# Statistical AVO Inversion

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# A road map

- fundamentals of statistical inversion
- multiple scenario testing
- rock property model
- AVO model
- statistical AVO implementation

# Applicability of AVO inversion

- **AVO with tuning**
- **uncertainty estimate**
- **probability of different geologic scenarios**

# Statistical inversion solves for probability of model

petrophysics (trend curves, neural networks)

$P(m|d_{petro})$ = probability of model given petrophysical data

seismic

$q_{<n>}(n)$ = noise distribution

$= \exp(-\Sigma\, n_k^2 / \langle n_k \rangle^2 )$

s(m) = synthetic seismic given model (forward modeling)

$d_{seismic}$ = seismic data

==> $P(d_{seismic}|m) = q_{<n>}(d-s(m))$ = probability of seismic given the model

$$P(m|d_{seismic},d_{petro}) \sim P(d_{seismic}|m)\ P(m|d_{petro})$$

# Iterative solution for N equally probable models

construct a sequence $\{ P_n(m) \}$ such that

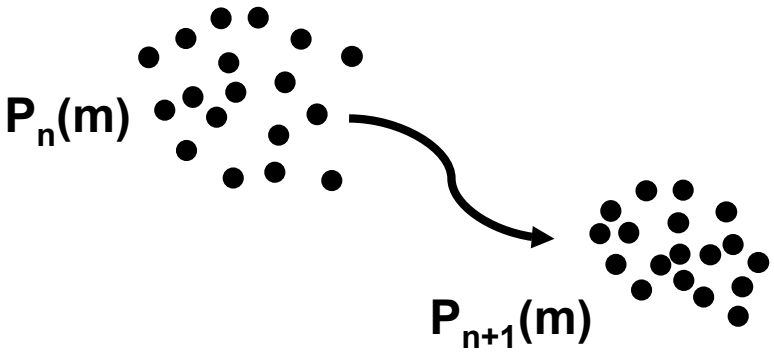
$$P_n(m) \rightarrow P( m \mid d ) \quad \text{as} \quad n \rightarrow \infty ,$$

$$P_0(m) = P(m),$$

and

$$P_{n+1}(m) = F( P_n(m) )$$

**F** = conjugate gradient or metropolis

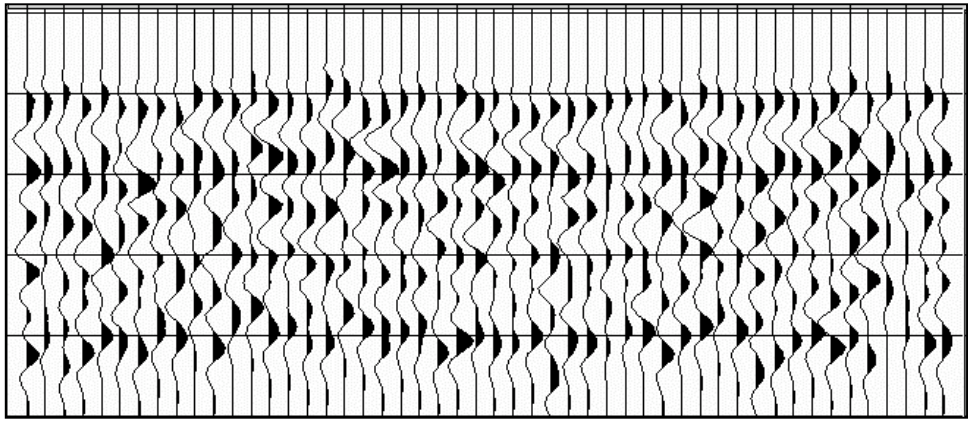


# Inversion improves match with seismic data

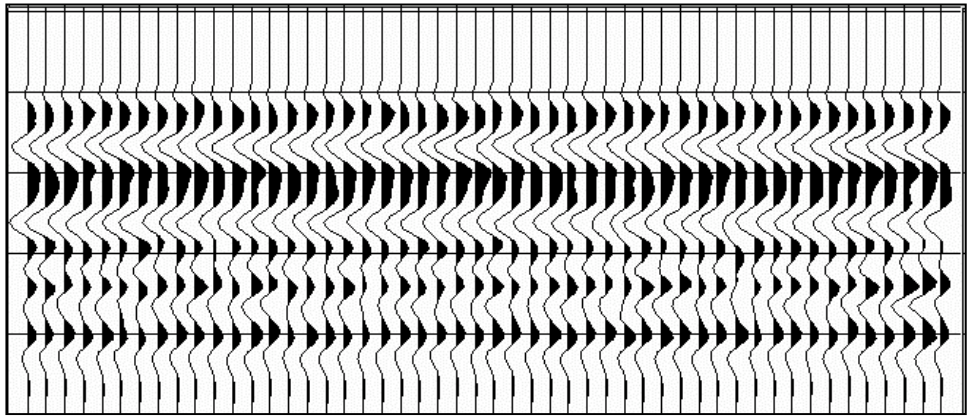
model

pre inversion
$P(m|d_{petro})$

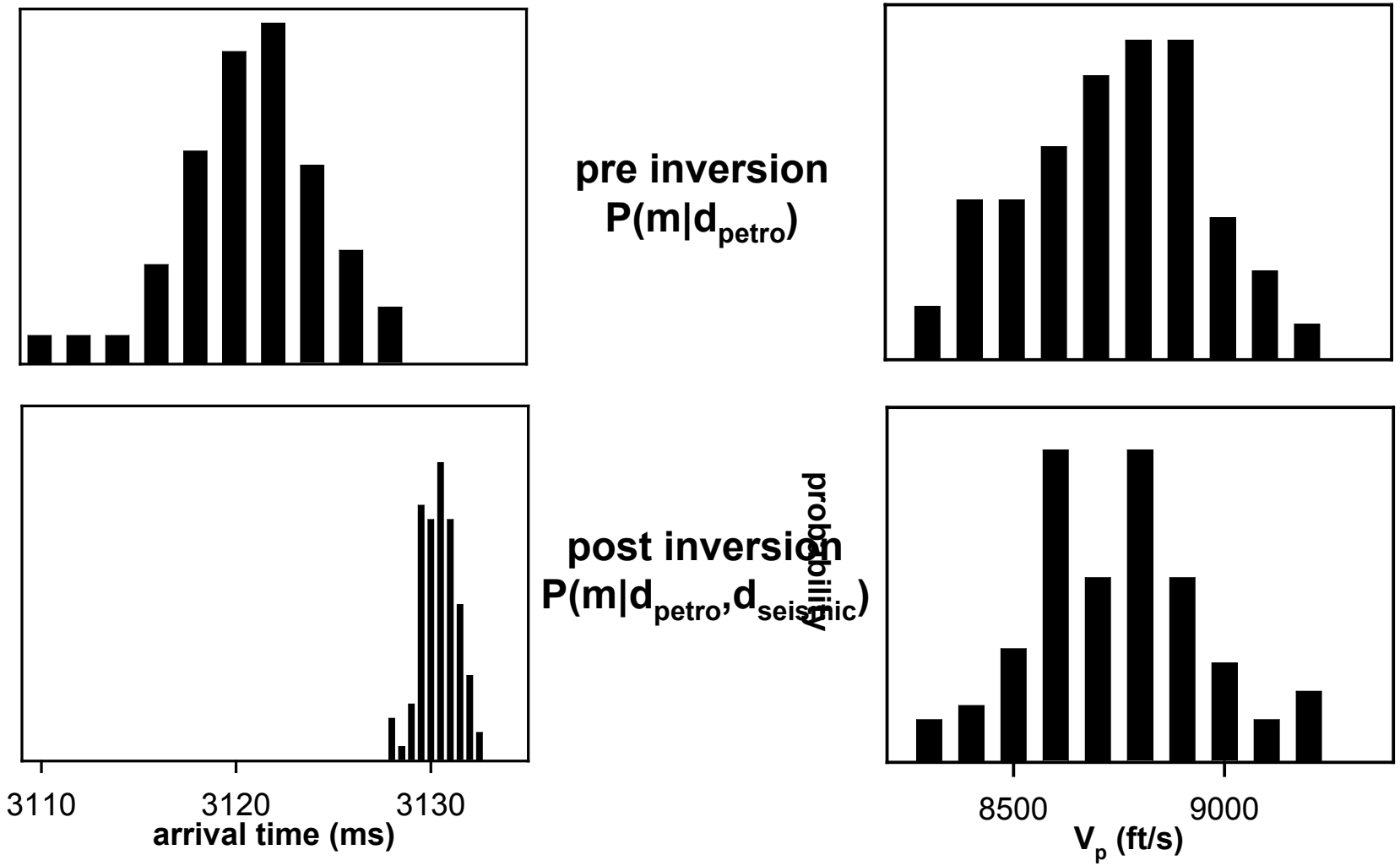
time



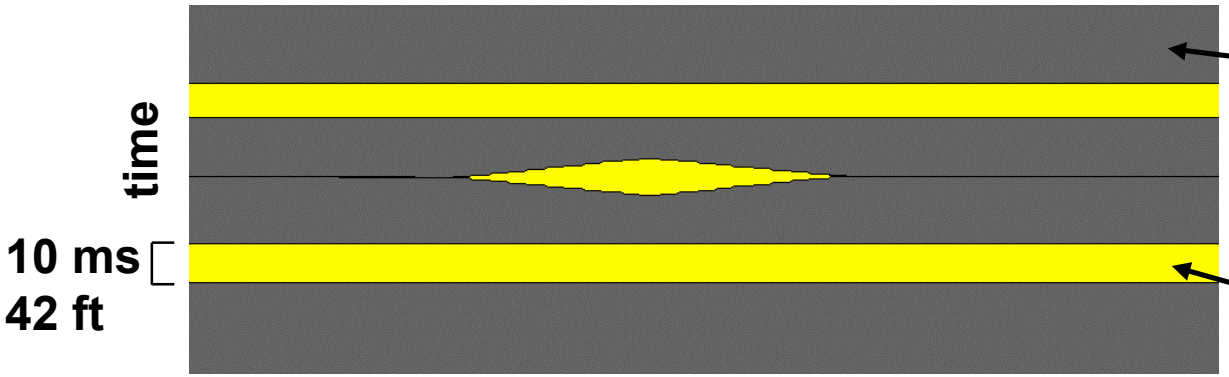
post inversion
$P(m|d_{petro},d_{seismic})$



# Inversion improves estimate of some reservoir properties

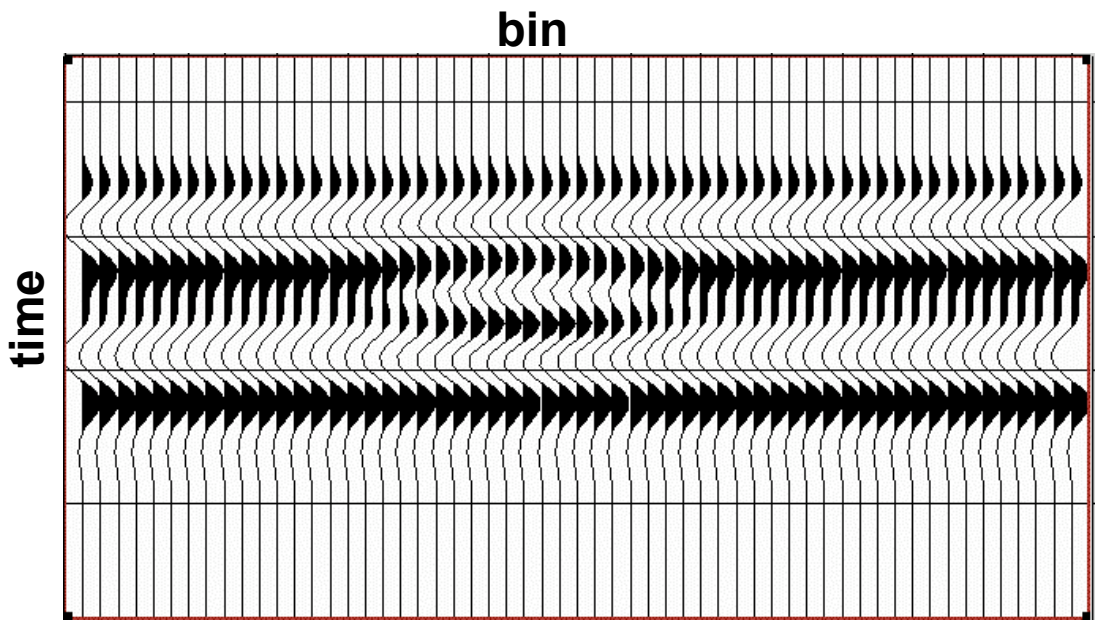


# An example of scenario testing: a lens model

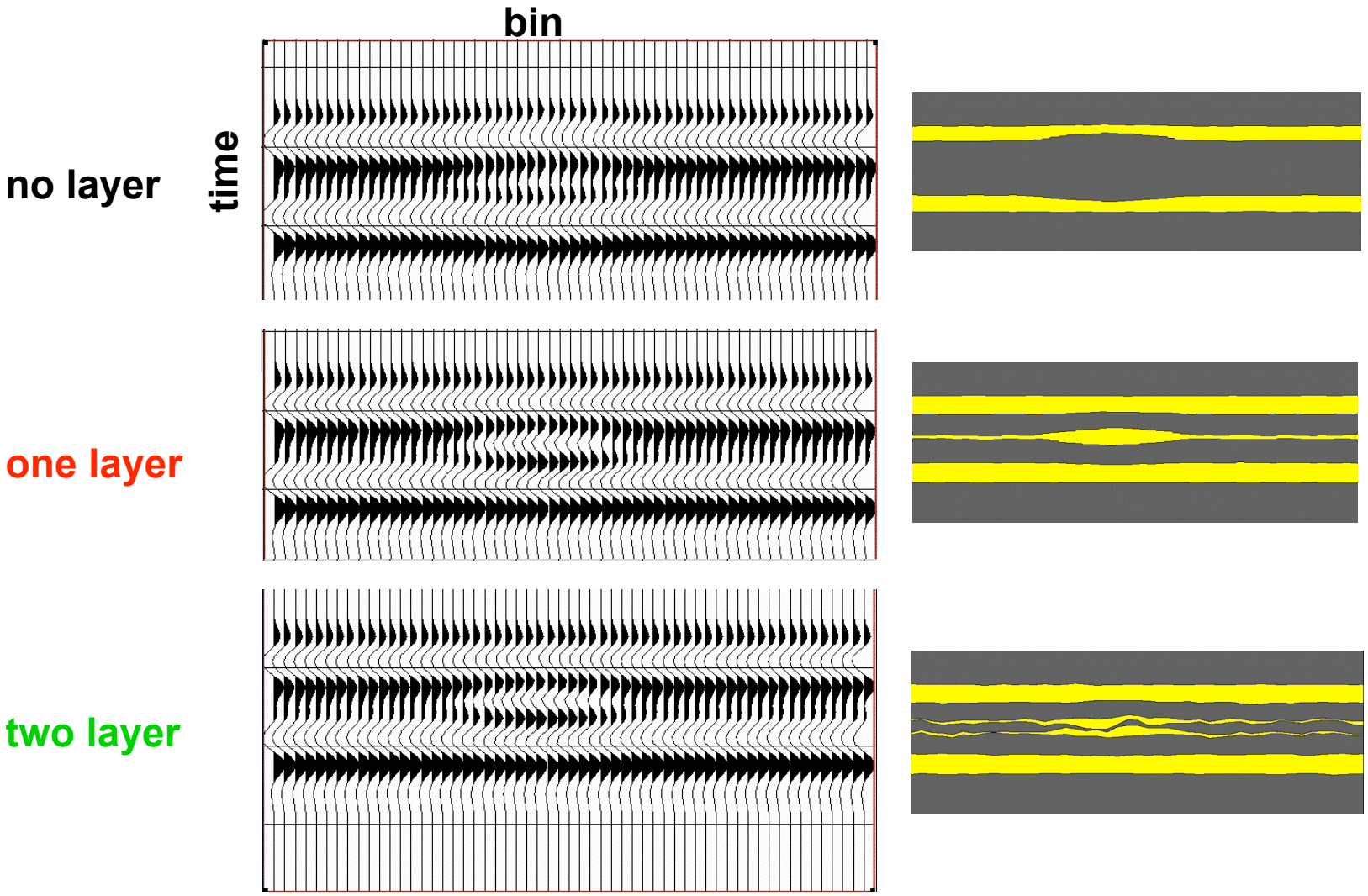



shale
$v_p$ = 9000±150 ft/s
ρ = 2.3±0.03 gm/cc

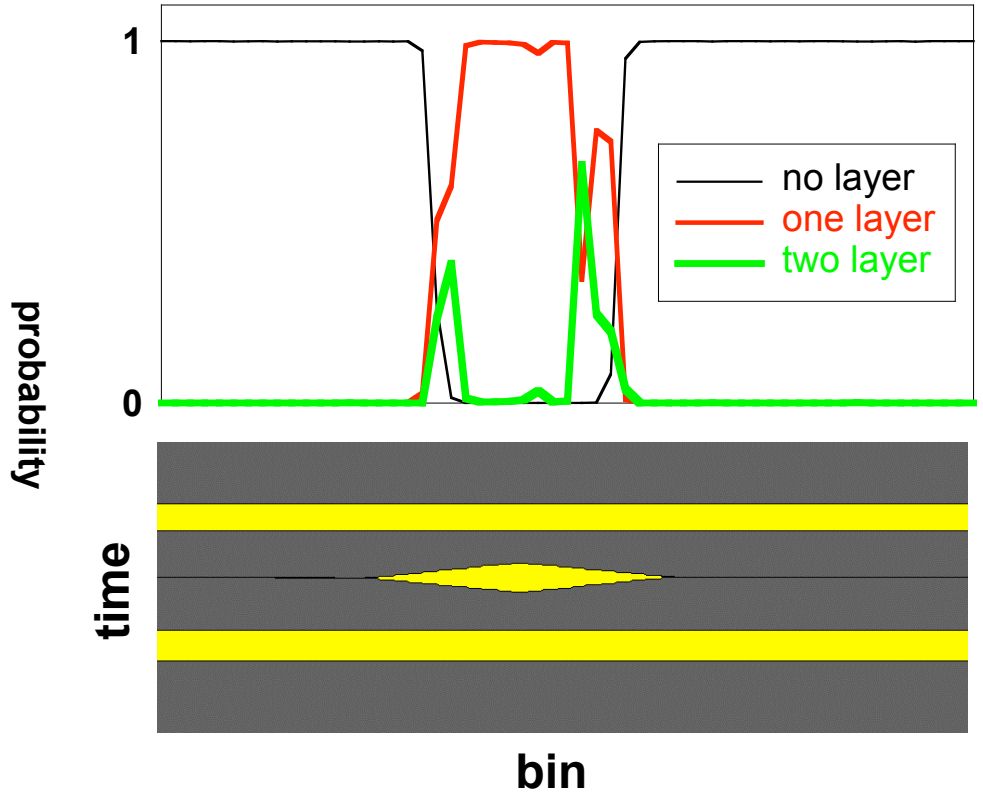
sand
$v_p$ = 8500±150 ft/s
ρ = 2.1±0.03 gm/cc



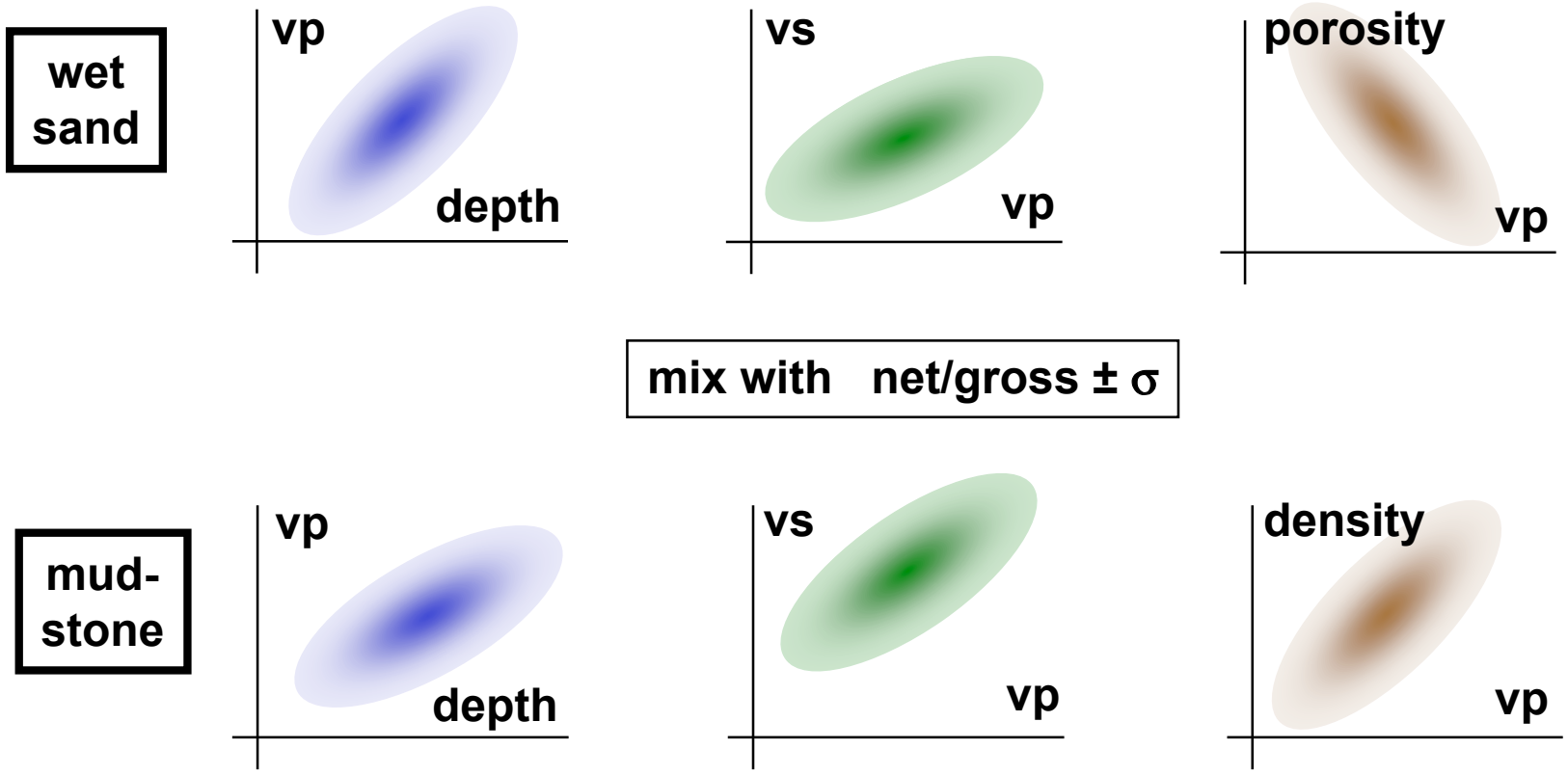
# Average synthetics with different scenarios (i.e., number of layers)



# Probabilities of different scenarios

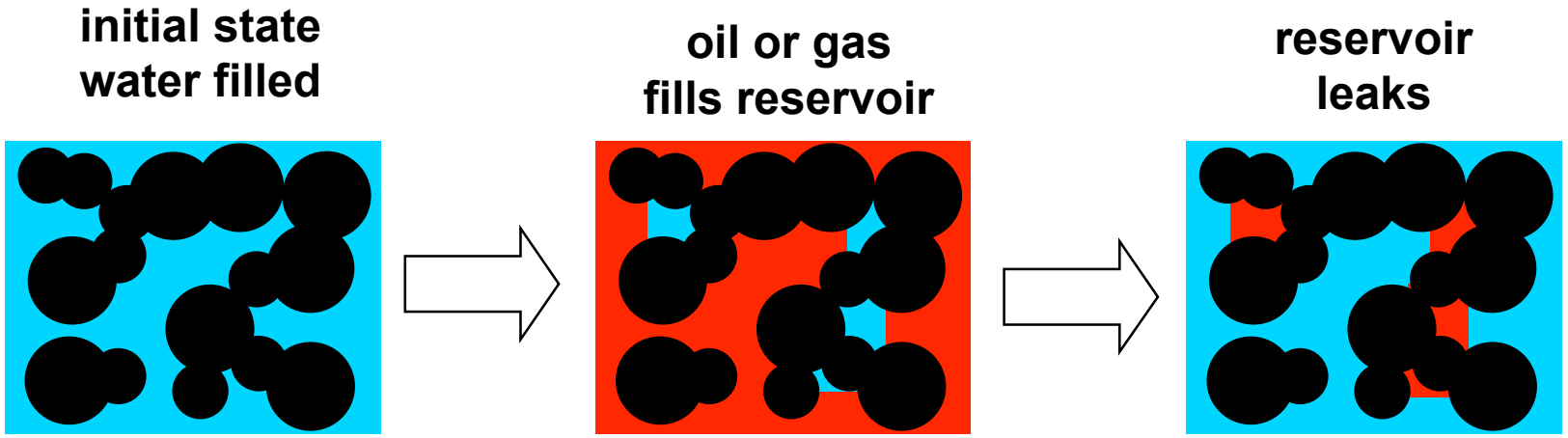


# GOM petrophysical end member trends used in prior probability




note: separate trend for each layer

# Discrete cases of fluid fill are used

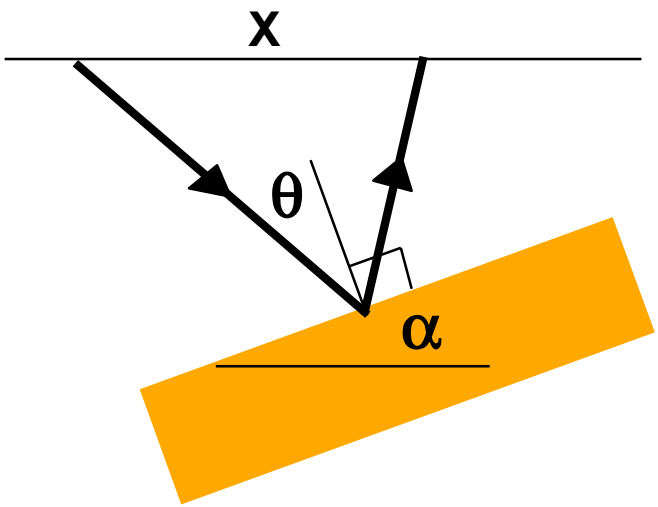



- **prior probability of each fluid fill case**
  - neural network fluid prediction
  - regional information (trap probability, leak probability, etc.)
- **posterior probability of each fluid fill case**
  - adds seismic AVO information

# A time migration approximation is used to model AVO

**expansion in ( X / V T ) and ( V dT/dx ) << 1**

where, X = offset
V = migration velocity
T = migrated time of reflector
x = migrated subpoint
v = interval velocity




$\theta = (v/V)\ ( X / V\ T ) + 3rd\ order$

$\alpha = 0.5\ ( V\ dT/dx ) + 3rd\ order$

# Equations that are used to model AVO

**reflection coefficient**

$$R(X) = A\,L + B\,M\,\overbrace{(v/V)^2\,(X / V\,T)^2}^{\sin^2\theta} + \text{4th order}$$

**wavelet stretch**

$$S(X) = 1 + \overbrace{0.5\,(X / V\,T)^2}^{\text{NMO}} + \overbrace{0.125\,(V\,dT/dx)^2}^{\text{dip}} + \text{4th order}$$

**offset average wavelet & reflection coefficient**

$$\text{wavelet} = W(X, t) = W_0(t / S(X))$$

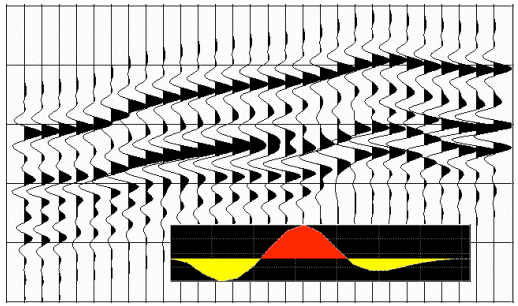
$$\langle R\,W \rangle_X = \langle R \rangle_X \langle W \rangle_X + \text{4th order}$$

# What effects are addressed in model

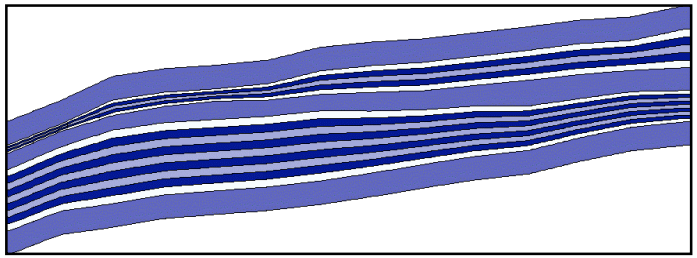
- amplitude variation with offset
- dip dependant NMO wavelet stretch
- background normal rotation
- buried absorbers and diffractors (statics)

# Inputs to inversion

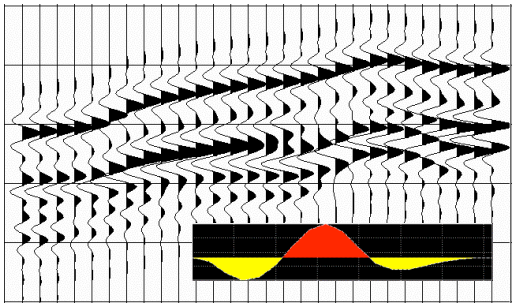
**near stack and wavelet**



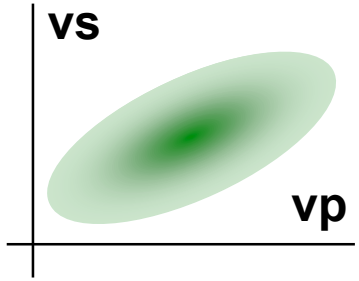
**initial DepSim model**



**far stack and wavelet**

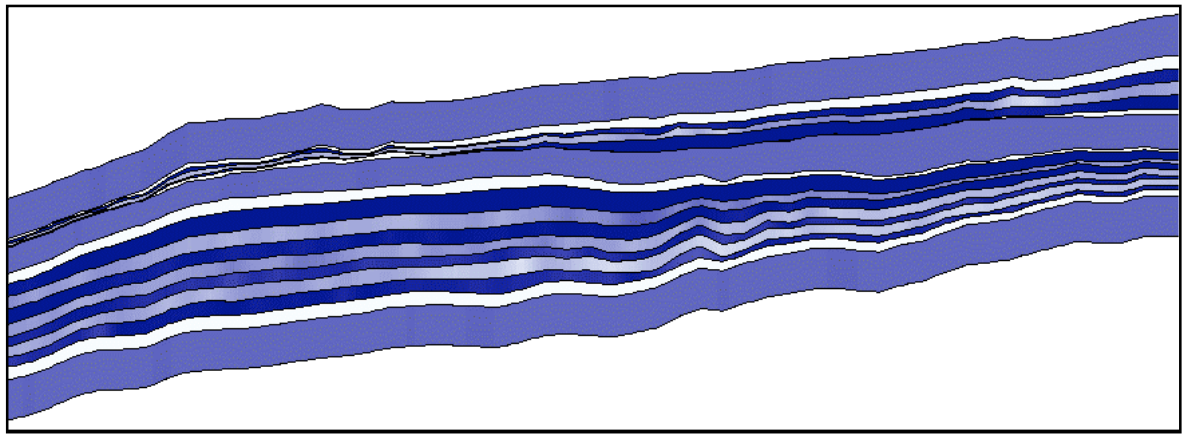


**rock properties**

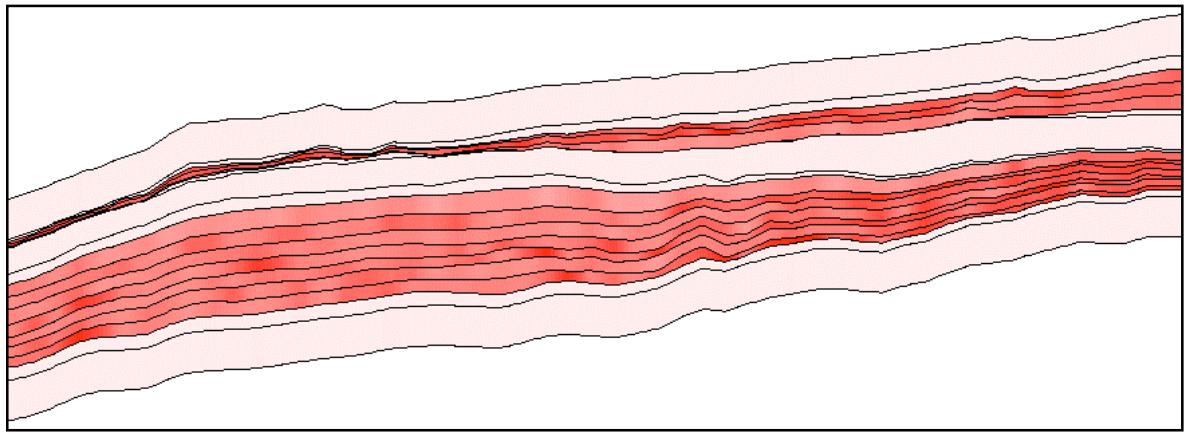


# Output of inversion

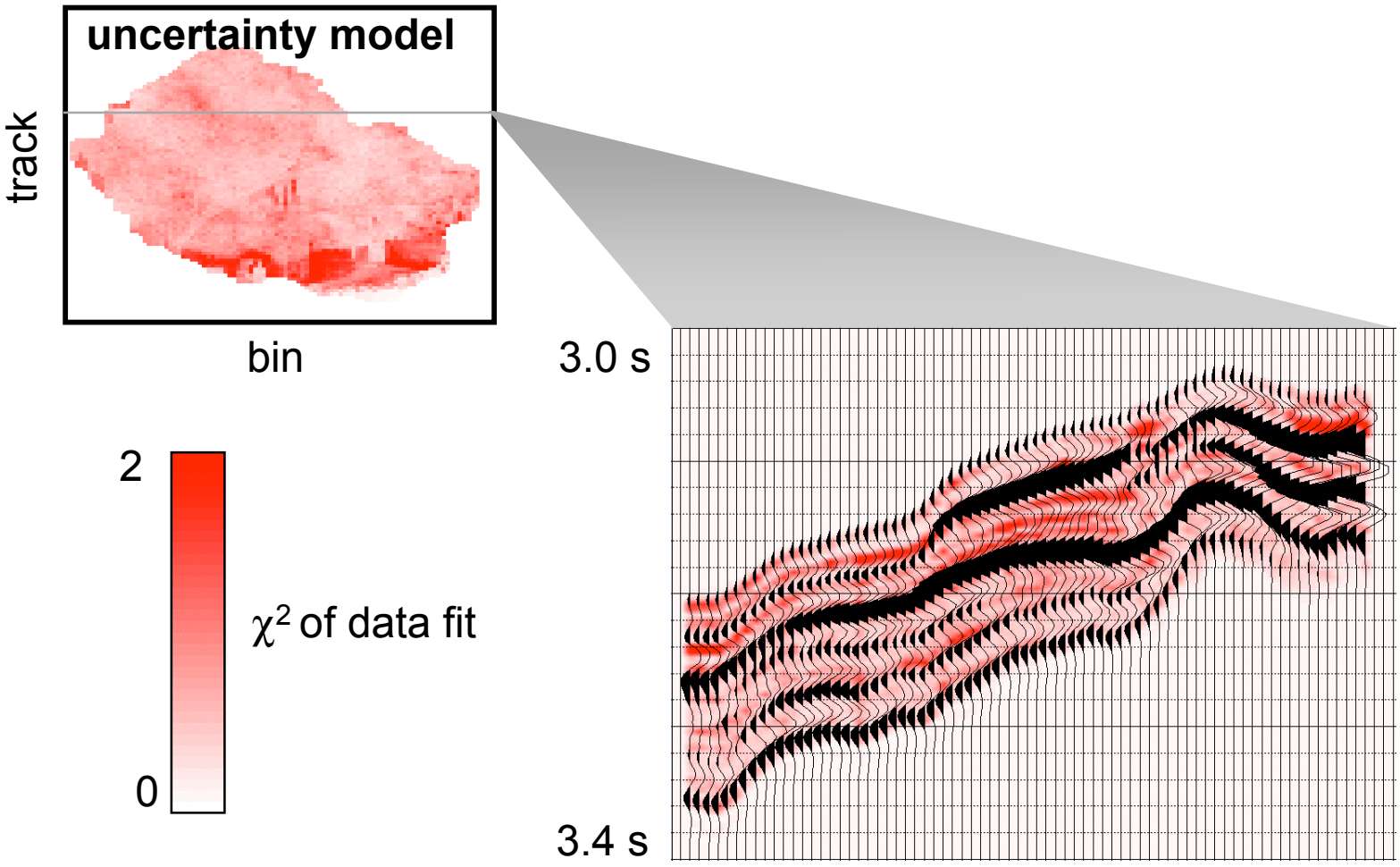
**updated DepSim model**



**uncertainty in DepSim model**



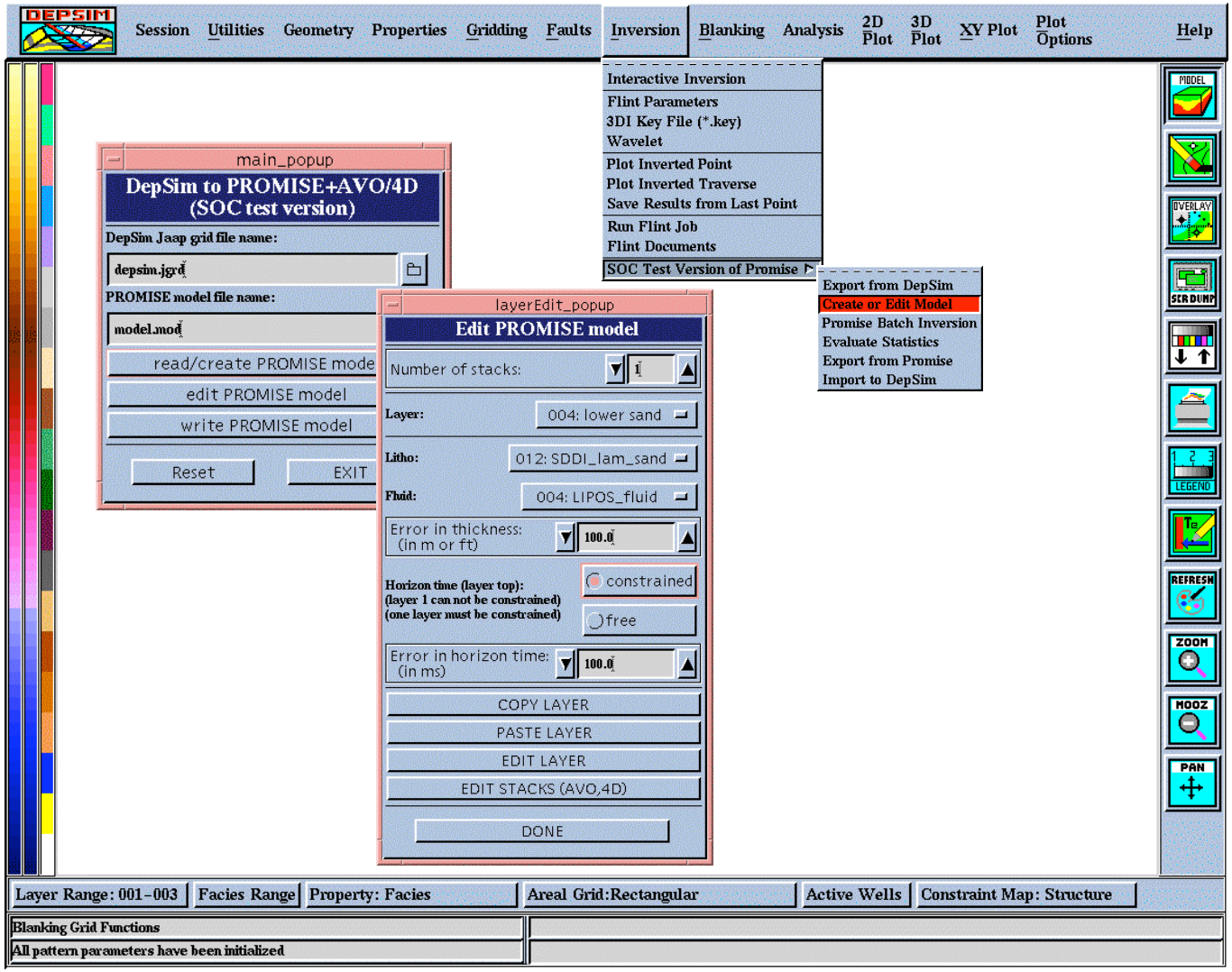
# Some interesting and useful error estimates



# Philosophy of development

- **DepSim IO engine for PROMISE**
- **SPIRIT II wrapper on prototype PROMISE**
- **compatible and expandable**
  - AVOMOD
  - neural net  (fluid prediction and beyond)
  - GOM petrophysics (trends and LIPOS)

# Implementation of AVO inversion



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**?? EXPLORATION ??**
**simple DepSim models from 123DI picks**