



4D Inversion and Draugen

Michael Glinsky

Shell E&P Technology Co.

Klaas Koster

A.S. Norske Shell

Goals of this discussion



- **present**
 - a general formalism
 - a possible simplification
 - justification & issues
- **implementation**
 - saturation change
 - compaction effects (available 4/99)
 - integration with DepSim and LSF
- **role in analysis of Draugen 4D survey**

Specification of model



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

= model

g = geometric + seismic variables (e.g., v_{po} , v_{so} , N/G , ρ_o , ϕ_o)

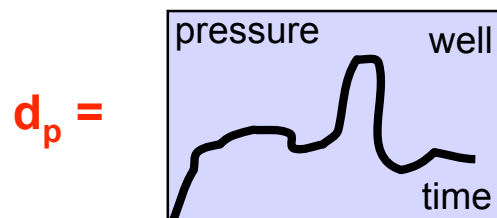
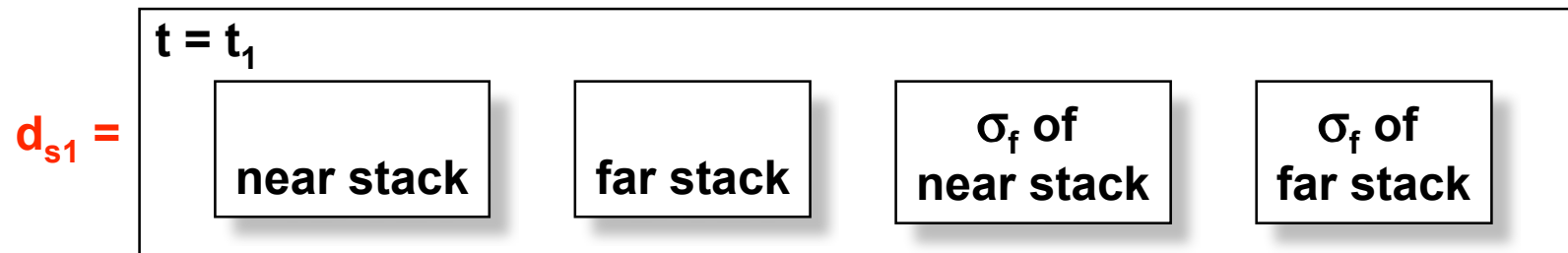
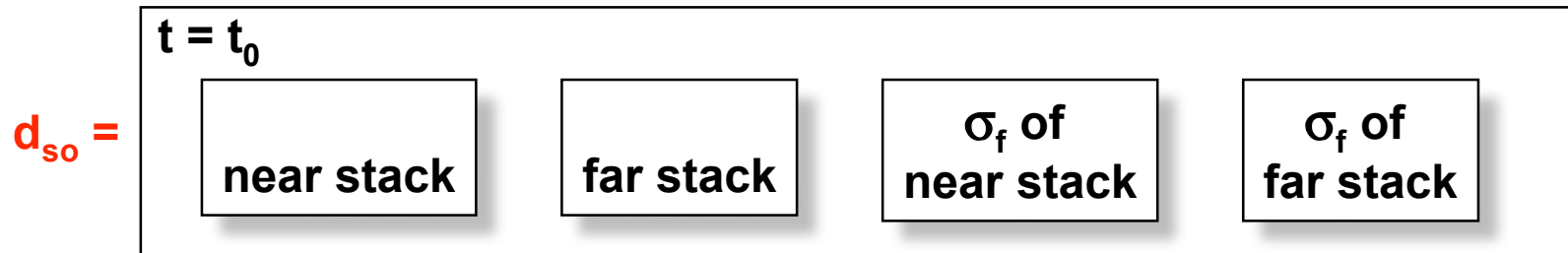
f = fluids in layers & effective stress

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

Data to match



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



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

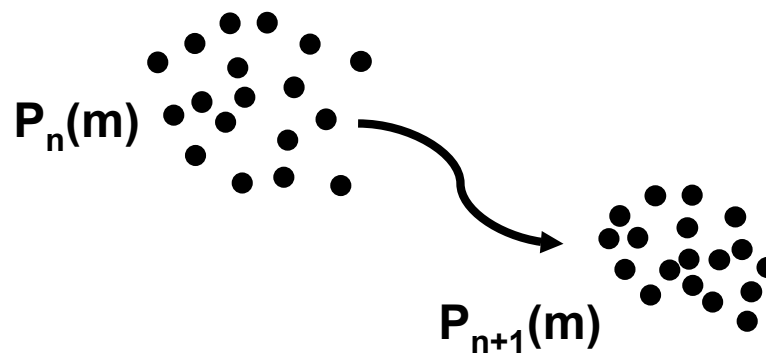
$$P_n(m) \rightarrow P(m | d) \quad \text{as } n \rightarrow \infty,$$

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

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 $g_1 = g_o$

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

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

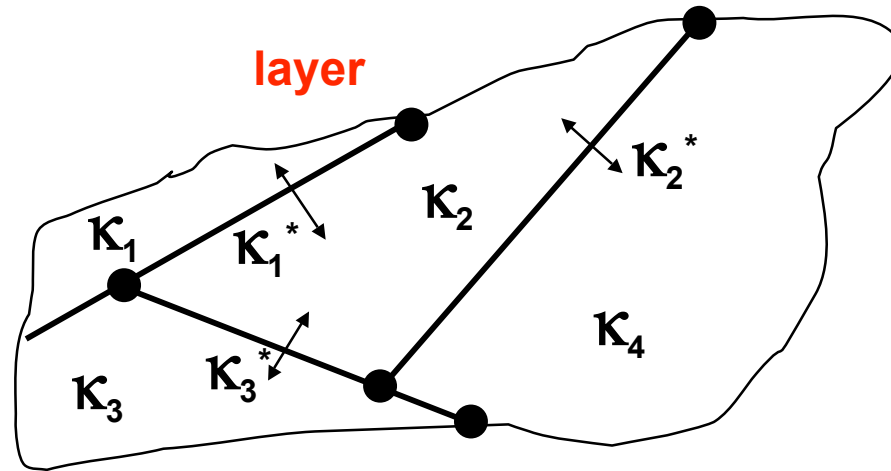
(conventional probabilistic seismic inversion)

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

Possible justifications for 4D inversion



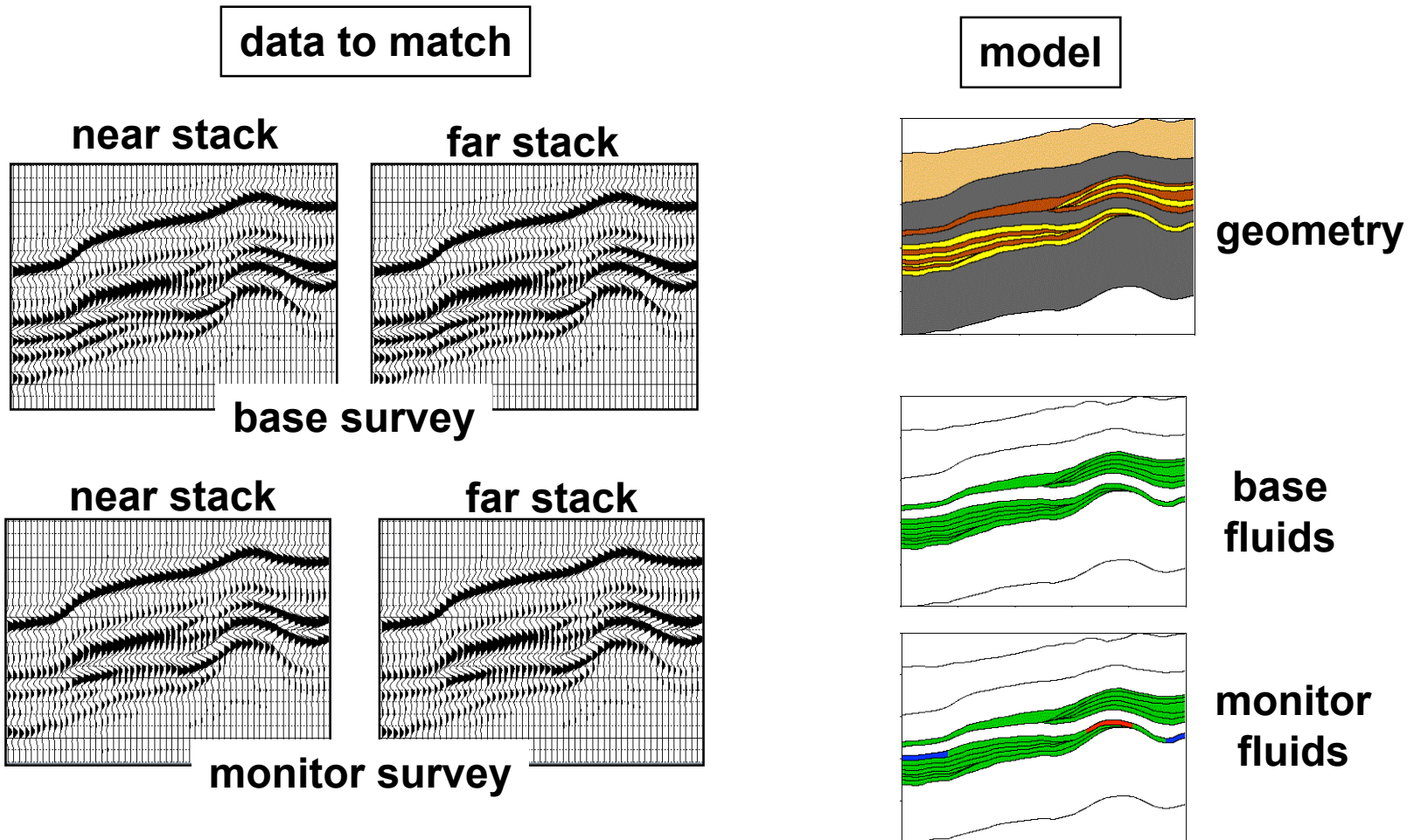
- **higher fidelity data preserved**
 - data equalization done via wavelet derivations
 - no degradation of higher fidelity data to match fidelity of earlier data
 - higher fidelity data and data with most contrast determines structure
 - earlier data determines original fluid saturations
- **significance of results calculated**
 - errors
 - probabilities

Major questions



- **should simplified approach be used?**
 - how independent are geophysical and reservoir parameters?
- **how should reservoir simulation be gridded and allowed to vary?**
- **others?**

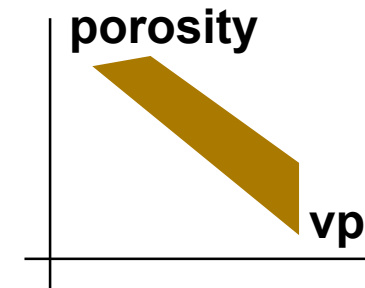
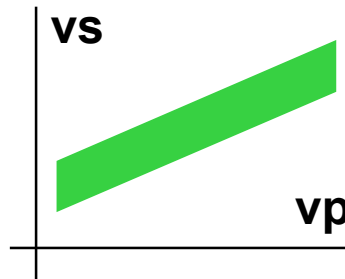
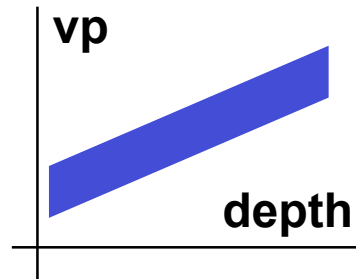
Formalism has been extended to 4D inversion



Start with GOM petrophysical end member trends

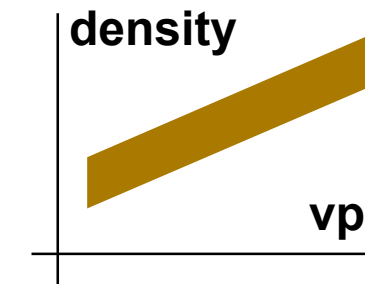
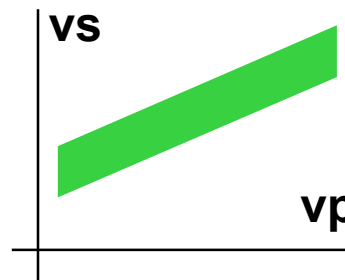
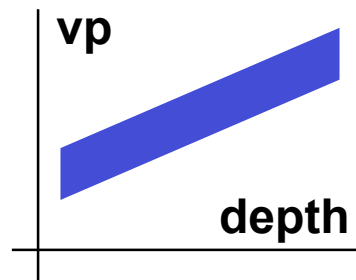


wet
sand



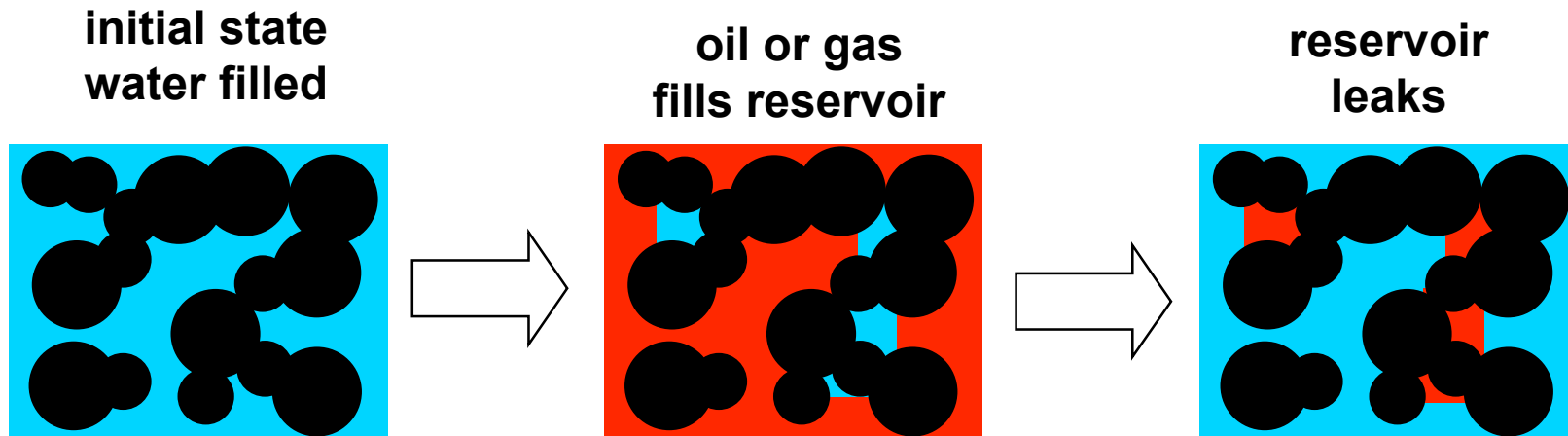
mix with net/gross $\pm \sigma$

mud-
stone



note: separate trend for each layer

Add two discrete cases of fluid fill



- **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

LIPOS_2_fluid menu



fluid_popup

Edit fluid

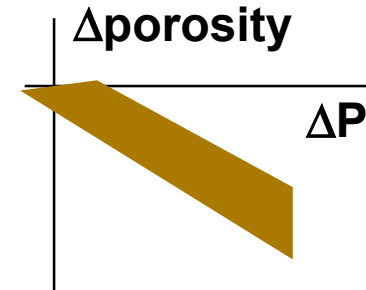
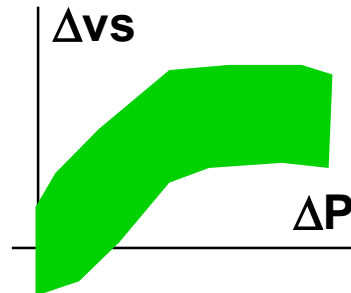
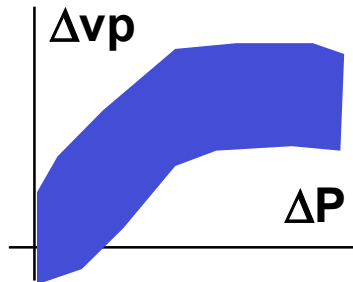
002: Top_F_Mudstone
005: LIPOS_2_fluid

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	▼ 0.85 ▲
residual_oil_prior2	▼ 0.03 ▲	gas_fraction	▼ 0.85 ▲
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 ▲

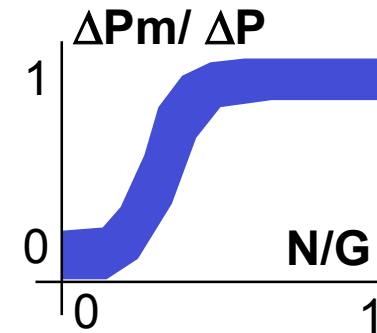
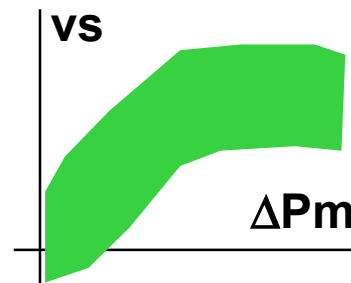
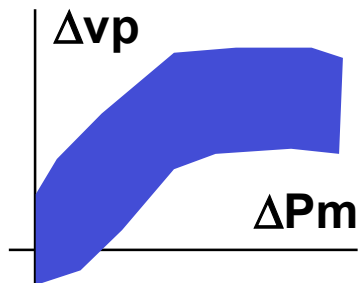
Add ROCKS effective stress dependence



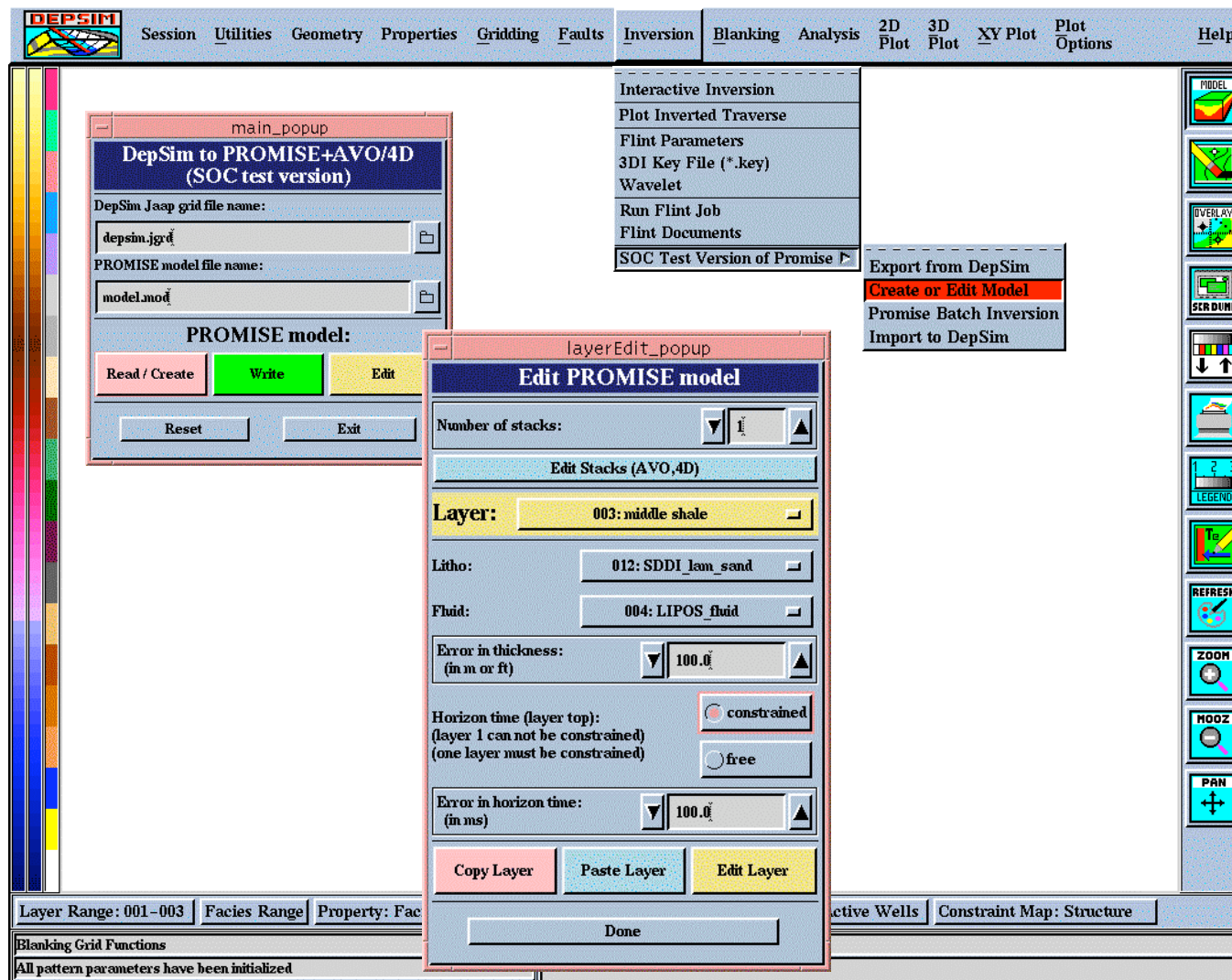
wet
sand



mud-
stone



Number of steps reduced and menus made more DepSim like



New interface for doing PROMISE inversion



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: deptsin.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

PROMISE inversion done on business relevant time scale



- **cycle time reduced to 8 calendar days (FRAM North Sea - Forties)**
 - DepSim model build
 - petrophysical analysis
 - wavelet derivation
 - PROMISE and FLINT inversion
- **1 day to invert 150x150 model with 7 layers (with LSF and 60 nodes)**

Interpretation 1



- Interpret key horizons
top Spekk, top and base reservoir
re-snap using existing horizons
- Extract loop attributes
- Generate recovery map
multi-linear regression of difference attributes

Quality assurance of seismic data sets.

Qualitative comparison between recovery maps derived from seismic and reservoir simulator.

At NSEP by Klaas + EPUP staff for 3 weeks.

Interpretation 1 - BTC



- **Match time-lapse seismic volumes
use Lamont software and more ...**
- **Generate difference volume**
- **Generate recovery map
optical stack through difference volume?**
- **Back to Interpretation 1**

Quality assurance of seismic data sets.

Qualitative comparison between recovery maps derived from seismic and reservoir simulator.

At BTC by Klaas + BTC staff for 4 weeks.

Interpretation 2



- **Set-up Promise prior model**
convert MoRes model to Promise input
- **Derive porosity, thickness and saturation**
invert time-lapse seismic data
- **Generate DepSim models**
use Promise posterior output

Static reservoir models consistent with seismic data.

Quantitative comparison between recovery maps derived from seismic and reservoir simulator.

At BTC by Klaas + BTC staff for 6 weeks.

Interpretation 3



- **Generate MoRes models
input DepSim models**
- **Calculate production histories
simulate fluid flow**
- **Update reservoir models
compare to actual production data**

Dynamic reservoir models consistent with seismic and production data.

At NSEP by EPUP staff + Klaas for 4 weeks.