

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
Shell E&P Technology Co.

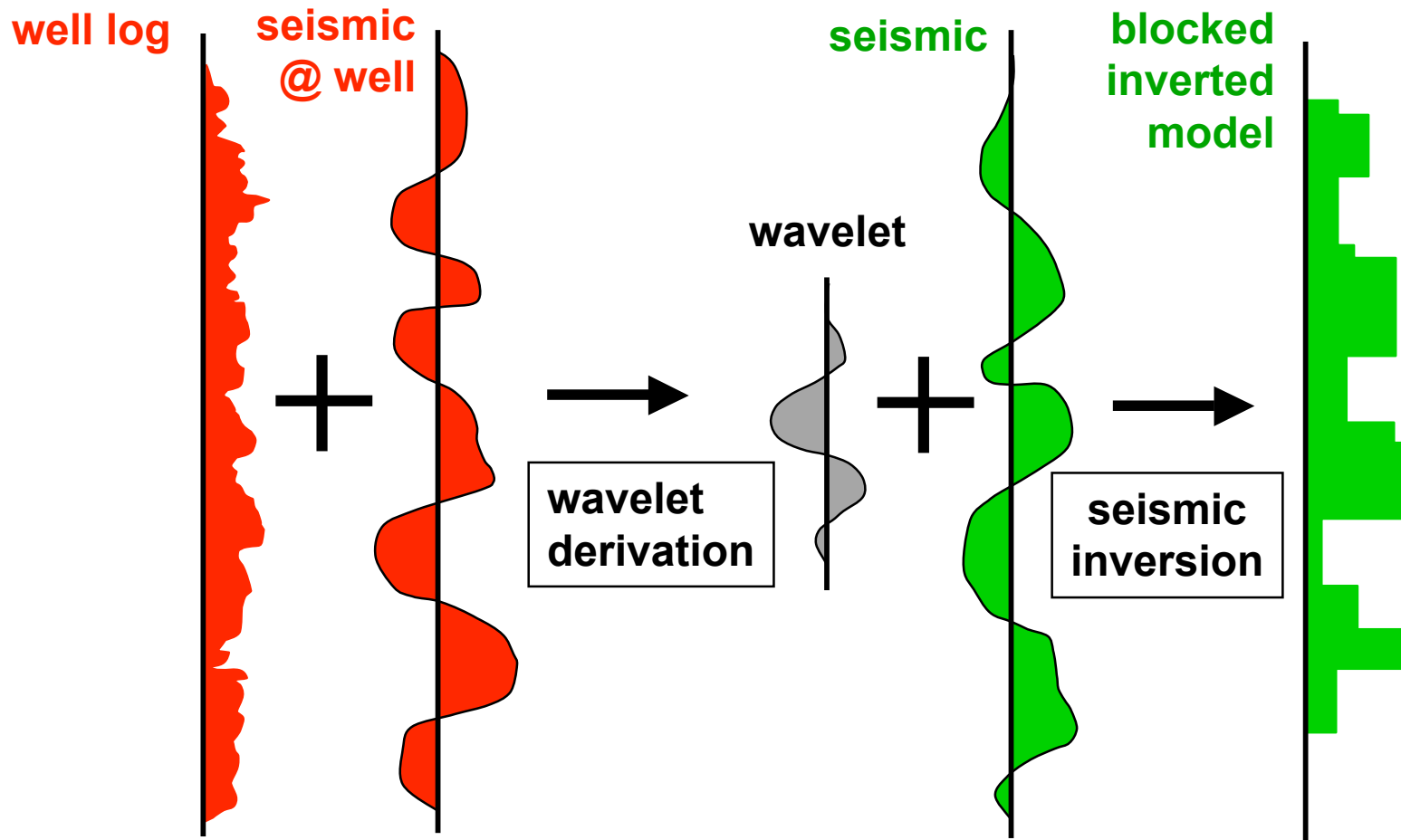
Jaap Leguijt
SIEP-RTS

Outline



- **description of inversion process**
- **statistical inversion - a general framework**
- **prior knowledge (aka constraints)**
 - petrophysics
 - 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)

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

seismic

$q_{\langle n \rangle}(n)$ = noise distribution
 $= \exp(-\sum n_k^2 / \langle n_k \rangle^2)$

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

d_{seismic} = seismic data

$\Rightarrow P(d_{\text{seismic}}|m) = q_{\langle n \rangle}(d-s(m))$
= probability of seismic
given the model

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

Iterative solution for N equally probable models



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

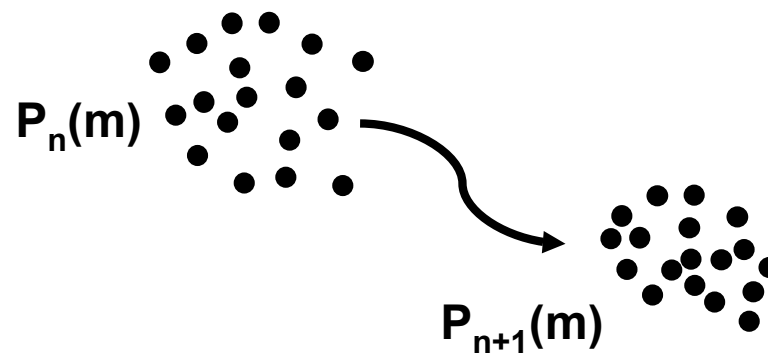
$$P_n(m) \rightarrow P(m | d) \quad \text{as } n \rightarrow \infty,$$

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

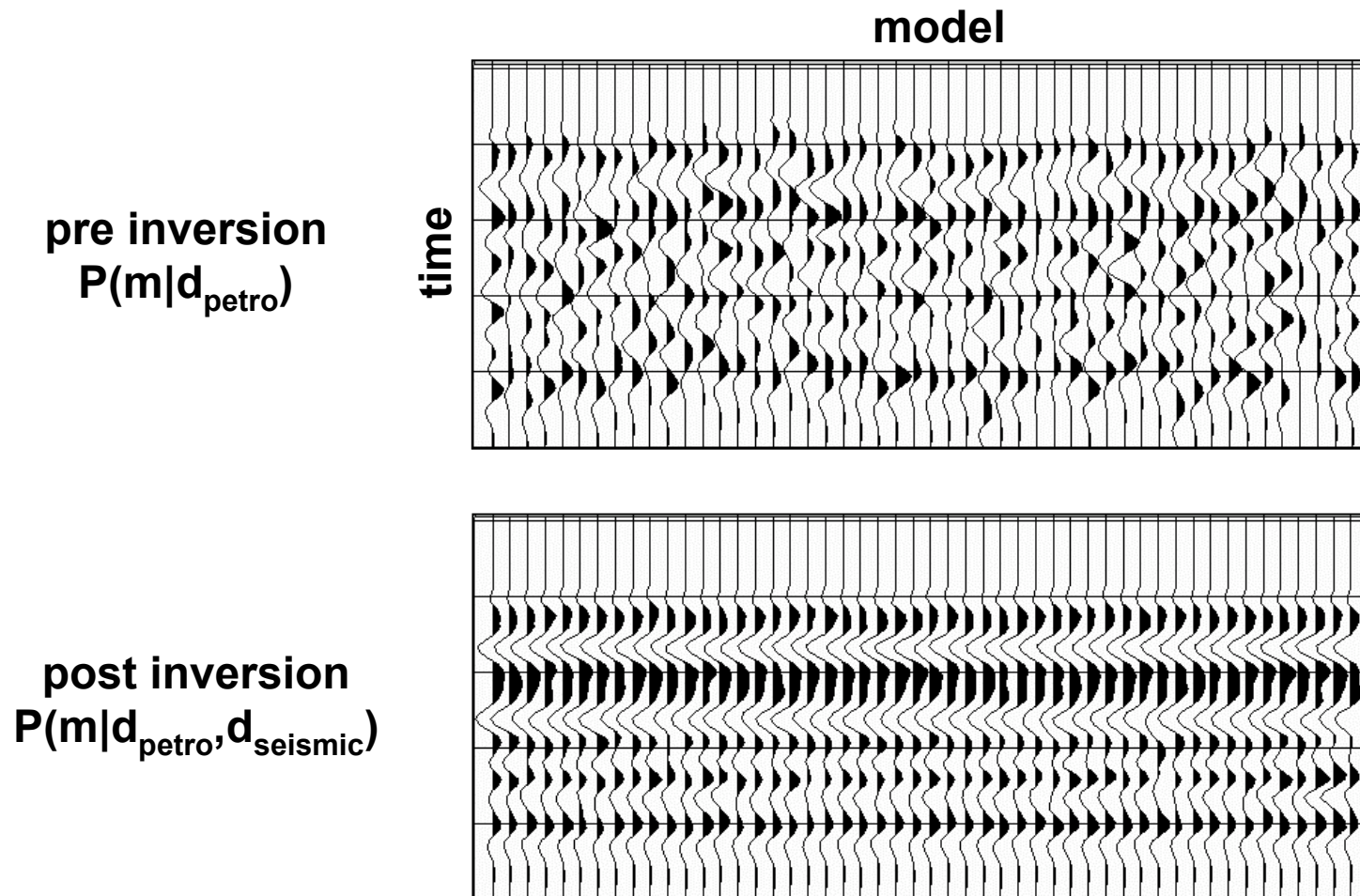
and

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

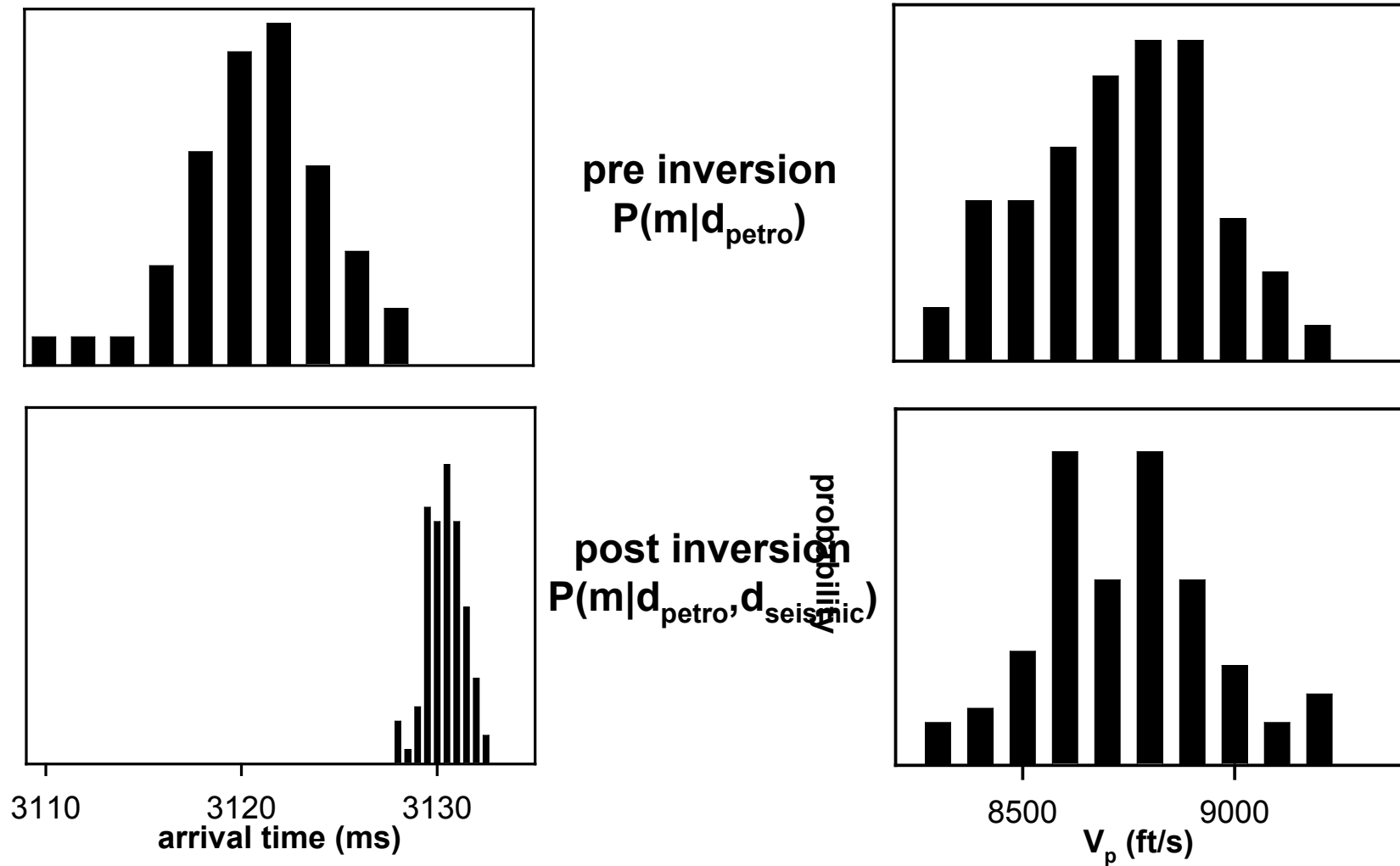
F = conjugate gradient or metropolis



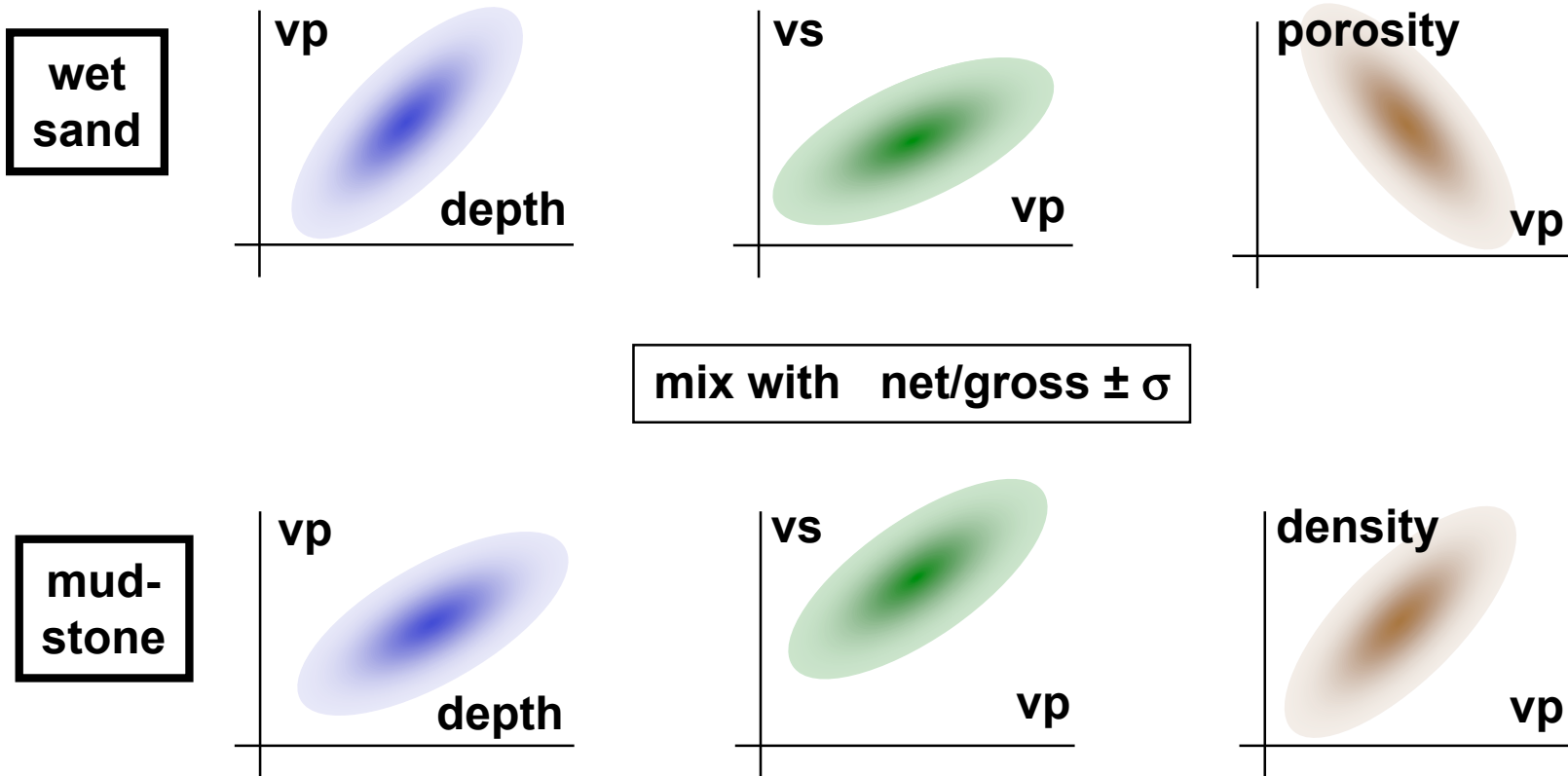
Inversion improves match with seismic data



Inversion improves estimate of some reservoir properties

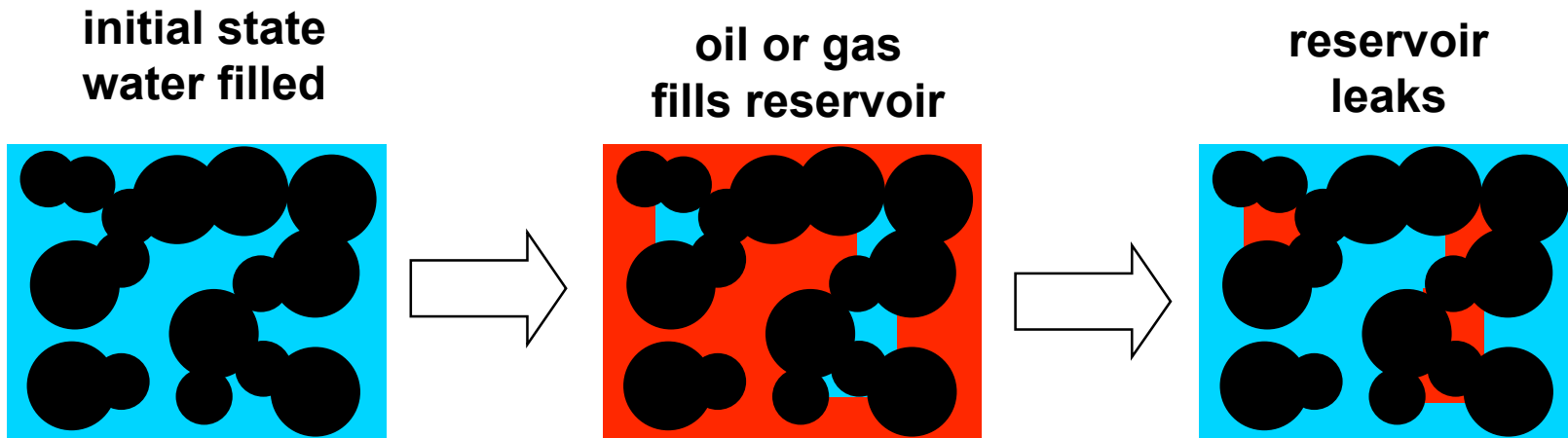


GOM petrophysical end member trends used in prior probability



note: separate trend for each layer

Discrete cases of fluid fill are used

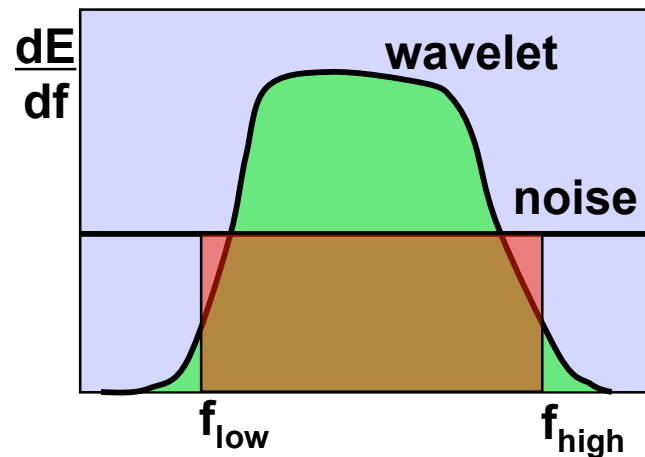


- **prior probability of each fluid fill case**
 - neural network fluid prediction
 - regional information (trap probability, leak probability, etc.)
- **posterior probability of each fluid fill case**
 - adds seismic AVO information

White noise specification

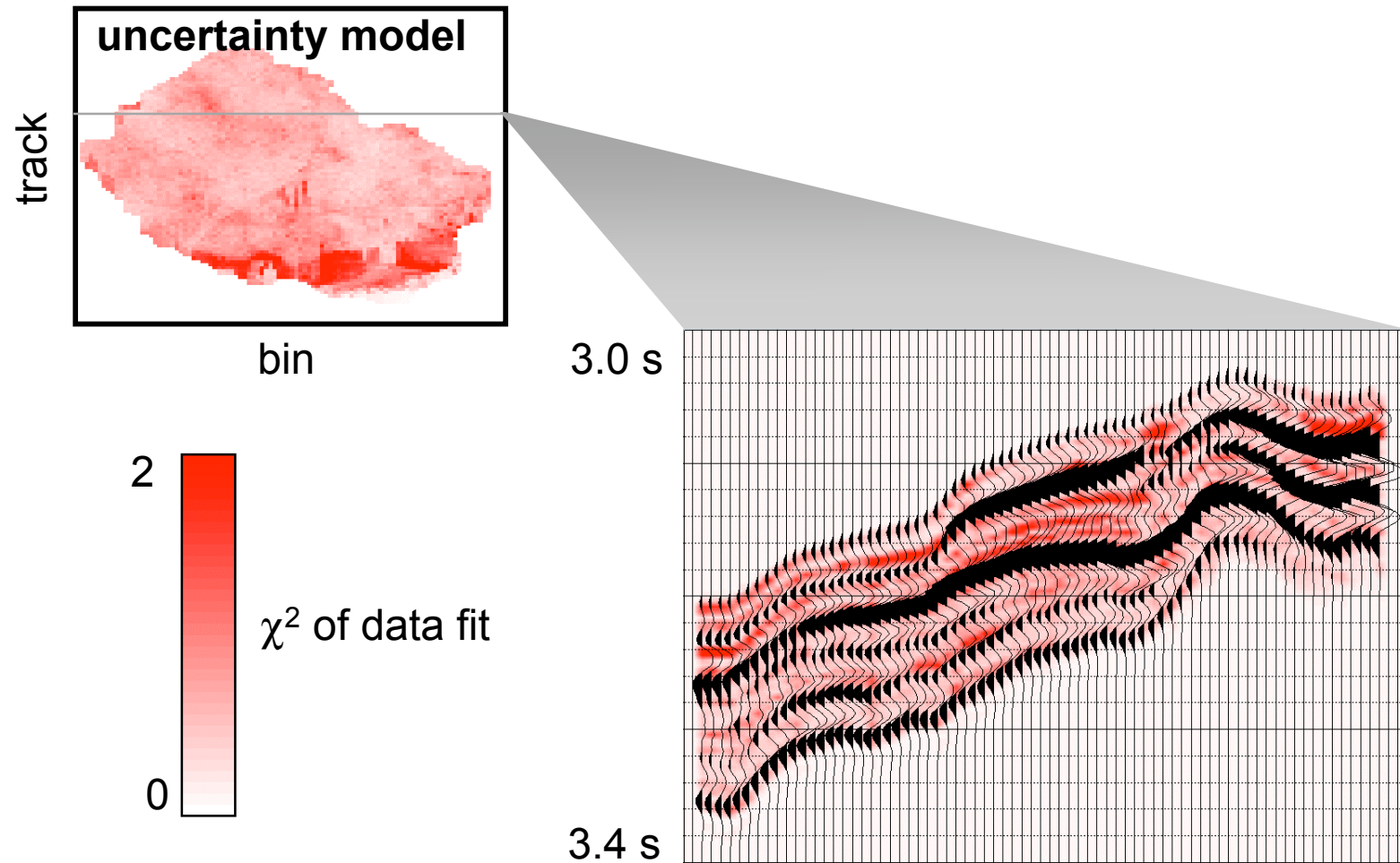


- seismic wavelet
- bandwidth of information content of seismic wavelet
 - f_{low} and f_{high} (Hz)
- average reflection coefficient
- SNR (dB)
 - parameter to vary (others set initial scale, use 10 dB)

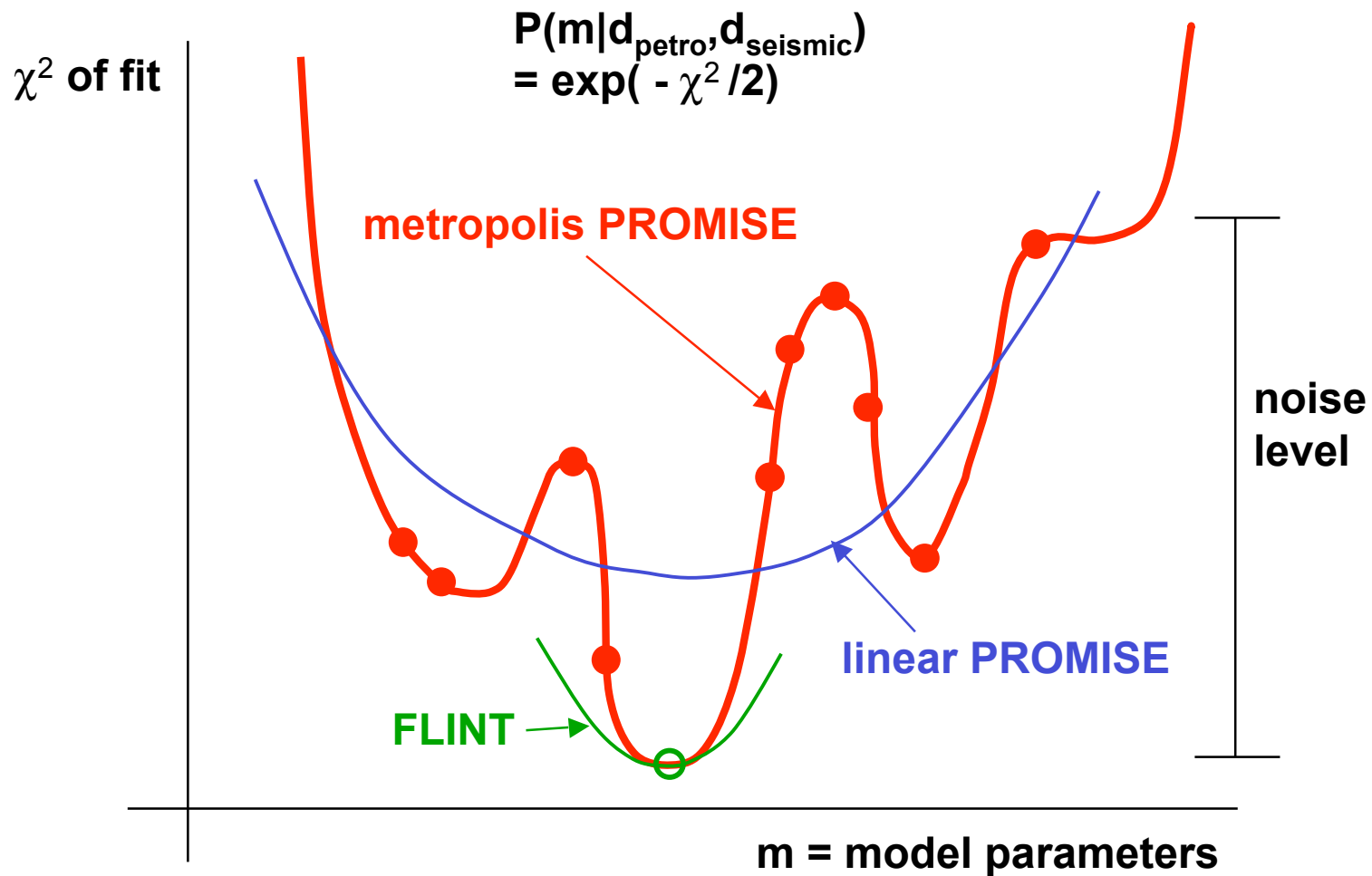


SNR = green / red

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



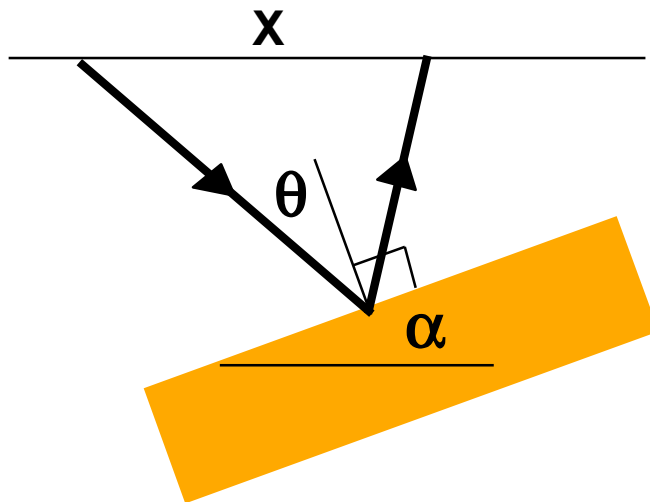
- **FLINT mode**
 - petrophysical trends and geometry in DepSim
 - error as soft constraints in FLINT or error in PROMIISE
- **PROMISE mode**
 - geometry in DepSim
 - petrophysical trends and errors in PROMISE

A time migration approximation is used to model AVO



expansion in $(X / V T)$ and $(V dT/dx) \ll 1$

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



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

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

Equations that are used to model AVO



reflection coefficient

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

wavelet stretch

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

offset average wavelet & reflection coefficient

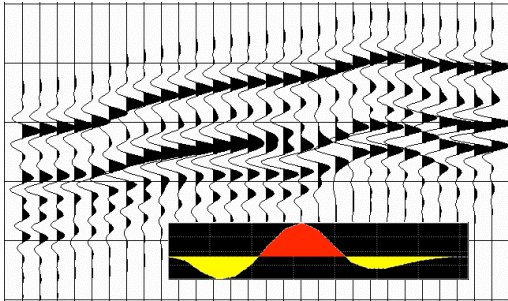
$$\text{wavelet} = W(X, t) = W_0(t / S(X))$$

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

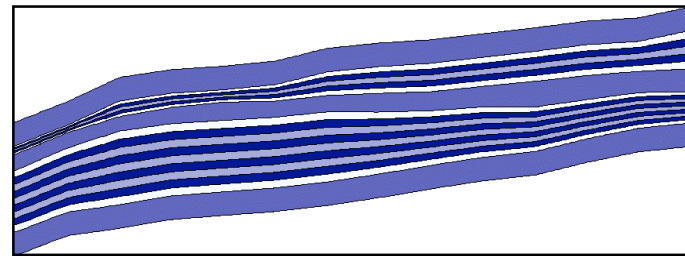
Inputs to inversion



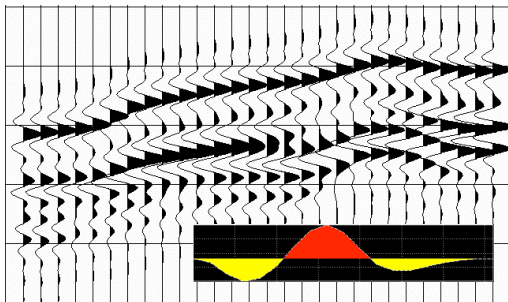
near stack and wavelet



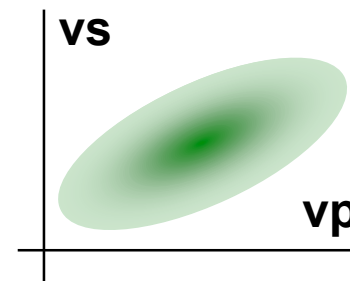
initial DepSim model



far stack and wavelet



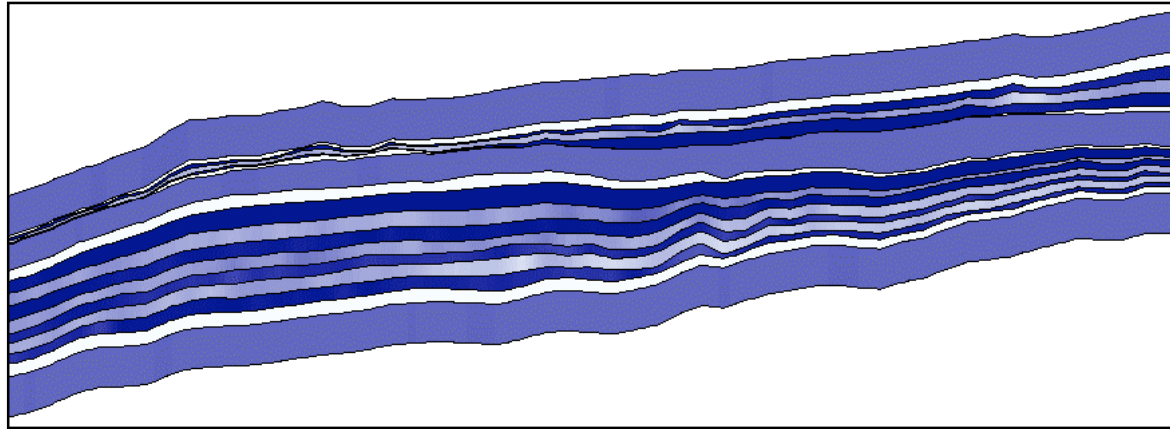
rock properties



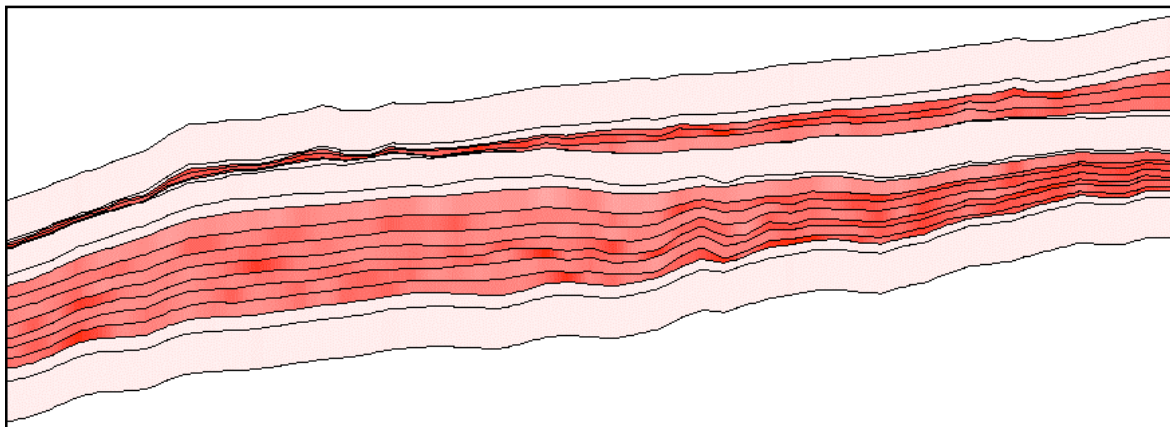
Output of inversion



updated DepSim model



uncertainty in DepSim model

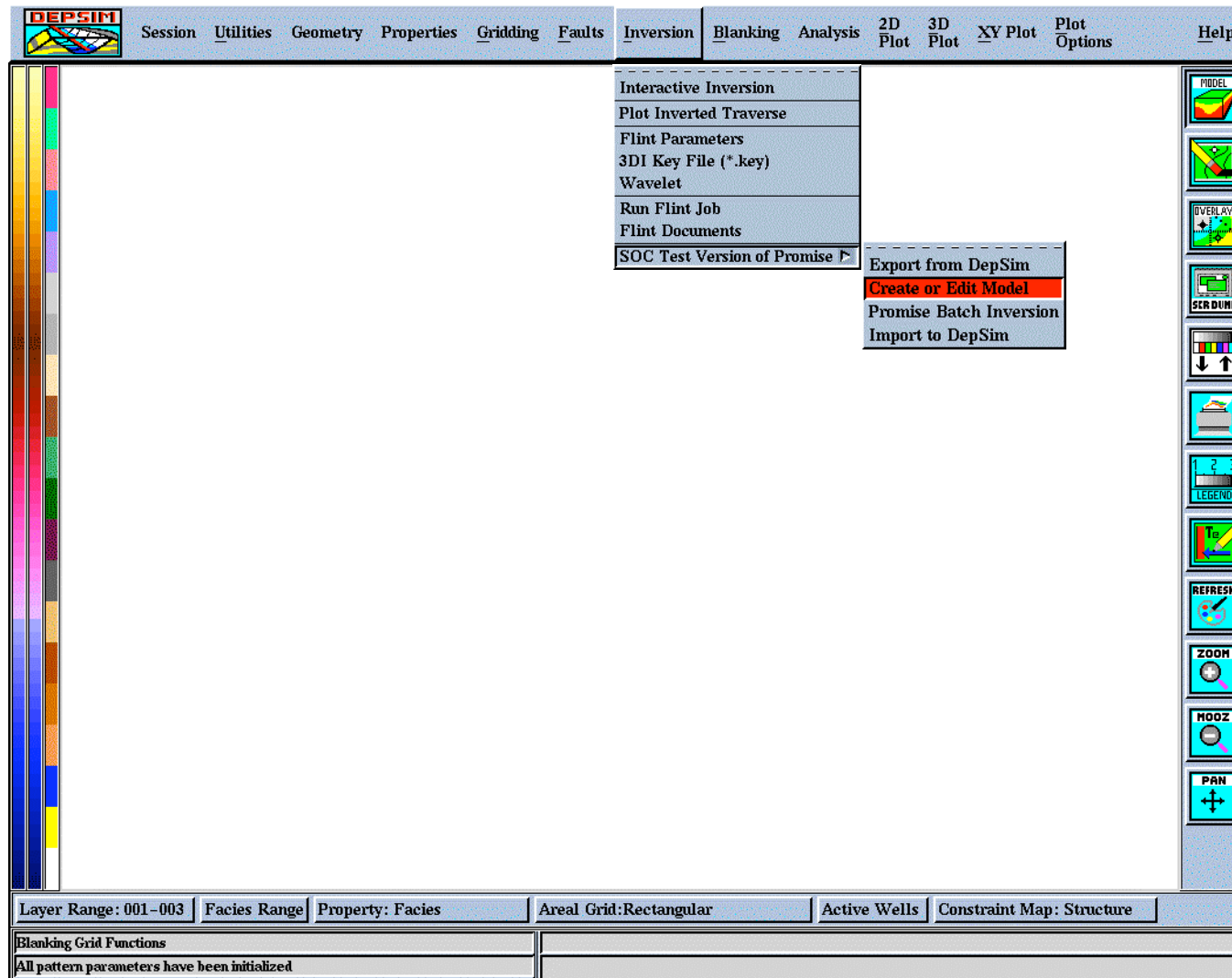


Principles of DepSim/PROMISE integration



- **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



main_popup

**DepSim to PROMISE+AVO/4D
(SOC test version)**

DepSim Jaap grid file name:

depsim.jgrd

PROMISE model file name:

model.mod

PROMISE model:

Read / Create Write Edit

Reset Exit

layerEdit_popup

Edit PROMISE model

Number of stacks: 1

Edit Stacks (AVO,4D)

Layer: 003: middle shale

Litho: 012: SDDI_lam_sand

Fluid: 004: LIPOS_fluid

Error in thickness:
(in m or ft) 100.0

Horizon time (layer top):
(layer 1 can not be constrained)
(one layer must be constrained)

☒ constrained
☐ free

Error in horizon time:
(in ms) 100.0

Copy Layer Paste Layer Edit Layer

Done

SDDI_lam_sand menu



SDDI_lam_sand_popup

Edit lithology

005: F2 LamSd
012: SDDI_lam_sand

Statistical parameters:		Fixed parameters:	
ntg_avg **** FROM DEPSIM ****	0.5	vp_mud_devia	536.0
ntg_devia	0.2	vs_mud_zero	-3373.0
vp_sand_zero	4988.0	vs_mud_slope	0.801
vp_sand_slope	0.3572	vs_mud_devia	206.0
vp_sand_devia	457.0	density_mud_factor	0.0977
vs_sand_zero	-3996.0	density_mud_exp	0.3467
vs_sand_slope	0.894	density_mud_devia	0.041
vs_sand_devia	226.0		
porosity_zero	0.579		
porosity_slope	-3e-05		
porosity_devia	0.0137		
vp_mud_zero	6162.0		
vp_mud_slope	0.2828		

depth 9000.0
density_grain 2.65
vp_grain 20151.0
vs_grain 13740.0
density_ref_fluid 1.0
vp_ref_fluid 5000.0
anisotropy 0.0

Copy Parameters Paste Parameters

Ok Reset Cancel

LIPOS_2_fluid menu



LIPOS_2_fluid_popup

Edit fluid

005: F2 LamSd
005: LIPOS_2_fluid

Statistical parameters:		Fixed parameters:	
oil_prior	0.09%	oil_density	0.7%
gas_prior	0.03%	brine_density	0.95%
residual_oil_prior	0.03%	gas_density	0.3%
residual_gas_prior	0.01%	oil_vp	4000.0%
lowsat_gas_prior	0.02%	brine_vp	5000.0%
oil_prior2	0.09%	gas_vp	3000.0%
gas_prior2	0.03%	oil_fraction	0.55%
residual_oil_prior2	0.03%	gas_fraction	0.55%
residual_gas_prior2	0.01%	residual_oil_fraction	0.15%
lowsat_gas_prior2	0.02%	residual_gas_fraction	0.15%
		lowsat_gas_fraction	0.05%

Copy Parameters Paste Parameters

Ok Reset Cancel

Edit stacks menu



stack_popup

Edit stacks

Veff:	8000.0	L factor: (dB)	0.0
Dip: (ms/10ft or 10m)	0.0	L error: (dB)	0.5
Time: (ms)	3000.0	M factor: (dB)	-3.5
		M error: (dB)	0.5

Stack: 001

Time of stack: ☒ base survey ☒ monitor survey

Sipmap or VT file name: rex29.40.nrstk.sip Wavelet file name: near.stk.wav

x_min:	130.0	x_mute_start_1:	0.0
x_max:	6500.0	x_mute_start_2:	0.0
t_mute_1: (ms)	0.0	x_mute_end_1:	1.0
t_mute_2: (ms)	0.0	x_mute_end_2:	1.0

Noise for the Stack:

snr: (dB)	20.0	f_low: (Hz)	10.0
refl_coeff:	0.02	f_high: (Hz)	60.0

Ok

Executing PROMISE menus



Master_Menu_popup

**PROMISE+AVO/4D
(SOC test version)**

Inversion (metropolis)

Number of Realizations: 200 Number of Models: 100

Input Model File: model.mod

Input Jgrd File: depsim.jgrd

Output Directory: trk600_post

Input Seismic: VT Output Seismic: SIPMAP

Time Range (ms)

Minimum: 2000 Above: 30

Maximum: 4000 Below: -30

Track Range

Minimum: 600 Maximum: 600 Increment: 2

Bin Range

Minimum: 2500 Maximum: 8100 Increment: 25

Load Parameters Save Parameters Edit Parameters

Ok Apply Reset Exit

Metropolis_Menu_popup

Metropolis Inversion

Distribute Inversion: Yes

Number of Traces Per Job: 10

Additional Options for the bsub Command: -q 'priority'

Entropy Step Threshold: 0.0

Ratio Log Threshold: 0.6

Maximum Number of Loops: 100

Step Size: 0.4

☐ Fitted Distribution ☐ Estimated Posterior

Ok Re

Diagnostics_Menu_popup

Diagnostics

☒ Yes JGRD Files ☐ No Synthetic Traces

☒ Yes GRD Files ☒ Yes Average Synthetic Traces

☐ No Detailed ASCII ☒ Yes Chi-squared Trace

☒ Yes Chi-squared

☐ No L&M Traces

☒ Yes Average L&M Traces

Variable Definition File: model.def

Statistical Parameter File: model.prg

Ok Reset Cancel

LSF is used to distribute inversion over many workstations



LSF Batch - Console

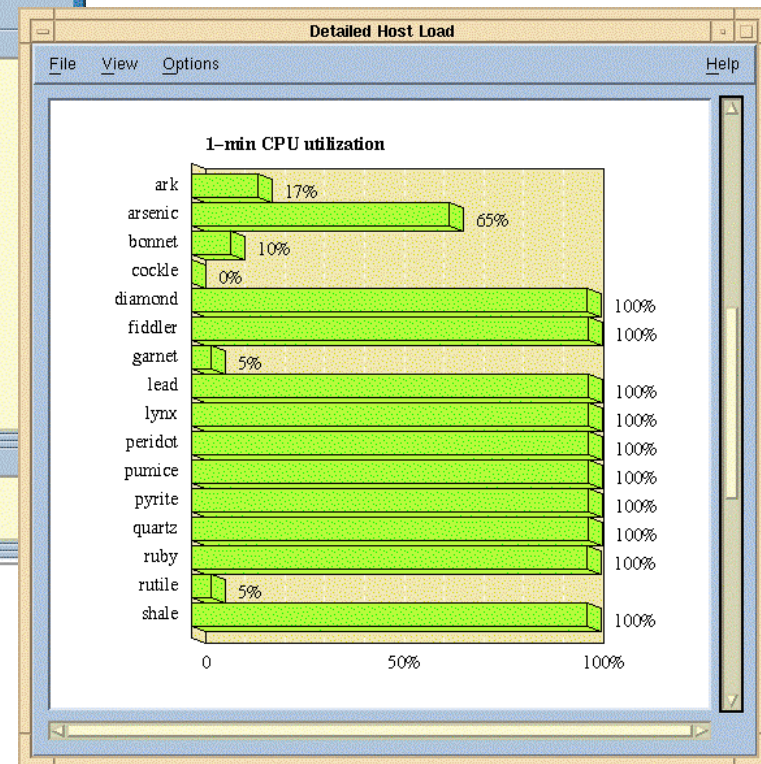
File Job JobArray Host Queue User Parameter Options Help

Job_Id	User	Stat	Queue	From_Host	Exec_Host	Sub_Time	Job_Name
732	eldon	SSUSP	normal	ark	rutile	Apr 1 14:38:59 1999	inversion9946[48]
732	eldon	SSUSP	normal	ark	arsenic	Apr 1 14:38:59 1999	inversion9946[54]
732	eldon	SSUSP	normal	ark	arsenic	Apr 1 14:38:59 1999	inversion9946[58]
732	eldon	RUN	normal	ark	pyrite	Apr 1 14:38:59 1999	inversion9946[59]
732	eldon	RUN	normal	ark	pyrite	Apr 1 14:38:59 1999	inversion9946[60]
732	eldon	RUN	normal	ark	diamond	Apr 1 14:38:59 1999	inversion9946[62]
732	eldon	RUN	normal	ark	diamond	Apr 1 14:38:59 1999	inversion9946[63]
732	eldon	RUN	normal	ark	lead	Apr 1 14:38:59 1999	inversion9946[64]
732	eldon	RUN	normal	ark	lead	Apr 1 14:38:59 1999	inversion9946[74]
732	eldon	RUN	normal	ark	quartz	Apr 1 14:38:59 1999	inversion9946[65]
732	eldon	RUN	normal	ark	quartz	Apr 1 14:38:59 1999	inversion9946[66]
732	eldon	RUN	normal	ark	lynx	Apr 1 14:38:59 1999	inversion9946[67]
732	eldon	RUN	normal	ark	lynx	Apr 1 14:38:59 1999	inversion9946[68]
732	eldon	RUN	normal	ark	lynx	Apr 1 14:38:59 1999	inversion9946[69]
732	eldon	RUN	normal	ark	ruby	Apr 1 14:38:59 1999	inversion9946[70]
732	eldon	RUN	normal	ark	ruby	Apr 1 14:38:59 1999	inversion9946[72]

Job_Id	Array_Name	User	NJOBS	PEND	DONE	RUN	EXIT	SSUSP	USUSP	PSUSP
732	inversion9946[1-254]	eldon	225	176	25	20	0	4	0	0
737	inversion9983[1-254]	eldon	254	254	0	0	0	0	0	0

Host	State
agate	unlicensed
ark	closed_Busy
arsenic	closed_Full
barite	unlicensed
bonnet	closed_Full
cockle	unlicensed
diamond	closed_Full
fiddler	closed_Full
garnet	closed_Busy
gems	unlicensed
lead	closed_Full
lynx	ok
peridot	closed_Full
pumice	closed_Full
pyrite	closed_Full
quartz	closed_Full
ruby	closed_Full
rutile	closed_Busy
shale	closed_Full

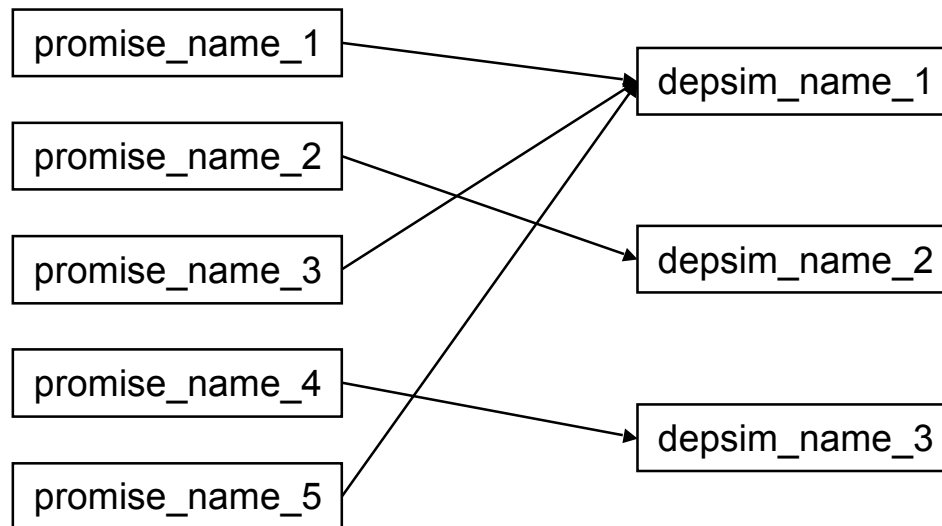
Loading done. Updated 16:37:42



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**

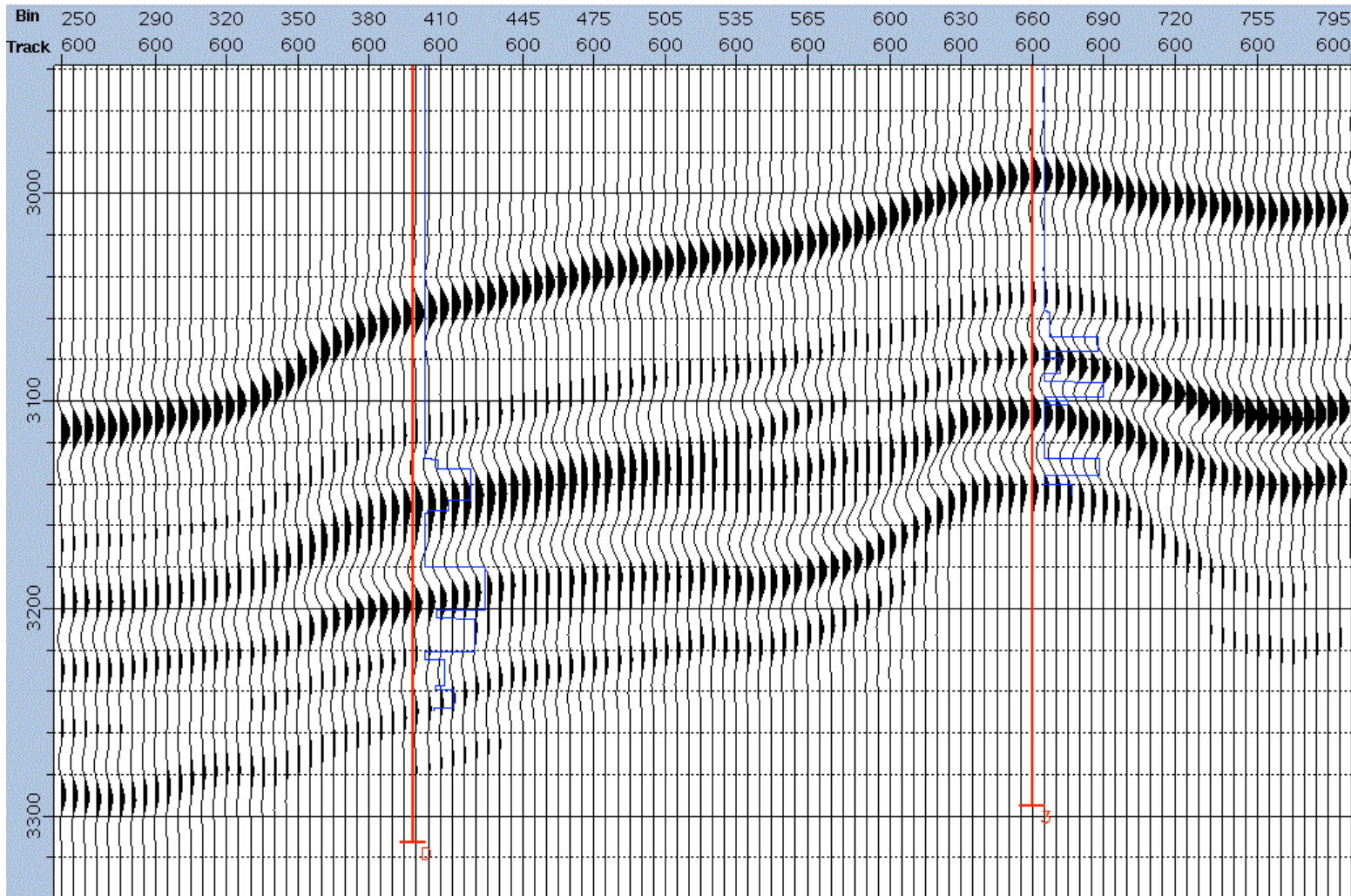


EXERCISE 1 (uncertainty model AVO)

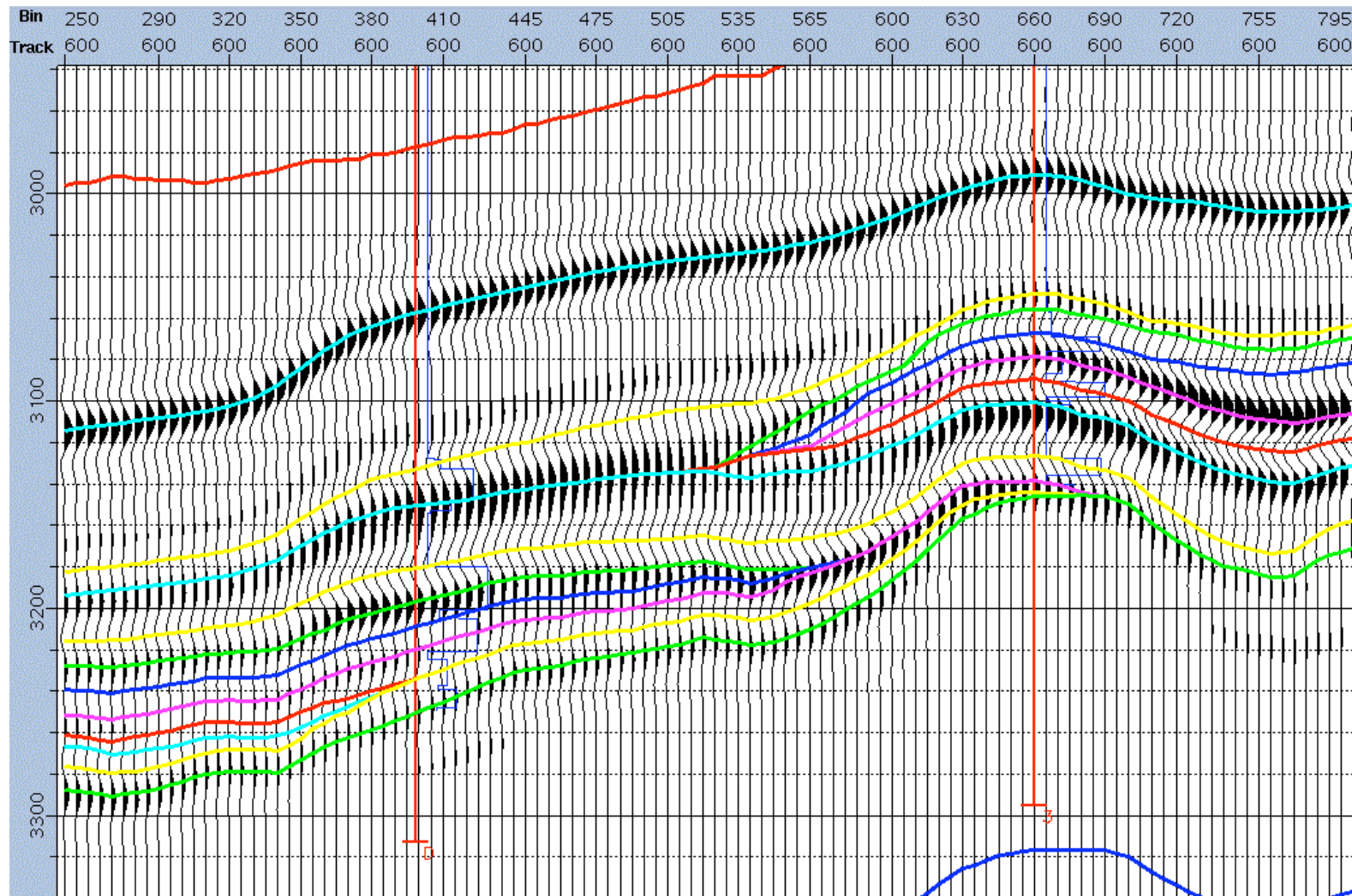


- **2D model build**
 - block model
 - determine and assign properties
- **interactive FLINT inversion**
- **PROMISE+ inversion**
 - determine proper lithologies and fluids
 - determine and assign properties (errors)
 - determine seismic noise level
 - do inversion and import results back into DepSim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

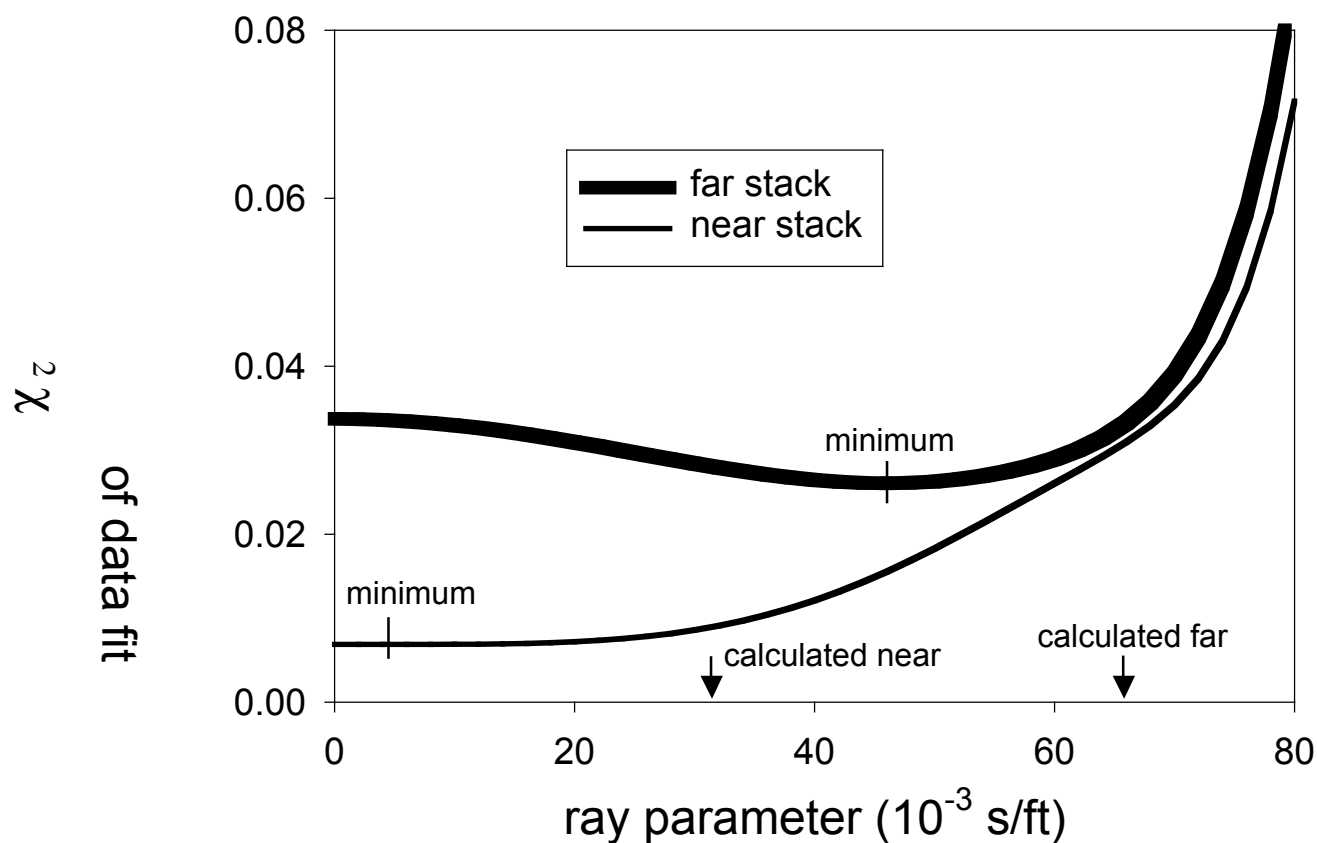
Near stack with well N/G



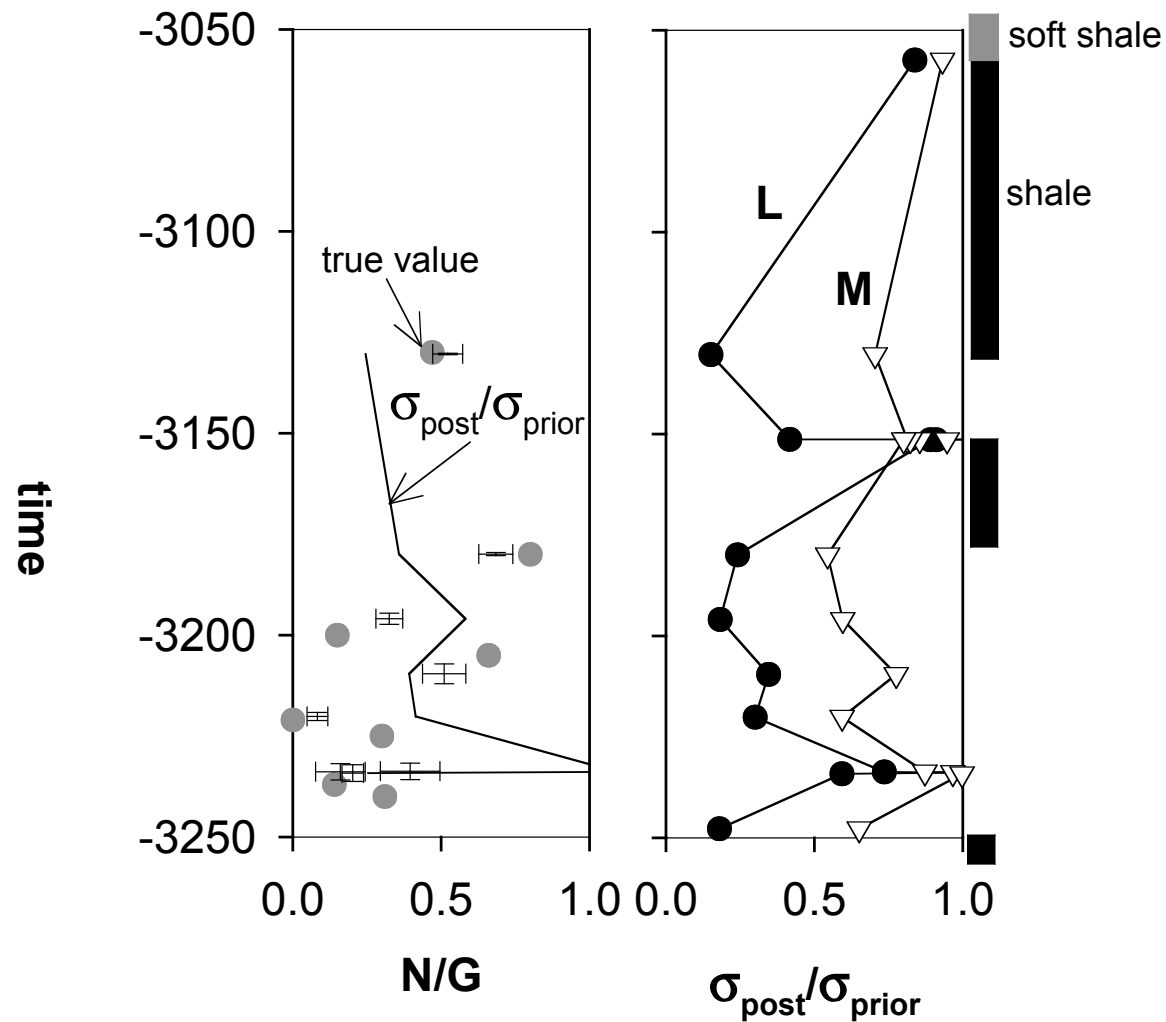
Near stack with hand picked events



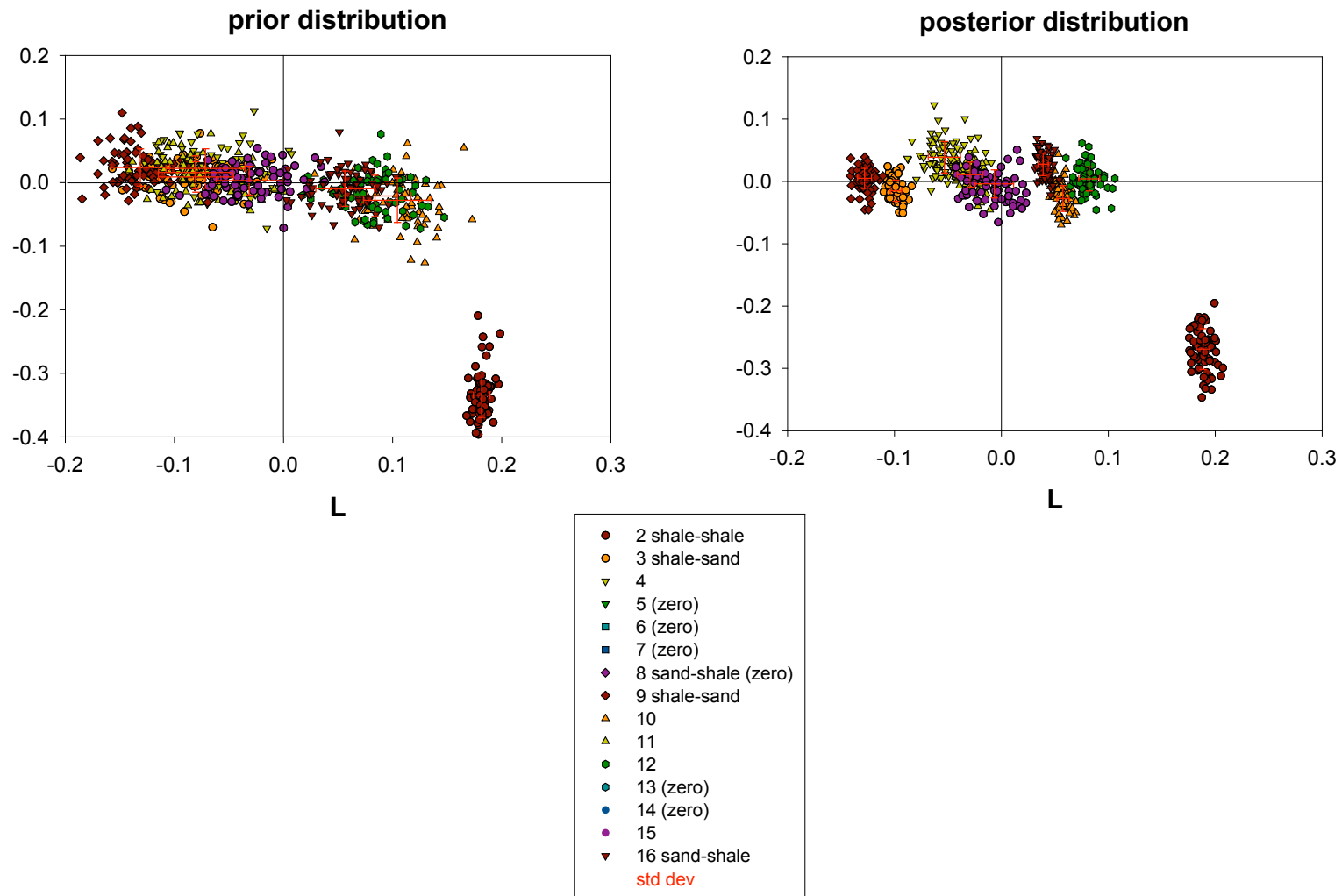
Effective ray parameter is determined by well matching during wavelet derivation



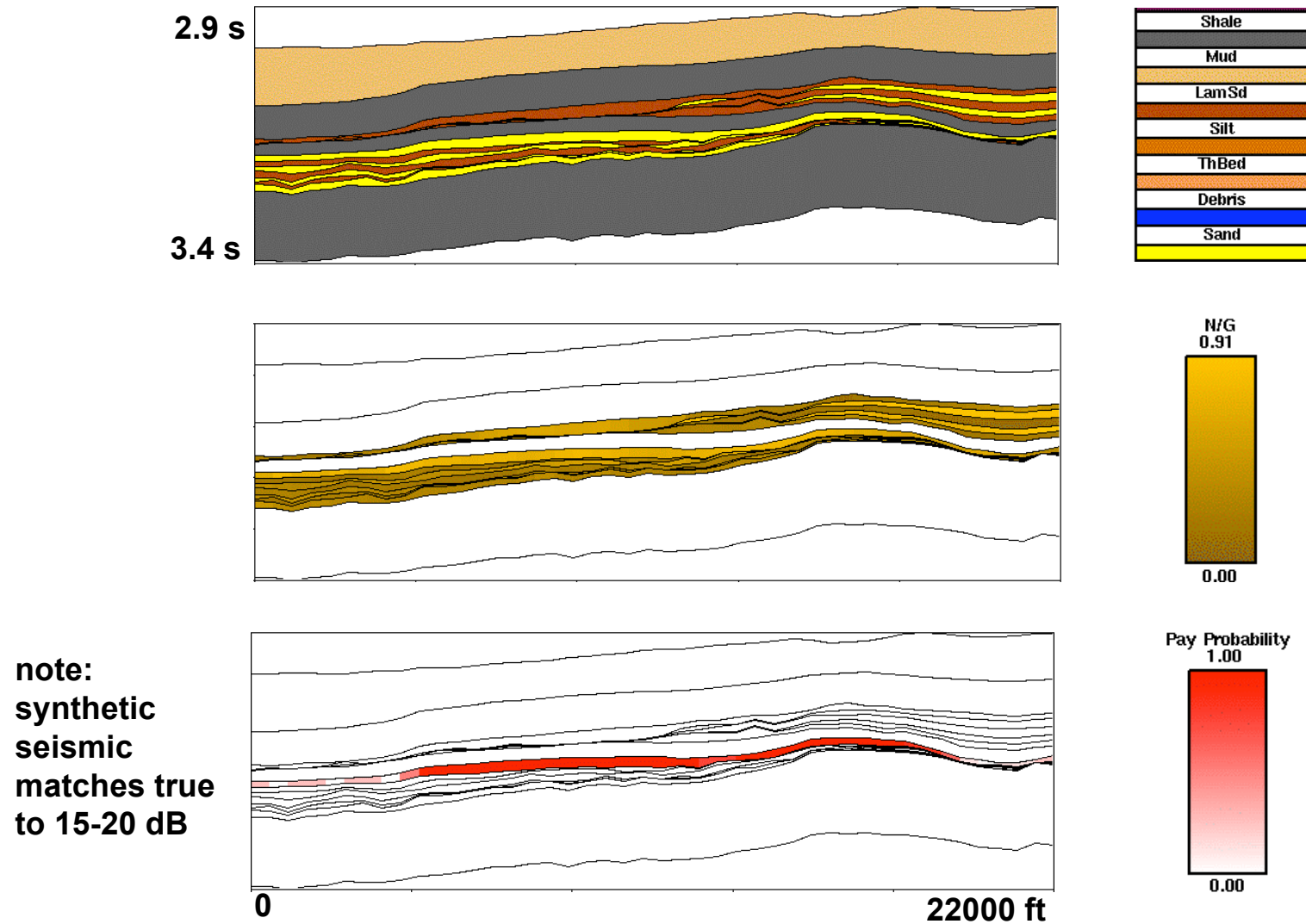
The quality of the well tie - inversion at the well



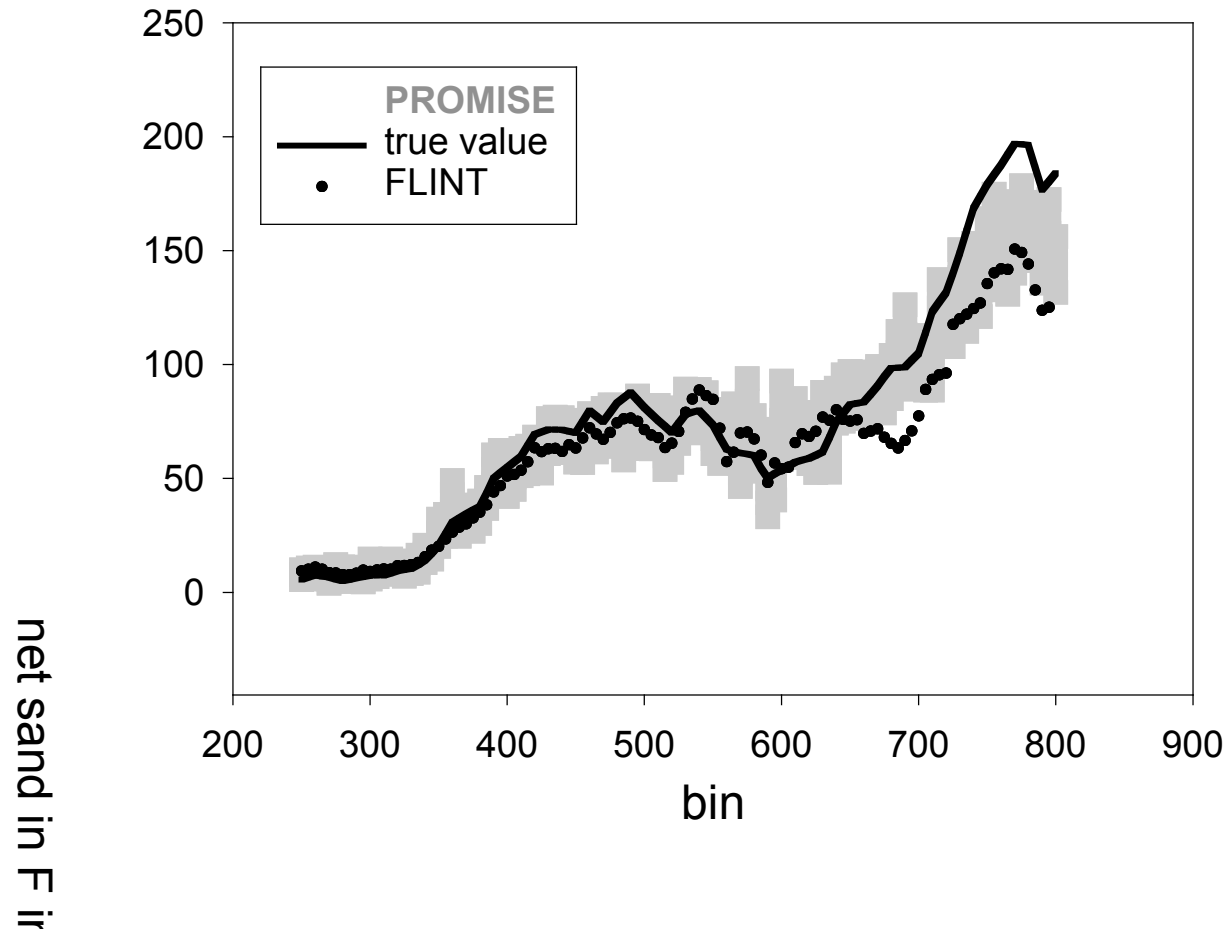
AVO inversion tightens clouds in L-M space



Uncertainty model after AVO inversion



Results of AVO inversion compared to true value and FLINT inversion

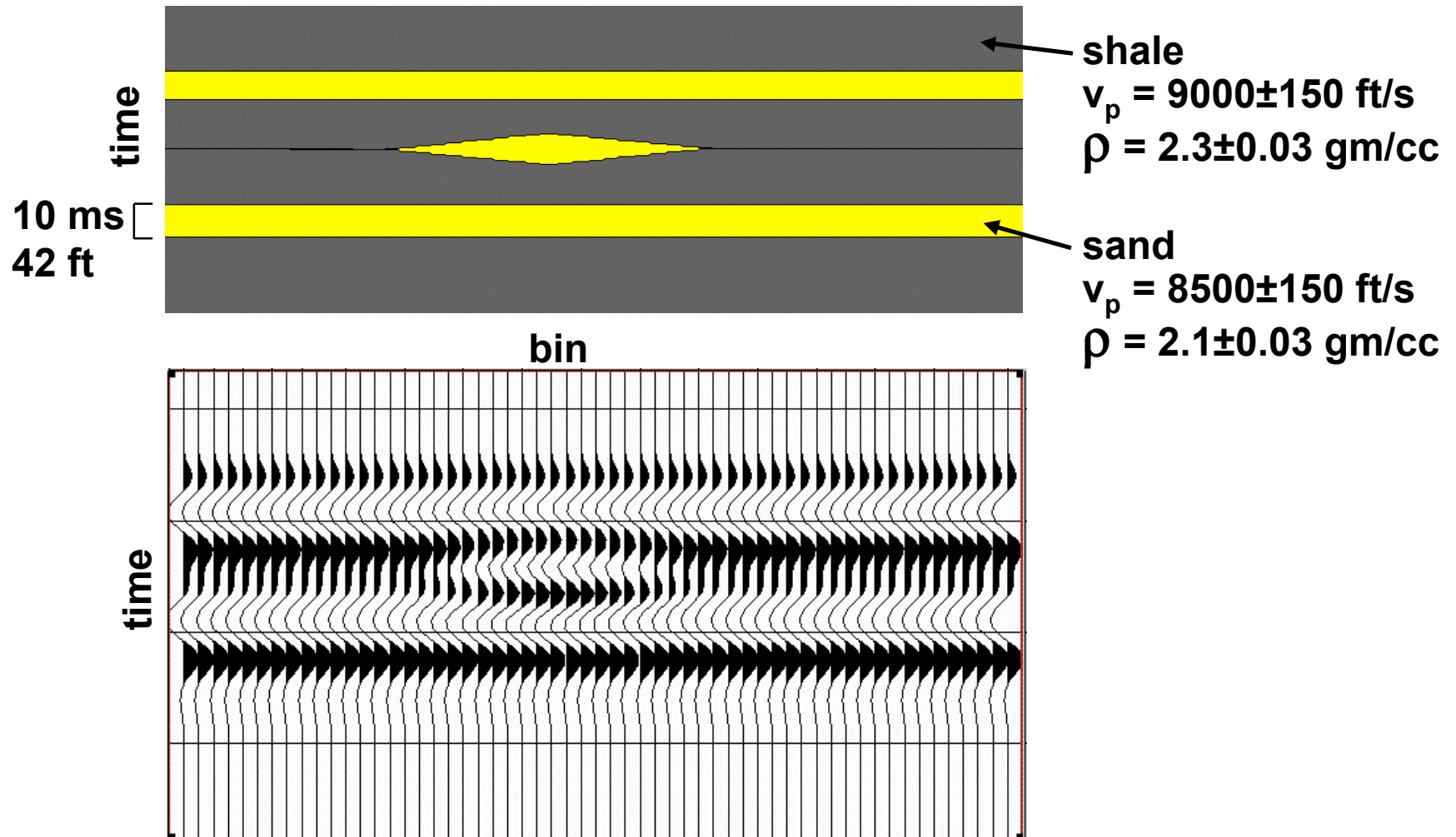


EXERCISE 2 (scenario testing lens model)

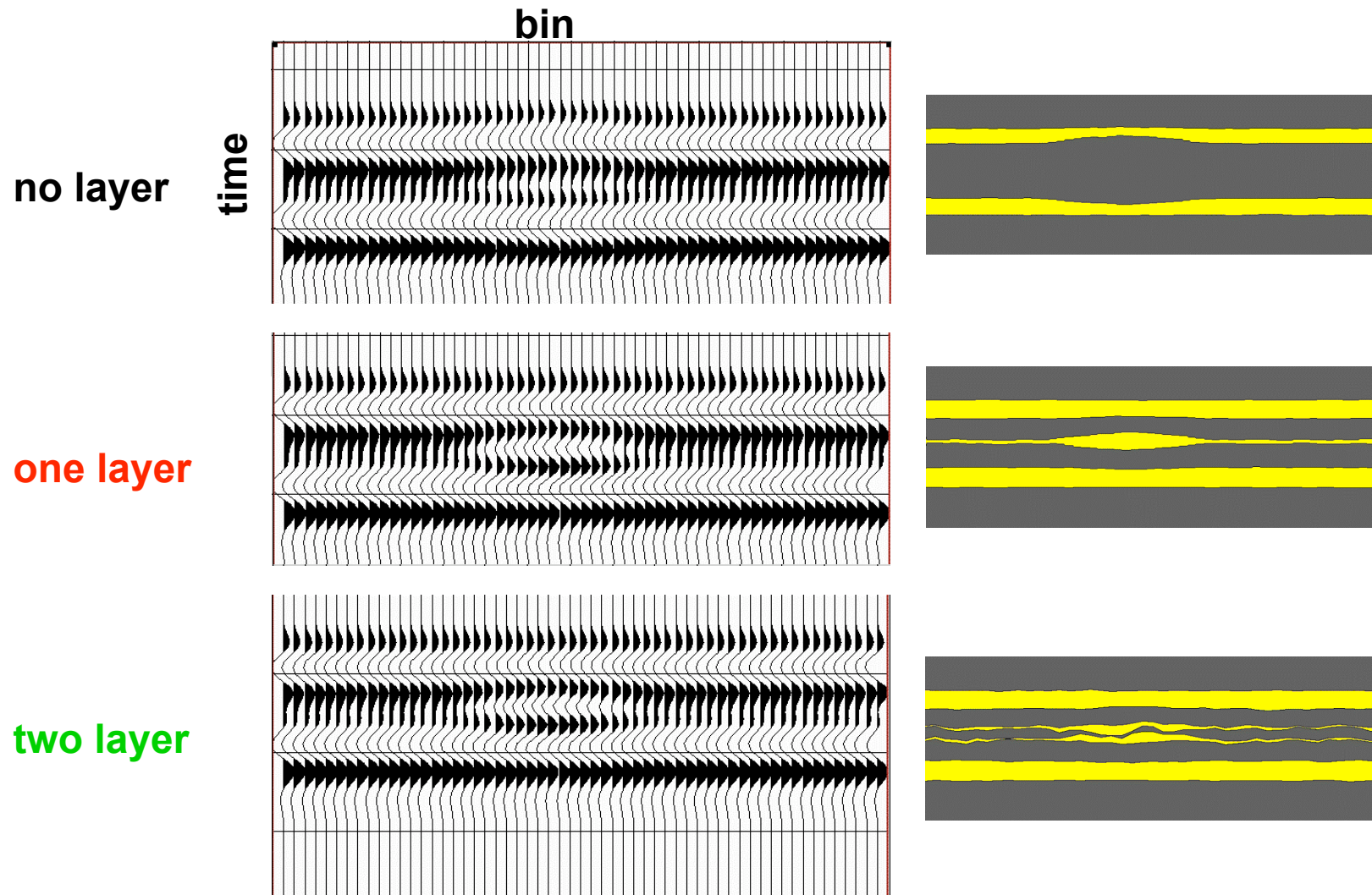


- **examine three initial DepSim models**
- **do three PROMISE+ inversions**
- **compare results and examine in DepSim**

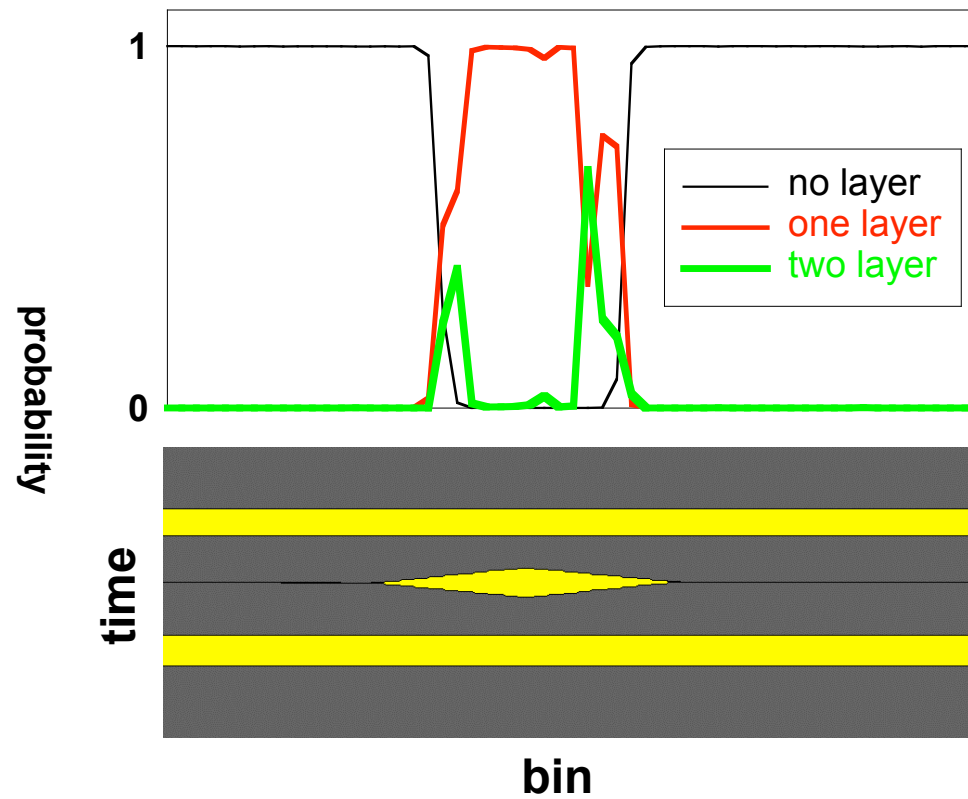
An example of scenario testing: a lens model



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



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

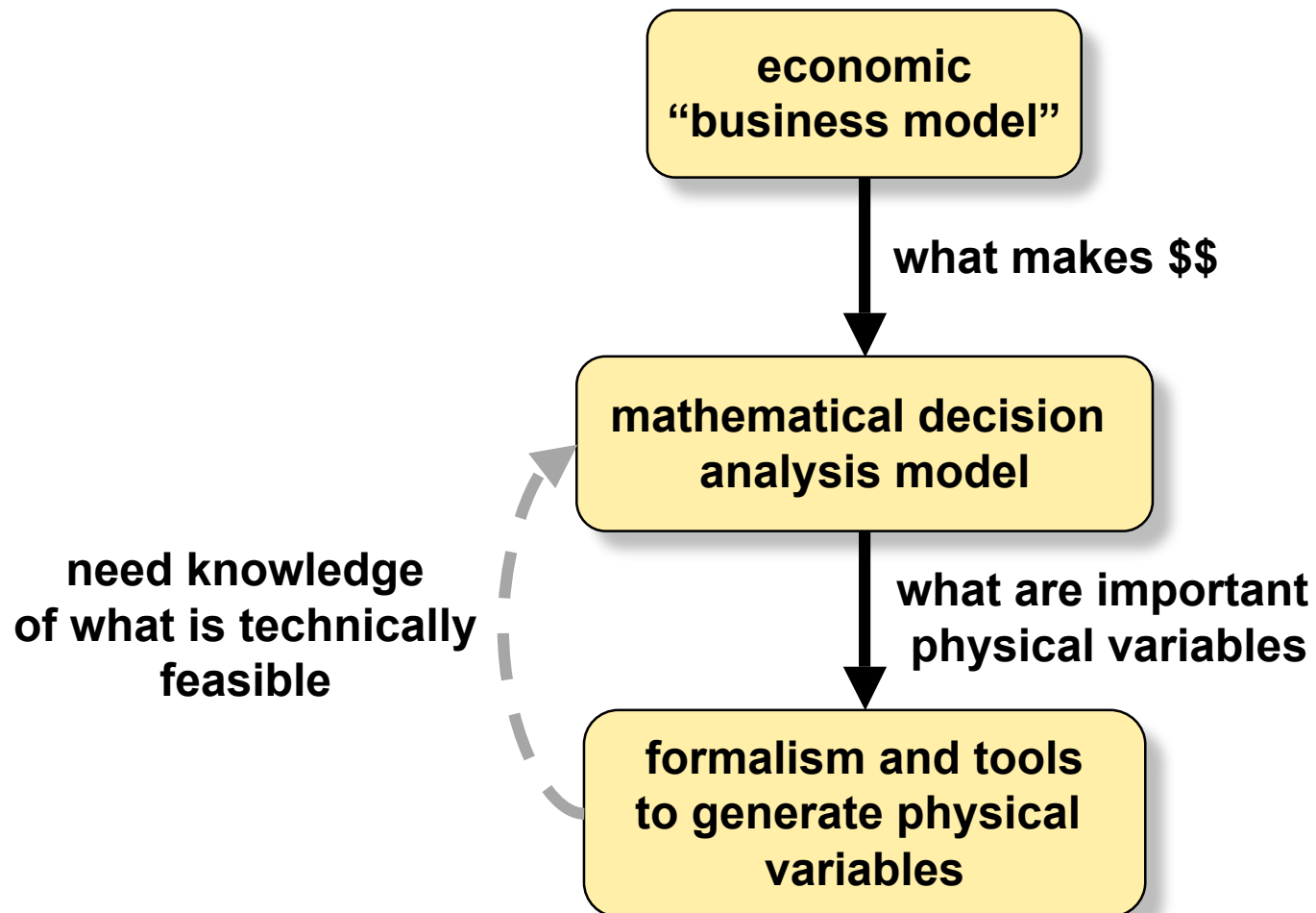
Michael Glinsky
Shell E&P Technology Co.

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

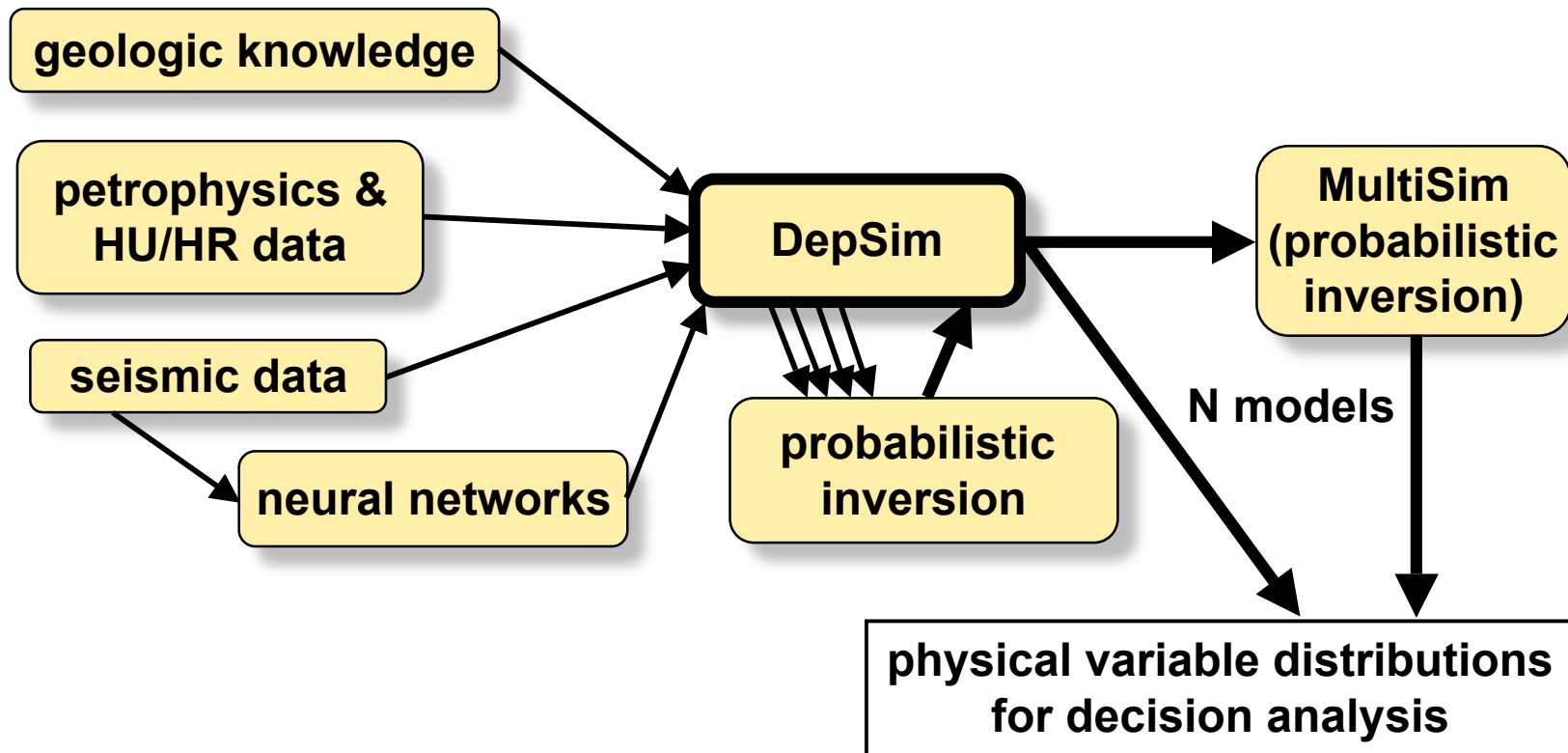


Approach to uncertainty - components



- **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
Shell E&P Technology Co.

Specification of model



$$\mathbf{m} = (\mathbf{g} , \mathbf{f} , \mathbf{\kappa})$$

= model

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

f = fluids in layers

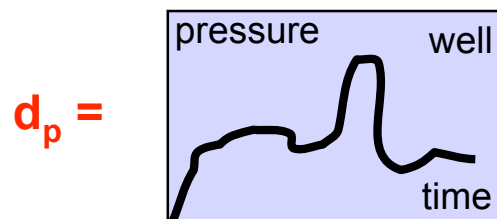
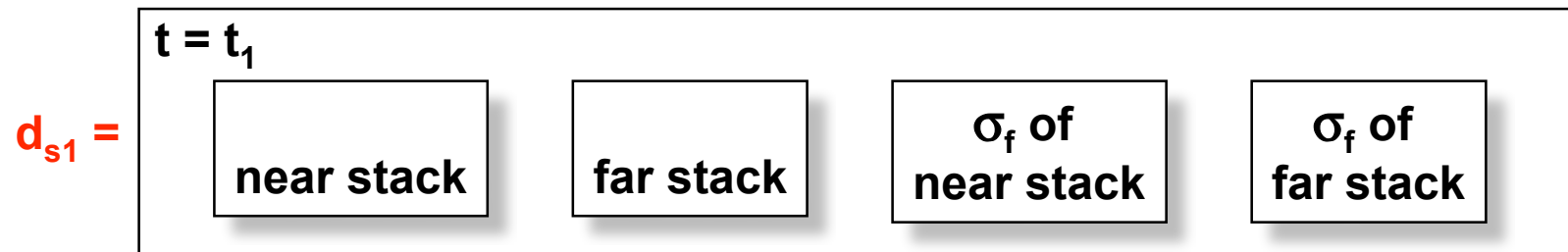
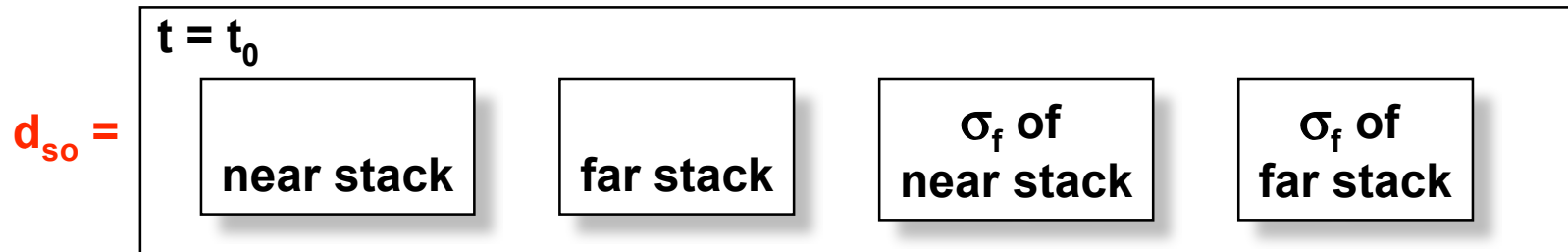
κ = production related properties not well correlated to seismic (e.g., permeability)

Data to match



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

= data



Fundamental equation



$$P(m | d) \sim P(m) P(d | m)$$

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

$$P(d | m) = q(s(m) - d)$$

q = noise spectrum

Iterative solution



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

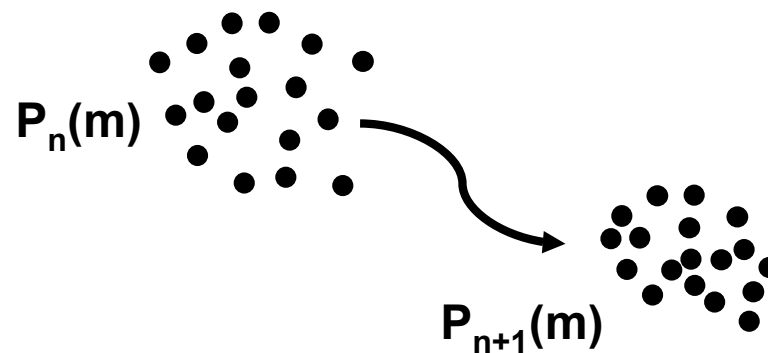
$$P_n(m) \rightarrow P(m | d) \quad \text{as } n \rightarrow \infty,$$

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

and

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

F = conjugate gradient or metropolis



A form for the noise distribution



$$q = q_{s_0}(s_s(g_o, f_o) - d_{s_0}) \quad q_{s_1}(s_s(g_1, f_1) - d_{s_1}) \\ q_f(s_f(g_o, f_o, \kappa) - f_1) \quad q_p(s_p(g_o, f_o, \kappa) - d_p)$$

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

$P_1(g_o, f_o, f_1) q_{s0} q_{s1}$

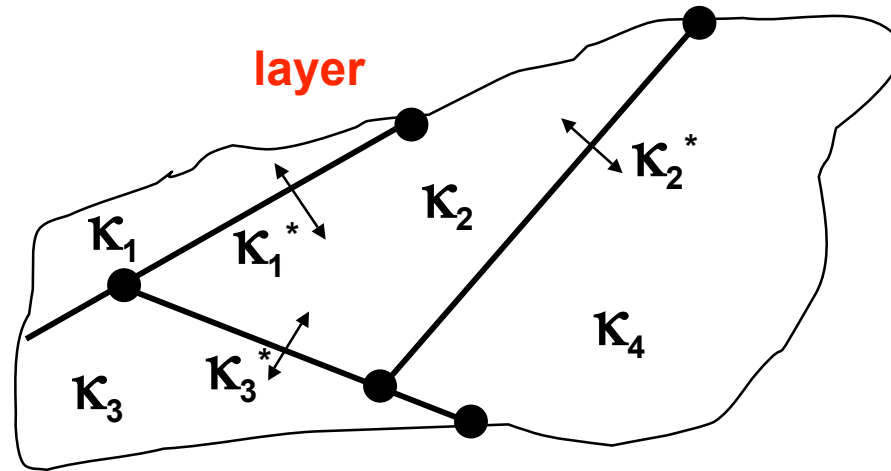
(conventional probabilistic seismic inversion)

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