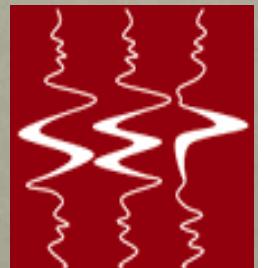


Constraining anisotropic WEMVA using rock physics modeling

Yunyue (Elita) Li*, Biondo Biondi, Dave Nichols, Gary Mavko, and Robert Clapp
SEP meeting, 06/18/2013
SEP-149, pp289



Agenda

- Least-squares problem and parameterization
- Rock physics modeling for anisotropy
- Constraining WEMVA using rock physics information
- Conclusion and discussion

Least-squares problem

Anisotropic WEMVA (Li and Biondi, SEP 143):

$$S(\mathbf{m}) = \frac{1}{2} \|\mathbf{D}_\theta \mathbf{I}(\mathbf{x}, \theta)\| + \lambda \frac{1}{2} (\mathbf{m} - \mathbf{m}_{\text{prior}})^T \mathbf{C}_M^{-1} (\mathbf{m} - \mathbf{m}_{\text{prior}})$$

\mathbf{m} : anisotropic Earth model

$\mathbf{I}(\mathbf{x}, \theta)$: angle domain common image gathers

\mathbf{D}_θ : derivative operator along the angle axis

$\mathbf{m}_{\text{prior}}$: prior model

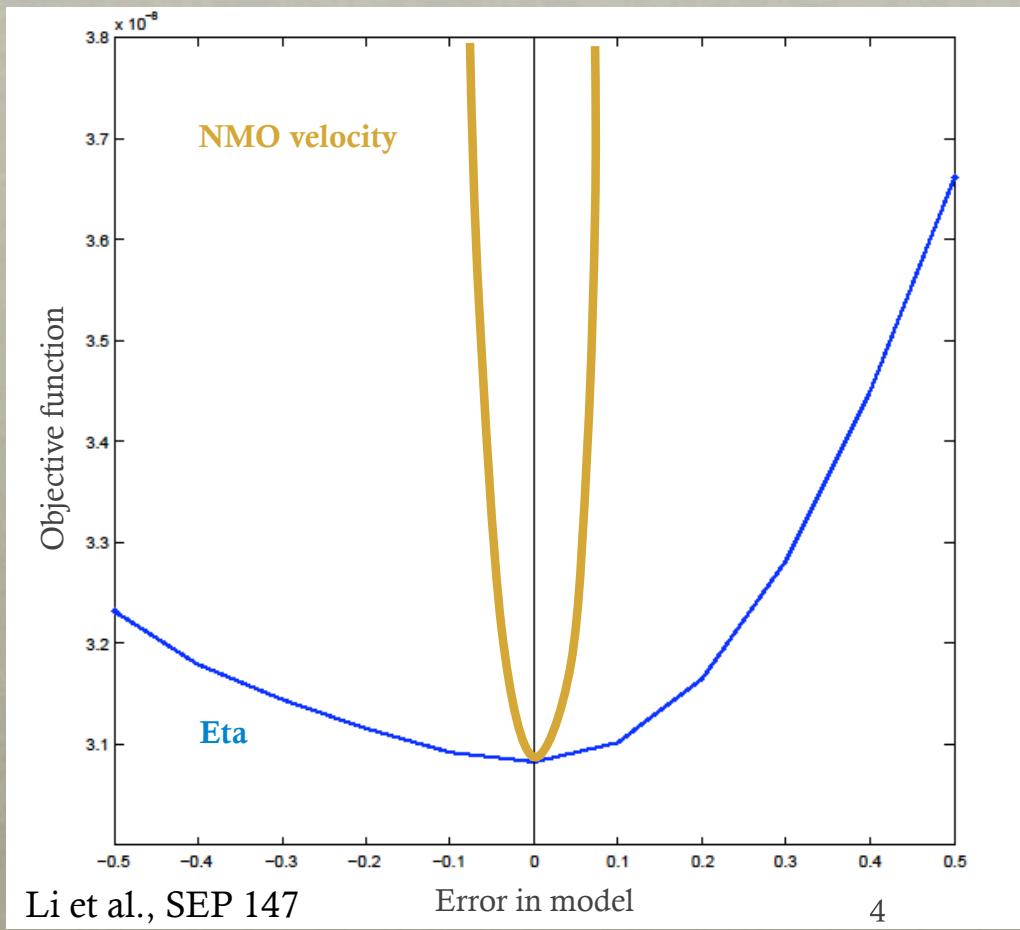
\mathbf{C}_M^{-1} : prior model covariance

λ : trade-off parameter

Data objective function

- DSO objective function

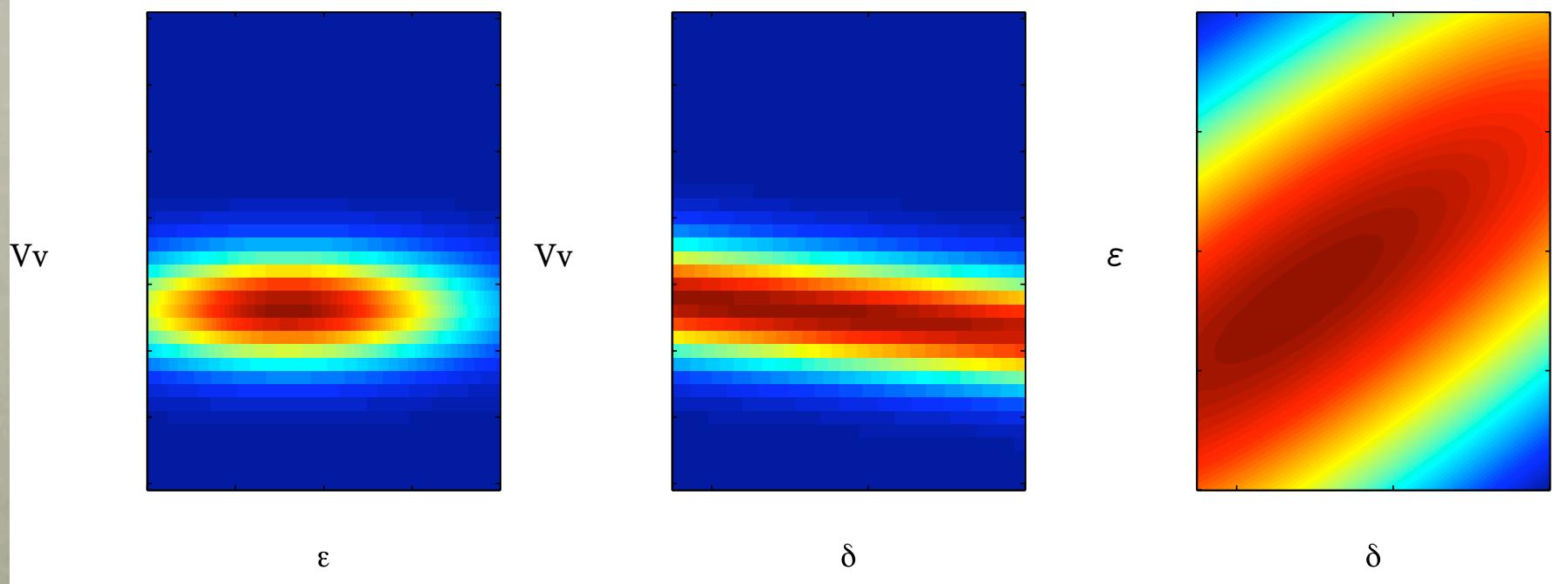
$$S_1(\mathbf{m}) = \frac{1}{2} \|\mathbf{D}_\theta \mathbf{I}(\mathbf{x}, \theta)\|$$



- Low resolution for eta
- High resolution for velocity

Data objective function

$$S_1(\mathbf{m}) = \frac{1}{2} \|\mathbf{D}_\theta \mathbf{I}(\mathbf{x}, \theta)\|$$



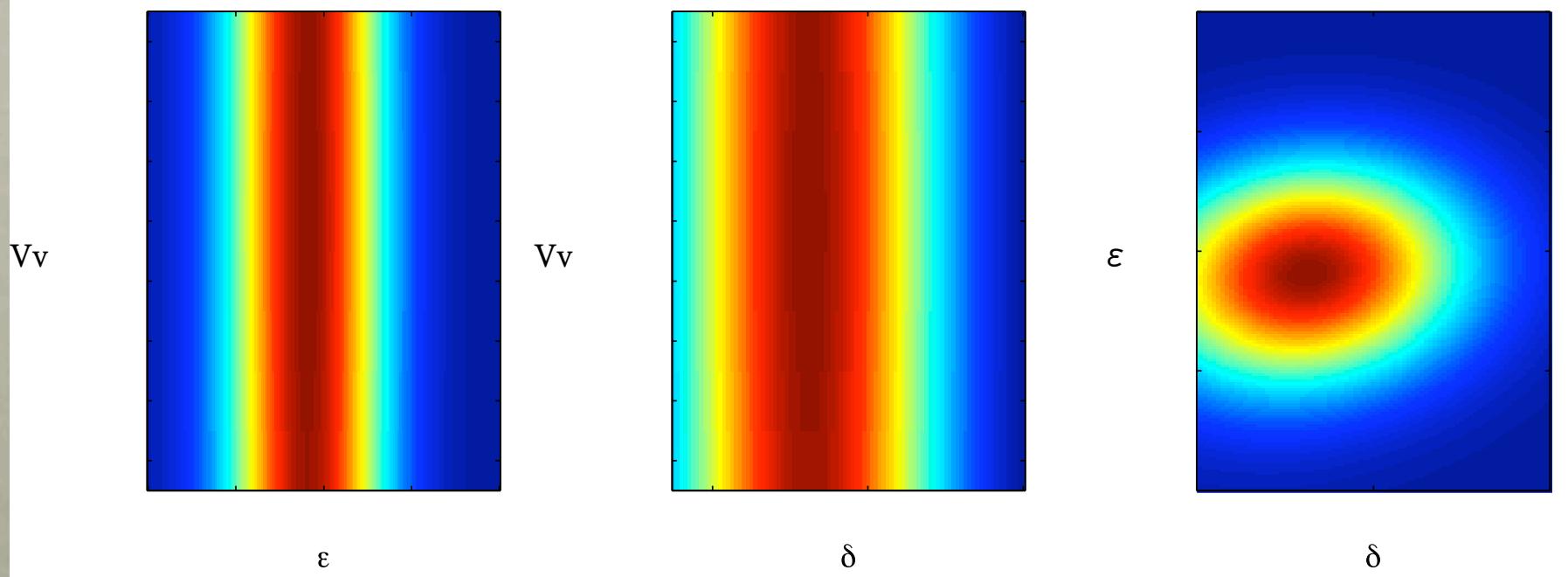
Model objective function

$$S_2(\mathbf{m}) = \frac{1}{2} \| (\mathbf{m} - \mathbf{m}_{\text{prior}})^T \mathbf{C}_M^{-1} (\mathbf{m} - \mathbf{m}_{\text{prior}}) \|$$

- Rock physics modeling
 - From well-log measurements
 - From lithological inversion results

Model objective function

$$S_2(\mathbf{m}) = \frac{1}{2} \| (\mathbf{m} - \mathbf{m}_{\text{prior}})^T \mathbf{C}_M^{-1} (\mathbf{m} - \mathbf{m}_{\text{prior}}) \|$$

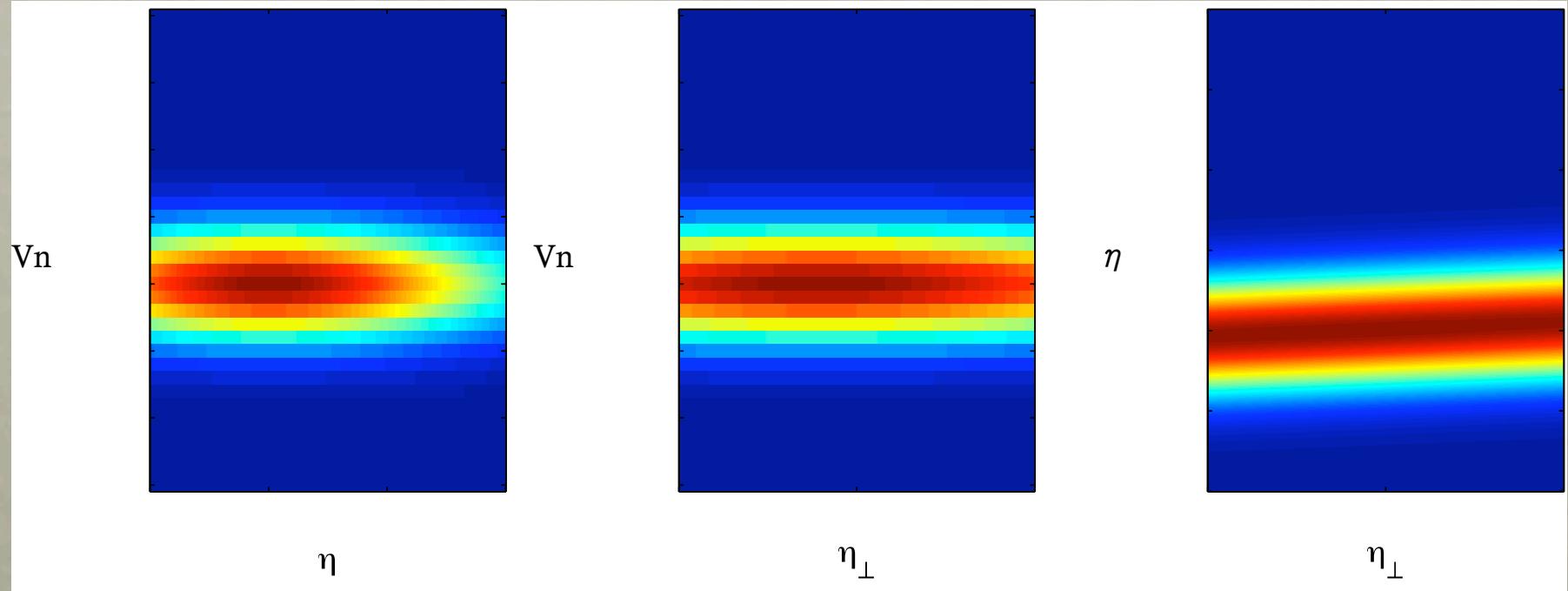


Parameterization

- Separate the well constrained and poorly constrained parameters by WEMVA on surface seismic data
 - v_n is the best constrained parameter
 - In $\epsilon - \delta$ plane, direction of η is better constrained
 - Introduce $\eta_{\perp} = \epsilon + \delta$ to describe the least constrained direction.
- Apply parameter-dependent weighting factor λ

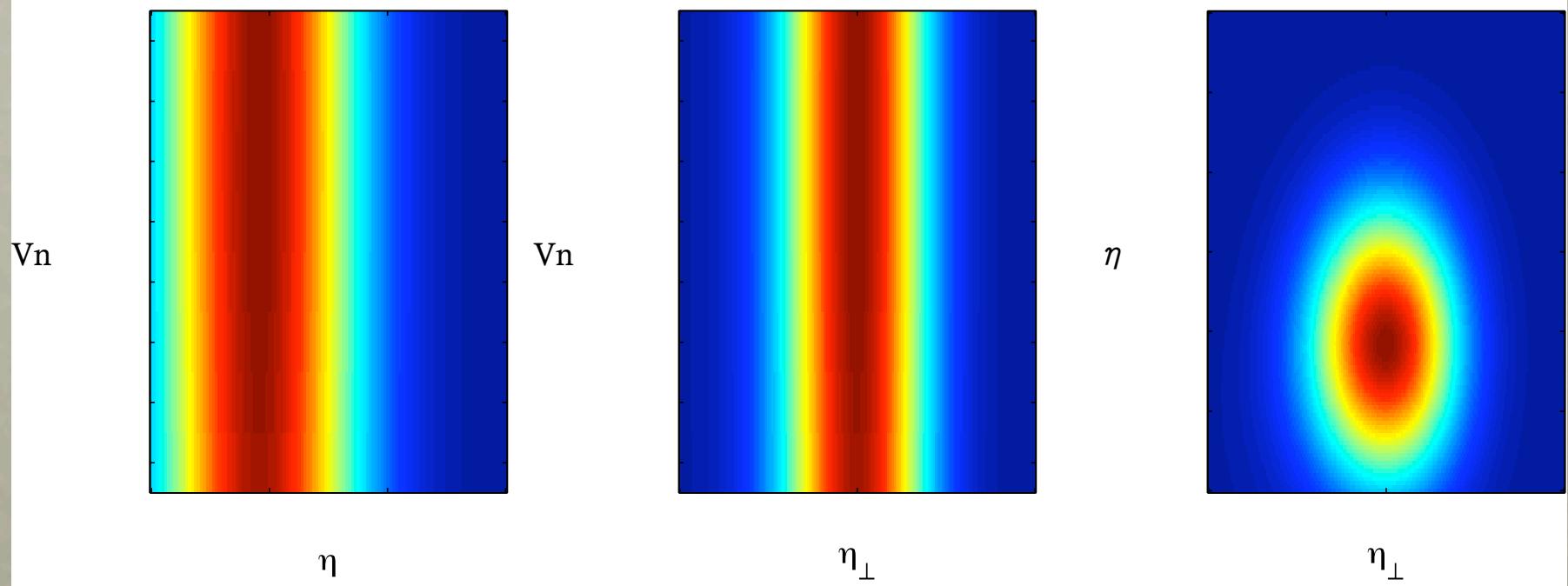
Data objective function

$$S_1(\mathbf{m}) = \frac{1}{2} \|\mathbf{D}_\theta \mathbf{I}(\mathbf{x}, \theta)\|$$



Model objective function

$$S_2(\mathbf{m}) = \frac{1}{2} \| (\mathbf{m} - \mathbf{m}_{\text{prior}})^T \mathbf{C}_M^{-1} (\mathbf{m} - \mathbf{m}_{\text{prior}}) \|$$



Agenda

- Least-squares problem and parameterization
- **Rock physics modeling for anisotropy**
- Constraining WEMVA using rock physics
- Conclusion

Rock Physics modeling

- Shale anisotropy
 - Bachrach (2010) and Bandyopadhyay (2009)
 - Mineral anisotropy
 - Particle alignment
 - Smectite-to-illite transition
 - Sand/shale lamination

Rock Physics – mineral

- Shale anisotropy
 - Mineral anisotropy (Hornby et al., 1995 and Wenk et al., 2007)

Mineral	density (g/cc)	Vp0 (km/s)	Vs (km/s)	ε	δ	Υ
Smectite	2.4	3.075	1.5	0.255	-0.05	0.48
Illite	2.4	4.94	2.6	0.618	0.409	0.452
Quartz	2.65	6.0	4.0	0	0	0

Rock Physics – mineral transition

- Shale anisotropy
 - Smectite-to-Illite transition (Bachrach 2010)

$$P_I(t) = \frac{1}{2} + \frac{1}{2} \tanh\left(\frac{t - t_0}{2\sigma_0}\right)$$

$P_I(t)$: percentage of illite

t : Earth temperature

t_0 : transition temperature

σ_0 : half length of the transition window

Rock Physics – mineral transition

- Shale anisotropy
 - Smectite-to-Illite transition (Bachrach 2010)

$$P_I(t) = \frac{1}{2} + \frac{1}{2} \tanh\left(\frac{t - t_0}{2\sigma_0}\right)$$

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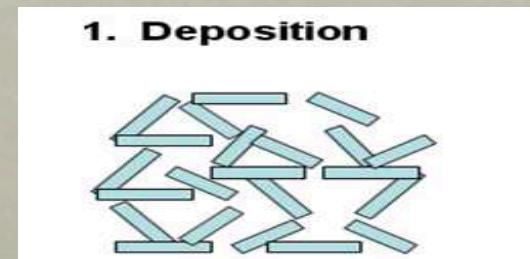
t_0 : transition temperature

σ_0 : half length of the transition window

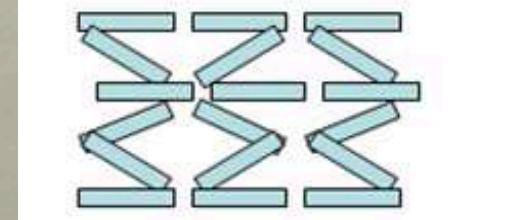
Rock Physics – alignment

- Shale anisotropy
 - Deposition and compaction (after Avseth et al., 2008)

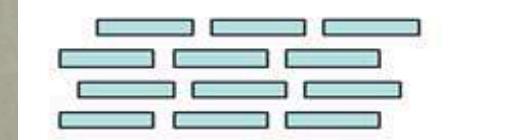
Initial state: randomly placed → isotropic medium



2. Partial “collapse”



3. “collapse”

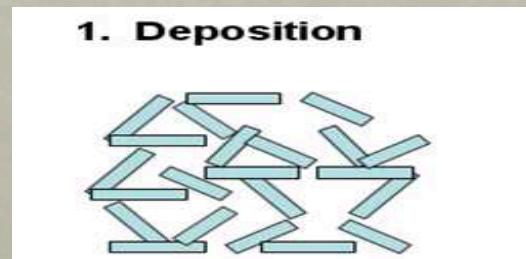


Final state: perfectly aligned → maximum anisotropy

Rock Physics – alignment

- Shale anisotropy
 - Deposition and compaction (after Avseth et al., 2008)

Initial state: randomly placed → isotropic medium

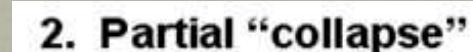


Intermediate state: partially aligned →

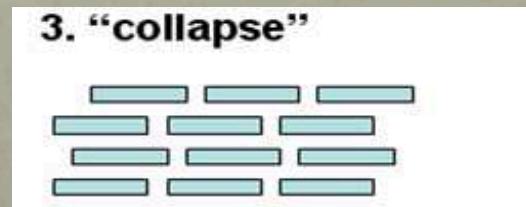
ϕ : porosity;

ϕ_0 : critical porosity;

m, n : rate of deformation

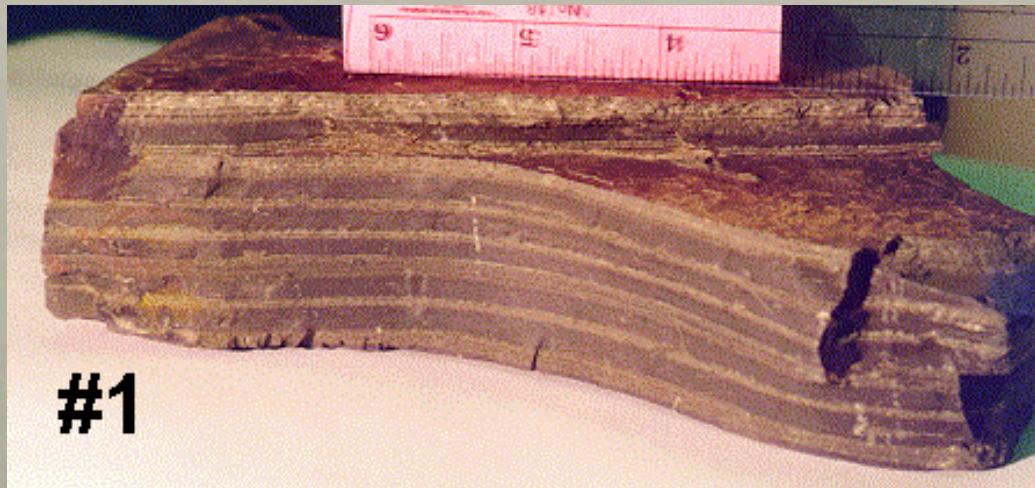


Final state: perfectly aligned → maximum anisotropy



Rock Physics – layering

- Shale anisotropy
 - Backus Average for (anisotropic) layered medium



$$P_{\text{quartz}} = 1 - v_{\text{shale}};$$

$$P_{\text{illite}} = v_{\text{shale}} * P_I;$$

$$P_{\text{smectite}} = v_{\text{shale}} * (1 - P_I);$$

Rock Physics Modeling

- Summary
 - Input: Porosity, Temperature, Shale content
 - Parameters: Critical porosity, Pore space deformation rate, S/I transition temperature/zone
 - Output: Multiple realizations of spatially varying ε and δ

Rock Physics Modeling

- Sources of input
 - Well log measurements
 - Lithological inversion results from seismic data

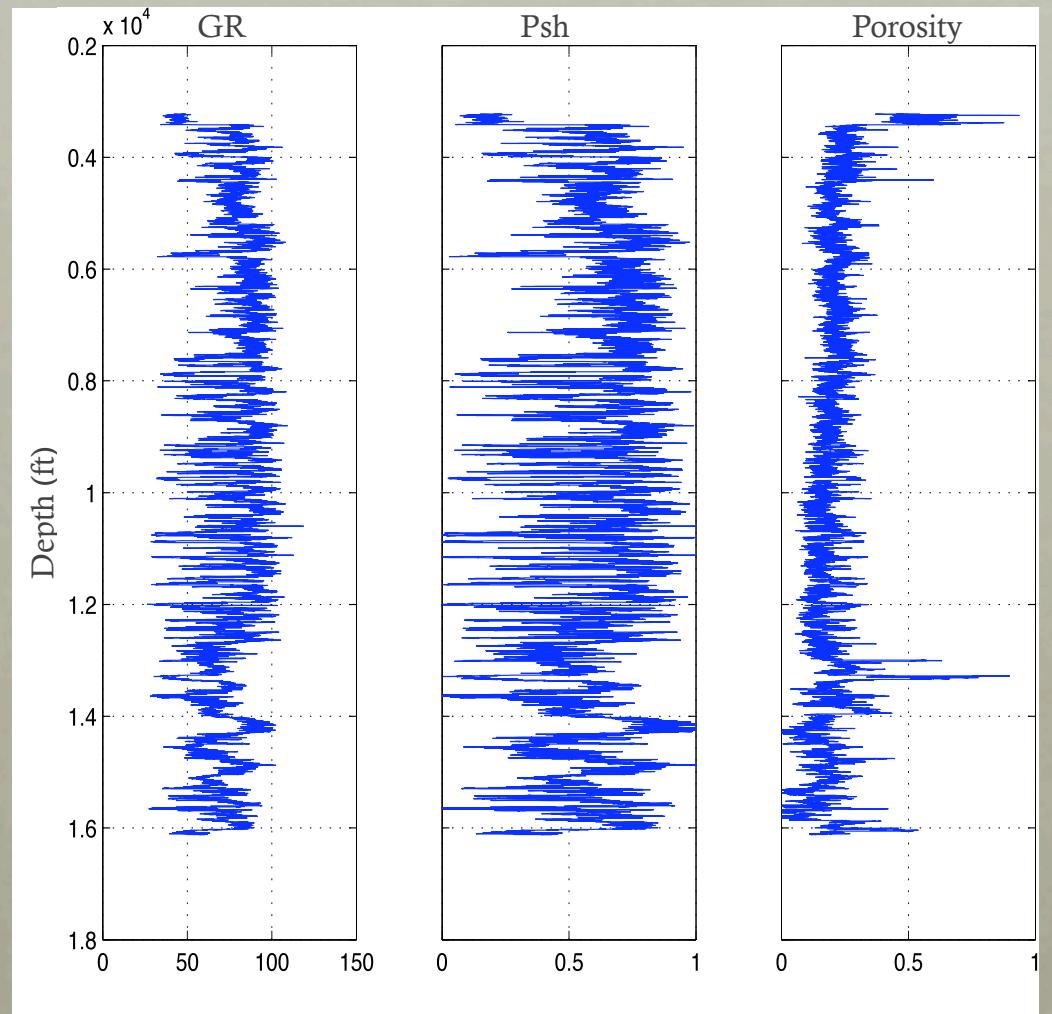
Rock Physics Modeling

- Input from well log

$$P_{sh} = \frac{G - G_{min}}{G_{max} - G_{min}}$$

- Temperature

$$t(z) = t_{\text{surf}} + z\Delta t$$



Rock Physics Modeling

- Well log modeling results
 - One realization using

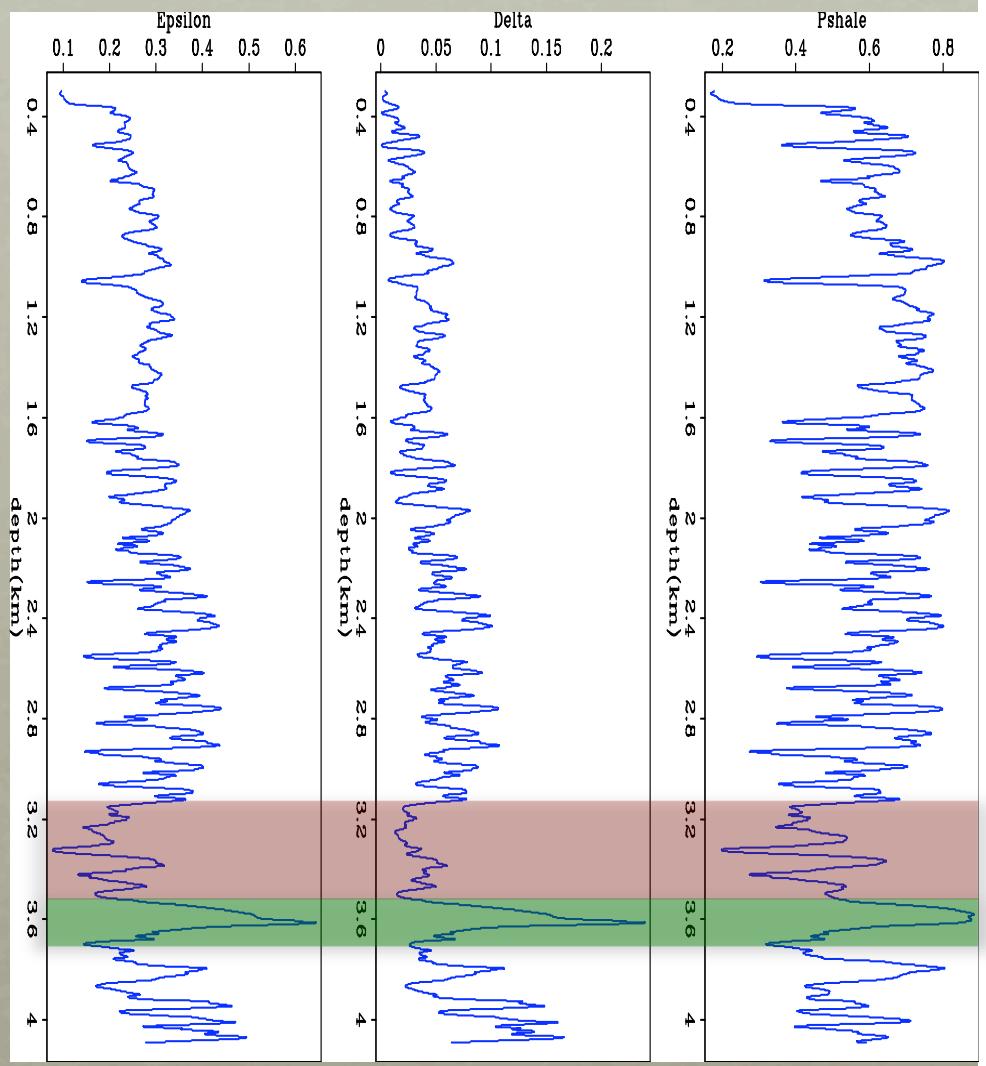
$$\phi_0 = 0.25$$

$$m = n = 1$$

$$t_0 = 58$$

$$\sigma_0 = 30$$

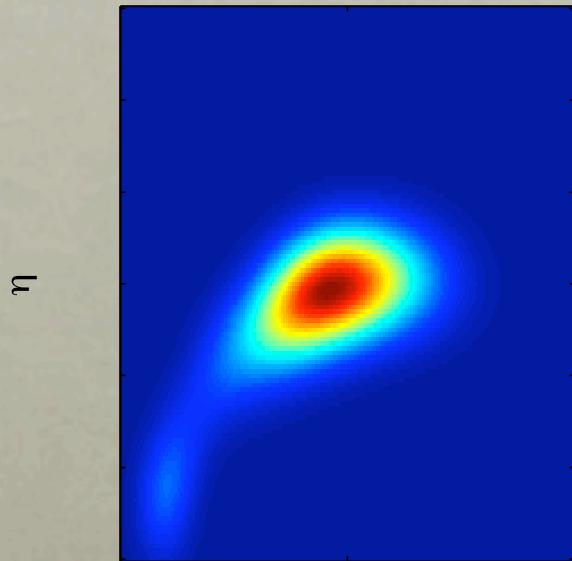
Sand →
Shale →



Rock Physics Modeling

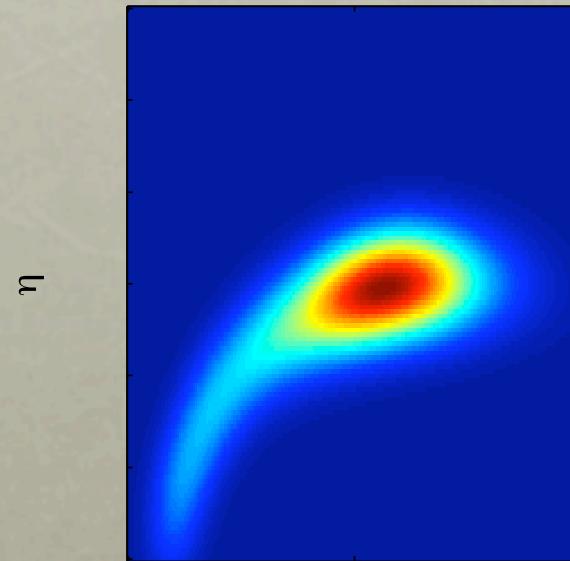
- Well log modeling results

$0 \text{ km} < z < 1.5 \text{ km}$



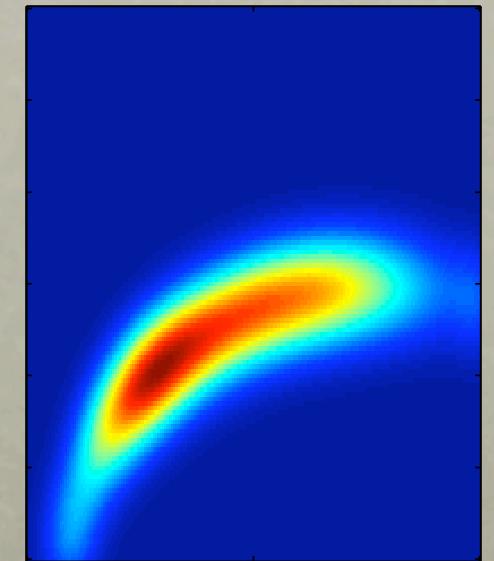
η_{\perp}

$1.5 \text{ km} < z < 3 \text{ km}$



η_{\perp}

$3 \text{ km} < z < 4 \text{ km}$

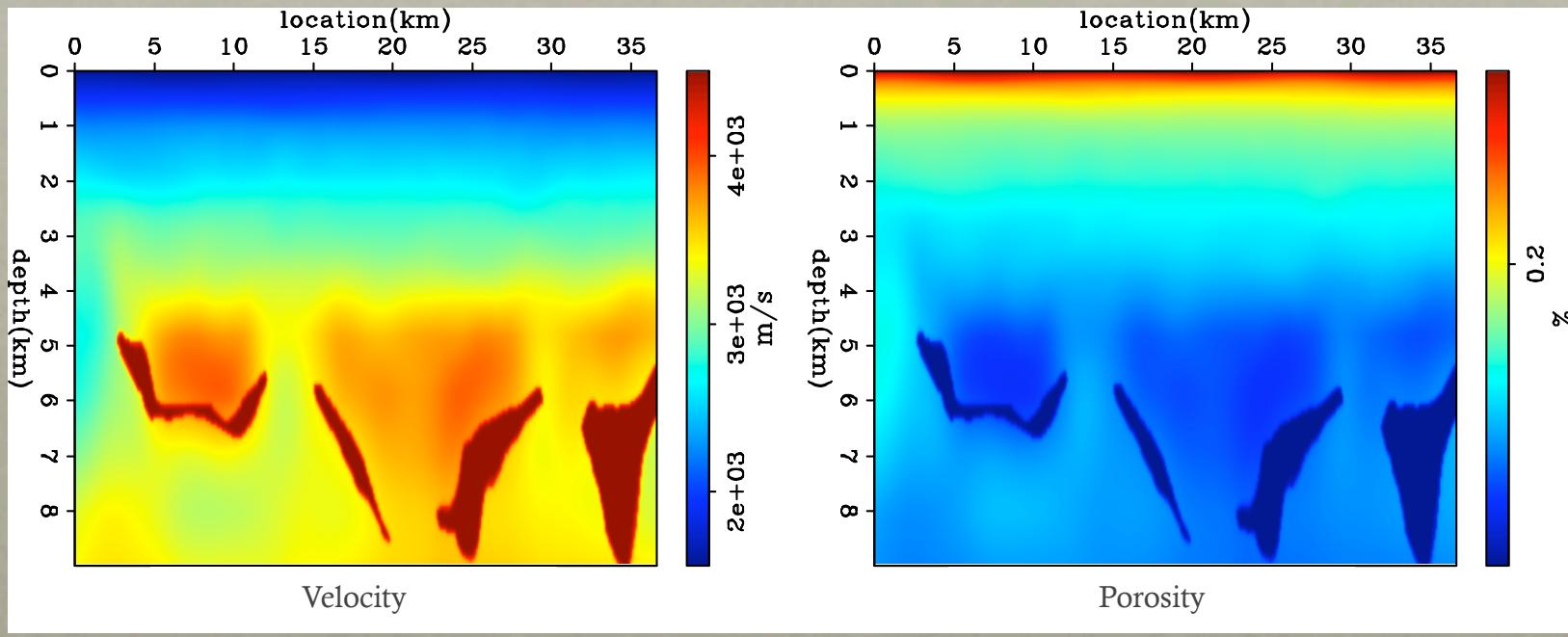


η_{\perp}

Rock Physics Modeling

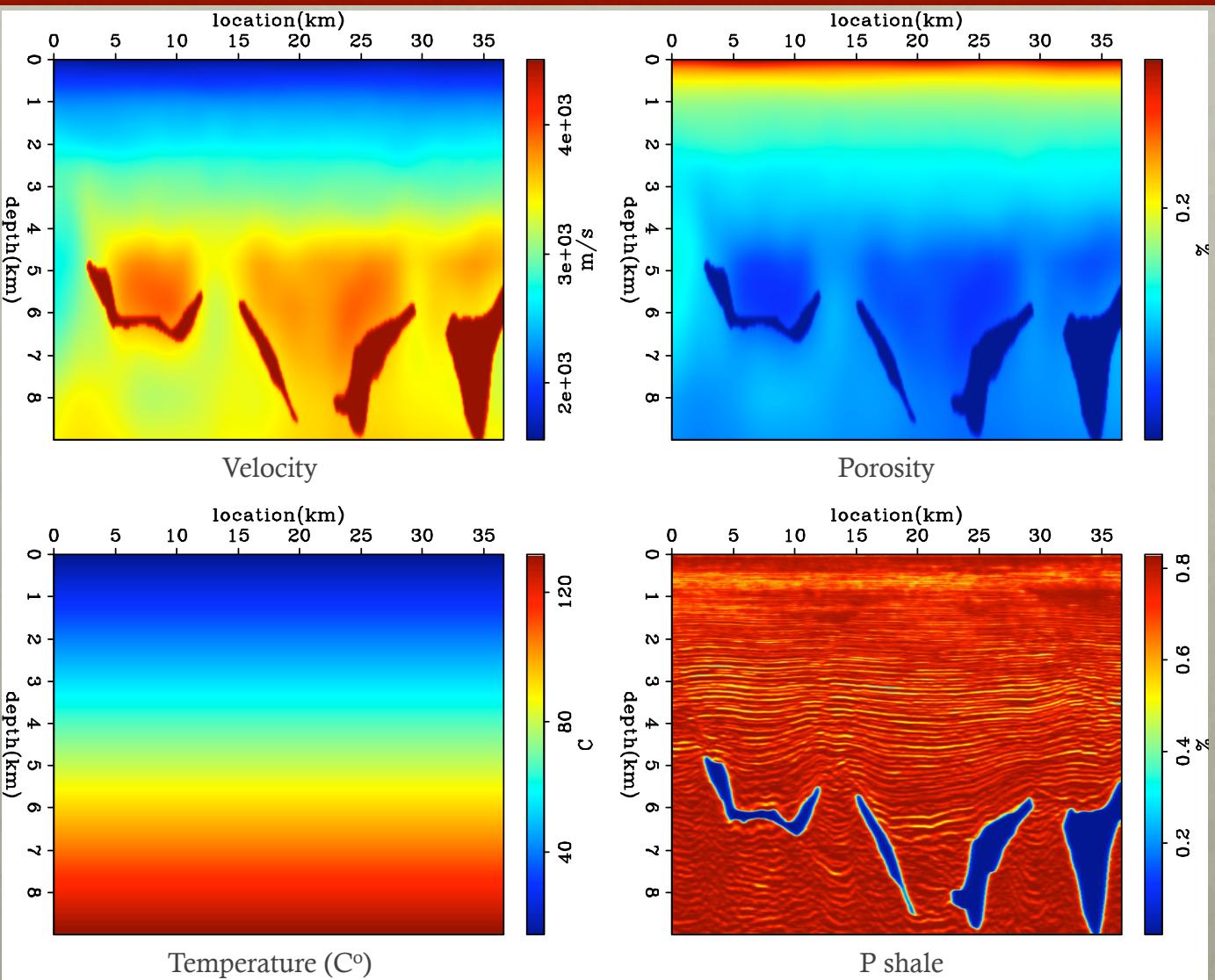
- Input from lithological inversion
- Velocity – porosity relation (Hyndman et al., 1993)

$$\phi = -1.180 + 8.607(1/v_n) - 17.89(1/v_n)^2 + 13.94(1/v_n)^3$$



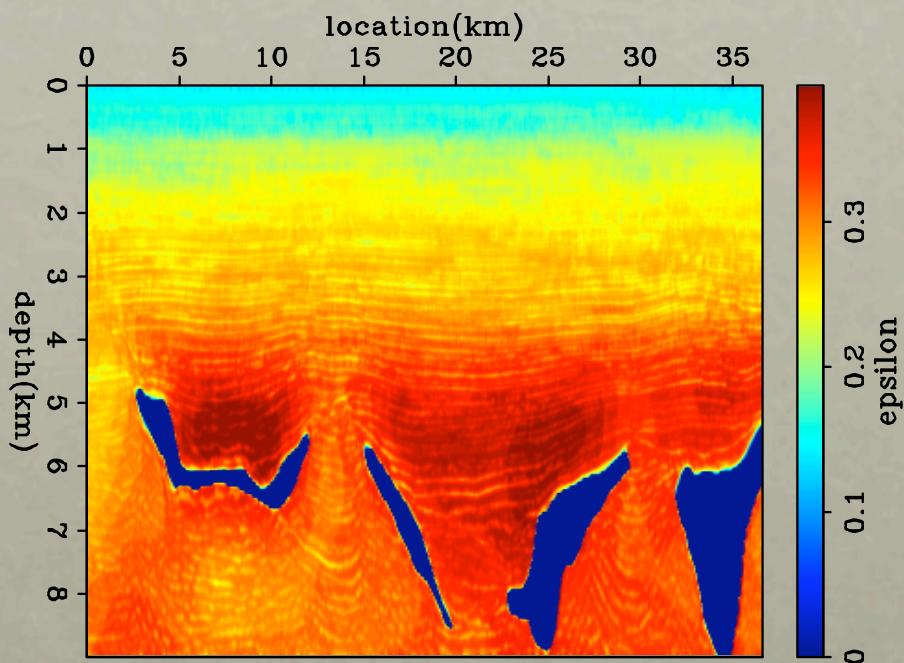
Rock Physics Modeling

- Input from lithological inversion

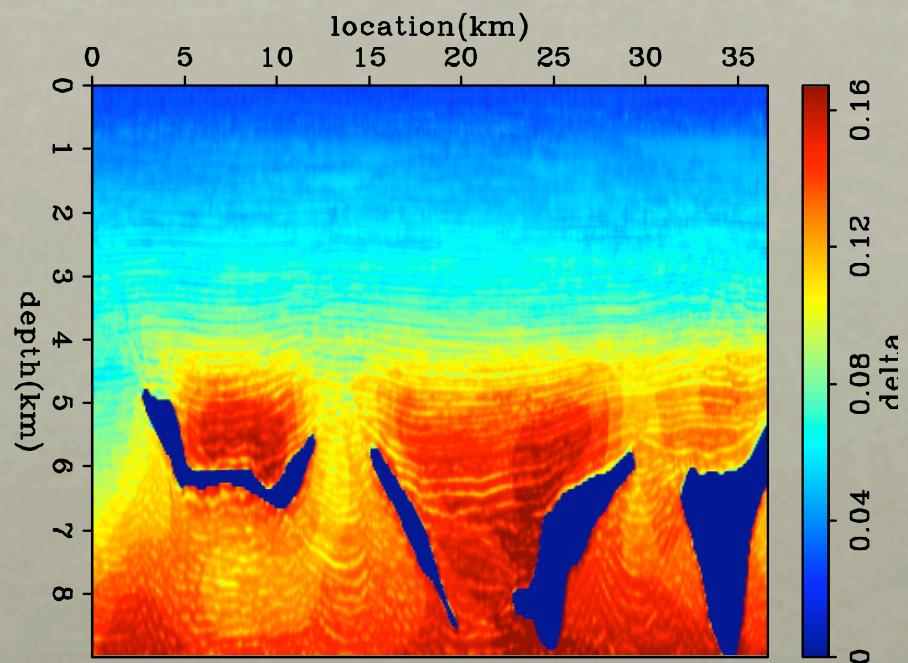


Rock Physics Modeling

- Modeling results using lithological inversion
 - one realization using $\phi_0 = 0.25; m = n = 1; t_0 = 58; \sigma_0 = 30$



Epsilon model

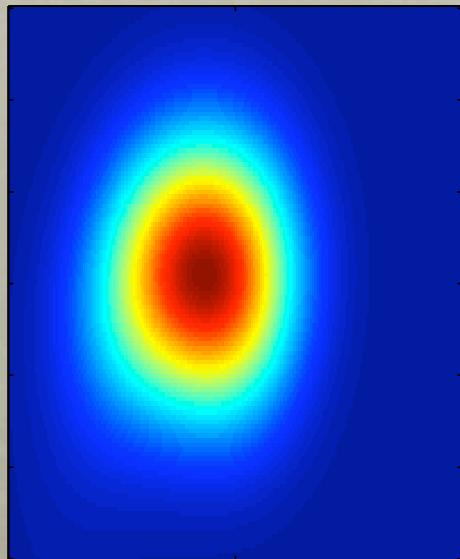


Delta model

Rock Physics Modeling

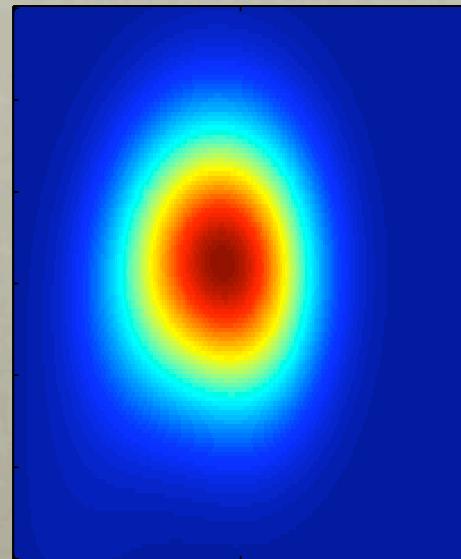
- Modeling results lithological inversion

$0 \text{ km} < z < 1.5 \text{ km}$



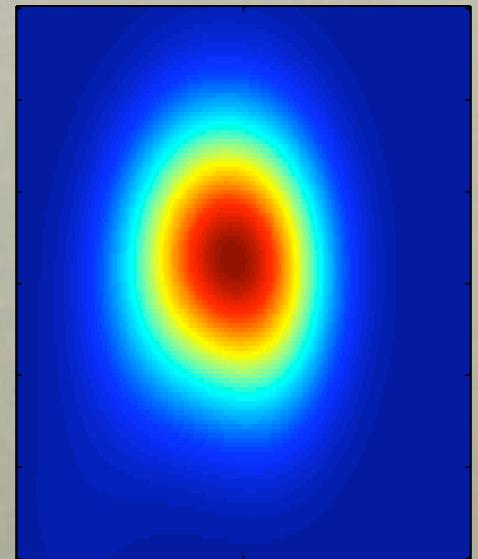
η_{\perp}

$1.5 \text{ km} < z < 3 \text{ km}$



η_{\perp}

$3 \text{ km} < z < 4 \text{ km}$

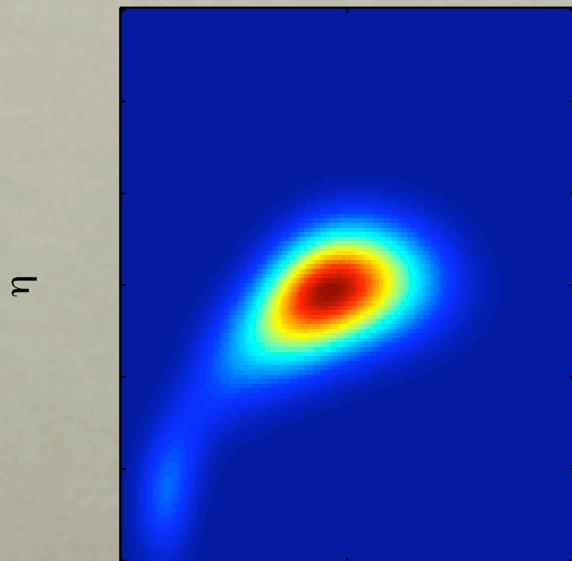


η_{\perp}

Rock Physics Modeling

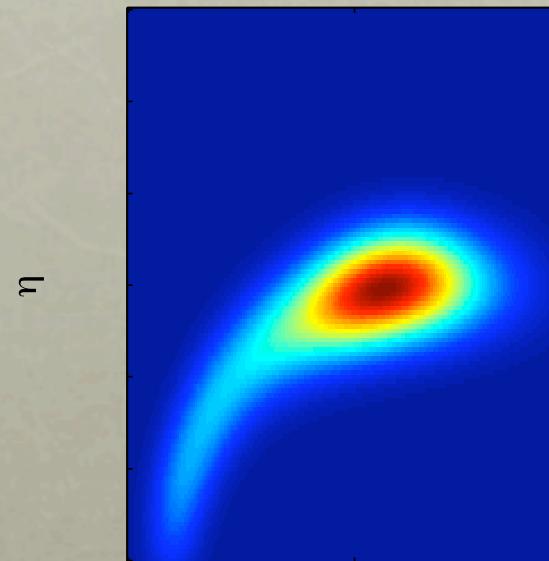
- Modeling results with well log inputs

$0 \text{ km} < z < 1.5 \text{ km}$



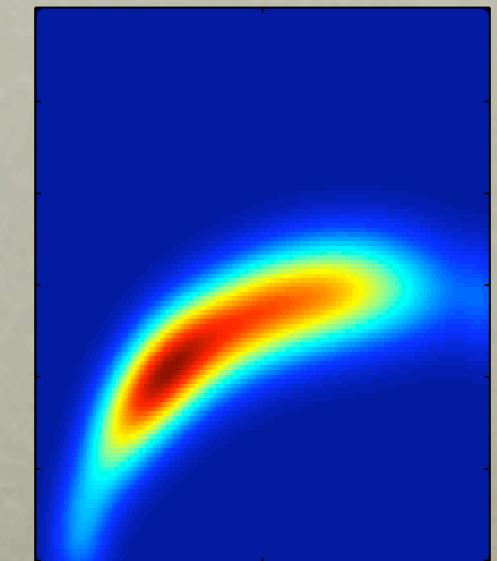
η_{\perp}

$1.5 \text{ km} < z < 3 \text{ km}$



η_{\perp}

$3 \text{ km} < z < 4 \text{ km}$



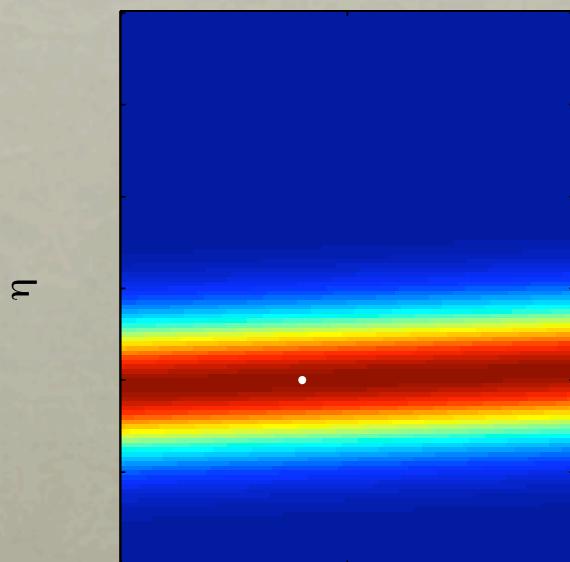
η_{\perp}

Agenda

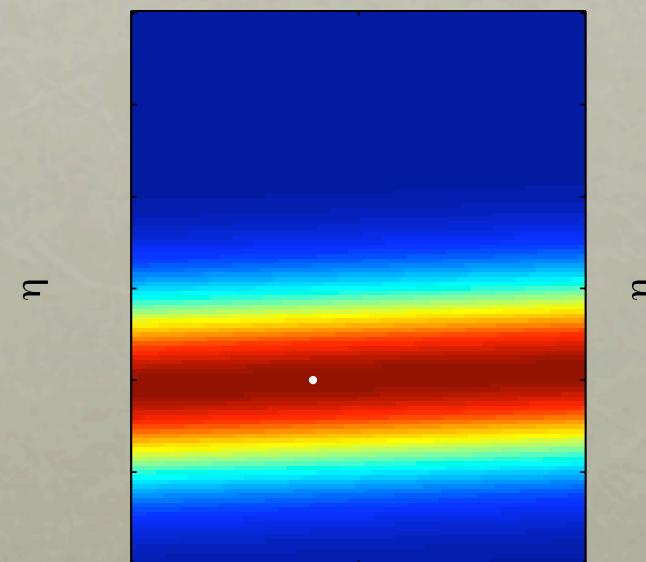
- Least-squares problem and parameterization
- Rock physics modeling for anisotropy
- **Constraining WEMVA using rock physics information**
- Conclusion

Data objective function

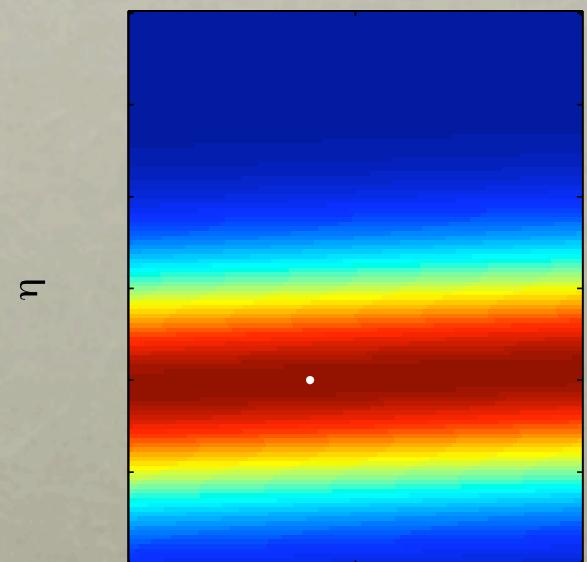
$0 \text{ km} < z < 3\text{km}$



$3\text{km} < z < 6\text{km}$

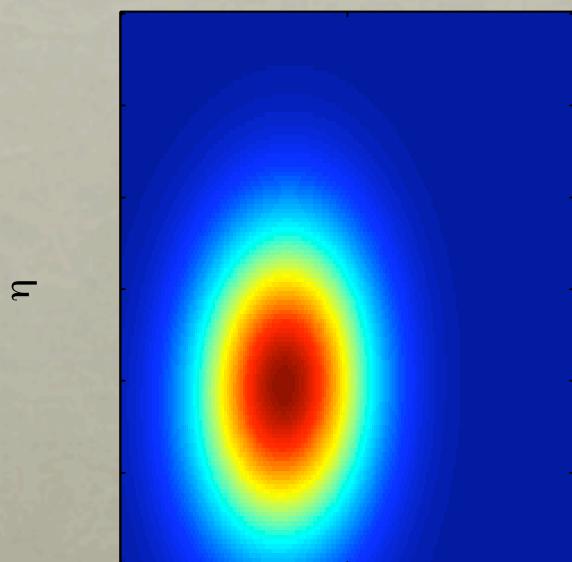


$z > 6\text{km}$



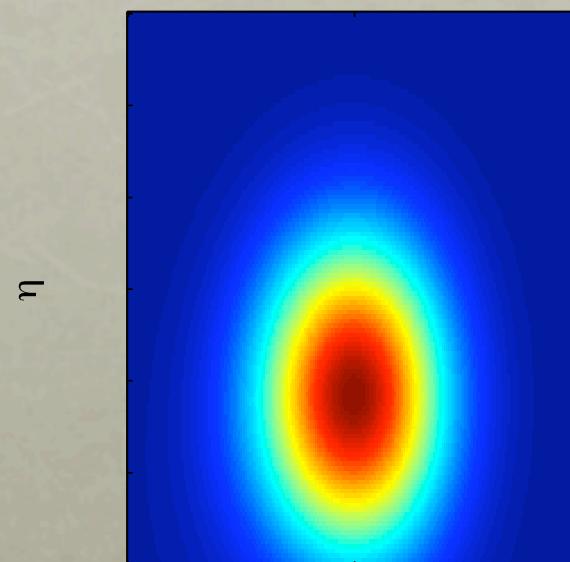
Model objective function

$0 \text{ km} < z < 3\text{km}$



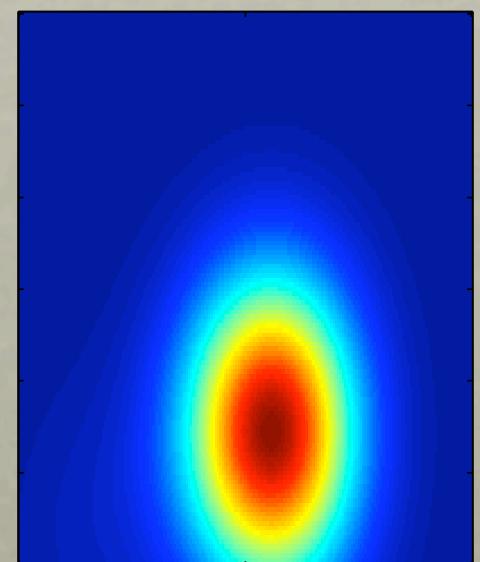
η_{\perp}

$3\text{km} < z < 6\text{km}$



η_{\perp}

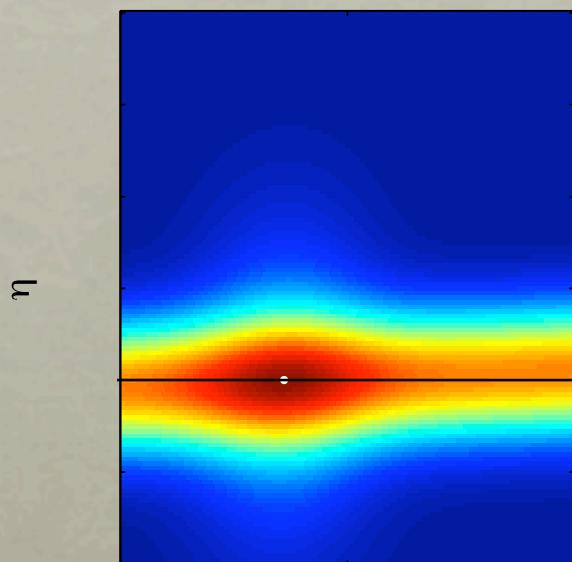
$z > 6\text{km}$



η_{\perp}

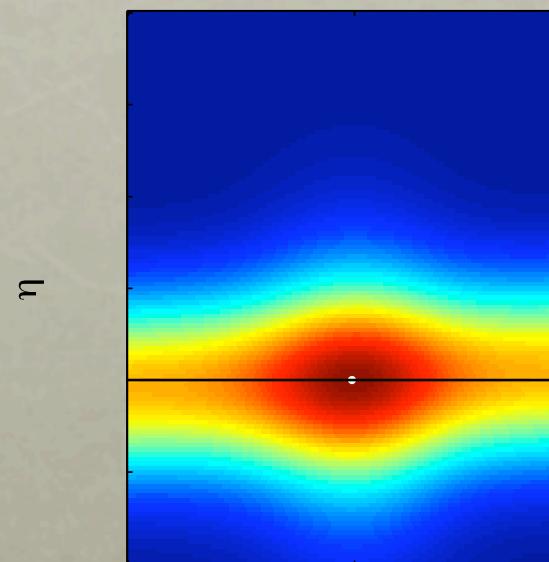
Combined objective function

$0 \text{ km} < z < 3\text{km}$



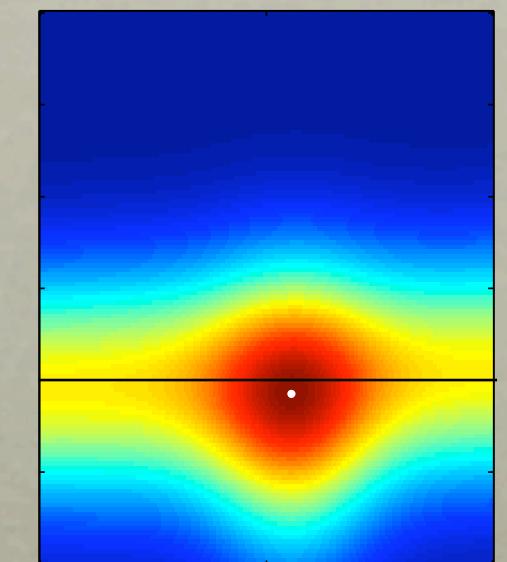
η_{\perp}

$3\text{km} < z < 6\text{km}$



η_{\perp}

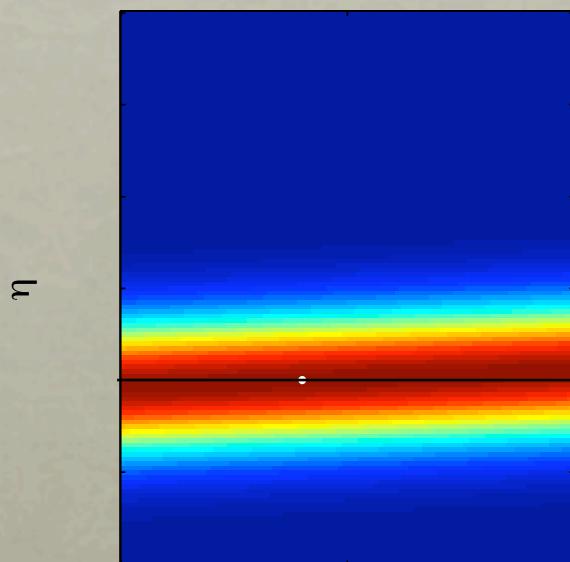
$z > 6\text{km}$



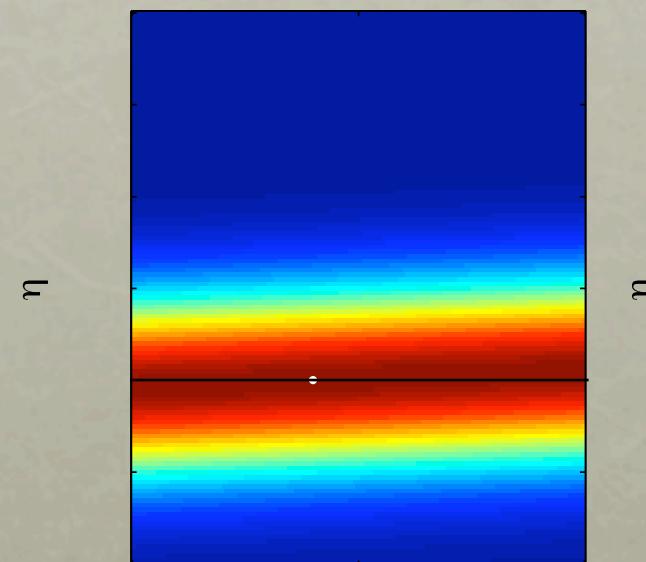
η_{\perp}

Data objective function

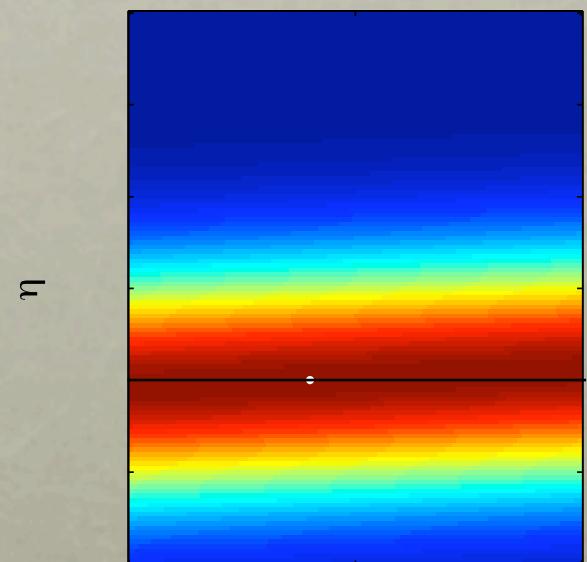
$0 \text{ km} < z < 3\text{km}$



$3\text{km} < z < 6\text{km}$



$z > 6\text{km}$



Agenda

- Least-squares inversion
- Rock physics modeling for anisotropy
- Constraining tomography using prior information
- **Conclusions and discussion**

Summary

- We propose a new parameter η_{\perp} to describe the least constrained direction by WEMVA.
- We model seismic anisotropy by rock physics modeling.
 - In 1D (using well log)
 - In 3D (using previous seismic inversion results)
- Stochastic rock physics modeling can potentially define the distribution of the anisotropic parameters.

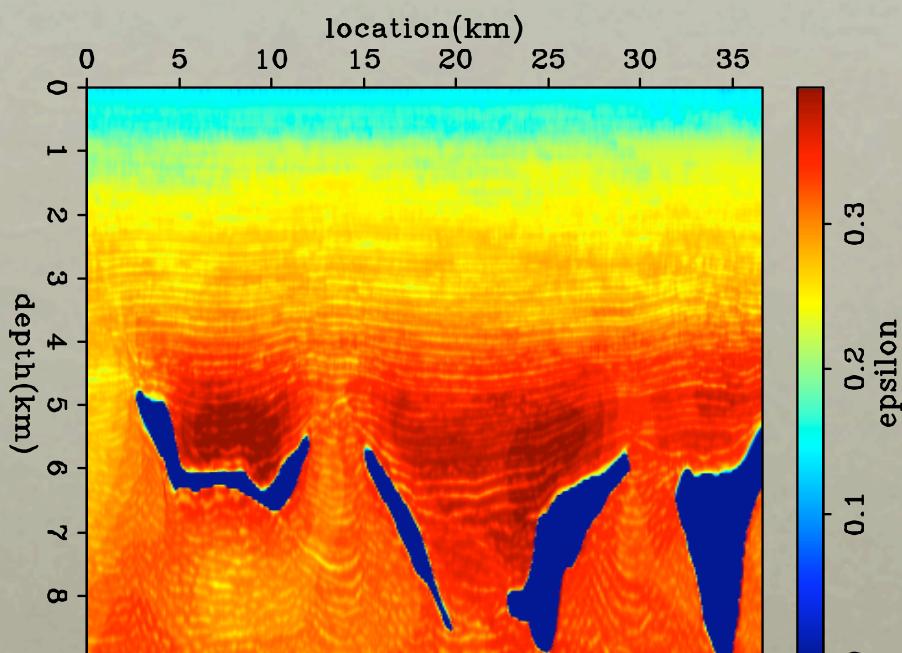
Discussion

- Build local $\eta - \eta_{\perp}$ covariance to constrain WEMVA.
- Adding rock physics information will not change the solution to the well-constrained parameter.
- Using inversion results of the previous seismic processing provides feedback from the reservoir properties back to the seismic data.

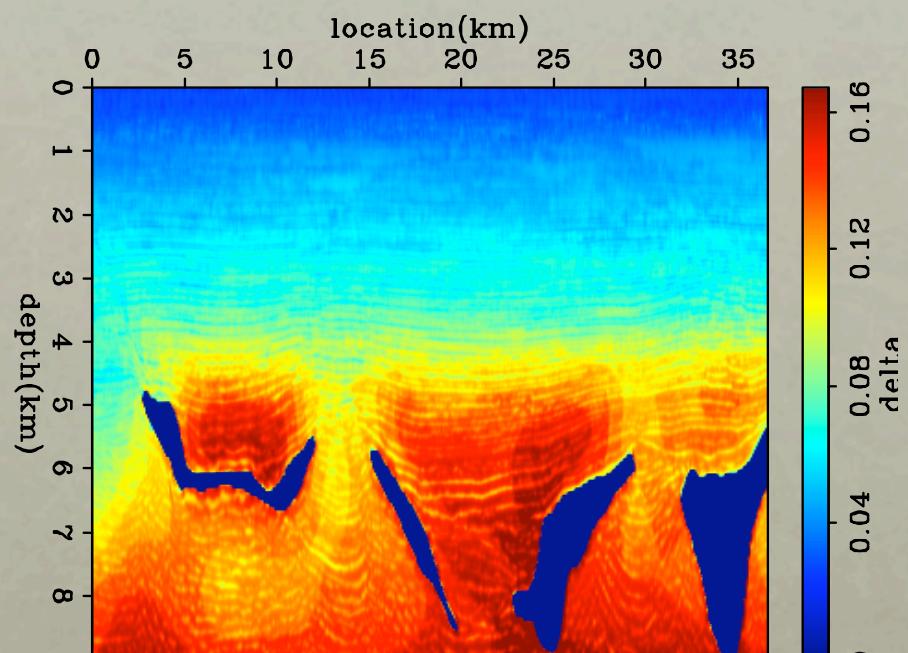
Acknowledgment

- We thank WesternGeco for providing the seismic data and the inverted attributes.
- Well log data was supplied by IHS Energy Log Services; Copyright (2013) IHS Energy Log Service Inc.

Thank you!



Epsilon model



Delta model