The fracture prediction of tight clastic gas reservoir of the XC gas field of west Sichuan depression

川西新场致密碎屑岩气藏裂缝预测

Speaker:Sujinyi

中国石化股份公司西南分公司
SOUTHWEST PETROLEUM BRANCH SINOPEC

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OUTLINE

- introduction

- Fracture prediction technology

- Fracture Comprehensive evaluation

introduction

XC气田位于川西坳陷中段孝泉-新场-丰谷北东东向大型构造带中部。

川西坳陷中段天然气资源量为 $1.23\times10^{12}m^3$

XC gas field is located west Sichuan depression

The amount of natural gas resources in the middle of West Sichuan Depression is about $1.23\times10^{12}m^3$

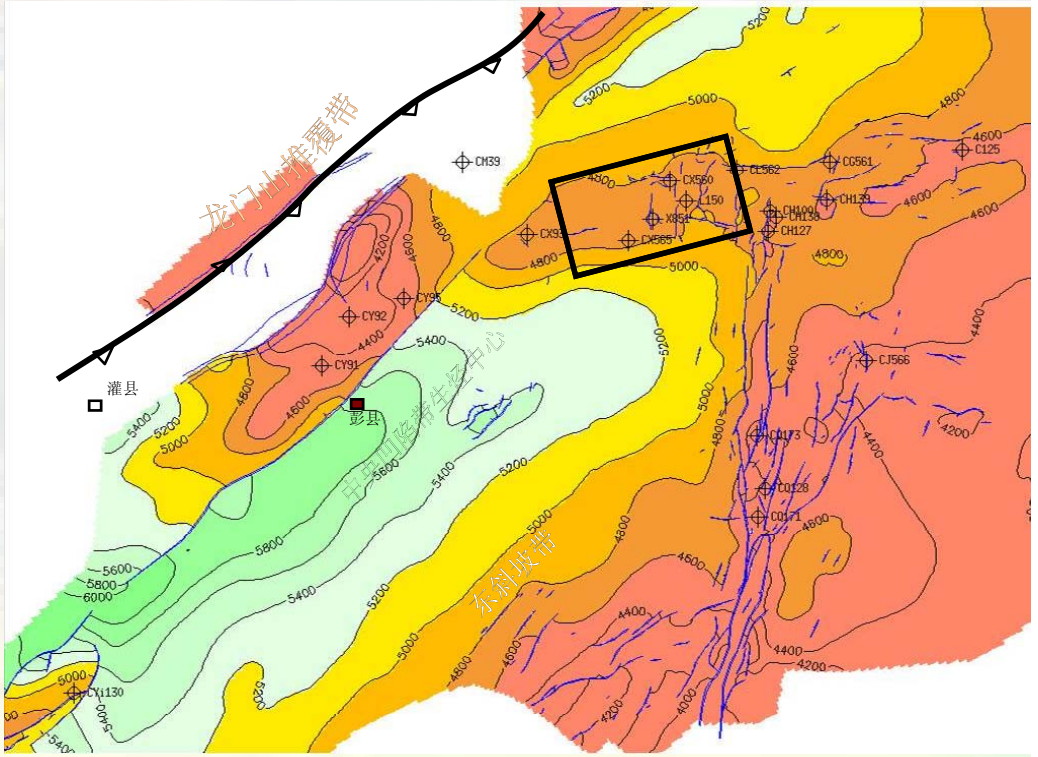
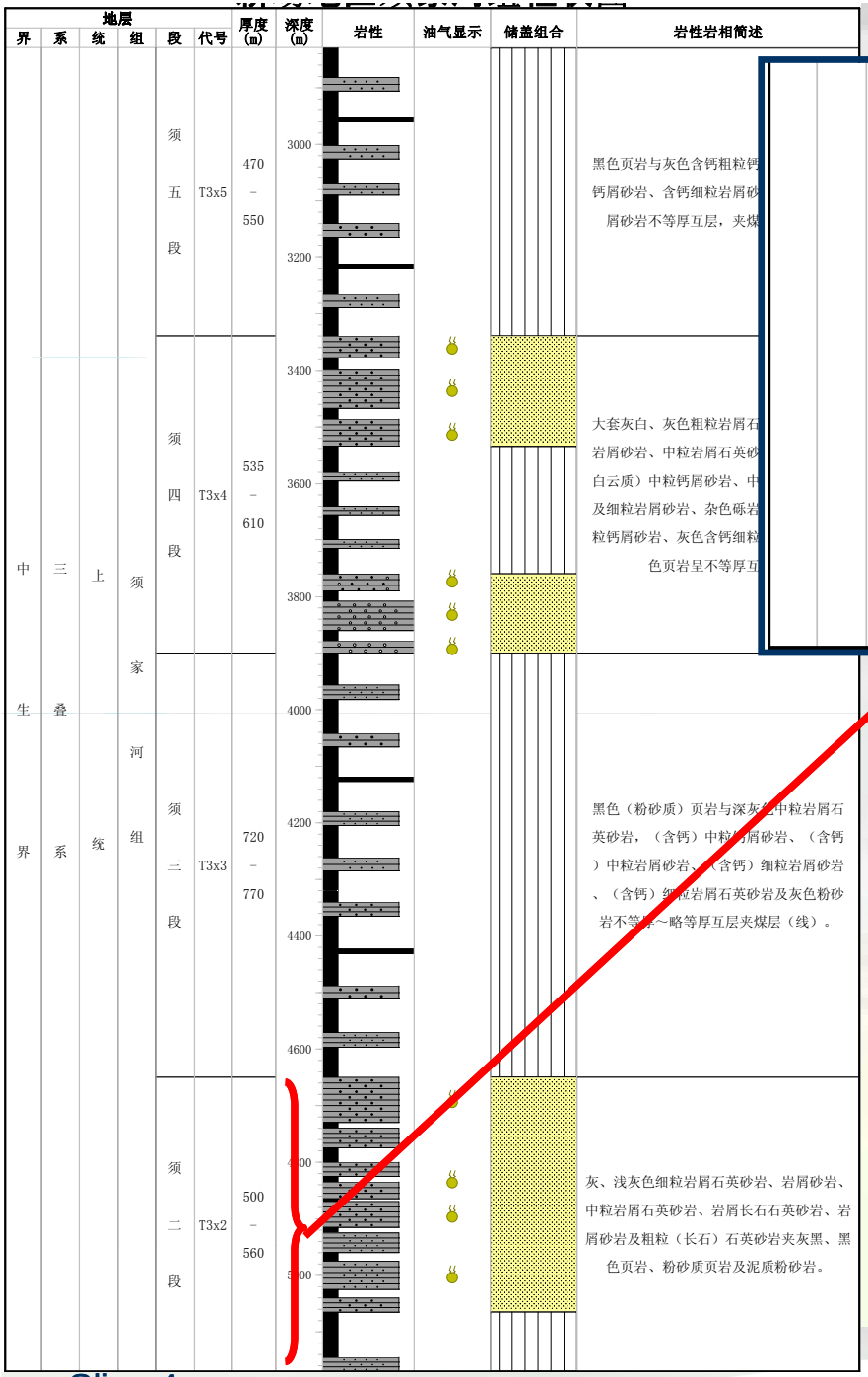
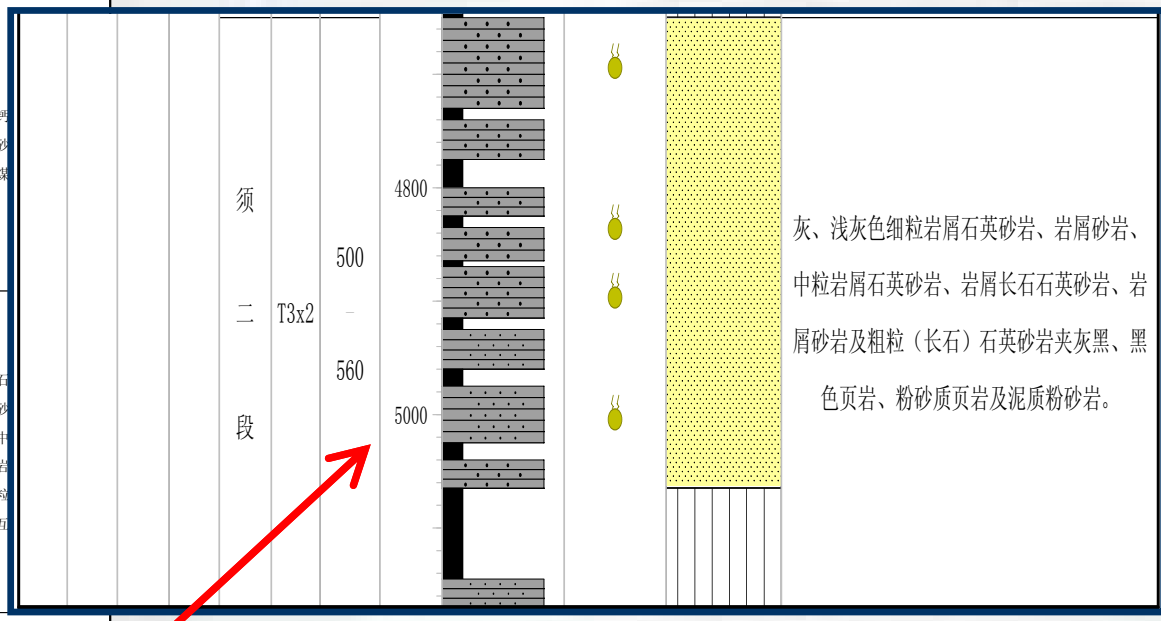


Figure1 location map of XC gas field
(based on SOUTHWEST PETROLEUM BRANCH SINOPEC)





the formation explored: Xujiahe-2

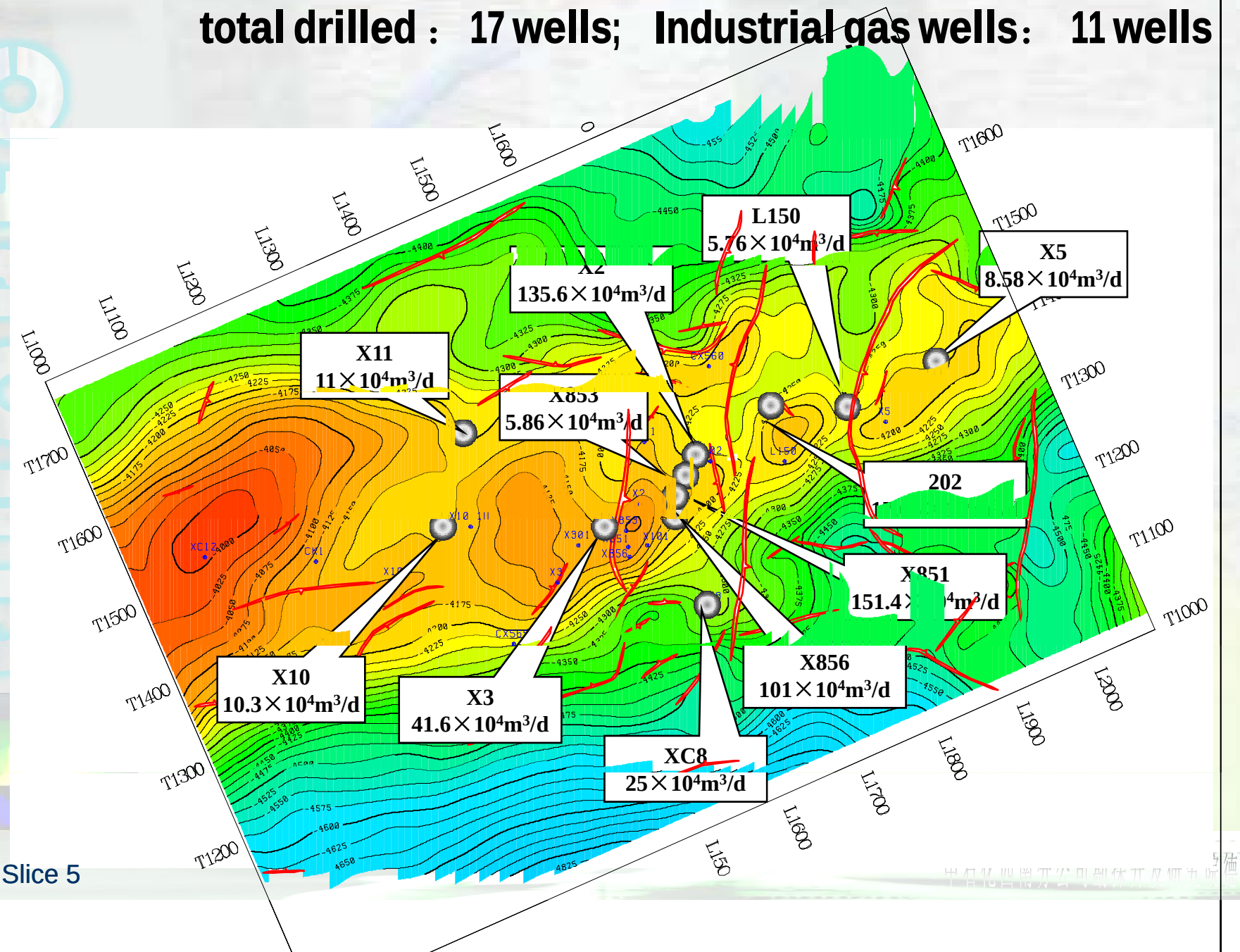
Thickness:500-600m

Sandstone/mudstone

Slice 4

For the xujiahe-2 foramtion:

total drilled： 17 wells; Industrial gas wells： 11 wells



What is the characteristics of Gas Reservoir ?

Characteristics of Gas Reservoir

1、 reservoir depth: more than 5000m

2、 super tight reservoir: porosity<4%

3、 strong reservoir heterogeneity

so these characteristics demermine the exploration is very difficulty

Reservoir type

- Three effective reservoir type:
  - porous reservoir：low yield、middle yield
  - fracture-pore reservoir: high yield、stable yield
  - fractured reservoir :unstable yield

Conclusion

❊良好的基质物性条件是川西陆相深层致密储层成藏的基础；

❊裂缝特别是高角度网状缝的发育是获得高产的必要条件。

For decades exploration of xujiahe-2 formation,we realize:

❊high-quality reservoir is the base of reservoir forming.

❊Fracture, especially high angle network fracture is the necessary condition to yield high.

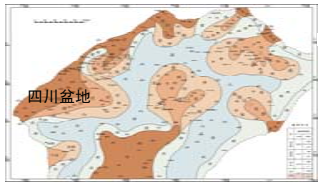
high-quality reservoir ＋ fracture

Now: Question ???

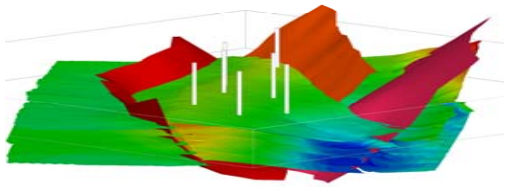
How to predict High-Quality reservoir and fracture

How to predict the fracture-pore reservoir

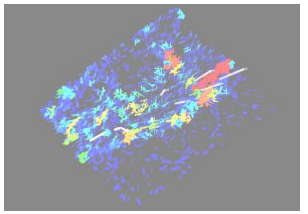
(裂缝—孔隙型储层预测技术路线)



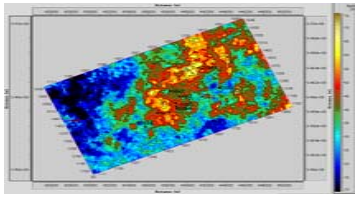
Regional lithofacies palaeogeography map



Structure model

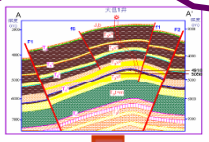


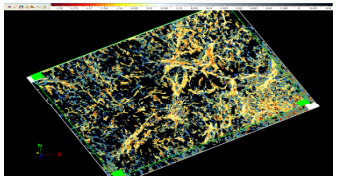
tectonic stress inversion



High-Quality reservoirs prediction

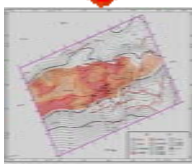
Gas reservoir model

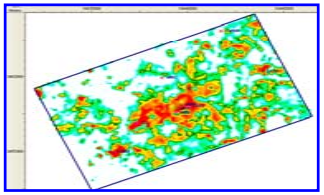




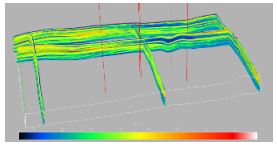
seismic attributes

Comprehensive evaluation



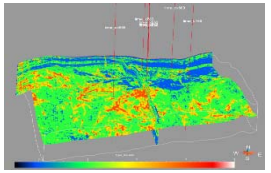


Gas-bearing detection

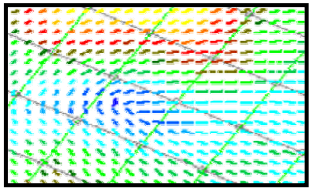


Reservoirs model

Reserves estimates

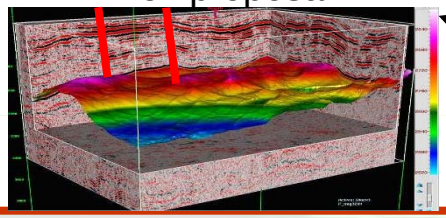


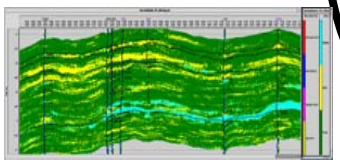
Fracture model



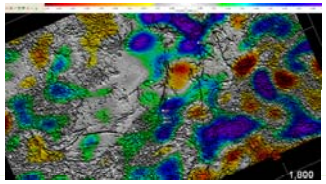
Azimuth anisotropy prediction

Well-proposal





Reservoirs parameter inversion



S splitting

OUTLINE

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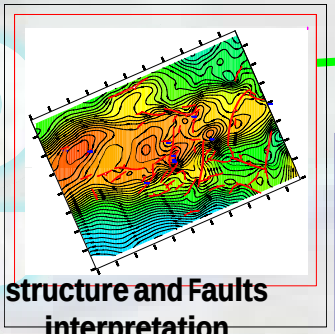
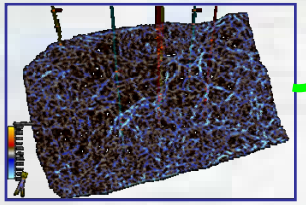
Fracture detection workflow

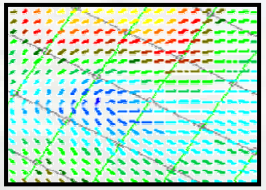


structure and Faults interpretation



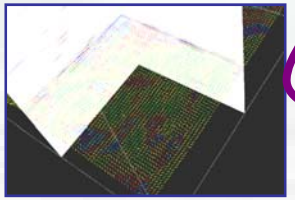
Based on Seismic Attributes fracture prediction

Big scaled fault and Fracture system prediction

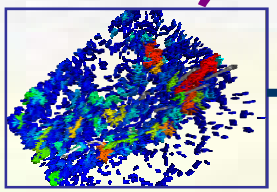


Based on PP fracture prediction

Small scaled fracture prediction

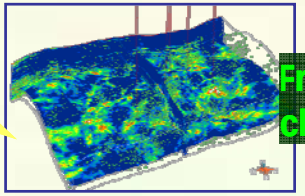


Based on PS-wave splitting fracture prdiction



Fracture effectiveness Analysis

Geohistory genesis fracture prediction



Fracture characteristic

Fracture network modeling

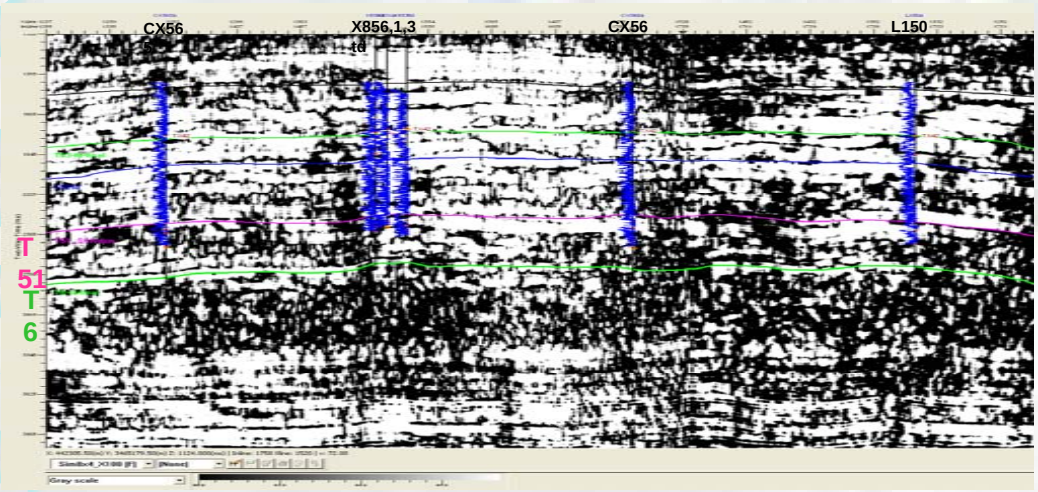
预测大尺度的断裂和破裂系统，采用P波和S波的相干体、倾角、方位角或SVI像素处理等；预测小尺度裂缝采用P波方位各向异性、S波分裂方法。

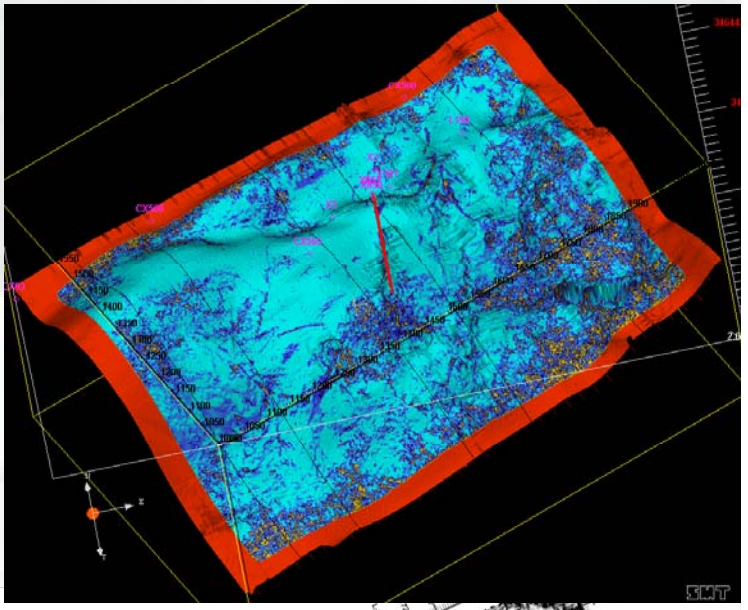
big scaled faults and fracture system using Faults interpretation 、PP&PS coherency、dip and azimuth cube ，and SVI processing，small scaled fracture using PP Azimuthal anisotropy and PS splitting technology.

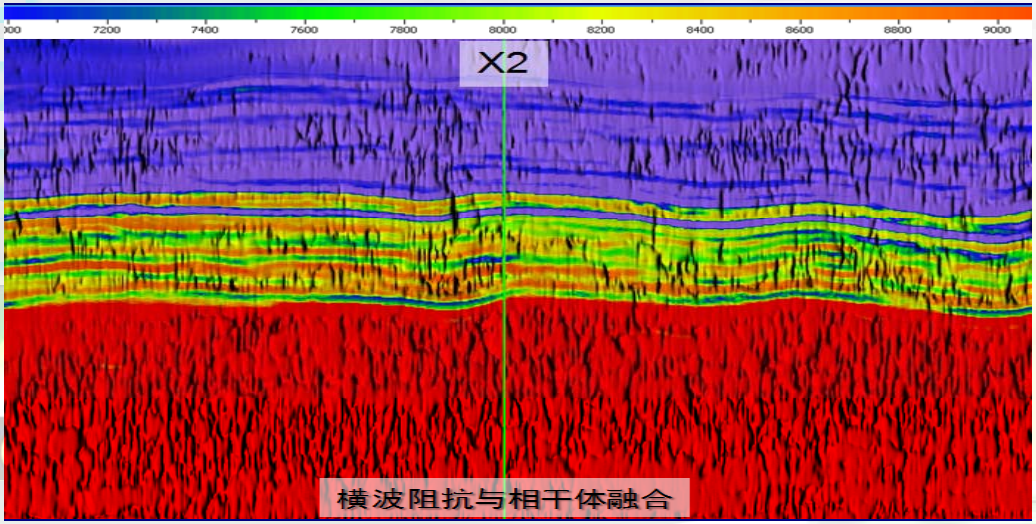
◆（1）Based on seismic attribute fracture prediction

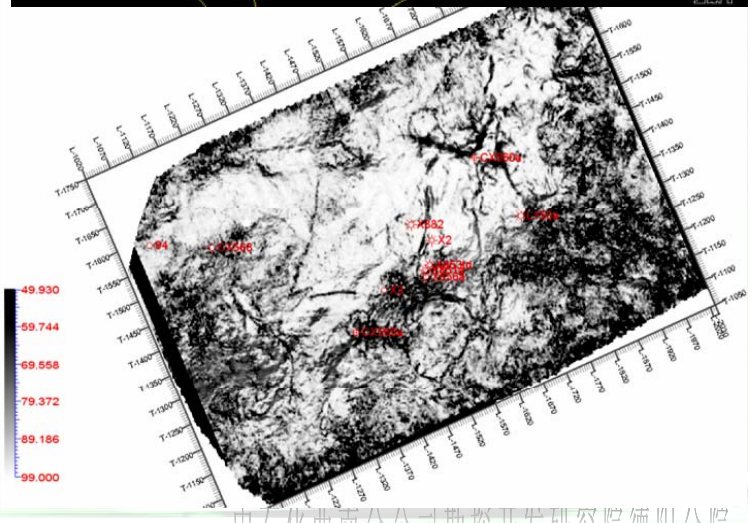
基于地震属性的裂缝预测

① C3 coherence cube



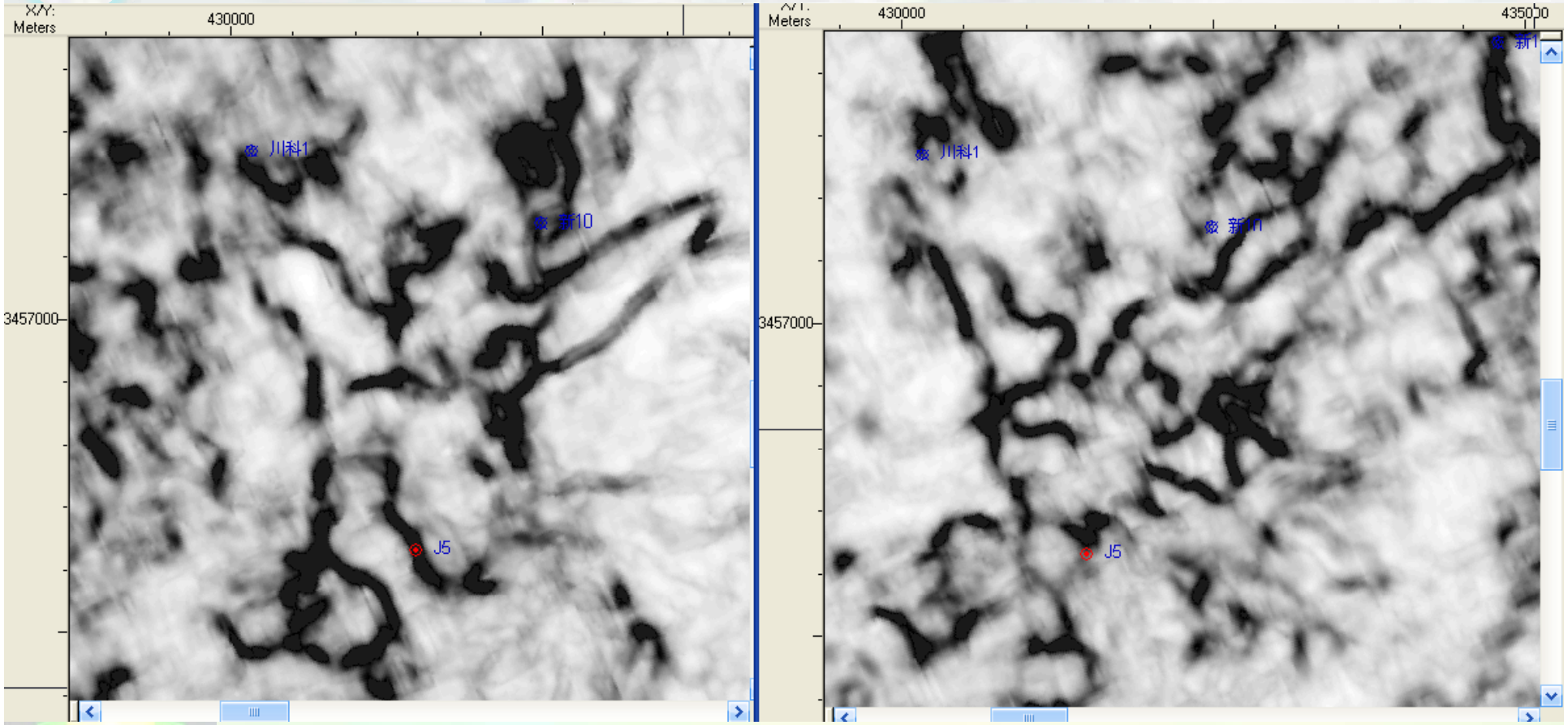






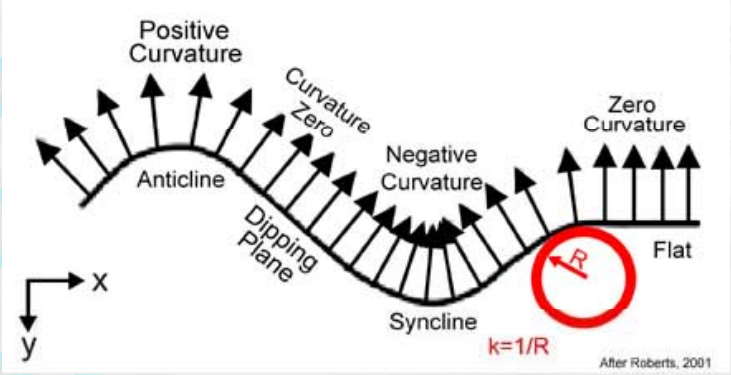
- The higher frequency is,the smaller the fault is indentified
- multi-wavelet decomposition & C3 coherence compution

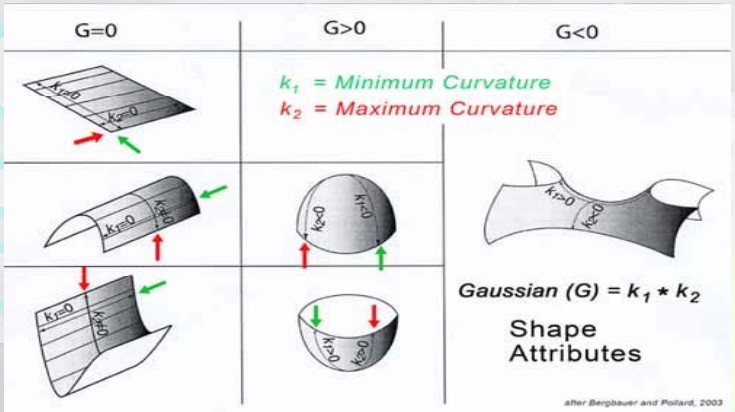
  micro faults can be identified!

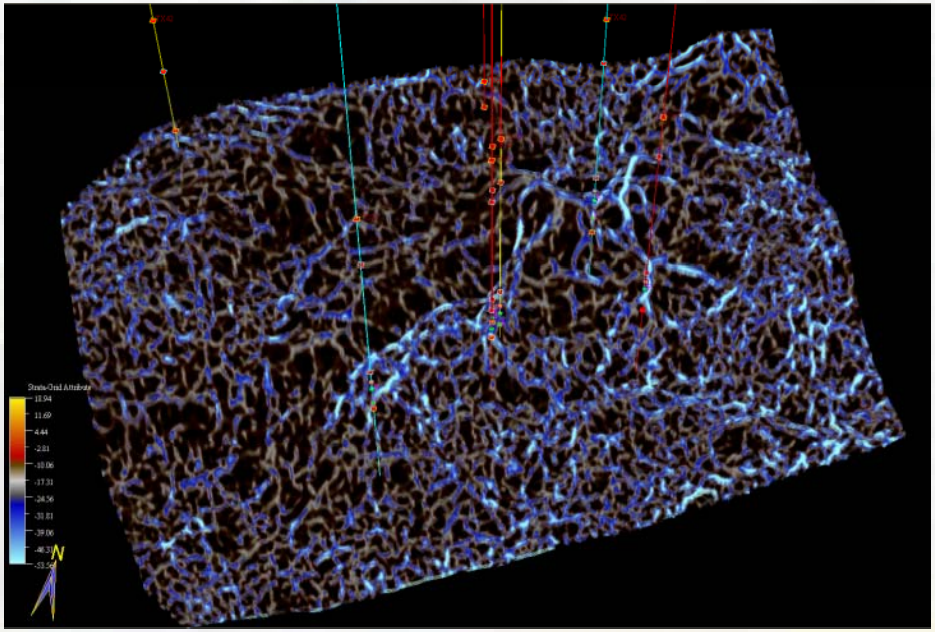


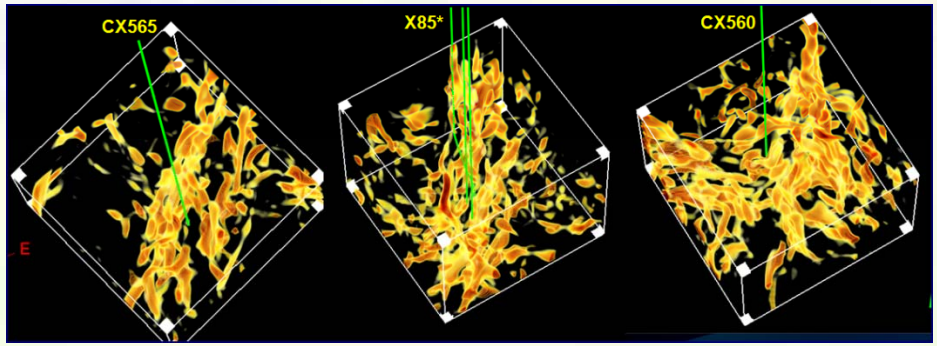
（2）Based on geometric attribute fracture prediction

②Curvature cube





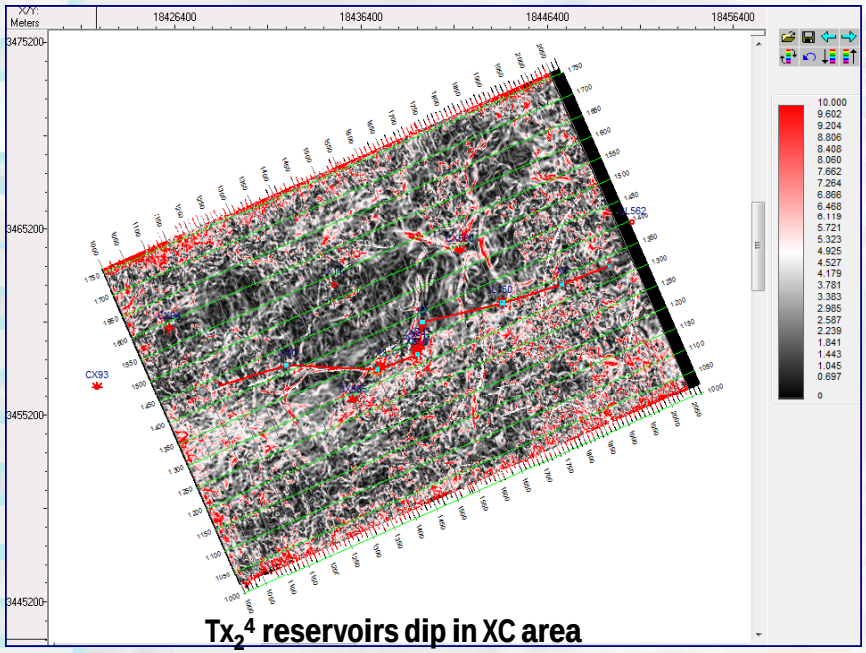




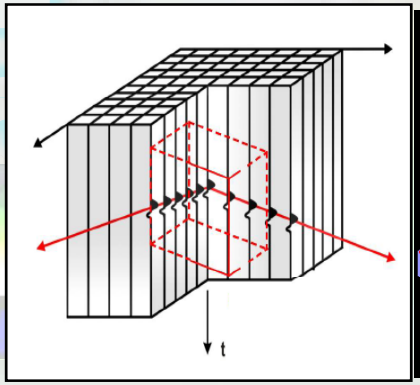
Cross wells 3D3C PP curvature data partly visualization in XC

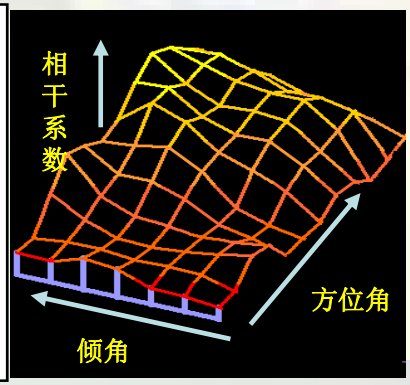
（2）Based on geometric attribute fracture prediction

③ Dip cub

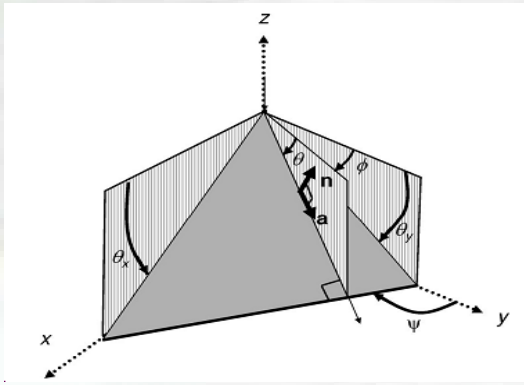


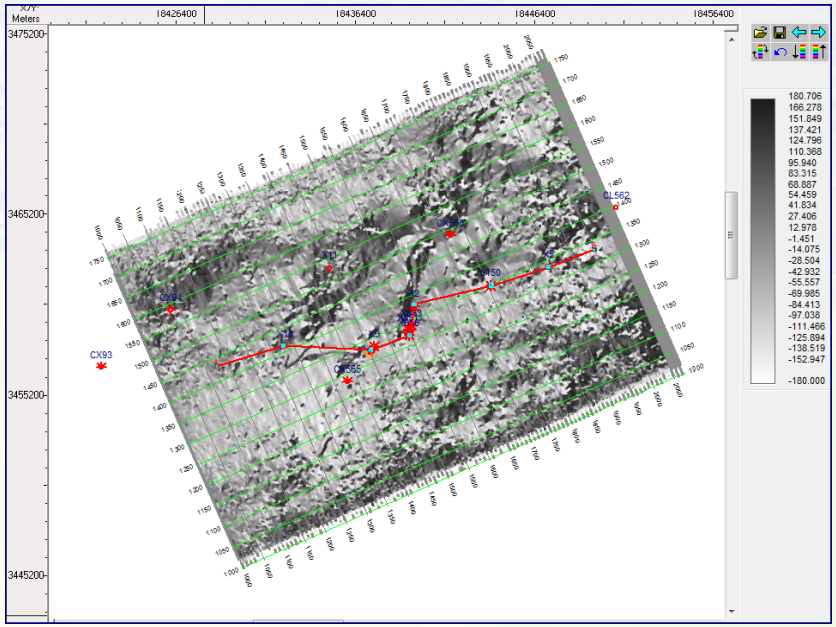
Tx_2^4 reservoirs dip in XC area





④ Azimuth cub





Tx_2^4 reservoirs Azimuth in XC area

（3） Weak Amplitude Delineation

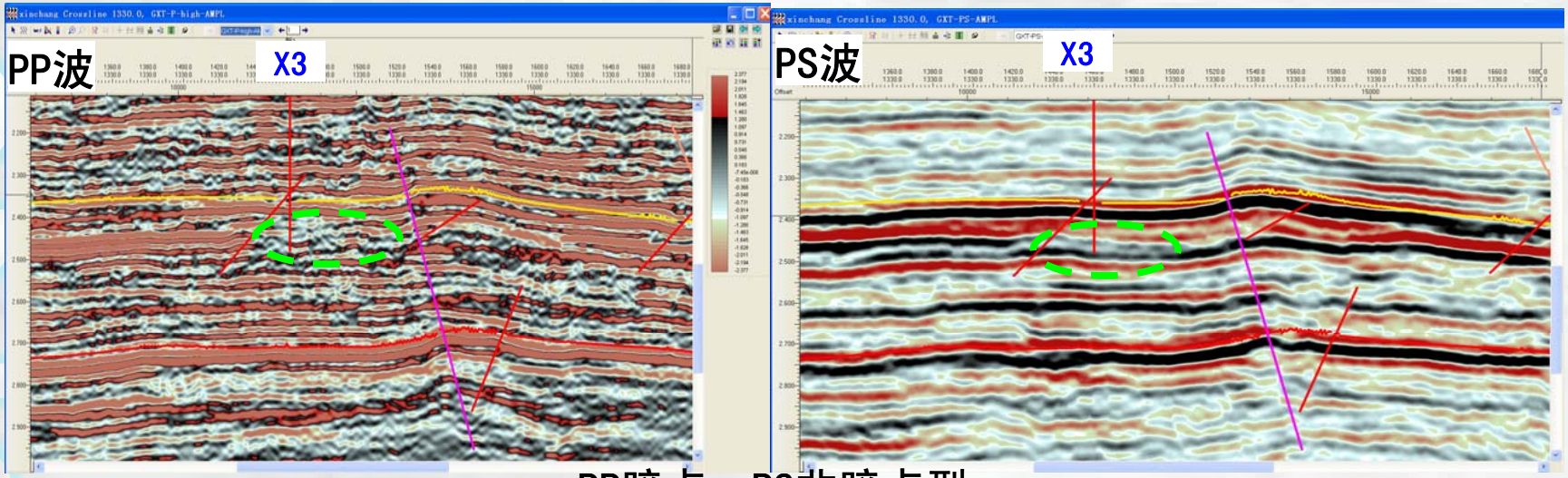
we realized:

1. PP&PS all “Dim spot ”： represent formation is ruptured， reservoirs have better Gas-bearing（X2、X856、CX565）；
2. “Dim spot ” in PP，PS is continuous reflection：represent fracture growth，good gas-bearing，But the formation Unruptured（X3）
3. PP&PS all continuous reflection：represent reservoirs fracture less development，having some Gas-bearing （L150）。

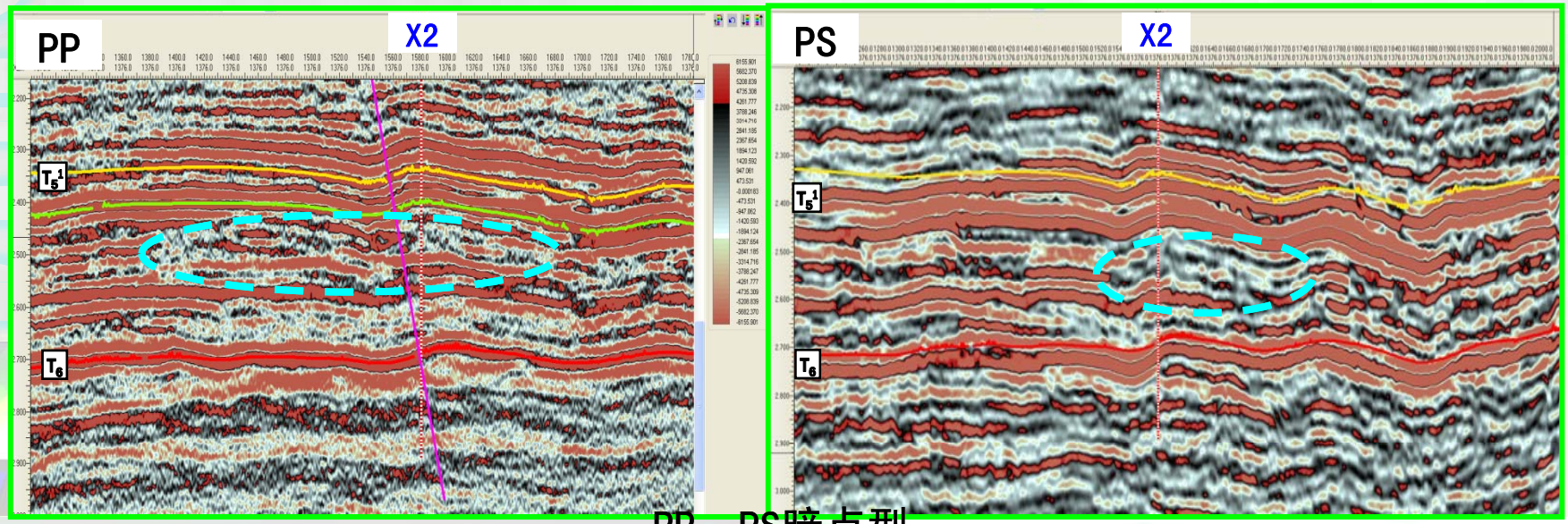
依托3D3C纵横波资料，深化暗点技术研究，认为：

1. 纵波、横波均为“杂乱弱反射”，反应地层结构发生断裂或破裂，储层含气性好（X2、X856、CX565）；
2. 纵波“杂乱弱反射”横波连续强反射，代表储层裂缝发育，含气性较好，但地层结构未破裂（X3）；
3. 纵横波都是连续反射，反映储层裂缝欠发育，具有一定含气性（L150）。

Weak Amplitude Delineation



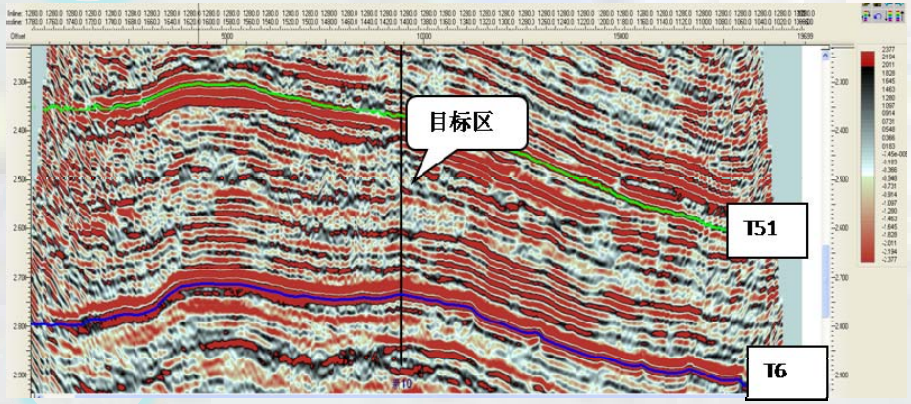
PP暗点、PS非暗点型

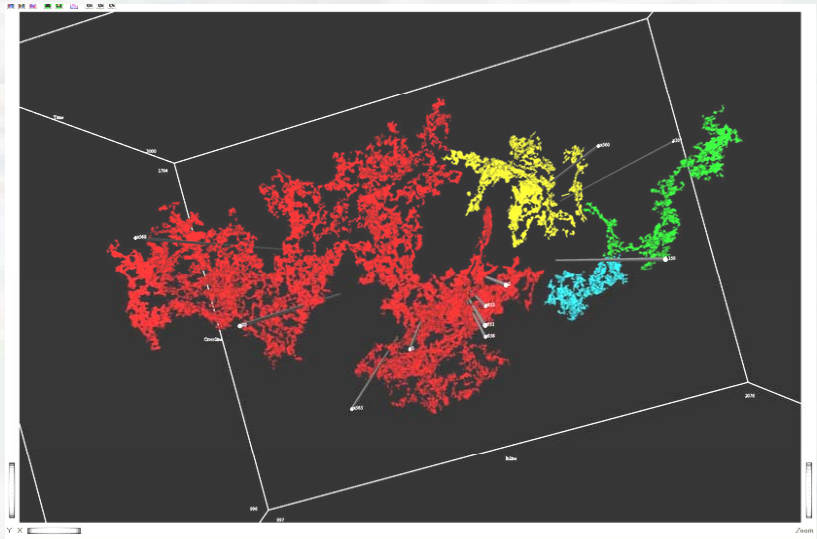


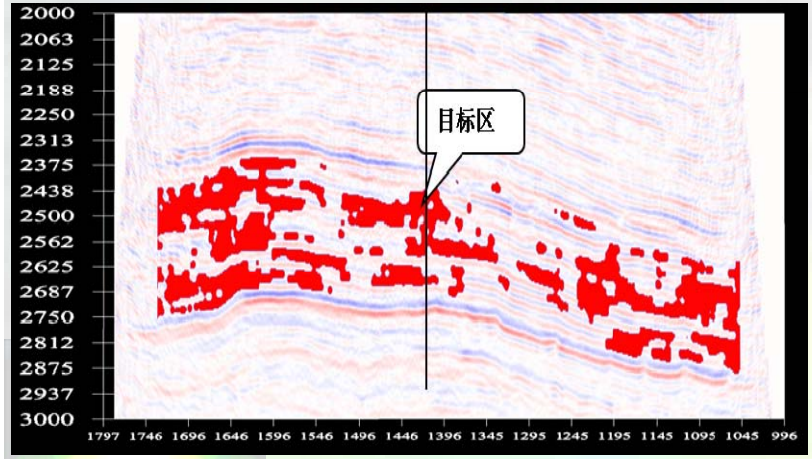
PP、PS暗点型

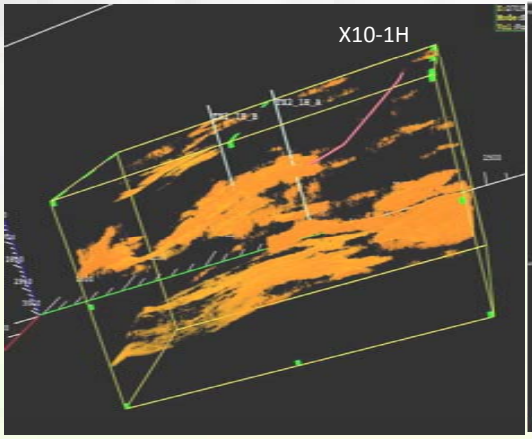
Weak Amplitude Delineation

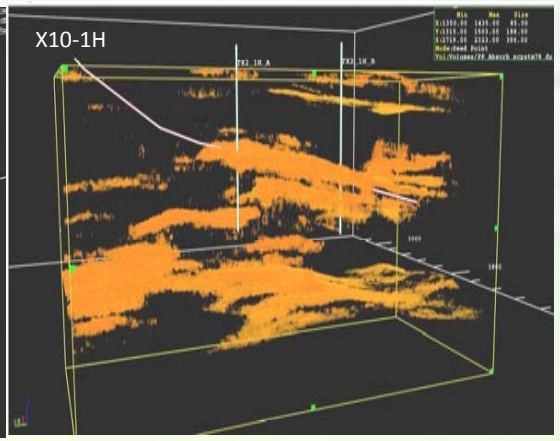
弱振幅表征



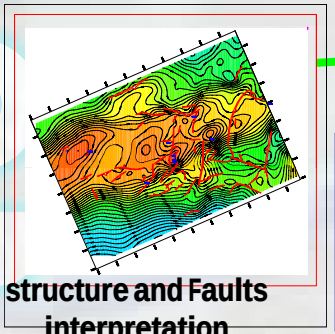




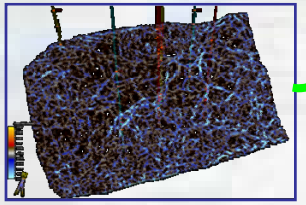




Fracture detection workflow

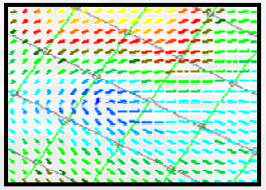


structure and Faults interpretation



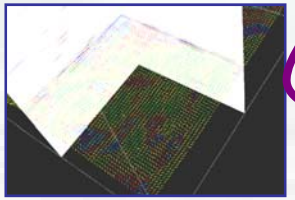
Based on Seismic Attributes fracture prediction

Big scaled fault and Fracture system prediction

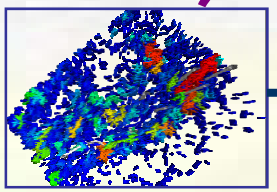


Based on PP fracture prediction

Small scaled fracture prediction

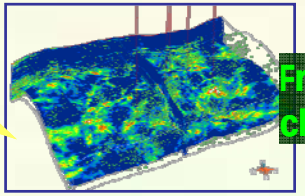


Based on PS-wave splitting fracture prdiction



Geohistory genesis fracture prediction

Fracture effectiveness Analysis



Fracture network modeling

Fracture characteristic

预测大尺度的断裂和破裂系统，采用P波和S波的相干体、倾角、方位角或SVI像素处理等；预测小尺度裂缝采用P波方位各向异性、S波分裂方法。

big scaled faults and fracture system using Faults interpretation 、PP&PS coherency 、dip and azimuth cub ，and SVI processing，small scaled fracture using PP Azimuthal anisotropy and PS splitting technology.

◆（4）PP azimuthal anisotropy for fracture prediction

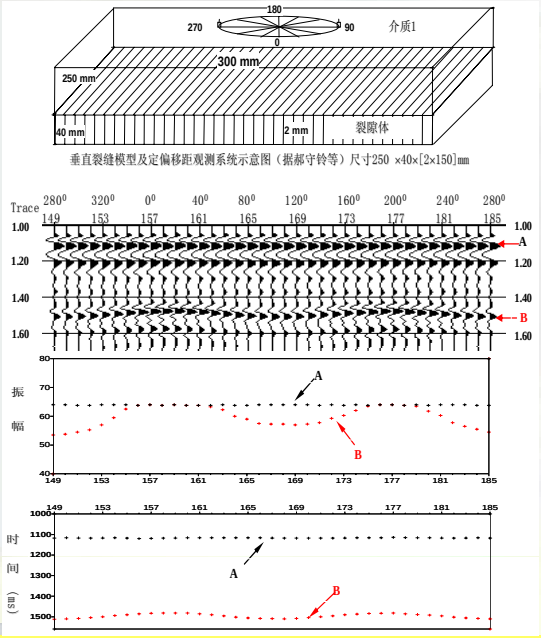
P波方位各向异性裂缝检测

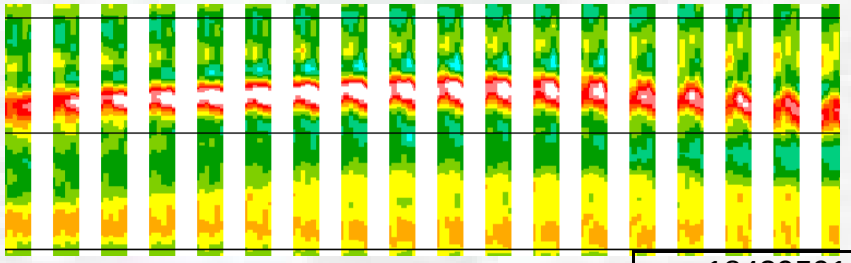
AVAZ＋VVAZ

①AVAZ

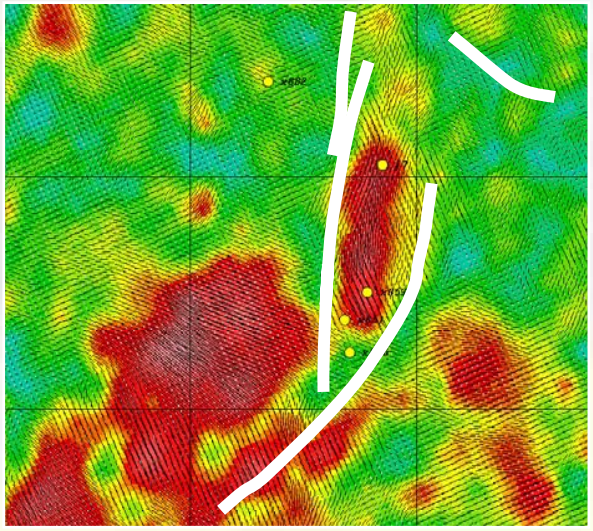
P波振幅方位各向异性

HTI media

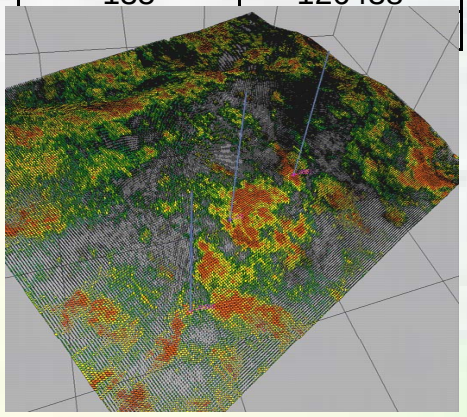




Attribute change in Azimuth gather



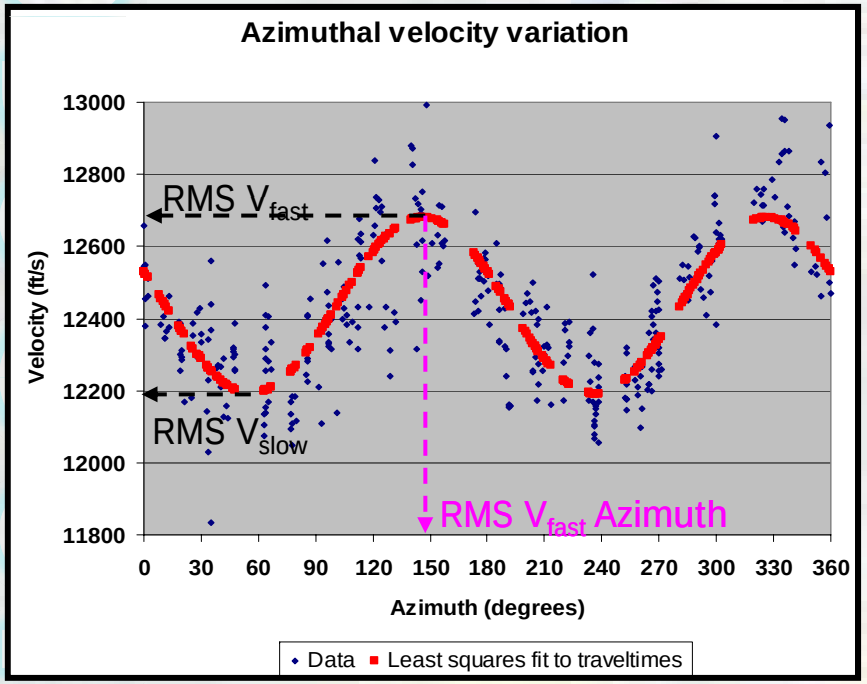
18439591、3459019	
方位	振幅
15	100143
45	78951
75	90015
105	129432
135	126438

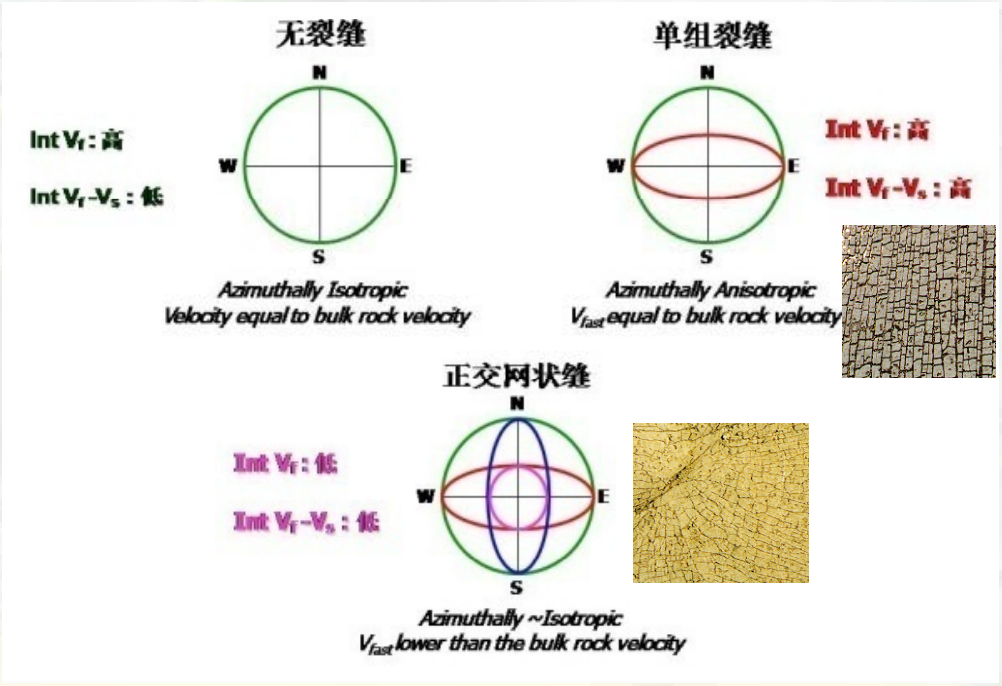


AVAZ is effective in detecting single direction fracture ,but it is not a good way to detect network fracture

AVAZ对于单组裂缝检测比较有效，但对于网状裂缝的检测具有局限性

②VVAZ P波速度方位各向异性对不同裂缝系统的响应





- RMS V_{fast}
- RMS V_{fast} Azimuth
- RMS V_{fast}- V_{slow}

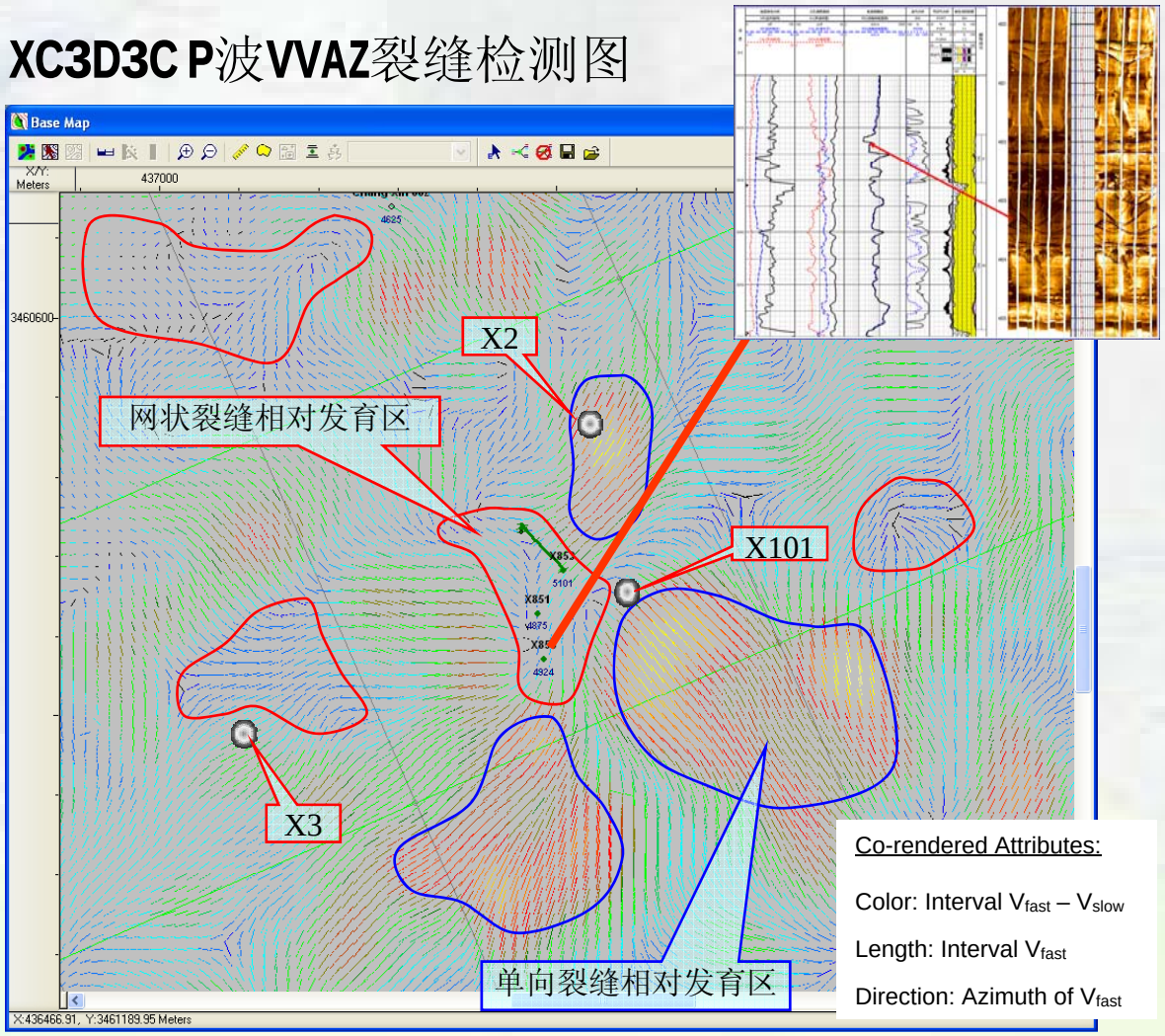
PP Azimuthal anisotropy different response to different network fracture

3D3C PP VVAZ fracture detection map of X851well area in XC

XC3D3C P波VVAZ裂缝检测图

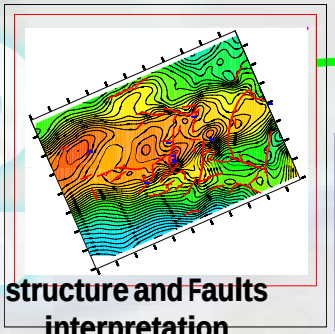
X851井、X856井附近：
Vf低值，Vf-Vs低值，短线段区，表明网状裂缝发育。
Vf高值、Vf-Vs高值，红色长线段区，表明单组裂缝较为发育。
Vf高值，蓝色长线段区，为裂缝不发育区。

Around well X851、X856，Vf in low-Value area，Vf-Vs is low too，reveal network fracture 。
red area showing high Vf value 、Vf-Vs is high too， reveal **single dirction** fracture 。
Blue & long line area: **fracture is not developed** 。

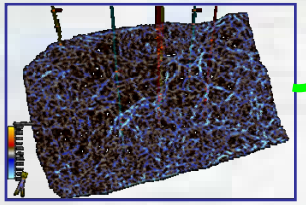


T5.1-T5.11 Layer – Interval AZIM™ Icons

Fracture detection workflow

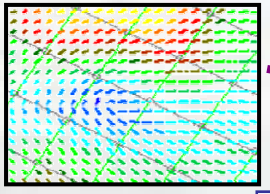


structure and Faults interpretation



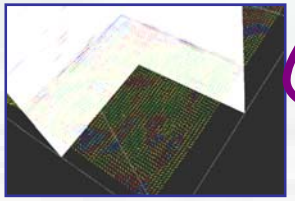
Based on Seismic Attributes fracture prediction

Big scaled fault and Fracture system prediction

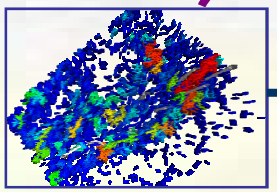


Based on PP fracture prediction

Small scaled fracture prediction

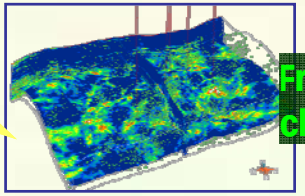


Based on PS-wave splitting fracture prdiction



Fracture effectiveness Analysis

Geohistory genesis fracture prediction



Fracture characteristic

Fracture network modeling

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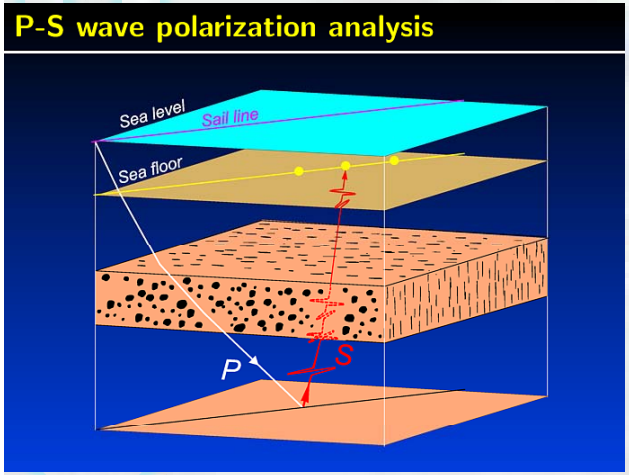
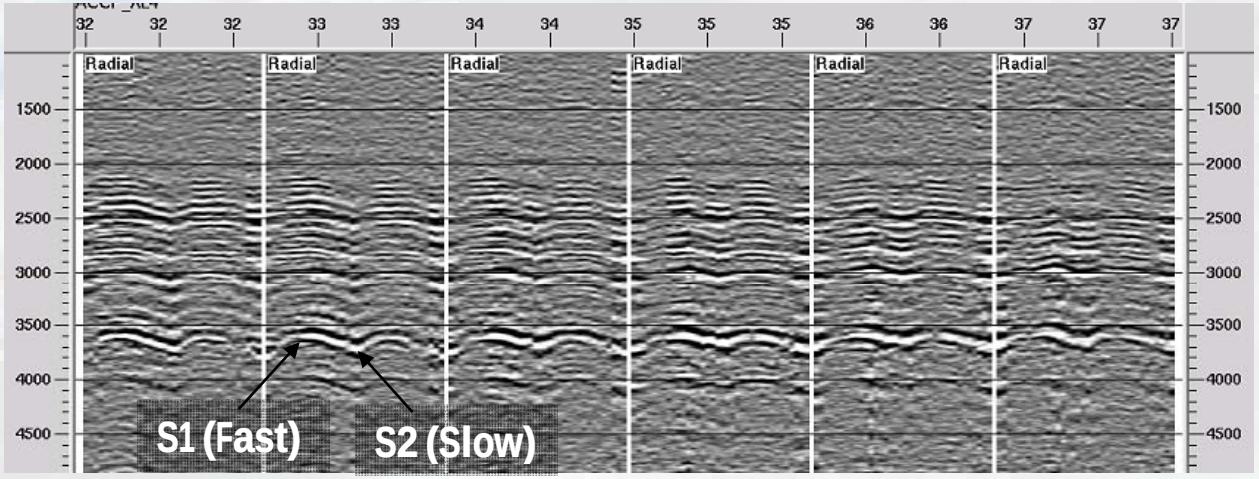
◆（5）PS-Wave Splitting

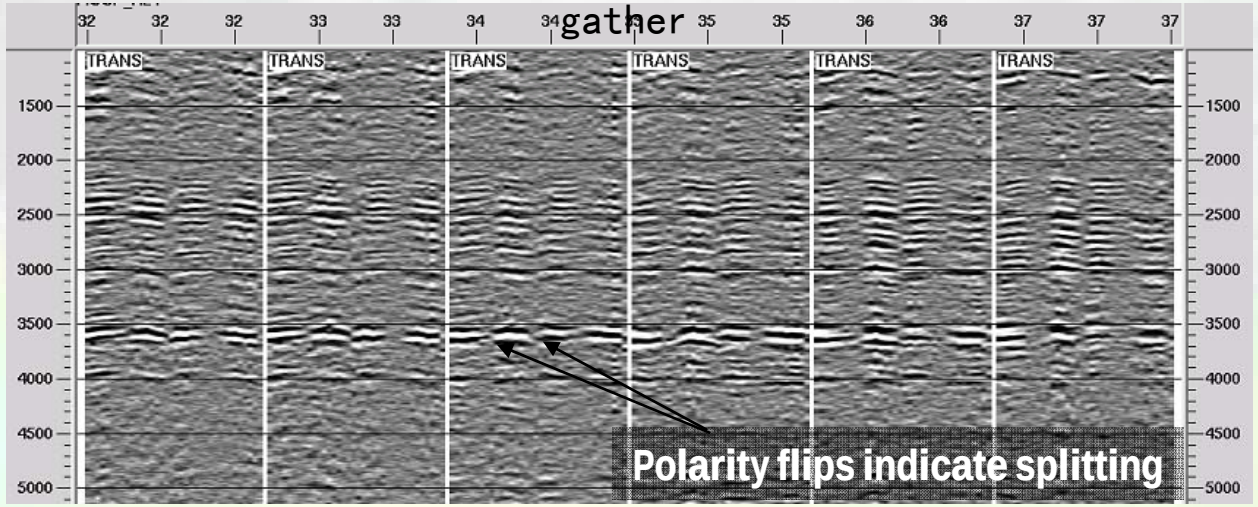
横波分裂裂缝检测





XC 3D3C Radial component Azimuthal stack gather

Fracture evidence growth in PS-wave Azimuthal PSTM gather



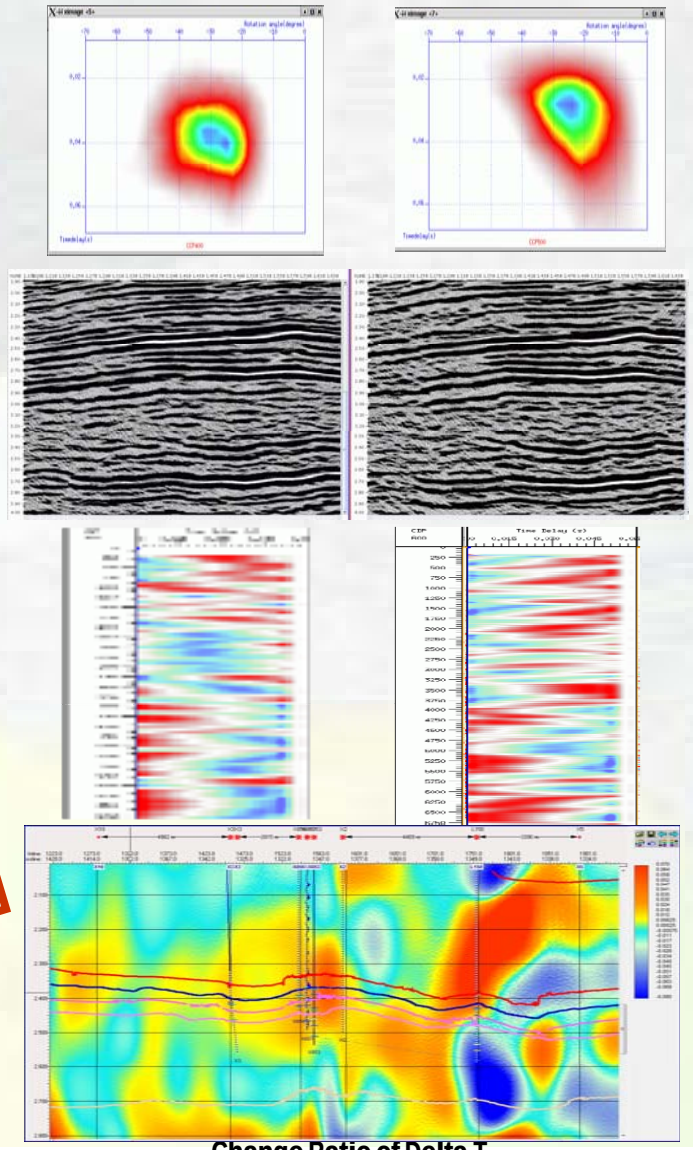
XC T-component Azimuthal stack gather

PS波方位PSTM道集中裂缝发育证据

①Mistiest gradient method 时差梯度法

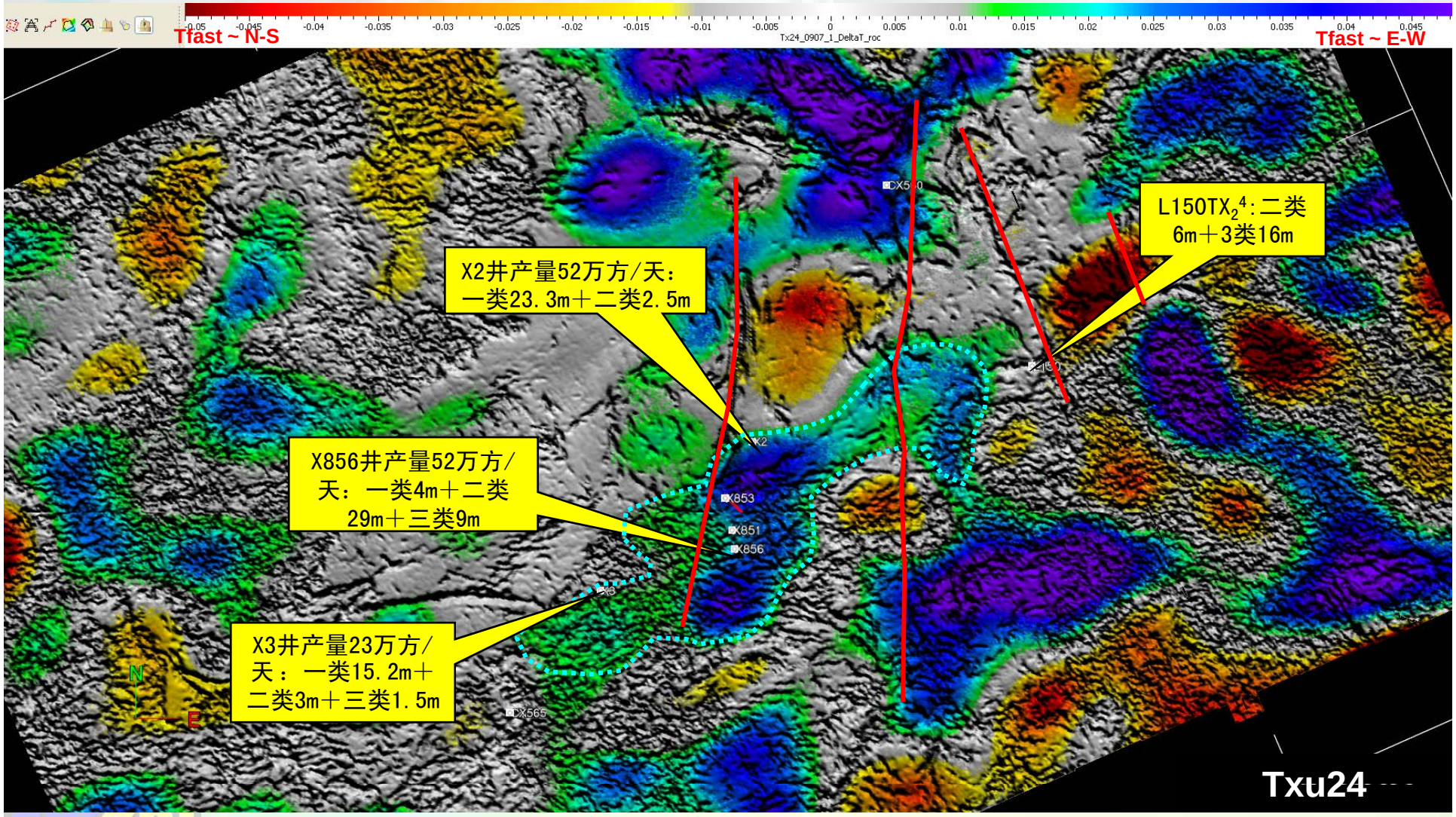
1. 在一定的时窗范围内通过角度扫描和时差计算，得到区域裂缝方位。
2. 将地震资料的径向分量和横向分量旋转到该方位上，得到近似的快波和慢波。
3. 根据快、慢波波形相似原则，对快慢波互相关谱进行延迟时扫描。
4. 对延迟时作梯度计算得到延迟时差的变化率。

1. In certan range of time windows, through angle scanned and mistiest calculated to obtain regional fracture azimuth。
2. Rotate the R and the T component to this azimuth to obtain approximate fast wave and slow wave
3. According to the principle that fast wave and slow wave have similar waveform, to delay- scanning crosscorrelation spectrum of fast wave and slow wave
4. Calculating time-delay gradient to obtain change ratio of time delay.

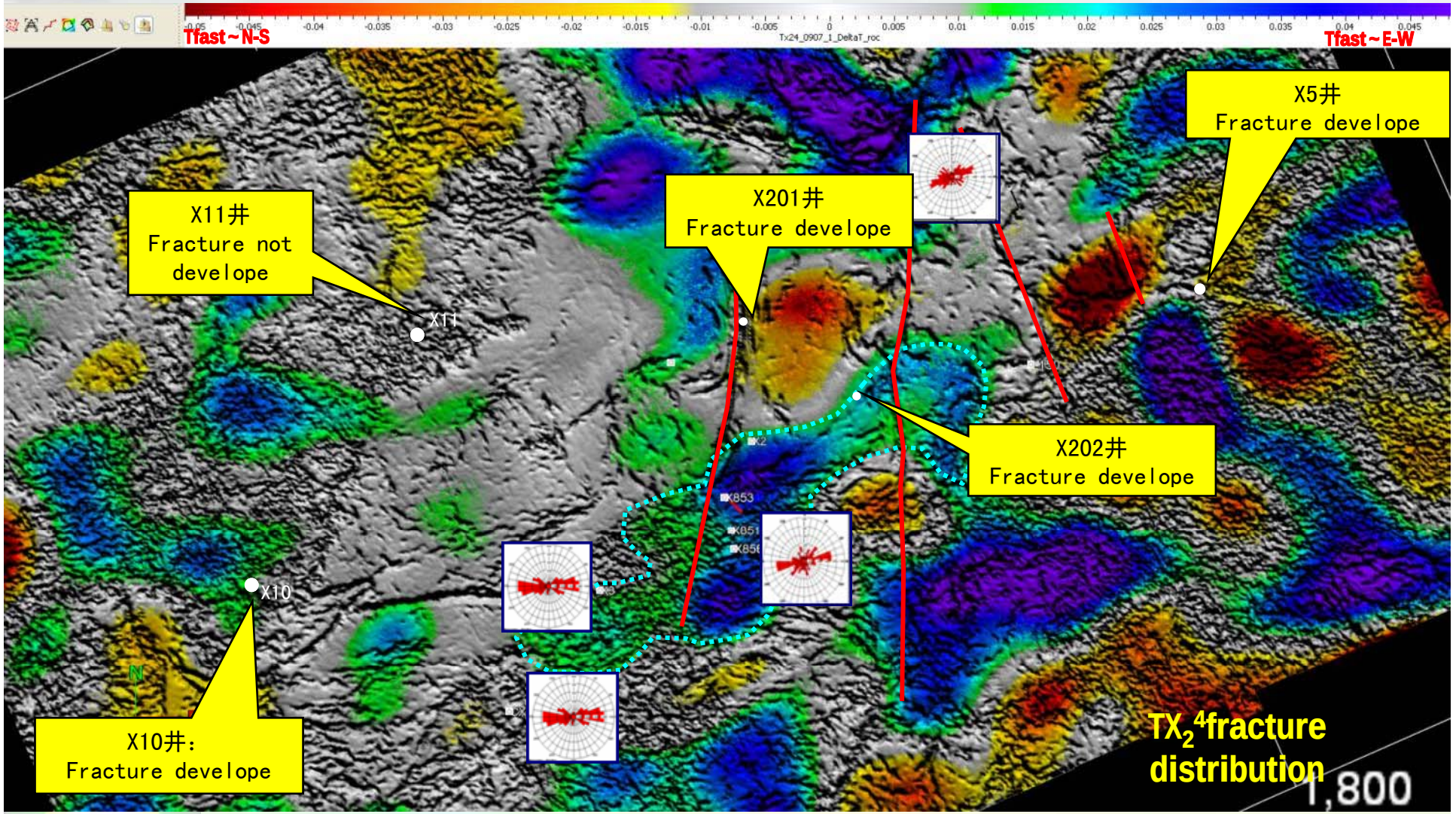


Change Ratio of Delta T

TX_2^4 fracture distribution



Prediction evaluation—fracture prediction



Worm-color zone , blue zone and low coherence zone are favorable, blue represent E_W fracture distribution, worm-color represent SN fracture distribution

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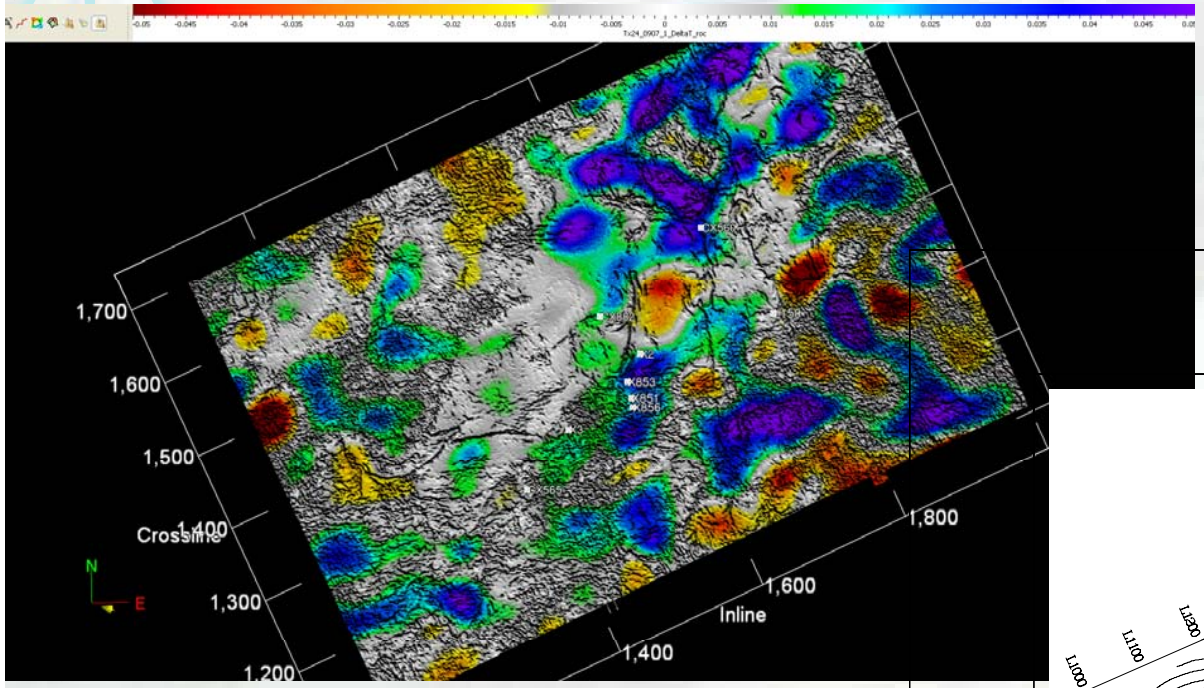
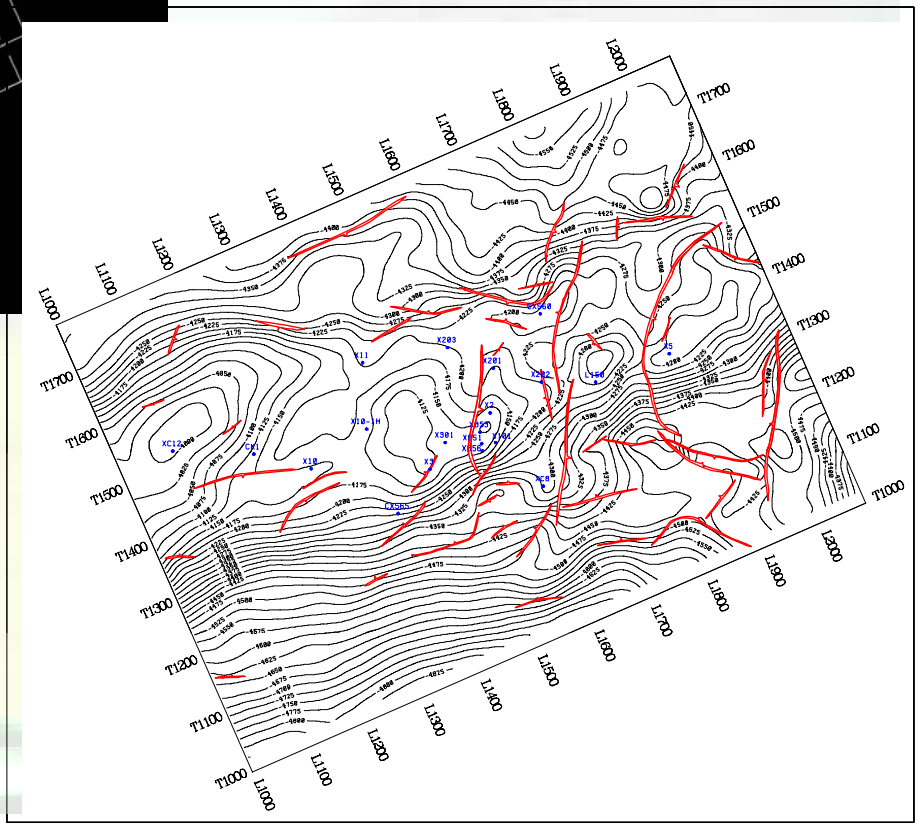
Reliability Demonstration： PS splitting detection fracture consistent with fault distribution

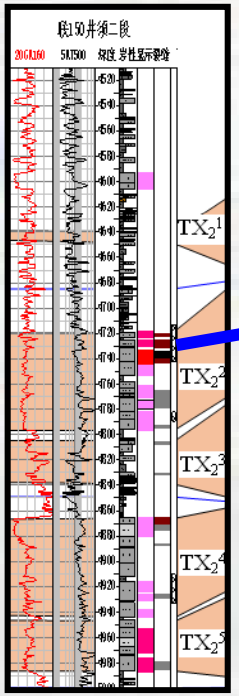


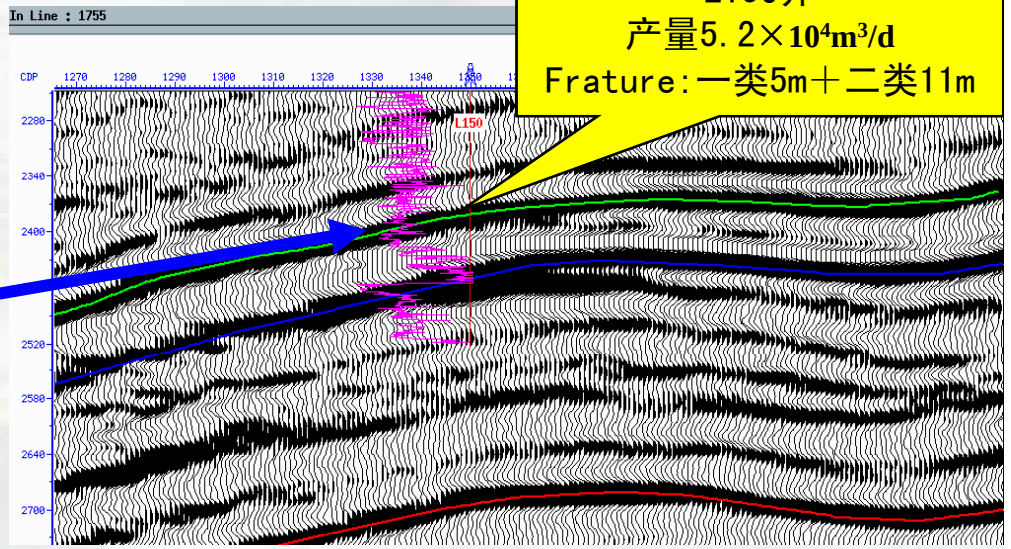


Slice 30

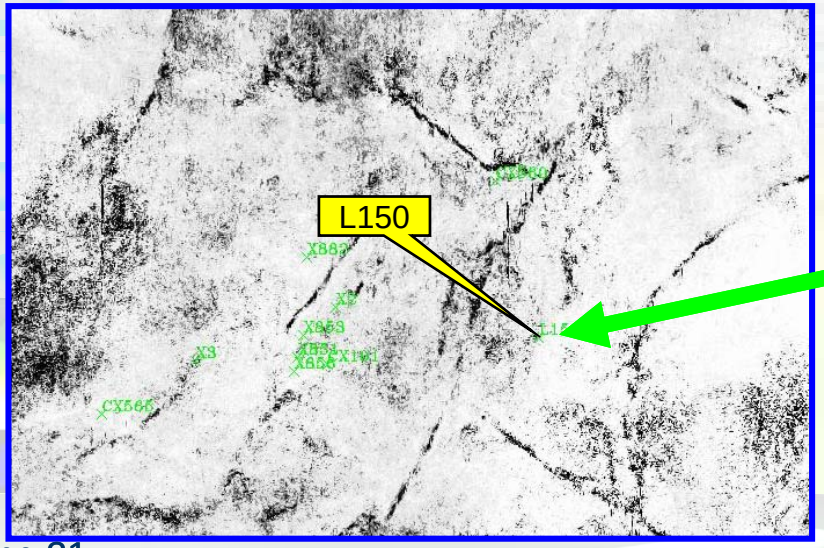
TX22 analysis the effect of prediction

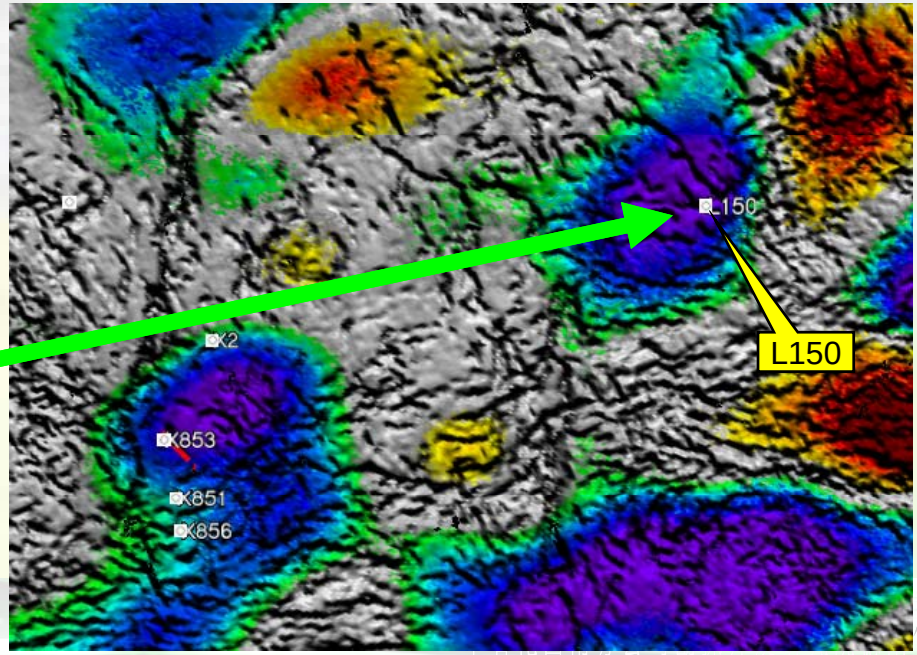
it can predict small scaled fracture, in this field PS splitting is better, than coherence





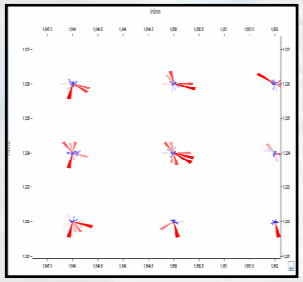
L150井
产量5.2×10⁴m³/d
Frature:一类5m＋二类11m

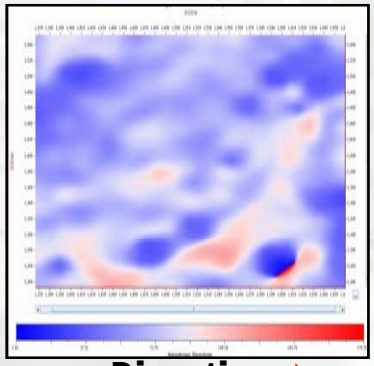




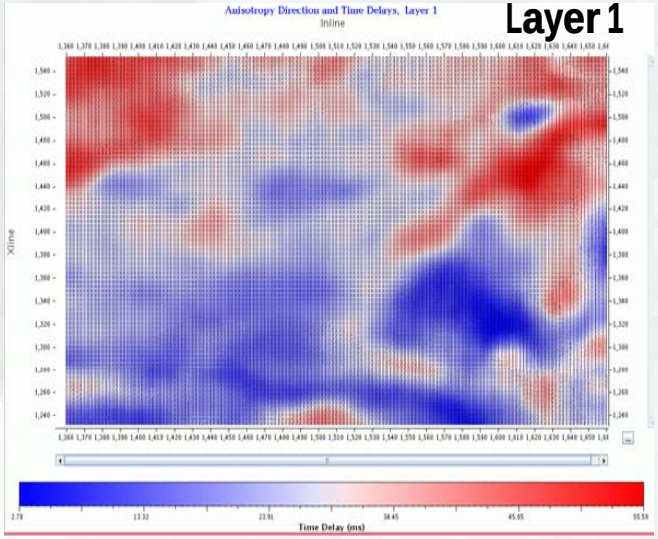
②Layer Stripping

层剥离法

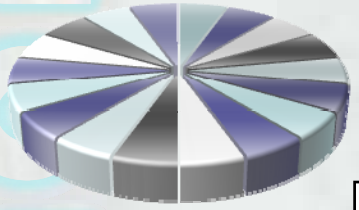


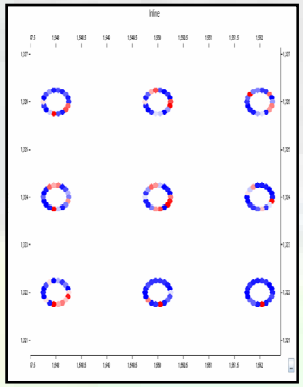


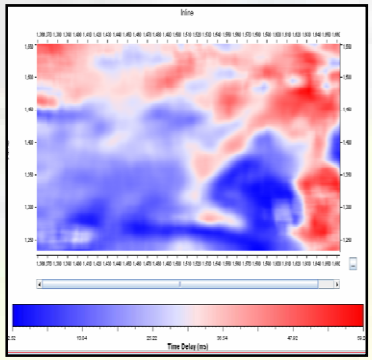
Direction



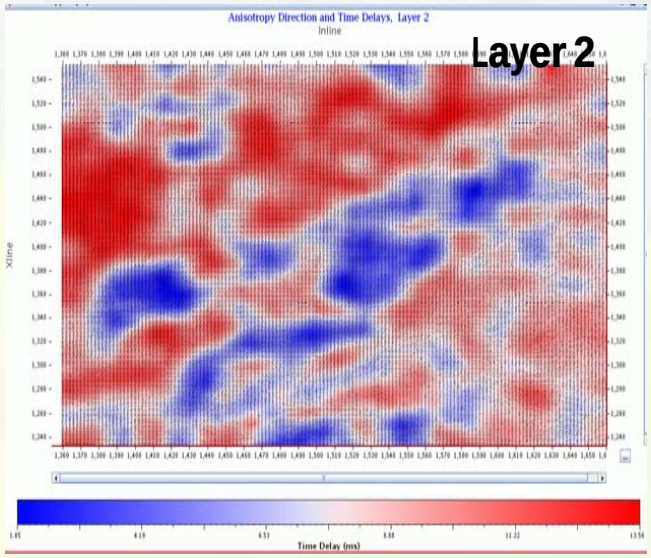
Layer 1







Time Delay

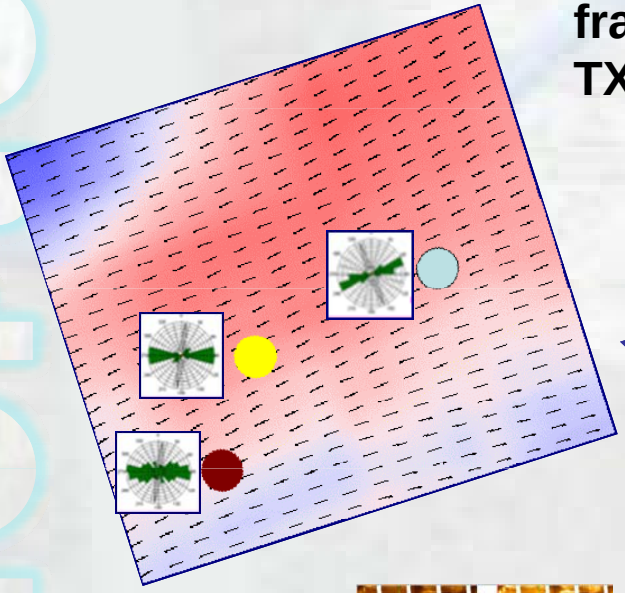


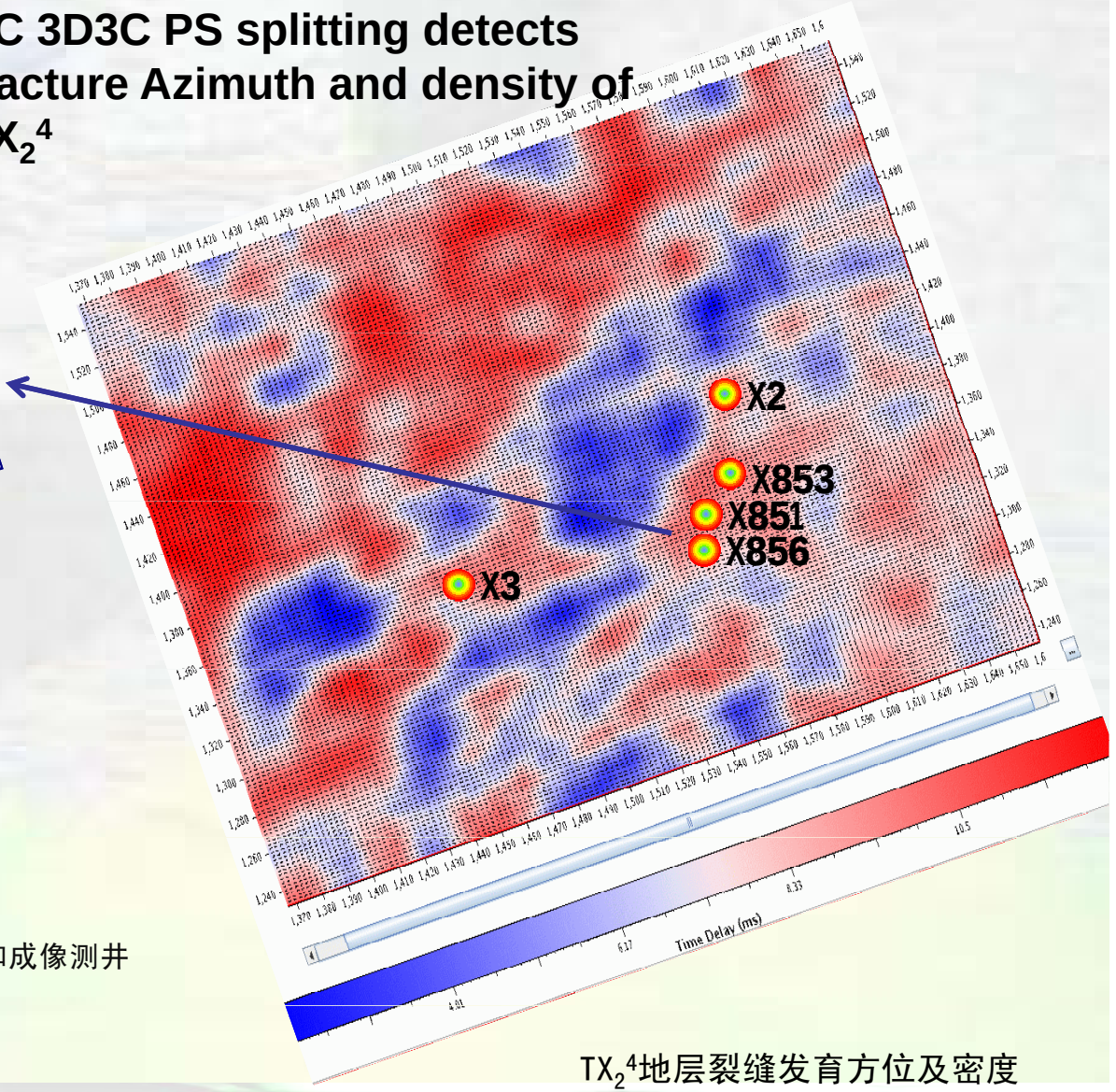
Layer 2

Layer Stripping

Layer Stripping

XC 3D3C PS splitting detects fracture Azimuth and density of TX_2^4

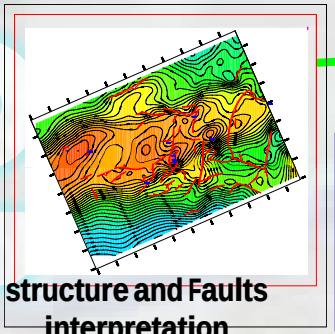




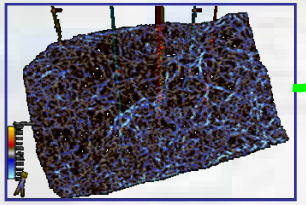
X856井4820m-4825m的方位电阻率（ARI）和成像测井（FMI）清楚地反映有效裂缝的发育情况。

TX_2^4地层裂缝发育方位及密度

Fracture detection workflow

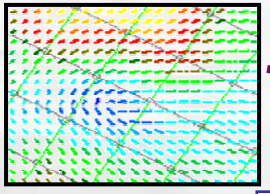


structure and Faults interpretation



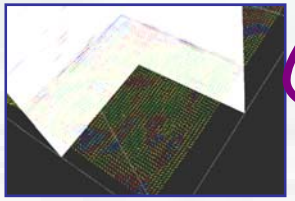
Based on Seismic Attributes fracture prediction

Big scaled fault and Fracture system prediction

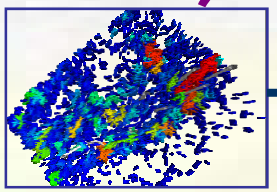


Based on PP fracture prediction

Small scaled fracture prediction

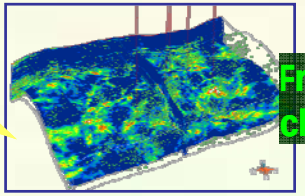


Based on PS-wave splitting fracture prdiction



Geohistory genesis fracture prediction

Fracture effectiveness Analysis



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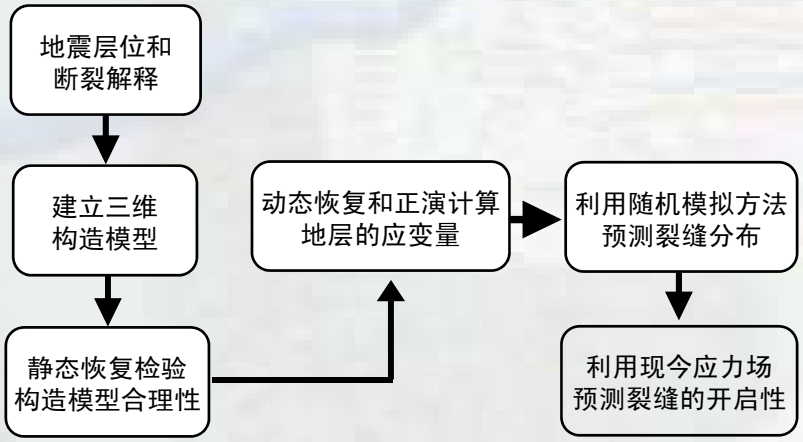
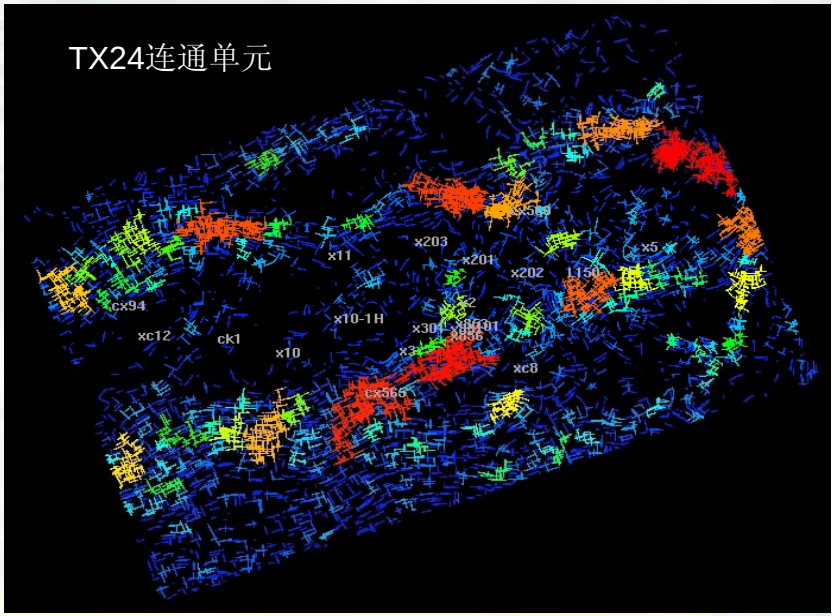
地史成因裂缝有效性分析

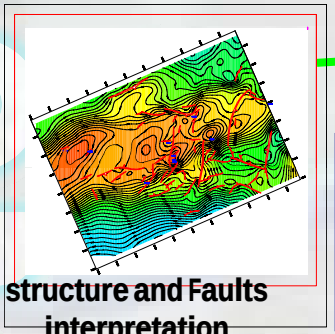
◆(6)Fracture effectiveness analysis of geohistory genesis fracture





- 地史成因裂缝预测是基于地应力场变化的地质成因预测方法，它通过对地层的构造发育史进行恢复，并通过构造演化过程的正演来计算构造运动对地层产生的应变量。

Fracture detection workflow



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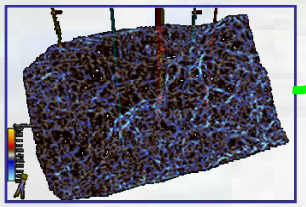
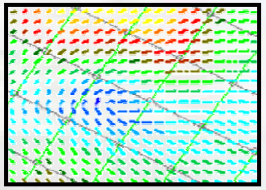


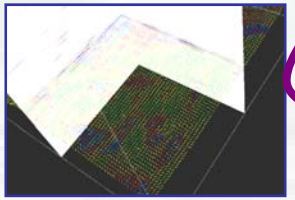
Based on Seismic Attributes fracture prediction

Big scaled fault and Fracture system prediction

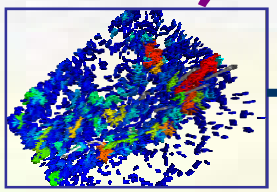


Based on PP fracture prediction

Small scaled fracture prediction

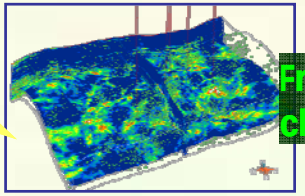


Based on PS-wave splitting fracture prdiction



Fracture effectiveness Analysis

Geohistory genesis fracture prediction



Fracture characteristic

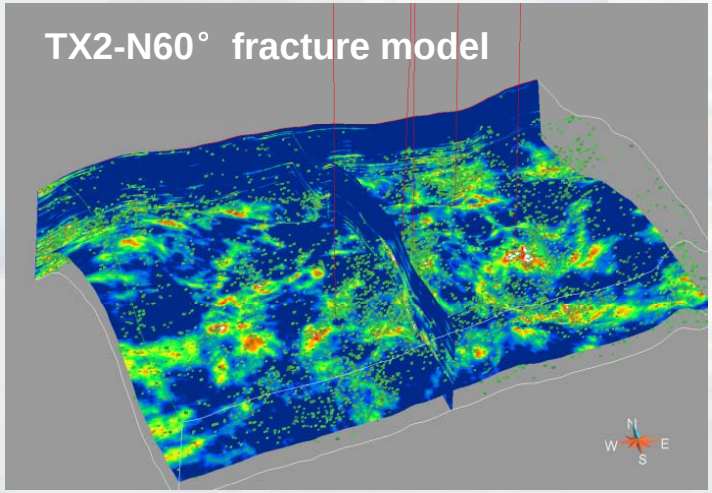
Fracture network modeling

预测大尺度的断裂和破裂系统，采用P波和S波的相干体、倾角、方位角或SVI像素处理等；预测小尺度裂缝采用P波方位各向异性、S波分裂方法。

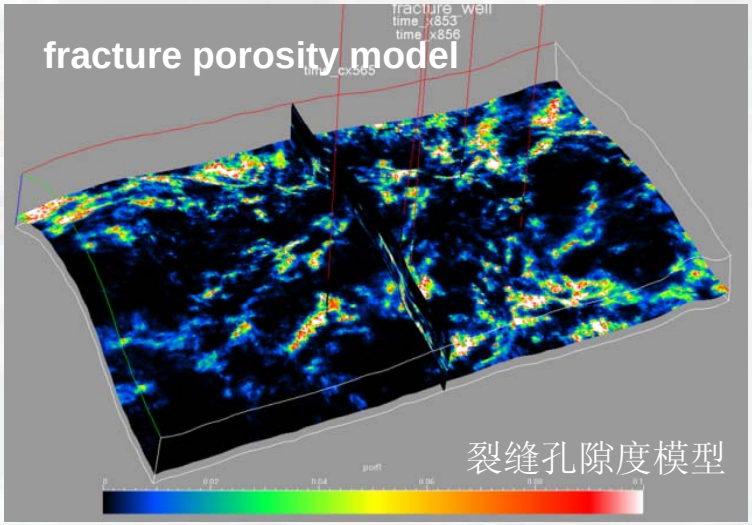
big scaled faults and fracture system using Faults interpretation 、PP&PS coherency 、dip and azimuth cub ，and SVI processing，small scaled fracture using PP Azimuthal anisotropy and PS splitting technology.

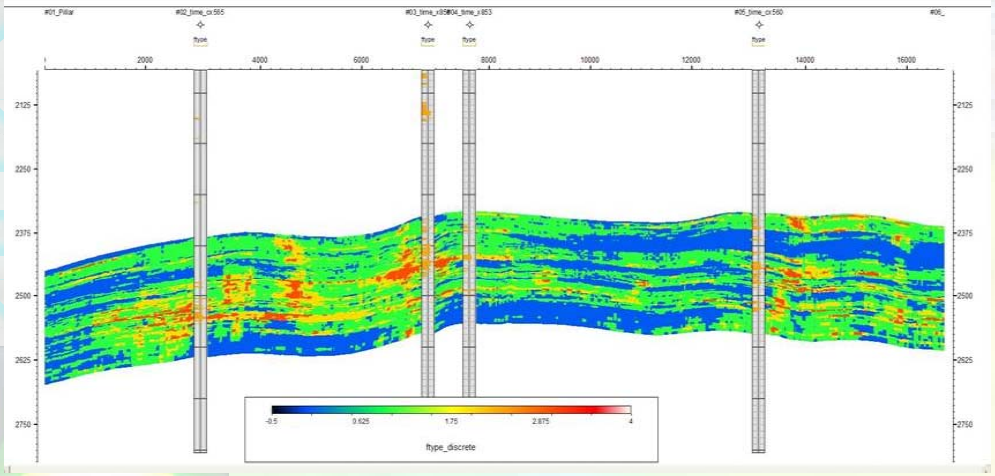
离散裂缝网络建模

◆(7)Scatter network Fracture modeling

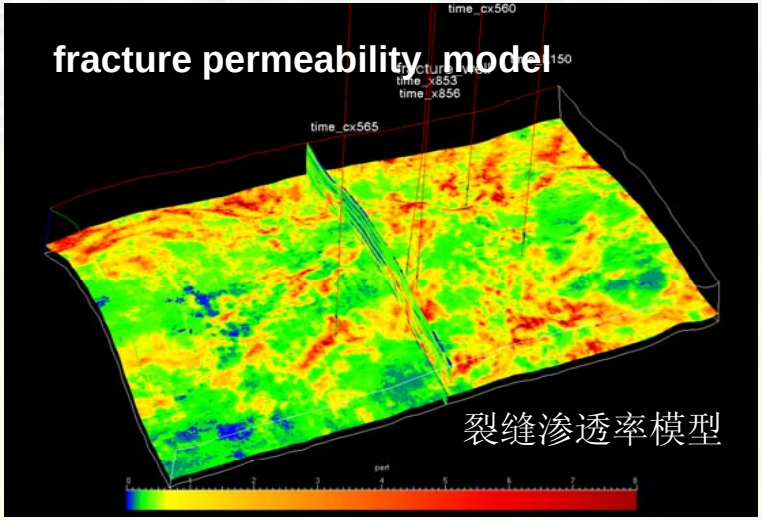


XC3D3C须二段N60方向裂缝模型





过川孝565—新856—新853—川孝560裂缝类型剖面



OUTLINE

general situation

Fracture prediction technology

Fracture Comprehensive evaluation

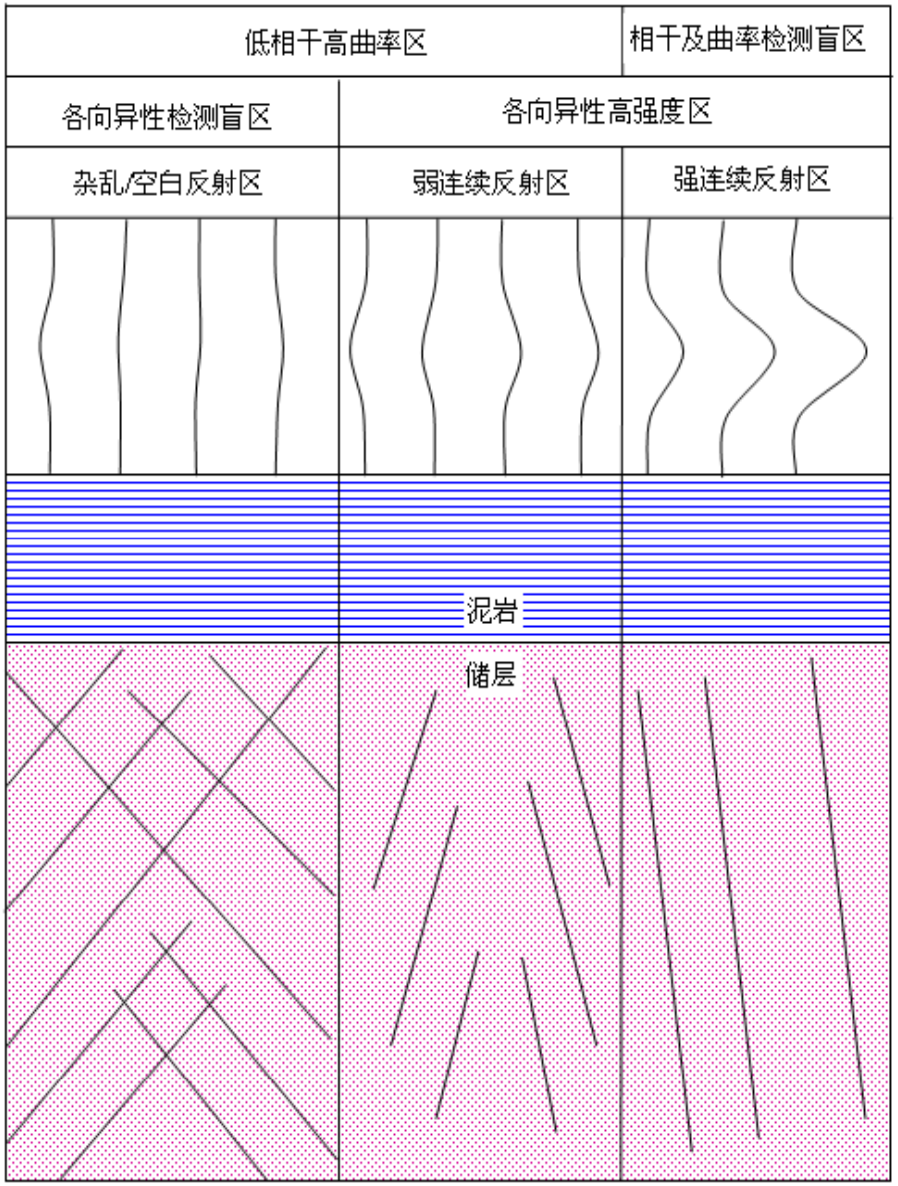
Fracture Comprehensive evaluation

地震裂缝预测适用性与技术配套分析

①就定向裂缝检测能力而言，PP\PS波方位各向异性裂缝预测最强、相干次之、振幅最差

②大型网状裂缝形成的地震杂乱/空白反射区为各向异性及横波分裂裂缝预测盲区，该区域为裂缝发育各向同性区域，几何属性有优势；

③地震几何属性与PP\PS波波方位各向异性及横波分裂裂缝预测技术配套的地震裂缝预测更为有效。



Which method is better?

- *1、when detecting directional fracture：*

  PP/PS azimuthal anisotropy is better than coherence and amplitude.
- *2、network fracture may shrivel the azimuthal anisotropy and PS split,but geometry attribute is good.*
- *3、Use these method together will be more effective.*

◆Fracture Comprehensive evaluation

裂缝综合评价

综合多种信息，依据成藏主控因素和参数敏感性测试结果，给各信息赋予不同的权值，按一定标准进行综合评价。

1. 构造信息
2. 地震相干、曲率属性
3. P波方位各向异性裂缝检测
4. 横波分裂裂缝检测
5. 地质，测井，录井，测试，生产等信息。

Factor of Fracture comprehensive evaluation including：

1.Structure information

2.Coherence and curvature attribution

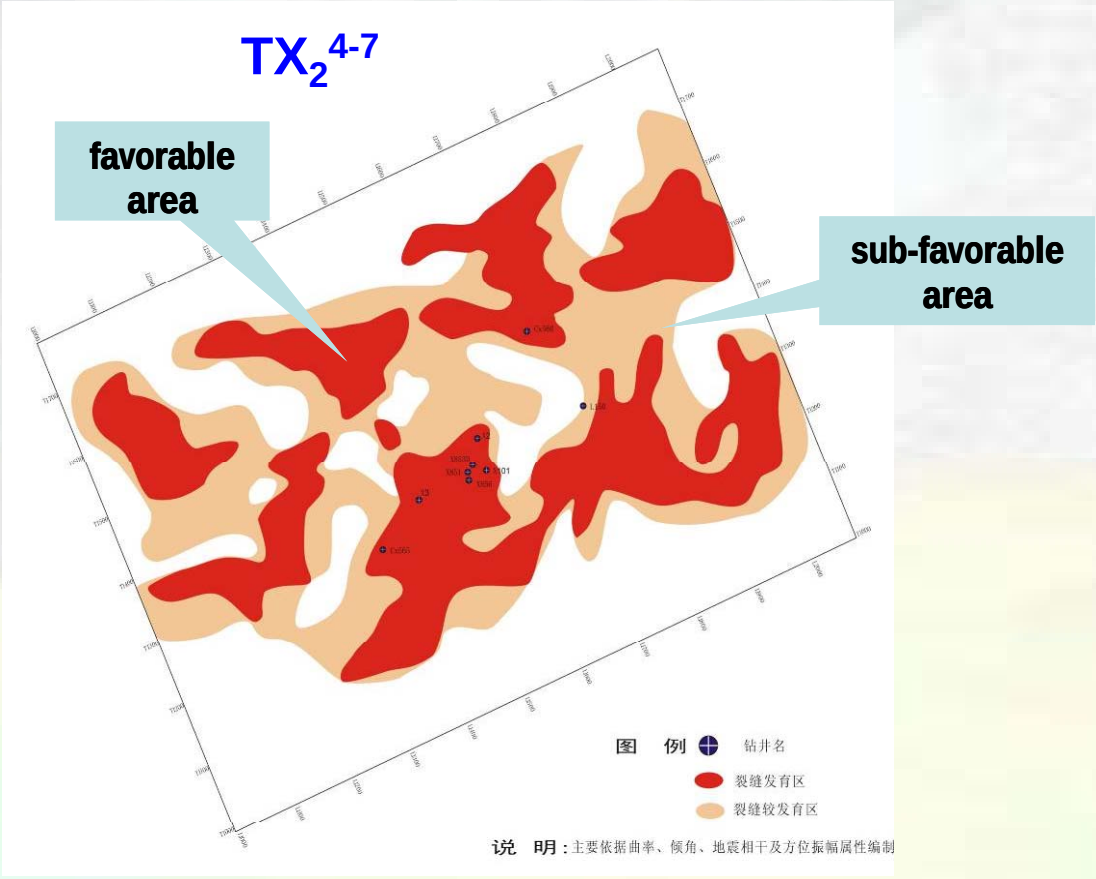
3.PP azimuthal anisotropy result

4.PS splitting result

5.geology,log, borehole, testing production etc.

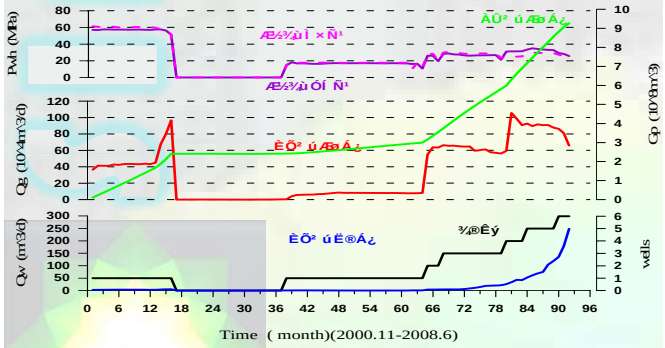
以储层为单元，以钻井裂缝评价为约束，进行裂缝发育带综合预测评价，分为发育区和较发育区两类

control by wells fracture information , Fracture Comprehensive evaluation result is divided into two types （favorable zone and sub-favorable zone）.



近两年取得了重要的油气成果，钻井成功率及高产率大幅度提高

- **Achieved important results of the gas in the past two years， drilling success rate and high yield rate increase greatly**
  - **(1)following the success of X851 well in 2000,drilling success rate promoted from 50% during 2001～2005 to 67%～80% during 2006～2008 in X4and X2 exploration.**
  - **(2)obtained a large number of high-yield wells， high-yield rate increased clearly.**



新场须家河组气藏 2001—2008 年钻探成功率比较

年份	实施井完成测试井				成功率	高产率
	层位	完成测试井	成功井	产量(万方/天)		
2001～2005	须四	X882、X884	X882	2.57	50%	0
		X855、CX568	X884	2.98		
	须二	X856、X853、CX560 CX565、CL562、L150	X856	55.46	50%	17%
			X853	5.38		
			L150	5.76		
2006～2008	须四	XC21、XC22、L116	XC22	17.8	67%	67%
			L116	8.1453		
	须二	X2、X3、X101 X10、X5	X2	52.0	80%	80%
			X3	23.08		
			X10	10.33		
			X5	14		

TX2 Gas reservoir cumulative gas production more than $9\times10^8m^3$

THANK YOU FOR YOUR ATTENTION!