Integration of Geomechanics, Stress Field and Reservoir Production to Predict Dynamic Fractures Behavior of a Tight Sandstone Reservoir*

Hui Gang[1]

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Abstract

The unconventional reservoirs, such as tight sandstone reservoirs in the Ordos Basin of China, have received widespread attention over the past two decades for the deepening of petroleum knowledge and incessant technology progress. Along with long-term water flooding in these reservoirs, the dynamic fractures are identified by the production performance, tracer test, microseismic data, etc., and their behaviors are summarized as the opening, extending and reclosing. An integrated study was conducted which integrates geomechanics, stress field, reservoir characteristics and production to describe dynamic fractures and optimize the development of reservoir. Controlled by the geomechanics and paleo-stress field, the natural fractures develop in the reservoir with their state originally closed or filled. Subsequently due to high pressure near the wellbore area of injection wells, the closed or filled natural fractures are reactivated, constantly extend, controlled by the in-situ stress field, and may reclosed under the decreasing pressure of moderate injection.

The complexity of the dynamic fractures is influenced by lithology-based geomechanics, the difficult to determine paleo and current stress field, varied production measures and history, which are necessary to predict dynamic fractures behavior. In this study, an integrated approach is proposed and applied to a tight sandstone reservoir in the Changqing Oil Field as a case study. The geomechanics model is first built up to predict potential natural fractures distribution under the paleo-stress field. These fractures are evaluated to determine the existence and behaviors of dynamic fractures based on the analysis of production performance and current stress field. The behaviors of dynamic fractures are determined by tests and benefit the optimization and adjustment for this tight sandstone reservoir development.

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RIPED, CNPC

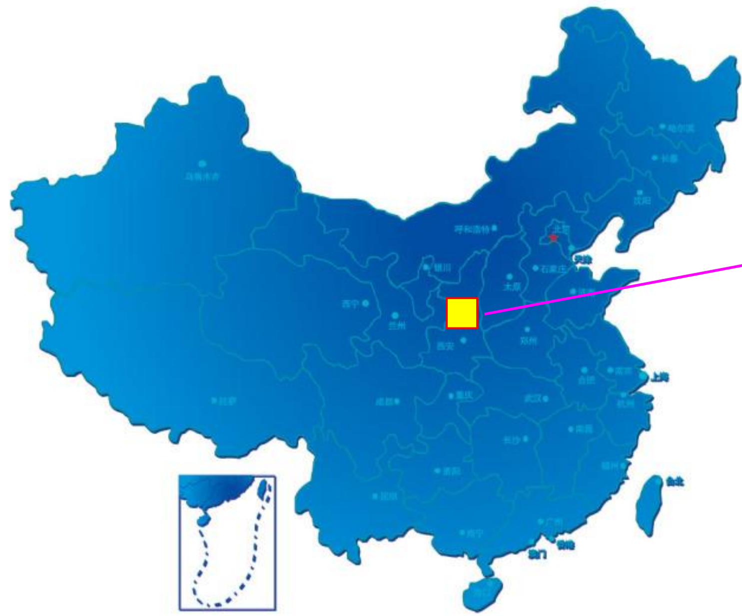
Apr. 4, 2016

Outline

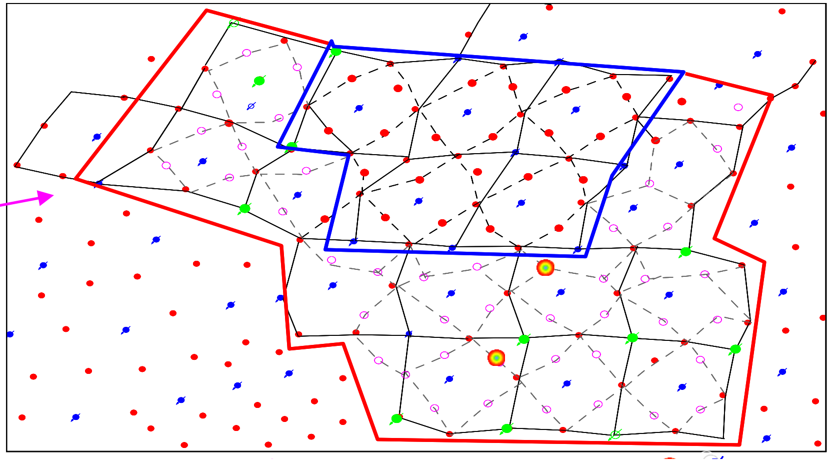
- **Overview**
- **Dynamic Fractures**
  - Forming mechanism
  - Features identification
  - Distribution prediction
- **Conclusions**

Overview

A Domestic Oilfield

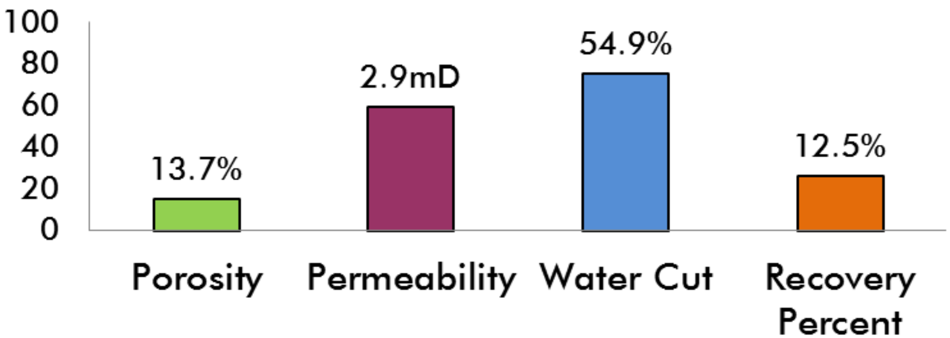


Changqing Oilfield



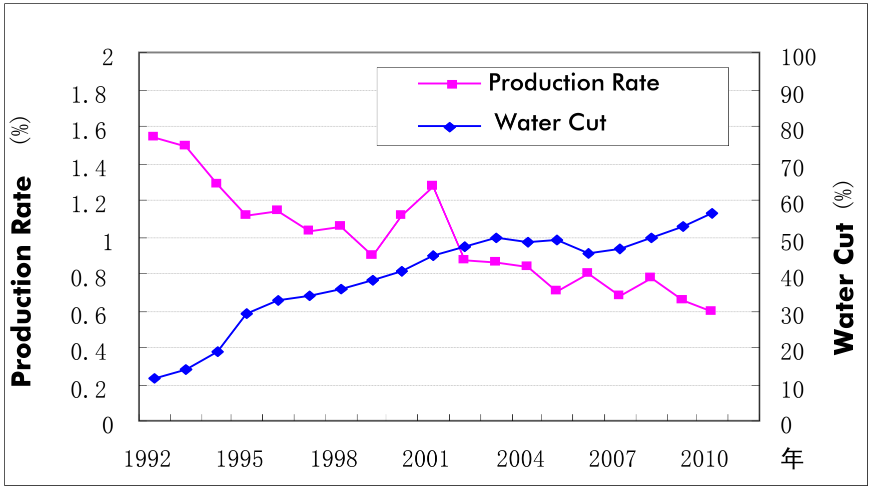
Oilfield Property

- Major layer: Chang 61 members in the Yanchang Formation
- Sedimentary: Delta facies
- Buried depth: 1100~1300m



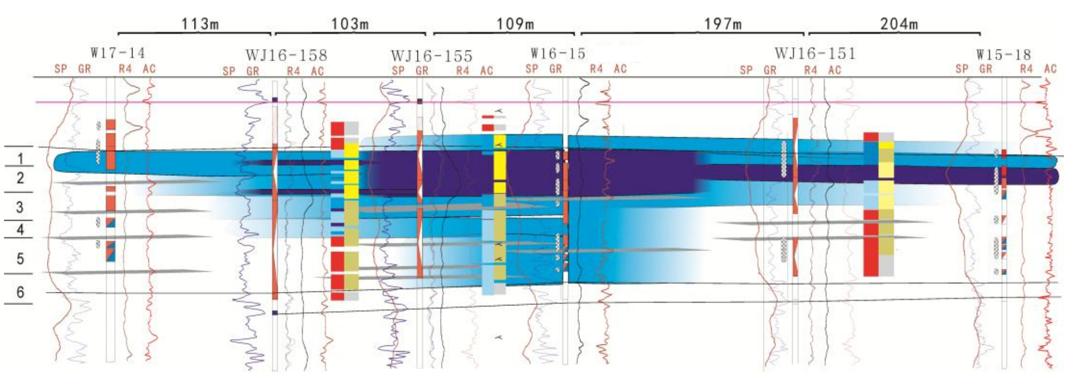
Overview

Production Performance

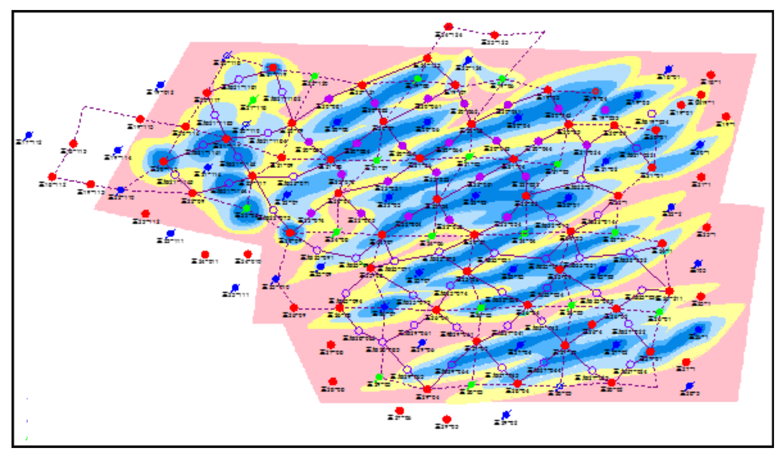


- Increasing water cut and extremely low oil production;
- Serere water-flooding in major layer
- Water flooded goes along with the directions of fractures

Reservoir Profile



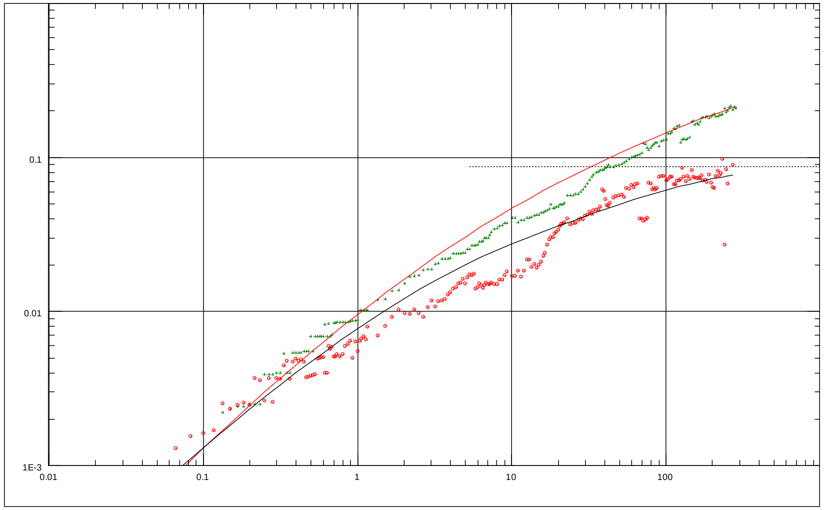
Water flooding Map



Overview

- **No fracturing** of injection well ;
- Indication of **fracture features** in logging, well testing and production;
- **Permeability** Interpretation reaches **10 times** more than core-analysis

W25-05 well testing



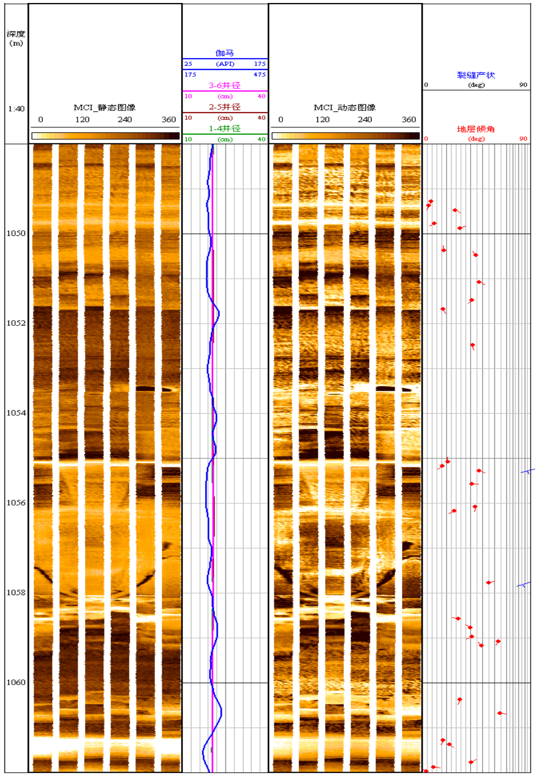
Log-Log plot: dp and dp' [MPa] vs dt [hr]

Formation Pressure: 20.61MPa

Formation Factor: 213.0mD·m

Effective Permeability:21.1 mD

Fracture Half-length: 221 m



FMI Logging（W16-155）

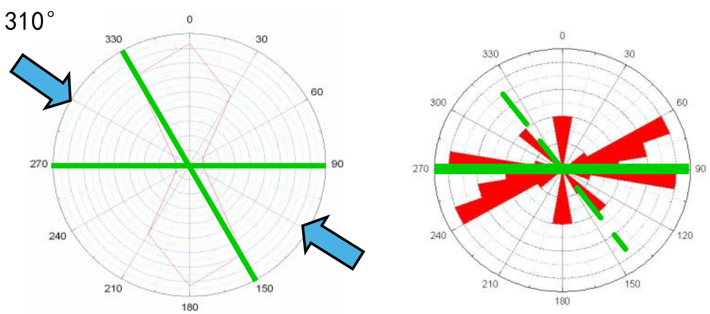
Outline

- ➢ **Overview**
- ➢ **Dynamic Fractures**
  - Forming mechanism
  - Features identification
  - Distribution prediction
- ➢ **Conclusions**

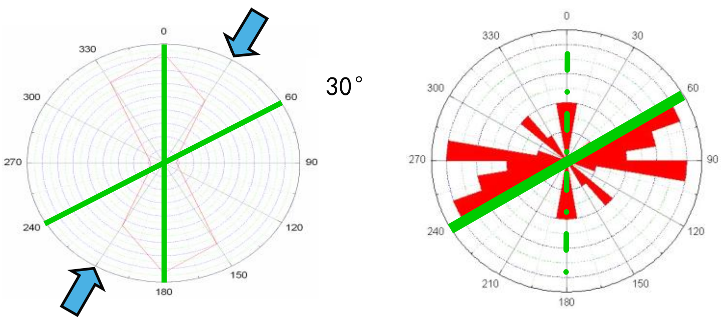
Forming Mechanism

1. Stress Field (Paleo)

Yanshan and Xishan Period Paleo stresses make two types of fractures

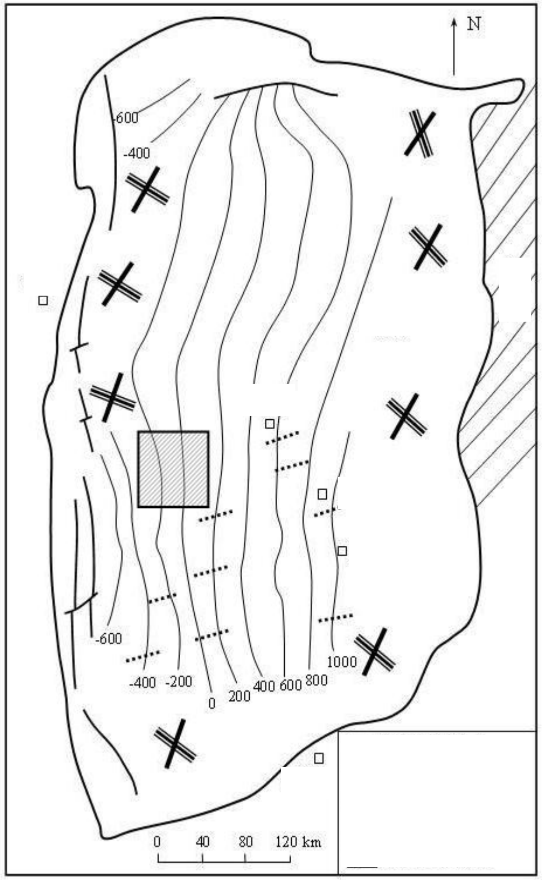


Yanshan Period: NW



Xishan Period: NE

Erdos Tectonic Stress Field Distribution



From Lianbo Zeng

Forming Mechanism

1. Stress Field (Paleo)

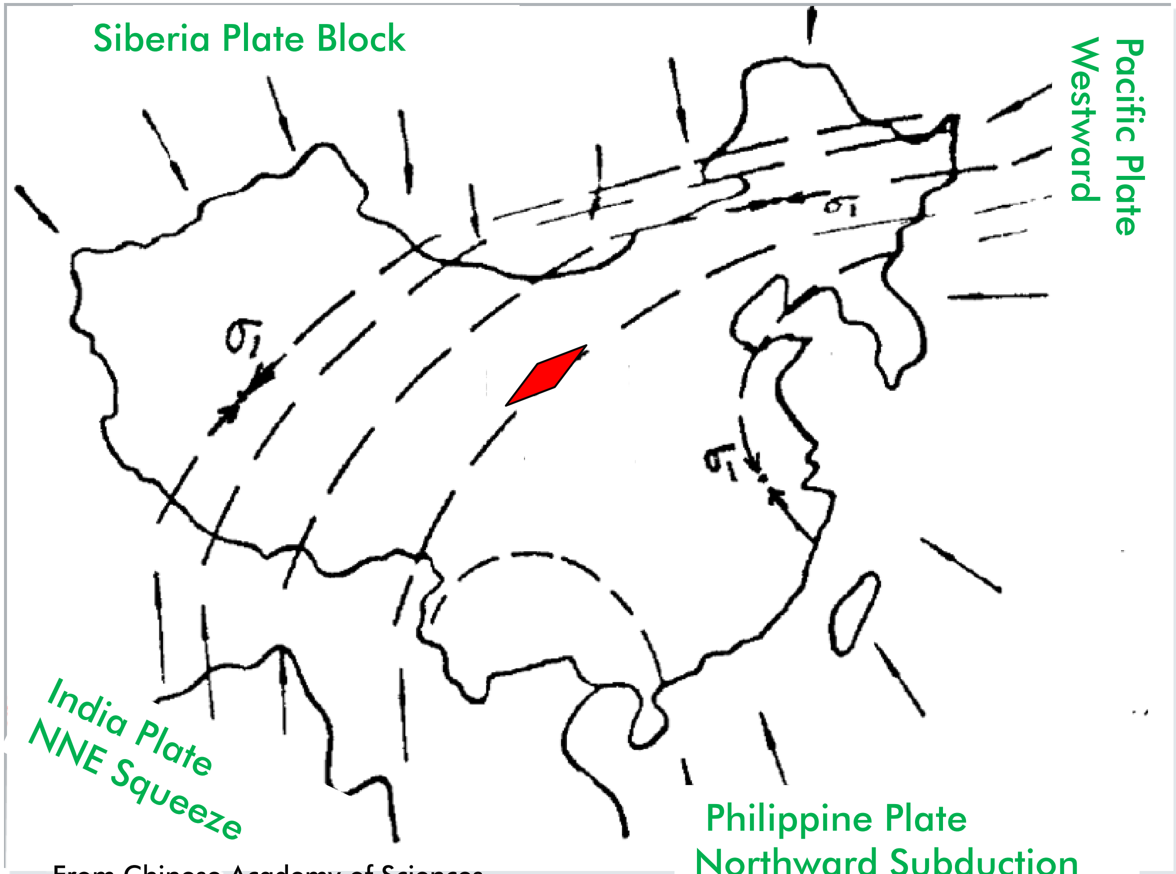
Outcrop Observation (25 miles, July, 2012)

Forming Mechanism

1. Stress Field (Current)

Influenced by new tectonics movement, maximum of current stress NE 70

Current Stress Field & Tectonic Plates

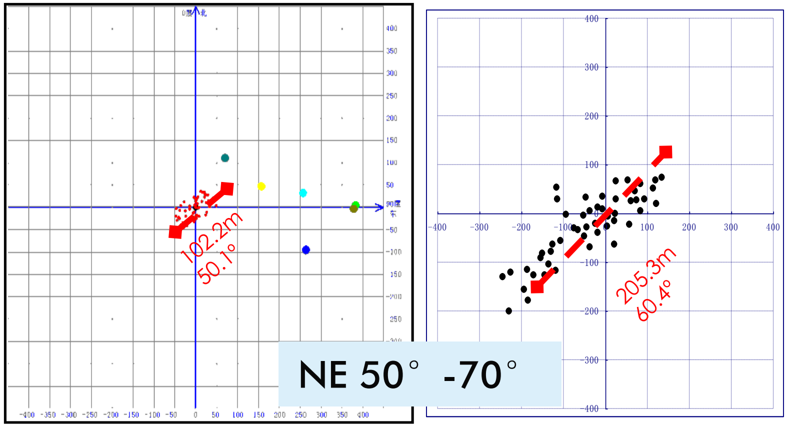


From Chinese Academy of Sciences

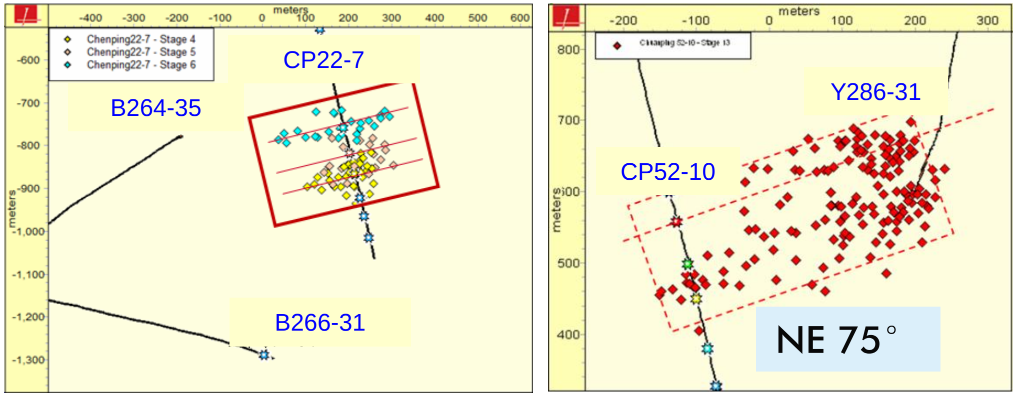
Forming Mechanism

1. Stress Field (Current)

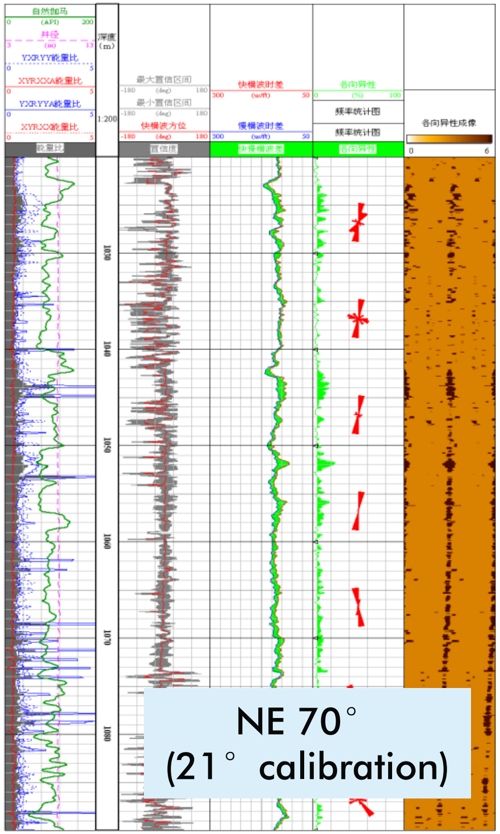
Influenced by new tectonics movement, maximum of current stress NE 70°



Artificial fractures measuring



Micro-seismic monitoring



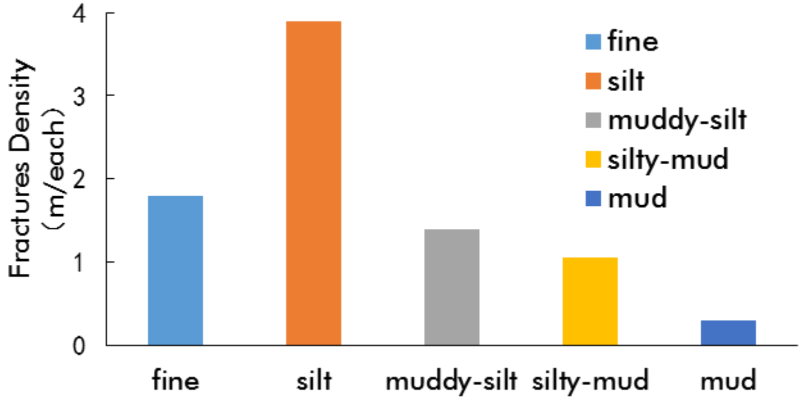
Dipole acoustic logging

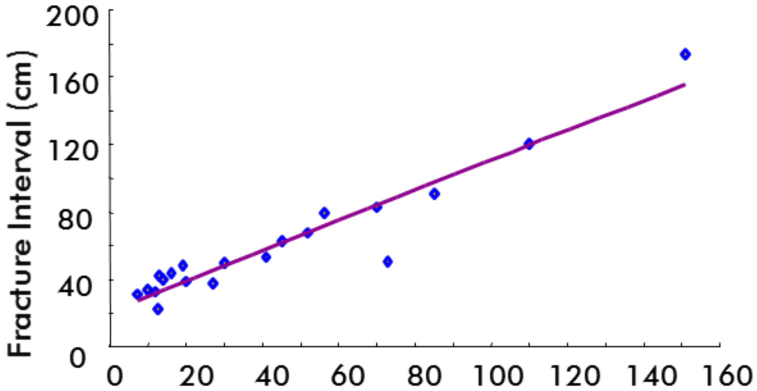
Forming Mechanism

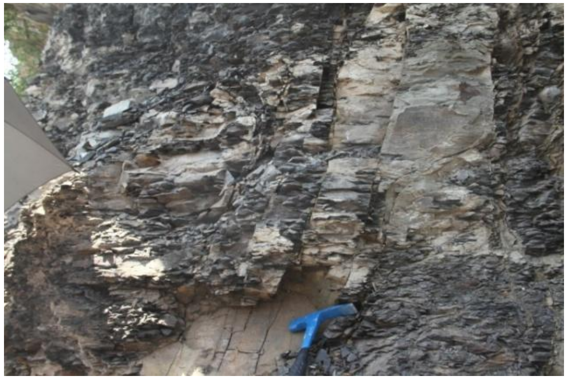
2. Geomechanics

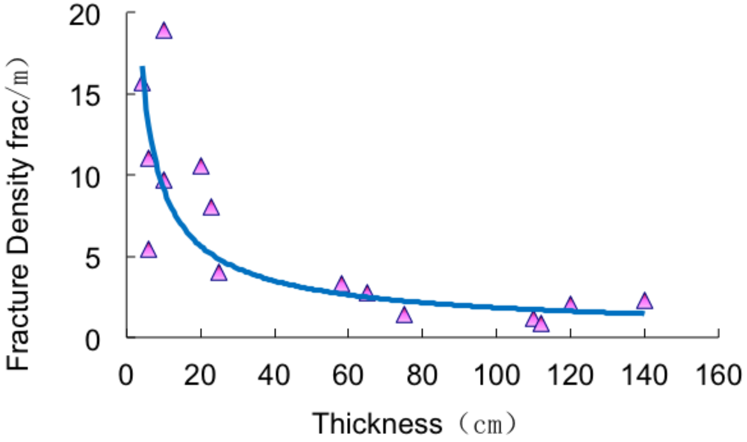
Lithology: fine sandstone/siltstone>muddy/calcareous>mudstone

Thickness: more thick→ increasing frac interval → less frac density









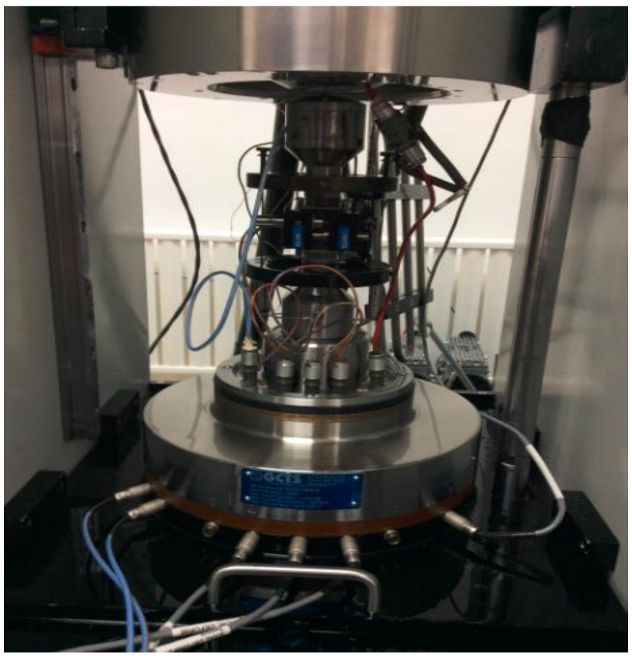
Forming Mechanism

2. Geomechanics (Experiment)

Objectives: geomechanic intensity parameters of different lithology

Content: rock acoustic and intensity via simulating actual underground condition

Condition: formation pressure 30MPa, pore pressure10MPa/13MPa/20MPa



Forming Mechanism

2. Geomechanics (Experiment)

Fracture Extension Pressure $$P_{tip} = \sigma_{H\min} + \sqrt{\frac{\pi UE}{2(1-U^2)r_f}}$$

Lithology： siltstone>fine sandstone>calcareous sandstone

Results of Geomechanics Experiment

Well	Lithology	Depth	FP/PP (Mpa)	σ_1(Mpa)	E(GPa)	μ	E/(1–μ ^{2})
WJ16–159	Calcareous Sandstone	1025.67	10/5	159.4	22.02	0.28	23.894
WJ16–158	Fine Sandstone	1026.4	10/5	107.8	16.15	0.179	16.686
WJ16–155	Siltstone	1035.1	10/5	102.6	14.96	0.176	15.436
WJ16–155	Fine Sandstone	1038.1	10/5	95.6	17.68	0.268	19.052

CP — Confining Pressure

PP — Pore Pressure

σ — Compressive strength

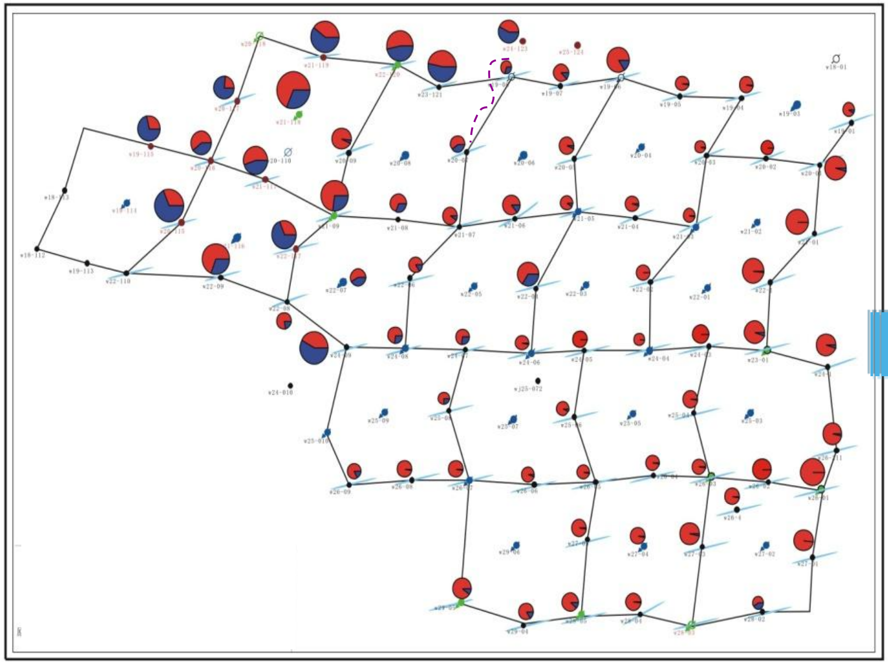
E — Young modulus

μ — Poisson's ratio

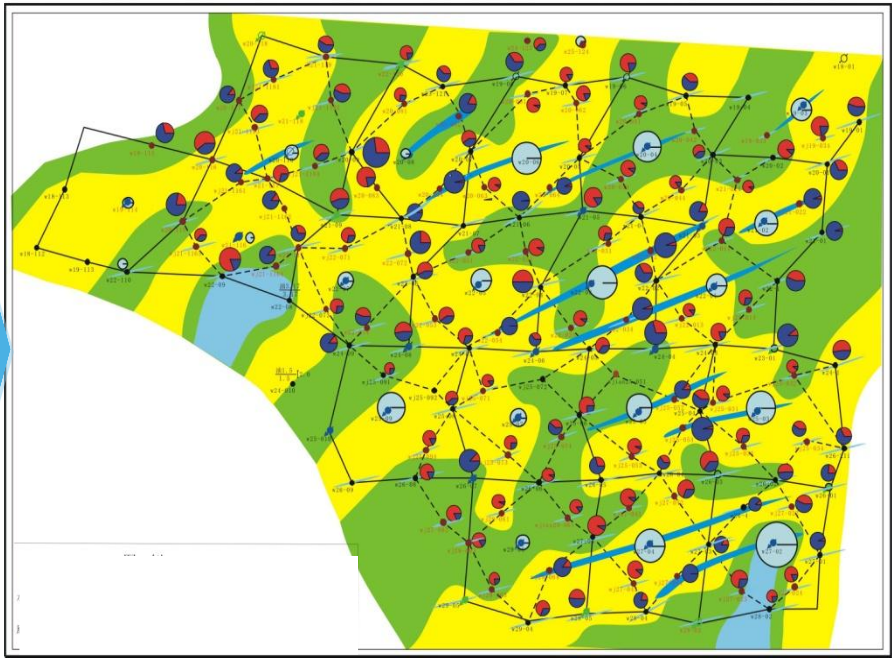
Forming Mechanism

3. Injection Performance

- Local stress changes during injection-production process
- Cumulative water injection pressure exceeds fracture pressure



Initial stage of development



Combination of facies, fractures and current development

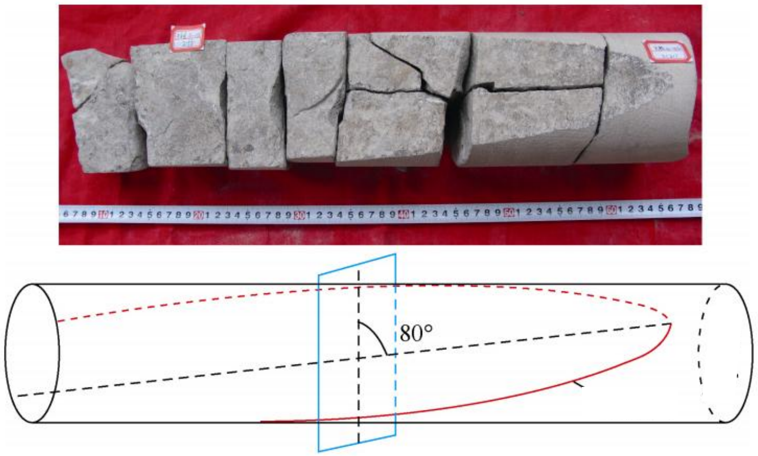
Outline

- **Overview**
- **Dynamic Fractures**
  - Forming mechanism
  - Features identification
  - Distribution prediction
- **Conclusions**

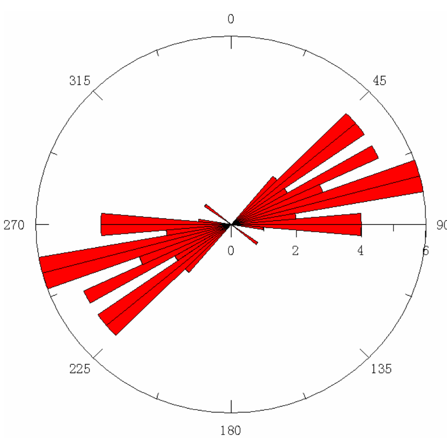
Features identification

1.Geology Features

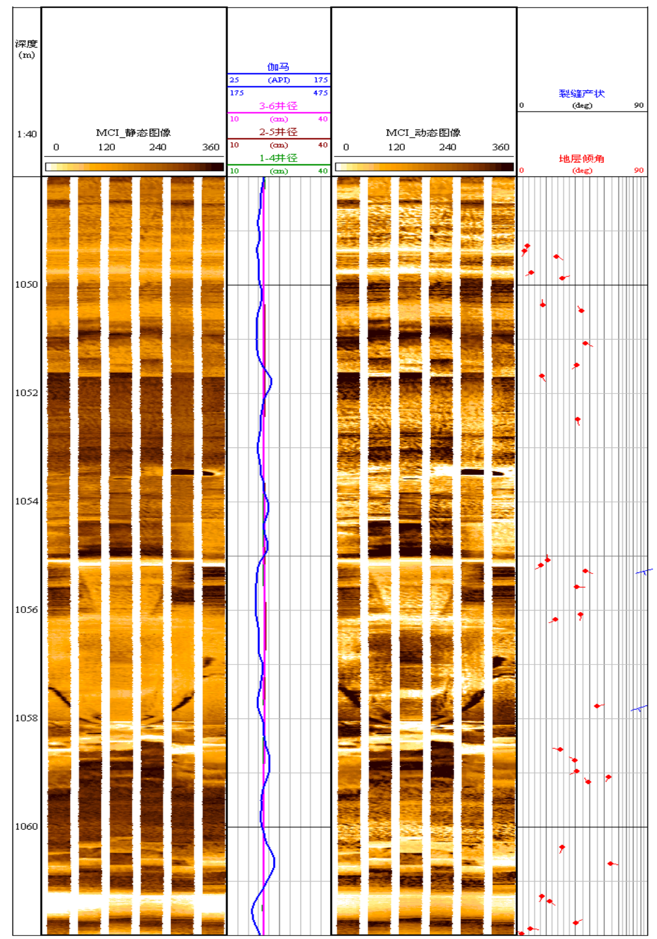
High-angle Fractures, mostly unfilled, NE direction 71～85°



Core Observation （W16-155）



Outcrop Observation

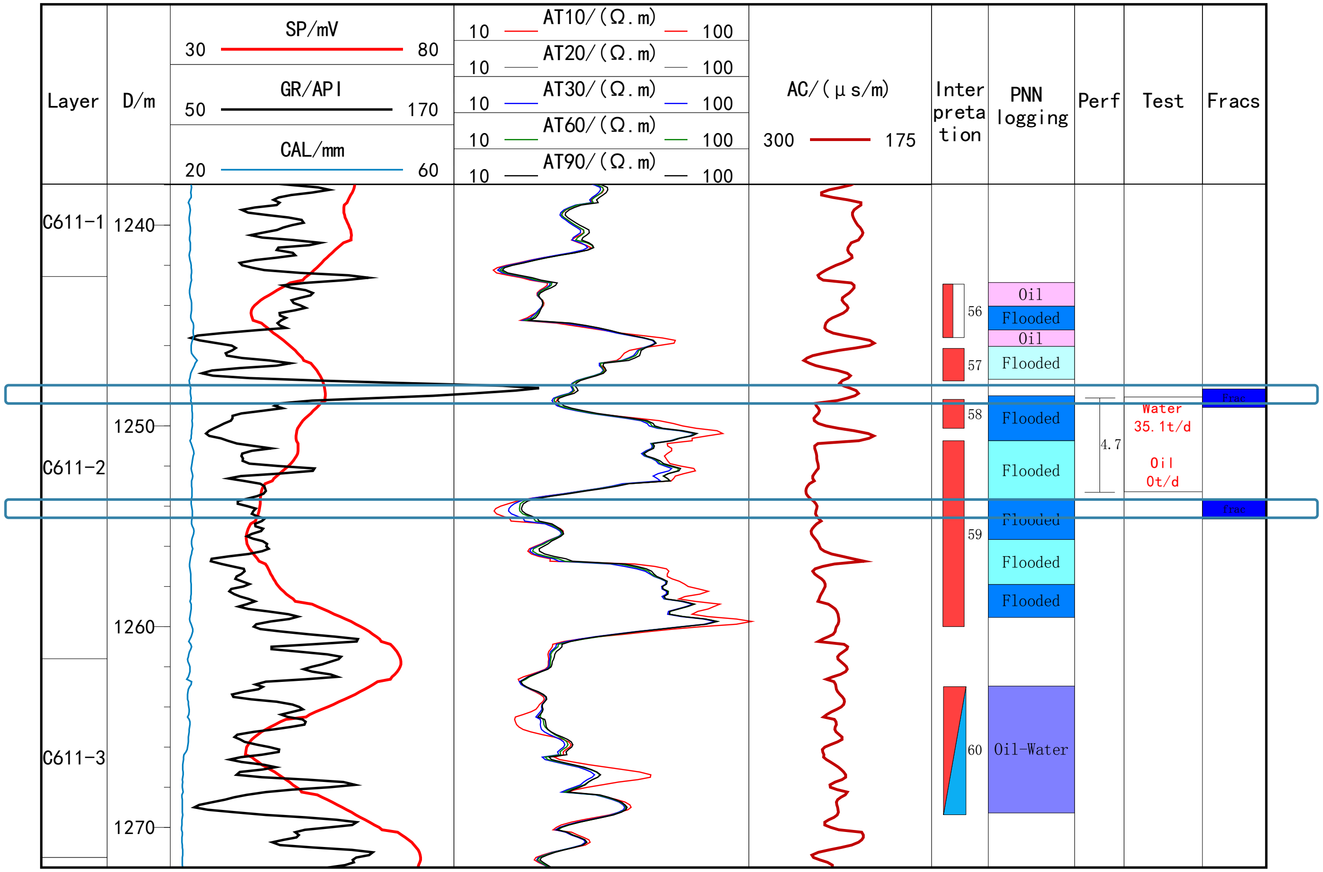


FMI Logging（W16-155）

Features identification

2.Geophysics Features

Logging Response: Low RT, High AC, abnormal GR, PNN flooded indication

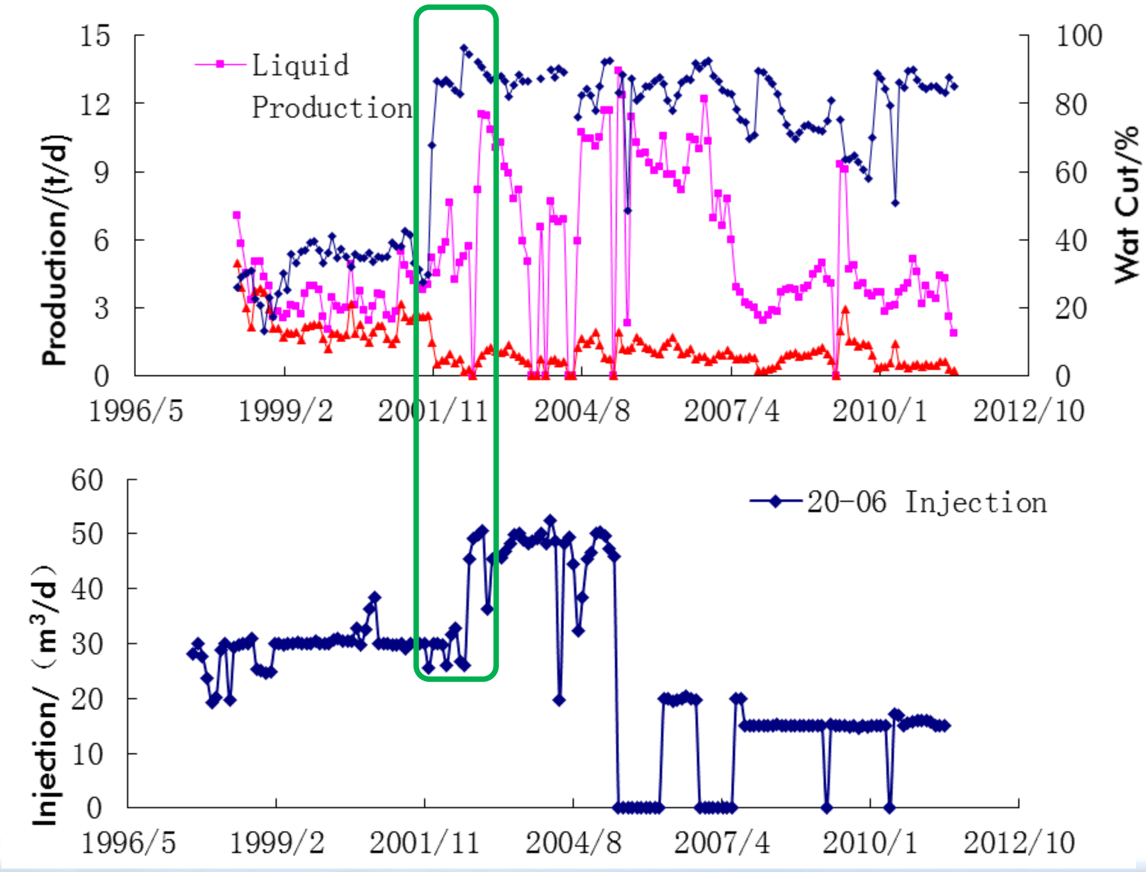


Fracture Logging Response（W20-064）

Features identification

3. Production Performance

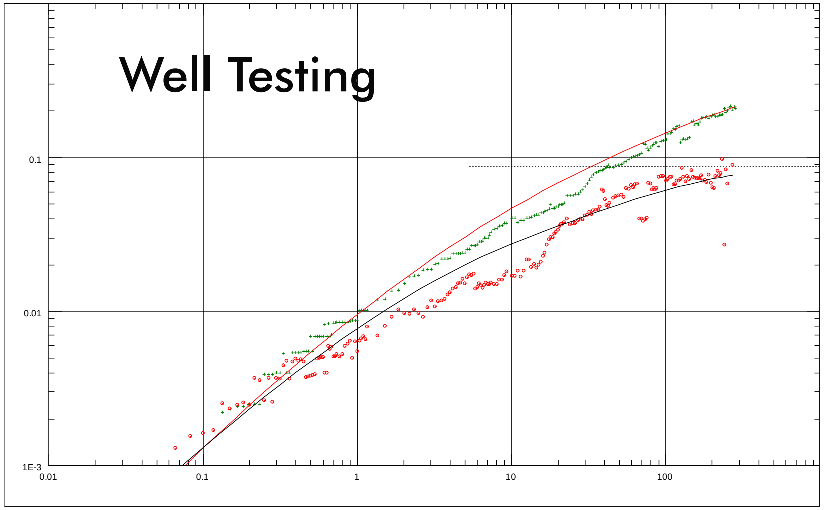
- Correspondence between injection and production process
- Oil Wells: significant rising of water cut and increasing liquid production
- Injection Wells: abrupt aggrandizement of water absorbing capacity



Features identification

4. Testing and monitoring

- Well Testing suggests fracture flow features
- Tracer Testing displays flow orientation NE60~70°



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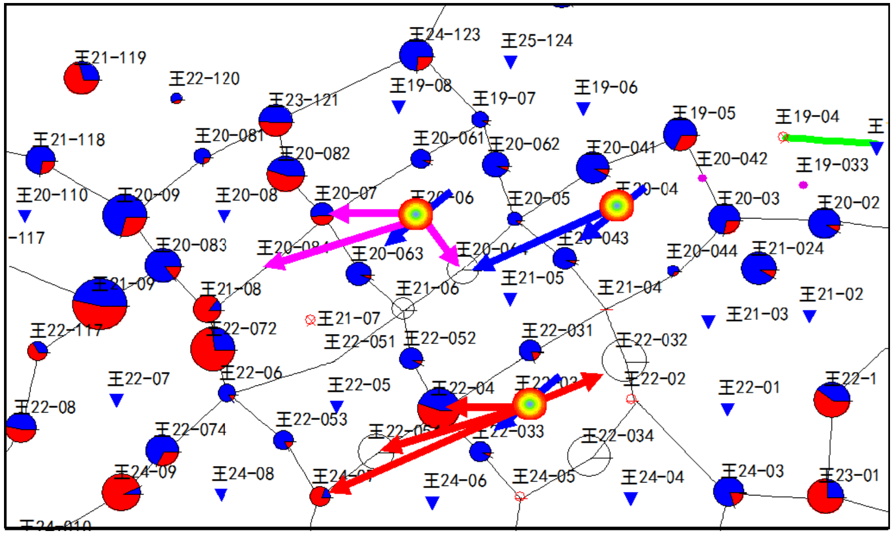
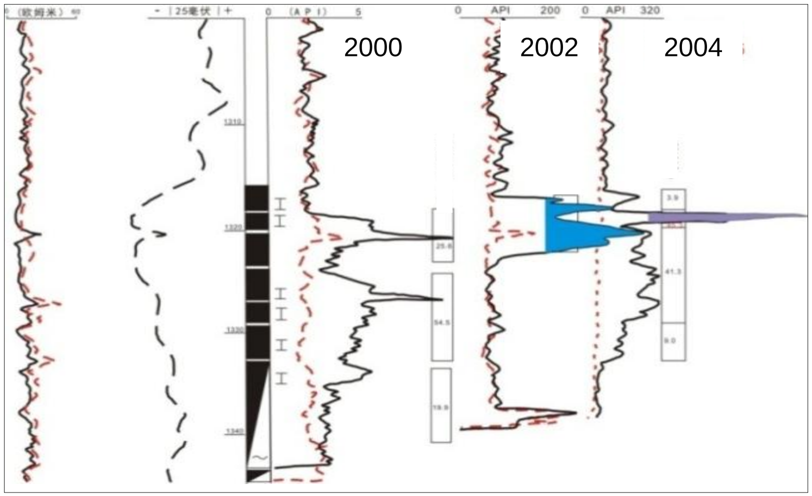


Tracer Testing

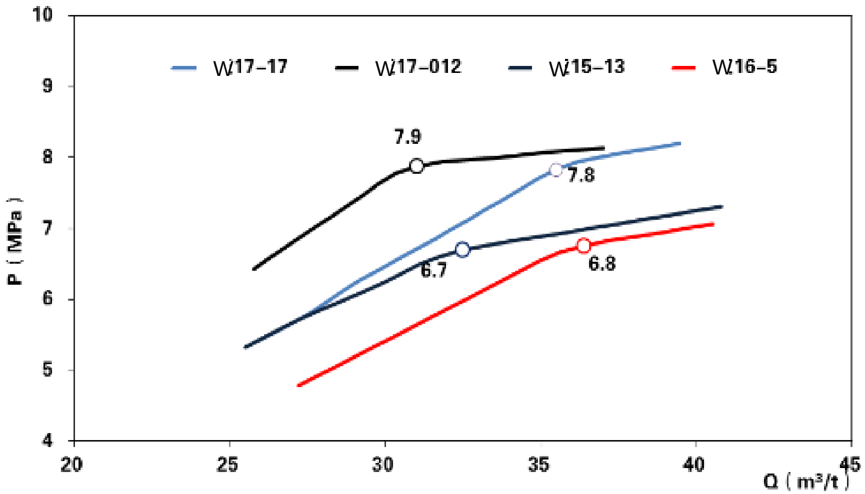
Features identification

4. Testing and monitoring

- Water absorbing profile: spike-type and growing
- Water index curves: turn-points indicates generation of fractures



4D water absorbing profile



water index curves

Outline

- Overview
- Dynamic Fractures
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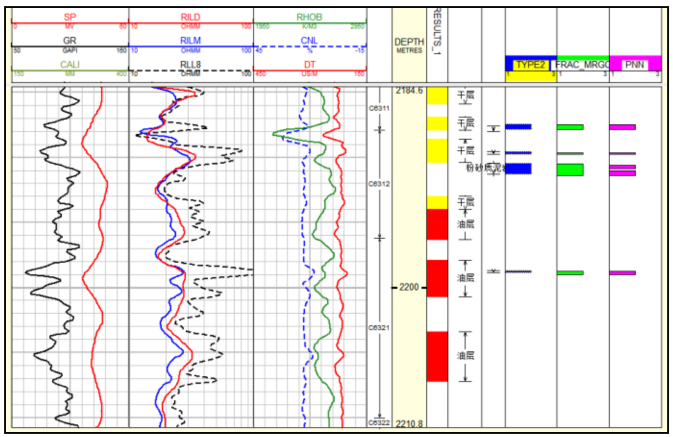
- Conclusions

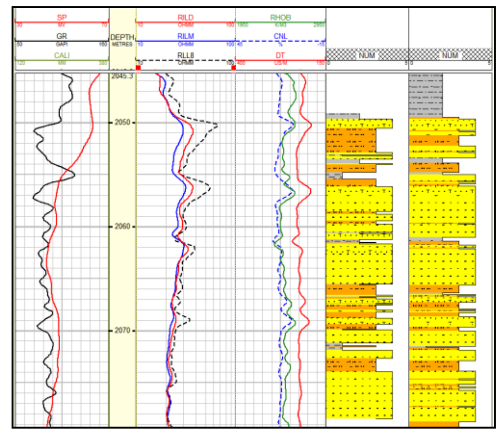
Distribution prediction

1. Natural Fractures

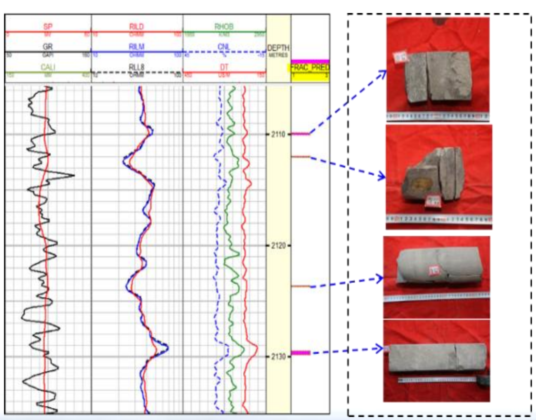
- **Calibration** between core-observation and well logging
- **Screening** of favorable parameters on fractures (GR、AC/DEN/RILD)
- **Identification** of Natural Fractures by Neural Network Approach



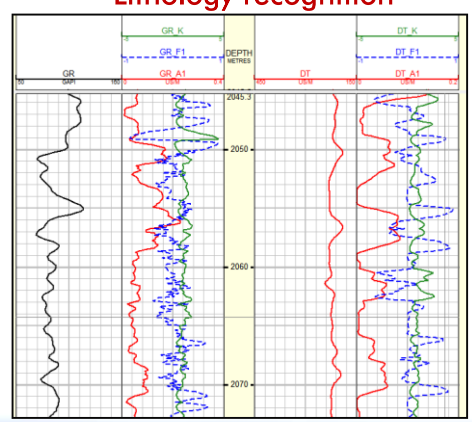
Calibration



Lithology recognition



Fractures Identification and Verifying

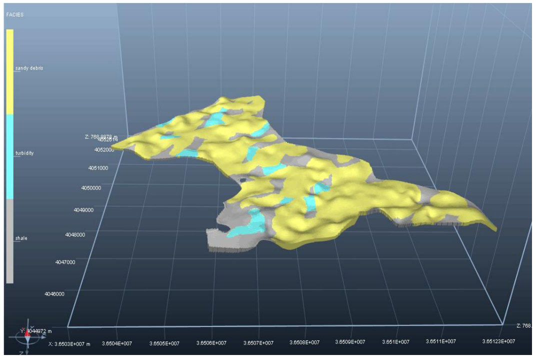


Parameter Screening

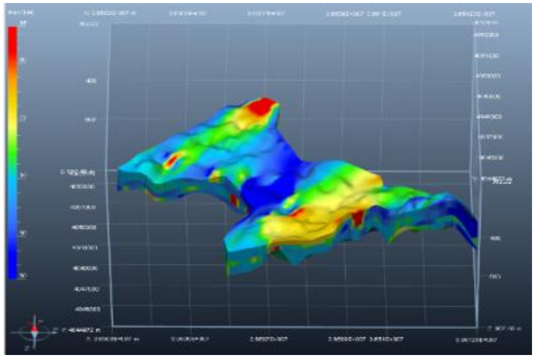
Distribution prediction

1. Natural Fractures

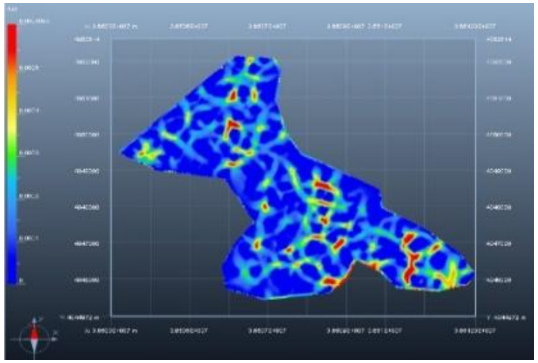
Lithology-facies

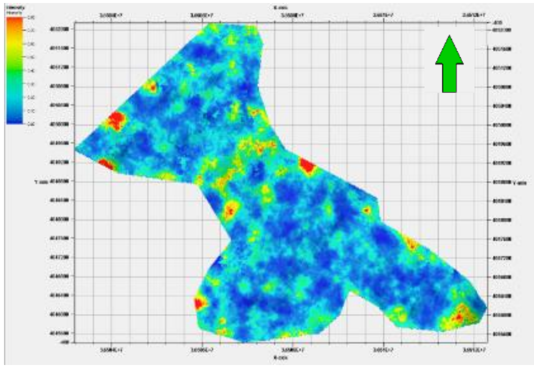


Paleo-Stress Field

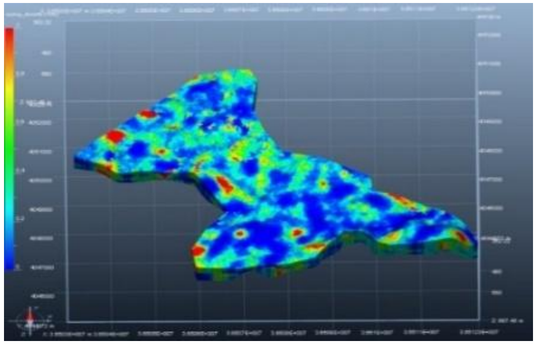


Maximal Curvature





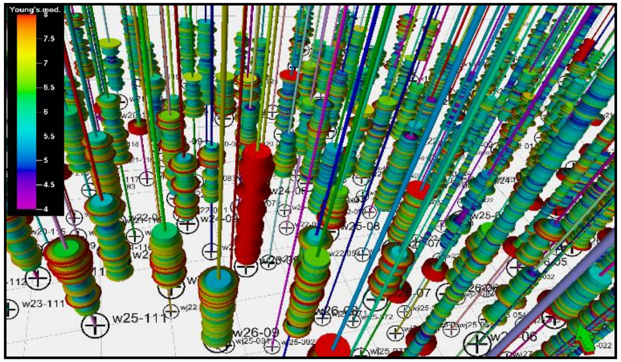
Fractures Intensity



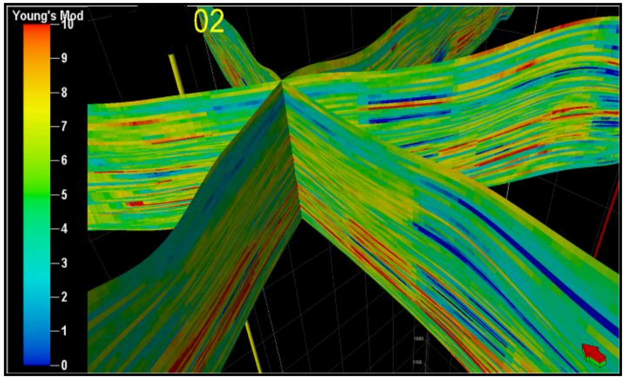
Fractures Density

Distribution prediction

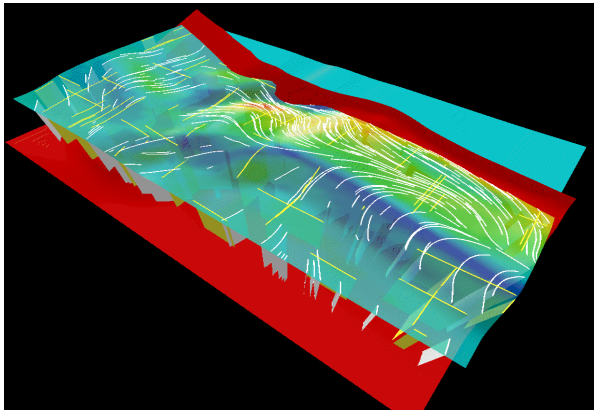
2. Artificial Fractures



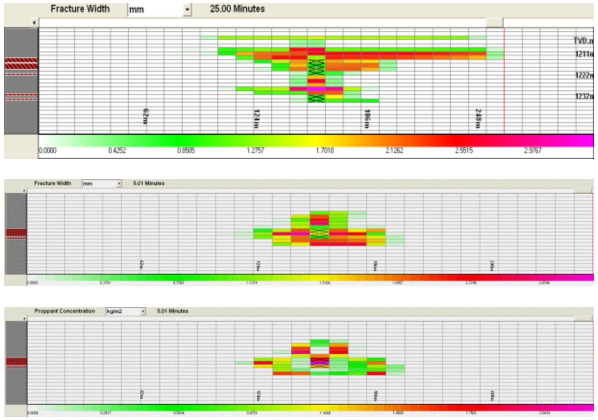
Wells' Young modulus



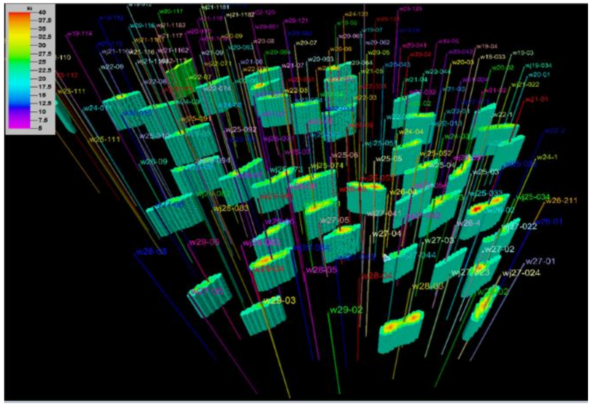
Poisson's ratio Profiles



Current Stress Field Recovery



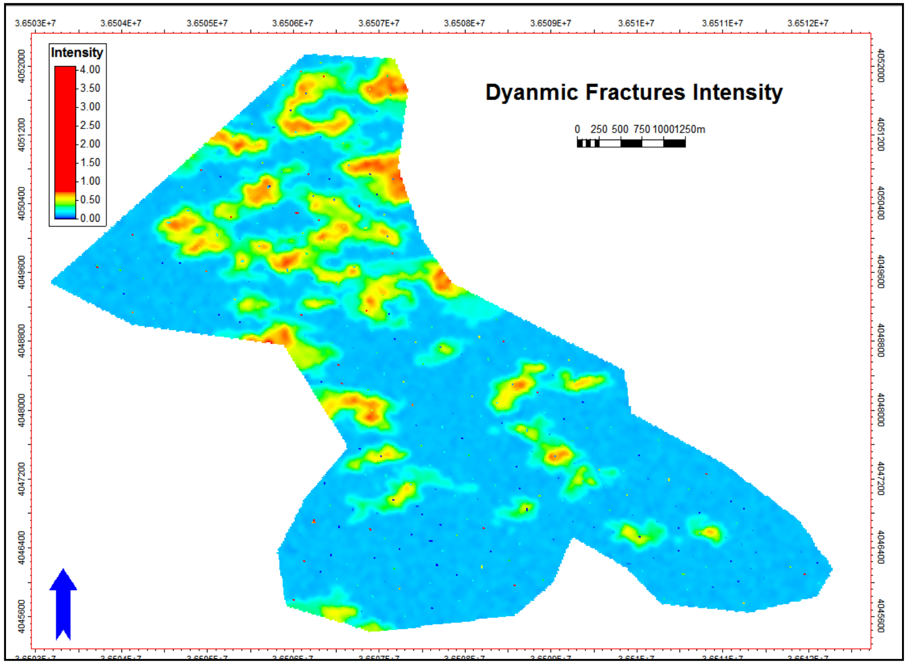
Artificial Fracturing Simulation



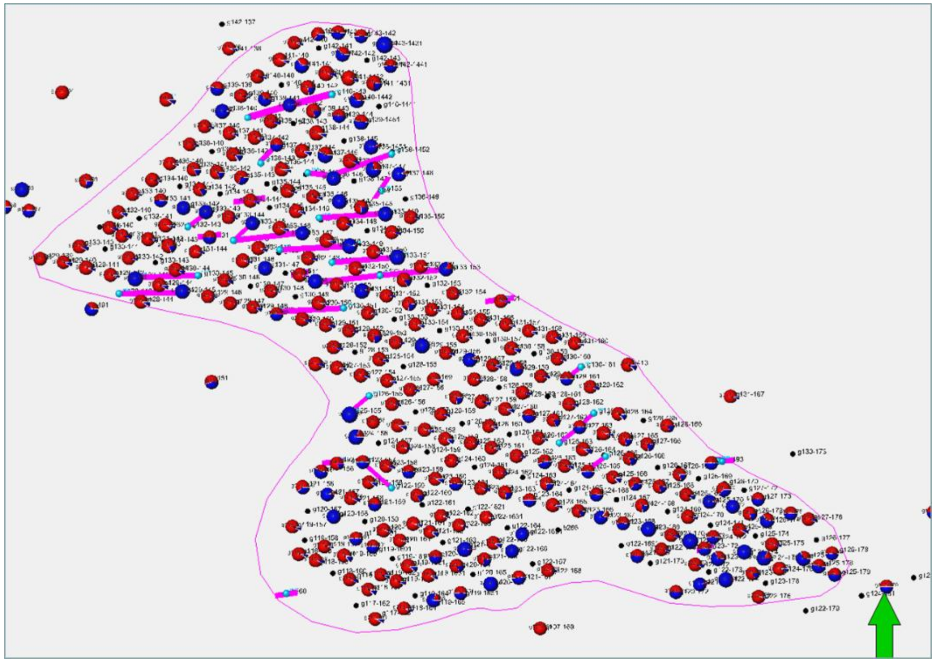
Artificial Fractures Model

Distribution prediction

3. Dynamic Fractures



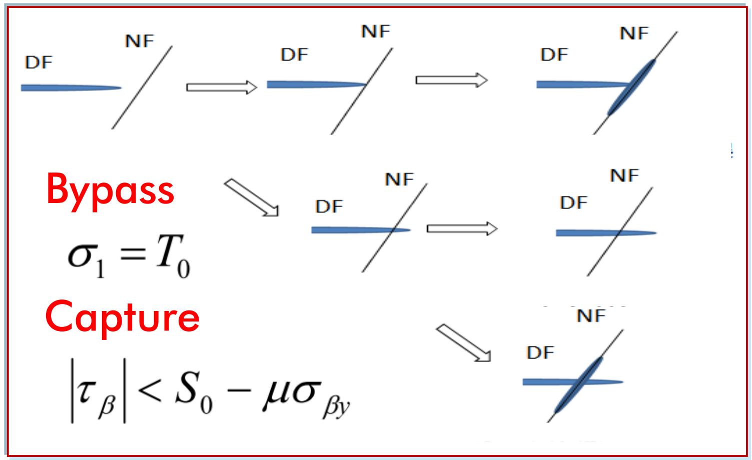
Dynamic Fractures Model

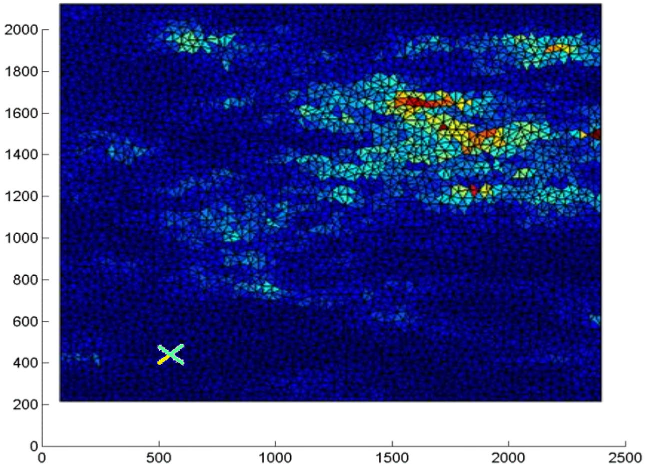


Production Testifying

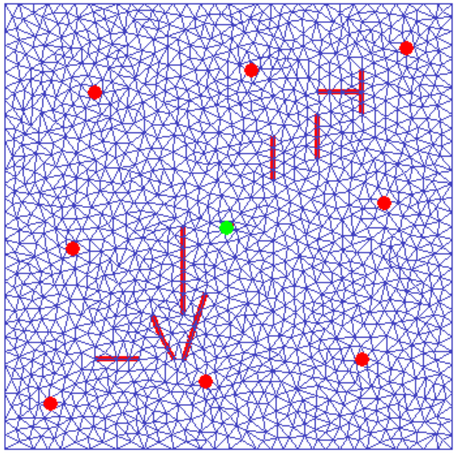
Distribution prediction

4. Numerical Simulation

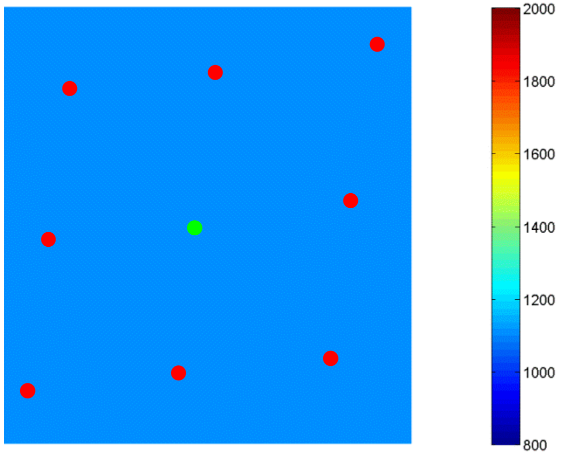




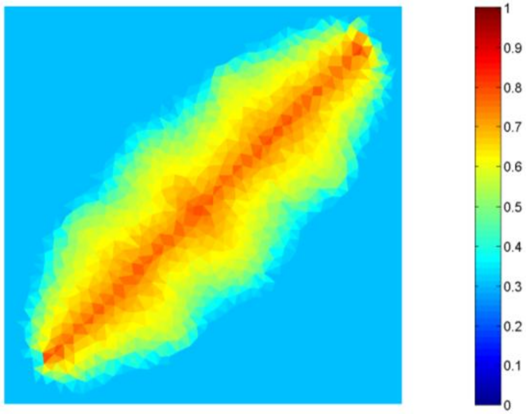
Dynamic Fractures Behavior



Growing Grid



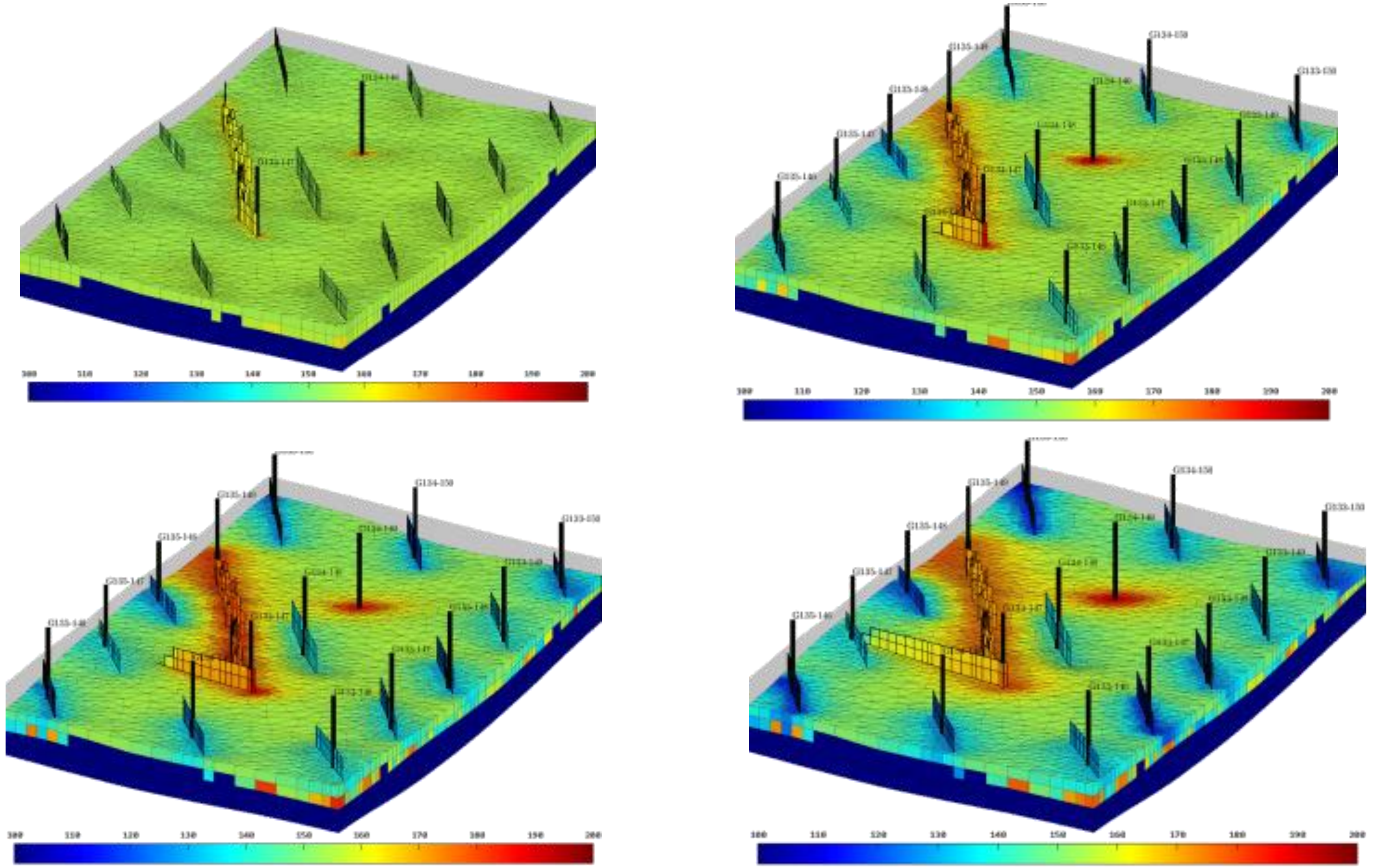
Pressure Field



Saturation Field

Distribution prediction

4. Numerical Simulation



4D Dynamic Fractures Behavior

Outline

- **Overview**
- **Dynamic Fractures**
  - Phenomenon
  - Forming mechanism
  - Identification methods
  - Characterization and Prediction
- **Conclusions**

Conclusions

Dynamic Fractures

Forming mechanism
- Paleo and Current Stress Field
- Lithology-based Geomechanics
- Reservoir Production Performance

Features identification
- Core Observation and FMI logging
- Production Performance
- Tracer Monitoring and Well testing

Distribution prediction
- Natural and Artificial Fractures Model
- Dynamic Fractures Characterization
- 4D Fractures Behavior Simulation