# [PS]Re-Exploratory Study Within an Area of the Tahe Oilfield, Western China: From Geological Characterization of Fractured Karst Carbonates to Prediction of the Most Prolific Sweet-Spots*

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## Abstract

This article outlines a multidisciplinary study of the very deep fractured karst carbonates of the Ordovician Yingshan Formation, which represent potential hydrocarbon reservoirs in an area of the Tahe oilfield, north of the prolific Tarim Basin, Western China. The complexity in characterizing and predicting irregular karst elements and their relationships with fracture networks, motivates the use of innovative techniques for identifying new sweet spots. This investigation aims to initially determine the distribution of karst elements in carbonates and recognize fracture rock-properties, through the construction of a fracture model that permits to detail the genetic relationship of fracture sets with the karst zones, consequently with reservoirs. In addition, we consider the tectonic features that occurred during the Caledonian and Hercynian orogenies which controlled the karstification processes. Likewise, the low connectivity among karst patterns and the production behavior of wells were evaluated. Using well logs from 163 wells, an average range of effective porosity between 1 - 6% in karst sections was estimated with very low drainage capacity. Also, utilizing borehole image logs analysis, three fracture sets were identified (azimuths: 285°, 355° and 235°). Moreover, Structural dip, Ant-tracking, and Relative acoustic impedance (amplitude) seismic attributes, were used as inputs data on a stratigraphic grid at the interface of unconformities T74-T76 (karsted interval). The lower amplitudes of the seismic attribute conformed suitably to the karst patterns and these, were utilized in the construction of 3D model. From the combination of structural attributes, a discontinuities volume was computed which highlights a major quantity of fracture planes in karsted interval, improving the fractures prediction in area. Subsequently, the fracture sets were extracted from the volume through the automatic fault extraction (AFE) technique and upscaled for the construction of discrete fracture network (DFN). We find that, the modeling showed two important karst patterns distributed irregularly in the area, northwestern and southeastern, where the pathways are aligned with the main striking faults. Additionally, fracture porosity and permeability (Kxx, Kyy and Kzz) models were computed. Finally, the integration of results predicted several sweet-spots along and in tip-lines of strike-slip faults W-E, where the fractured karst patterns that maintain the same orientation of faults and are aligned with the azimuth 355°'s fracture set that have greater aperture between 0.5 - 1 mm. This study also revealed various non-perforated karst segments in the intermediate zone. These are located near the regions with high fracture density and wells with accumulated volumes of oil production between 0.5-1 MMBBL, which may meaningful opportunities for the oil and gas industry.

# RE-EXPLORATORY STUDY WITHIN AN AREA OF THE TAHE OILFIELD, WESTERN CHINA: FROM GEOLOGICAL CHARACTERIZATION OF FRACTURED KARST CARBONATES TO PRECTION OF THE MOST PROLIFIC SWEET-SPOTS

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## Abstract

This research outlines a multidisciplinary study of the very deep fractured karst carbonates of the Ordovician Yingshan Formation, which represents potential hydrocarbon reservoirs in an area of the Tahe oilfield, north of the prolific Tarim Basin, western China. The complexity to characterize and predict the karst elements and their relationship with fracture networks, motivates the use of innovative techniques for identifying new sweet-spots. This investigation aims to determine fracture rock properties through the construction of a fracture model (static model) that details the genetic relationship of fracture networks (large-scale) with the karst zones in a carbonate platform. In addition, we take into account the tectonic features that occurred during the Caledonian and Hercynian orogeny which controlled the karstification processes. In area, three fracture sets were identified: I, II and III, utilizing the borehole image logs analysis.

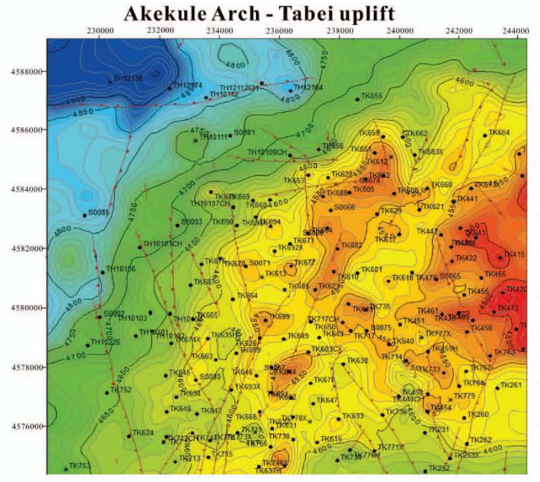
Moreover, the use of an enhanced-attribute obtained from the combination of Local structural dip and Ant-tracking, which permit identifying discontinuities associated to the fracture sets. Subsequently, these discontinuities are extracted in interface of the unconformities T74-T76 (karsted interval), using the automatic fault extraction (AFE) process and upscaled in a simulation grid for the construction of discrete fracture network (DFN) model. Fracture porosity and permeability tensor models are computed in this grid, observing an improvement in the prediction of fractures in the area. We find that, this model adjust notably the main striking faults with karst patterns distributed irregularly. Finally, the integration of results suggests several sweet-spots along and in tip-lines of fracture sets I and II (SWS-NEN and W-E, respectively), where aperture range is around 0.6-1 mm. This study also reveals a great clustering of partially dissolved fractures in forelimb and backlimb of thrust (main structure) in the intermediate zone, which has accumulated volumes of oil production between 0.5-1 MMBBL, which means good opportunities for the oil and gas industry.

## Geological framework of study area

People's Republic of China


The study area is located in the **Akekule arch**, an ancient tectonic structure where horizontal stresses were transmitted in multiple periods, essentially during the Caledonian and Hercinian orogeny. During the Middle Ordovician, the paleomorphology of this arch contemplated a karst landscape on a gentle slope uplifting to northwest.

Akekule Arch - Tabei uplift

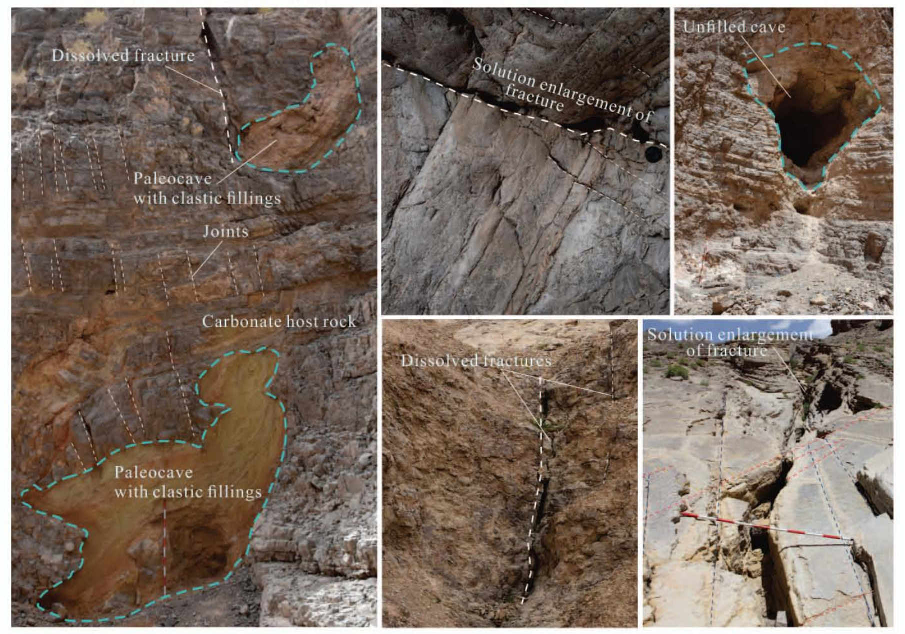


Study area is around 450 km² and covers 5 operating zones of the Tahe oilfield, where 165 wells have been drilled.

The **Ordovician Yingshan Formation** represents the key stratigraphic unit, characterized by grainstone and dolomitic limestone highly affected by karstification processes and fractures. This unit, with a relative thickness of 680 m, is limited at the top and bottom by the unconformity T74 and Penglaiba Formation, respectively. Although, the karsted interval is between the unconformities T74 - T76.

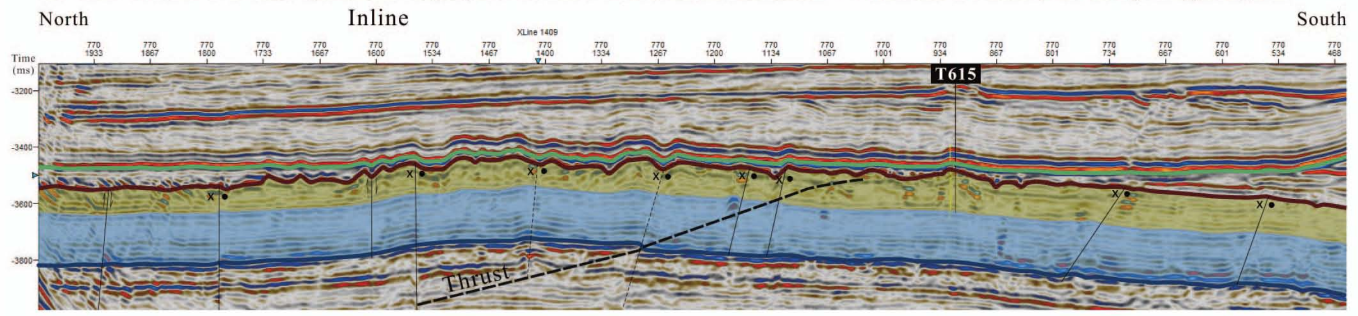
## Analogue models of karst and dissolved fractures

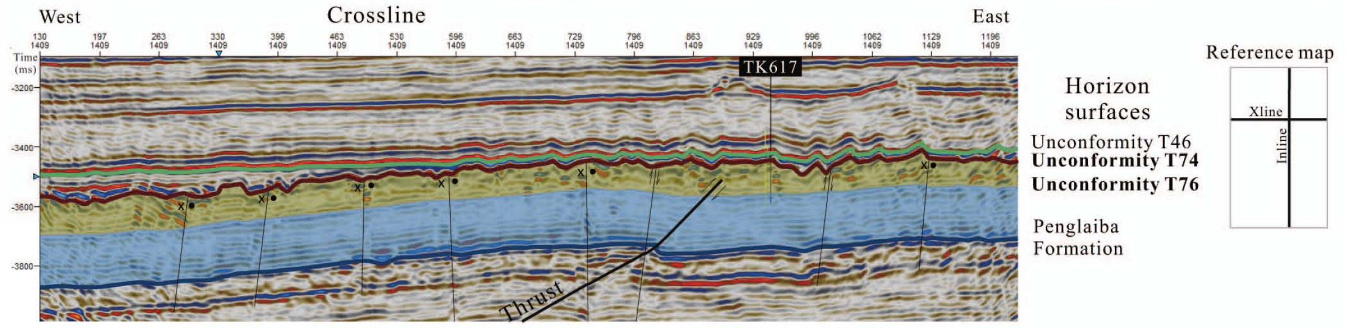
The following photos show clear examples (analogues) of the paleokarst elements and dissolved fractures in outcrops within the Tarim basin:



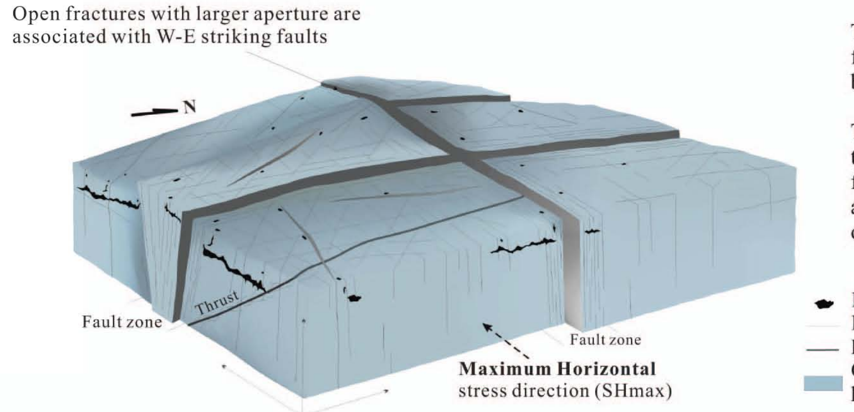

## Structural seismic interpretation of area

The structural seismic interpretation displayed in seismic sections is taken into account for the construction of geological grid.




## Conceptual model of the Yingshan Formation proposed for the study area

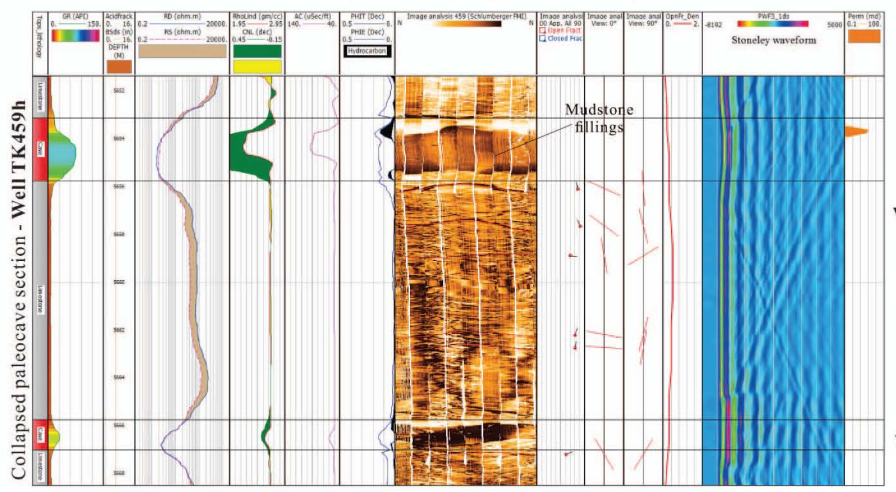


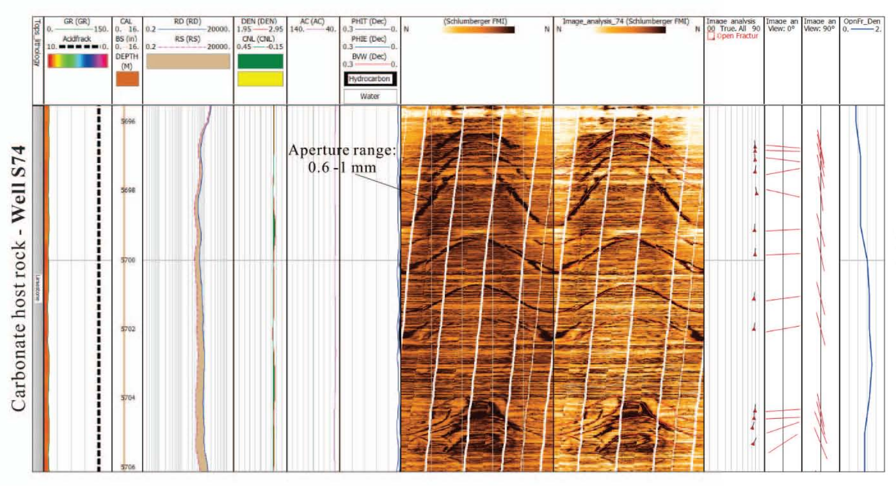

The structural interpretation of fractures-faults and karst features can be explained by a simple conceptual model.

The model exemplifies a partially eroded thrust (main structure) and a highly fractured carbonate platform. This model also shows three different fracture orientations for the area in question.

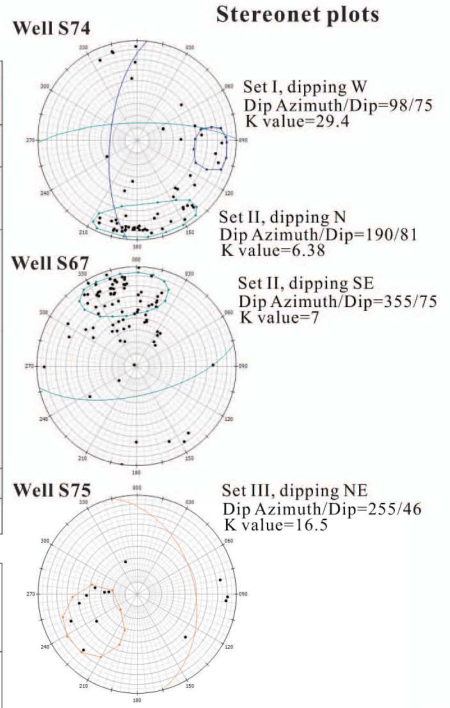
**Legend**
- Karst facies
- Fractures
- Faults
- Carbonate host rock

## Identification of the fractures using well logs (FMI and DSI)




Stereonet plots

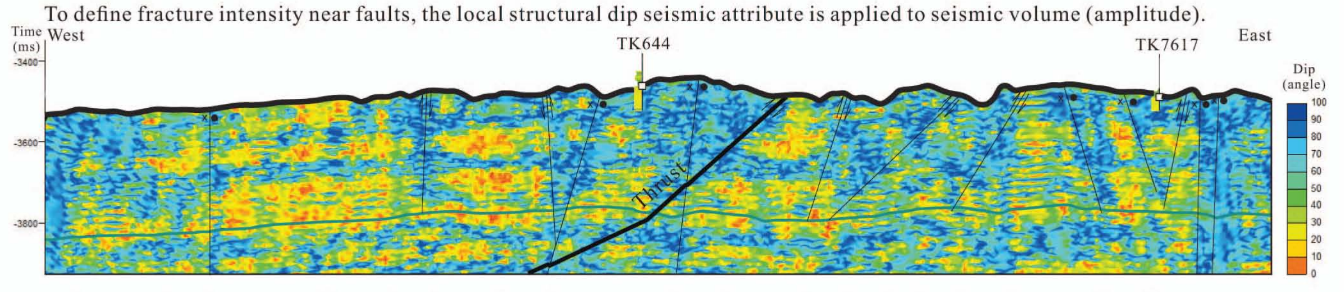



The Fisher coefficient (K) is statistically calculated for estimating the orientation randomness (dispersion) of fractures in the DFN model. The Shmax orientation was estimated SWW-NEE. Fracture analysis determined three fracture sets for the study area:

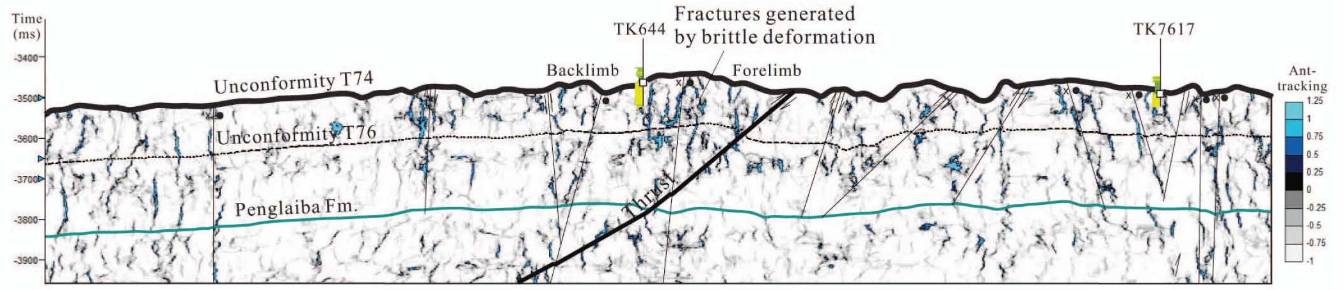
| Fracture set | Orientation (Dip azimuth) | Dip angle | Fisher K | Length (m) Min | Length (m) Max | Picked fractures |
|---|---|---|---|---|---|---|
| I | 285°(deviation +/-10) | 75° | 29 | 40 | 120 | 115 |
| II | 355°(deviation +/-30) | 85° | 6.5 | 40 | 120 | 122 |
| III | 255°(deviation +/-20) | 46° | 16.5 | 40 | 120 | 95 |

## Applying the structural seismic attributes

To define fracture intensity near faults, the local structural dip seismic attribute is applied to seismic volume (amplitude).



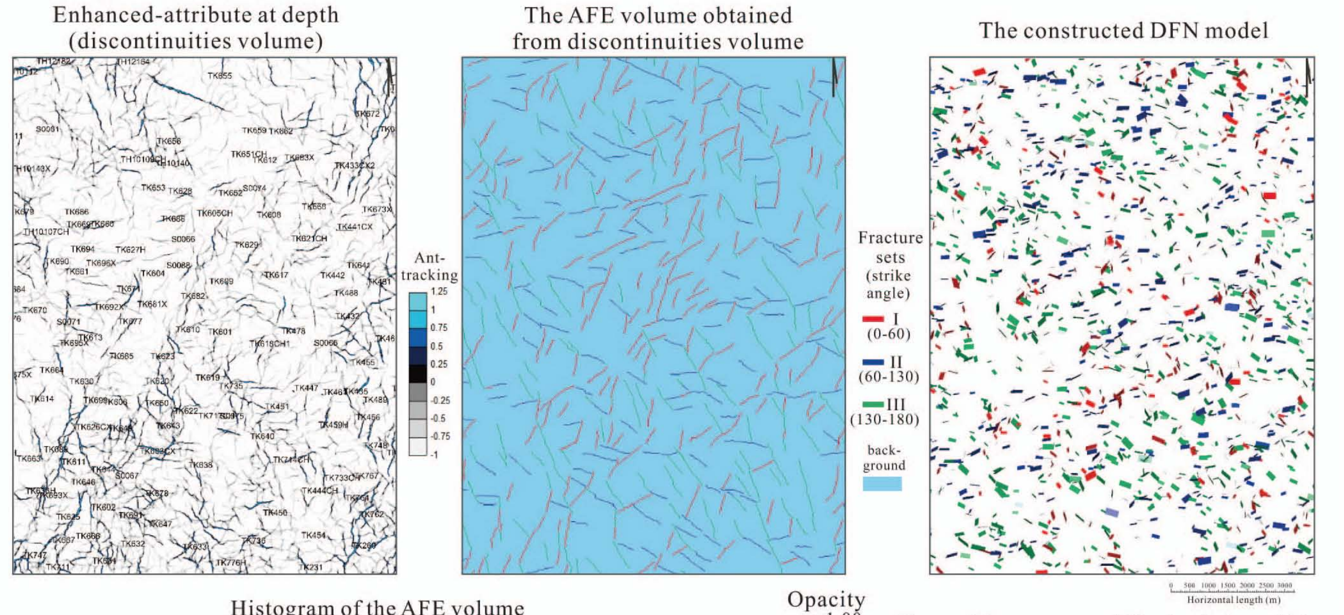

Subsequently, the ant-tracking seismic attribute is computed on the previously obtained attribute to identify a greater number of discontinuities associated with the fracture networks.

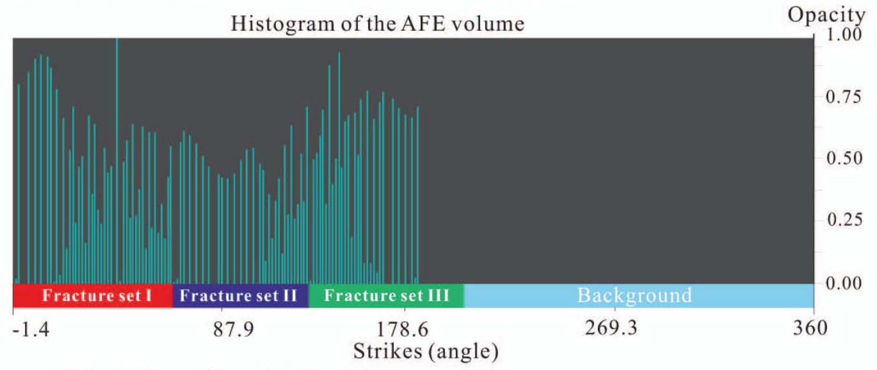



## Constructing the Discrete Fracture Network (DFN)

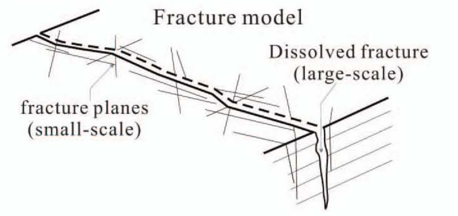
From a discontinuities volume computed of the enhanced-attribute, were extracted the fracture sets using the Automatic Fault Extraction (AFE) process. Based on stated parameters and extracted fracture sets, the following DFN model is calculated.

**Fracture intensity measure:** number of fractures per cubic meter (1/m) **Length distribution:** Power law **Length parameters:** Max= 120 m; Min=40 m; Exponent=-2



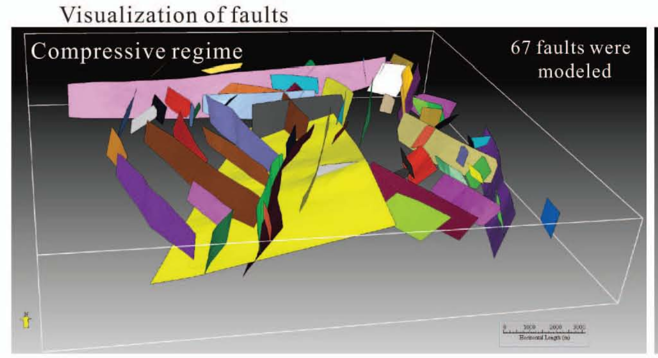

- The total fracture area within simulation grid is around 97.1%.
- Based on results, the fracture set II (parallel to Shmax) has the largest number of planes in the DFN model.



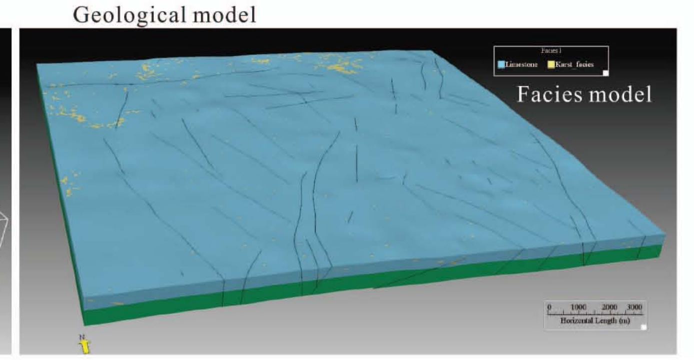

## Modeling of geological framework

Geological model was performed using the previous structural seismic interpretation, surface horizons of the unconformities, and the karst facies. From this geological model is computed the simulation grid for estimating the fracture rock properties.

Visualization of faults

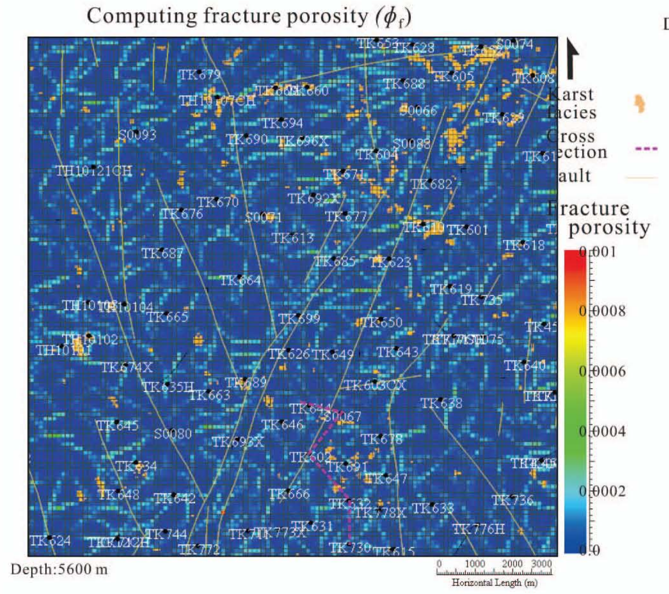



Geological model

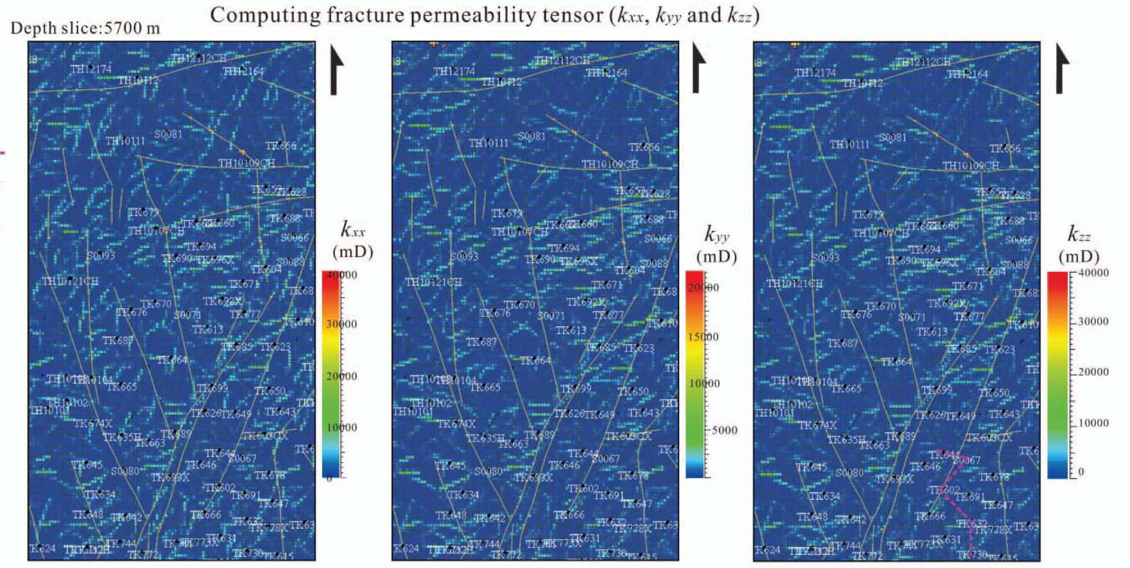



## Processing fracture rock properties ($\phi_f$ - $k_f$)

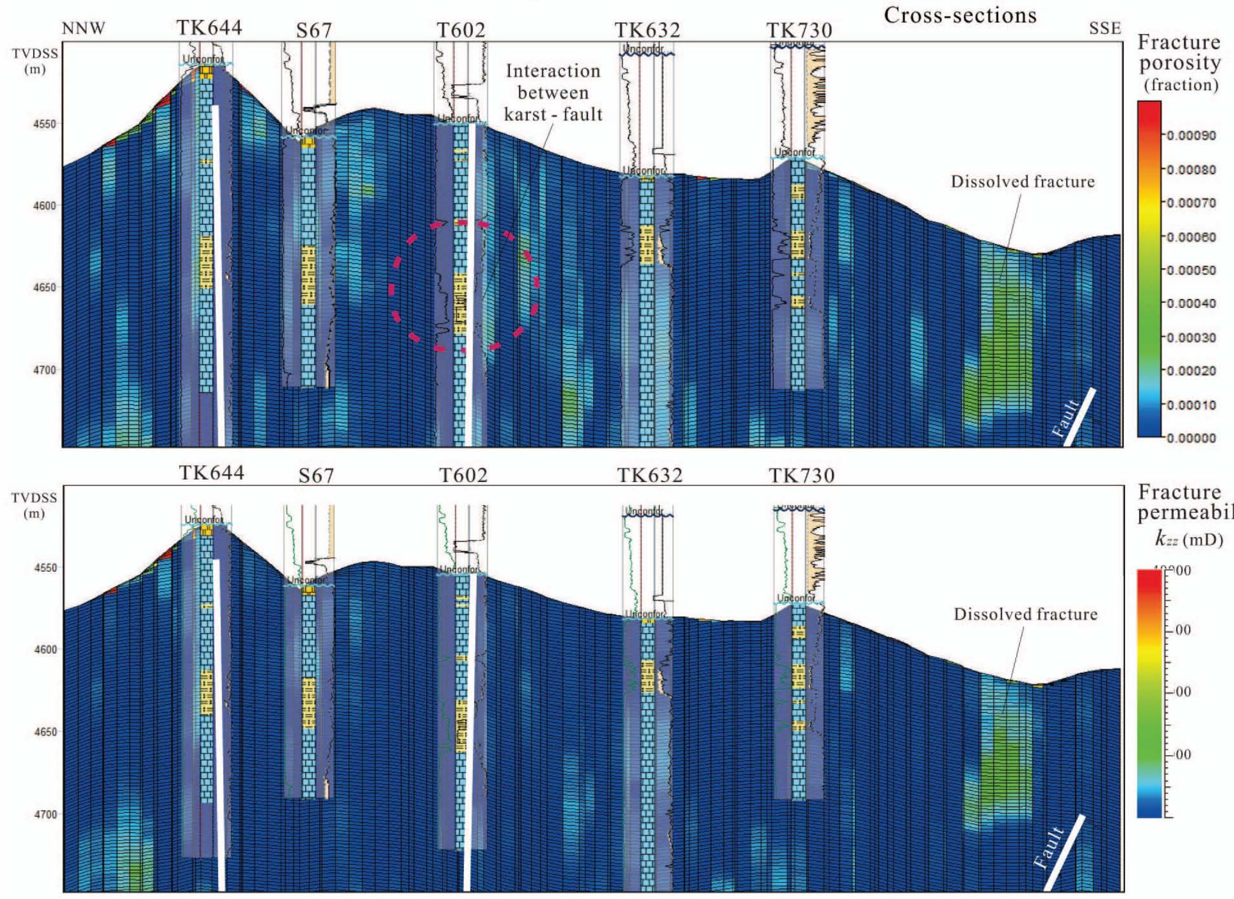
Computing fracture porosity ($\phi_f$)

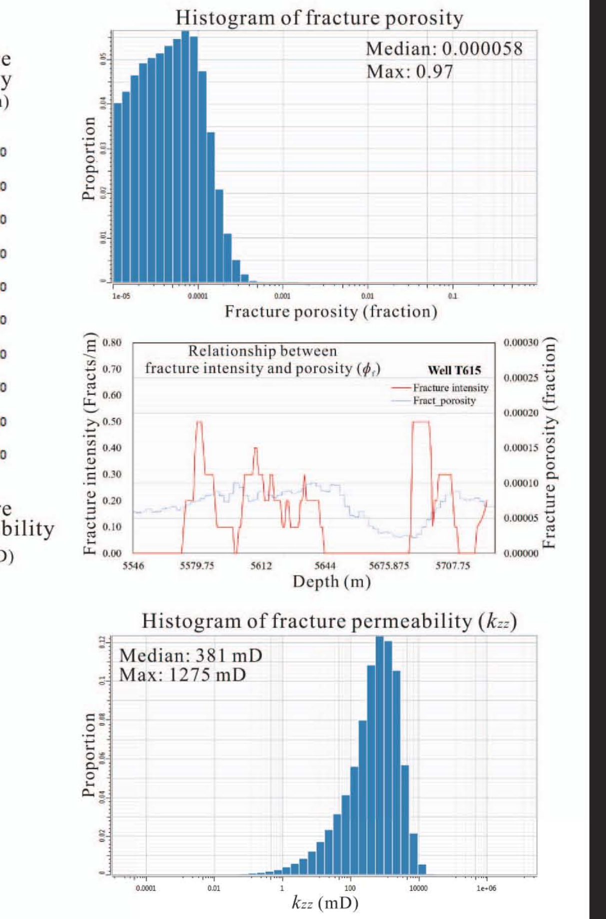



Computing fracture permeability tensor ($k_{xx}$, $k_{yy}$ and $k_{zz}$)

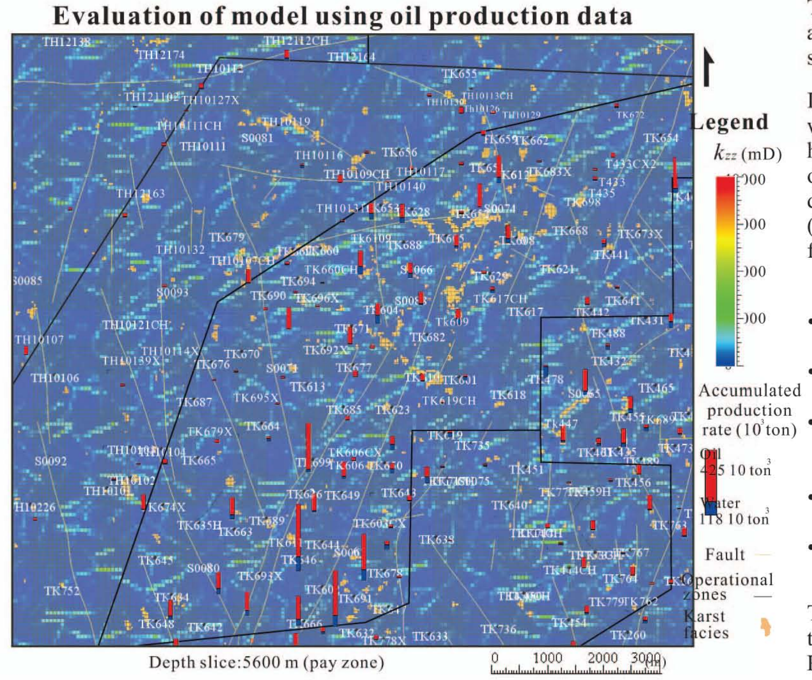



Cross-sections



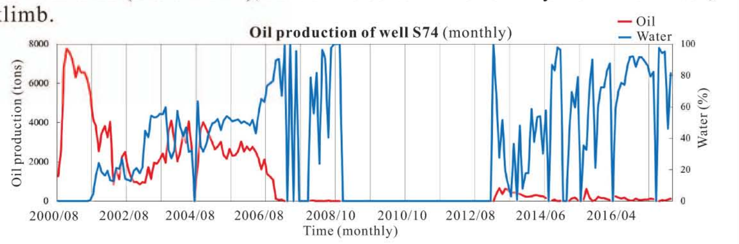




## Evaluation of model using oil production data




The highest oil production of area is in the forelimb of thrust which coincides with the greater abundance of extensional fractures (SWW-NEE), as well as several areas away from the thrust, specifically, in the backlimb.

In an initial stage, wells sited in forelimb have had a significant oil production, which decreases rapidly (typical behavior of fractured reservoirs).




### Conclusions

- The DFN model generated from the enhanced-attribute exhibits a prediction of fracture intensity (large-scale) very similar to the obtained using the borehole image logs.
- The fracture model allows to determine several non-perforated sweet-spots essentially in the western area.
- Fracture networks determined in the area represent the main pathway for fluid flow in these reservoirs with very low porosity and permeability by matrix, which have an high oil production that decreases rapidly.
- The results contribute to the understanding of effective reservoir space related with the large-scale partially dissolved fractures.
- This fracture model can reduce the risk related to well planning in fractured reservoirs.

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