[PS] An Integrated Modeling Approach for Fault-Related Fractures in Tight Sandstone Reservoirs Based on Structural Control and Geomechanical Method*

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Abstract

The distribution of fault arrays and fault-related natural fractures greatly improve the heterogeneity of reservoir matrix, and strongly influence the fluid flow. In consideration of the strongly irregular shape of natural fractures and the uncertainty of spatial distribution laws, guided by the actual geological pattern of a study area, a matrix model and fracture model are established based on well log, seismic, core, and rock mechanics data with the modeling method of finite element numerical simulation, ant tracking, discrete fracture network, and trend model. The fault scale model is established by seismic structural interpretation utilizing deterministic modeling method; the sand body scale model is established by core and well log interpretation and seismic horizon interpretation utilizing deterministic modeling and stochastic modeling method. For the model of natural fracture scale, discrete fracture network modeling method is used to model the natural fracture in different scales, which is divided into large and small-mid scales. Taking the fracture modeling of the third member of the Paleogene Shahejie Formation tight sandstone in eastern China as a case study. On the basis of matrix model, by analyzing the relationship between natural fractures and fault from well log and core data, establishing the conceptual model between fracture density and fault damage zone, which show a decay trend. With the guidance of conceptual model, the large scale natural fracture model is established by ant tracking utilizing deterministic modeling; for small-mid scale natural fracture, firstly, a single well brittleness evaluation is established based on uniaxial compression, brazil split and triaxial compression experiment data; then the fracture density is identified and calculated through well log data; with the constraint of brittleness and sedimentary facies, a calibrated fracture density model of a single well is established. With the lithofaices distribution as the main driver, a 3D young's modulus and brittleness index model are established based on rock mechanic experiments data. Additionally, the relationship between tectonic stress field and fracture parameters is quantitatively established by finite elements numerical simulation based on rock mechanic experiments. Taking the calibrated fracture density of a single well as hard data, with constraint of conceptual model, the 3D brittleness index model and tectonic stress field is fitted utilizing trend modeling, which forms a 3D fracture density volume as soft data. Then the discrete fracture network is established. By coupling the fracture model with the matrix model, fitting with dynamic data shows that the model has higher fitting consistency.

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Introduction

The distribution of fault arrays and fault-related natural fractures greatly improve the heterogeneity of reservoir matrix, and strongly influence the fluid flow. Modeling the spatial distribution of natural fractures existing in subsurface sedimentary strata (1-5km depth), is of great importance. In consideration of the uncertainty of natural fractures' spatial distribution laws, guided by the geological concept model of study area, a matrix model and fracture model are established with the method of finite element numerical simulation, geological statistics and discrete fracture network.

Geological setting

F162 Block is located in the north of Shandong Province, East China (Fig.1). The block is in Boxing Sag, Bohai Bay Basin. Boxing Sag is one of secondary tectonic unit in Dongying Depression. A series of nearly EW or NEE-SWW trending normal faults are developed in the study area, most of faults have a high dip angle, and the tectonic form is relatively simple, showing with a monoclinal structure which is high in the south and low in the north.

The Es Formation is divided into four members, Es1-Es4 from youngest to oldest. The target layer of study area is Es3z (Fig.2). The Es3z with a thickness of 200-500m, developed stably and was mainly deposited in density current. The lithology compositions mainly include siltstone, fine sandstone, medium sandstone, sand conglomerate and mudstone with high brittleness, high Young's modulus and a low Poisson's ratio.

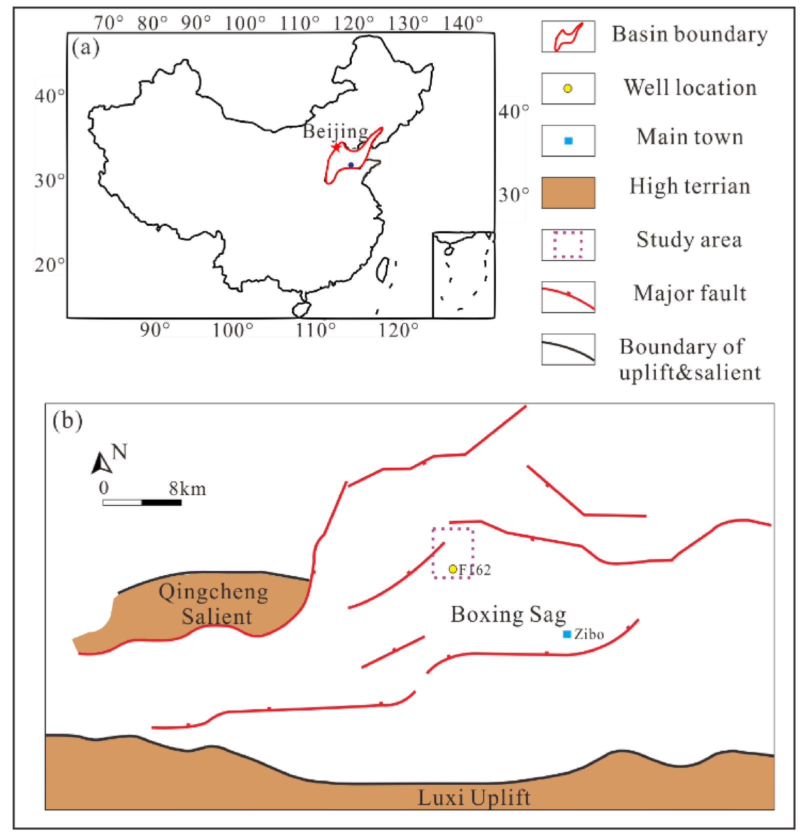

Fig.1 Location of study area.

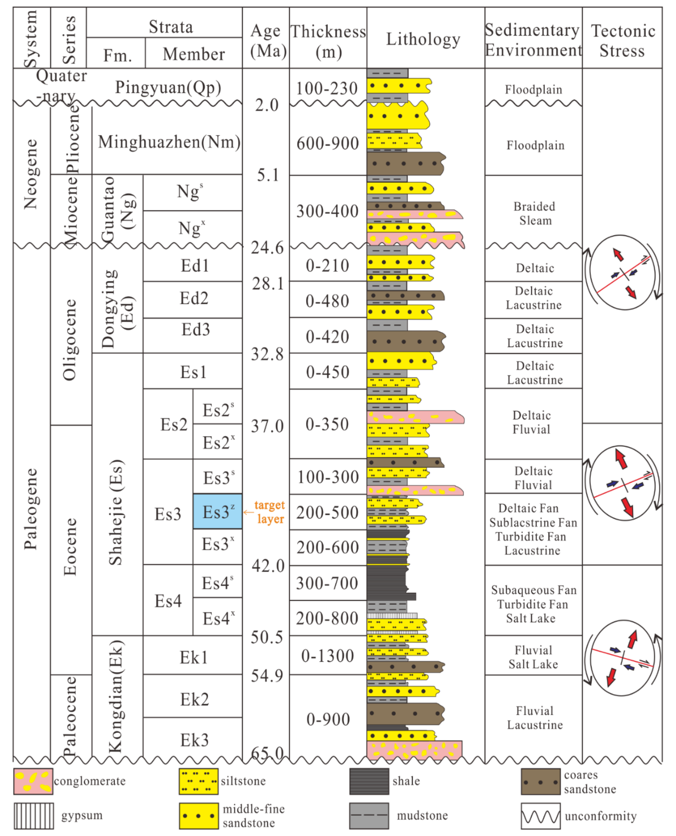

Fig.2 Generalized stratigraphic sequences, lithology and tectonic evolution of the Cenozoic-Quaternary strata.

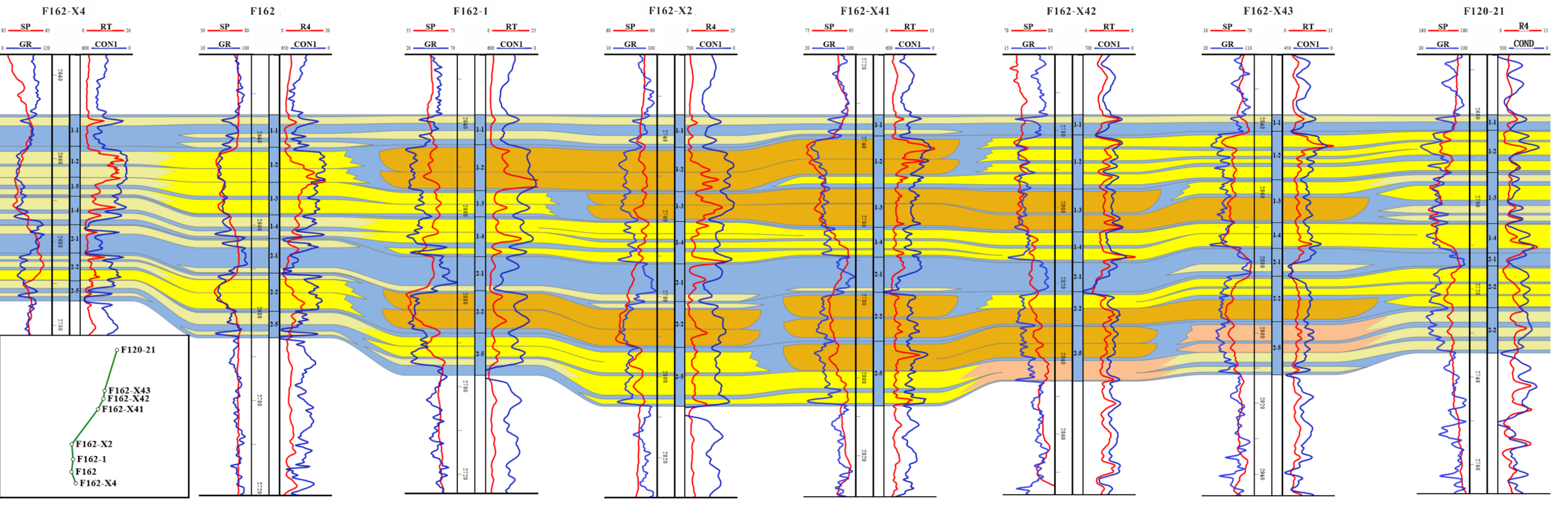

Fig.3 Profile of the sequence stratigraphic framework of the study area.

Methods and workflow

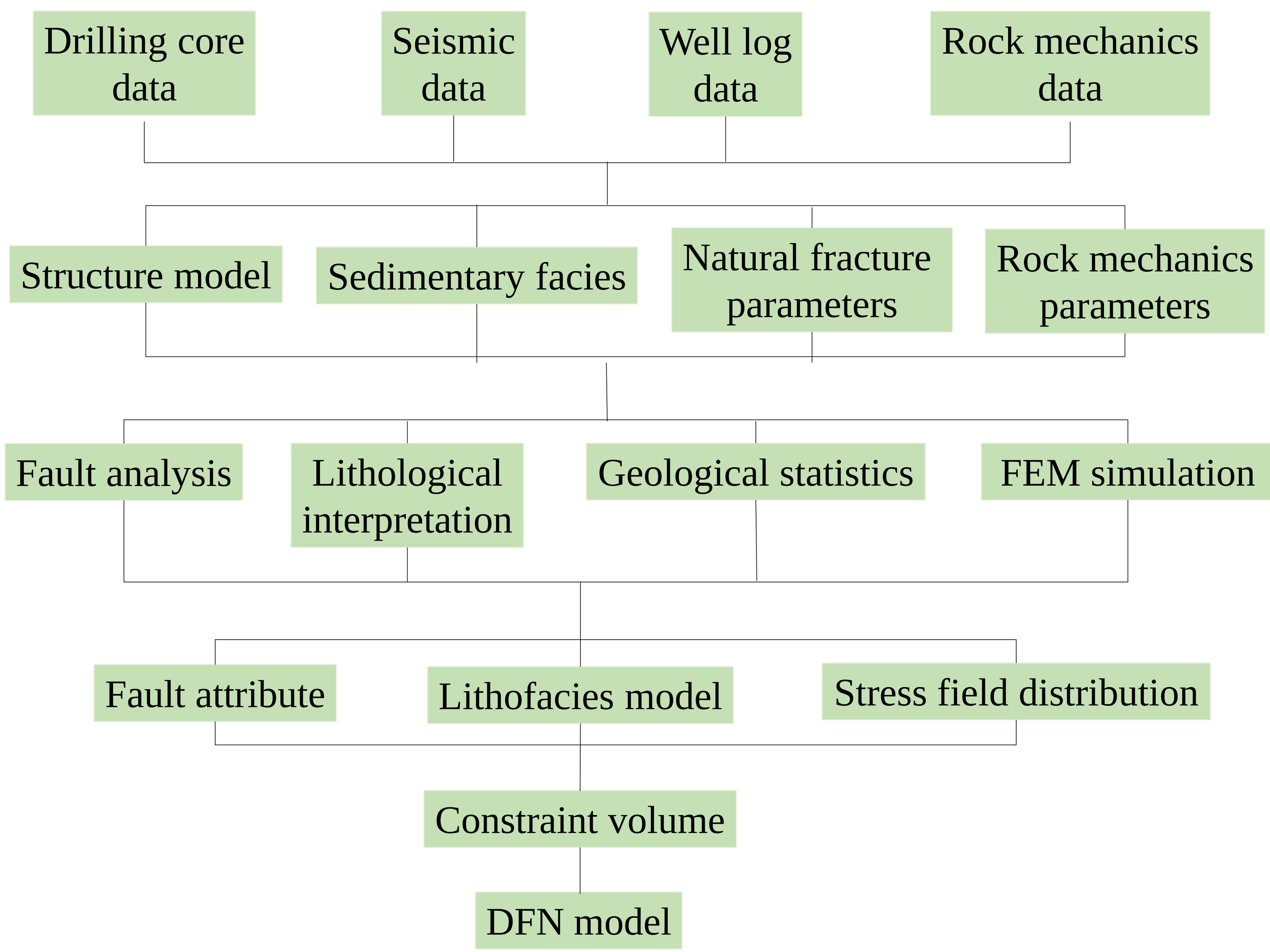

Fig.4 Methods and the workflow of discrete fracture network model.

Structural Model

Based on core and well log curve, combined with seismic data, stratigraphic correlation in the whole area is realized. On the basis of isochronal stratigraphic framework, the distribution of sedimentary facies belts in the whole area is divided (Fig.3).

Based on seismic interpretation data, fault model, surface model and structural model is successively established(Fig.5).

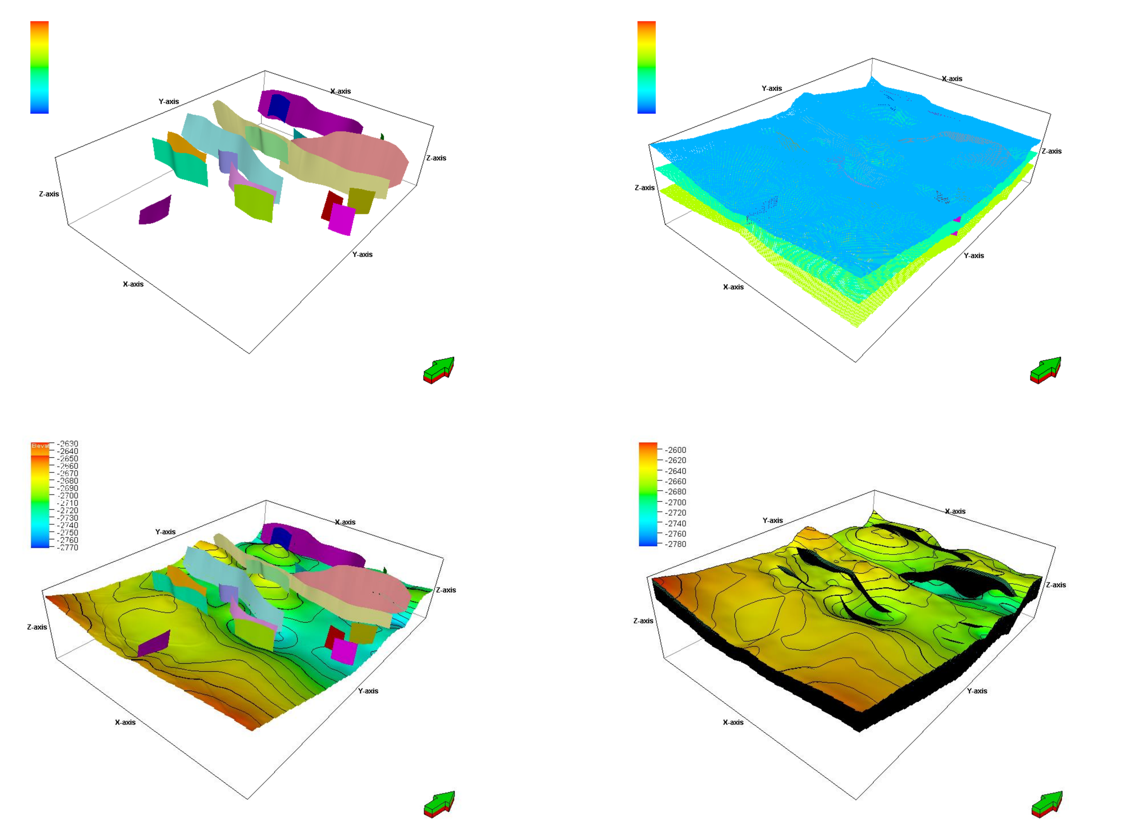

Fig.5 Three-Dimensional structure model and stratigraphic spatial distribution in the study area.

Sedimentary facies and lithofacies model

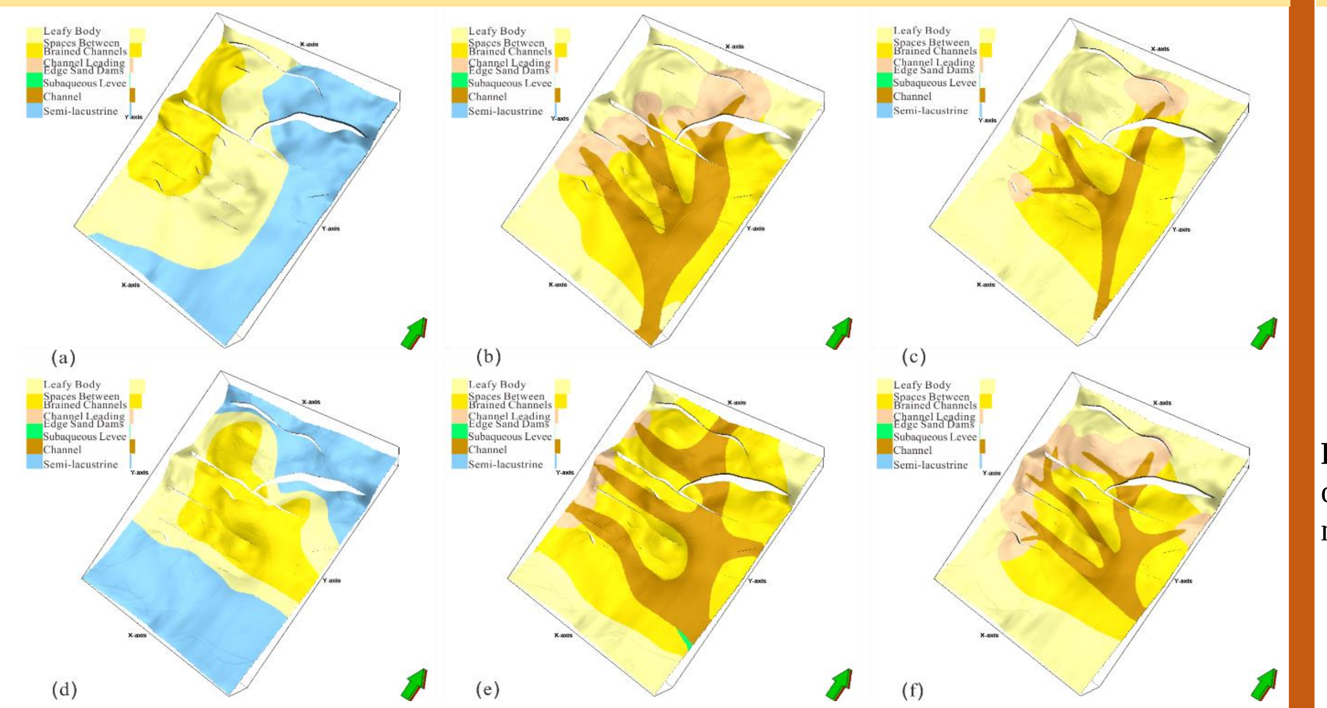

Fig.6 Three-dimensional sedimentary facies model of study area.

Sedimentary facies model is established by using deterministic modeling method. Lithofacies model is established by sequential indicator simulation.

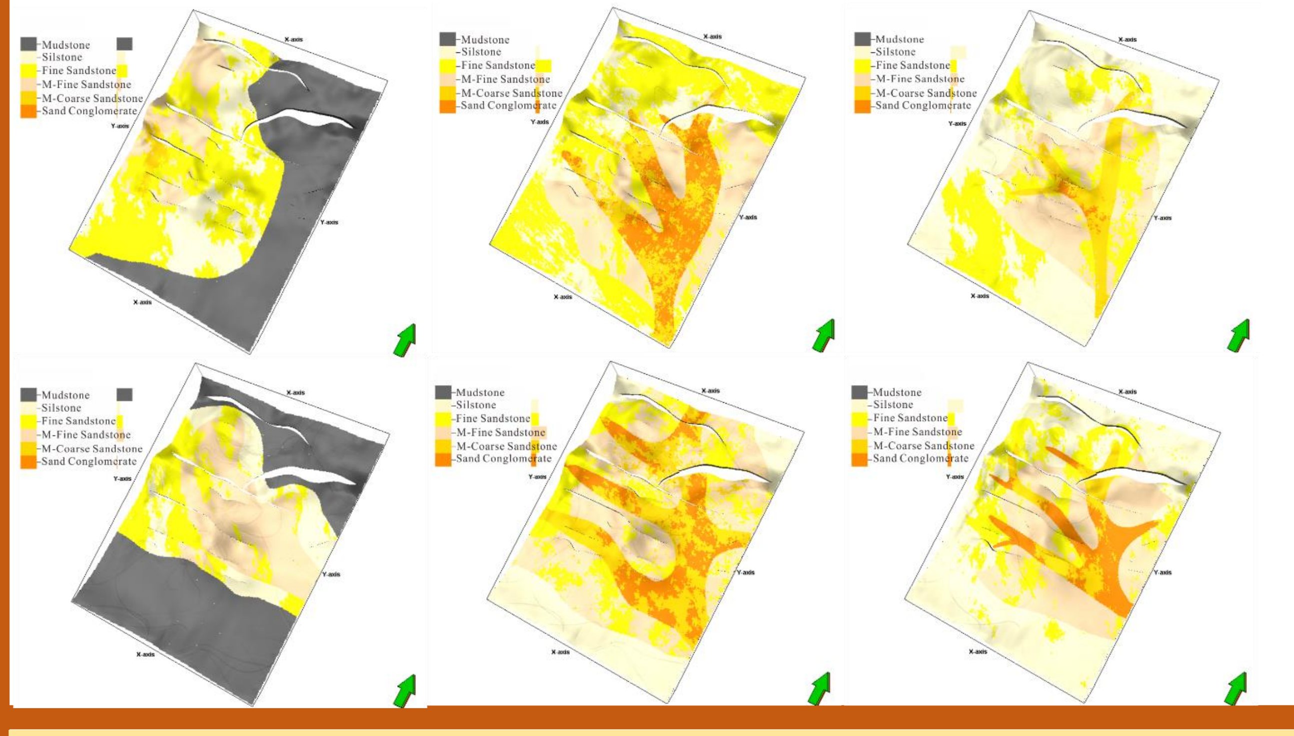

Fig.7 Three-dimensional lithofacies model of study area.

Rock mechanics model of single well

Based on conventional and special logging data, rock mechanics parameters are calculated, the interpretation model of single well rock mechanics are established.

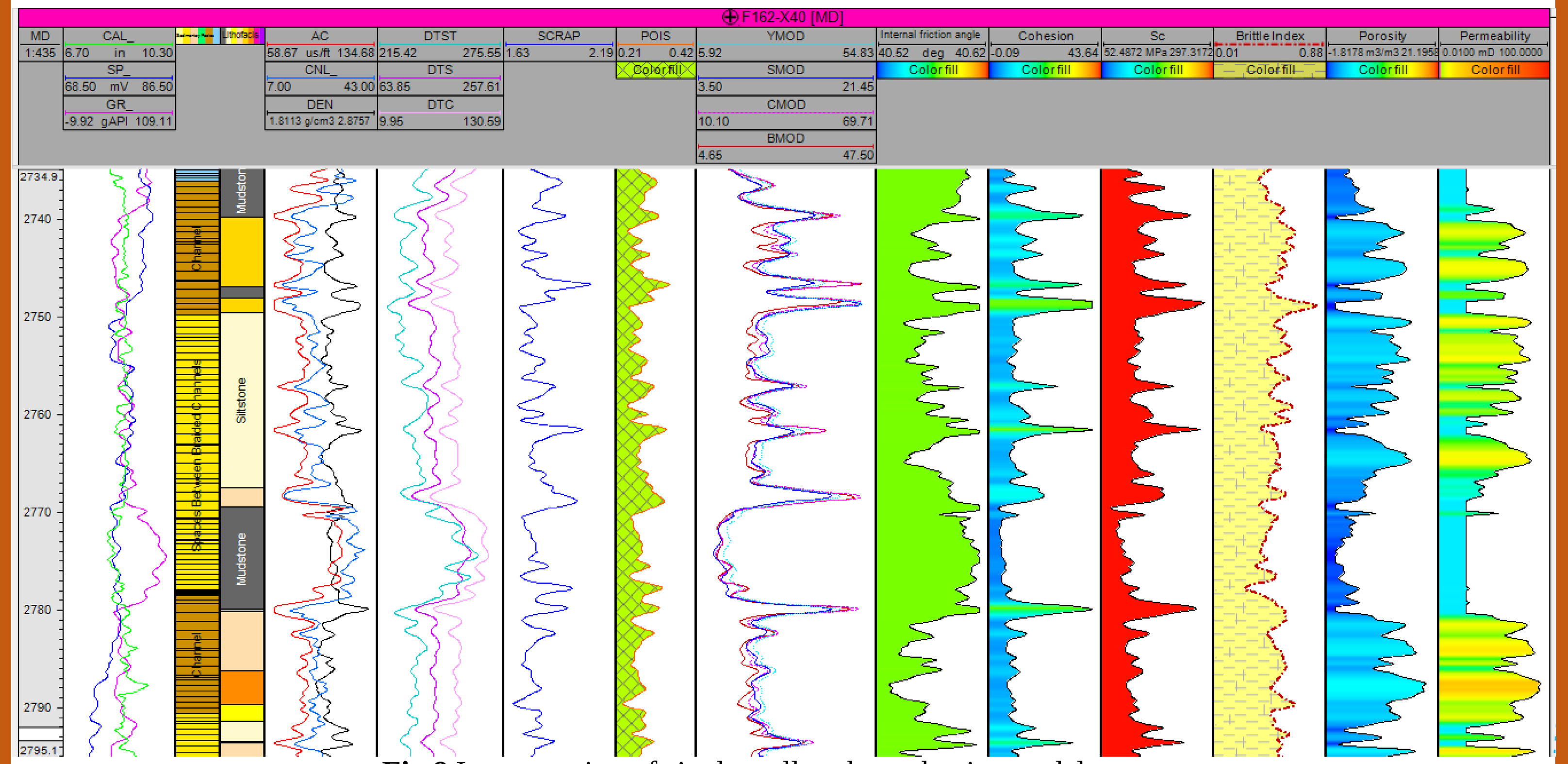

Fig.8 Interpretation of single well rock mechanics model.

Stress field simulation

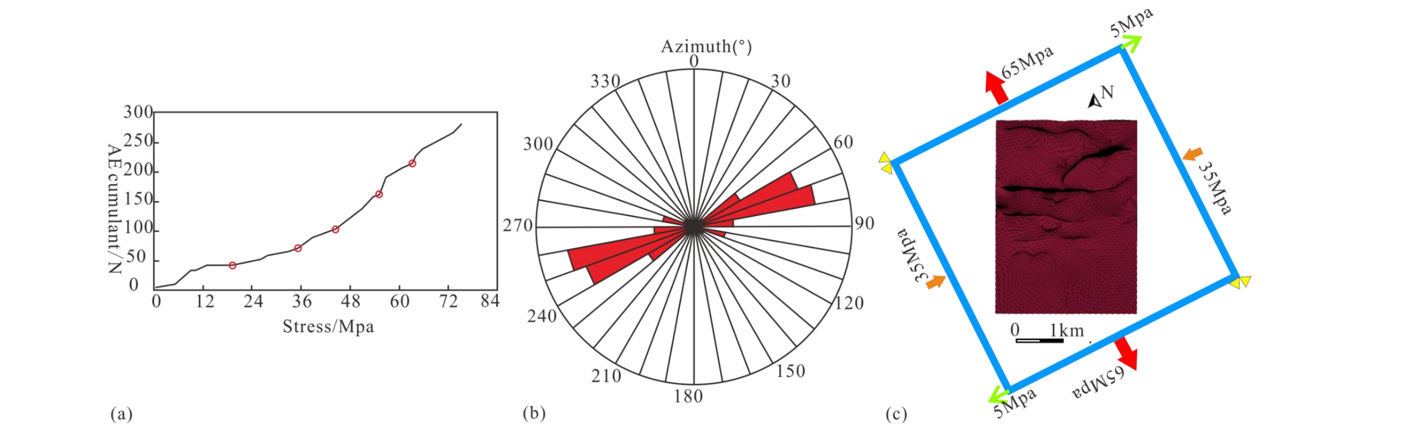

Fig.9 Graph of boundary conditions for finite element numerical simulation. (a) Curve of stress measurements based on the acoustic emissions foe rock samples from the study area. (b) Strikes of hydraulic fracture based on microseismic monitoring data. (c) A sketch map of boundary conditions for the stress simulation.

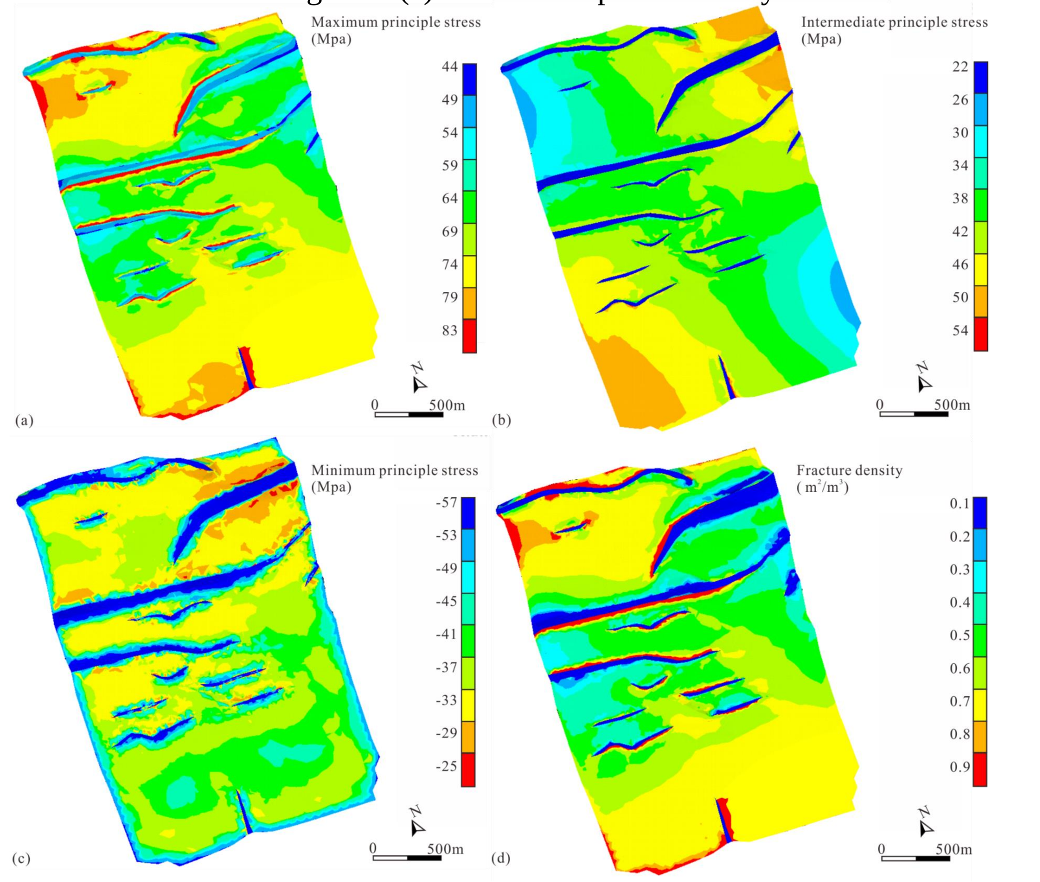

Fig.10 Distribution of stress field and fracture density. (a) Distribution of maximum principle stress. (b) Distribution of intermediate principle stress. (c) Distribution of minimum principle stress. (d) Distribution of fracture density. Note: Compressive stresses were considered as positive and tensile stresses were negative.

Discrete fracture network model

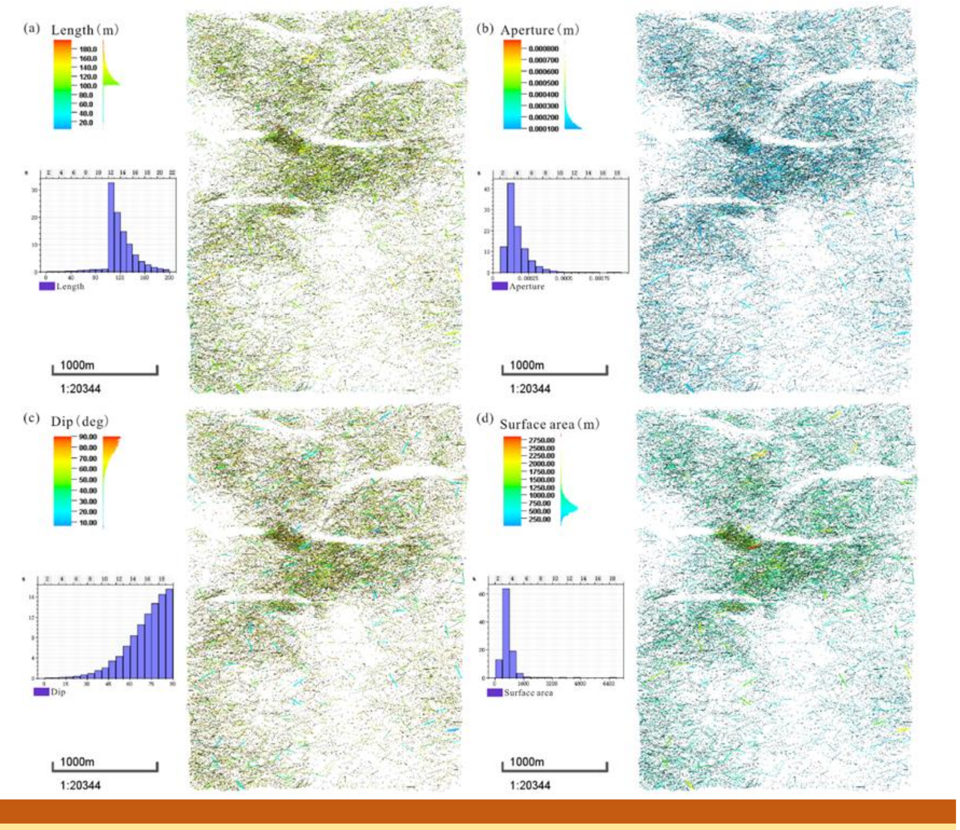

Fig.11 3D discrete fracture network model of the study area. (a) Fracture length model of discrete fracture network, and the frequency distribution histogram of fracture length (b) Fracture aperture model of discrete fracture network, and the frequency distribution histogram of fracture aperture. (c) Fracture dip model of discrete fracture network, and the frequency distribution histogram of fracture dip. (d) Fracture surface area model of discrete fracture network, and the frequency distribution histogram of fracture surface area.

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