Schedule of presentation

- **DAY 1**
  - “intro to inversion, lithologies and DepSim/PROMISE+” (2 hrs)
  - EXERCISE 1 (uncertainty model AVO, 4 hr)
- **DAY 2**
  - finish EXERCISE 1 (1 hr)
  - EXERCISE 2 (2 hr)
  - “uncertainty analysis and 4D inversion” (1 hr)
  - finish EXERCISE 2 (1 hr)
  - general discussion (1-2 hr)

DepSim/PROMISE+AVO+4D

Michael Glinsky and Eldon Sims
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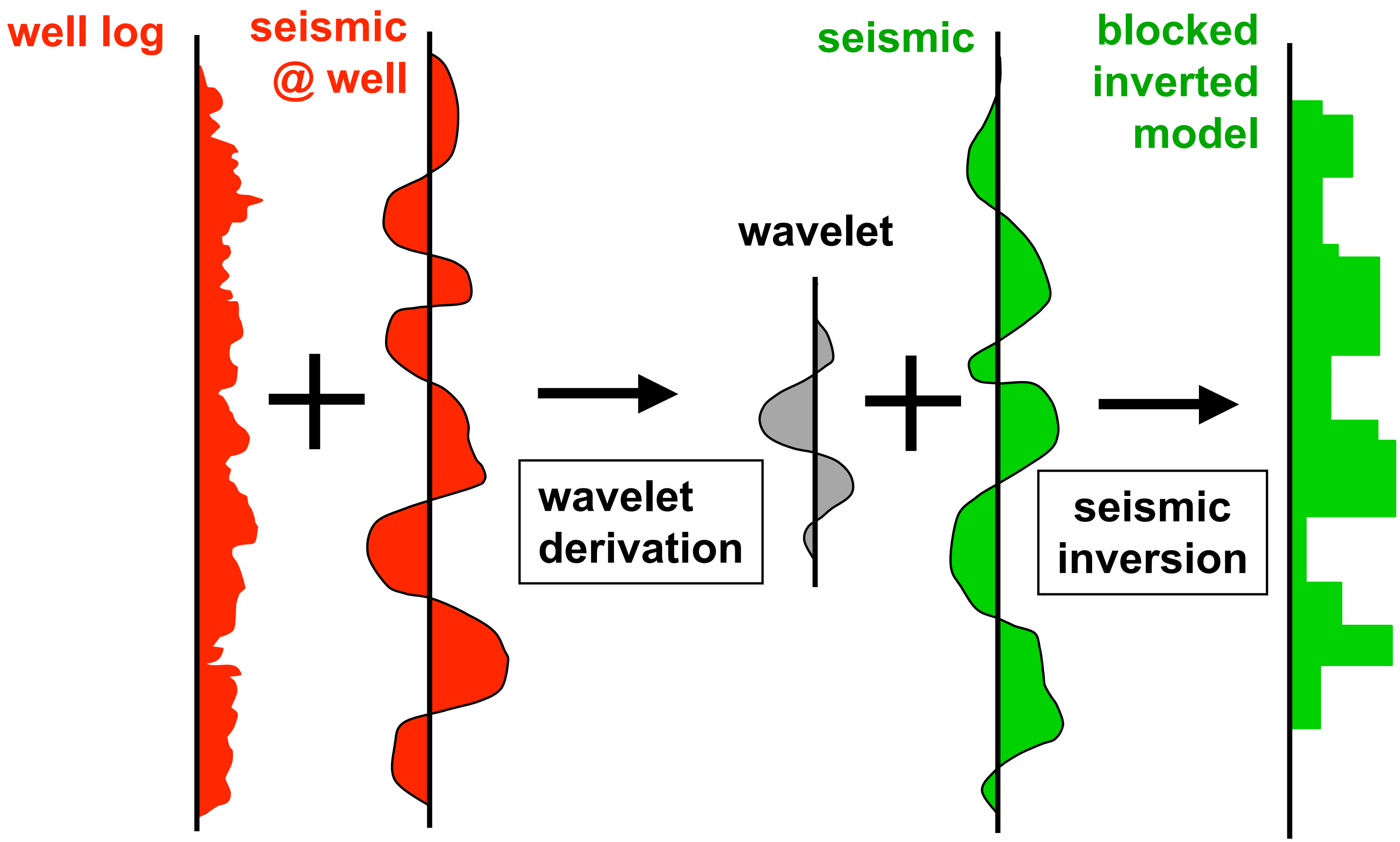
Outline

- **description of inversion process**
- **statistical inversion - a general framework**
- **prior knowledge (aka constraints)**
  - petrophyscis
  - well information
  - seismic interpretation
  - seismic uncertainty (error)
- **particular inversion methods as instantiations of general framework**
  - FLINT
  - linear PROMISE
  - metropolis PROMISE
- **DepSim/PROMISE+AVO+4D links**

Basic concept of inversion



Shell software tools of inversion

- **wavelet derivation**
  - XTRACT
  - COMPARE
  - WEWELL
- **seismic inversion**
  - FLINT
  - FLINT2
  - PROMISE
  - PROMISE+AVO+4D

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
$= \exp(-\Sigma\, n_k^2 / <n_k>^2)$

$s(m)$ = 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

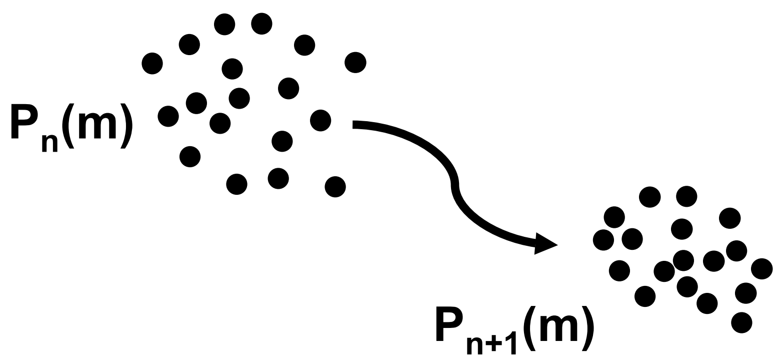
$$P_n(m) \rightarrow P(\,m \mid d\,) \quad \text{as} \quad n \rightarrow \infty,$$

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

and

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

$\mathbf{F}$ = conjugate gradient or metropolis

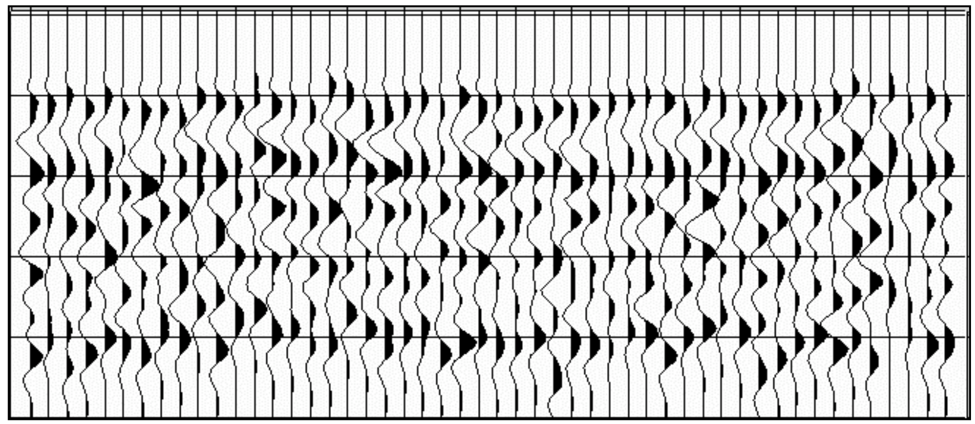


Inversion improves match with seismic data

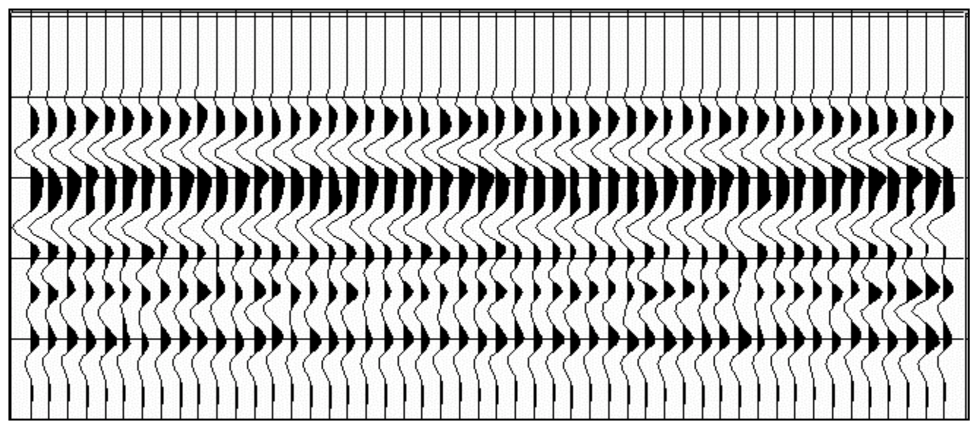
model

time

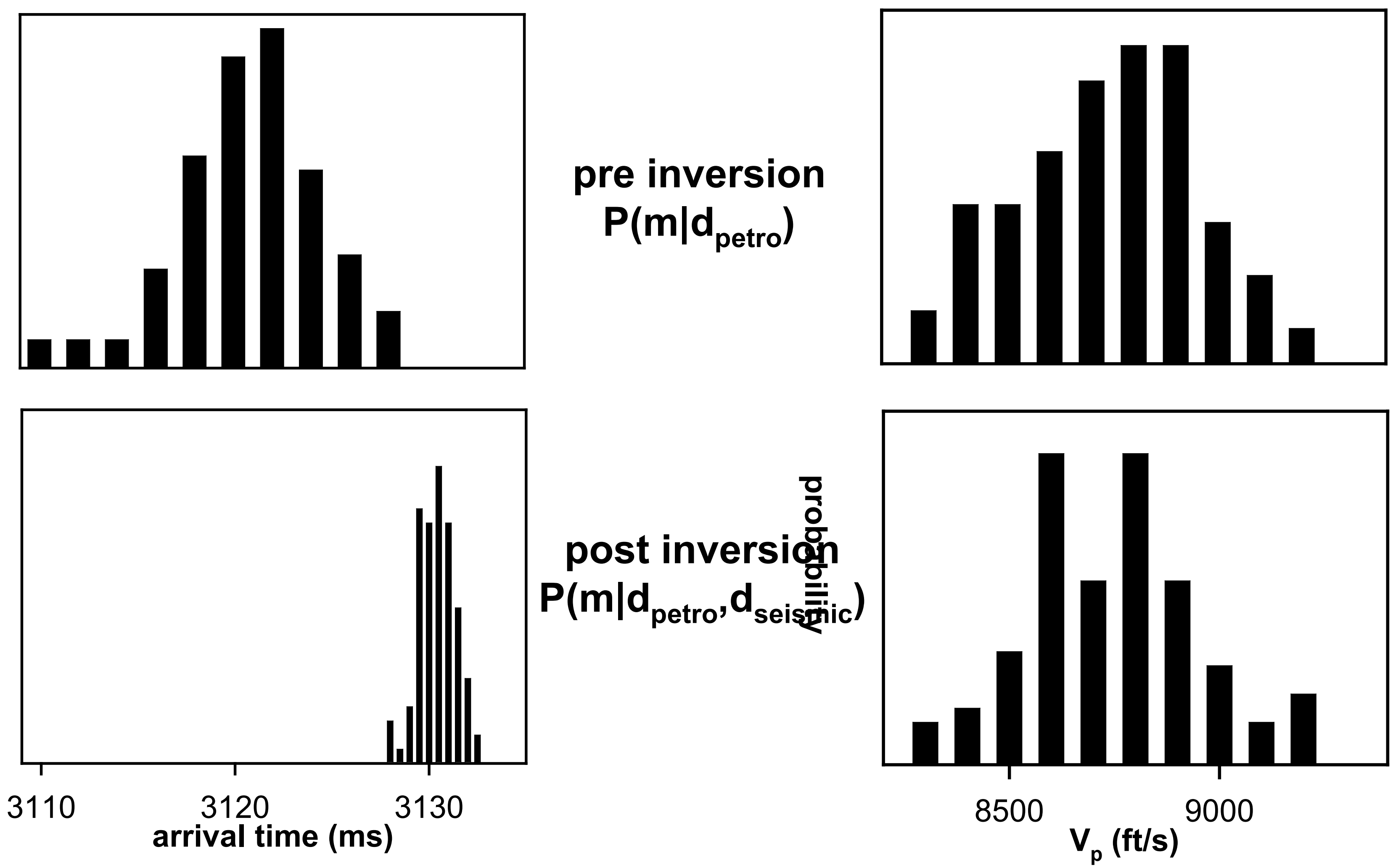
pre inversion
$P(m|d_{petro})$



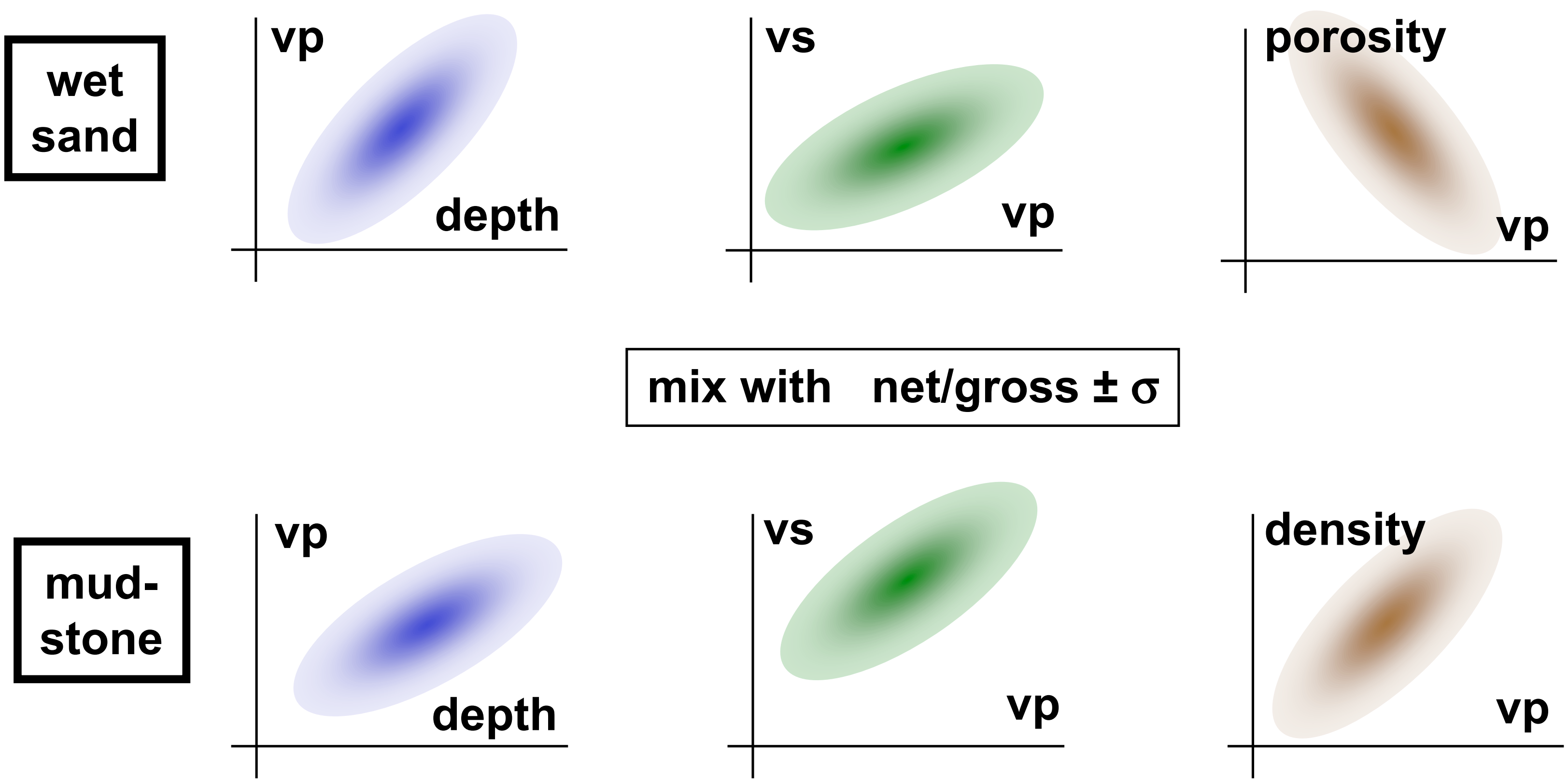
post inversion
$P(m|d_{petro},d_{seismic})$



Inversion improves estimate of some reservoir properties

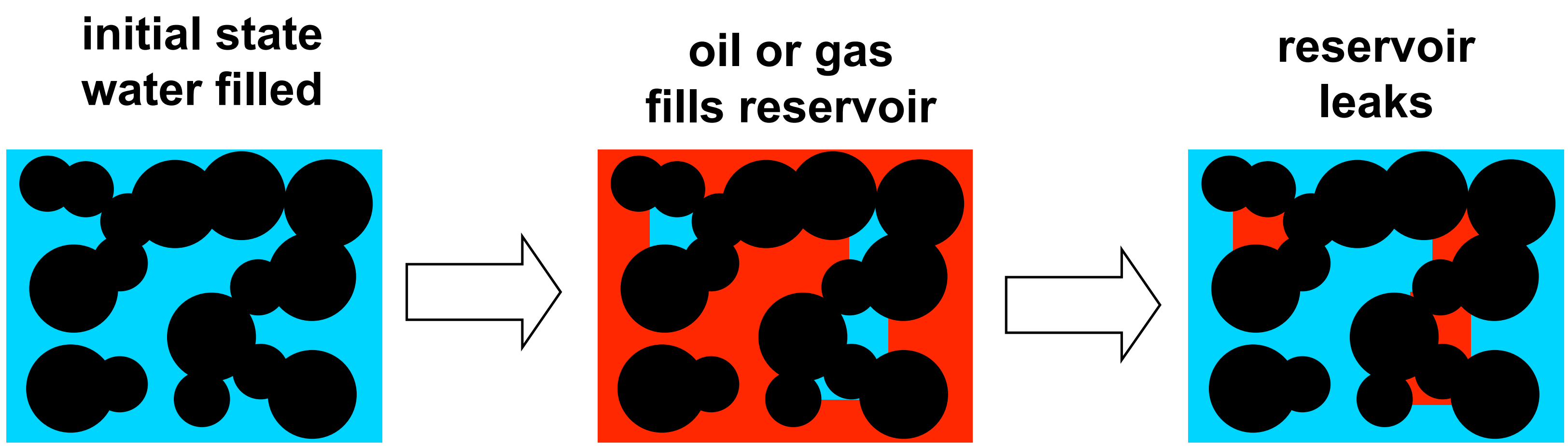


GOM petrophysical end member trends used in prior probability



note: separate trend for each layer

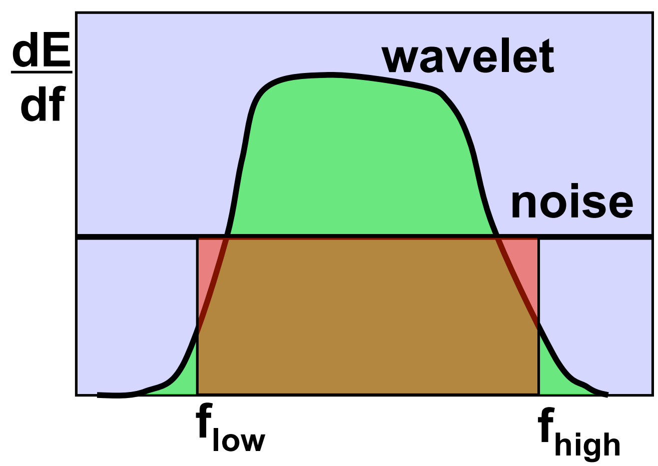
Discrete cases of fluid fill are used



- **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

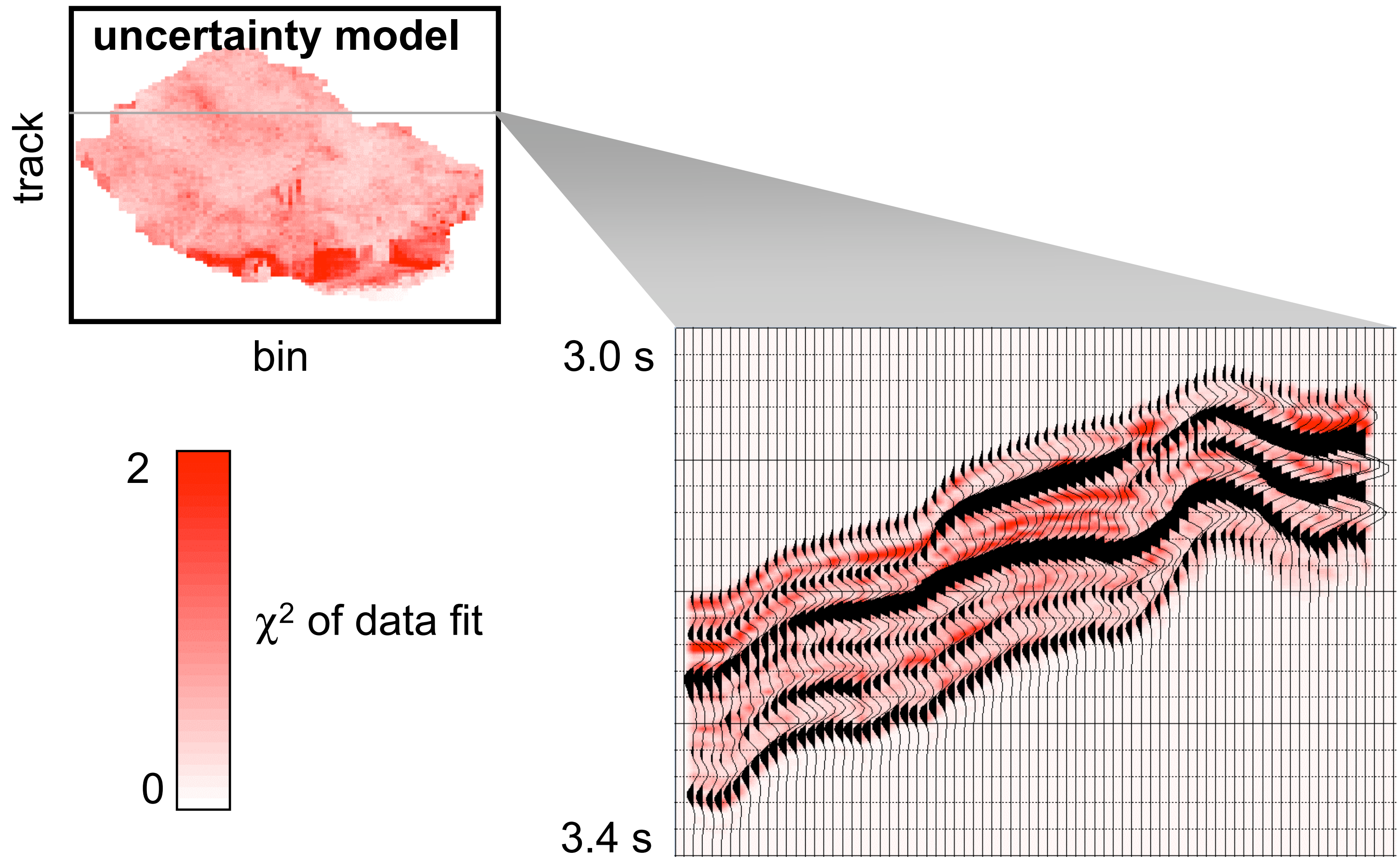
White noise specification

- **seismic wavelet**
- **bandwidth of information content of seismic wavelet**
  - f_{low} and f_{high} (Hz)
- **average reflection coefficient**
- **SNR (dB)**
  - parameter to vary (others set initial scale, use 10 dB)

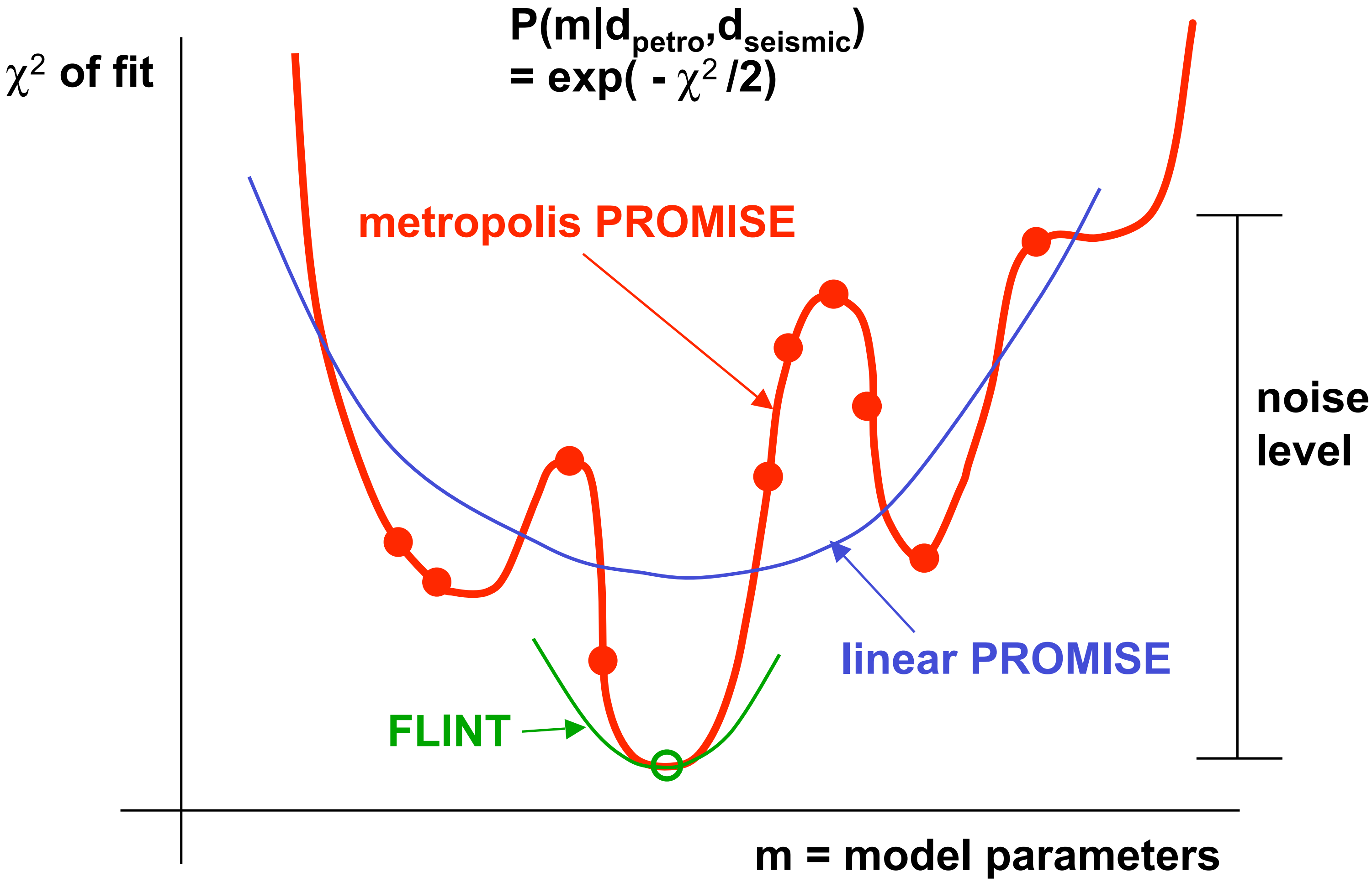


SNR = green / red

Error output



Connection of different inversion methods



Difference between different inversion methods

- **FLINT**
  - gaussian form of distribution
  - zero noise limit (zero temperature)
- **linear PROMISE**
  - gaussian form of distribution
  - finite noise level (finite temperature)
- **metropolis PROMISE**
  - arbitrary form of distribution (includes multi-modes. Geology may well be multi-modal by nature)
  - finite noise level
  - linear acceleration (force weighting)

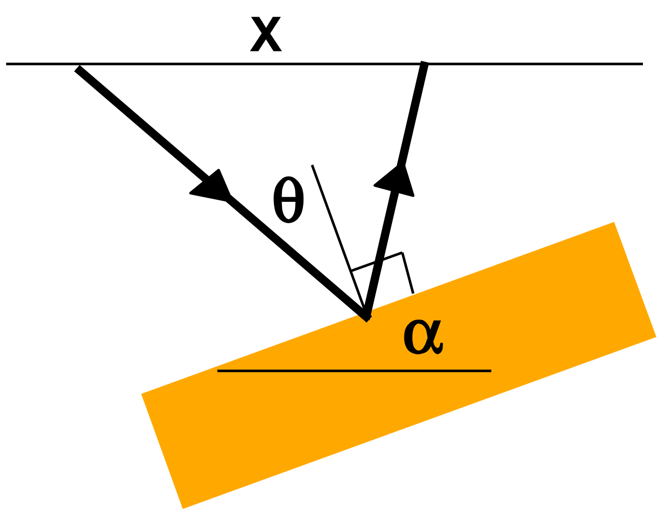
Approaches to using inversion methods

- **FLINT mode**
  - petrophyscial trends and geometry in DepSim
  - error as soft constraints in FLINT or error in PROMIISE
- **PROMISE mode**
  - geometry in DepSim
  - petrophyscial trends and errors in PROMISE

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



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

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

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

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

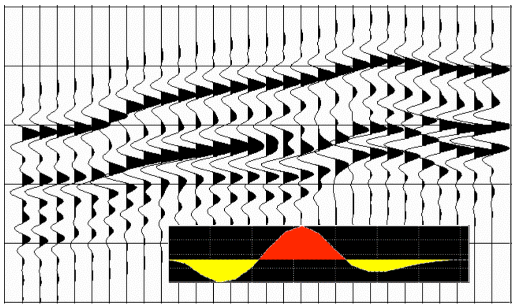
offset average wavelet & reflection coefficient

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

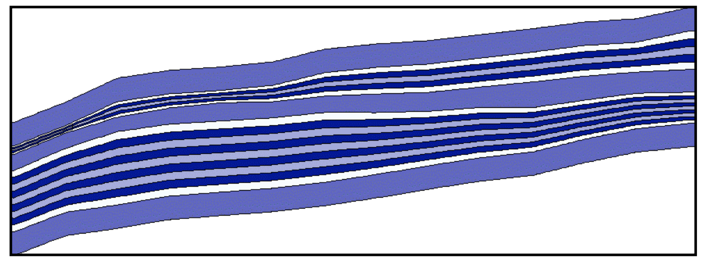
$$\langle R\,W \rangle_X = \langle R \rangle_X \langle W \rangle_X + \text{4th order}$$

Inputs to inversion

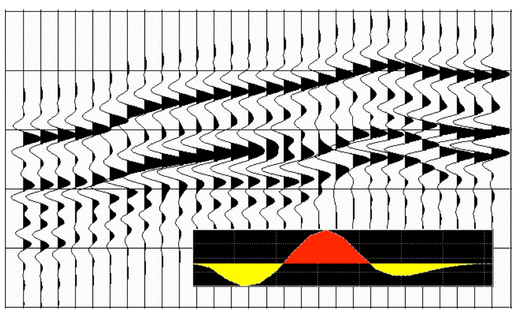
near stack and wavelet



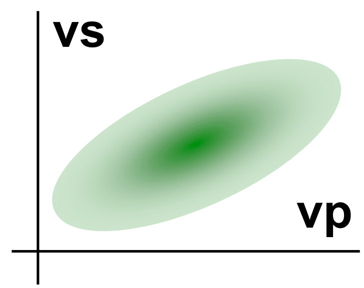
initial DepSim model



far stack and wavelet

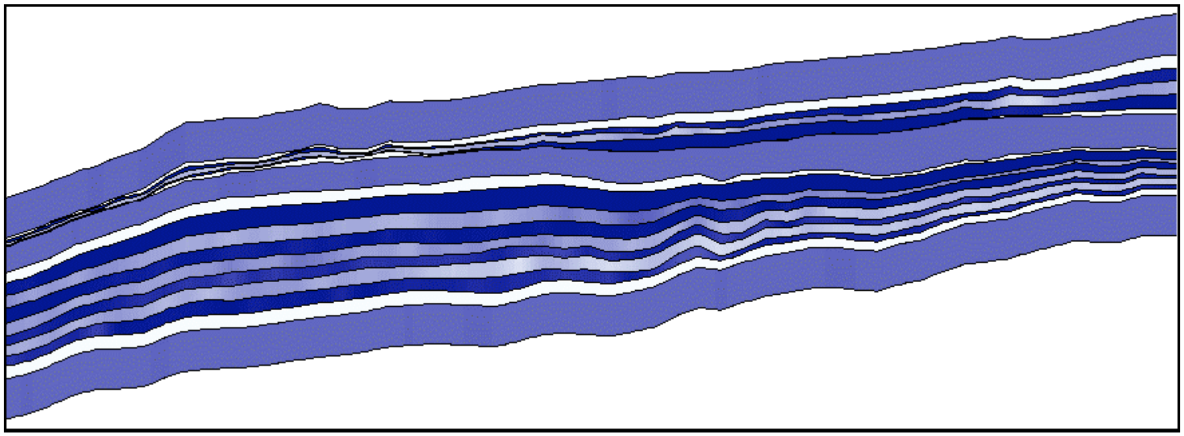


rock properties

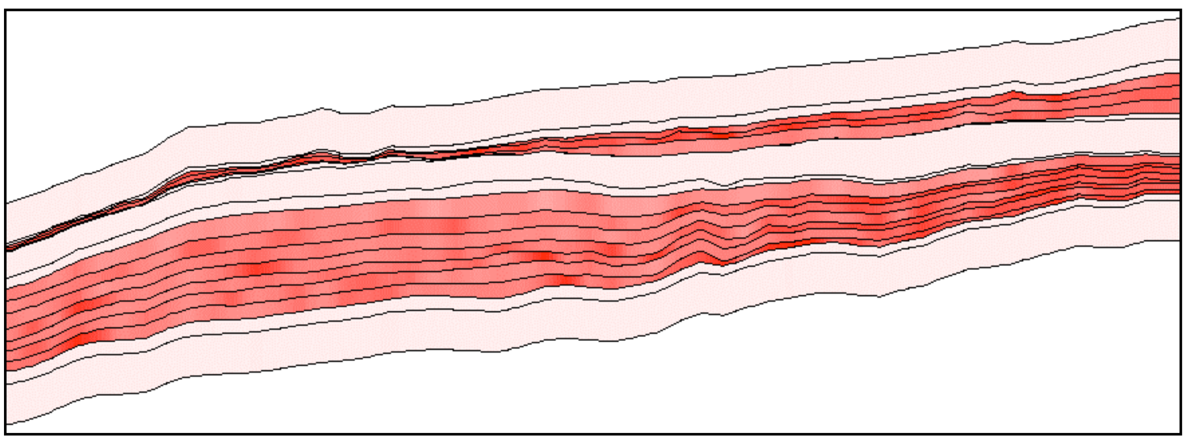


Output of inversion

updated DepSim model



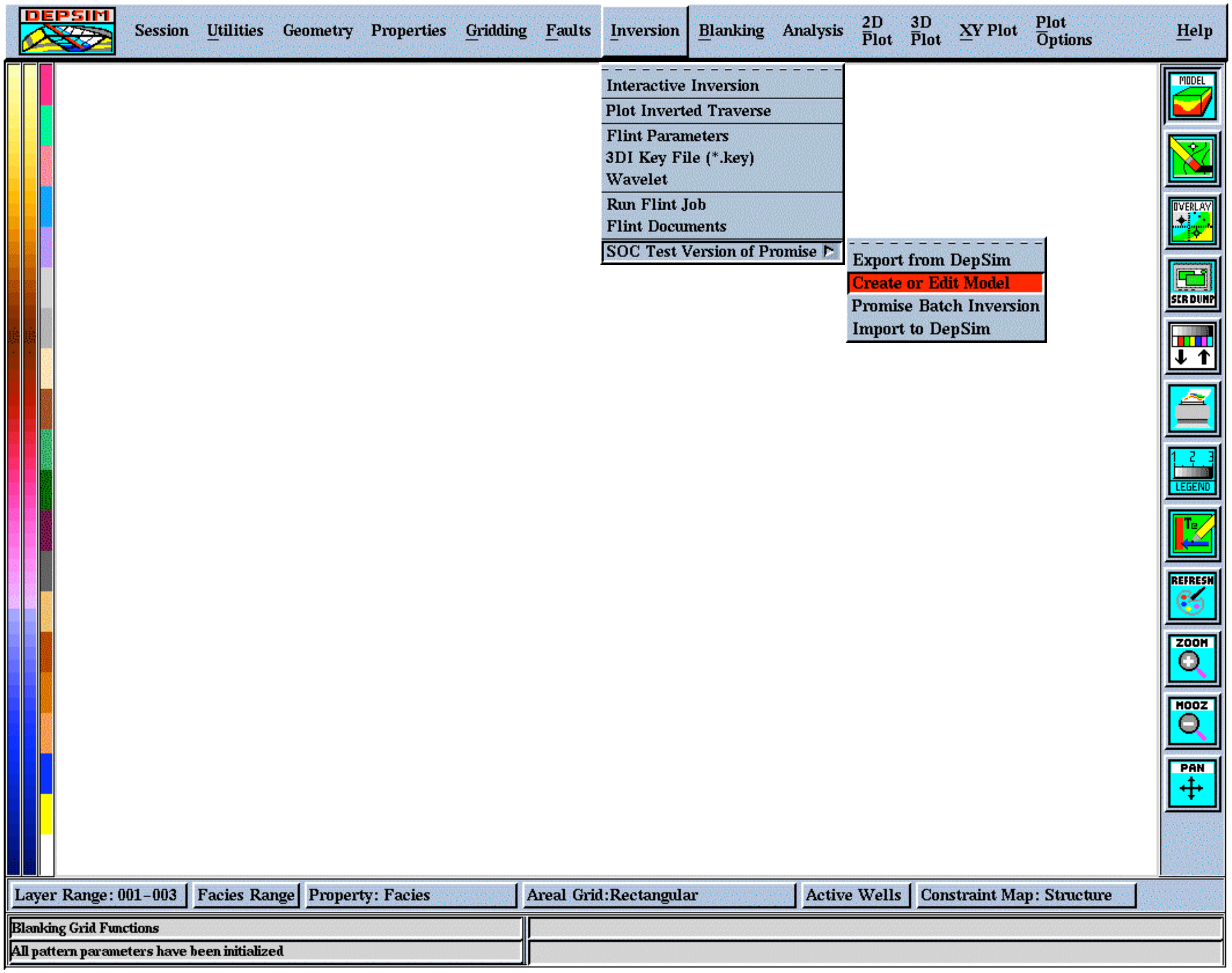
uncertainty in DepSim model



Principles of DepSim/PROMISE integration

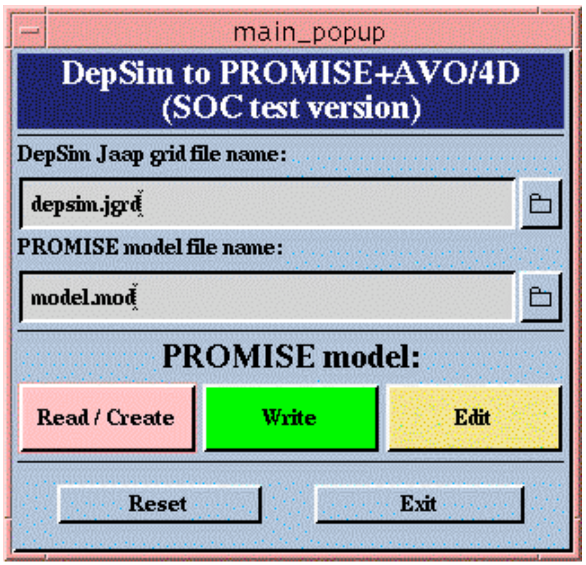
- **DepSim IO engine for PROMISE**
- **SPIRIT II wrapper on prototype PROMISE code**
- **easy specification of seismic noise**
- **compatible and expandable**
  - AVOMOD and AVO inversion
  - neural net (fluid prediction and beyond)
  - GOM petrophysics (trends and LIPOS)

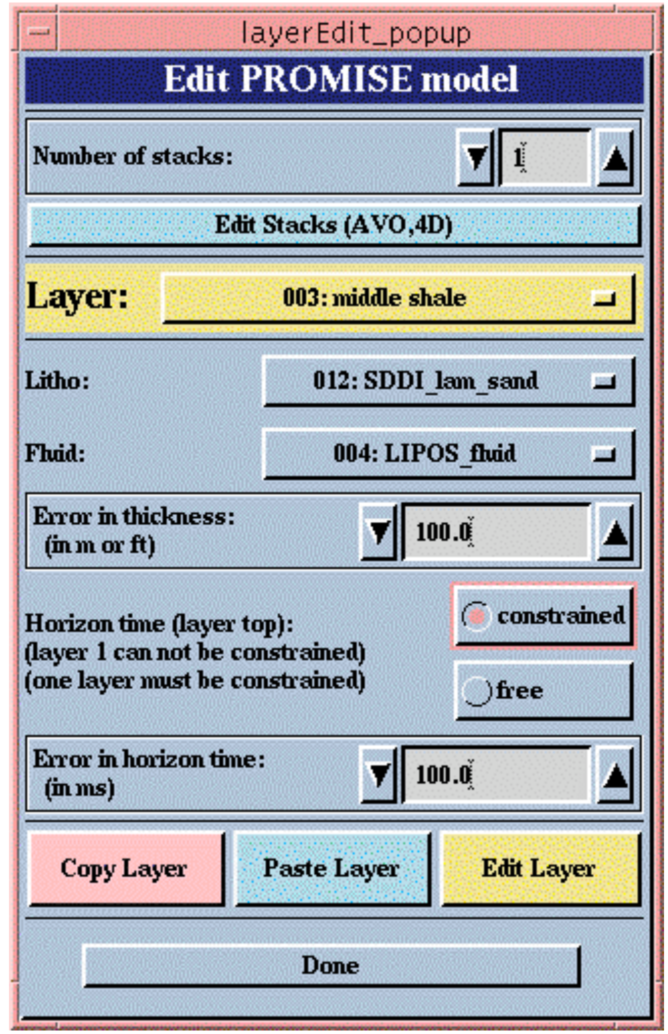
DepSim/PROMISE integration



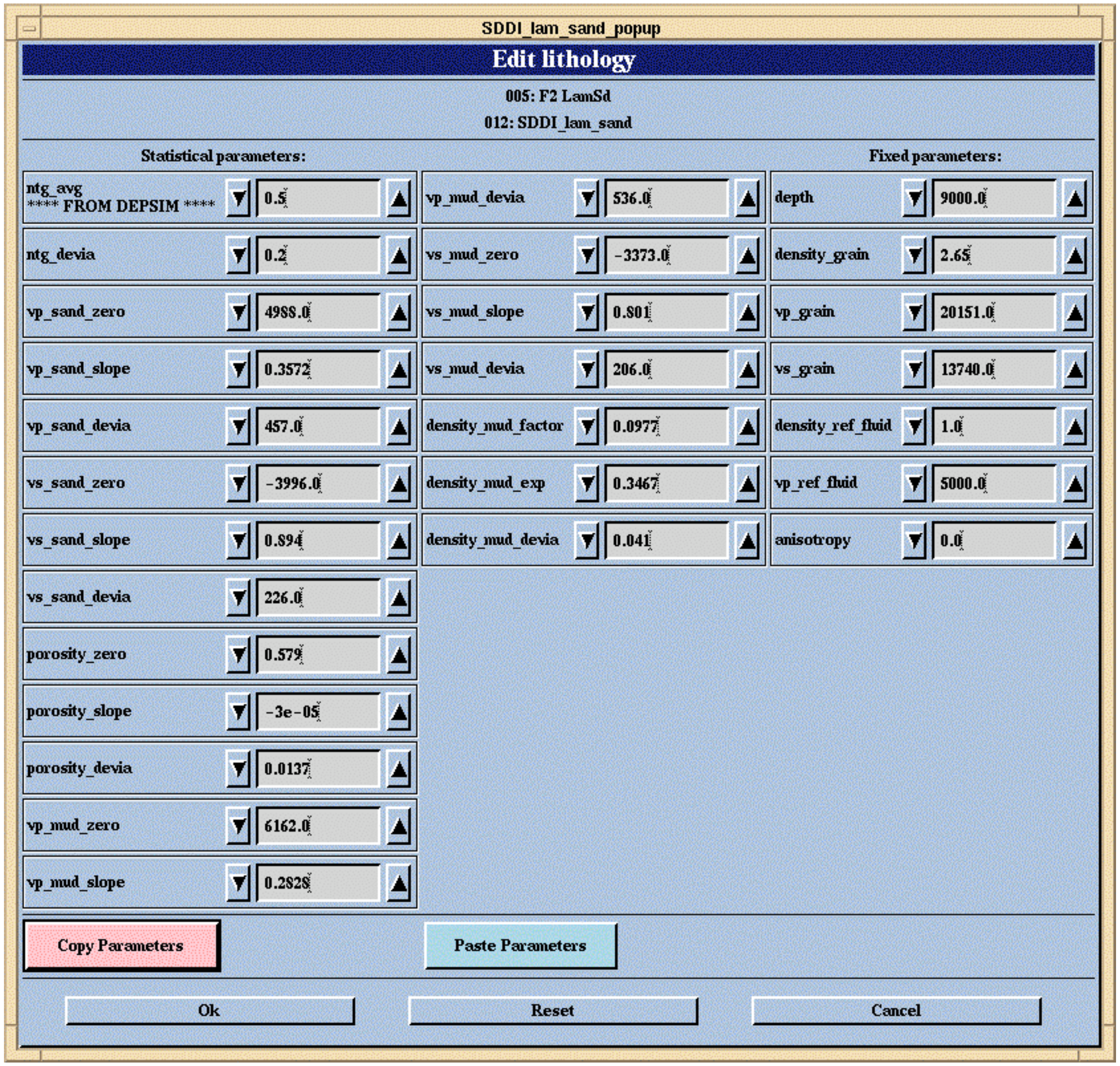
FLOW CHART

Definition of PROMISE model menus

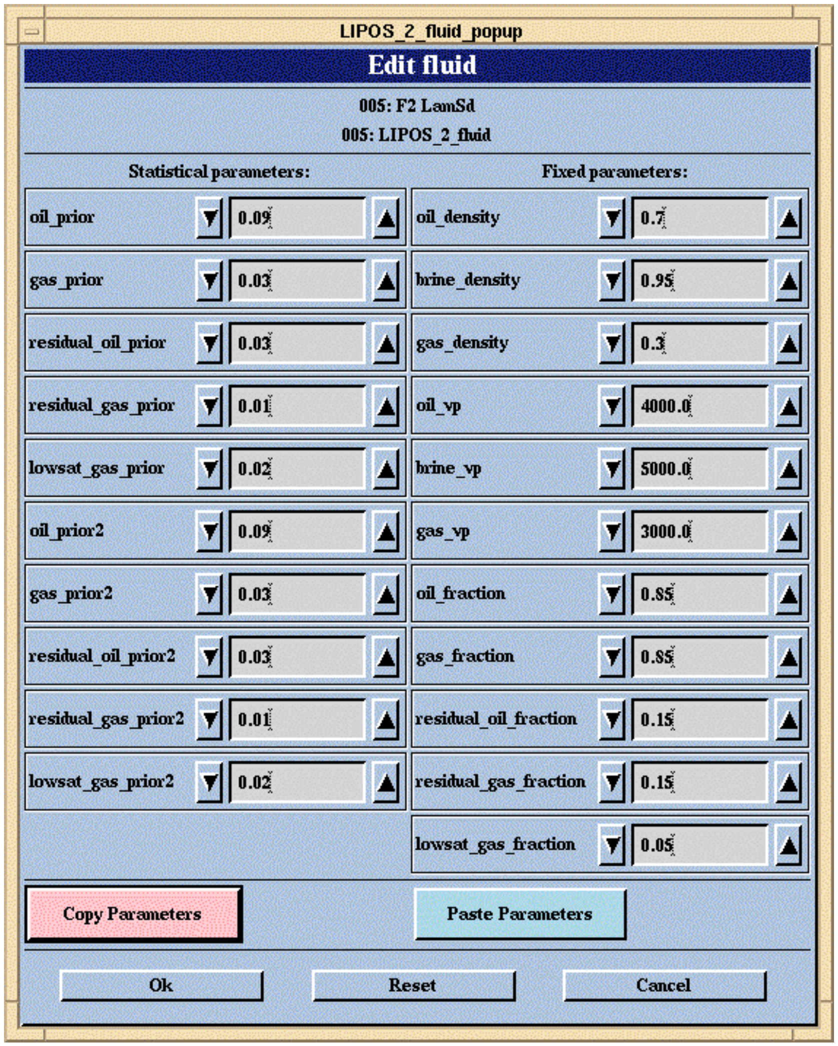




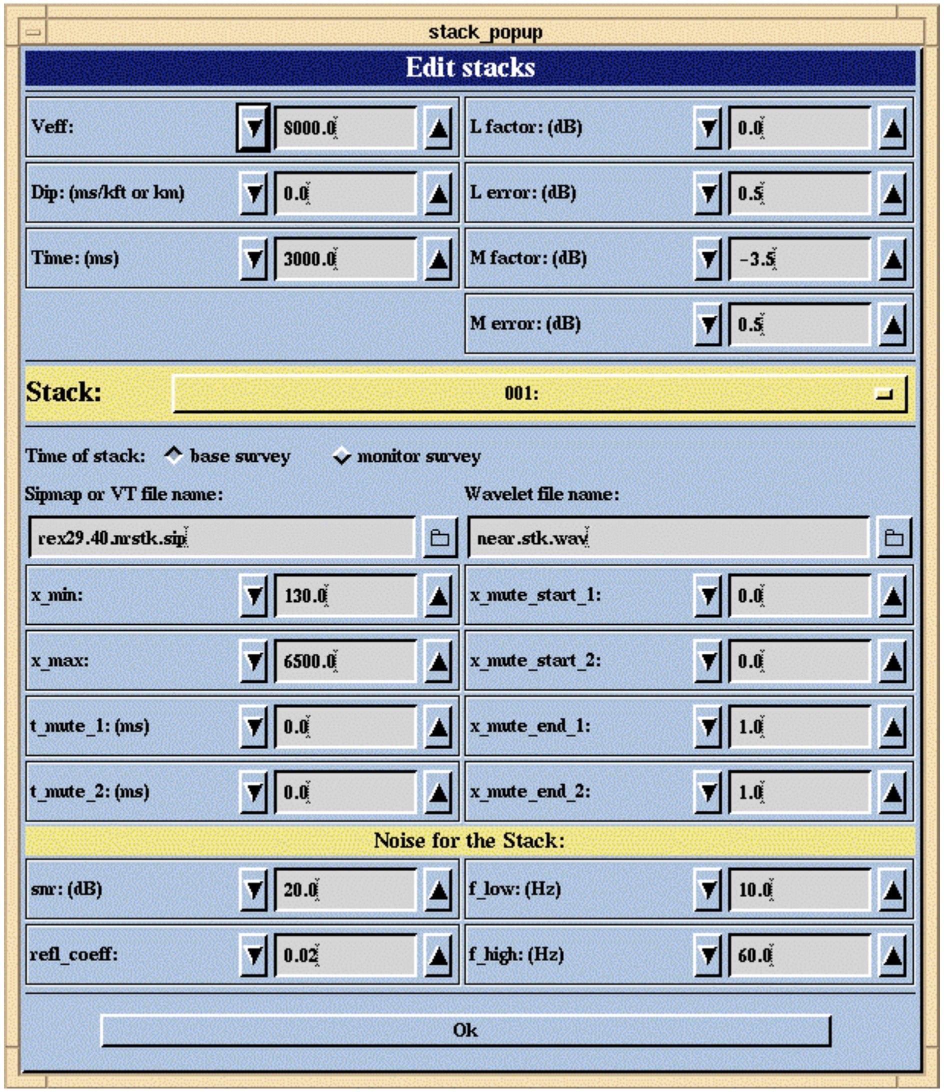
SDDI_lam_sand menu



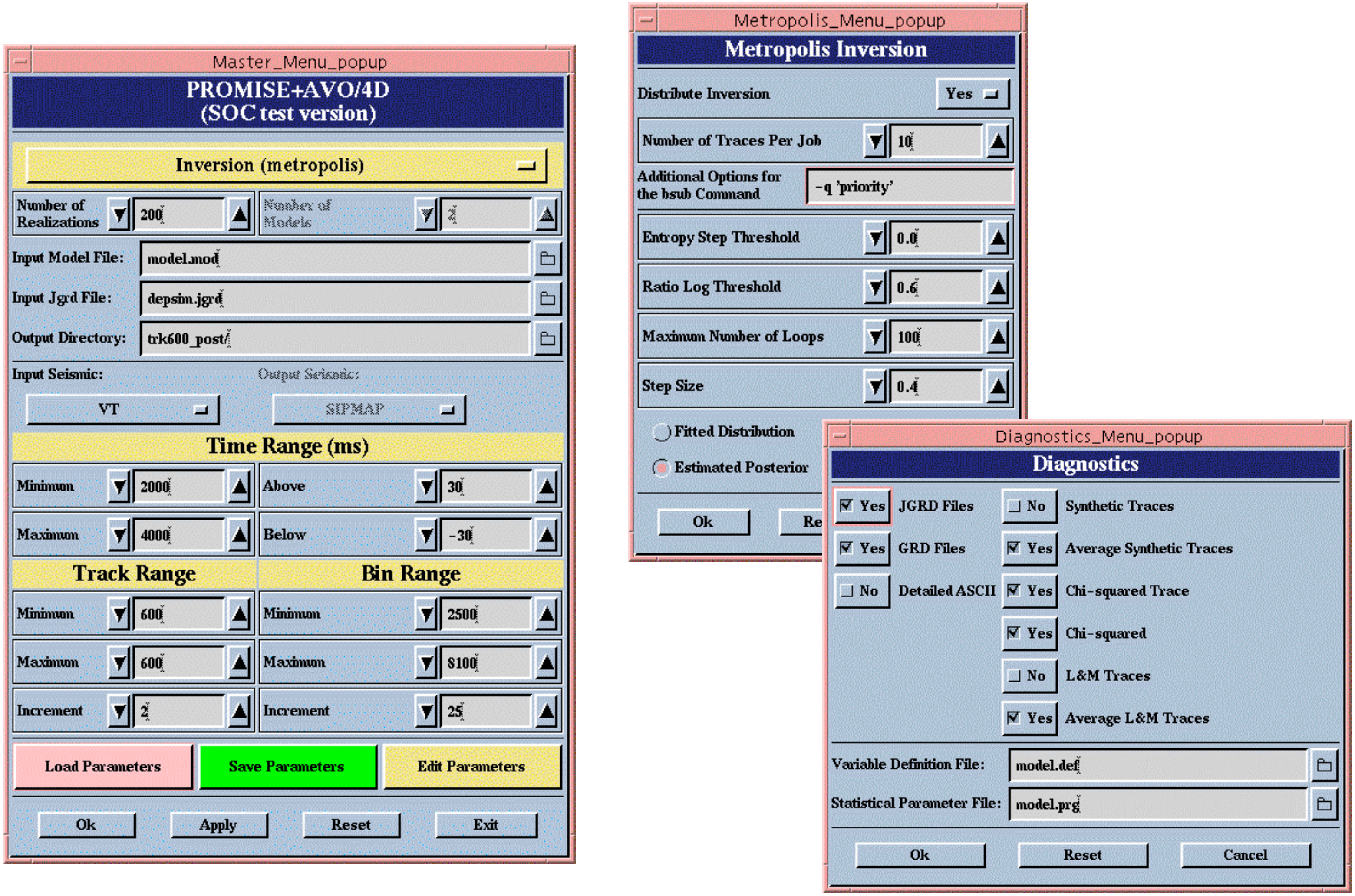
LIPOS_2_fluid menu



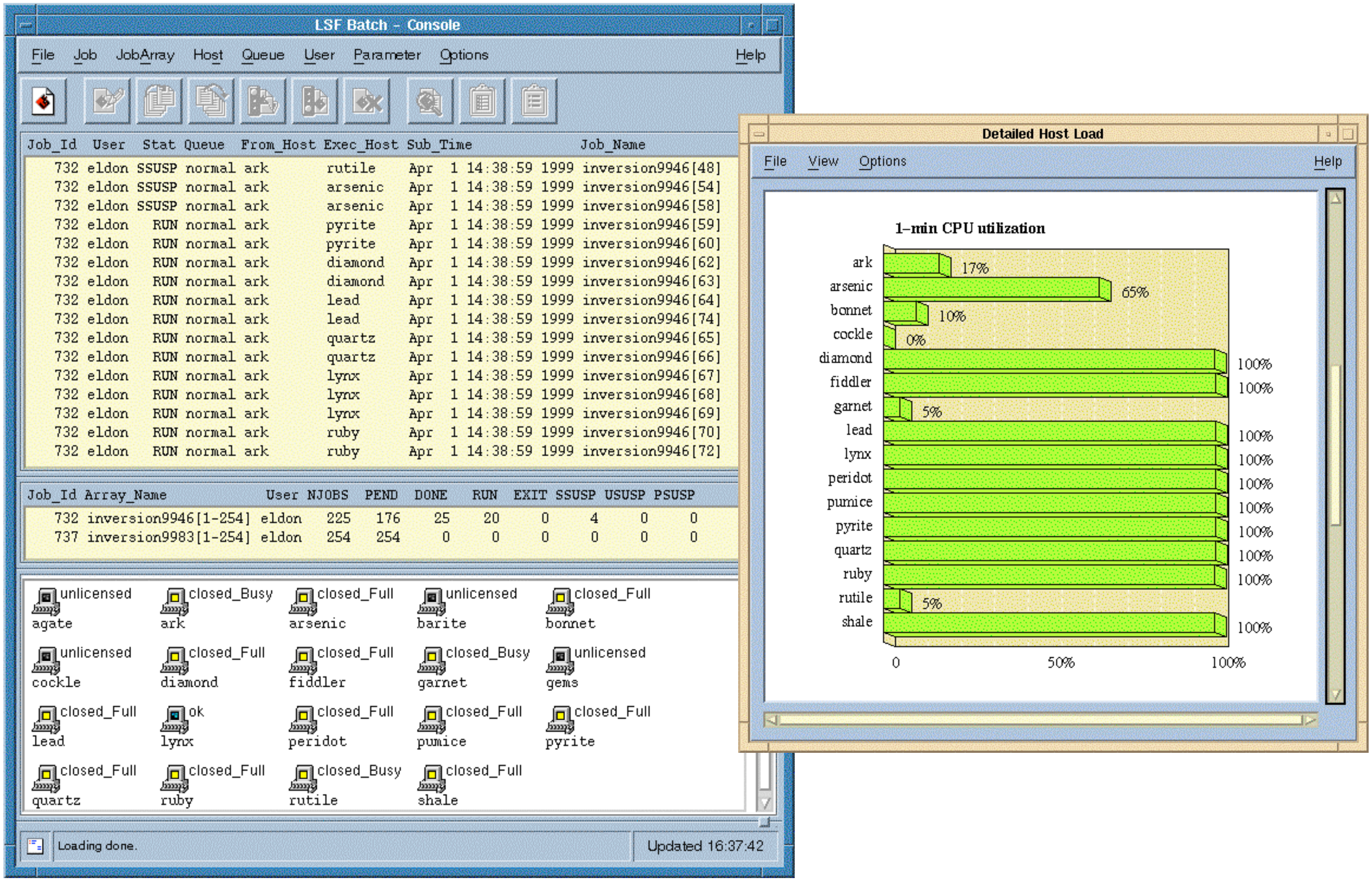
Edit stacks menu



Executing PROMISE menus

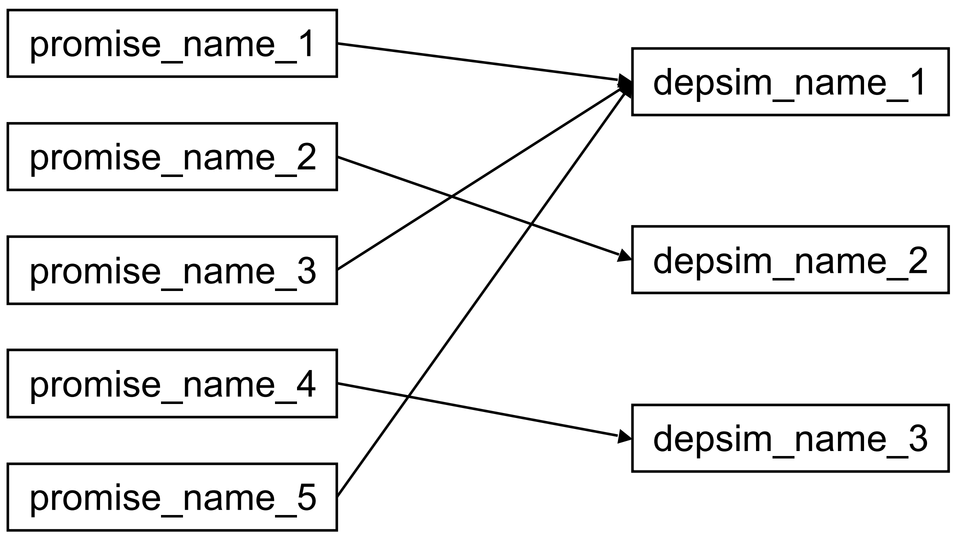


LSF is used to distribute inversion over many workstations



PROMISE to DepSim translator

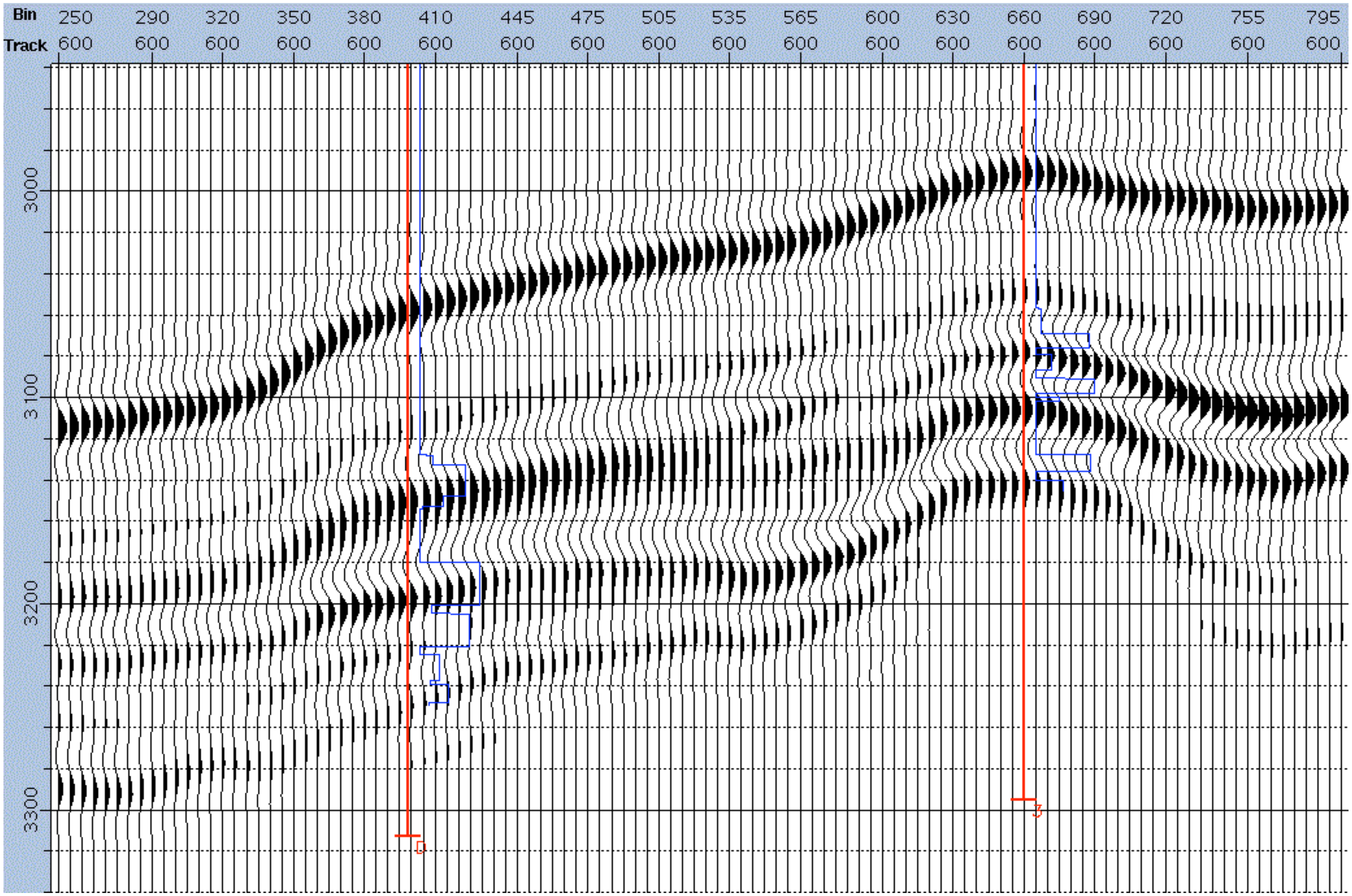
- **finds DepSim equivalent of PROMISE parameters**
  - import to PROMISE
  - export from PROMISE
- **uses ASCII file dictionary (depsim_promise_dictionary)**
- **default is no translation**



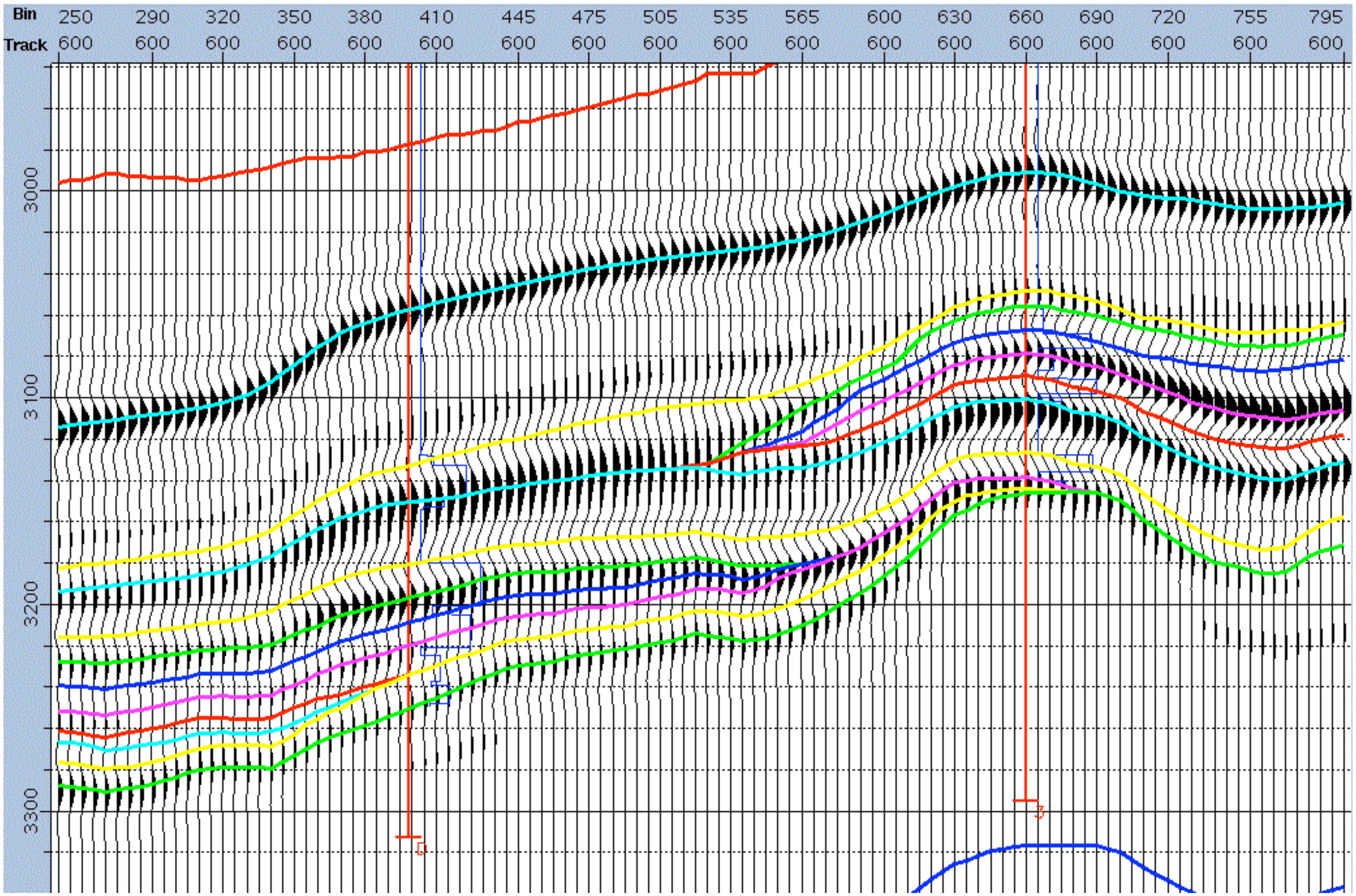
EXERCISE 1 (uncertainty model AVO)

- **2D model build**
  - block model
  - determine and assign properties
- **interactive FLINT inversion**
- **PROMISE+ inversion**
  - determine proper lithologies and fluids
  - determine and assign properties (errors)
  - determine seismic noise level
  - do inversion and import results back into DepSim
- **examine and analyze results of inversion**

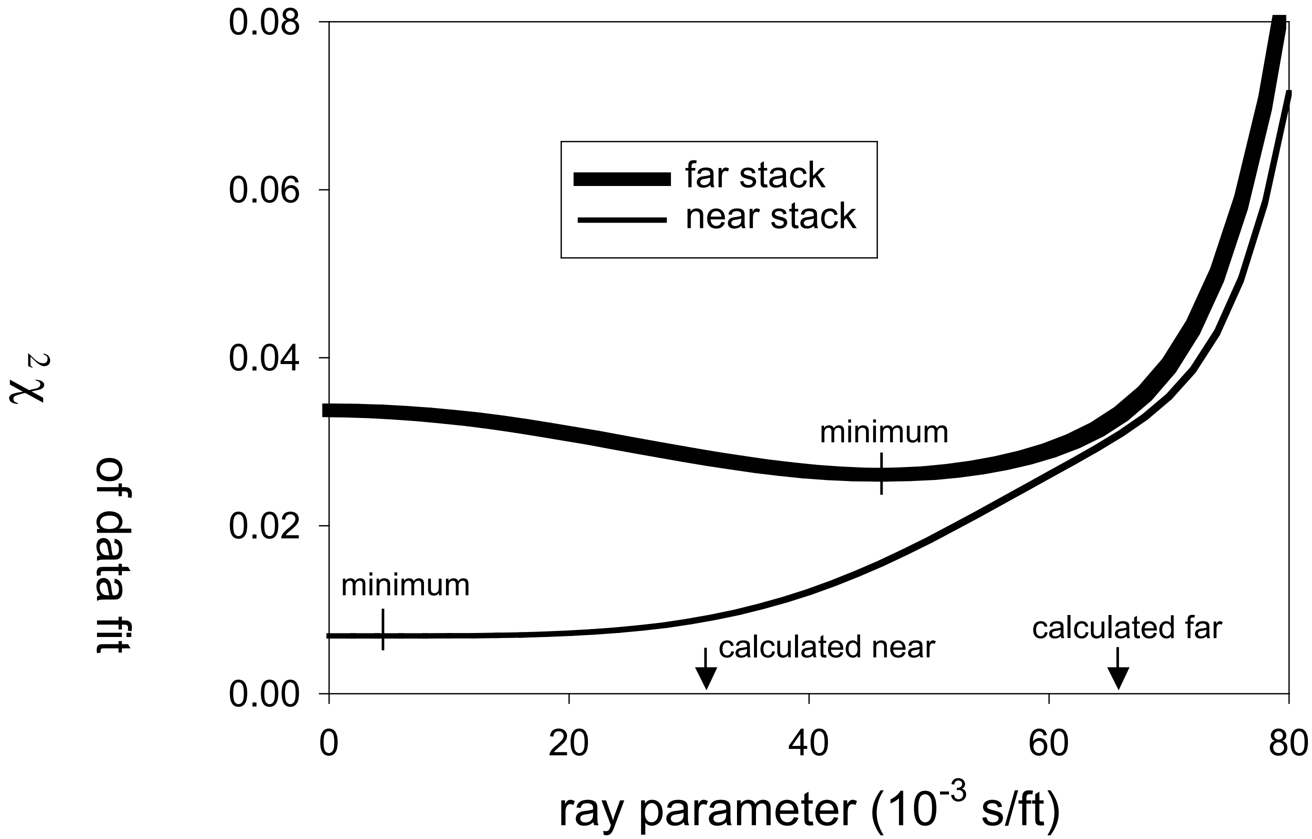
Near stack with well N/G



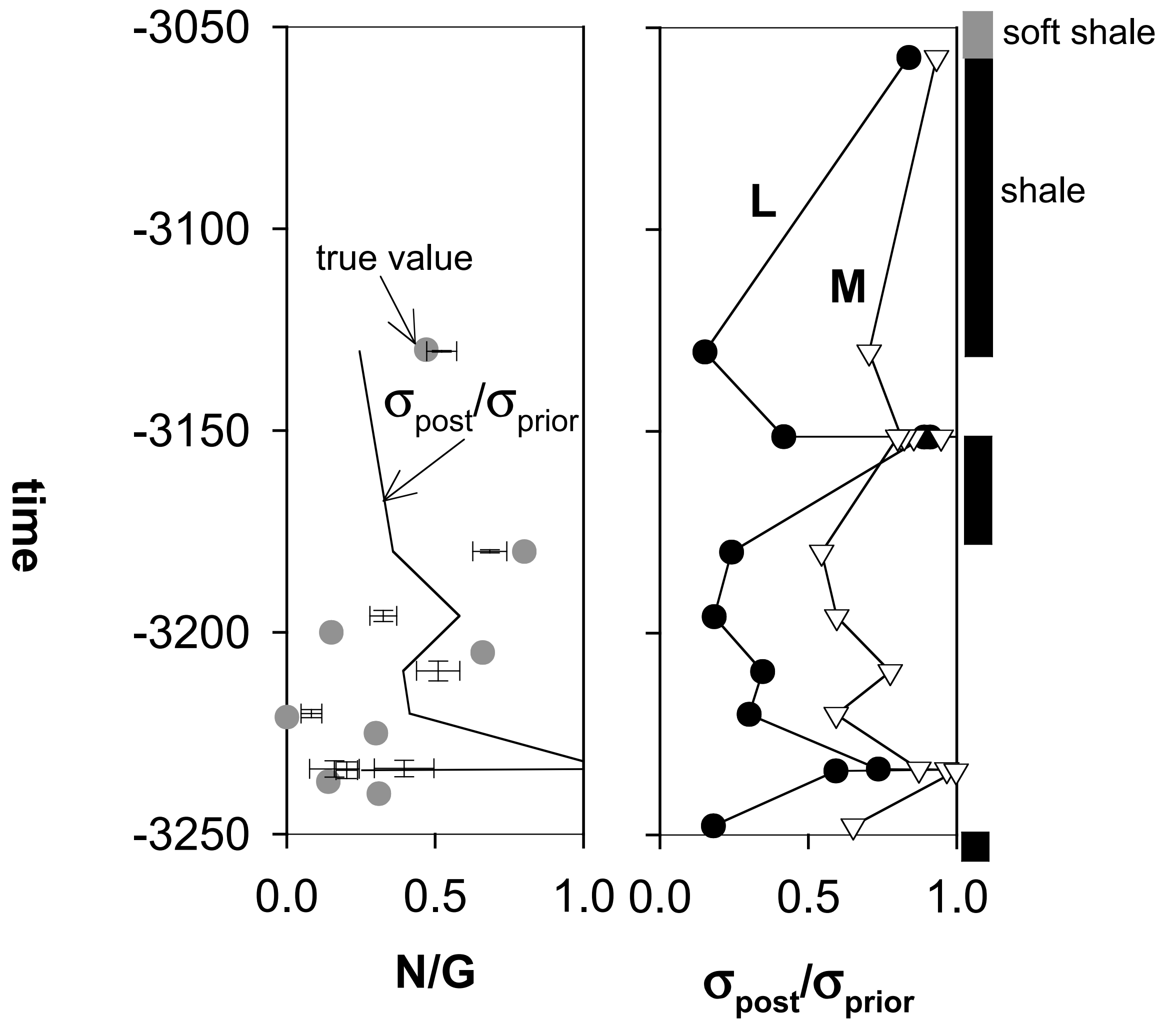
Near stack with hand picked events



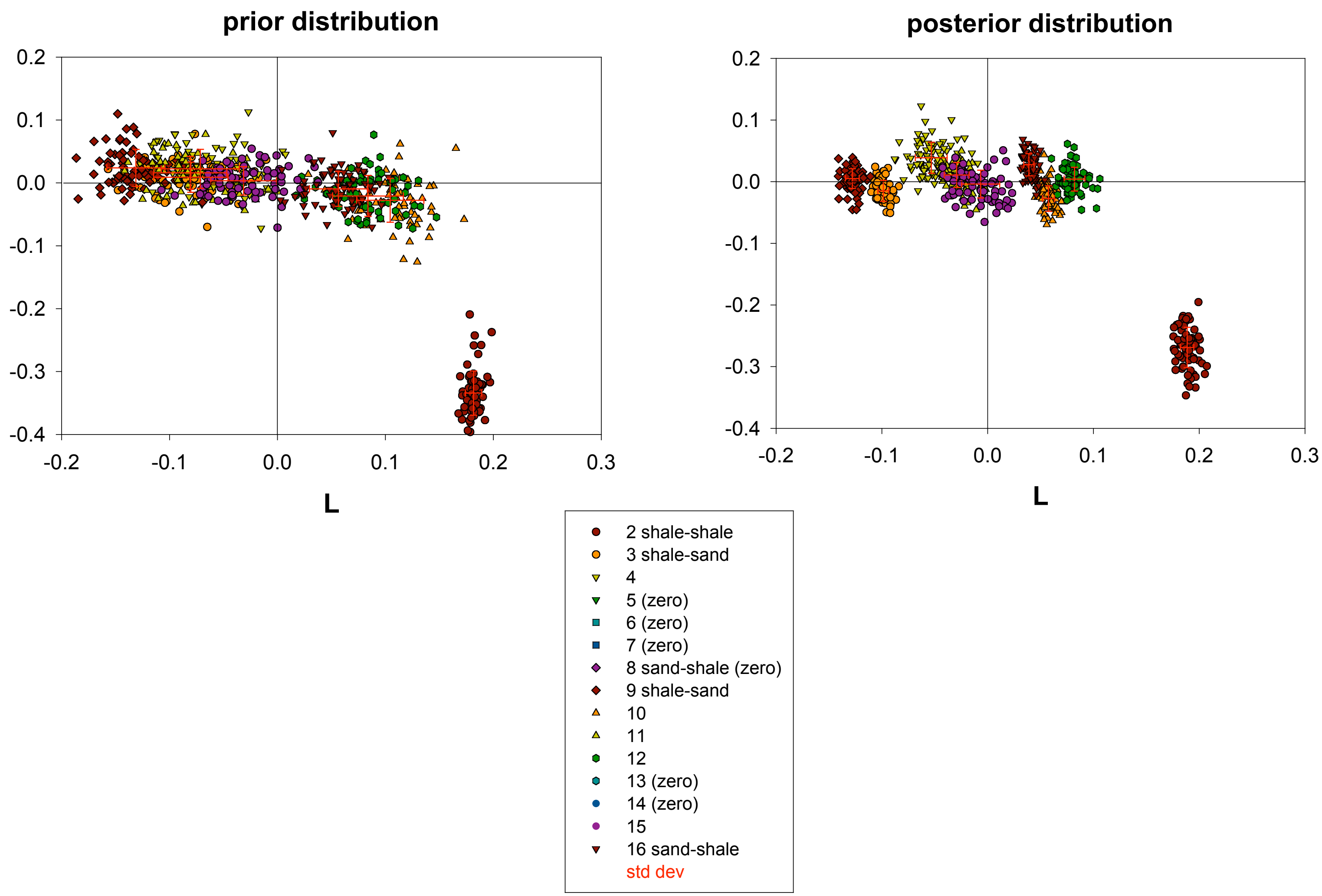
Effective ray parameter is determined by well matching during wavelet derivation



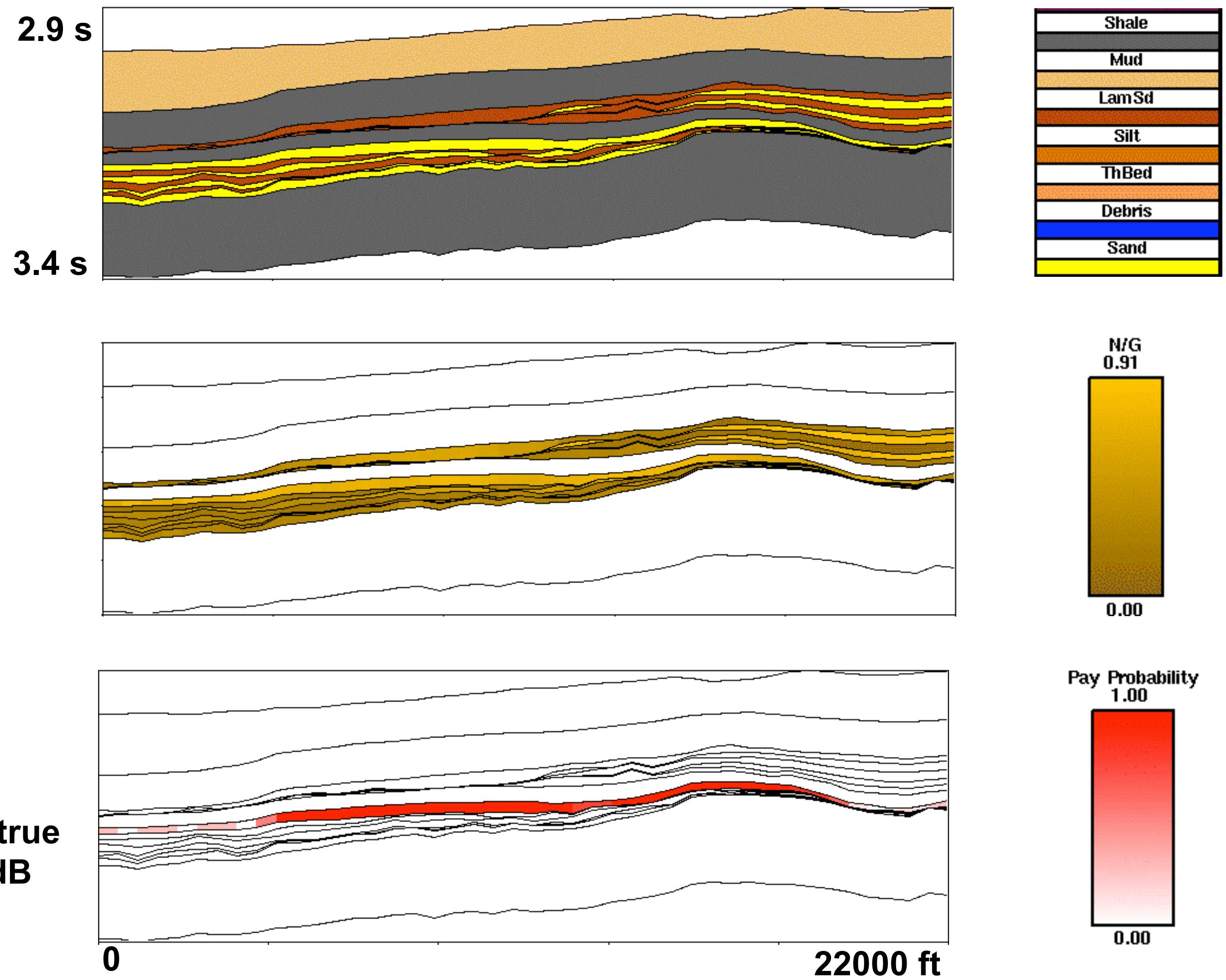
The quality of the well tie - inversion at the well



AVO inversion tightens clouds in L-M space

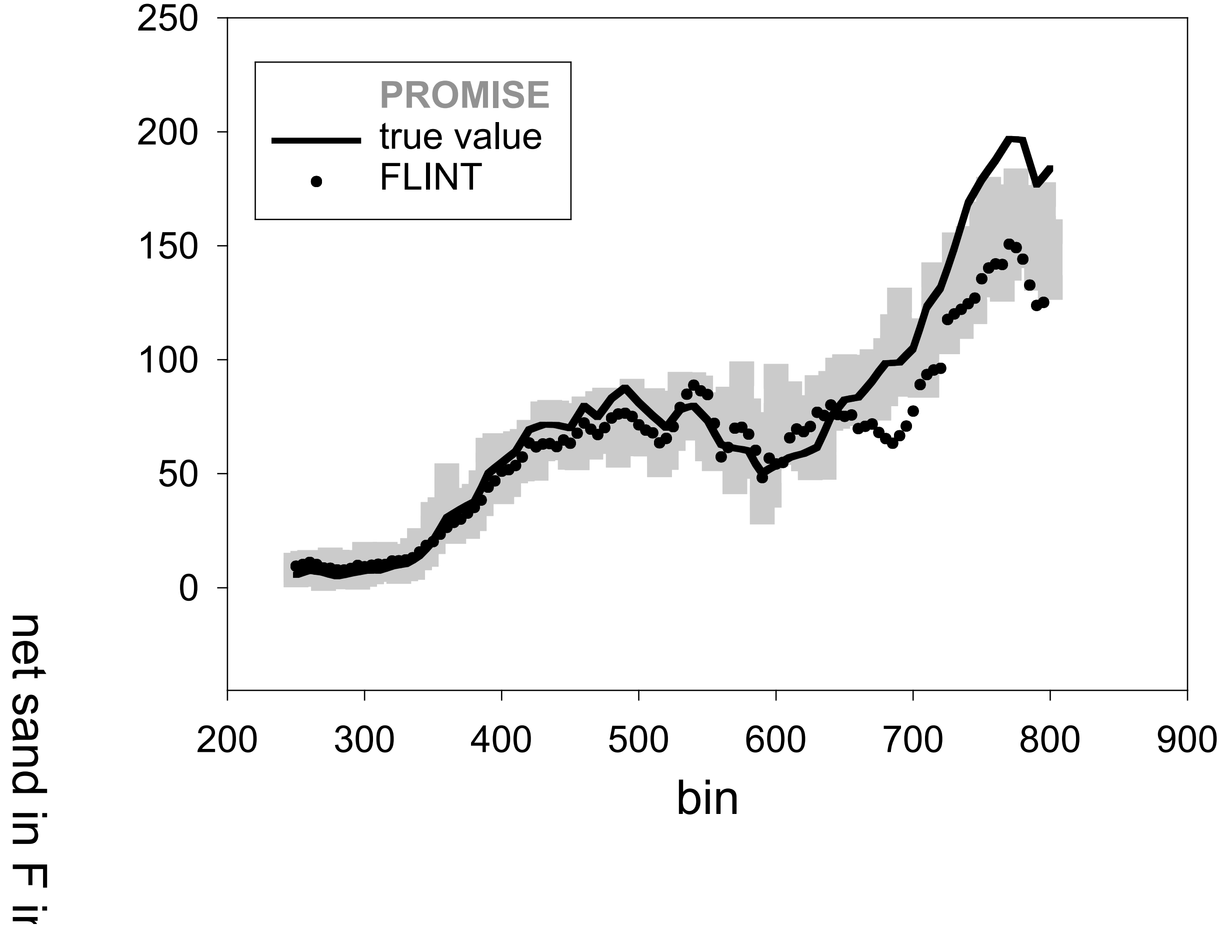


Uncertainty model after AVO inversion



note: synthetic seismic matches true to 15-20 dB

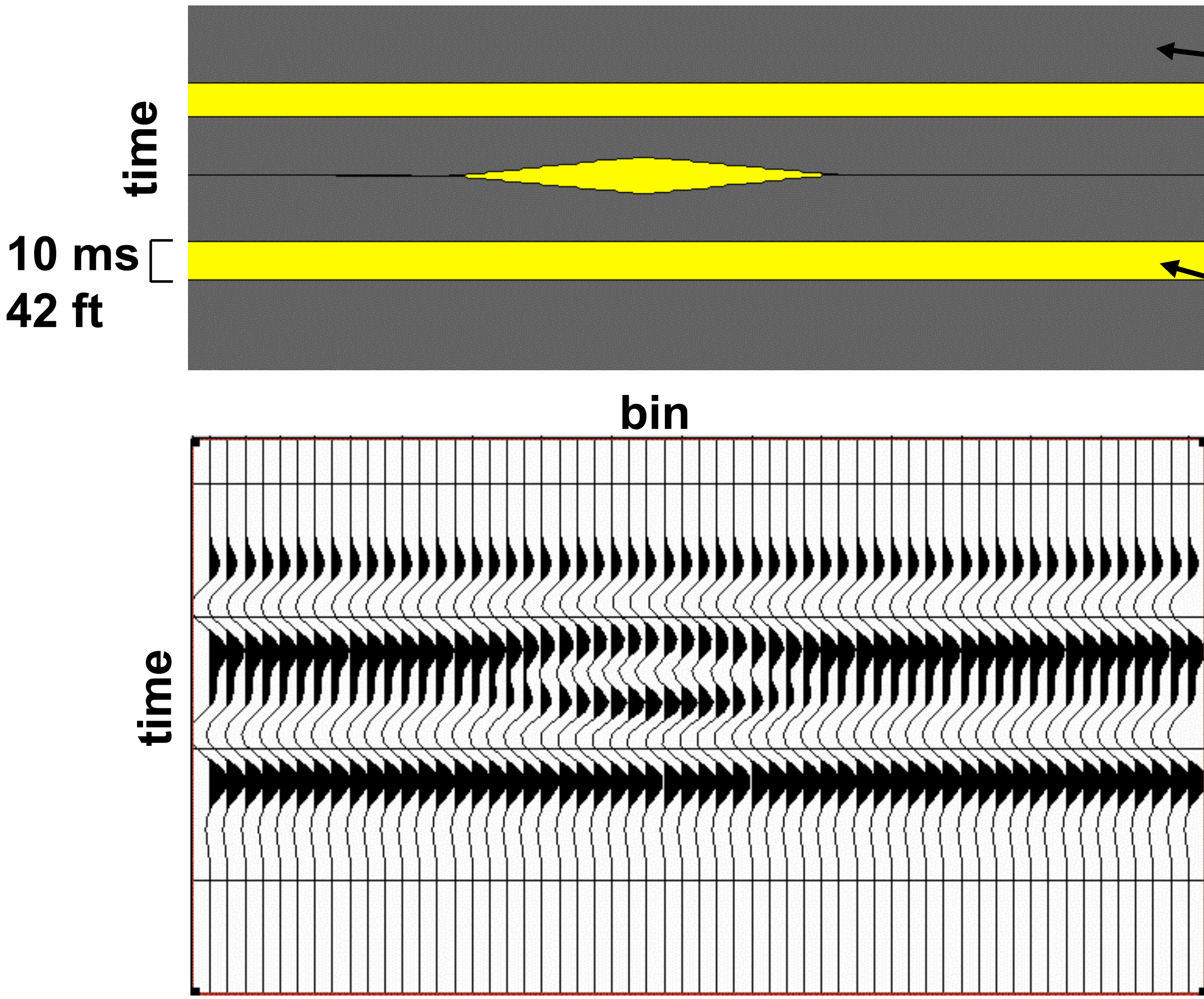
Results of AVO inversion compared to true value and FLINT inversion



EXERCISE 2 (scenario testing lens model)

- examine three initial DepSim models
- do three PROMISE+ inversions
- compare results and examine in DepSim

An example of scenario testing: a lens model

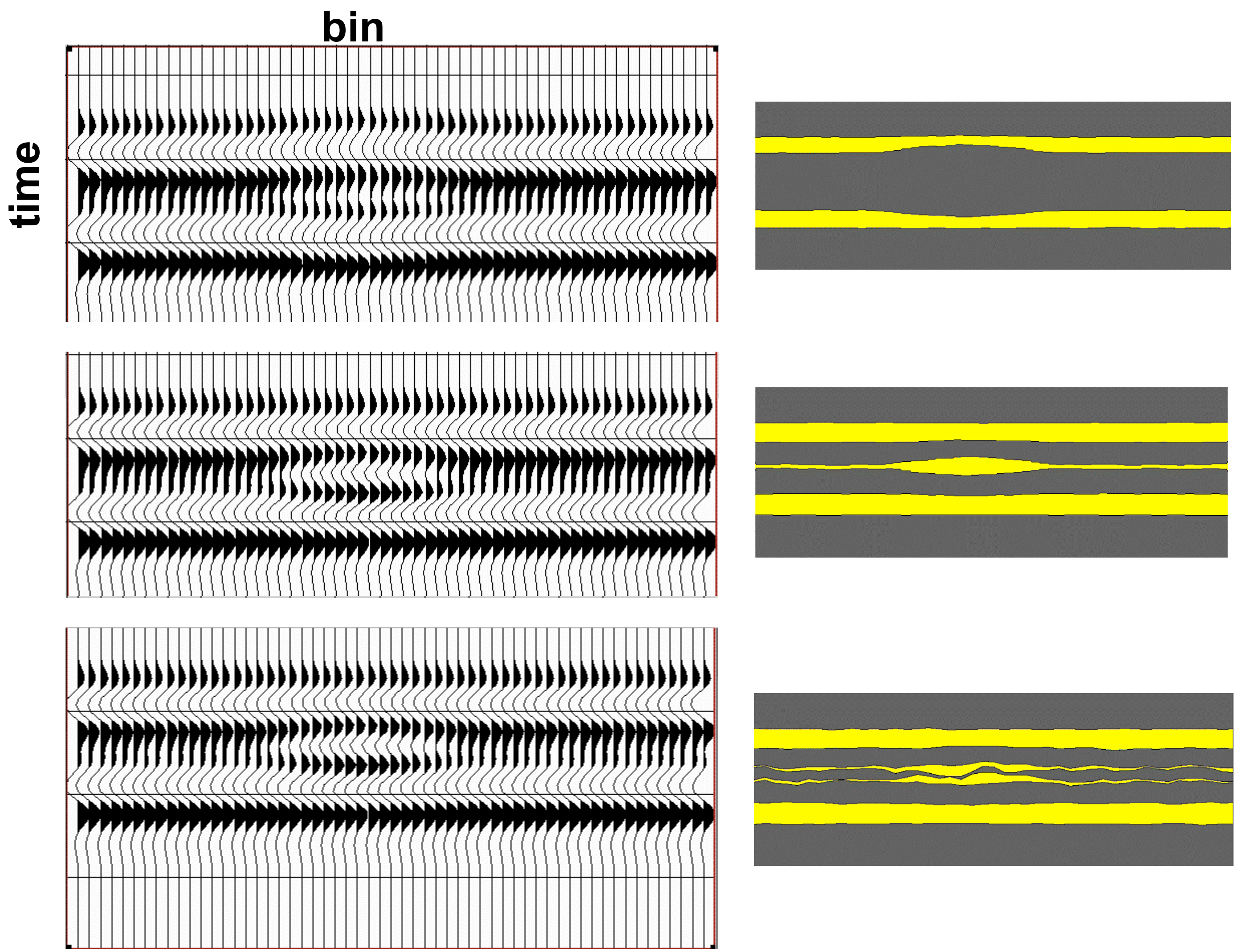


Average synthetics with different scenarios (i.e., number of layers)

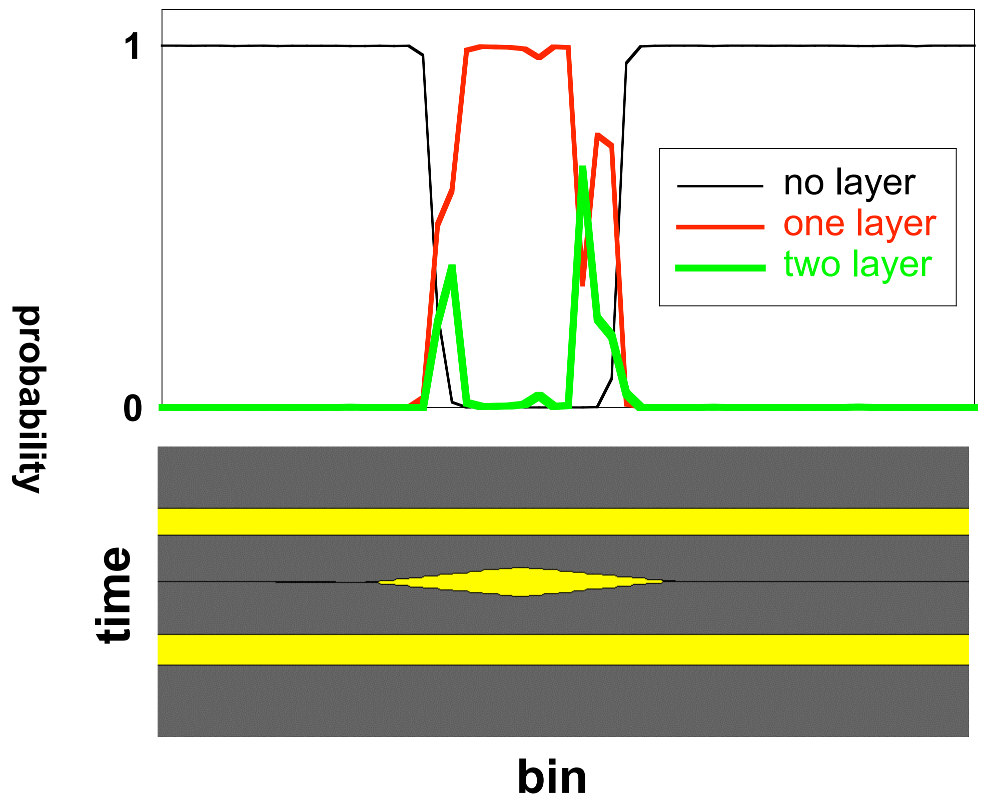
no layer

one layer

two layer



Probabilities of different scenarios



Uses of multiple scenarios and multiple stacks

- **multiple stacks**
  - wavelet variation
  - AVO inversion
  - 4D inversion
  - AVF inversion
  - other simultaneous consistencies??
- **multiple scenario**
  - number of layers to use
  - presence of channel, reef or shingle
  - other quantitative comparisons ???

Sundry discussions

- **how many layers to use**
- **appropriate grid spacing**
- **consistency checks (are some constraints a self fulfilling prophecies?)**
  - fluid levels
  - well ties
  - areal correlation

A view on uncertainty

Michael Glinsky
Shell E&P Technology Co.

Vistas of this view

- **high level look**
  - 3rd generation (research size = business impact)
- ***bourgeois* perspective**
  - DepSim switchyard
  - role of probabilistic inversion

Approach to uncertainty - top down

economic
"business model"

what makes $$

mathematical decision
analysis model

what are important
physical variables

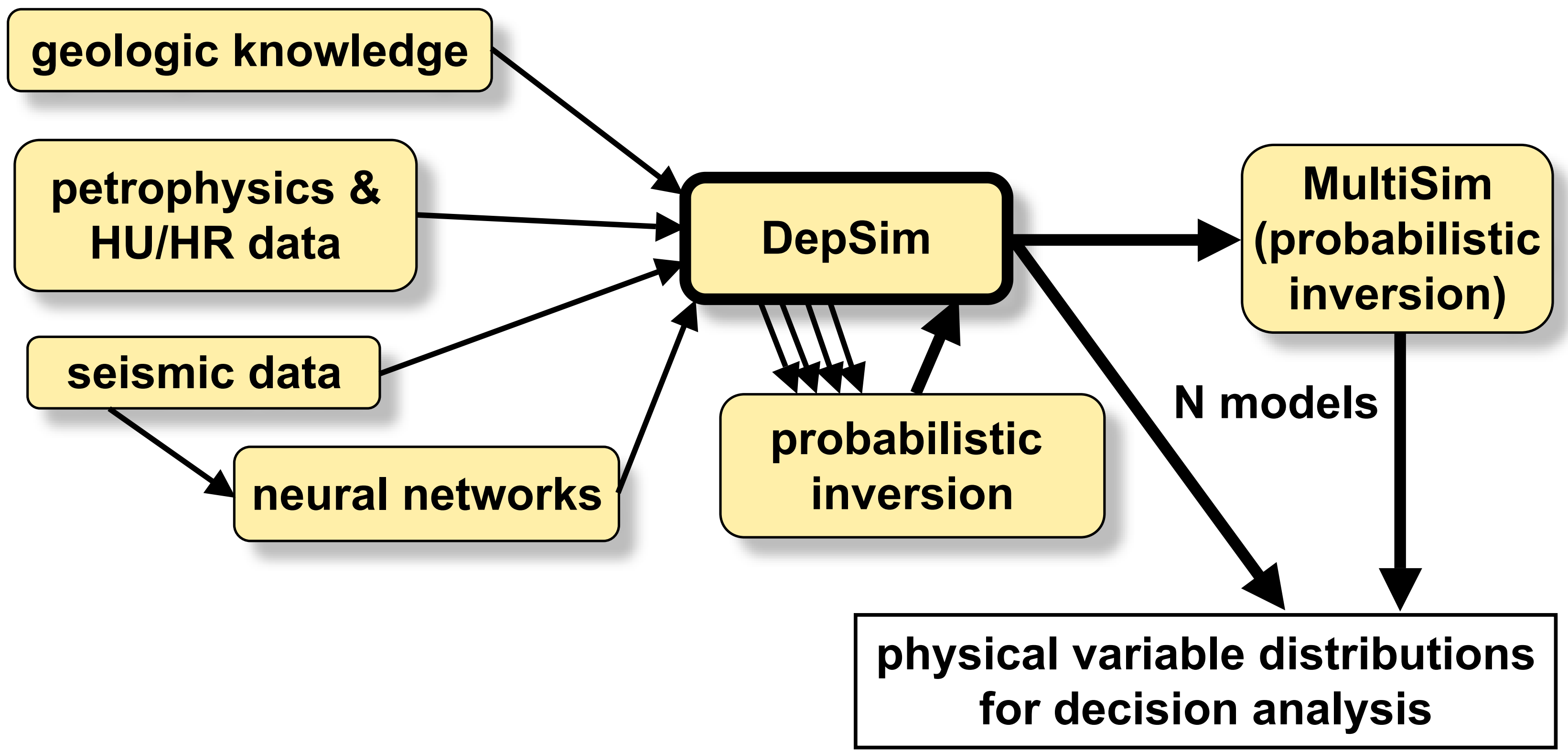
formalism and tools
to generate physical
variables

need knowledge
of what is technically
feasible

Approach to uncertainty - components

- **mathematical decision “option” analysis model**
  – simple analytic
  – Monte Carlo simulation
    - gaussian or non-gaussian distributions
  – others ??
- **tools and formalism**
  – PROMISE
  – AVO inversion
  – AVF inversion
  – 4D inversion
  – scenario testing
  – HU/HR database for priors
  – neural nets
  – others ??

DepSim switchyard with seamless flow to decision analysis



Possible role of probabilistic inversion

- **generate equally probable models (distributions) according to**
  - seismic data
    - AVO (shear)
    - AVF (scale)
  - production history (including 4D seismic)
  - geologic knowledge (prior)
  - petrophysics (prior)
  - neural networks (prior)
- **evaluate the probability of different scenarios**
  - i.e., shingled or not
- **reduce variable distribution to gaussian?**
  - mean value
  - error

Reflections on 4D Inversion

Michael Glinsky
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Specification of model

$m = (g, f, \kappa)$
= model

g = geometric + seismic variables (e.g., v_p , v_s , NtG , ρ , φ)

f = fluids in layers

κ = production related properties not well correlated to seismic (e.g., permeability)

Data to match

$d = (d_{so} , d_{s1} , d_p)$
$= \text{data}$

$t = t_0$

$d_{so} =$

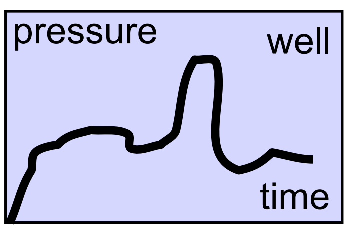
- near stack
- far stack
- σ_f of near stack
- σ_f of far stack

$t = t_1$

$d_{s1} =$

- near stack
- far stack
- σ_f of near stack
- σ_f of far stack

$d_p =$



Fundamental equation

$$P(\, m \mid d \,) \sim P(m) \;\; P(\, d \mid m \,)$$

$P(m) =$ prior probability
= (neural nets, trends, interpolated well logs)

$P(\, d \mid m \,) = q(\, s(m) - d \,)$

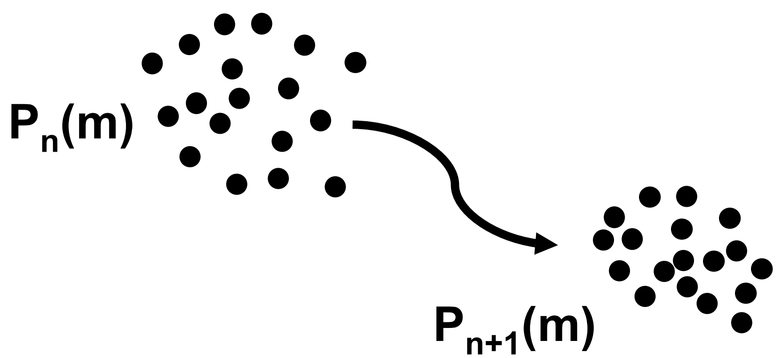
$q =$ noise spectrum

Iterative solution

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

$$P_n(m) \rightarrow P(\, m \mid d \,) \quad \text{as} \quad n \rightarrow \infty,$$
$$P_0(m) = P(m),$$
$$\text{and}$$
$$P_{n+1}(m) = \mathbf{F}(\, P_n(m) \,)$$

F = conjugate gradient or metropolis



A form for the noise distribution

$$q = q_{so}(\, s_s(g_o,f_o) - d_{so}\,) \quad q_{s1}(\, s_s(g_1,f_1) - d_{s1}\,)$$

$$q_f(\, s_f(g_o,f_o,\, \kappa) - f_1\,) \quad q_p(\, s_p(g_o,f_o,\, \kappa) - d_p\,)$$

s_s = seismic forward modeling

s_f and s_p = reservoir simulation

A simplified approach: phased inversion

assume $g_1 = g_o$ (i.e., ignore compaction effects)

and $P(m) = P_1(g_o, f_o, f_1)\ P_2(\kappa)$

PHASE I: find $\{ (g_o, f_o, f_1)_i \}$ distributed according to

$$P_1(g_o, f_o, f_1)\ q_{so}\ q_{s1}$$

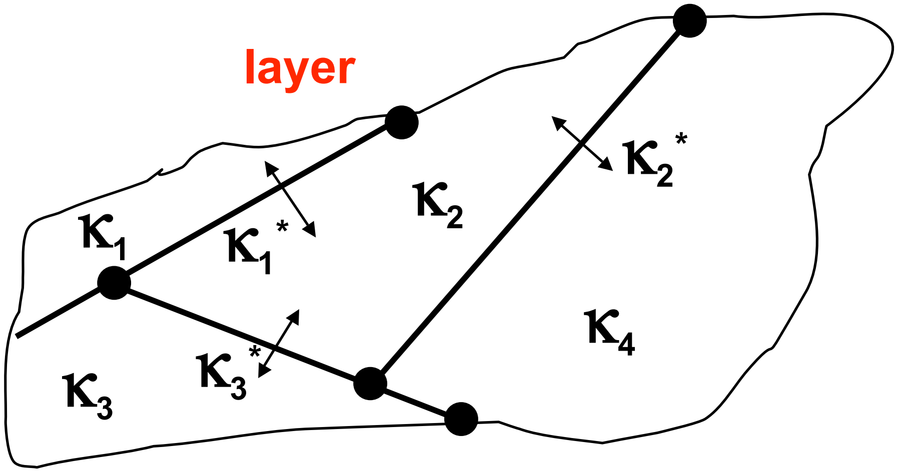
(conventional probabilistic seismic inversion)

PHASE II: find $\{ (i, \kappa)_j \}$ distributed according to

$$P_2(\kappa)\ q_f\ q_p$$

(probabilistic reservoir simulation inversion)

A simplified reservoir model?



κ_i = permeability

κ_i^* = interface permeability

allow κ_i^*, κ_i and endpoints to vary