# Resolution Improvement Study and Application of 3D Surface Seismic Data using Borehole Seismic Data*

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## Abstract

Most of oilfields in China are located in continental sediment basins. Compared with oil fields in marine basins, they have much more complex fault systems, small-scale sand bodies, poorer sand connectivity, greater variation in facies and heterogeneity, therefore more difficulties in finding the remaining oil reserve. Conventional 3D surface seismic data, one of the best methods for reservoir characterization at the beginning of petroleum exploration, is efficient for bigger traps and structures while its vertical resolution is not high enough to meet the needs of reservoir characterization for petroleum production in these continental sediment basins. This study focuses on resolution improvement of 3D seismic data using borehole seismic data. Firstly, Q-value is directly computed from zero-offset VSP and shot gathers are filtered by modified inverse-Q operator. Secondly, the deconvolution operator derived from zero-offset VSP with higher vertical resolution is applied to the post-stack section. Thirdly, under the control of modified Cauchy distribution, impedance inversion is done by adding the constraint of cross-well seismic data. Finally, the fine description of thin layer can be completely achieved. Test results in one oilfield in Eastern China show that it has improved the vertical resolution from 6-7m to 3-5m in thickness. The workflow for seismic resolution improvement done by this study therefore has supplied reliable aids to reservoir characterization, remaining oil finding and well design planning in the tested field.

# Resolution Improvement Study and Application of 3D Surface Seismic Data Using Borehole Seismic Data

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# OUTLINE

- Introduction
- Joint processing constrained by zero offset VSP
- Joint inversion based on multi-geophysical data
- Conclusions

# Introduction

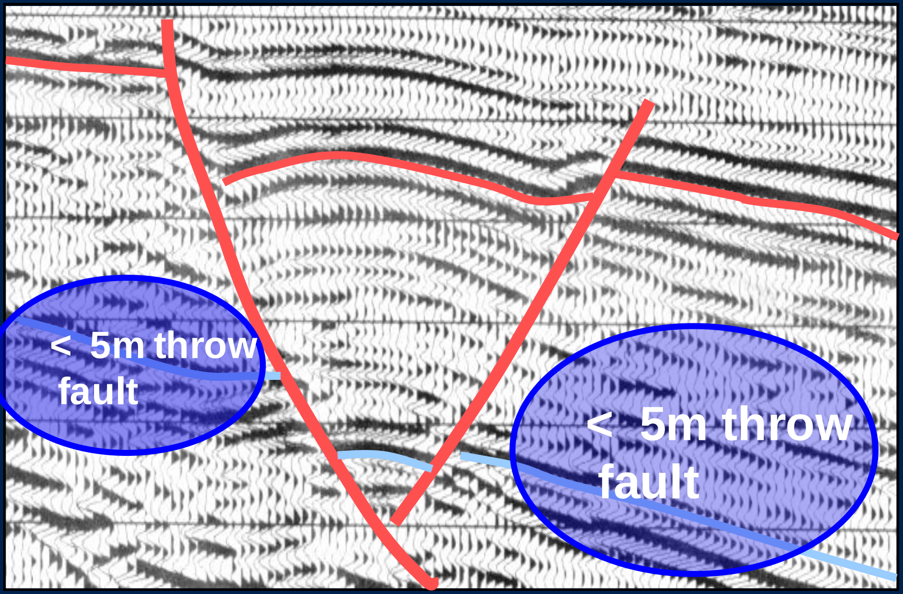
**Difficulties in exploration and production in eastern Chinese oilfields:**

- More complex fault systems
- Low-order fault identification
- Lower-level structure description
- Thin sandbody characterization

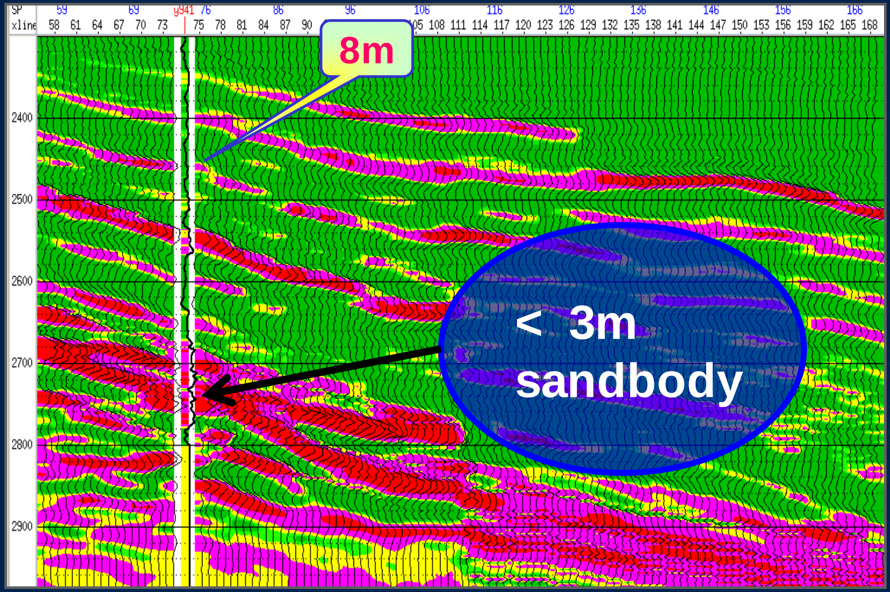
**Main Challenges for Geophysics:**

1) < 5-meter-throw fault;

2) <3-meter-thickness sandbody.

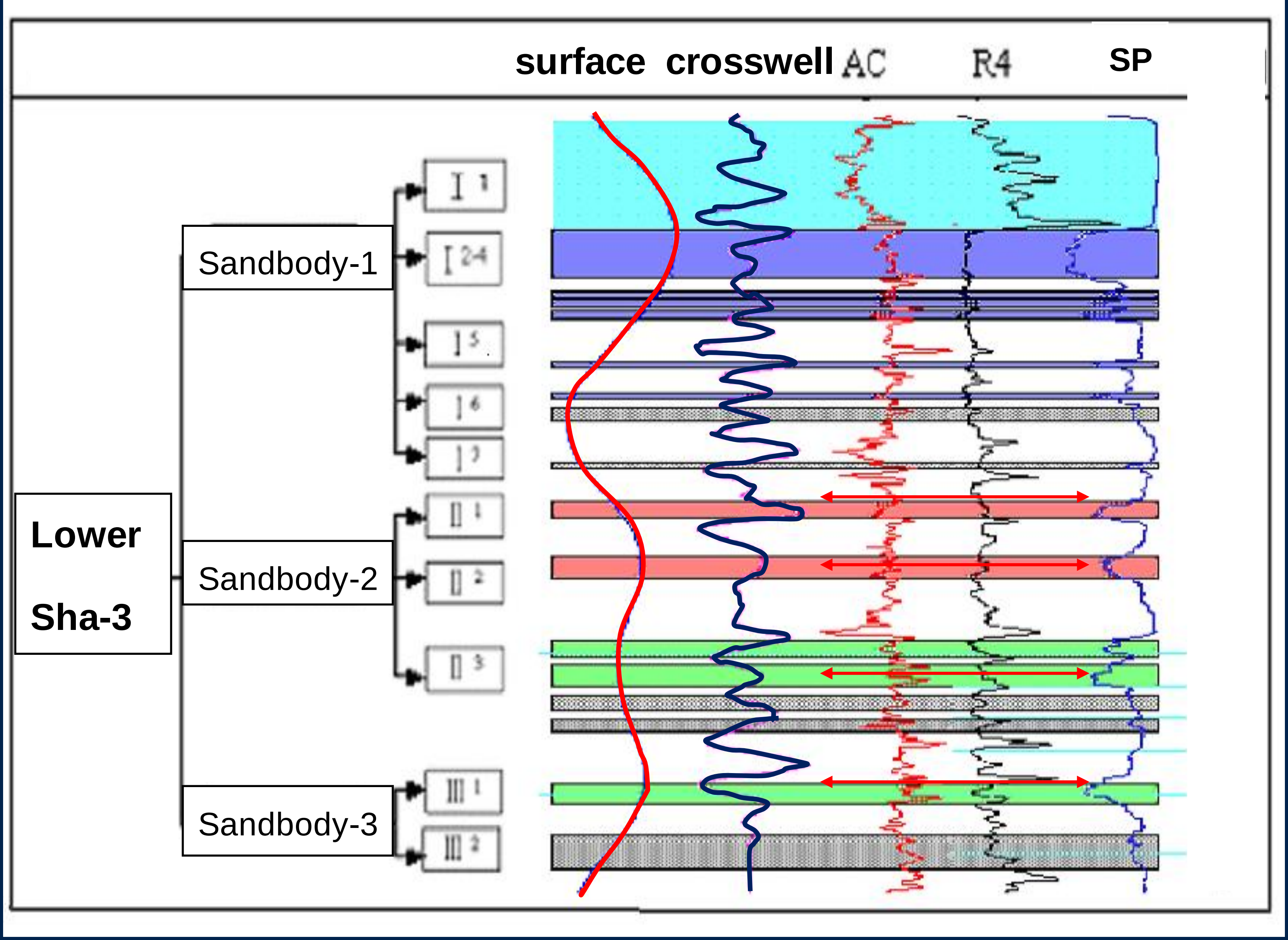



Seismic profile

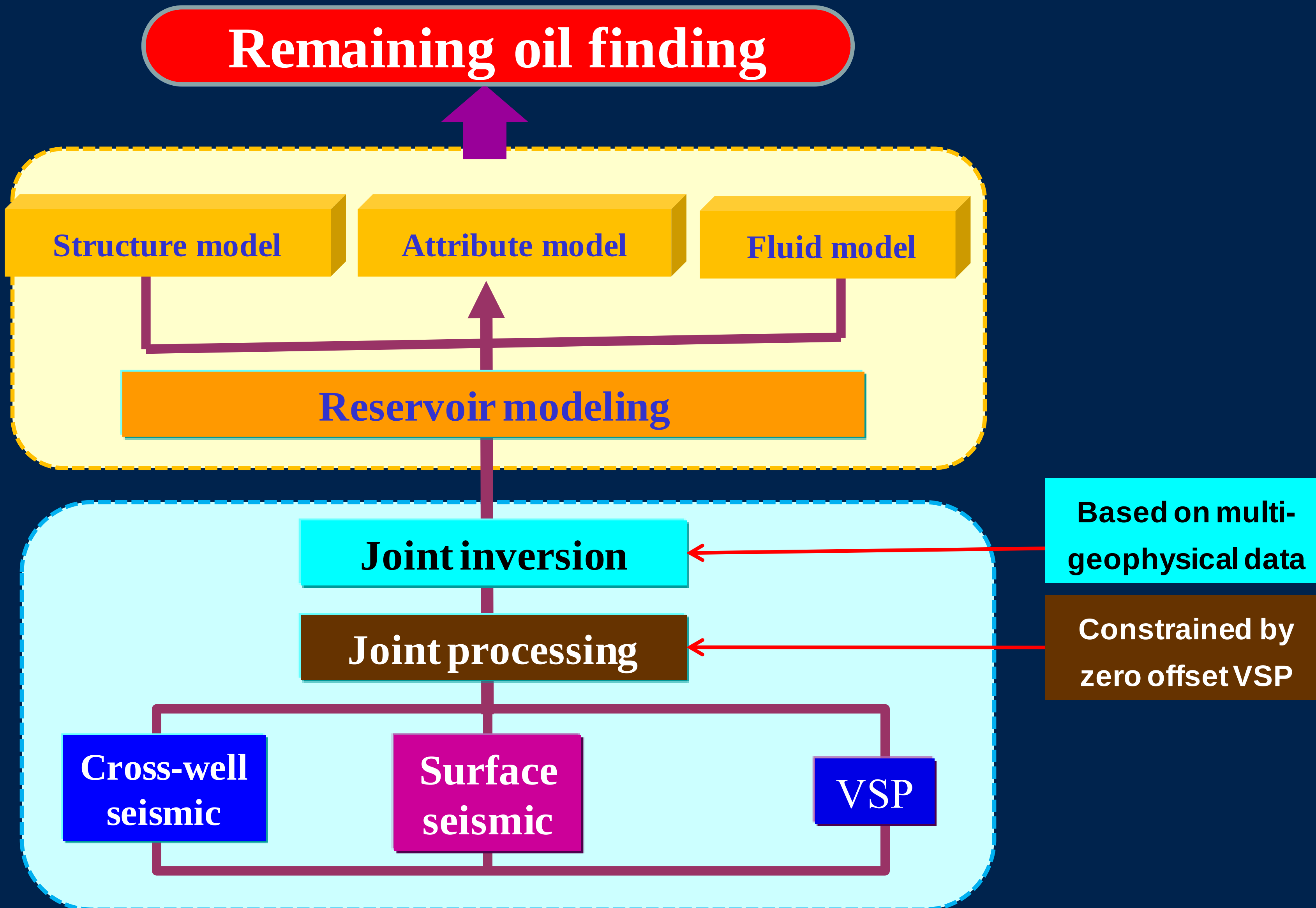



Impedance section

# Introduction



# Reservoir Modeling Work Flow Using Geophysical Data



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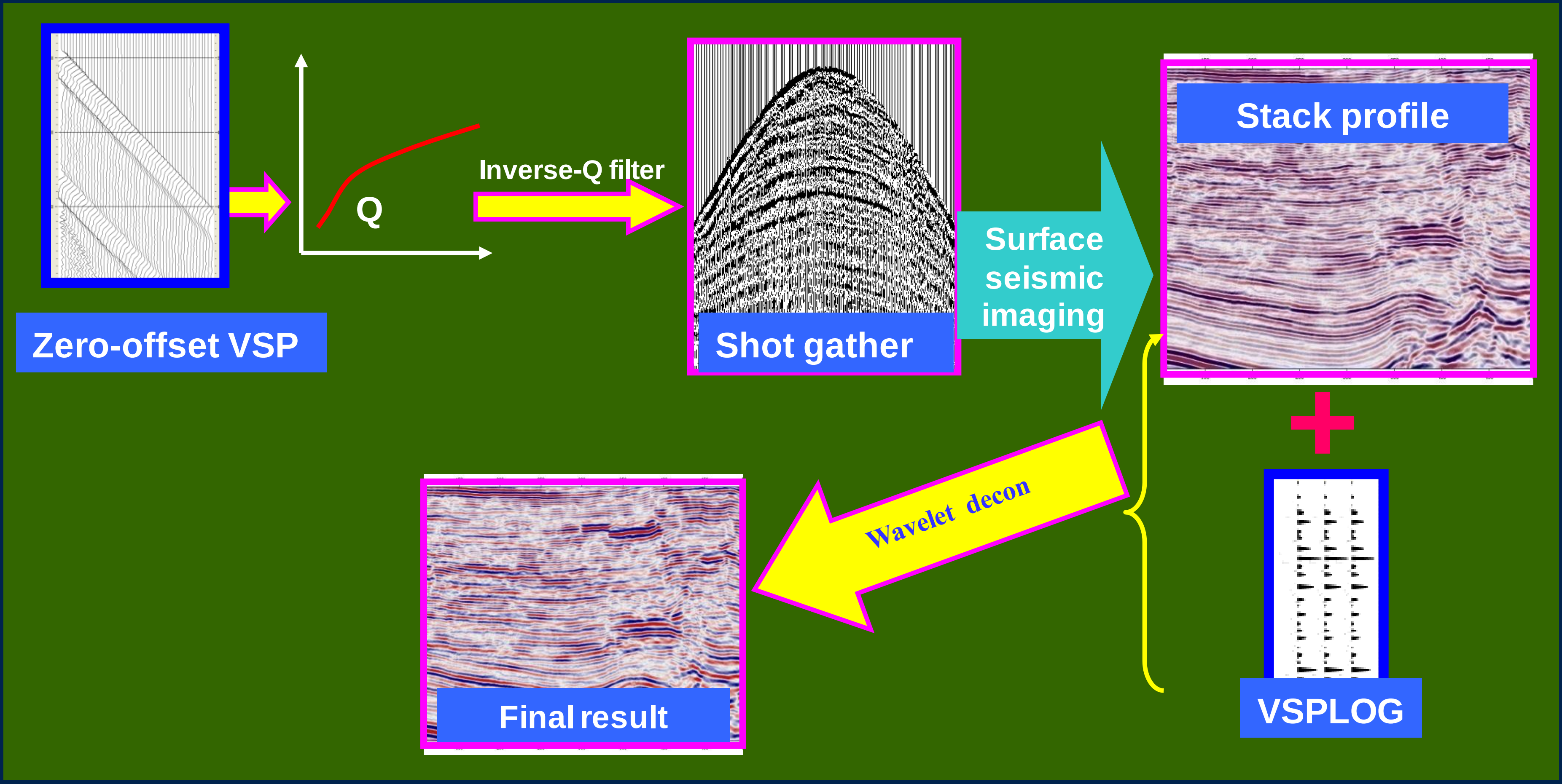
# joint processing constrained by zero-offset VSP

- Q calculation by zero-offset VSP
- Modified inverse-Q filter
- Wavelet deconvolution from zero-offset VSPLOG

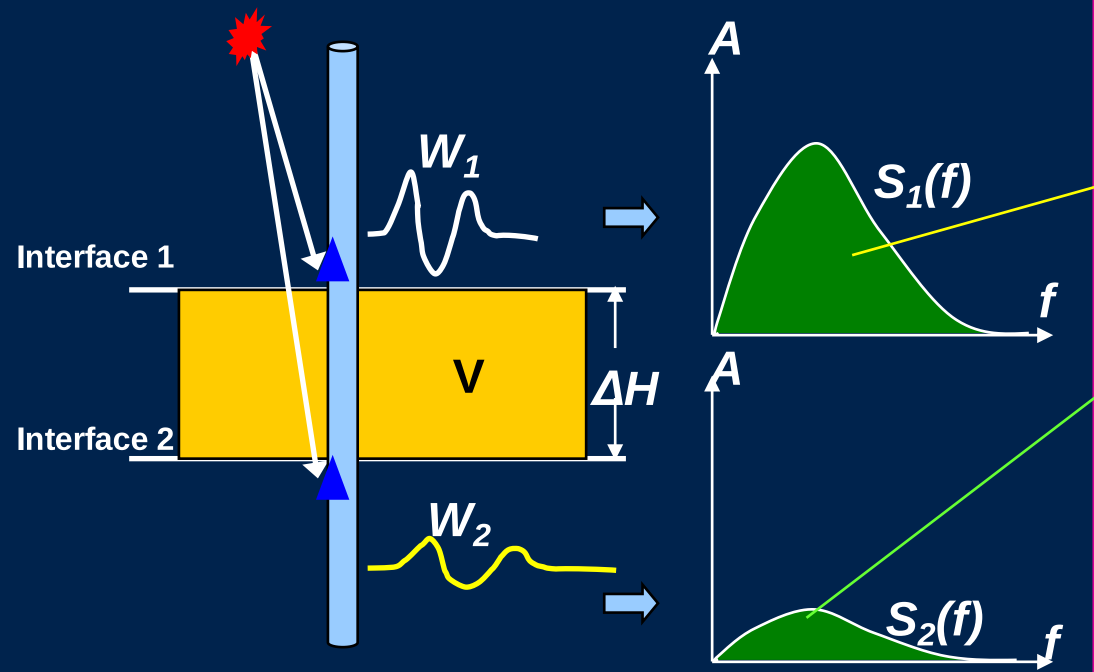


# • Q calculation - spectral ratio method

**Definition of Q :** $$Q = 2\pi \frac{E_0}{\Delta E}$$

**Relationship between Q and absorption coefficient:**

$$\alpha(f) = \frac{\pi f}{Q}$$

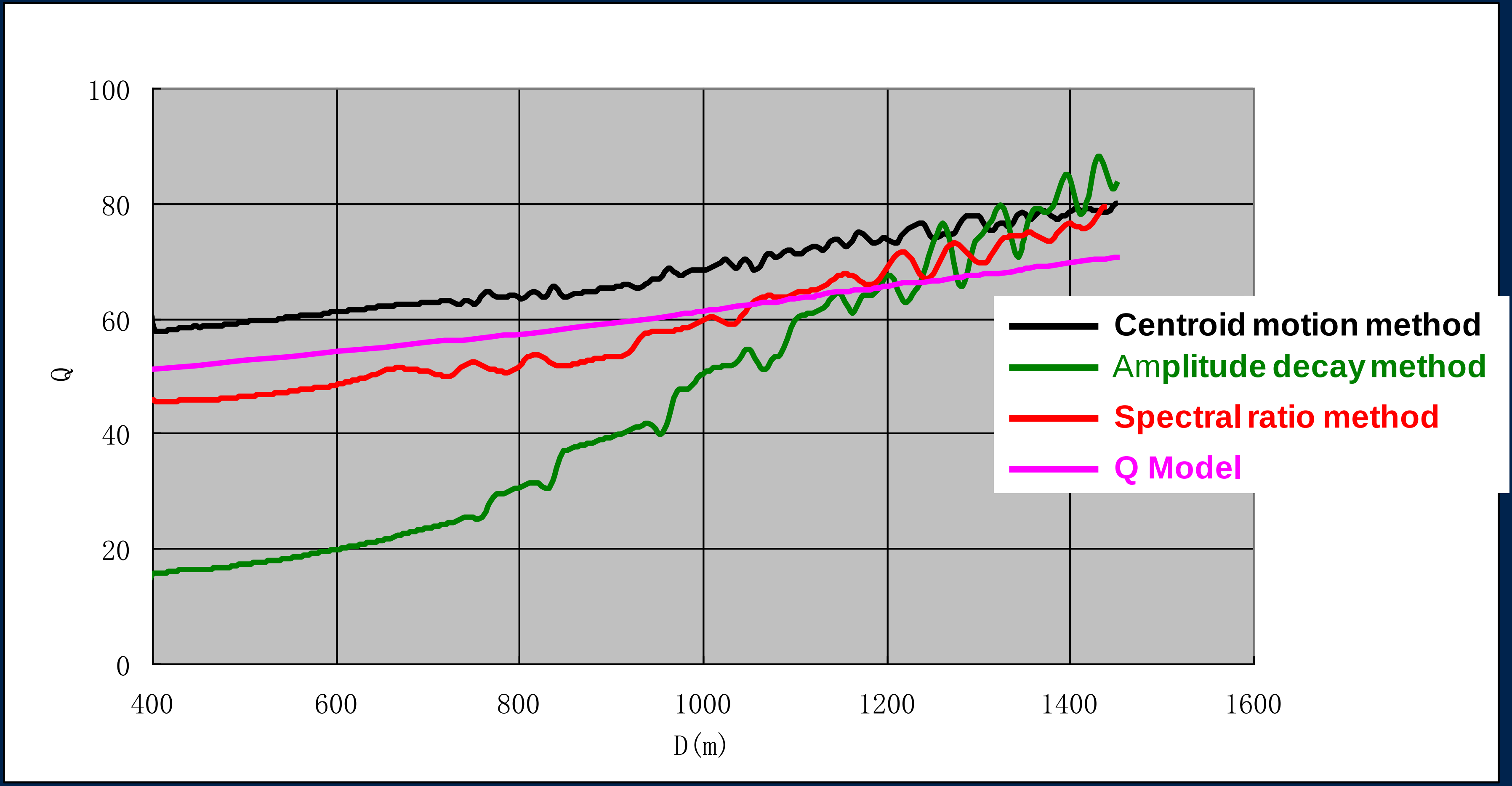



$$S_1(f) = S_0(f) e^{-\alpha(f) t_1}$$

$$S_2(f) = S_0(f) e^{-\alpha(f) t_2}$$

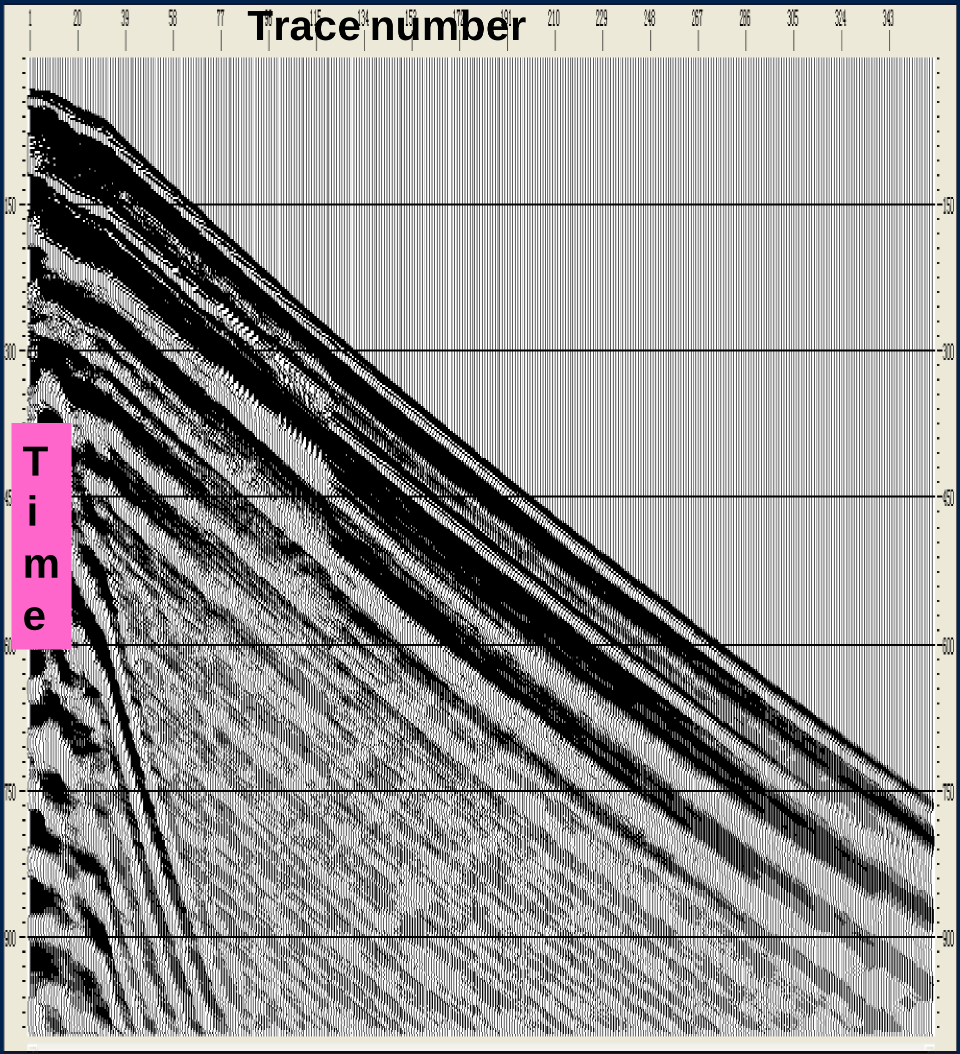
$$\ln\left[\frac{S_2(f)}{S_1(f)}\right] = -\alpha(f)(t_2 - t_1) = \frac{-\pi \Delta t}{Q} f$$

# • Q calculation - synthetic data

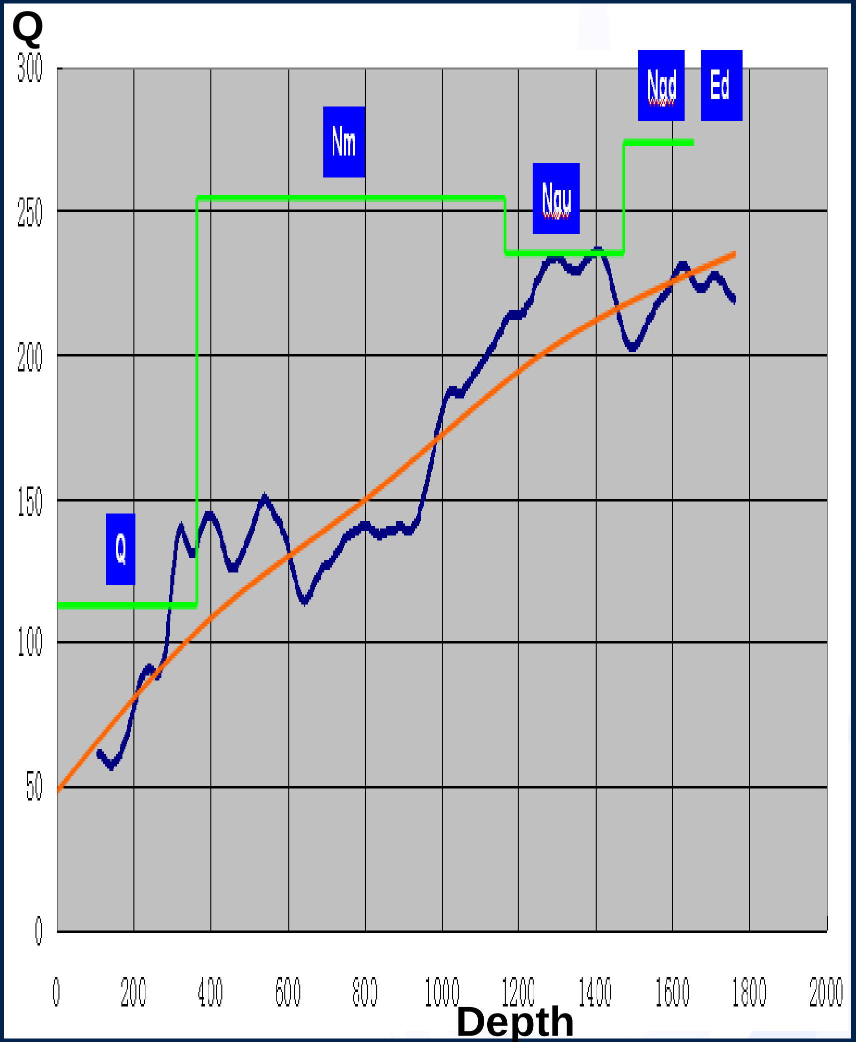



Comparison between model and results from different methods

# • Q calculation - field data

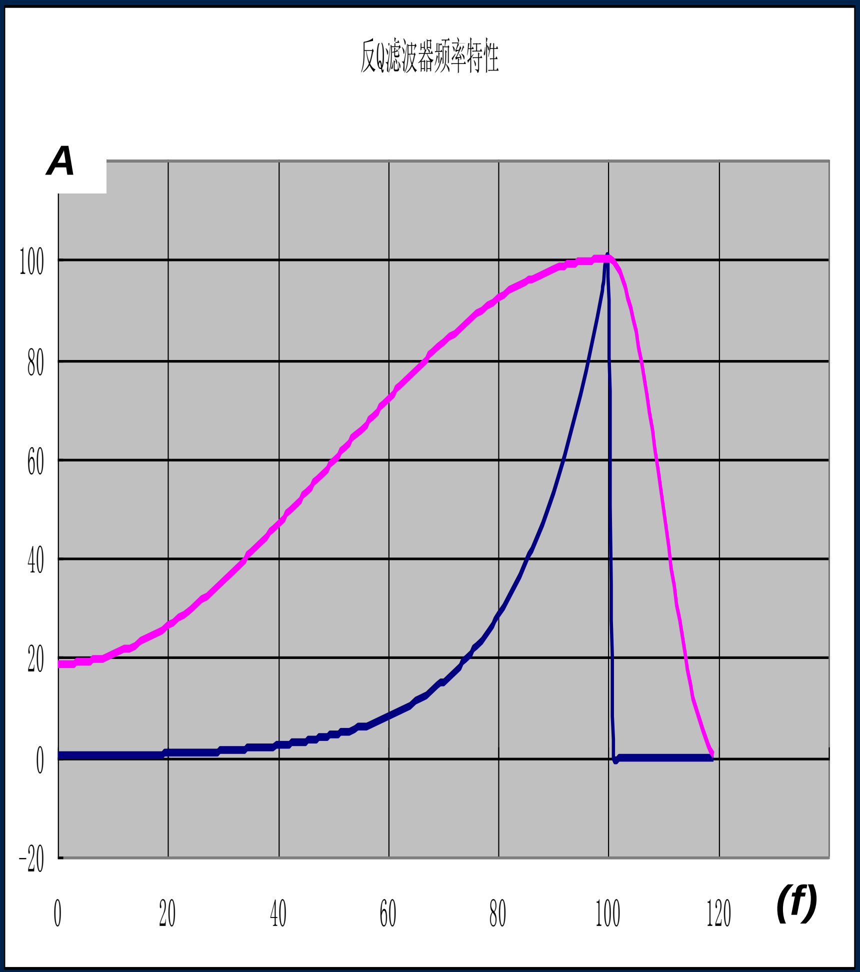



Zero-offset VSP record

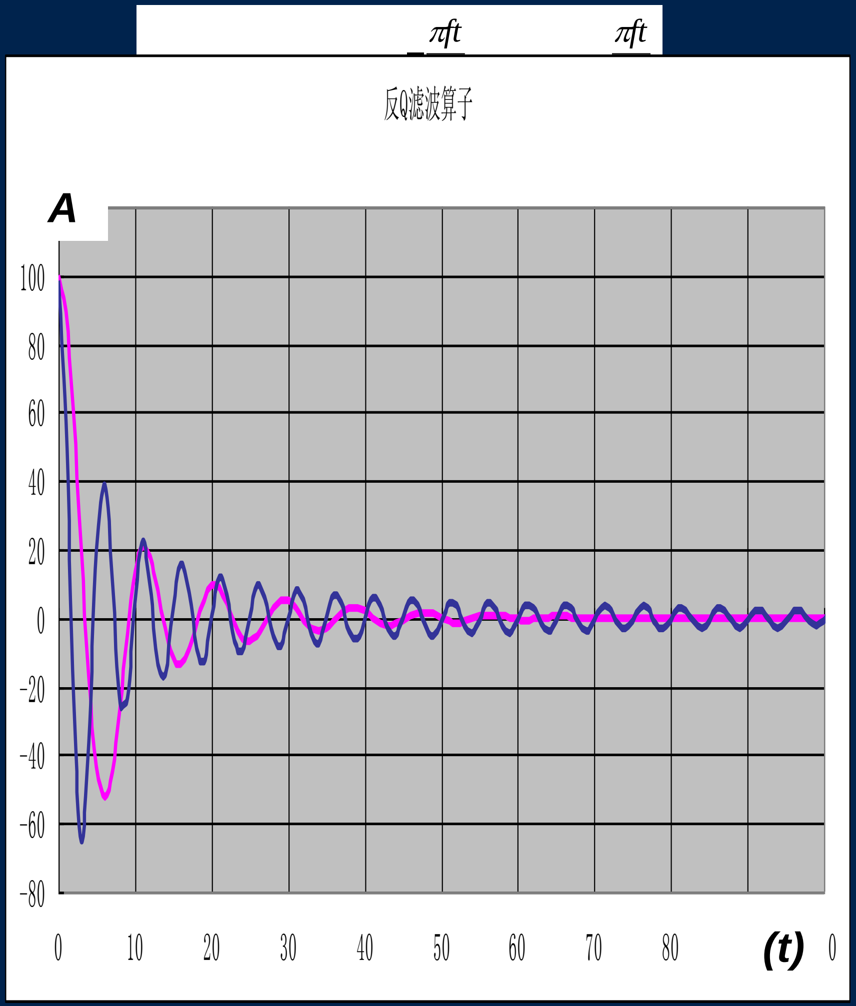



Computed Q

# • Modified inverse-Q filter

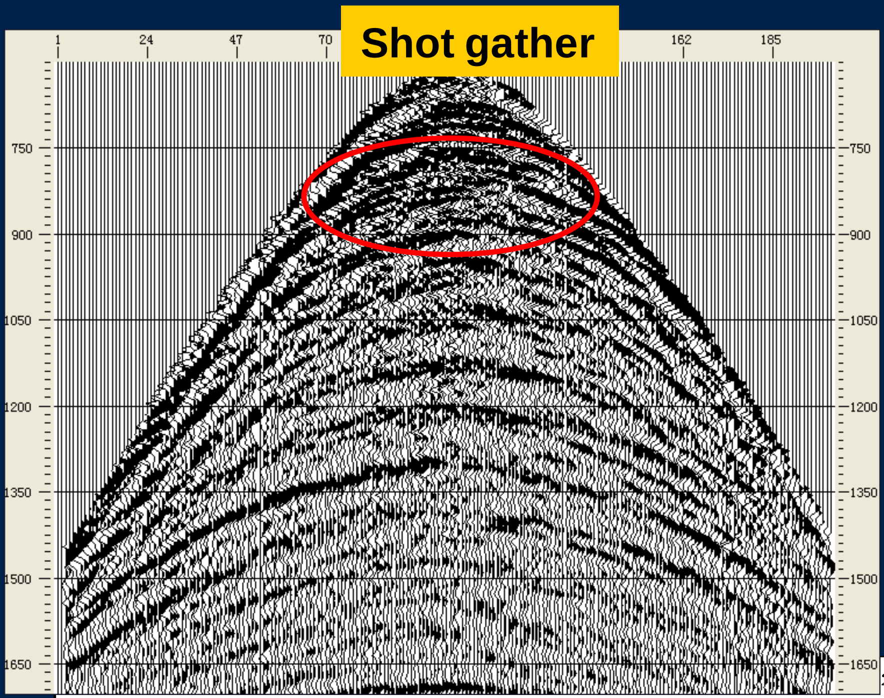


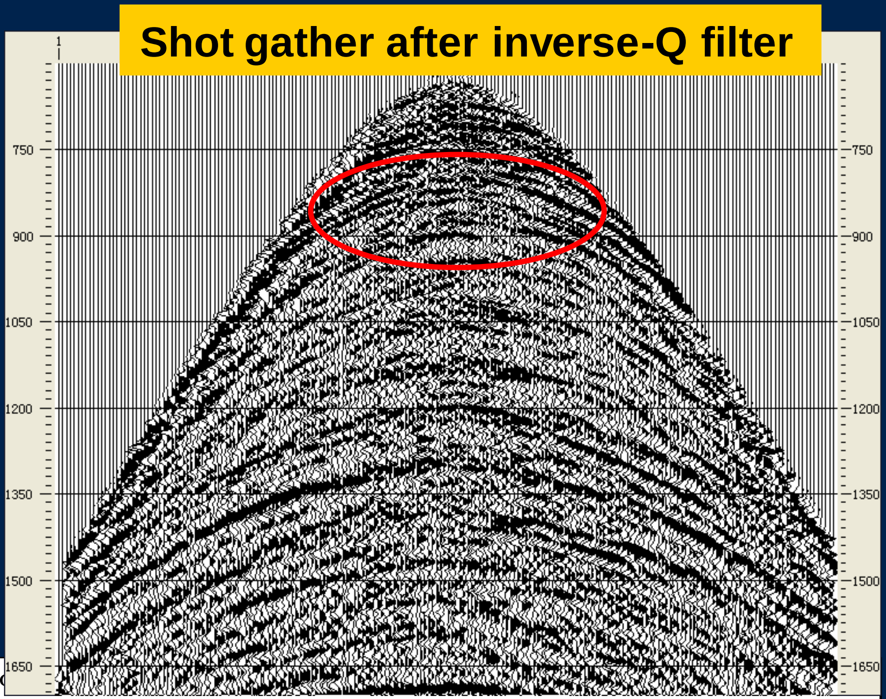

Spectral comparison

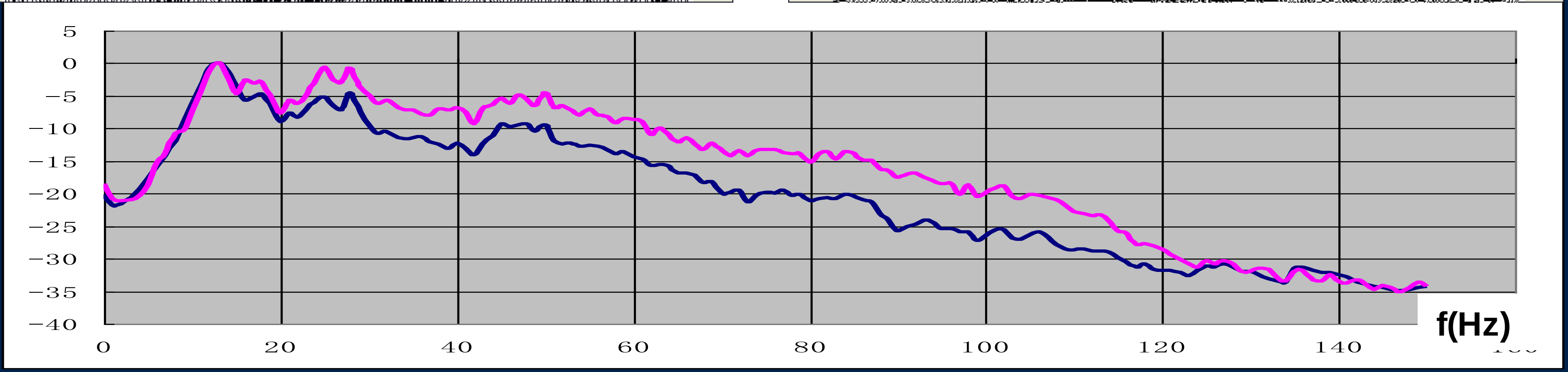



Vibrating curve comparison

# • Modified inverse-Q filter – field data




Comparison between two spectrums

# • Wavelet deconvolution from zero-offset VSPLOG

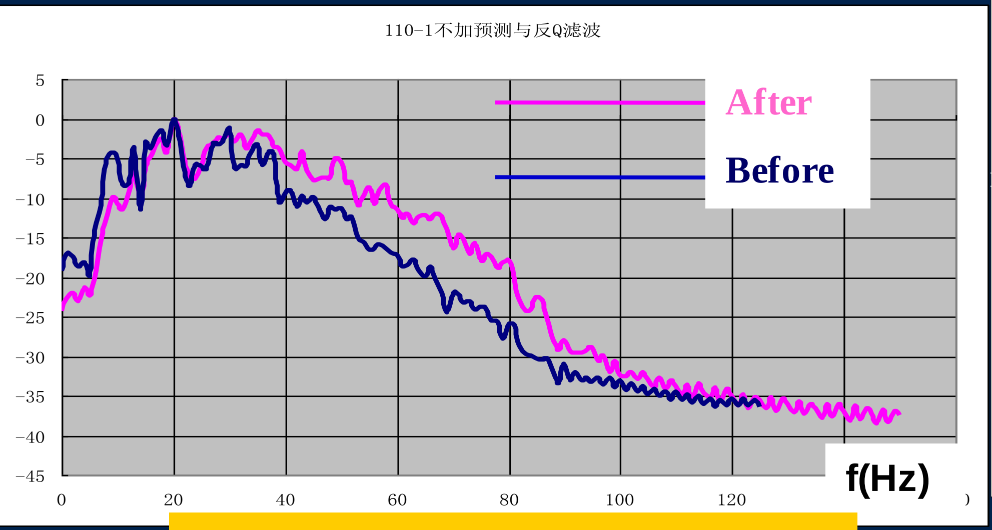
VSPLOG

Seismic record beside well

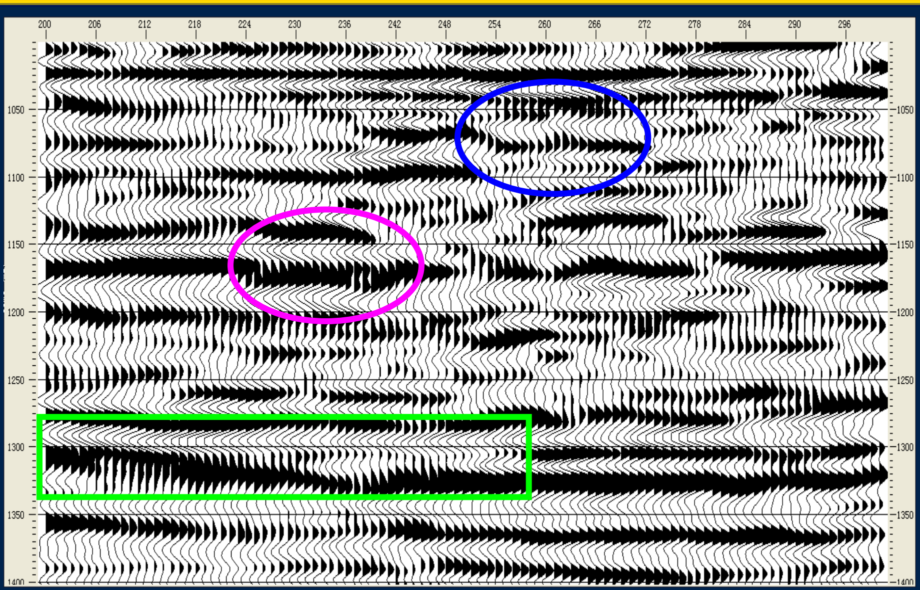
$$x_v = w_v * \zeta_0$$
$$x_d = w_s * \zeta_0$$

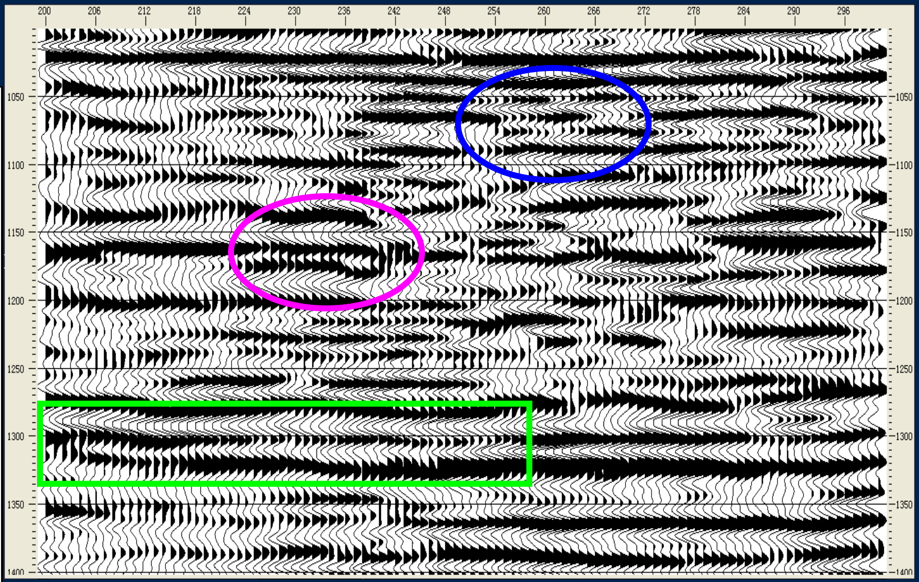
**Expression of decon operator:**

$$Operator \quad \sum (\alpha \cdot x_d - x_v)^2$$




**Comparison between two spectrums**





**Comparision between two profiles**

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➡ Joint inversion based on multi-geophysical data

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# Joint Inversion Framework

**Bayesian Inversion Framework**

$$p(r \mid d) \propto p(r) \bullet p(d \mid r)$$

Known information of reflection coefficient

Likelihood function

$$p(\mathbf{d} \mid \mathbf{r}) = p(\mathbf{d}_S \mid \mathbf{r}) \cdot p(\mathbf{d}_C \mid \mathbf{r}) \cdot p(\mathbf{d}_V \mid \mathbf{r})$$

Likelihood function

Surface seismic

crosswell seismic

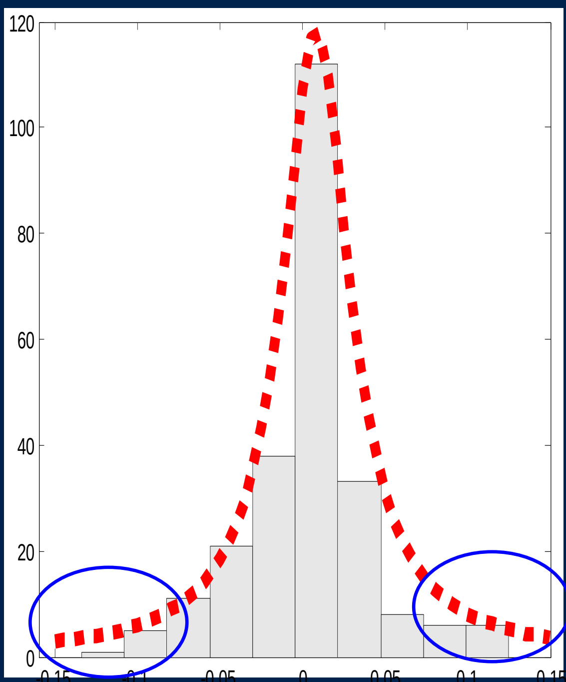
VSP

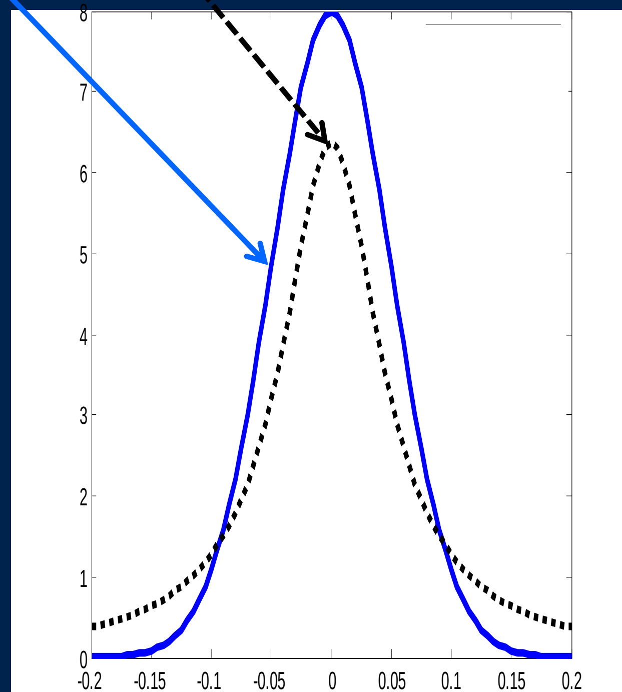
# Comparison between three constraint distributions

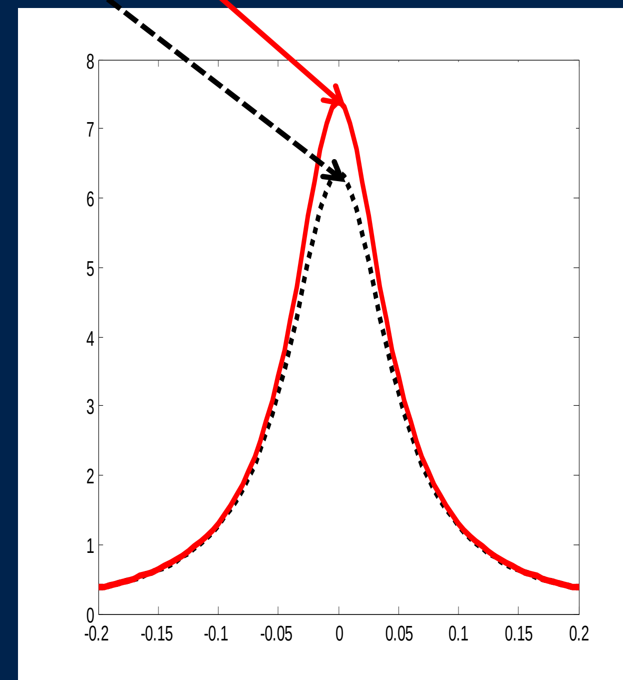
**Gaussian distribution** $p(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$

**Cauchy distribution** $f(x; x_0, \gamma) = \frac{1}{\pi}[\frac{\gamma}{(x-x_0)^2+\gamma^2}]$

**Modified Cauchy distribution** $f(x; x_0, \gamma) = \frac{1}{\pi\gamma} e^{\frac{-(x-x_0)^2}{\gamma^2+(x-x_0)^2}}$




Reflection coefficient series have characteristic of long tail

Long tail is helpful for sparse spike inversion

Modified Cauchy distribution can protect smaller reflection coefficient.

# Target function

$$J(r) = J_S + \alpha J_V + \beta J_C + \mu J_r + \rho J_I$$
$$= \frac{1}{2}\left(d_S - G_S r\right)^T\left(d_S - G_S r\right) + \frac{\alpha}{2}\left(d_V - G_V r\right)^T\left(d_V - G_V r\right)$$
$$+ \frac{\beta}{2}\left(d_C - G_C r\right)^T\left(d_C - G_C r\right) + \frac{\mu}{2} r^T r + \frac{\rho}{2}\left(Cr - \xi\right)^T\left(Cr - \xi\right)$$

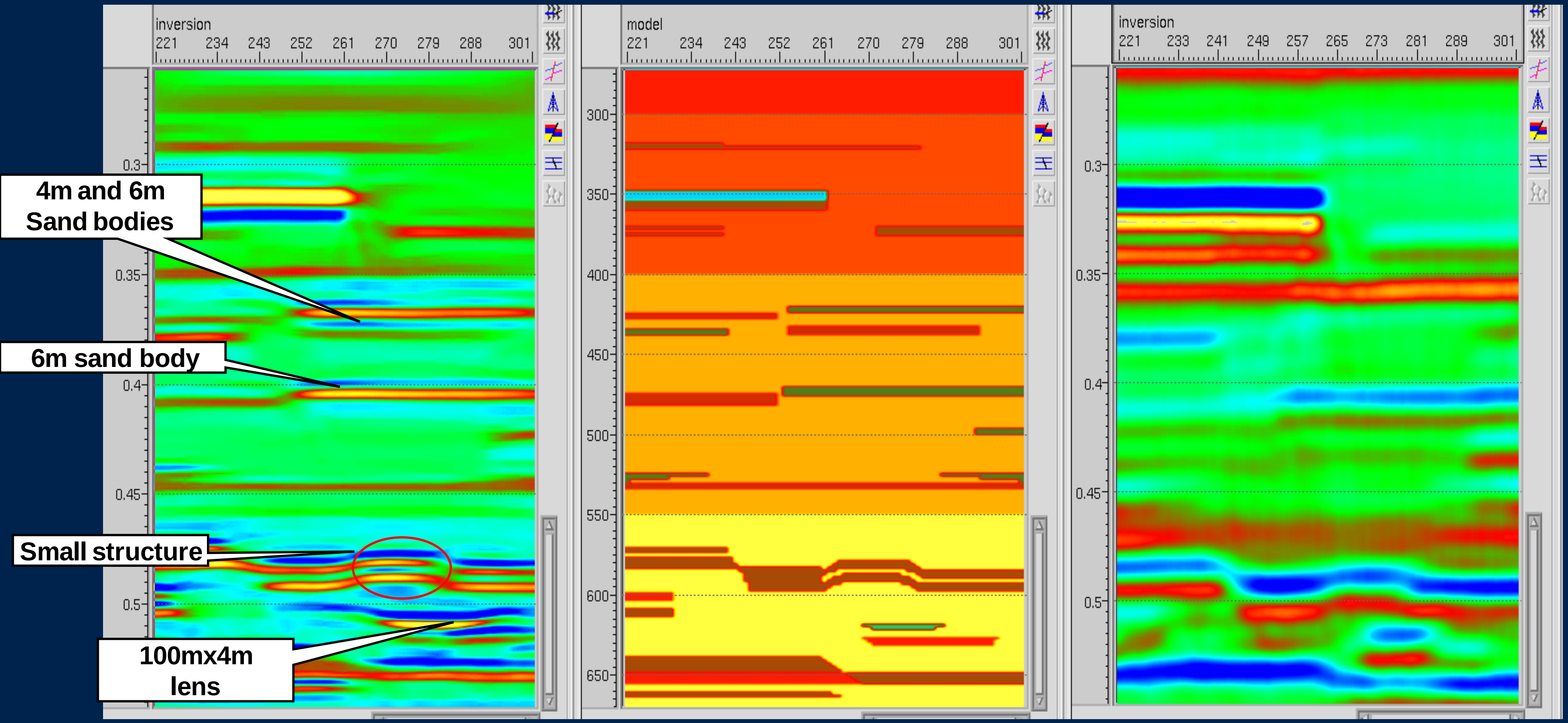
Where: $\alpha$、$\beta$、$\mu$、$\rho$ are weight coefficients

The differential coefficient of above function:

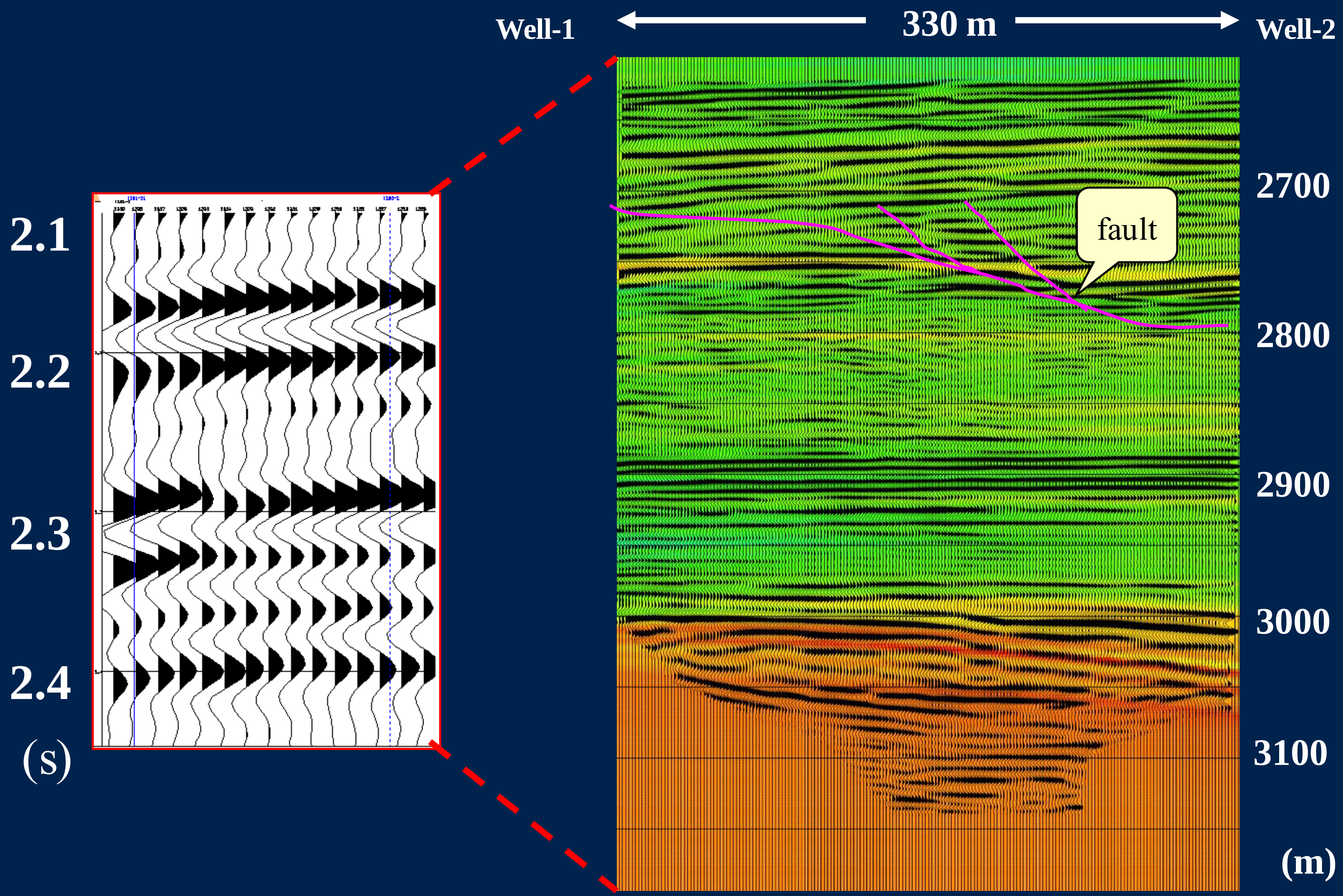
$$\nabla J_r(r) = \left(G_S^T G_S r - G_S^T d_S\right) + \alpha\left(G_V^T G_V r - G_V^T d_V\right) + \beta\left(G_C^T G_C r - G_C^T d_C\right) + \mu Q r + \rho\left(C^T C r - C^T \xi\right)$$

# Joint inversion– synthetic data

new inversion | model | conventional inversion



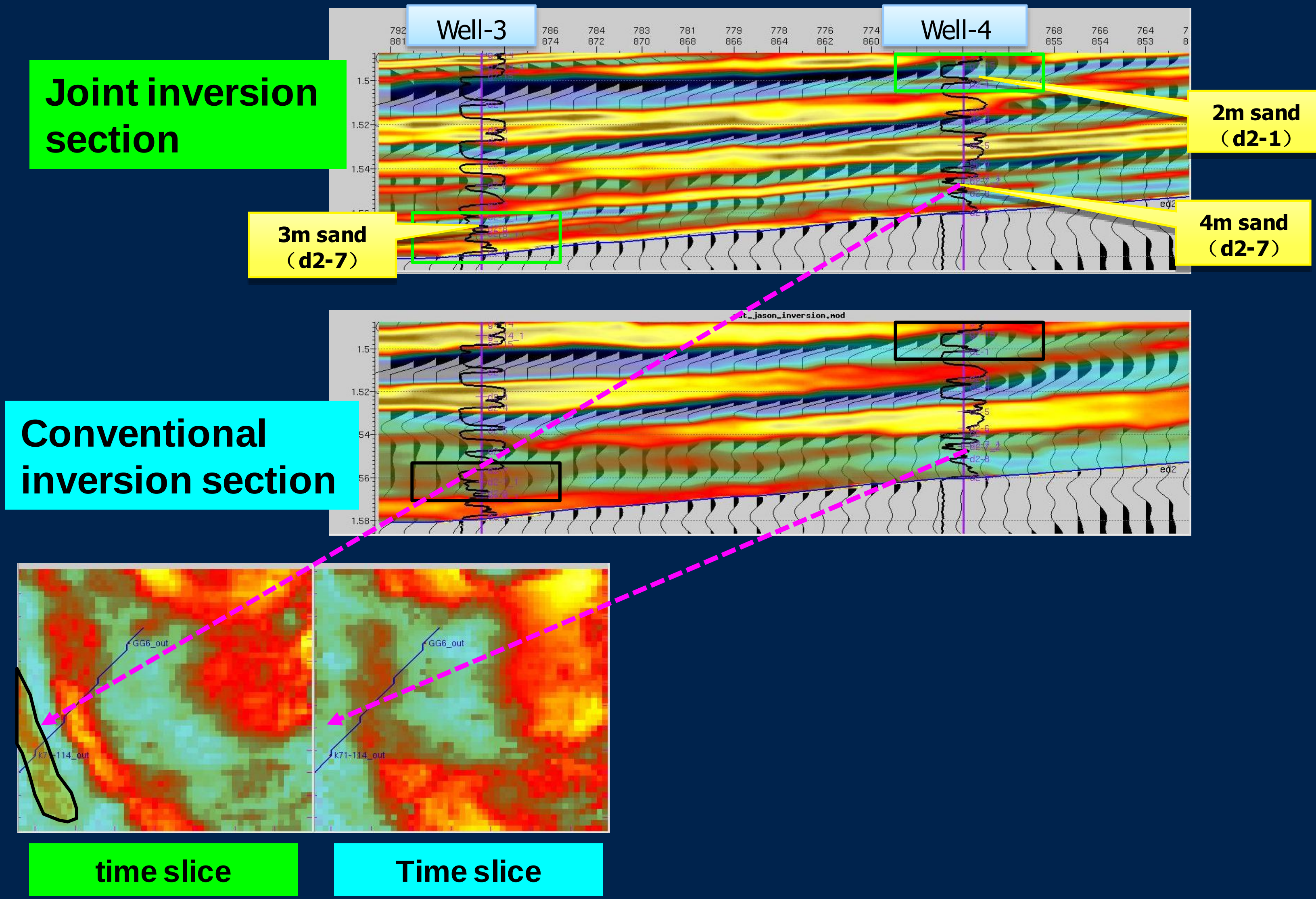
# Comparison between surface seismic and crosswell seismic



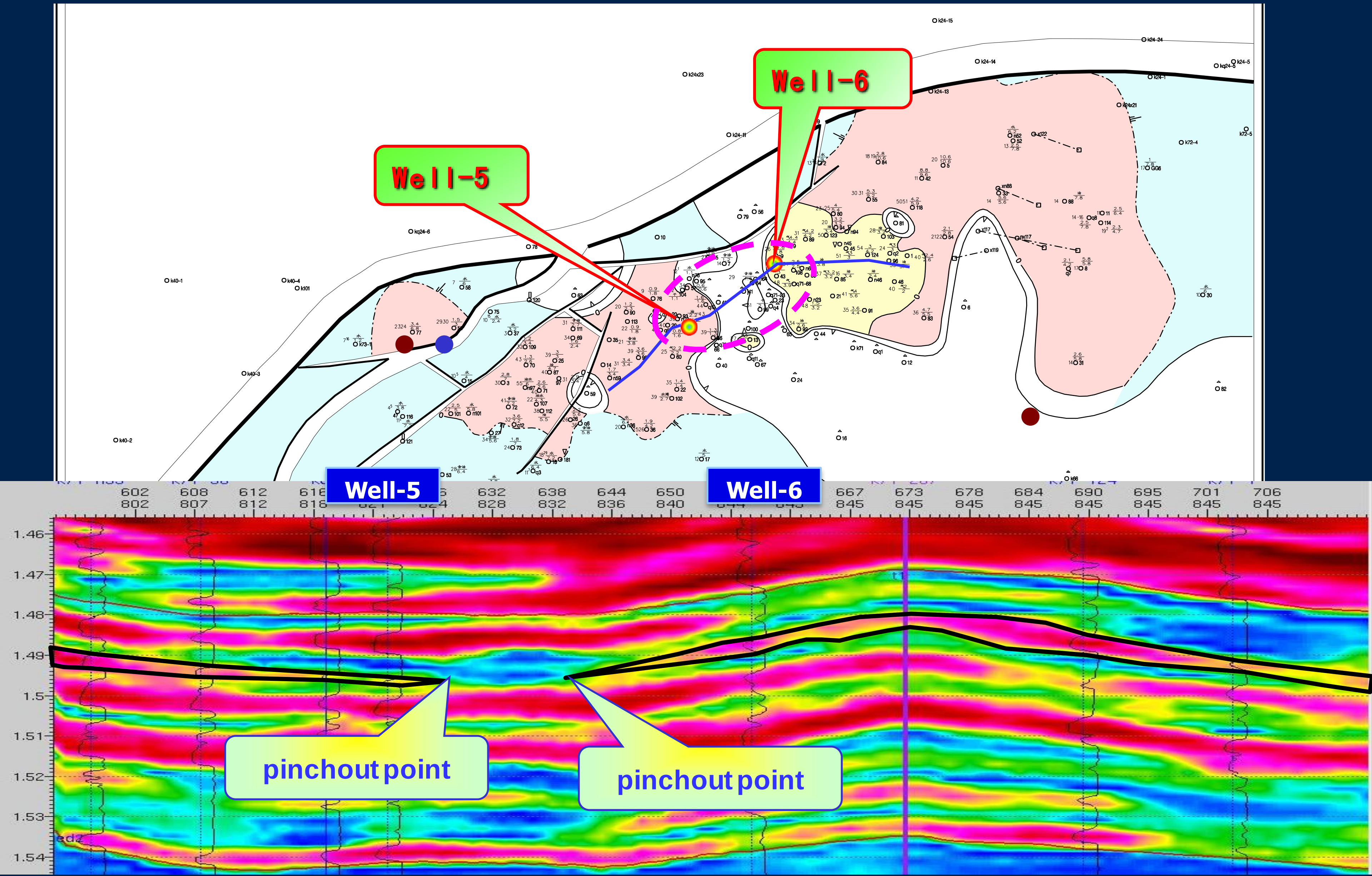

surface seismic section

crosswell seismic section

# Joint inversion– field data



# sandbody discontinuity



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➡ Conclusions

# Conclusions

1. This is direct method and has higher fidelity than others.
2. Joint processing can efficiently extend the frequency bandwidth.
3. Joint impedance inversion can enhance the ability of thinner sand-body by multiple geophysical seismic data.
4. Joint processing and inversion can make full use of individual advantage from different geophysical data.


Thanks for your attendance!