Seismic Velocity Modeling in the Northwest Pearl River Mouth Basin, South China Sea

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Abstract: Accurate seismic velocity can determine the depth, dip angle and location of the stratum, and study the properties of rocks and pore fluid, such as rock density, reservoir location, gas hydrate anomaly and deep tectonic characteristics. The South China Sea (SCS) has special tectonic location and complex evolution history, which has always been the focus of geologists and geophysicists. At the same time, the SCS is rich in oil/gas resources, and is one of the four major marine oil-gas accumulation zones in the world. In this paper, three-dimensional velocity modeling was carried out in northwest Pearl River Mouth Basin of the SCS based on the three-dimensional geological framework model. Minimum Curvature Interpolation was used in the three-dimensional velocity modeling. Results showed that the three-dimensional velocity model can visually display sedimentary boundary and basin basement. The geological framework model makes the lateral velocity change of strata more in line with the actual geological structure. Considering the key role of the underground layer velocity in the exploration of oil, gas, hydrate and lower-crustal structure, it will be of great scientific and resources significance to carry out the three-dimensional velocity modeling research in the SCS.

1. Introduction

Three-dimensional velocity modeling plays an important role in gas hydrate exploration in the South China Sea (SCS), Mesozoic-Cenozoic basin structure and lithospheric structure research. Hydrate formation often has high P-wave velocity, and the higher the hydrate content, the higher the velocity. Three-dimensional velocity model can delineate the hydrate reservoir [1-3]. Sedimentary layer and basement of the basin can be judged according to stratum velocity model [4,5]. In addition, three-dimensional velocity model can show lithospheric structure with complex spatial variations, and it has important significance to insight the lower-crustal structure [6,7].

Three-dimensional seismic velocity modeling is based on logging sound velocity, vertical seismic profile and stack velocity obtained by seismic data processing, and constrained by seismic interpretation horizons, faults and igneous bodies [8-11]. In recent years, with the continuous
enrichment and improvement of marine basic geological data in the SCS [12,13], the research conditions of three-dimensional velocity modeling based on geological model have been met. In this paper, three-dimensional velocity modeling was carried out in the northwestern Pearl River Mouth Basin (PRMB) of the SCS. Geological interpretation such as faults, seismic reflection horizons (SRH) and igneous bodies were used as constraints of velocity interpolation among construct the three-dimensional velocity model. The Cenozoic strata, the tectonic units and the basement structure of the northwest PRMB are studied based on the obtained three-dimensional velocity model, which is of great significance to the study of Mesozoic-Cenozoic basins in the SCS.

2. Geological Setting
The PRMB is the largest Mesozoic-Cenozoic sedimentary basin in the northern SCS (Fig. 1). Moreover, the PRMB is one of the most important petroleum basins in the SCS [14, 15]. It has great exploration potential in both oil/gas resources and natural gas hydrate resources [14, 16-19]. The PRMB is a continental margin fault basin developed on the basis of extensional fault depression. It is NE-SW oriented and affected by the convergence of Pacific Ocean Plate, Eurasian Plate and Indian Ocean Plate [20, 21]. The PRMB is divided into five tectonic units from north to south: the northern uplift belt, northern depression belt (Zhusan Depression, Yangchun Depression, Enping Depression, HzD-Huizhou Depression, LfD-Lufeng Depression, HjD-Hanjiang Depression, KpD-Kaiping Depression, ByD-Baiyun Depression, LwD-Liwan Depression, CsD-Chaoshan Depression, YkU-Yunkai Low Uplift).

Fig. 1. The location of the study area and the layout of seismic survey lines (red solid). The yellow dotted line frame area is the PRMB. YcD-Yangchun Depression, ZsD-Zhusan Depression, EpD-Enping Depression, HzD-Huizhou Depression, LfD-Lufeng Depression, HjD-Hanjiang Depression, KpD-Kaiping Depression, ByD-Baiyun Depression, LwD-Liwan Depression, CsD-Chaoshan Depression, YkU-Yunkai Low Uplift.

The study area is located in the northwestern of the PRMB (Fig. 1). The PRMB is well developed with Cenozoic strata, mainly mudstone, sandstone and limestone (Fig. 2a)[23]. The basement of the PRMB is composed of pre-Cenozoic metamorphic rock and granite. Cenozoic sedimentary strata velocity in the SCS is generally less than 4,000 m/s [4], and mainly between 1,500 m/s and 3,500 m/s according to the velocity model of Zhongsha Trough Basin [5].
3. Data and Method

3.1. Data

There are eight multi-channel seismic survey lines in the study area. Five in-lines are NW-SE direction, and three cross-lines are NE-SW direction (Fig. 1). The vessel is "Fen Dou Si Hao" of the Guangzhou Marine Geological Survey. The acquisition parameters are shown in Table 1. Seismic data processing completed in Omega software system, consist of noise suppression (De-multiples, background noise suppression and large-value interference suppression), signal processing, velocity analysis and time migration [11]. Velocity analysis is the key of this study and determine the accuracy of three-dimensional velocity model. More than three times velocity analysis have been carried out, including initial velocity pickup, multiple wave velocity pickup and migration velocity pickup. The secondary velocity analysis is adjusted according to the effect of multiple wave removal. The third velocity analysis is adjusted

![Fig. 2. (a) Lithological stratigraphic of the western PRMB, modified after reference [23]; (b) Stack velocity spectrum of two-dimensional multi-channel seismic survey lines several times according to the results of time migration. Finally, the stack velocity spectrum along the survey lines is obtained (Fig. 2b). The velocity spectrum spacing along the line is one kilometer.](image)

| Profile | 1,2,3,4,5,6,7,8 |
|---------|-----------------|
| Vessel  | Fen Dou Si Hao  |
| Streamer channel | 120 |
| Record length (ms) | 7000 |
| Sampling rate (ms) | 1 |
3.2. Three-dimensional Geological Modeling
Geological framework model based on marine geological survey, including SRH, faults and igneous bodies data. Among them, without considering small-scale faults which are characterized by undeveloped faults and mostly small fault gaps. On the basis of SRH, faults and igneous bodies data, the geological framework model consistent with the actual situation of the study area. Horizon layers are continuously extended without faults (Fig. 3). The SRH and igneous bodies will control the velocity interpolation process.

3.3. Velocity Conversion
In order to obtain accurate interval velocity profile, the stack velocity obtained from normal moveout formula (hyperbola flattened in the gather is considered to be reasonable interpretation of common middle point stack velocity) is used to determine the root-mean-squared velocity (Fig. 4), and then Dix formula is used to convert it into average velocity (or interval velocity) [24].

3.4. Three-dimensional Velocity Modeling
Converting two-dimensional velocity profile to three-dimensional velocity cube is the key of this study. Spatial interpolation is involved in attribute modeling, structural modeling and reservoir facies-controlled modeling. At present, the commonly used interpolation methods are Kriging interpolation (KI) and sequential Gauss stochastic simulation interpolation. Minimum Curvature Interpolation (MCI) is used in the three-dimensional velocity modeling. MCI is an interpolation method widely used in the field of geoscience. This method requires that a surface with minimum curvature be constructed to pass through every point of the space field. While respecting data as strictly as possible, the surface should be smooth as possible [25]. The MCI and KI have the same starting point, that is, to get the local optimal weight coefficient,
but the minimum curvature weight coefficient is obtained by limiting the minimum curvature. The process is different from KI. The whole interpolation process is iterative, and the results are most in line with the human visual perception. For surface interpolation, the MCI can achieve a better balance in large trends and local rationality. Moreover, the final result of the MCI method is always very stable. Although the amount of computation is much larger than that of KI, it can be solved by parallel operation.

3.4.1. Iterative Interpolation
Suppose to interpolate a 100×100 mesh. We start with calculating 10×10 sized mesh, then 20×20, then 40×40 and so on, until the final mesh size is greater than 100×100 (Figure 4a, b). Each new node will be assigned according to the known data points. The advantage of this method is that the interpolation process can be decomposed into parallel processes based on each small area, which can be accelerated by parallel computing (such as graphics GPU).

3.4.2. Node Interpolation
To solve each local area, we establish the minimum-curvature ruled function and solve it to get the current solution. Repeat this process with the refinement, the known node is updated each time also. The advantage of this method is minimum-curvature relation satisfied. And more important, the mesh nodes satisfy both the global-law and local-law (Figure 4c, d). With refinement going, the “local area” become more and more small, the minimum-curvature relation are more and more locally also. Which makes the solution more objective. This method also has it limitations. This method required the input data has to be in good regularity. In the case of weak regularity, or even local chaos, using this method need some skill to get an objective result [26, 27].

![Fig. 4. Stack velocity spectrum in 3D view](image-url)
Fig. 5. Diagram of the calculation process of the minimum curvature interpolation method, modified after reference [11]

4. Discussion
In this velocity modeling, the lateral velocity distribution characteristics of the region are understood from the regional geological background and sedimentary model. Based on the existing SRH data, combined with faults and igneous bodies data, the appropriate fault modeling method and velocity interpolation algorithm are selected to more rationally express the influence of geological structure on velocity distribution, so as to obtain accurate velocity model. Before velocity interpolation, the model also needs to analyze the region velocity law and extract the correct position of velocity seed points for subsequent velocity interpolation. In this modeling, the velocity is corrected according to the established geological model, and the arbitrariness of velocity interpolation is reduced under the constraints of SRH, faults and igneous bodies, so that the velocity model can conform to the real underground situation as much as possible.

After iterative interpolation and node interpolation by MCI method, the three-dimensional velocity model of the study area is constructed (Fig. 6). On the whole, the lateral velocity field changes steadily, the velocity interface is smooth, and the vertical velocity also conforms to the law of formation velocity change. The velocity in the western part of the study area is larger than that in the middle and eastern part (Fig. 6). From the view of tectonic location, the northwest part of the study area is the margin of South China Block, and the southeast part is within the scope of the PRMB [15, 20]. The southeastern part of the study area is the depression belt of the PRMB, the northeastern part is the northern uplift belt of the basin, and the high-speed layer distributed in the southwestern corner is the basement (metamorphic rock and granite) of the basin.
5. Conclusions
Velocity model plays an important role in the formation and evolution, crustal structure, sedimentary basin analysis and energy resources exploration of the SCS. The three-dimensional velocity modeling research based on the three-dimensional geological framework model has achieved good results in this paper. The three-dimensional velocity model can visually display the boundary between basin sedimentary and basement. The geological framework model makes the lateral velocity change of strata more in line with the actual geological structure.

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