An AVO PROMISE Application at Ram/Powell Field, Gulf of Mexico

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Everyone who has worked on Ram/Powell and added to our understanding of the field.

Outline

- Overview of the AVO implementation in PROMISE
- Background on Ram/Powell field and challenges
- Data gathering for inversion
- PROMISE inversion results
- Business impact

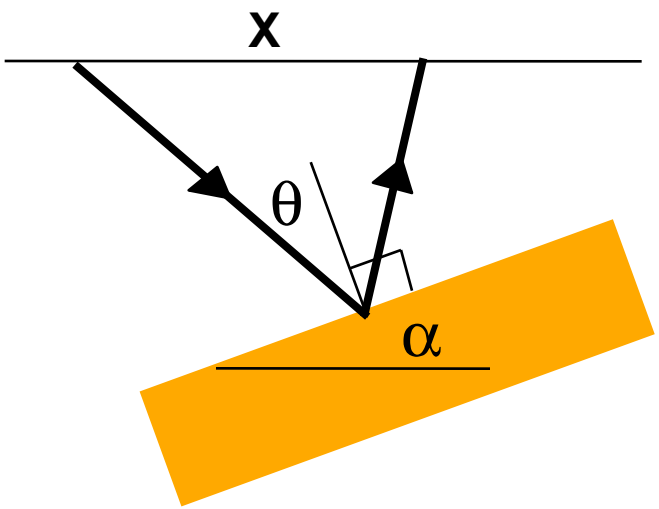
Advantages of AVO Inversion

- Multiple stacks provide additional information on rocks and fluids
- Determine probabilistic model that is consistent with all data
- Inversion removes tuning and interference
- More complicated models - not limited to standard 2-spike model
- Uncertainty estimate

Time Migration Approximation 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



θ = (v/V) (X / V T) + 3rd order

α = 0.5 (V dT/dx) + 3rd order

Equations 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

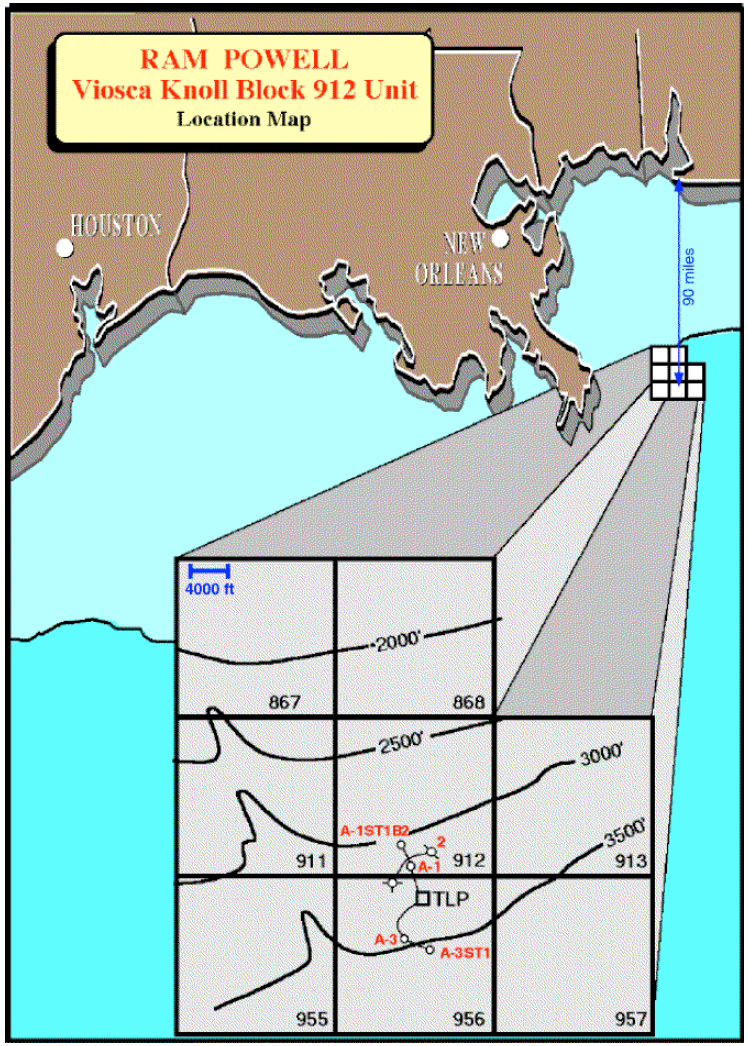
$$S(X) = 1 + \overbrace{0.5\,(X / V\,T)^2}^{\text{NMO}} + \overbrace{0.125\,(V\,dT/dx)^2}^{\text{dip}} + \text{4th order}$$

offset average wavelet & reflection coefficient

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

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

Ram/Powell Field



90 miles south of Mobile Bay

Discovery Well: 1985

First Production: 1997

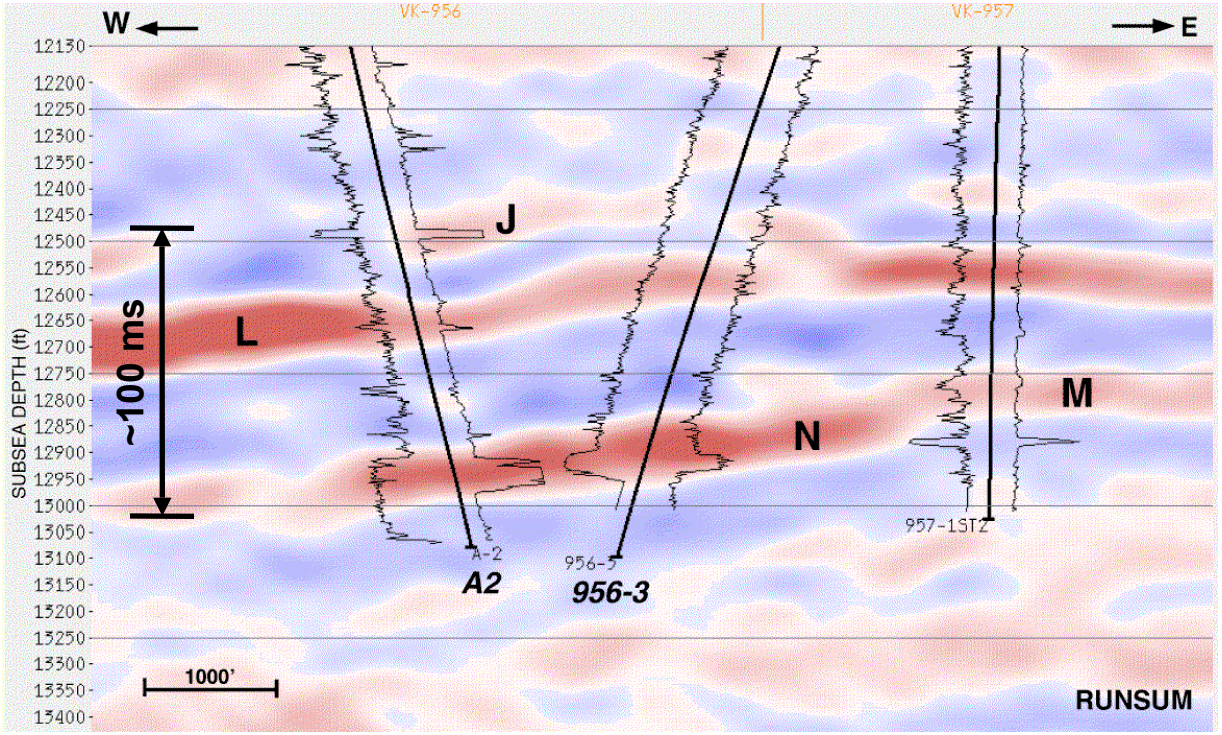
Water Depths: 2400-4000 ft.

Reserves: ~250 MMBEQ

Partnership:

Shell	**38%**
Exxon	**31%**
Amoco	**31%**

Ram/Powell Field



Stratigraphically trapped unconfined turbidites

J-sand	amalgamated sheet sand	Gas w/ oil rim
L-sand	channel levee sequence	Gas w/ oil rim
M-sand	amalgamated channel	Oil
N-sand	amalgamated channel	Oil

Tuning and interference

Data Gathering

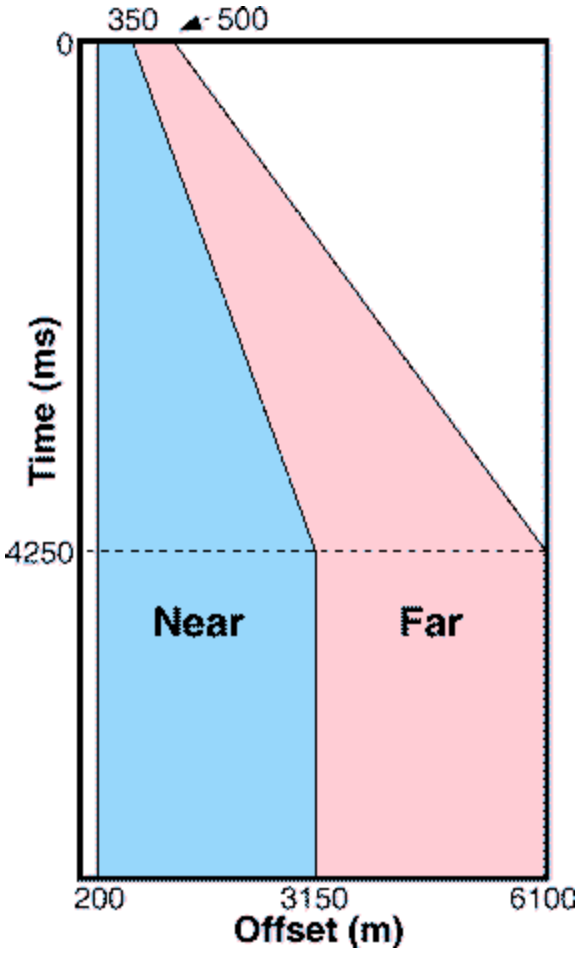
- Seismic data
- Wavelet derivation
- Rock and fluid properties
- DepSim model

Seismic Dataset

- Digicon 3D spec survey - long offset (6100 m)
- Reprocessed in-house for:
  - Better velocities
  - Better migration
  - AVO analysis
- 3D DMO points were input for:
  - PSI migration
  - Near and far stack followed by ONEPAS migration
- 0 dB/oct RUNSUM (i.e. 90° phase rolled RFC)

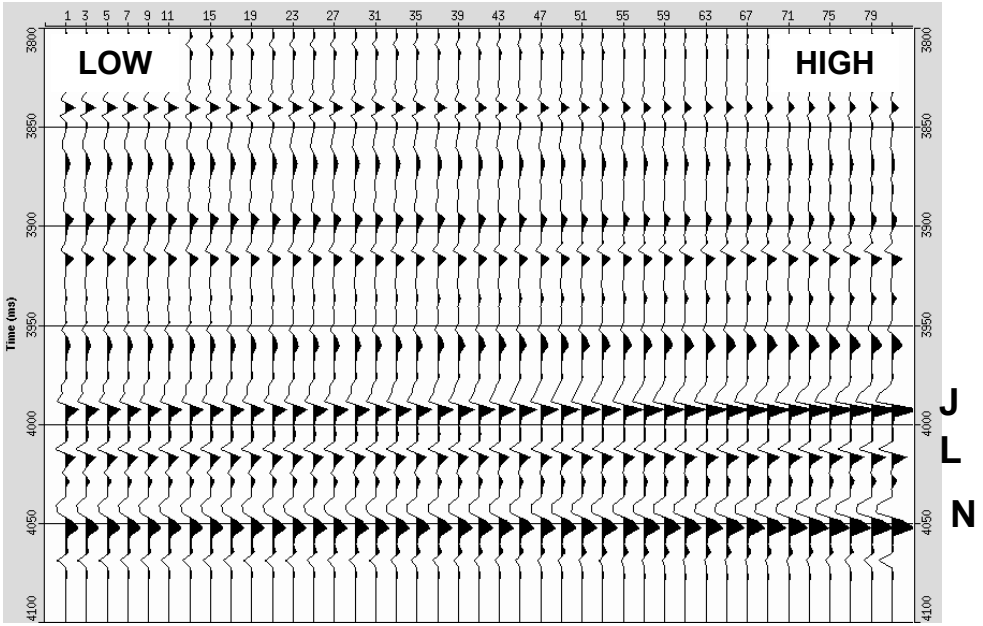
- Estimate of S/N on stacks
- If dip changes are significant - migration velocity and event dips

Wavelet Derivation



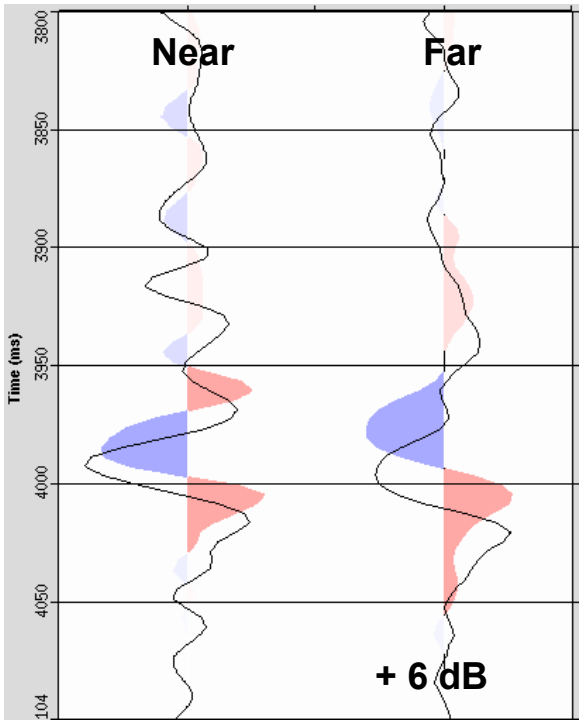
1. **Determine effective ray parameter (or effective angle) of stack**
2. **Generate elastic reflection logs from Vp, Vs, and Density**

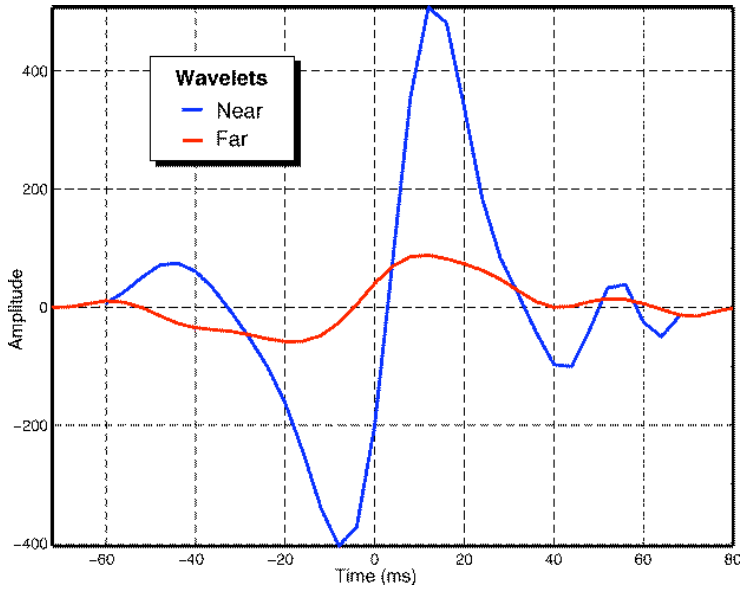
Effective Ray Parameter



Wavelet Derivation

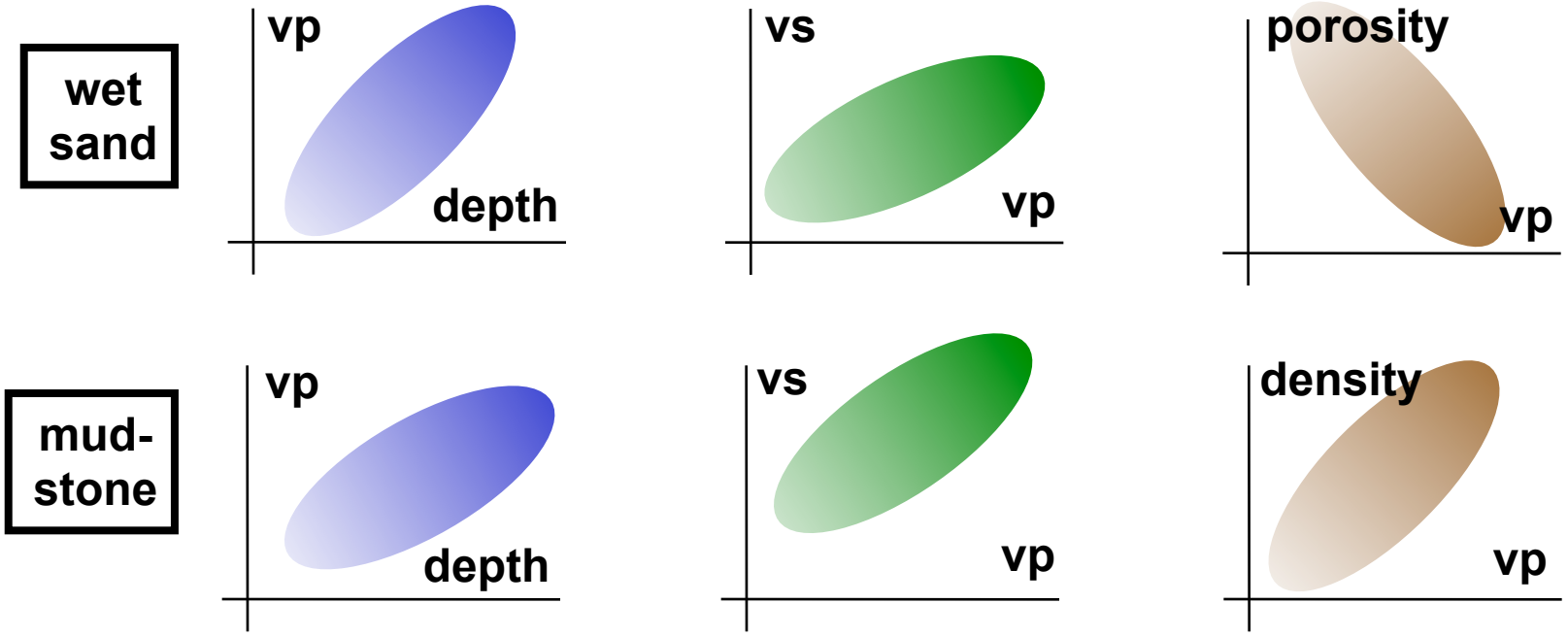
3. Derive wavelet for near stack and far stack
4. Scale wavelet appropriate for each stack





Wavelet includes scaling and stretch differences between the near and far stacks

Petrophysical Model - Rocks

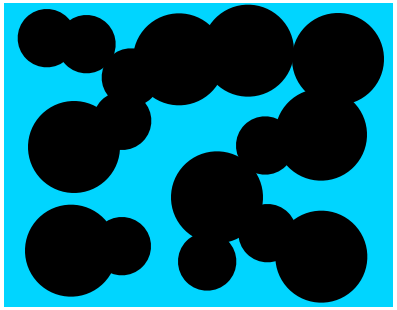


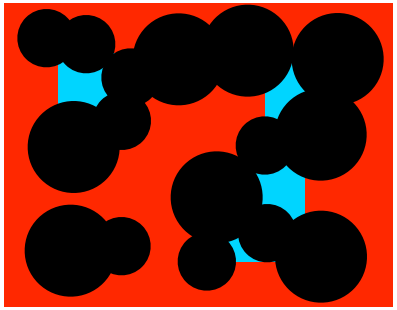
Laminated sands are modeled using Backus averaging

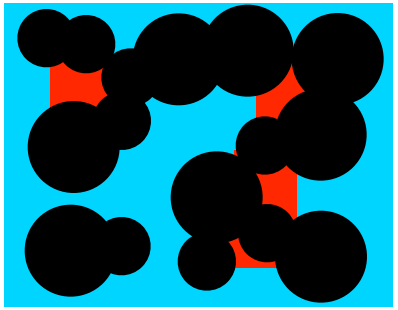
$$\rho = \rho_{sd}*NtG + \rho_m*(1-NtG)$$

$$1/(\rho*V^2) = NtG/(\rho_{sd}*V_{sd}^2) + (1-NtG)/(\rho_m*V_m^2)$$

Petrophysical Model - Discrete Fluid Cases

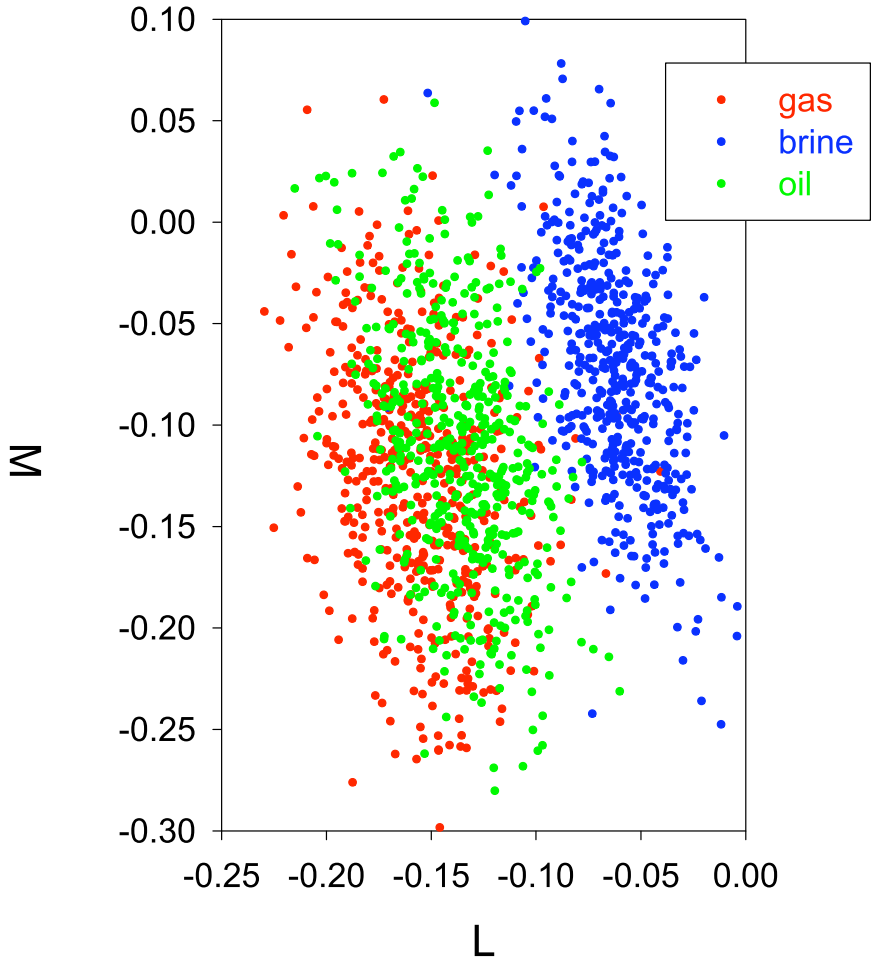






- **Use Gassmann equation for fluid substitution**
- **Assign prior probability of each fluid fill case**
  - neural network fluid prediction
  - regional information (trap probability, leak probability, etc.)
- **Examine posterior probability of each fluid fill case**
  - adds seismic AVO information

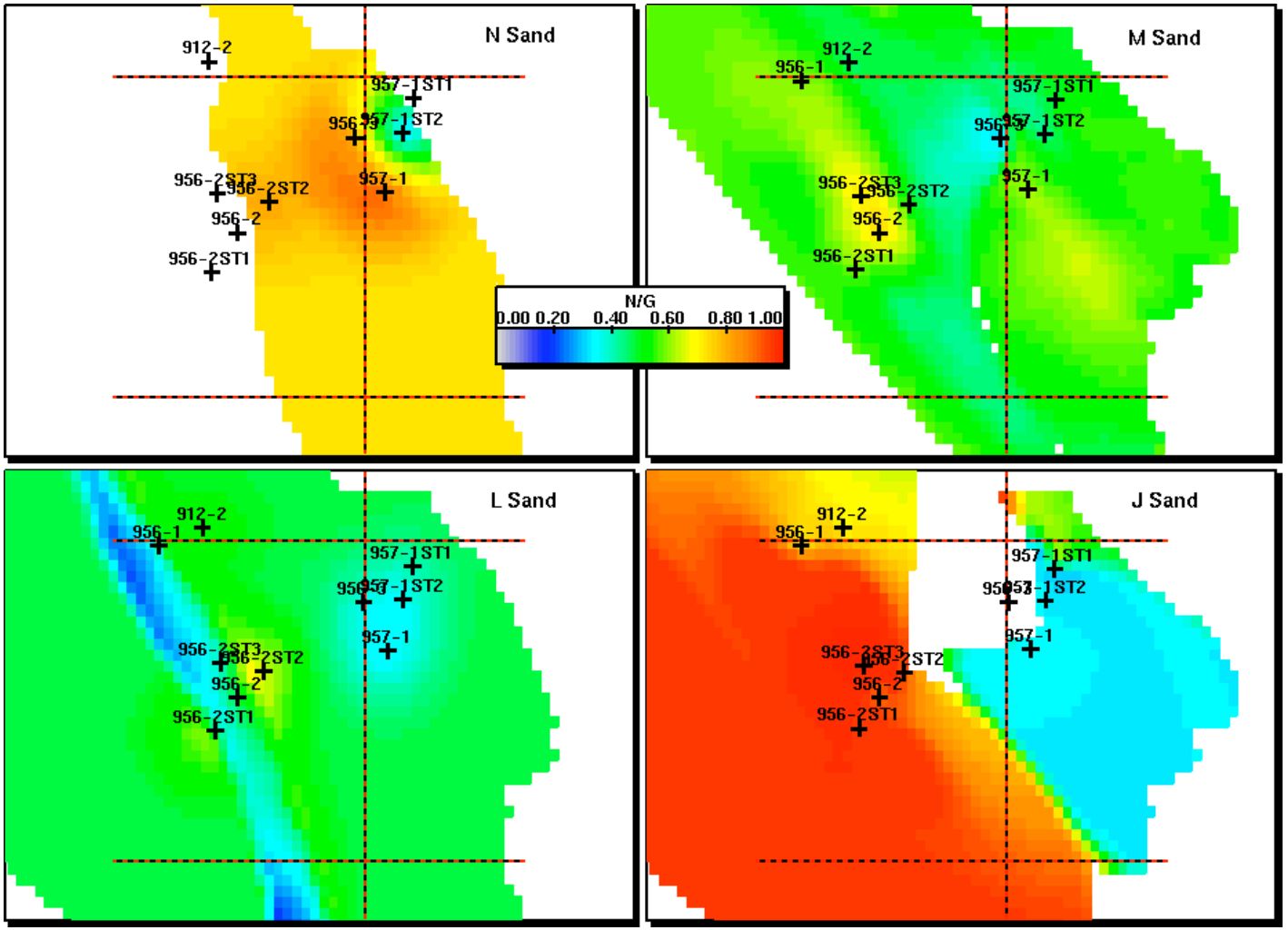
Fluid effects in L-M space



Brine is distinct for oil and gas

It will be difficult to distinguish oil from gas

DepSim Model



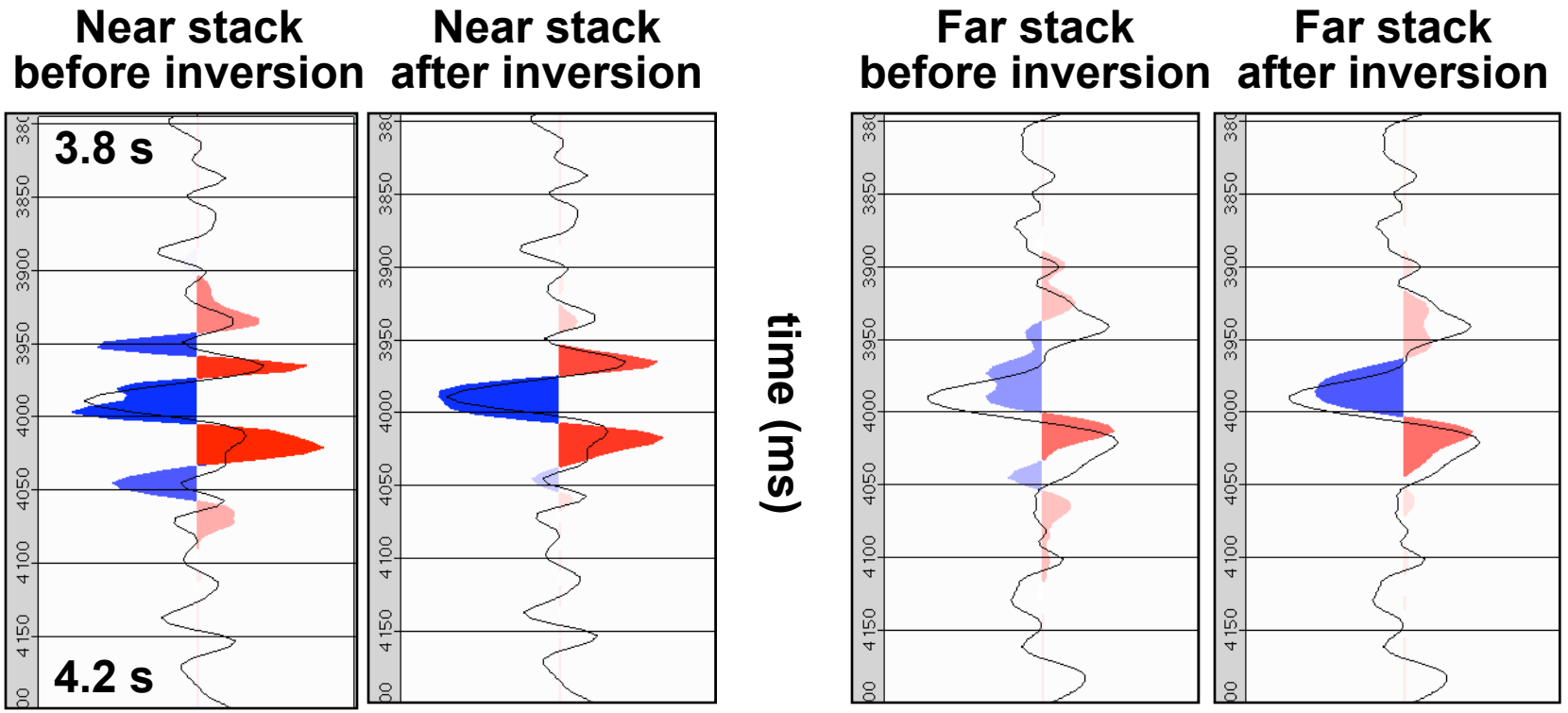
Constrained to thickness and N/G at all appraisal wells

PROMISE Inversion

- Used Metropolis algorithm
- Refreshed priors at each trace
- Used LSF (load sharing facility) linking 7 Ultra2 workstations to reduce cycle time for an inversion run from 2+ weeks to 2 days
- Inverted at DepSim model resolution (every 5th track and bin - ~400 ft. grid)

- Key parameters
  - 200 realizations (58 stochastic variables)
  - standard deviation for N/G was ± 10%
  - prior fluid probabilities were set equal for oil, gas, or water
  - standard deviation for thickness was ~1/3 the average thickness

PROMISE Inversion at Well (912-2)

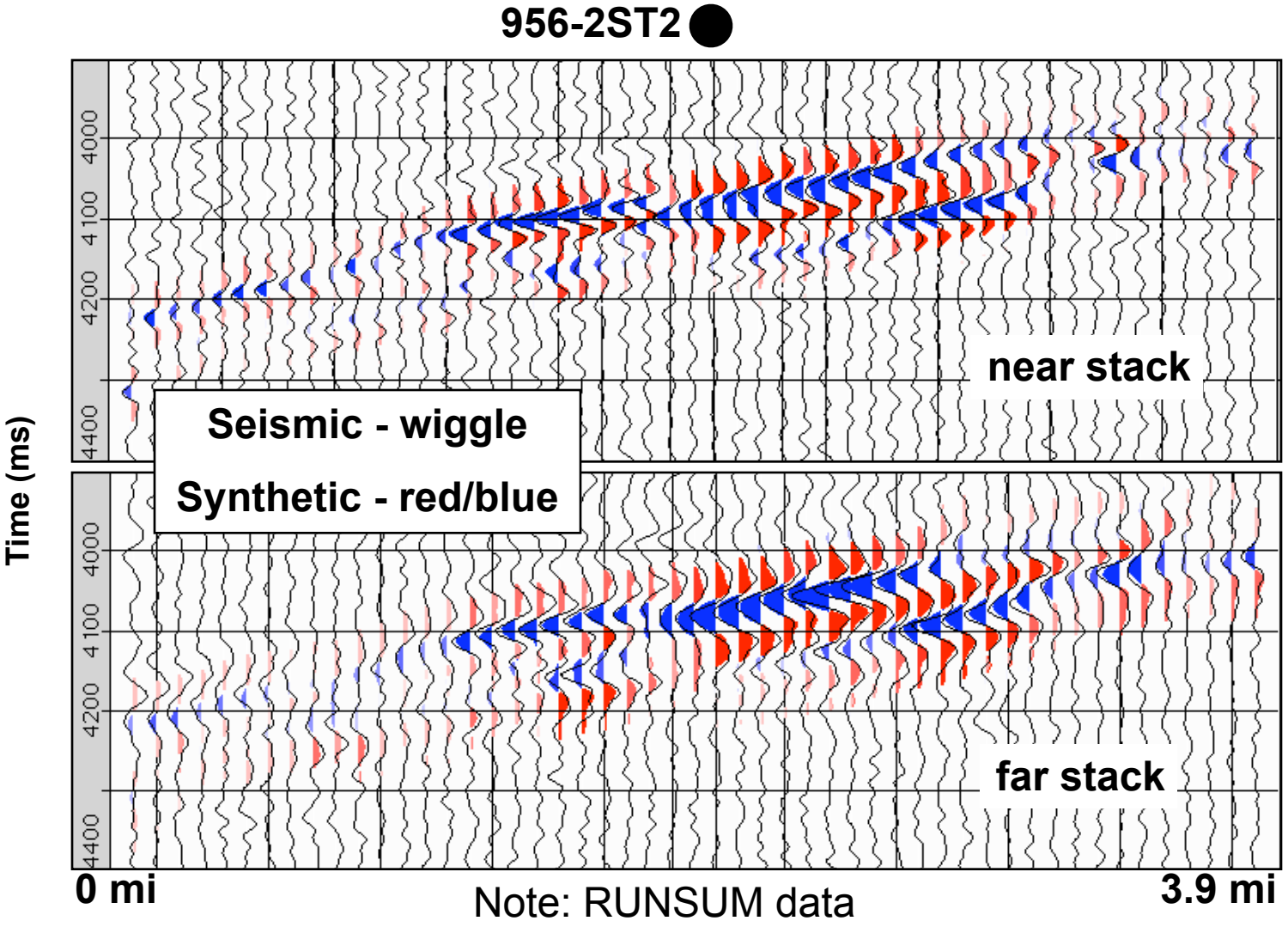


Seismic - wiggle

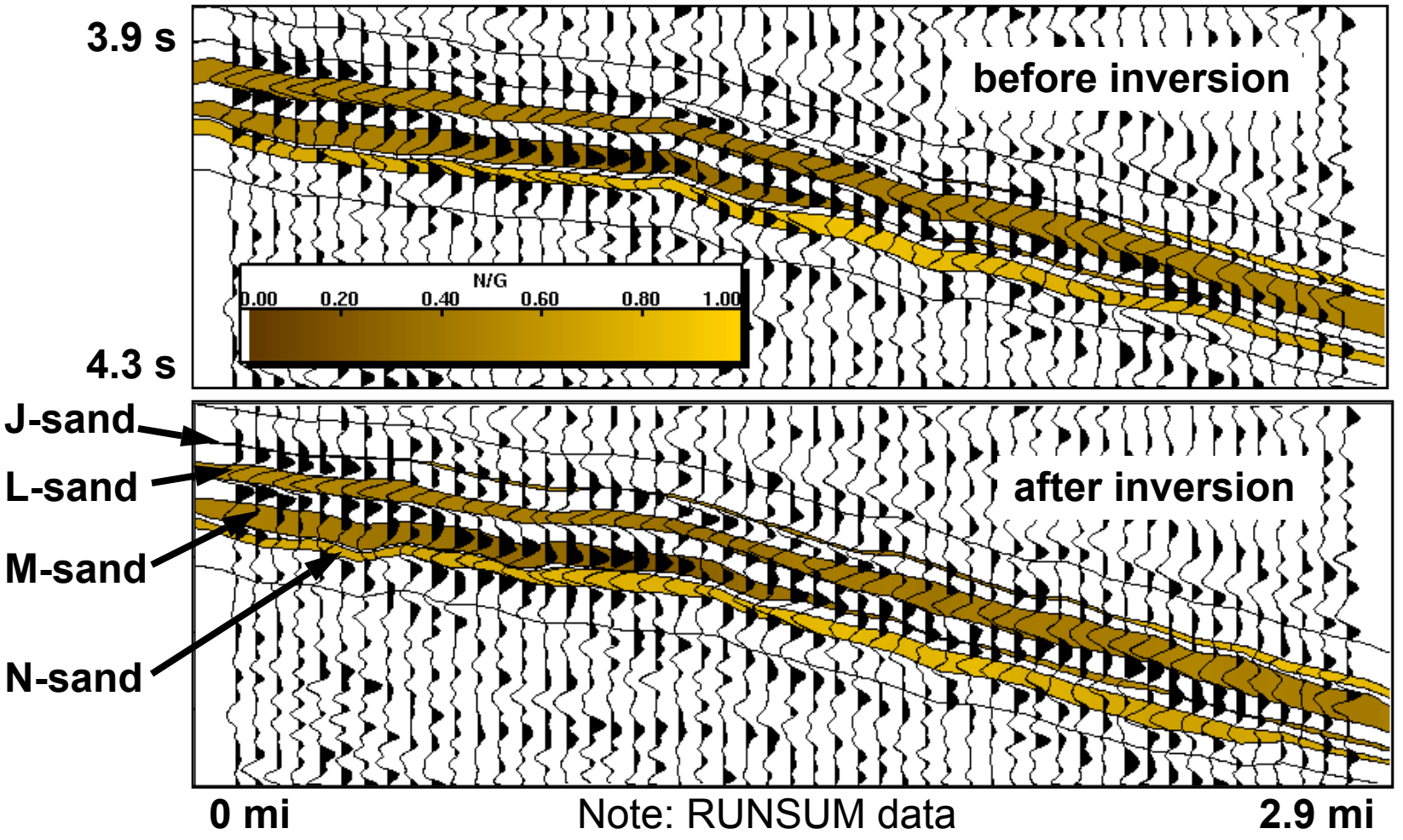
Synthetic - red/blue

Note: RUNSUM data

Data Comparison after Inversion

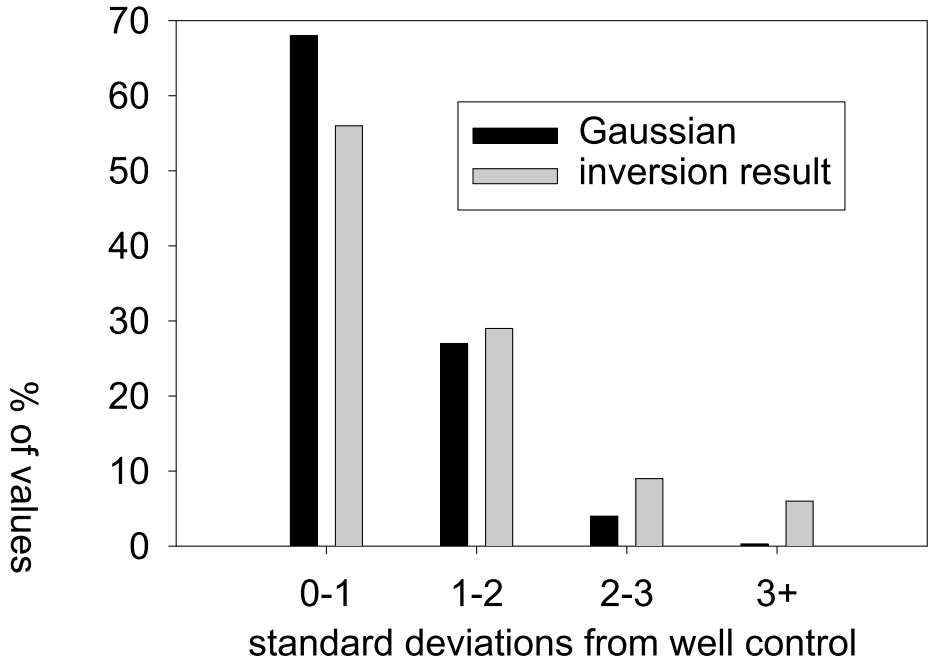


PROMISE Inversion - P50 model on Near Stack



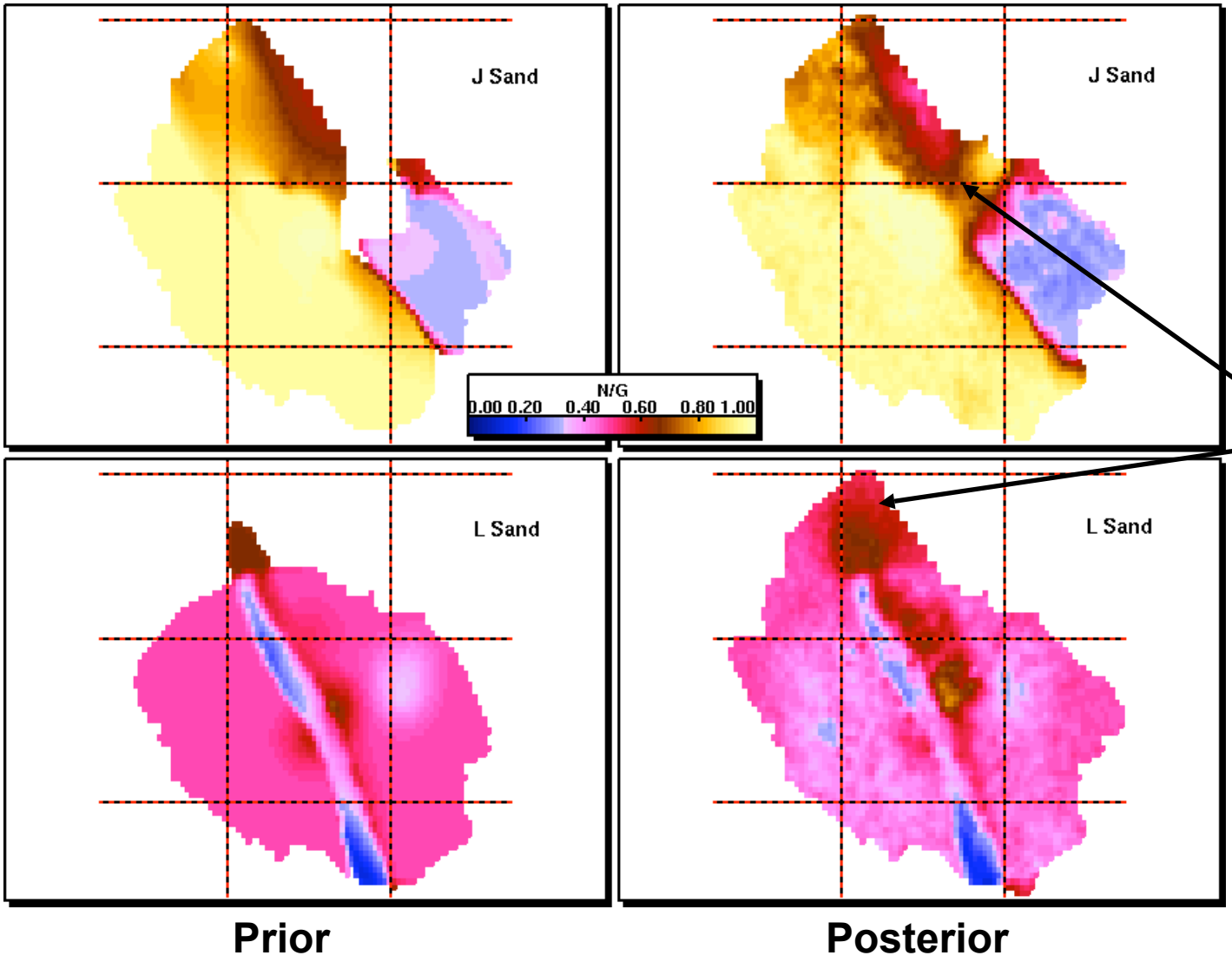
Comparison to Well Control

- **41 penetrations in the 4 reservoir levels**
- **Thickness, N/G and fluid for each sand penetration**
- **146 values to match**



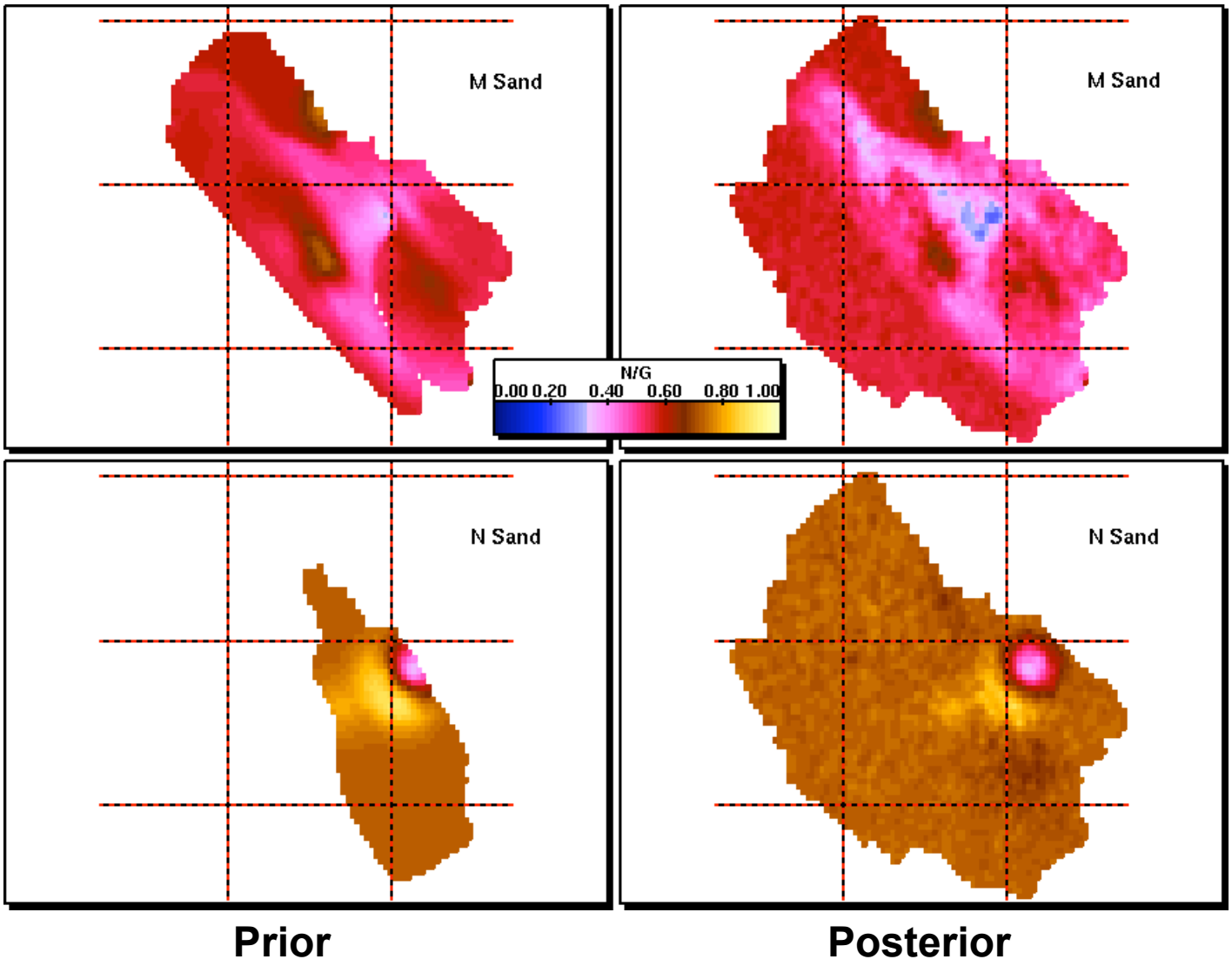
Large number of 3+ in J-sand (prior model in error)

N/G changes with Inversion - J & L

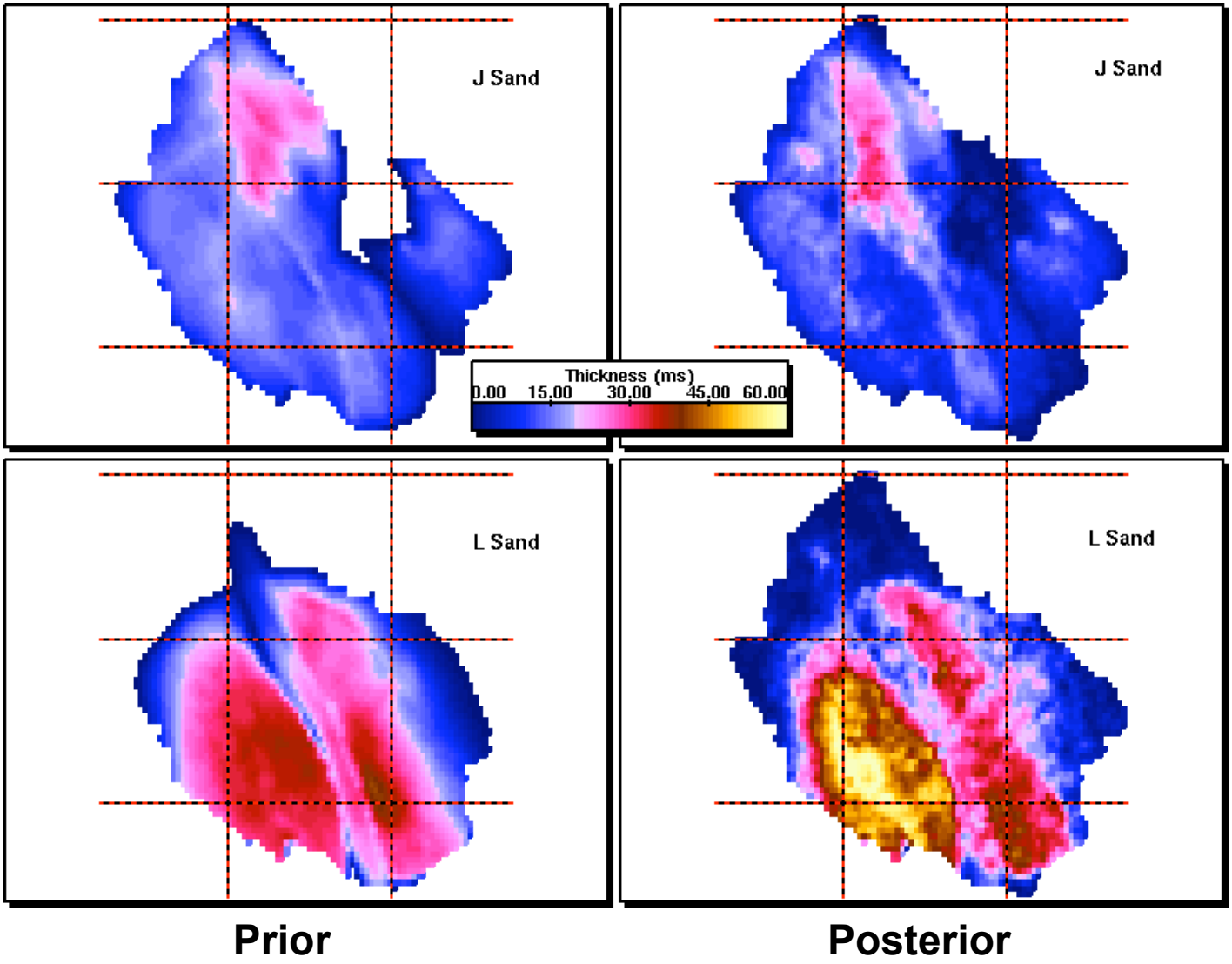


Promise expands layers to full inversion area

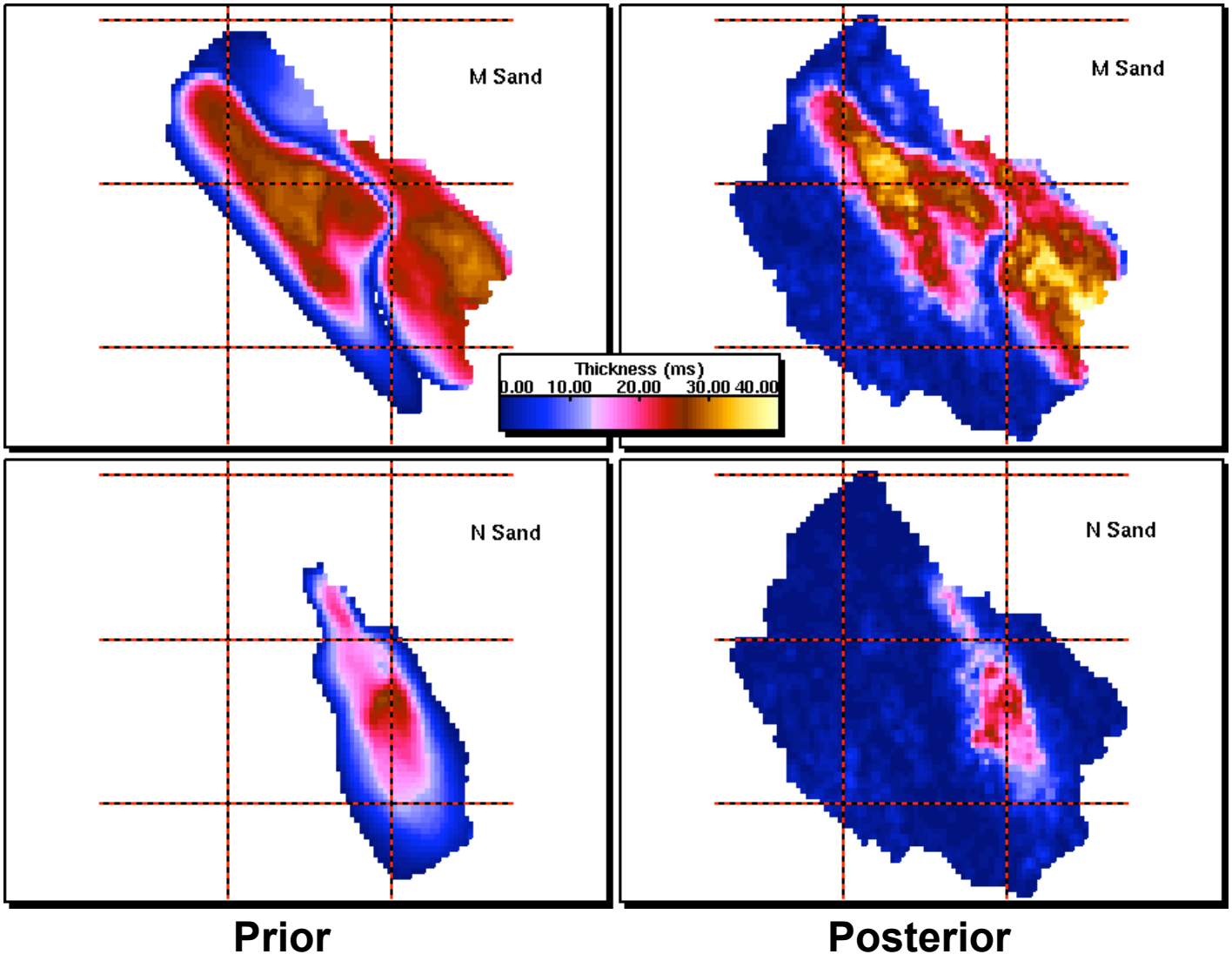
N/G changes with Inversion - M & N



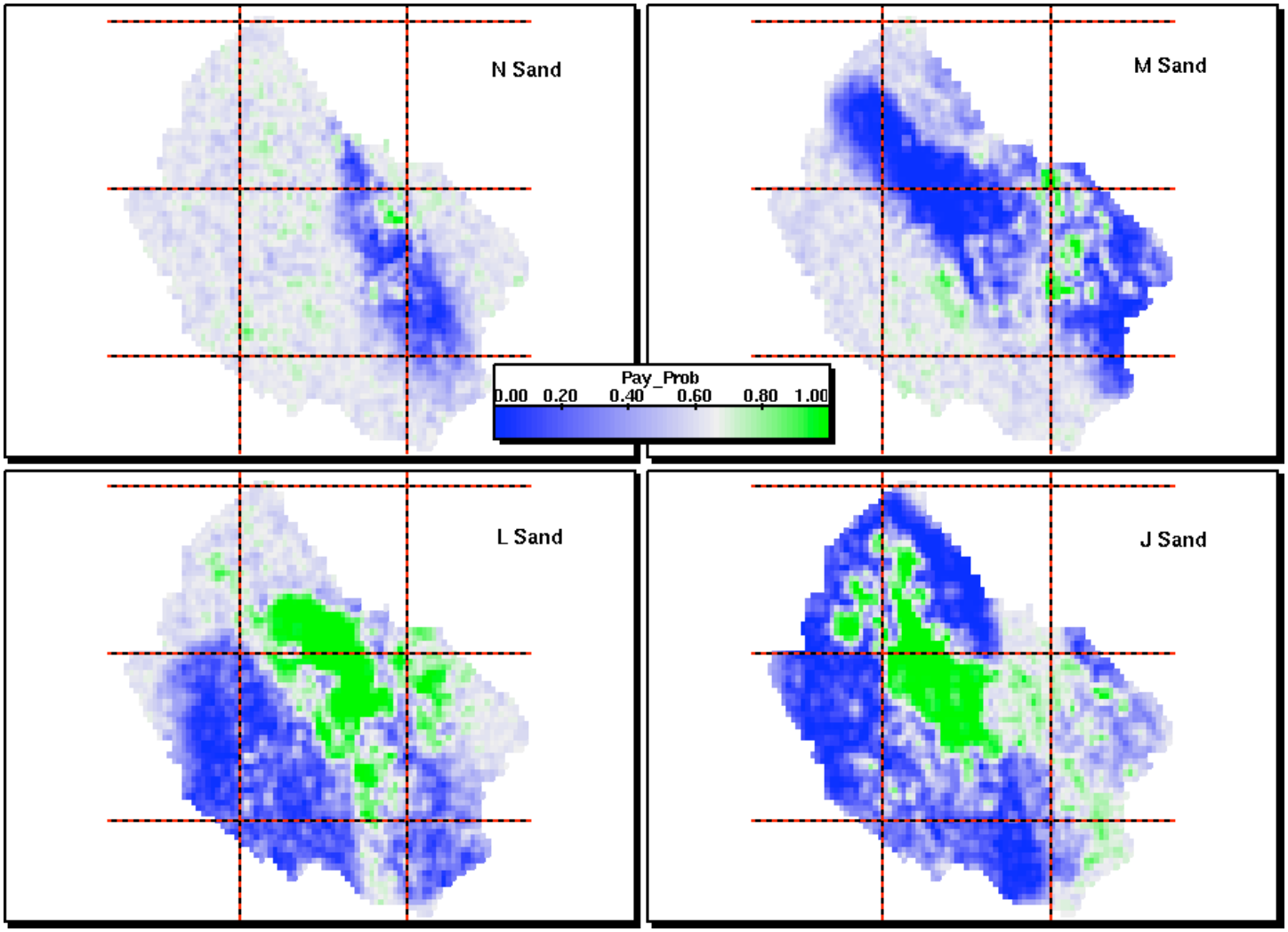
Thickness changes with Inversion - J & L



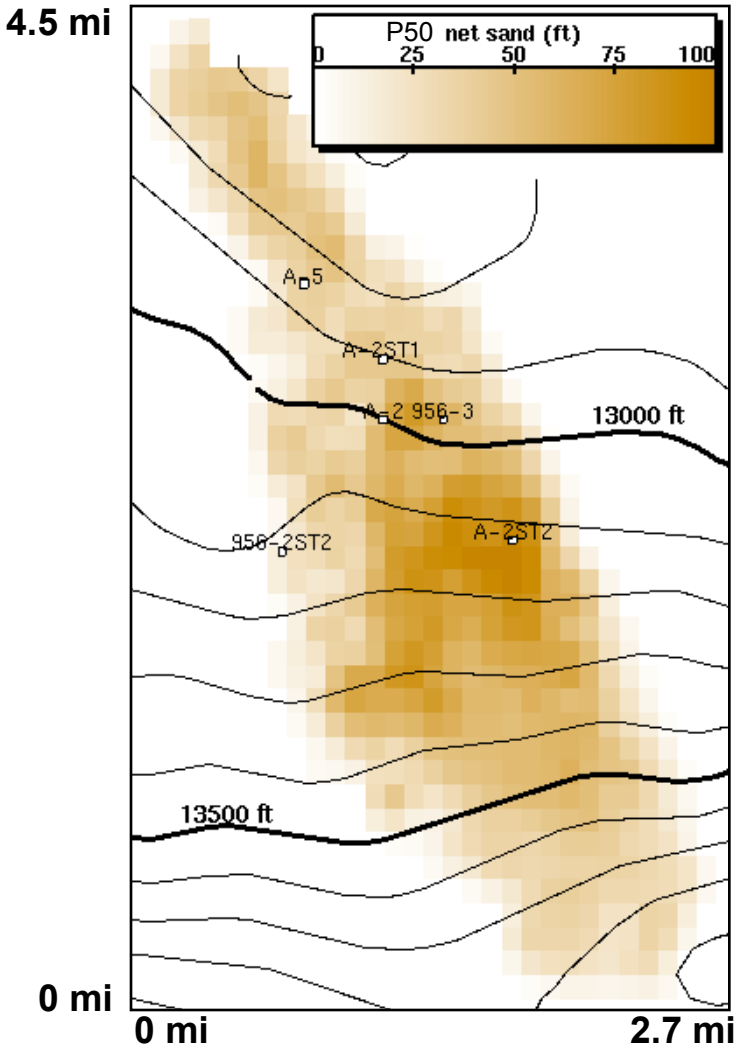
Thickness changes with Inversion - M & N

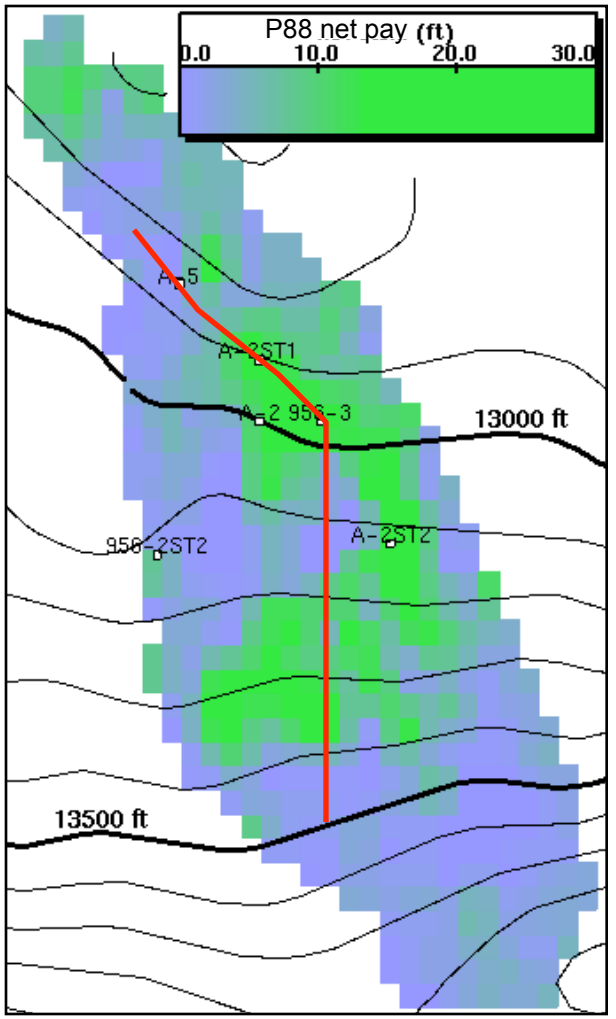


Posterior Pay Probabilities



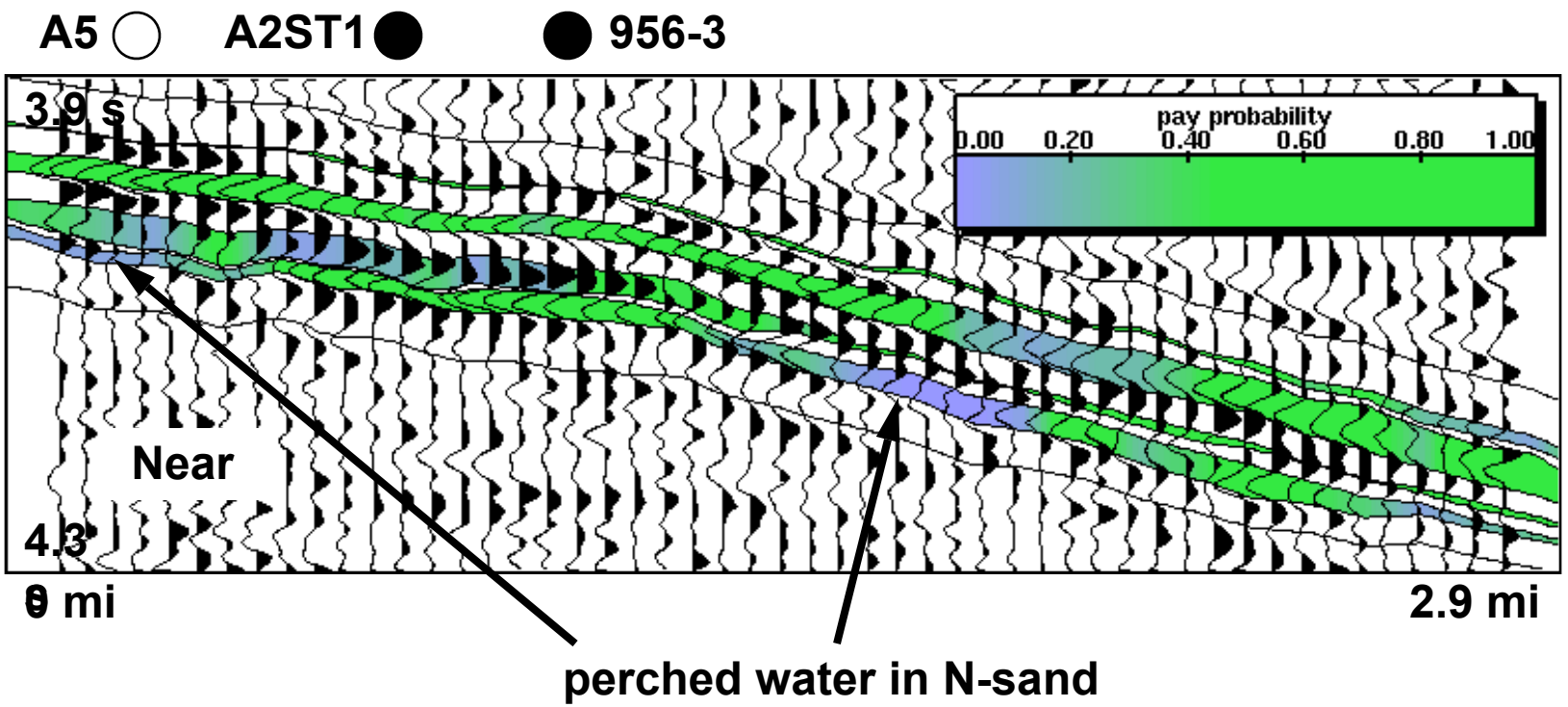
Inversion at N-sand indicates perched water





NetPay = Thickness * N/G * Porosity * Pay_prob

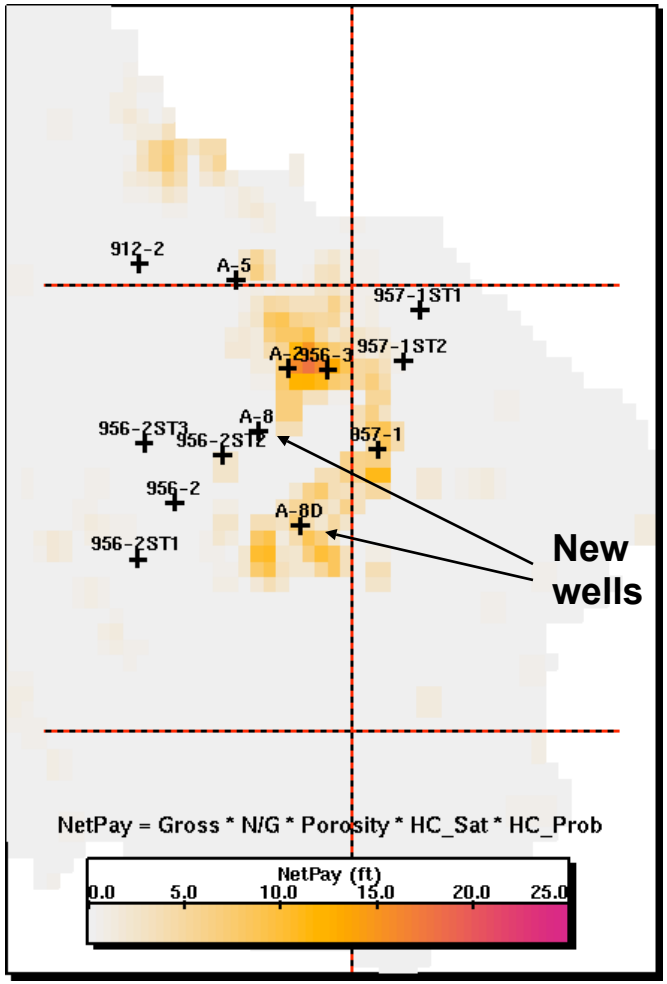
Cross section showing perched water



Note: RUNSUM data

Inversion is consistent with well information

N-sand P50 NetPay Map



- 956st2, 956-3, and 957-1 oil
- A2st1 and A2st2 oil
- A2 near OWC and A5 wet

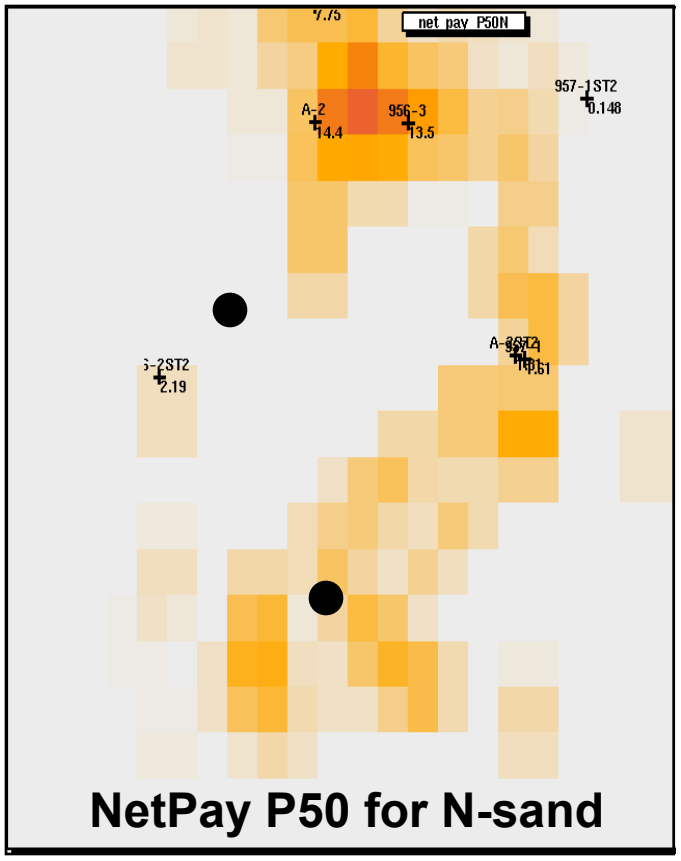
- A5st2 and A2st2 in pressure communication
- 3 barriers @ 200, 200 & 900 ft. from A2st2
- 2 barriers @ 800 &1600 ft. from A2st1

- 42 MMBEQ connected to A2st2

  (70 MMBEQ - includes connection to M)

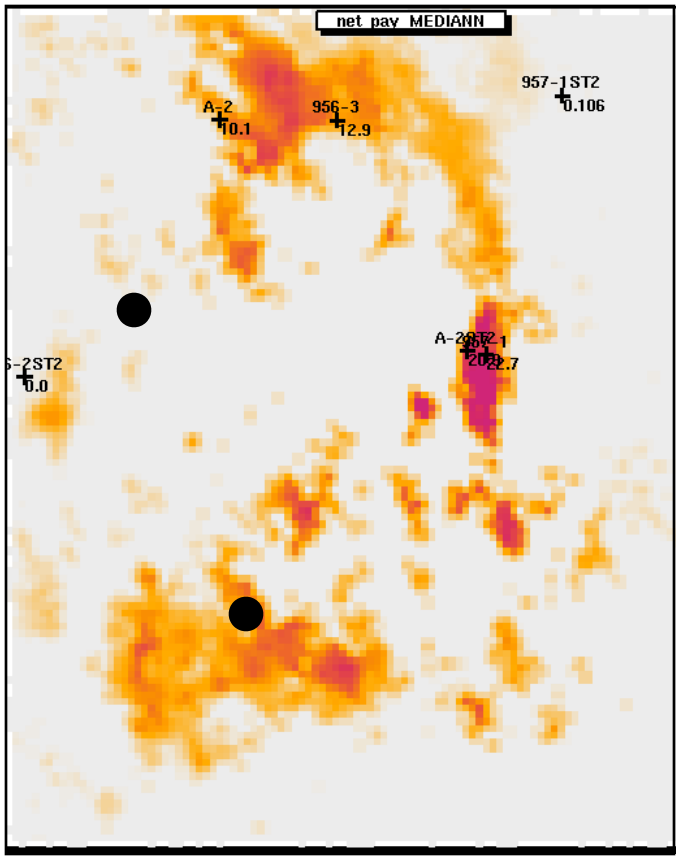
Inversion at Seismic Resolution

DepSim model resolution



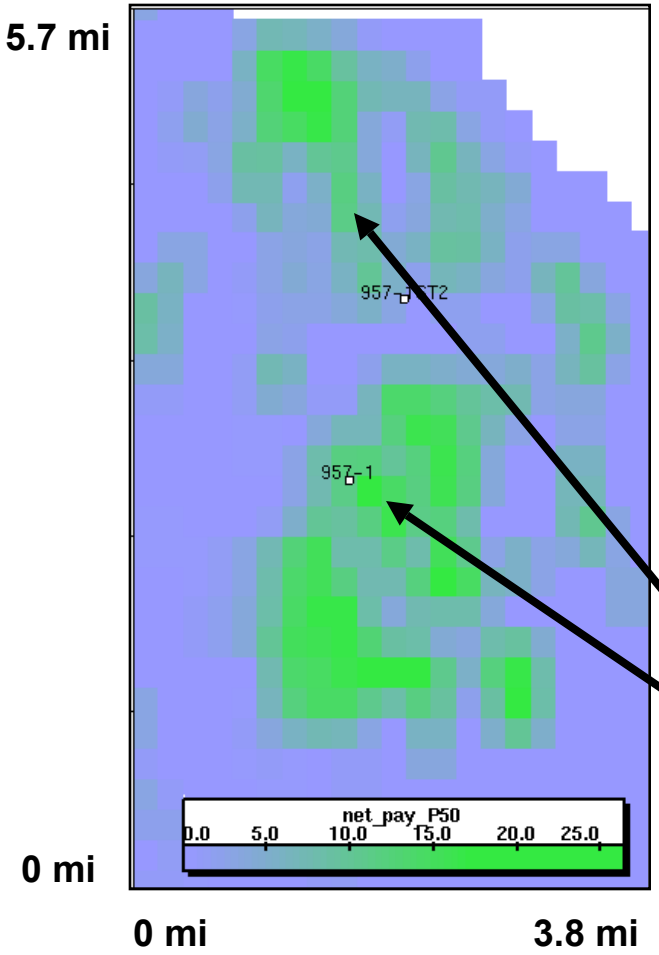
NetPay P50 for N-sand

seismic resolution (5x)



Inversion Results at M-sand

P50 NetPay Map



- **957-1ST2 : Geochem outlier**
- **957-1 : Pressure depleted by N-sand production**

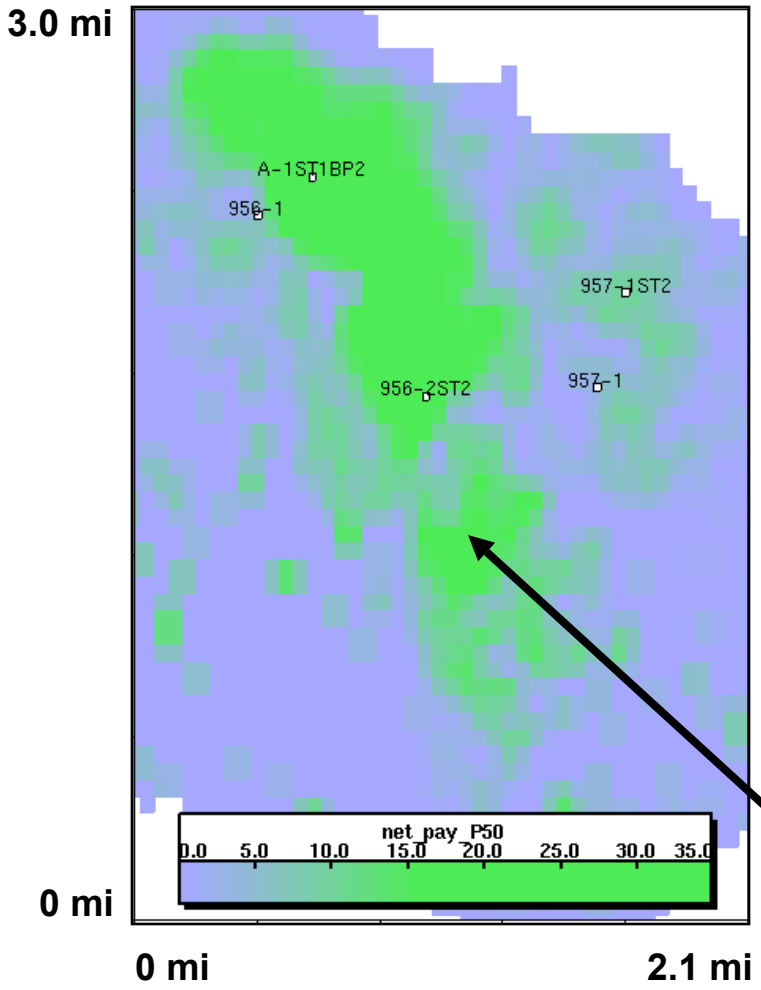
Lower-Pod Volumes

- **Predicted: 37-69-118 MMBEQ**
  (P12,P50,P88,w/ 4000 ft correlation)
- **Booked: 82 MMBEQ**

2 separate compartments ???

Inversion Results at L-sand

P50 NetPay Map



- 957-1 & 956-2st2 pressure profiles do no line up
- 956-2ST2 oil over water with shale in between - fluid level?
- 956-1 gas over water with shale in between
- 957-1 OWC

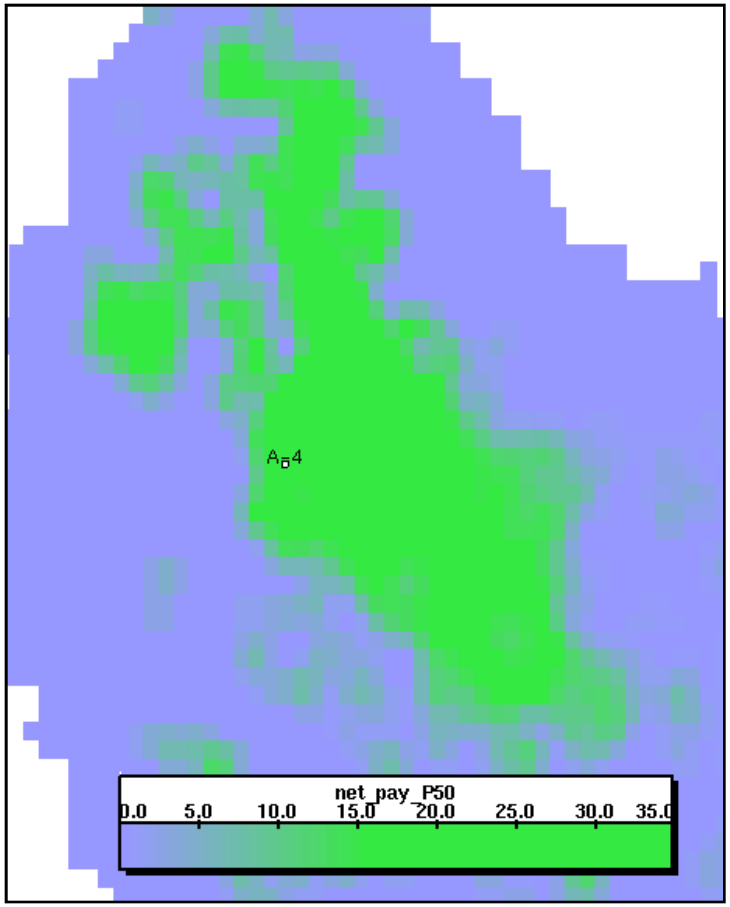
Volumes in Upper Pod

- Predicted: 266 - 301- 334 MMBEQ
  (P12,P50,P88,w/ 3000 ft correlation)
- Booked: 191 MMBEQ
- Mass balance: >260 MMBEQ

??Additional reserves??
Needs more work

Inversion Results at J-sand

P50 NetPay Map



- **A-4 OWC**

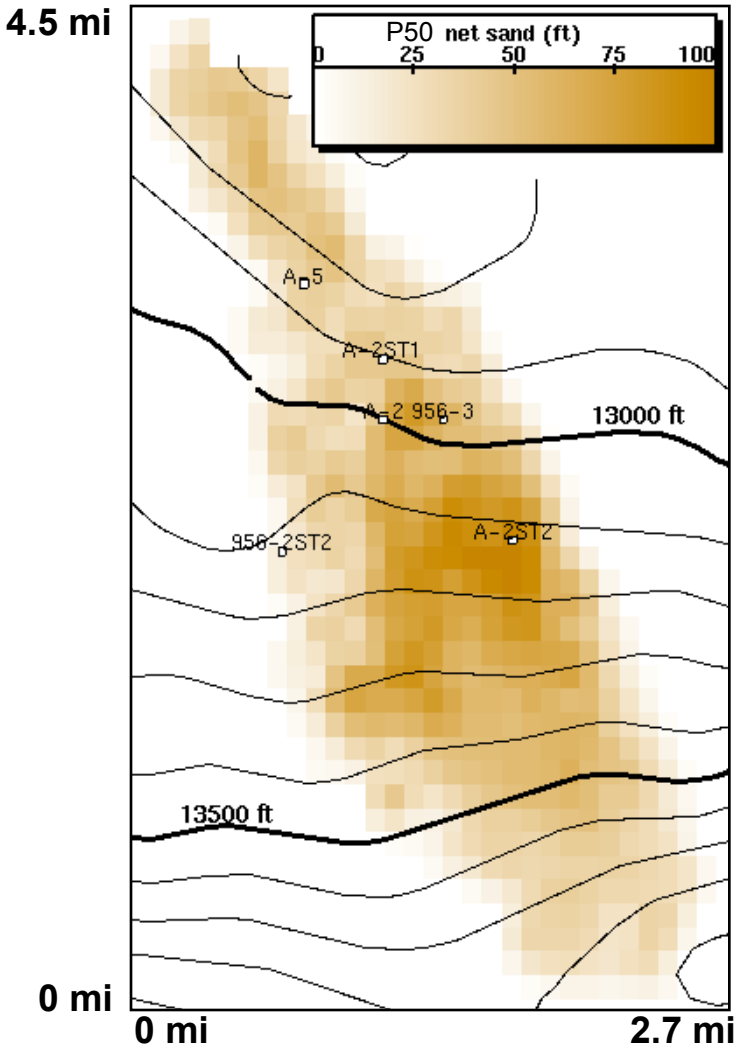
Volumes

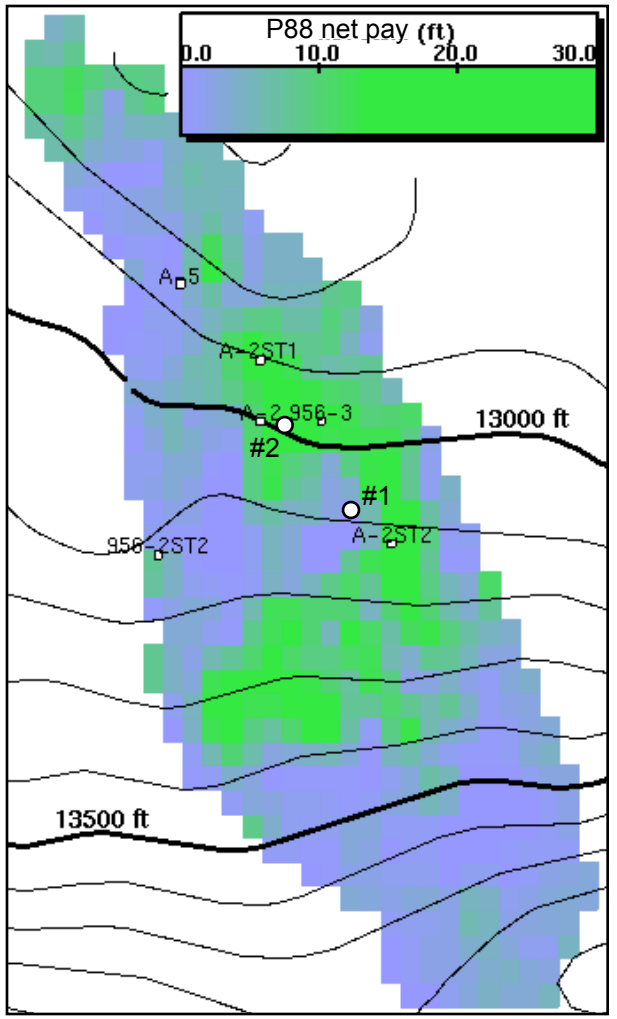
- **Predicted: 368- 422 - 470 MMBEQ**
  (P12,P50,P88,w/ 8000 ft correlation)
- **Booked: 601 MMBEQ**

Inversion increased volumes by >2 sigma over input model

Revisit input!!

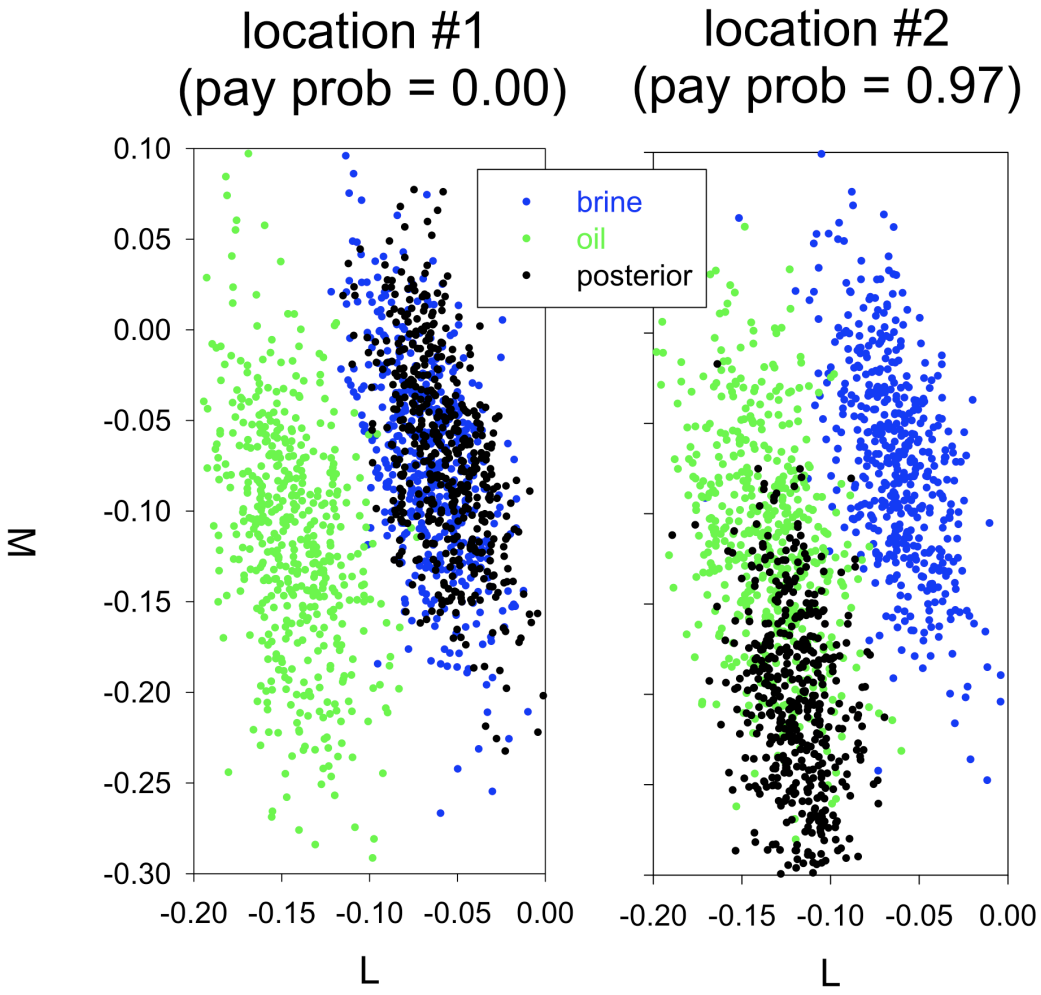
Value of AVO in the Inversion (N-sand)





NetPay = Thickness * N/G * Porosity * Pay_prob

View of Inversion Results in L-M space



Oil points move to larger negative M values after inversion

For normal incidence - many of the oil points overlap with brine

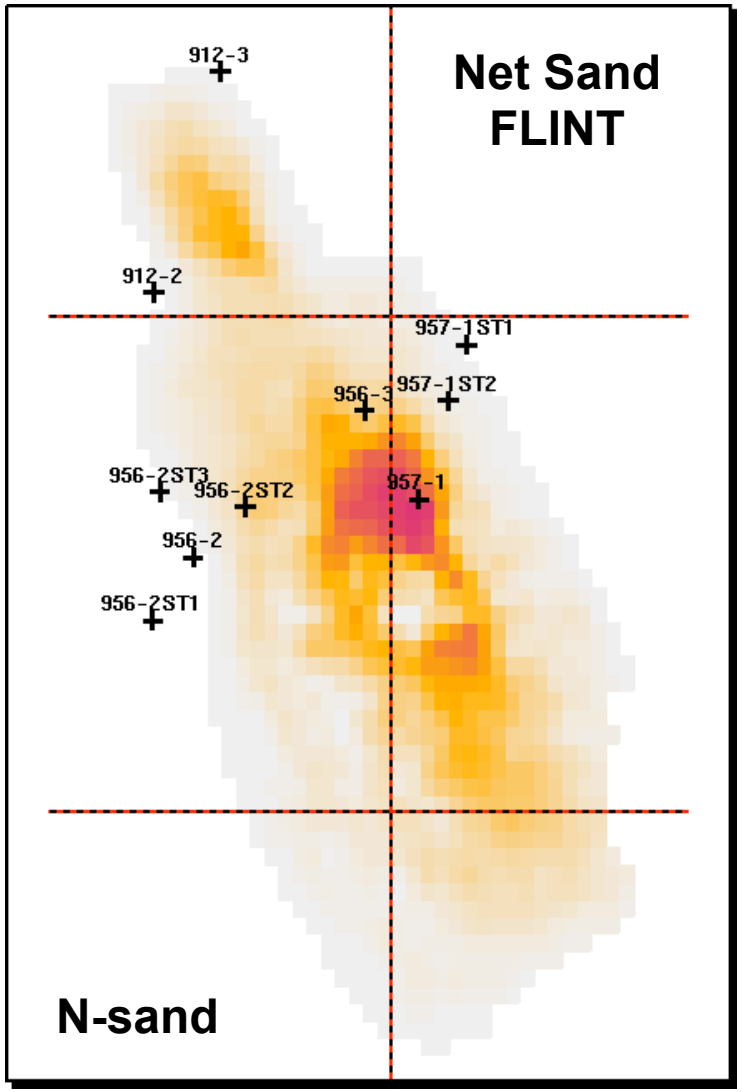
Fluid Probabilities at location #2 (oil in N-sand)

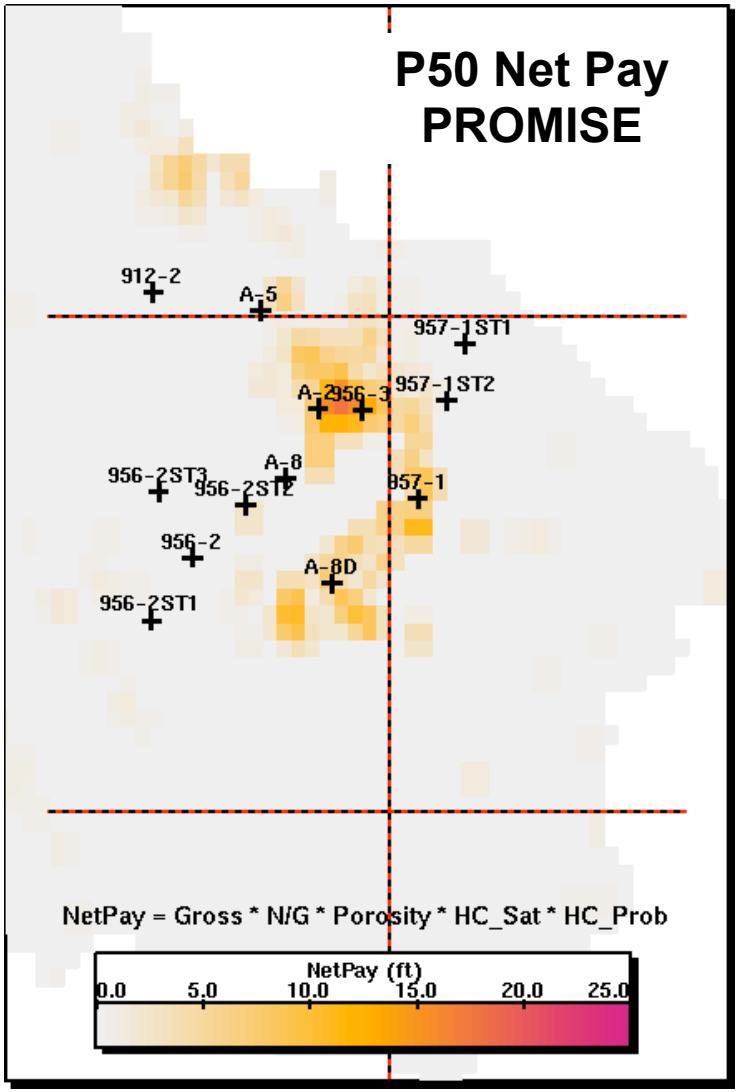
fluid prediction	without AVO	with AVO
oil	41%	**65%**
gas	38%	**32%**
residual gas	3%	**3%**
brine	18%	**0%**

AVO increases the probability of oil and pushes the probability of brine to zero

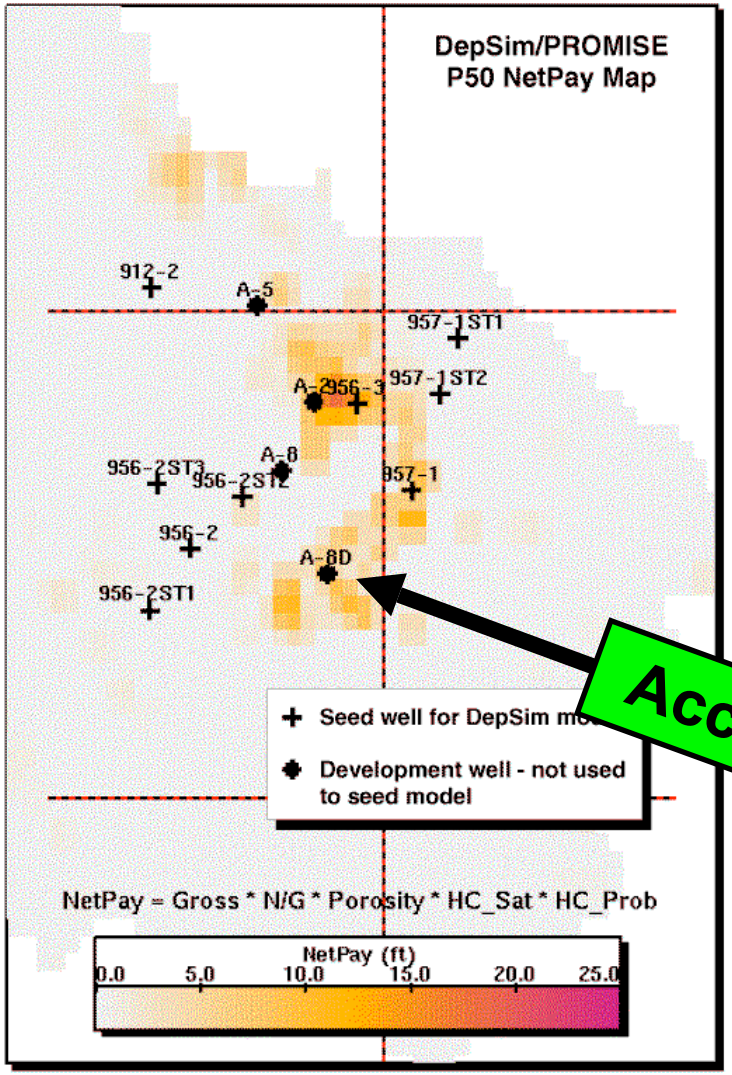
Multiple stack inversion adds value

Business Impact - N-sand





Business Impact - N-sand



Development Well	Actual Net Sand (ft)	PROMISE Prediction* (P12-P50-P88)	
A-2 (water level)	63 oil --- 78 wet	50 - [illegible]	er predicted earby - move to heart of netpay
A-5 (water level)	14 oil ---	[illegible]8 - 55 wet	Don't drill this location
A-8 (water l[illegible]	[illegible]2 wet	11 - 25 - 47 wet	Don't drill this location (partner driven)
	83 oil	54 - 85 - 110 oil	Good location for development well

d was modeled as one layer

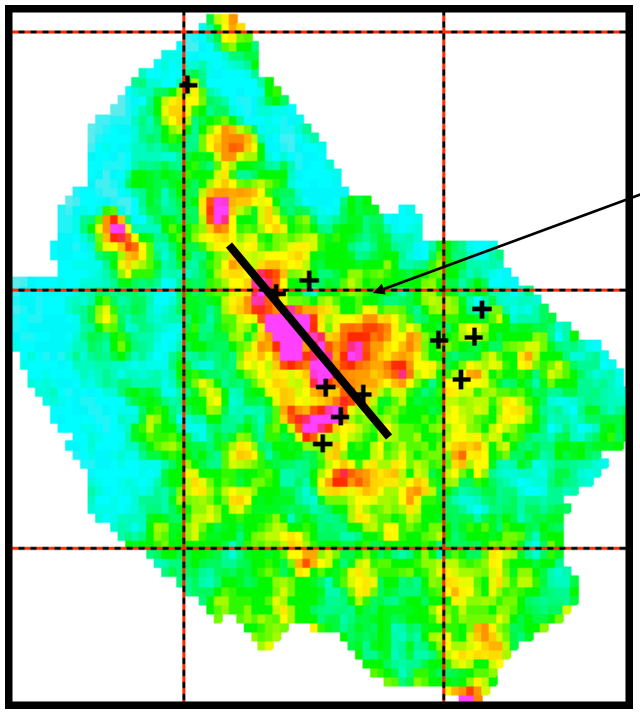
[illegible]ble for decision

PROMISE av[illegible]

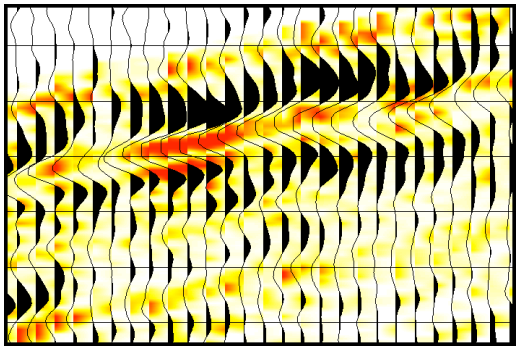
Save CAPEX ~ $20MM

Accelerate Production ~ $5MM

Strategies to Analyze Inversion Results



Chi-Squared Error Map



Chi-Squared Error Traces

Smaller standard deviation of key uncertainties after inversion - twtt and AI

Mean value systematically moves higher or lower