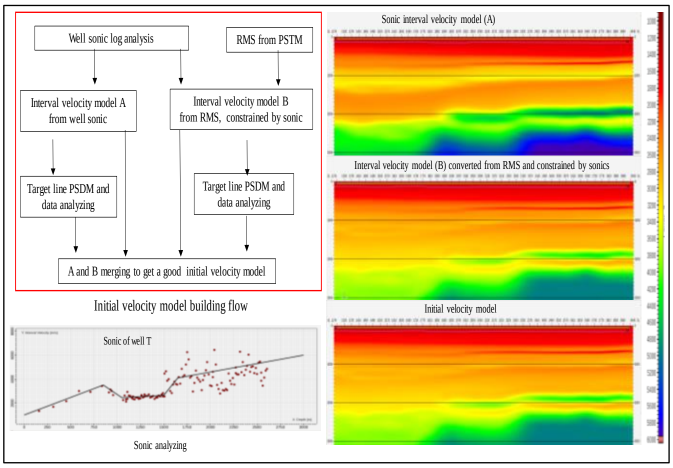

Figure 2 Initial velocity model building with sonic and RMS

Full Waveform Inversion Basic theory

Full waveform inversion, abbreviated as FWI, is a high-resolution, high-fidelity velocity modeling method by minimizing the mismatch between modeled and observed real seismic waveforms, which is a nonlinear inverse problem of matching modeled seismic data to recorded field data. The matching is quantified by the residuals of a least-squares misfit function, and the model update is computed as a scaled representation of its gradient (Lailly, 1984; Tarantola A., 1984,1986,1988,2005).

FWI updated velocity models are preferred in full wave field imaging algorithms such as RTM to resolve complex geological features, e.g., salt and subsalt structure, and thrust belts. The high resolution velocity model inverted by FWI includes low frequency components of 1~4Hz, which is missed for seismic data wavelet, and it is in line with the structure, so it can be used as a seismic attribute and a background model of impedance inversion.

Compared with reflection tomographic inversion for PSDM velocity modeling, the waveform inversion with refraction is more stable and reliable, and mass velocity anomaly will not be produced. The inversed high resolution model is consistent with geology structure. Compared with the travel time tomographic inversion via first beak, FWI can obtain a deeper and higher resolution velocity model which reverse velocity can be identified.

FWI does not require seismic data preprocessing besides accurate wavelet estimation, the inversed depth interval model can be obtained quickly and it can be running parallel with other seismic data processing.

In our copyright software, FWI can be optionally performed in the following domains and dimensions: Time domain (3D), Frequency domain (2D), and Pseudo analytic in time-wavenumber domain (3D). The multi-domain FWI is characterized by its unique functionalities (Xiang Li et al, 2010) (Fig. 3).

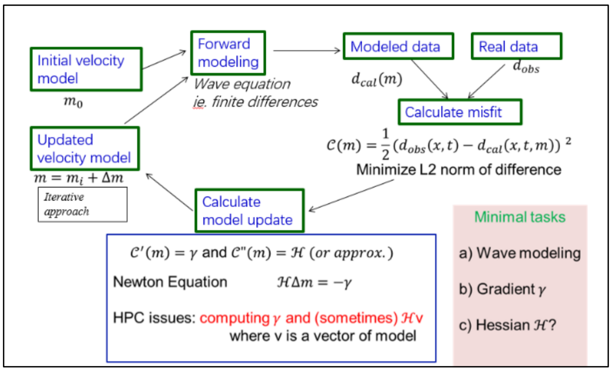

Figure 3 Sequence of Full Waveform Inversion

FWI updating velocity model in the study area

First, forward modeling tests are carried out by the initial velocity model, i.e. 2nd updated depth interval velocity model from reflection grid tomography, on selected small number of shots (Fig.4 upper left, upper middle). The density is set to 1.02 for the water and 1.7 for the sediment. A mask is used to preserve the water column with a constant water velocity 1535 m/s. A high-resolution wave propagation operator comprising both velocity and density fields is employed in inversion algorithm in Pseudo analytic in time-wavenumber domain (3D) to avoid spatial frequency dispersion. The quality of wavelet can be judged according to the comparison of forward and real data by cross-correlation (Fig.4 upper right, down right) and other means, and the phase and amplitude of wavelet are adjusted by the near offset difference between forward and real shots (Fig.4 down middle).

Then, FWI starting frequency is to determine through the model forward tests. It is determined that there is no cycle skipping phenomenon according to the signal-to-noise ratio of data in different frequency bands and the matching degree of events between the forward and the real data.

The third step is to start FWI iteration, which apply specific wavelets to different OBC shots and streamer shots. In FWI iteration, time-variant phase shifting is implemented to prevent from time frequency dispersion and aliasing due to insufficient sampling during time differencing to guarantee the resolution of inversion. Velocity, density and impedance inversion are carried out simultaneously. The inversion gradient can be divided into three parts: tomography, imaging and refraction with gradient regularization enabling quick convergence and stable inversion. Forward modeling is carried out according to the wavelet of each shot. At the same time, the problem that the gradient and amplitude of different shots are inconsistent is determined and solved based on the principle of illumination compensation. The process is identical for running FWI at 6 Hz, 8 Hz, 12 Hz, 14 Hz, 16 Hz and 24 Hz.

Quality control is the key to achieve good results in FWI. Main QC methods include the cross-correlation between forward data and real one, the PSDM by FWI velocity model improvement or not, PSDM gathers flatten or not, and the objective function of FWI reduced to a preset threshold (Fig.4 down left) and so on.

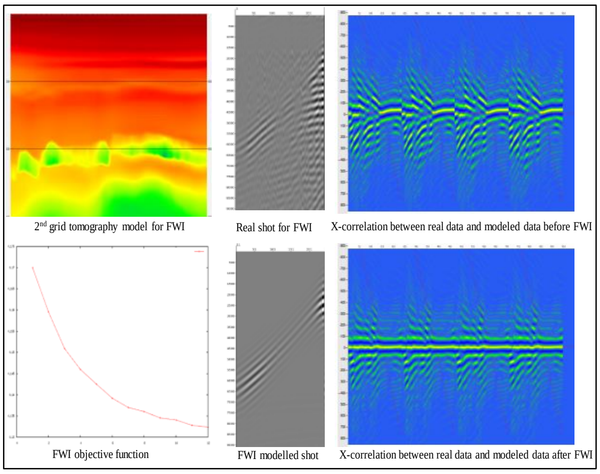

Figure 4 Main QCs of FWI in the study area

Global tomographic velocity model building

Optimizing depth-interval velocity is very important and time-consuming for pre-stack depth migration. Grid-based tomography is an important supplement for horizon-based tomography to improve the precision of the velocity model, hammering at flattening each stronger event in CRP gathers after depth migration. Final horizon-based tomography interval velocity model in depth domain as input velocity for grid-based tomography velocity update. RMO Auto-pick is designed to perform auto-picking of residual moveouts along depth migrated gathers of PSDM target lines.

Seismic wave propagates within rock medium in the form of rays. These can be divided into a series of small rectangular grid, every underground reflection point is considered in rays input, so as to realize velocity updating at each point and obtain high precision velocity model. Grid-based tomography will perform 4 iterations as necessary. Until the RMO value focus to zero after iterations.

Real example and effects

FWI was employed to achieve high resolution velocity model and the velocity function in the seismic volume have good correlation between seismic data and wells in the study area. In PSDM cube, pull up effect caused by Carbonate was resolved and image quality in target was significantly improved, and CRP gathers that was sensitive for AVO, inversion, and overpressure study were got. Depth slices and seismic sections clearly show the development characteristics of reefs and faults (Fig. 5 middle and down right). Meanwhile, diving wave tomography for ultra-shallow low velocity, geology targeted initial velocity model building with sonic and RMS, FWI, incorporating with Grid tomography plays a great role in reducing turnaround time and cost while improving the imaging quality of PSDM (Fig. 5). The reef represents as mound shape on the seismic section and atoll reef on the slice display. In the PSDM section, the reef is characteristics as convex up of top and flat down of base, the inner events become thicker than outside and the reef boundary looks sutured contacting and onlap contacting with the surrounding mudstone (Fig. 5 down right).

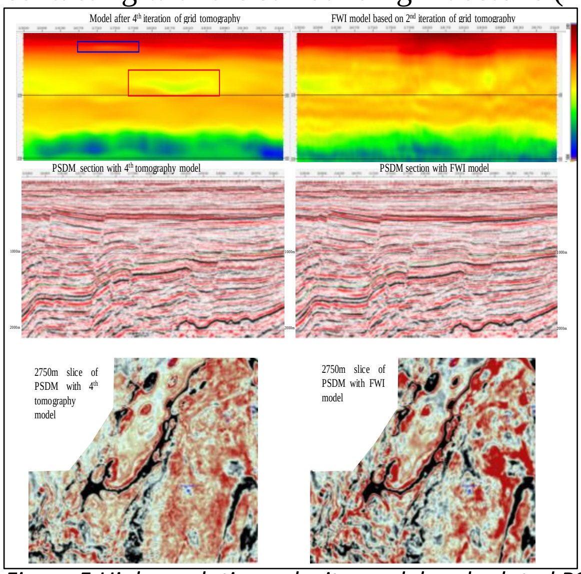

Figure 5 High resolution velocity model and related PSDM

Conclusions

High resolution velocity model building techniques, including near surface low velocity layer model building through refraction tomography, geology targeted Initial velocity model building with sonic and RMS, FWI, and global grid tomography are necessary to improve image quality, reduce turnaround time and cost. FWI is helpful tool to get accurate velocity model, even for the acquisition data with limited offset, such as only 3km in the study area, and bandwidth, FWI is still applicable to optimize velocity. The more precision of velocity model, the higher image of PSDM such as sharpen faults and more details of carbonate reefs in our study area.

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