4D Inversion and Draugen

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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

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

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

$t = t_0$

$d_{so} =$

near stack

far stack

σ_f of near stack

σ_f of far stack

$t = t_1$

$d_{s1} =$

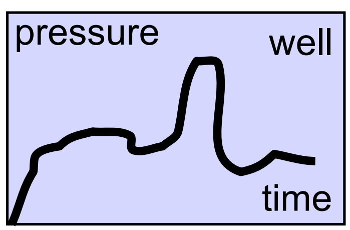
near stack

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)

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

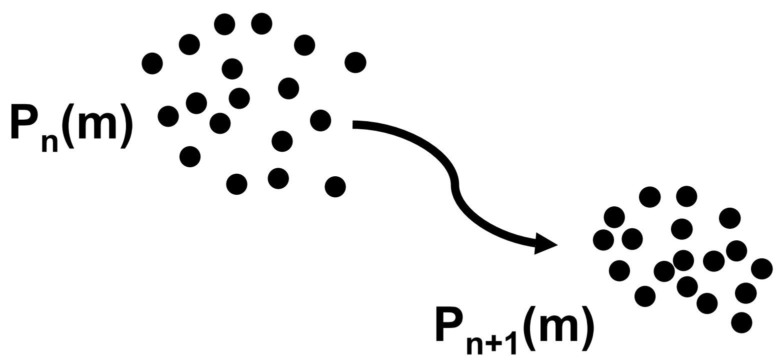
q = noise spectrum

Iterative solution

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

$$P_n(m) \rightarrow P(\, m \mid d \,) \quad \text{as} \quad n \rightarrow \infty,$$
$$P_0(m) = P(m),$$
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 $g_1=g_o$

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

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

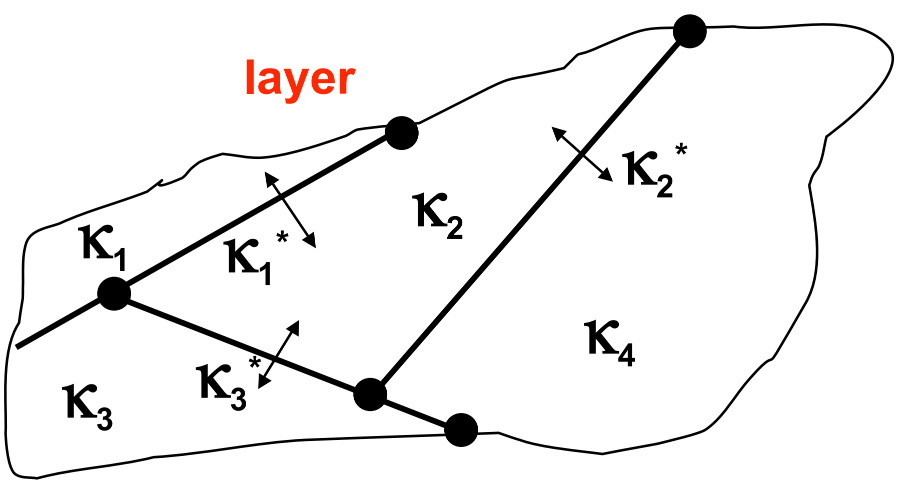
(conventional probabilistic seismic inversion)

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

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

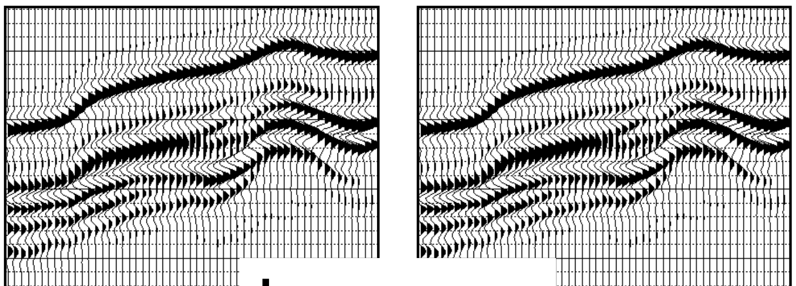
- **should simplified approach be used?**
  – how independent are geophysical and reservoir parameters?
- **how should reservoir simulation be gridded and allowed to vary?**
- **others?**

Formalism has been extended to 4D inversion

data to match

near stack

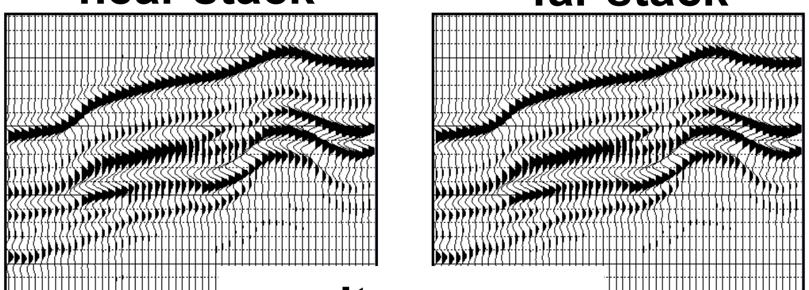
far stack



base survey

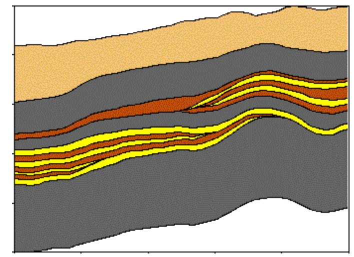
near stack

far stack

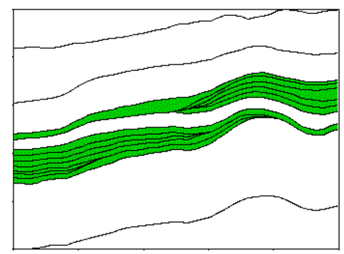


monitor survey

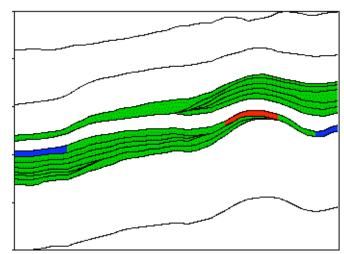
model



geometry

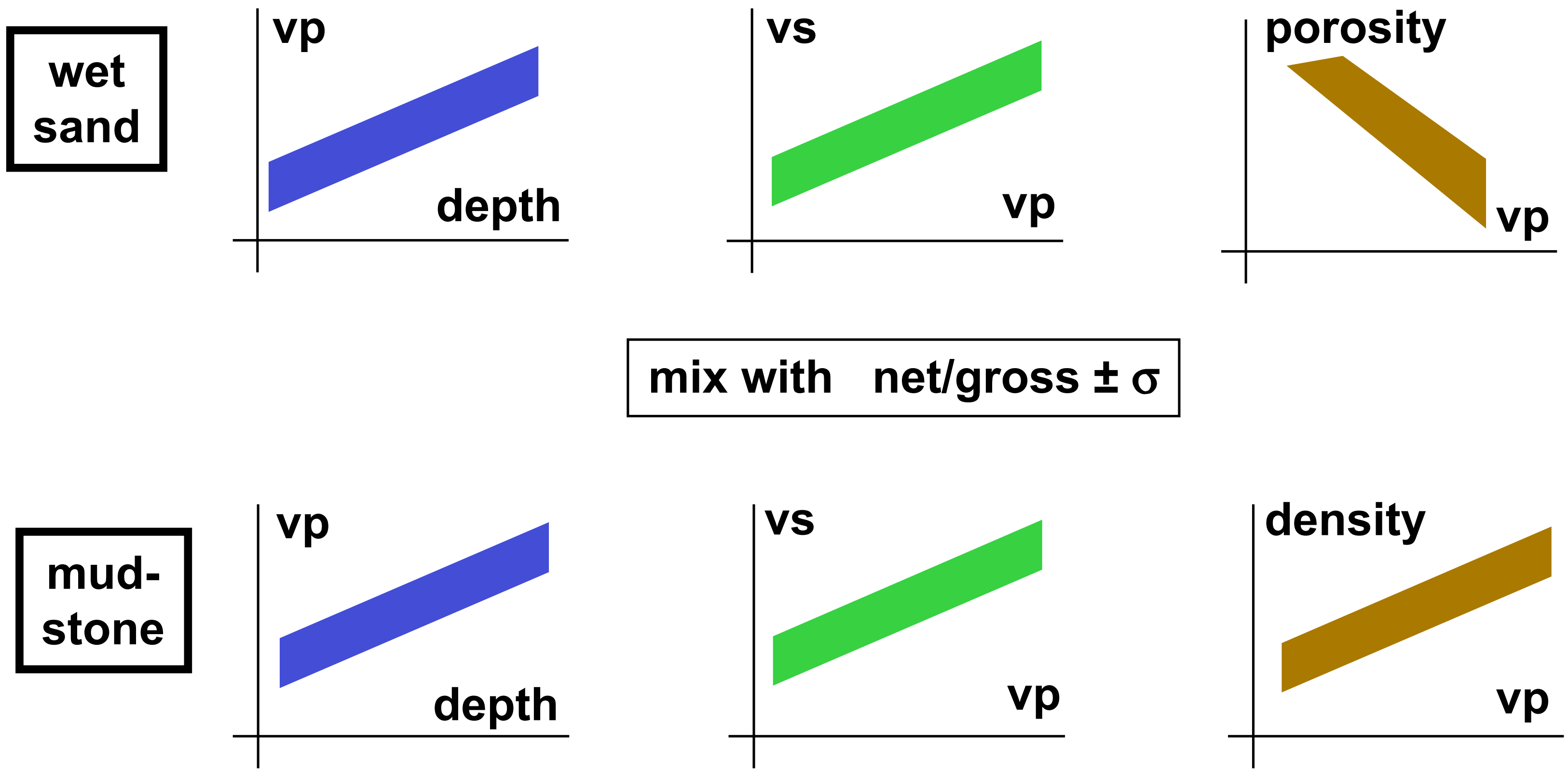


base
fluids



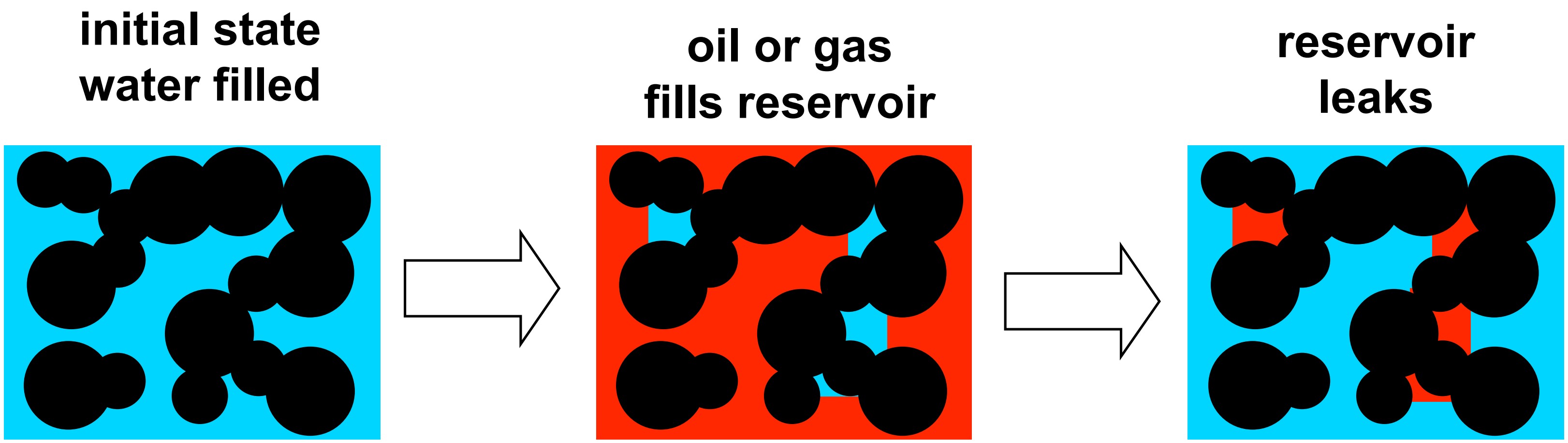
monitor
fluids

Start with GOM petrophysical end member trends



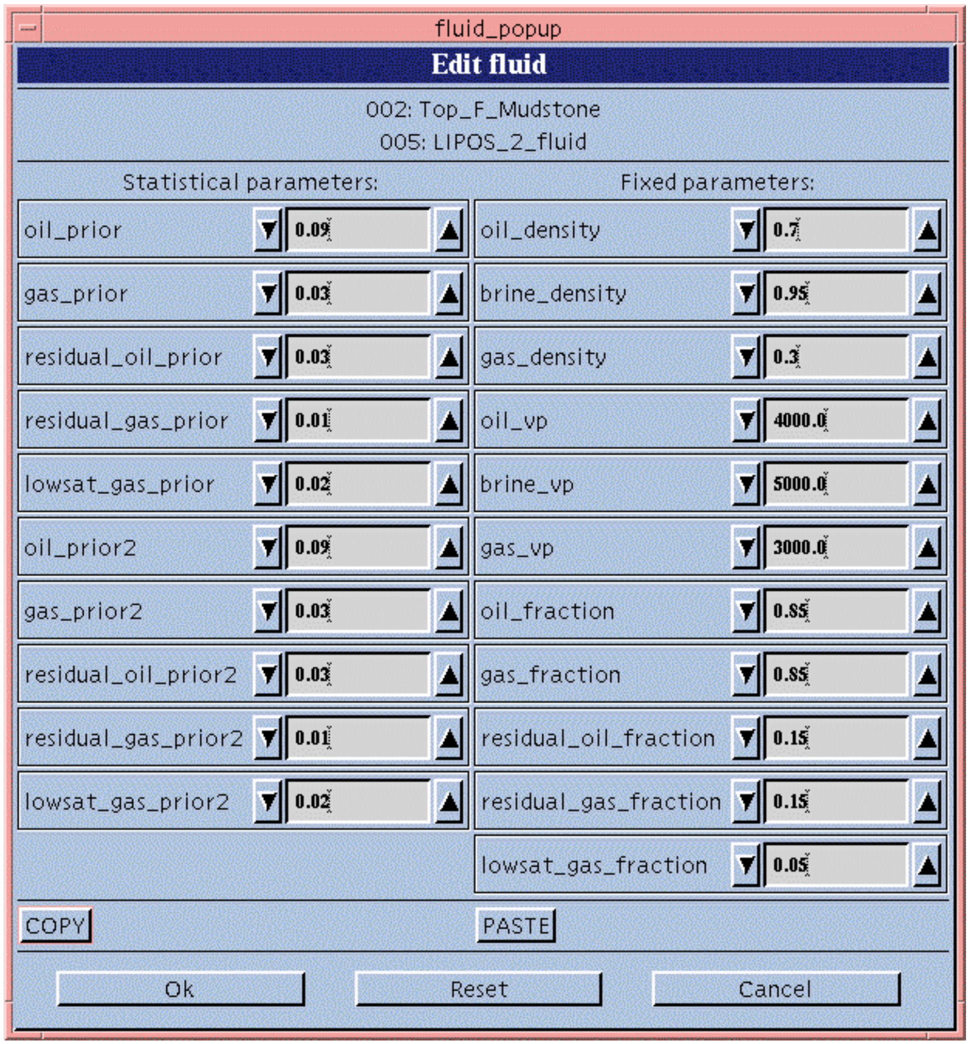
note: separate trend for each layer

Add two discrete cases of fluid fill



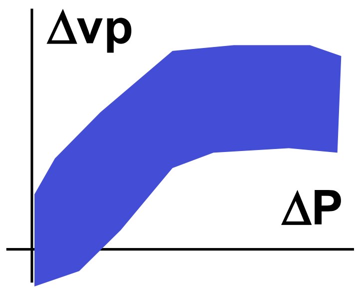
- **prior probability of each fluid fill case**
  - neural network fluid prediction
  - regional information (trap probability, leak probability, etc.)
- **posterior probability of each fluid fill case**
  - adds seismic AVO information

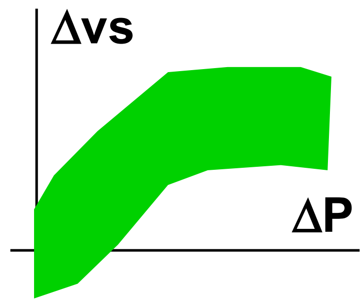
LIPOS_2_fluid menu

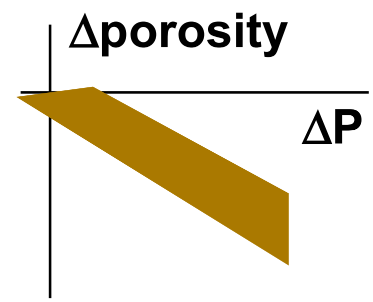


Add ROCKS effective stress dependence

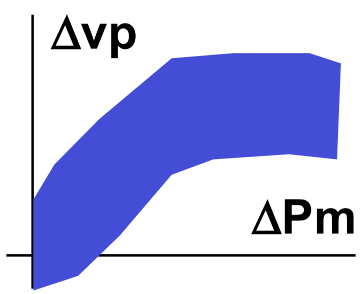
wet sand

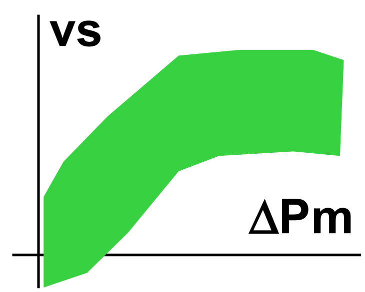


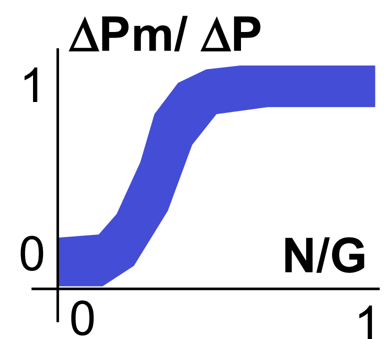




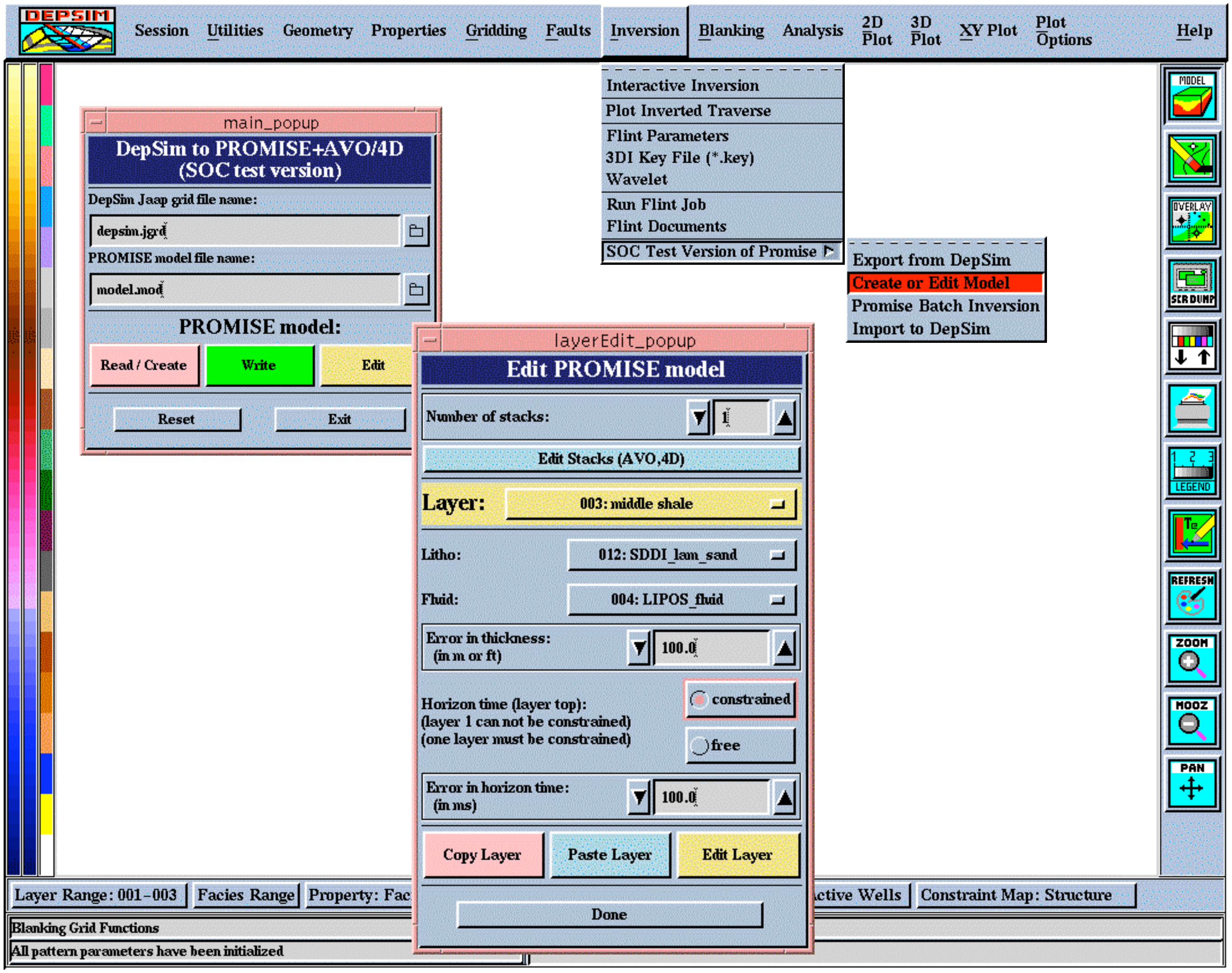
mud-stone



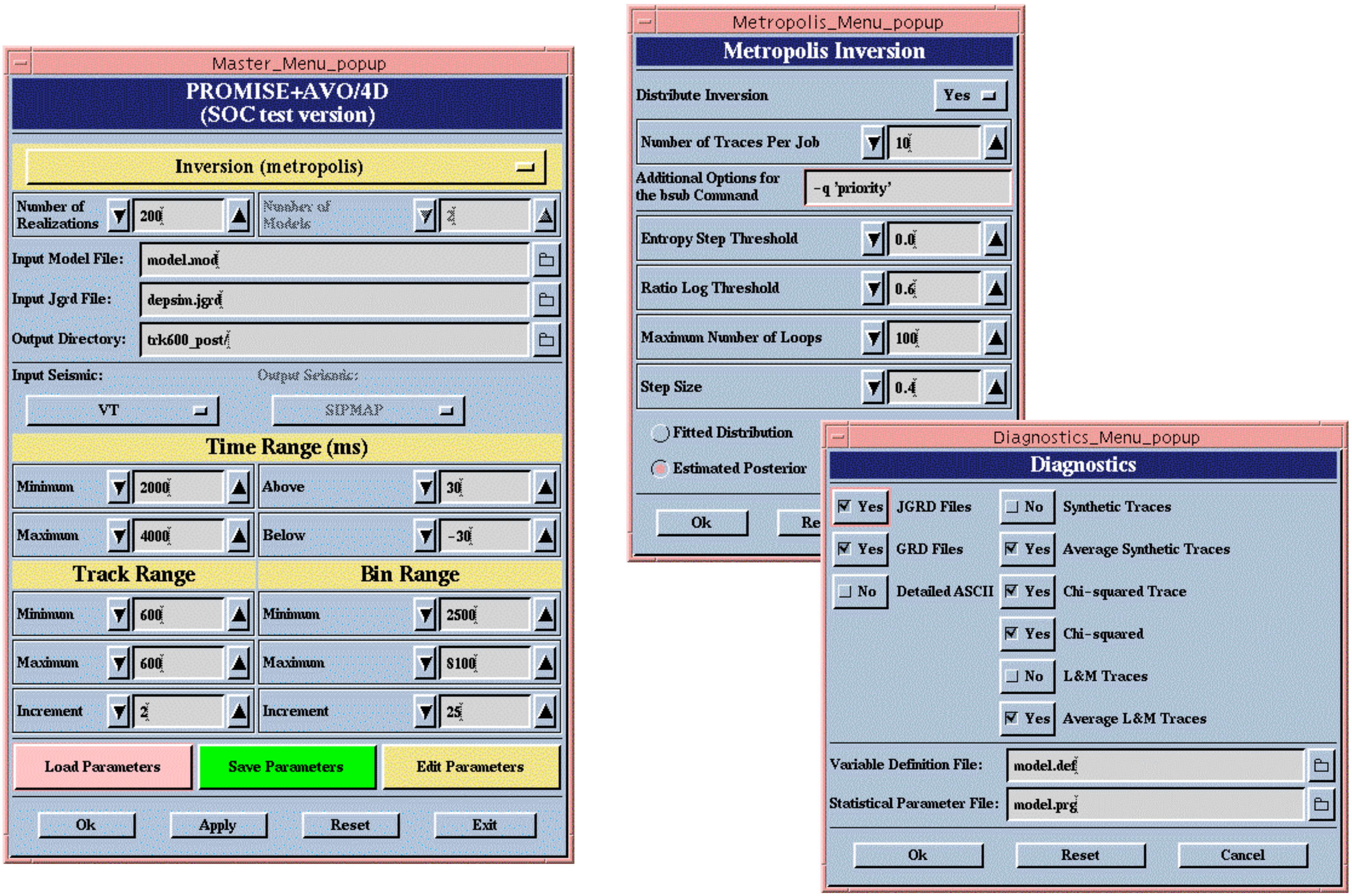




Number of steps reduced and menus made more DepSim like



New interface for doing PROMISE inversion



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.