Tight Gas Reservoir Characterization with 3D3C Data*

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Abstract

In this paper, we showed our recent and improved results using land-based multi-component (MC) surveys in the largest gas filed in China, Sulige gas filed. The main gas reservoir, known as He8 formation, is located between 3,200 and 3,600 m in depth and is interbedded with sand and shale. Because the reservoir is thin (3-10 m) and strongly anisotropic, the average porosity ranges 5-10% and permeability is 0.06-2 mD. It is a typical tight gas sand reservoir with low porosity low permeability, which is very difficult to characterize using P-waves alone. Compared to the conventional one-component P wave exploration, MC method is more effective in lithology prediction and fluid identification for the integration of both PP and PS data.

Based on detailed rock physics analysis, we select the most sensitive elastic properties for reservoir characterization in Sulige gas filed. Through PP and PS event matching and alignment, the PP and PS data in PP domain applies to joint interpretation and inversion is obtained. Much more seismic attributes could be extracted from MC seismic data than from PP; sensitive MC attributes are selected through detailed analysis of wells and seismic attributes. Joint prestack inversion of MC data based on Knot-Zoeppritz equation is applied for more accurate elastic properties. Most prospecting area is selected with crossplots of multiple sensitive elastic properties and analysis of MC attributes.

The joint simultaneous inversion of PP&PS effectively improves the precision of fluid identification. In addition, the integration of MC attributes analysis and joint simultaneous inversion of MC data significantly enhance reservoir characterization and has greatly improved the success ratio of exploration well in the study area. The integrated MC techniques have been applied in the 3D3C area of tight gas sand and have been supported by more than 80 wells with a success ratio of 86.6%.

Tight gas reservoir characterization with 3D3C data

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05-22-2013

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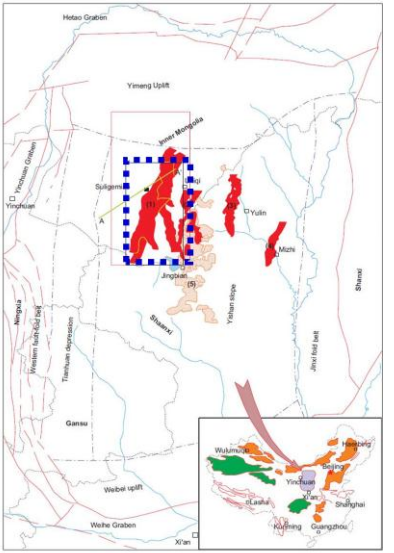
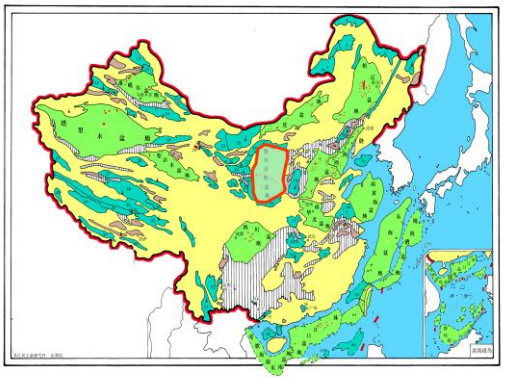
Outline

- Introduction
- Technologies of PP&PS
- Applications in Sulige Gasfield
- Conclusions

Background



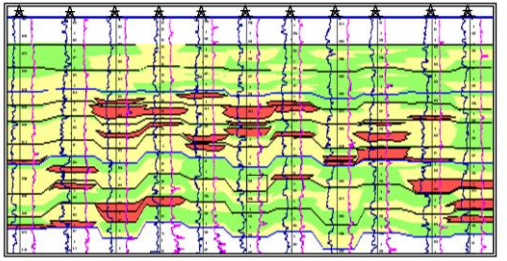
Sulige Gasfield, the biggest gasfield in China, in the northwest of Erdos Basin, the second largest one in China.

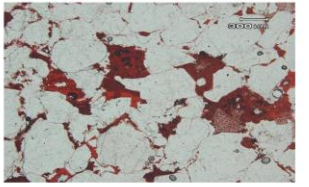


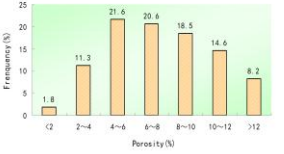
Reservoir features

The main pay zone is Formation He 8 which is a braided river sediment, and the main reservoir is tight sand.

Well tie section







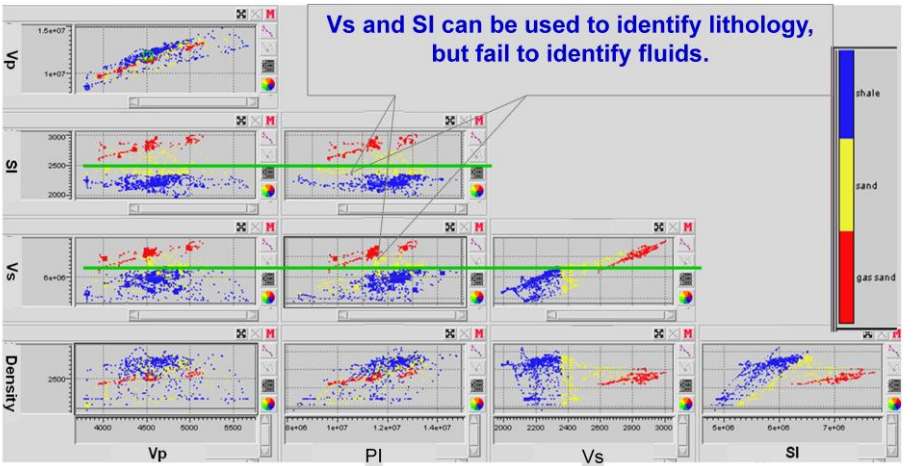
Average porosity 2～12%

Average permeability 0.06～2×10^{-3}μm^2

Thin bed Low porosity and permeability Strong anisotropy

Main challenges of reservoir characterization

- Thin bed
- Small PI contrast between reservoir and host



Advantages of MC seismic

- *Lithology and fluid identification*
- *Flat spot analysis*
- *Imaging through gas clouds*
- *Fracture detection*
- *Improved time-lapse interpretations*

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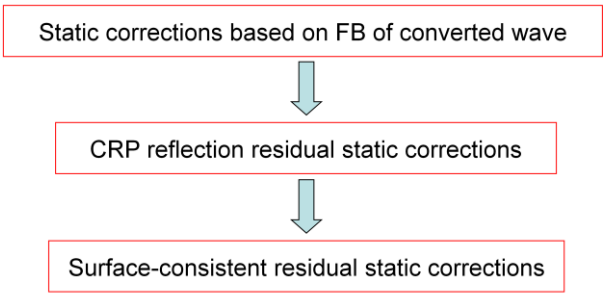
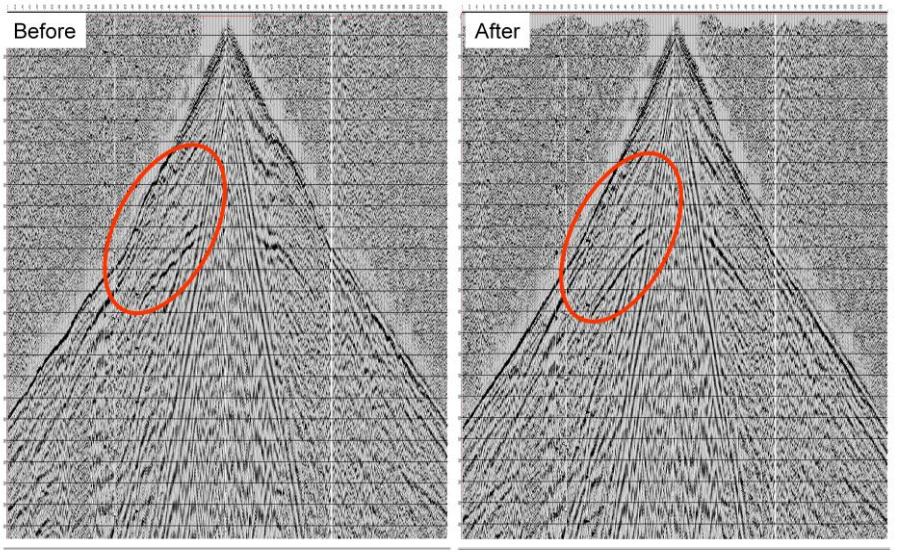
Data processing

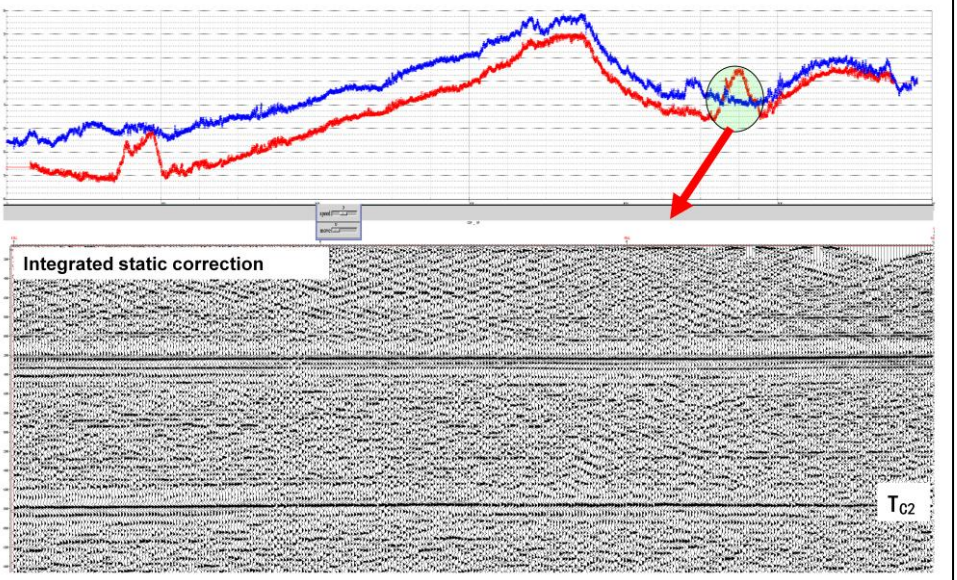
1. Integrated static corrections of converted wave



Integrated static corrections



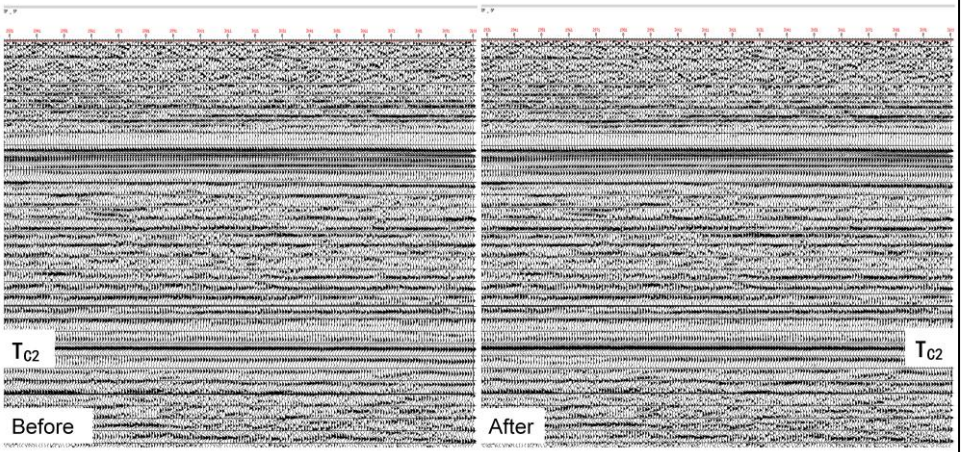
Stack before and after integrated static corrections



2. Resolution improvement

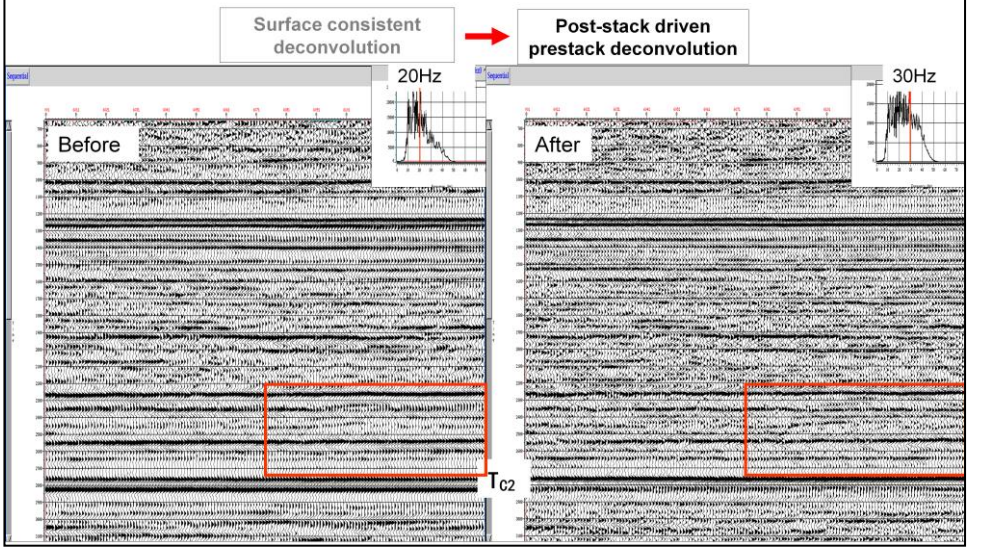
Stack before and after surface consistent deconvolution

Surface consistent deconvolution (Wavelet Shaping) → Post-stack driven prestack deconvolution



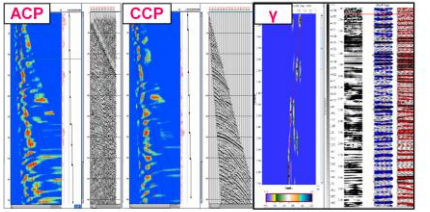
2. Resolution improvement

Stack before and after post-stack driven prestack deconvolution

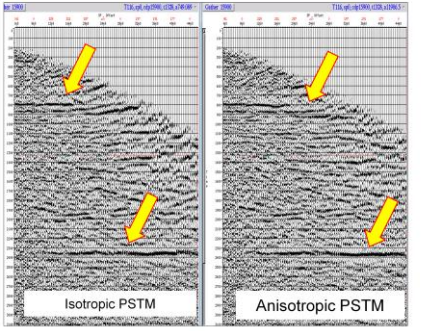


3. Anisotropic PSTM for PS data

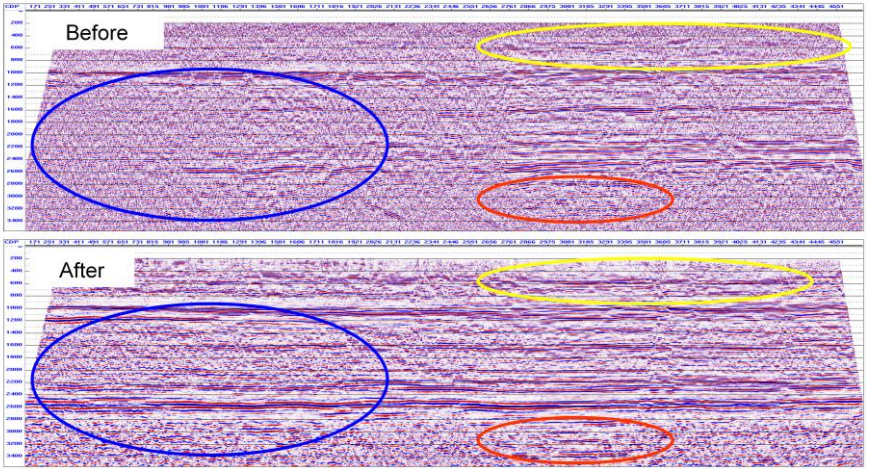
Common converted wave imaging



- **ACP Stack**
- **CCP Stack**
- **PSDMO**
- **PSTM**

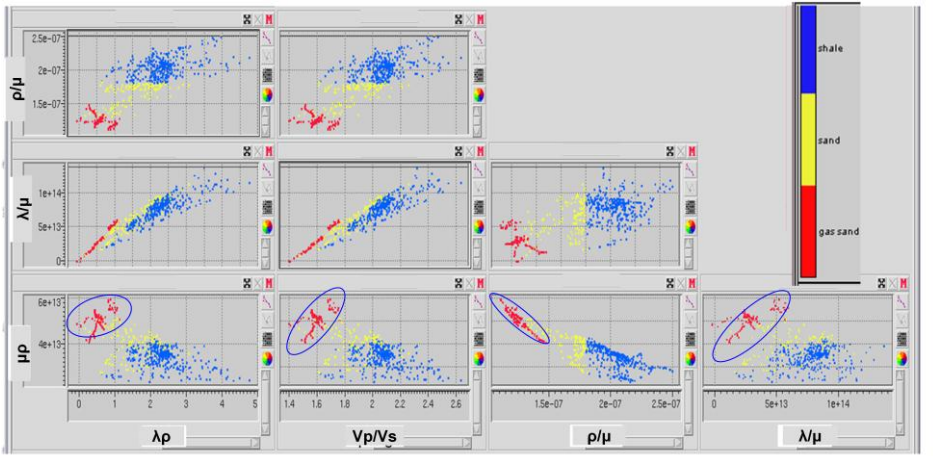


PS data before and after research



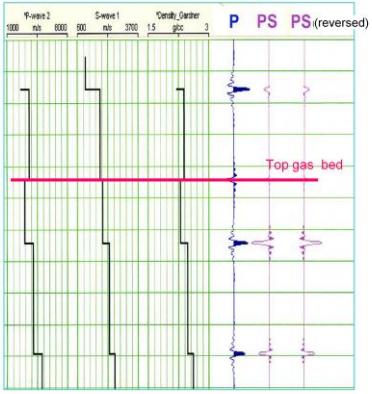
Reservoir characterization

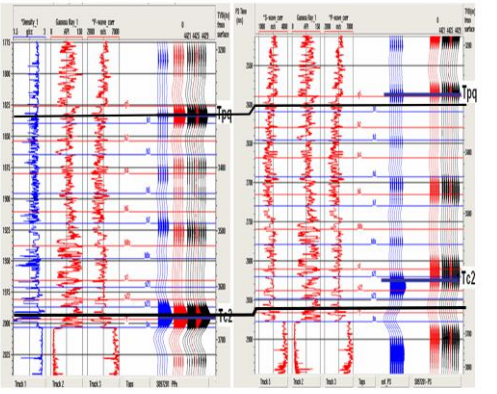
1. Selection of sensitive elastic properties



Vp/Vs, λ/μare sensitive to fluid. Crossplot of μρ,λρ and Vp/Vs can help to identify fluids.

2. Identification of key horizons on PP and PS data





Phase difference between PP and PS

3. Horizon Matching

Due to the different TWT, frequencies and reflectivities, PS data will not be generally aligned with PP data.

- **Compression with the Vp/Vs calculated from the logging data**
- **Matching with the key horizons**

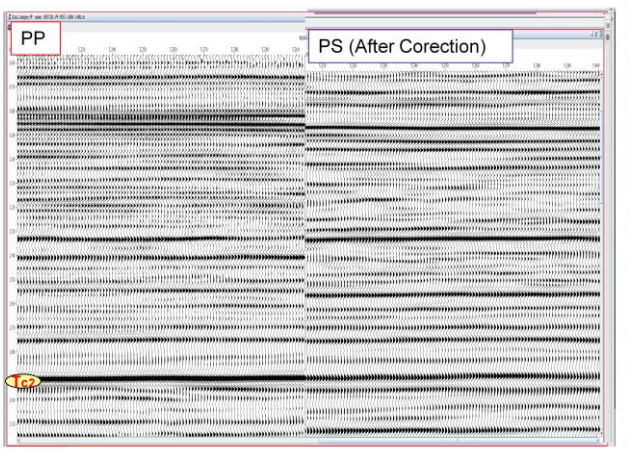
$$\gamma = \frac{V_p}{V_s} = \frac{2h/\Delta t_{pp}}{2h/\left(2\Delta t_{ps} - \Delta t_{pp}\right)} = \frac{2\Delta t_{ps} - \Delta t_{pp}}{\Delta t_{pp}}$$

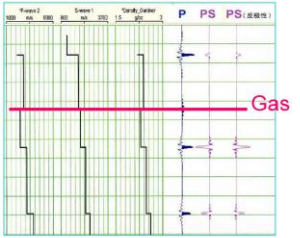
- **Compression with the Vp/Vs from model**
- **Compression with GAMMA data**

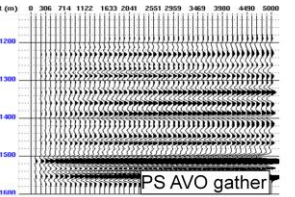
A 3 step method developed for PP & PS matching

A new PP & PS matching method

- Well data driven processing

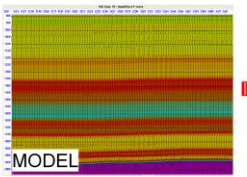


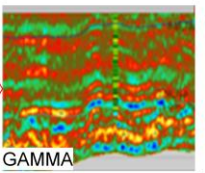


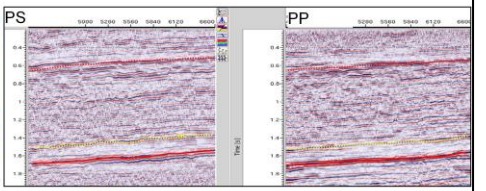


A new PP & PS matching method

- Domain conversion with GAMMA



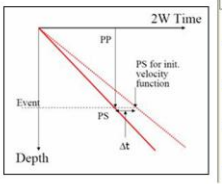


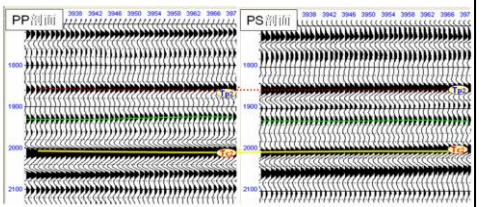


PS (After domain conversion) vs PP

- Horizon matching

$$\gamma = \frac{V_p}{V_s} = \frac{2h/\Delta t_{pp}}{2h/\left(2\Delta t_{ps} - \Delta t_{pp}\right)} = \frac{2\Delta t_{ps} - \Delta t_{pp}}{\Delta t_{pp}}$$

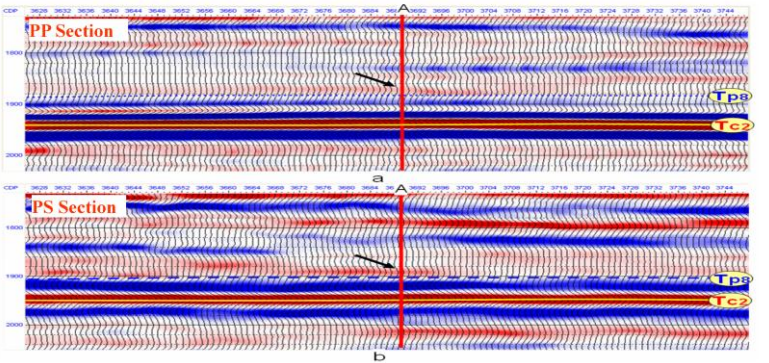




PS (After horizon matching) vs PP

4. MC attributes analysis

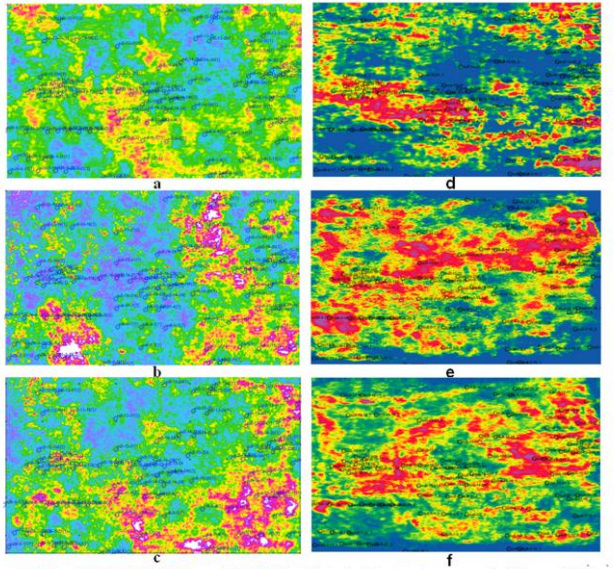
"Bright spots" analysis



"Bright Spot" Section

High lighted volume

Much more seismic attributes can be used with MC data than P-wave alone. This can be very helpful for the prediction.



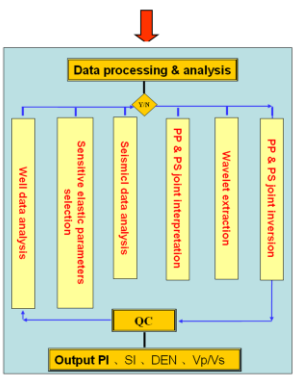
RMS a) PP b) PP/PS c) PP*PS High lighted volume：d) PP e) PS f) PP*PS

Presenter's notes: Figure f demonstrates the product of Hpp and Hps, and is a combination of PP and PS's Highlighted Volume and represents the best results of the three methods.

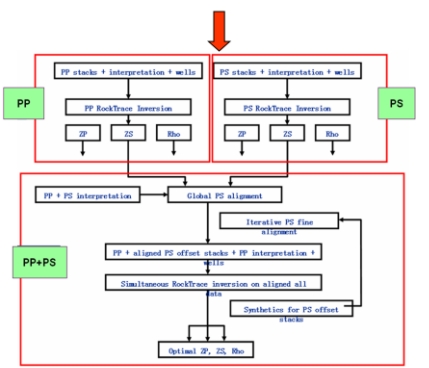
5. Joint inversion of PP and PS data

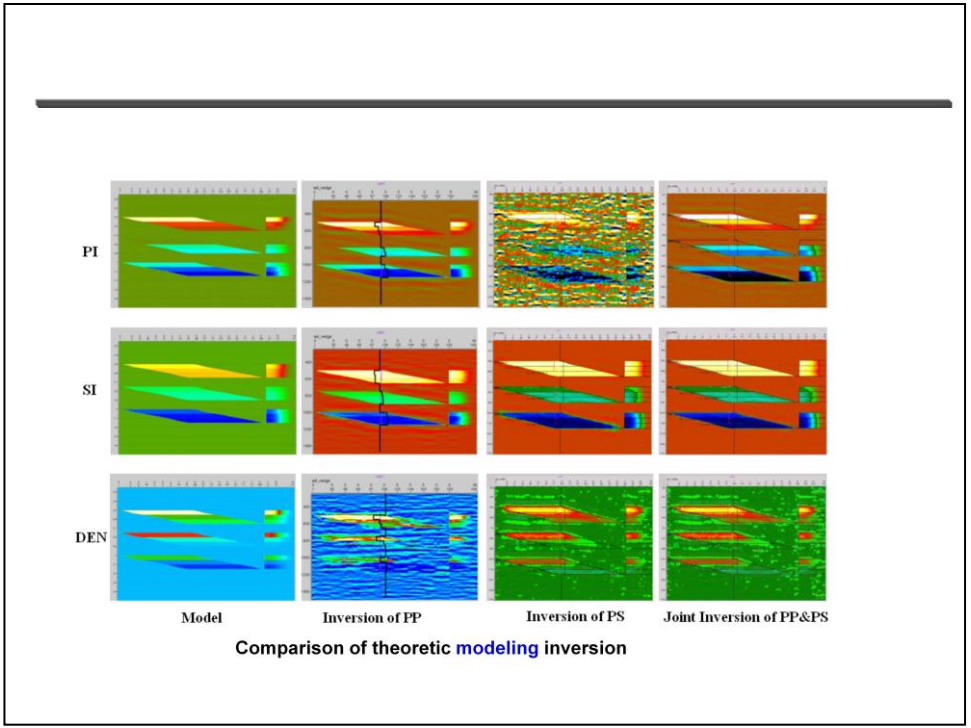
When only P-wave data is available, we can estimate S-wave attributes from PP data with some assumptions. Joint inversion of PP and PS data allow to obtain more accurate SI.

Joint inversion based on stack data

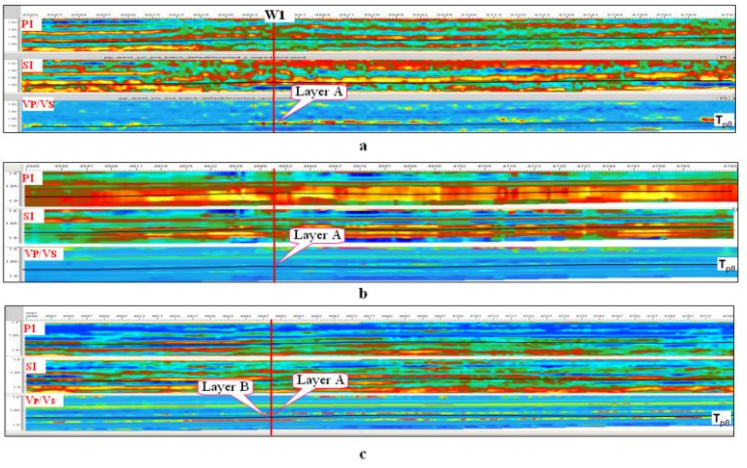


Joint inversion based on partial stack data





Presenter's notes: In the figure, from left to right, they are model; PP simultaneous inversion, PS simultaneous inversion and PP&PS joint simultaneous inversion. From top to bottom are the corresponding PI, SI and density. It's obvious that PP simultaneous inversion may obtain PI with high S/N (signal to noise ratio) and SI with common S/N; PS simultaneous inversion obtain SI with high S/N; and PP&PS joint simultaneous inversion may obtain PI, SI, density all with high S/N at the same time.



Comparison of real data inversion a) PP b) PS c) PP&PS

Presenter's notes: Both theoretic modeling and real data inversion show that the accuracy of joint simultaneous inversion is greater than simultaneous inversion of PP or PS alone, and that joint simultaneous inversion has distinct advantages in identifying lithology and fluids.

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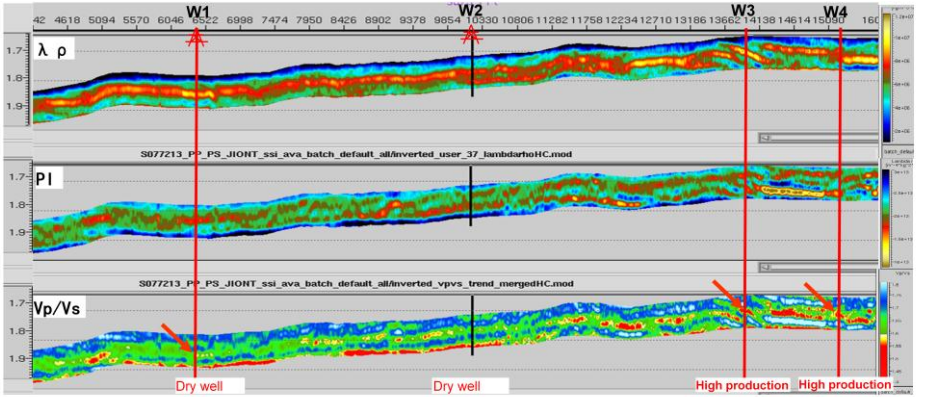
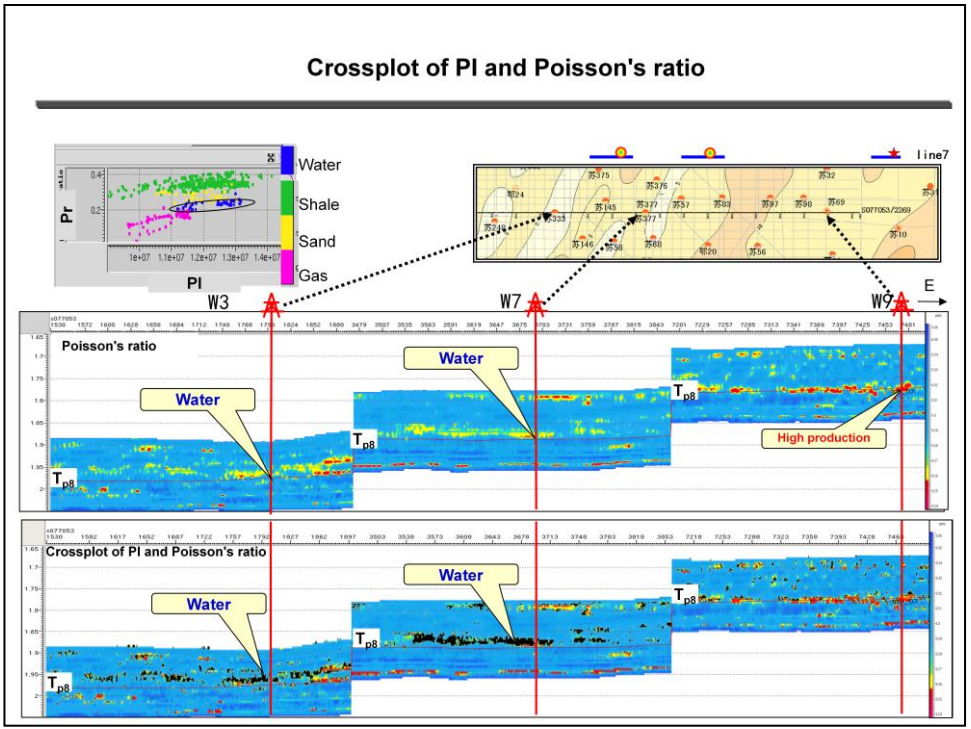
Applications

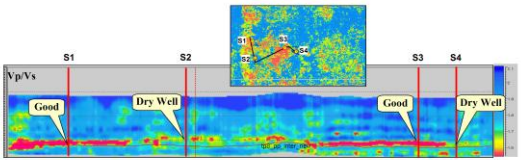


Joint inversion section based on partial stack data

Crossplot of PI and Poisson's ratio



In 3D3C area

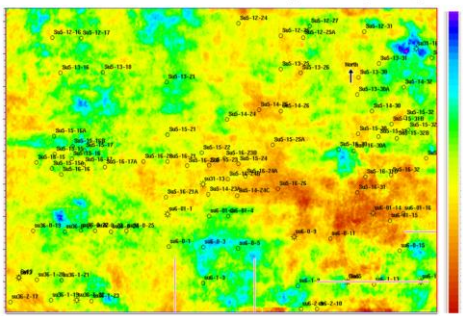


Vp/Vs section of joint simultaneous inversion in the 3D3C area (Arbitrary line)

Drilling result proven:

Success rate: 86.6%

10% more than that of P-wave alone



Prospective area in the 3D3C survey

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Conclusions

- In data processing, static corrections, resolution improvement, and anisotropy of converted wave should be focused on .
- PP and PS matching is the foundation for application. The matching involves inversion, modeling, key markers and well data.
- PS is sensitive to reservoir thickness; PP is sensitive to fluids and lithology. Moreover, the integration of PP and PS attributes are more sensitive to fluid than single PP data. The product of PP and PS Highlighted Volume is the most sensitive in the study area.
- Joint simultaneous inversion with full Knot-Zoeppritz equation may help obtain more stable and accurate elastic parameters. Comprehensive integration of PP and PS data can effectively enhance the reservoir characterization.