

# Method for Constructing High-precision Structural Models Based on Seismic

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**Abstract:** The three-dimensional geological models facilitate mineral localization and stratigraphic distribution studies. As the foundation of 3D geological modeling, structural models often fail to accurately reflect subsurface conditions due to insufficient precision. This study, based on seismic data and employing a well-seismic integration approach, determines the stratigraphic undulations by analyzing seismic wave directions. Utilizing well logging geological stratification data as constraints, we establish a high-precision 3D structural model that accurately represents stratigraphic distribution features and regional fault characteristics. This provides a solid foundation for the construction of a comprehensive geological model and offers intuitive insights into the structural characteristics of the study area.

**Keywords:** 3D geological modeling; High resolution; seismic; ant body tracking.

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## 1. Introduction

Traditionally, stratigraphic distribution characteristics have been studied by constructing stratigraphic well-to-well profiles, where multiple well-to-well profiles are drawn within the same study area to establish stratigraphic framework information[1]. This method is essentially a two-dimensional representation, which can only show geological layer variations within a single plane. However, subsurface geological structures are typically three-dimensional[2], making well-to-well profiles inadequate for fully capturing the 3D characteristics of geological formations[3]. For complex geological bodies, a single two-dimensional profile may fail to provide sufficient information and cannot comprehensively reflect the spatial relationships between layers.

Three-dimensional geological models are typically constructed based on drilling data, meaning they can only represent geological features around the drilling locations. If the distance between drilling points is large, or if certain areas lack drilling data, the geological conditions in these regions may not be accurately reflected. Inadequate drilling data can lead to inaccurate stratigraphic connections on the profiles, thereby affecting the overall geological interpretation[4]. Therefore, relying solely on discrete drilling data and interpolation fitting is insufficient to fully represent the complex and variable subsurface conditions.

This study employs a combined well-seismic approach to convert seismic data into depth-domain volumes that align with well data. By performing seismic inversion, the large-scale stratigraphic trends and structural trace distribution characteristics are determined. The stratigraphic model is constrained using well stratification information, and a stratigraphic model corresponding to the actual layer distribution is constructed using Petrel geological modeling software.

## 2. Seismic data volume processing

### 2.1. Time-Depth Conversion

Time-to-depth conversion refers to the process of transforming seismic data from the time domain to the depth domain. Seismic data is typically recorded in time, while the actual subsurface targets are often represented in depth (such as meters or kilometers), requiring conversion using a velocity model[5]. Performing time-to-depth conversion helps to more accurately determine the actual position, thickness, and distribution of strata and resources. The key to this process is the construction of an accurate velocity model, typically derived by integrating lithological density and using empirical formulas based on well data from the region.

### 2.2. Ant Body Tracking

Ant Colony Tracking Method is a seismic data processing method primarily applied in the post-processing and interpretation of seismic data, particularly in the exploration of complex geological structures[6]. The Ant Colony Optimization algorithm is a heuristic approach inspired by the foraging behavior of ants in nature. Ants mark their paths by releasing pheromones, and by sensing pheromone concentrations, they select the shortest route. As multiple ants explore, the pheromones reinforce shorter paths, ultimately leading to the optimal solution. This principle is applied to the processing and tracking of seismic data volumes, especially in complex datasets. By simulating the "ant" behavior in path selection and optimization within these datasets, this method helps identify the most optimal seismic wave propagation paths and the clearest seismic wave reflection interfaces.

Using seismic reflection data, key reflection interfaces within the seismic profiles are identified, which typically correspond to boundaries between different strata. Faults, folds, and other structural features are recognized within the reflection interfaces, and their geometric shapes and distributions are accurately delineated (Fig. 1).

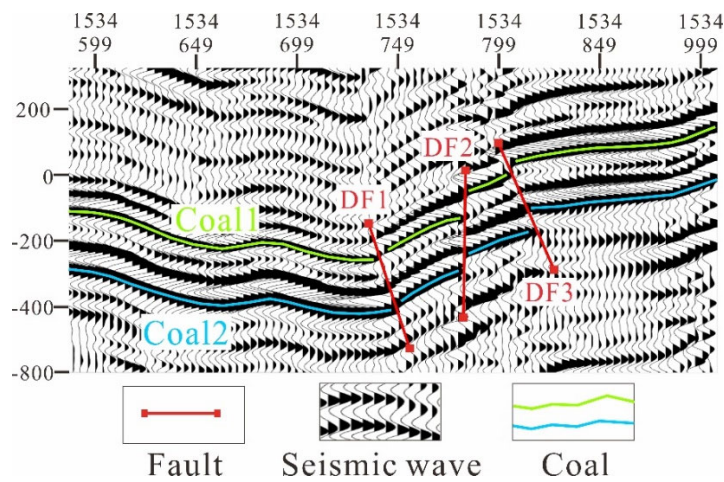


Figure 1. Fault and main coal seam construction based on seismic data.

### 3. Build A Structural Model

#### 3.1. Stratigraphic Model

Seismic data volumes generally have relatively low resolution[7], and certain target reservoirs, such as coal seams, may have thicknesses of less than 1 meter. Therefore, relying solely on seismic data cannot accurately reflect information such as the burial depth and thickness of strata. To address this issue, the incorporation of well data and other geological information as constraints is necessary.

Based on seismic reflection data and known geological

information (such as well data and lithological information), strata with significant differences in physical property attributes between the top and bottom layers and extensive distribution areas are selected as reference layers[8]. The spatial distribution characteristics of these layers are then constructed. Using well log data as constraint information, the reference layer is progressively expanded outward to model the surrounding strata, with the reference layer serving as a boundary condition for the lateral extent. By interpreting seismic reflection features and well data, the burial depth, thickness, and dip of each stratum can be accurately delineated (Fig. 2).

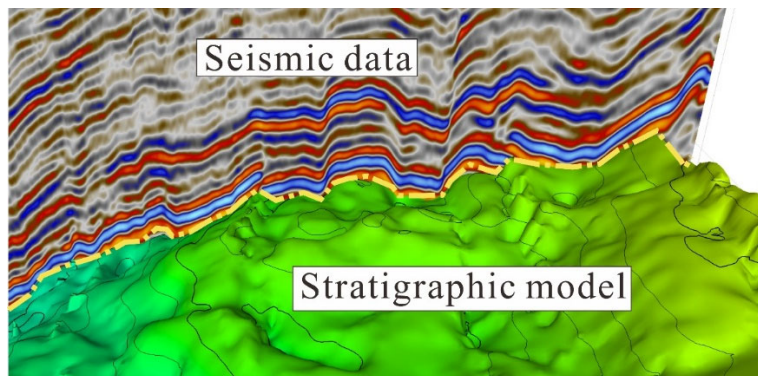


Figure 2. Formation construction constrained by seismic data

The construction of stratigraphic models that integrate seismic data and well data is one of the core tasks in geological exploration. It is primarily used to more accurately describe the characteristics, distribution, and variation of subsurface strata, providing a more comprehensive understanding of the subsurface geological structures and resource distribution.

#### 3.2. Fault Model

Fault identification and fault model construction are crucial tasks in seismic exploration. The main process includes data preprocessing, fault extraction, geometric model construction, and fault attribute analysis[9].

Based on the completed seismic data volume, which has undergone filtering and time-depth conversion, fault development is detected by analyzing anomalies in seismic waveforms and the positioning information of target strata.

This allows for the construction of fault surface positions, geometric shapes, and displacements. The accuracy of the fault surface model is further constrained by incorporating well data, core analysis, and other geological information. Fault attribute analysis further explores the physical properties of the faults, such as the width of the shear zone and displacement, in order to reflect the fault's movement characteristics and regional geological context. This ensures high accuracy in the fault model and enhances its application value in fields such as oil and gas exploration and seismic hazard assessment.

#### 3.3. Planar Gridding

In three-dimensional geological modeling, the planar meshing of structural models is a crucial step for achieving a detailed representation of geological bodies and subsequent analyses. The primary objective is to discretize complex

geological structures into a computationally suitable discrete model through an efficient meshing approach[10]. The main goal of planar meshing is to provide accurate spatial resolution for subsequent geological inversion, fluid flow simulation, and resource assessment, while ensuring the model reflects the geological body's detailed features and spatial heterogeneity. By discretizing the geometric shape of the geological body, meshing not only enables the spatial localization of subsurface structures but also enhances the computational efficiency and accuracy of the model.

The principle of planar meshing is based on the spatial discretization of the geological body. Initially, boundary conditions for grid division are defined within the study area, and an appropriate preliminary grid density is selected based on the scale and complexity of the geological body. Subsequently, grid refinement is applied, particularly in areas with complex geological structures such as faults and folds, where the grid resolution is increased to ensure detailed geological expression. During the meshing process, it is essential to consider the variations of structural features (such as faults, folds, and bedding dips) to ensure that the mesh refinement accurately captures the local changes within the geological body.

### 3.4. Small Layer Division

The construction of a high-precision stratigraphic model primarily relies on ensuring accurate stratigraphic division. In three-dimensional geological modeling, the subdivision of stratigraphic units during structural modeling aims to refine the description of subsurface geological bodies, providing high-resolution stratigraphic information for subsequent geological analysis, resource assessment, and fluid flow simulation[11]. Stratigraphic unit subdivision allows for precise expression of sequence characteristics and spatial variability in geological structures, ensuring that the model aligns spatially with the actual geological conditions. By subdividing the stratigraphy into smaller units, it is possible to more comprehensively reflect lithological variations, faulting, folding, and other local geological features, thus enhancing the resolution and accuracy of the geological body. This approach is particularly beneficial in complex structural environments, as it provides refined input data for dynamic simulations, supporting more accurate predictions and assessments.

The principle behind stratigraphic unit subdivision is based on the analysis of the continuity and trends of the strata, integrating factors such as lithology, sedimentary environment, and geological history. Initially, a comprehensive analysis of existing borehole data, exposed rock layers, and other geological information is conducted to identify stratigraphic interfaces with significant geological features. Stratigraphic subdivision is then carried out at these interfaces. The process typically considers variations in sedimentary environments, physical property differences, and tectonic deformations to ensure accurate representation of the geological body. Reservoirs are usually subdivided with higher precision (resolution of 0.2–0.5 m), while typical sandstone and shale layers are subdivided with a vertical resolution of 1 m. This process enables the reflection of local geological feature changes within a global perspective, providing a reliable foundation for subsequent geological research.

## 4. Summary

Through detailed analysis and modeling of seismic data volumes, a high-precision three-dimensional geological structural model can be constructed, providing a solid foundation for the subsequent development of facies and property models. This serves as a critical support for oil and gas exploration, mineral resource assessment, and groundwater resource investigation. In this process, key steps for achieving high-precision 3D structural modeling include data preprocessing, velocity model construction, reflection interface identification, fault modeling, and inversion techniques.

## CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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