



What Probabilistic Inversion Can Tell You About the Geology

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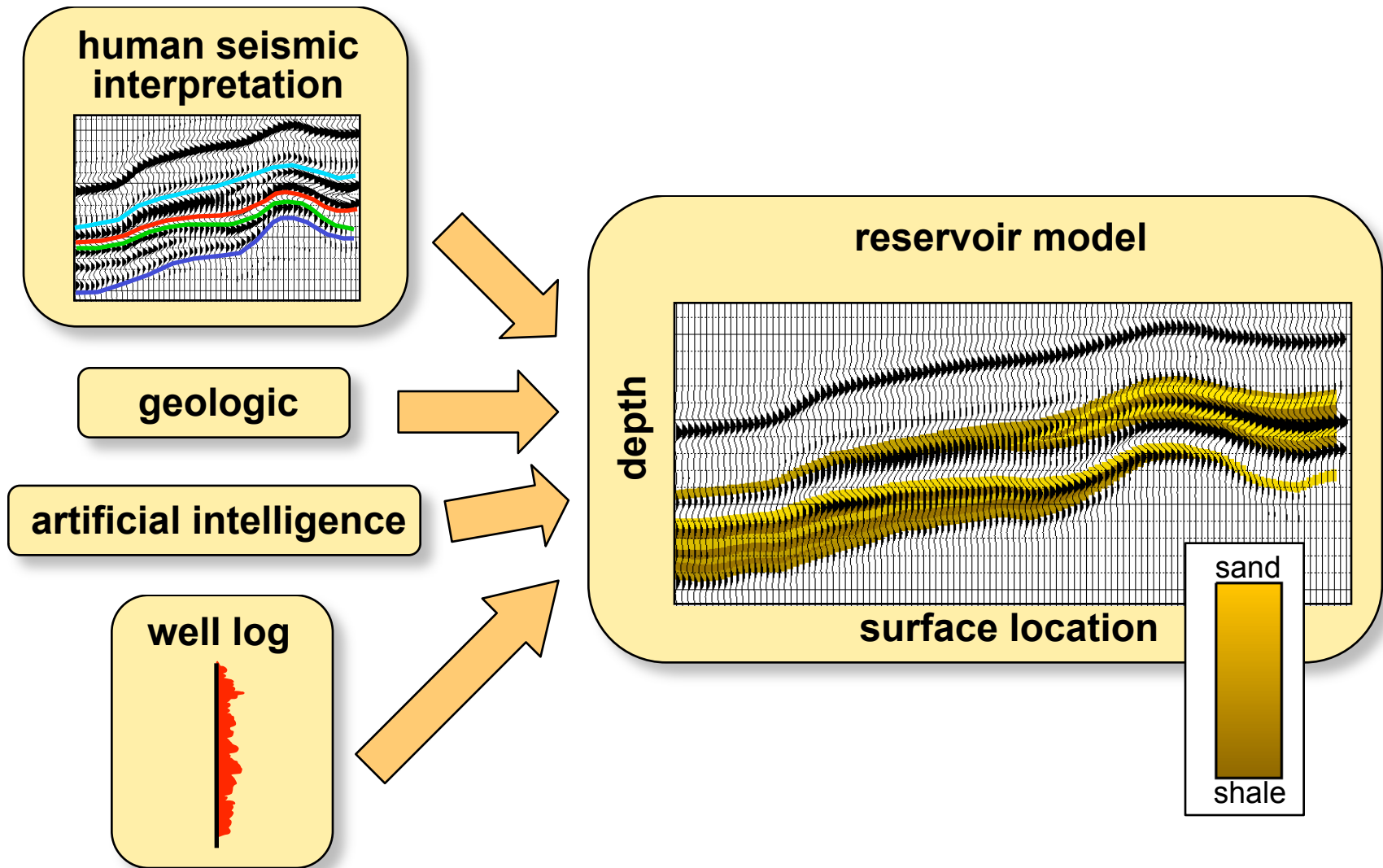
Shell Deepwater Development Inc.

Outline



- **Overview of inversion**
- **Ram/Powell**
 - AVO inversion
 - fluid saturations
- **Fourier BS20**
 - effect of correlation on net sand
- **Goodwyn**
 - structural uncertainty
- **FRAM**
 - net sand estimation
 - chaotic structure (slumping marl)
- **Conclusion**

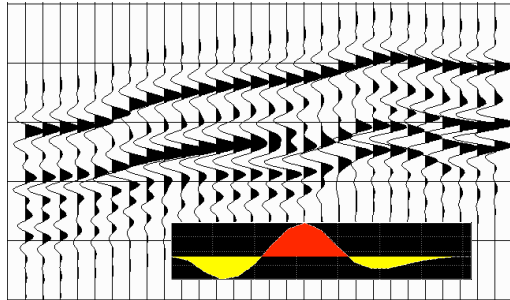
Reservoir modeling combines many types of information



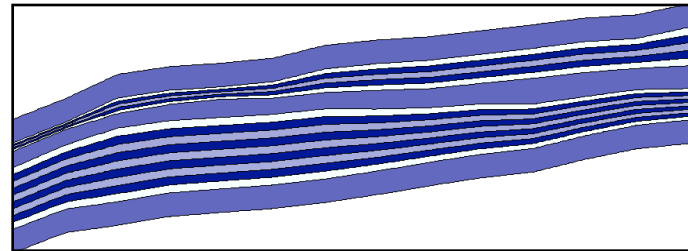
Inputs to AVO inversion



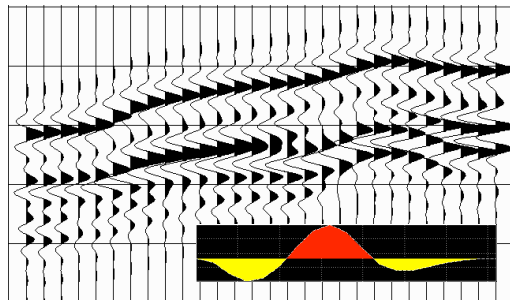
near stack and wavelet



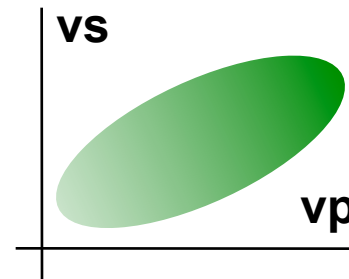
initial DepSim model



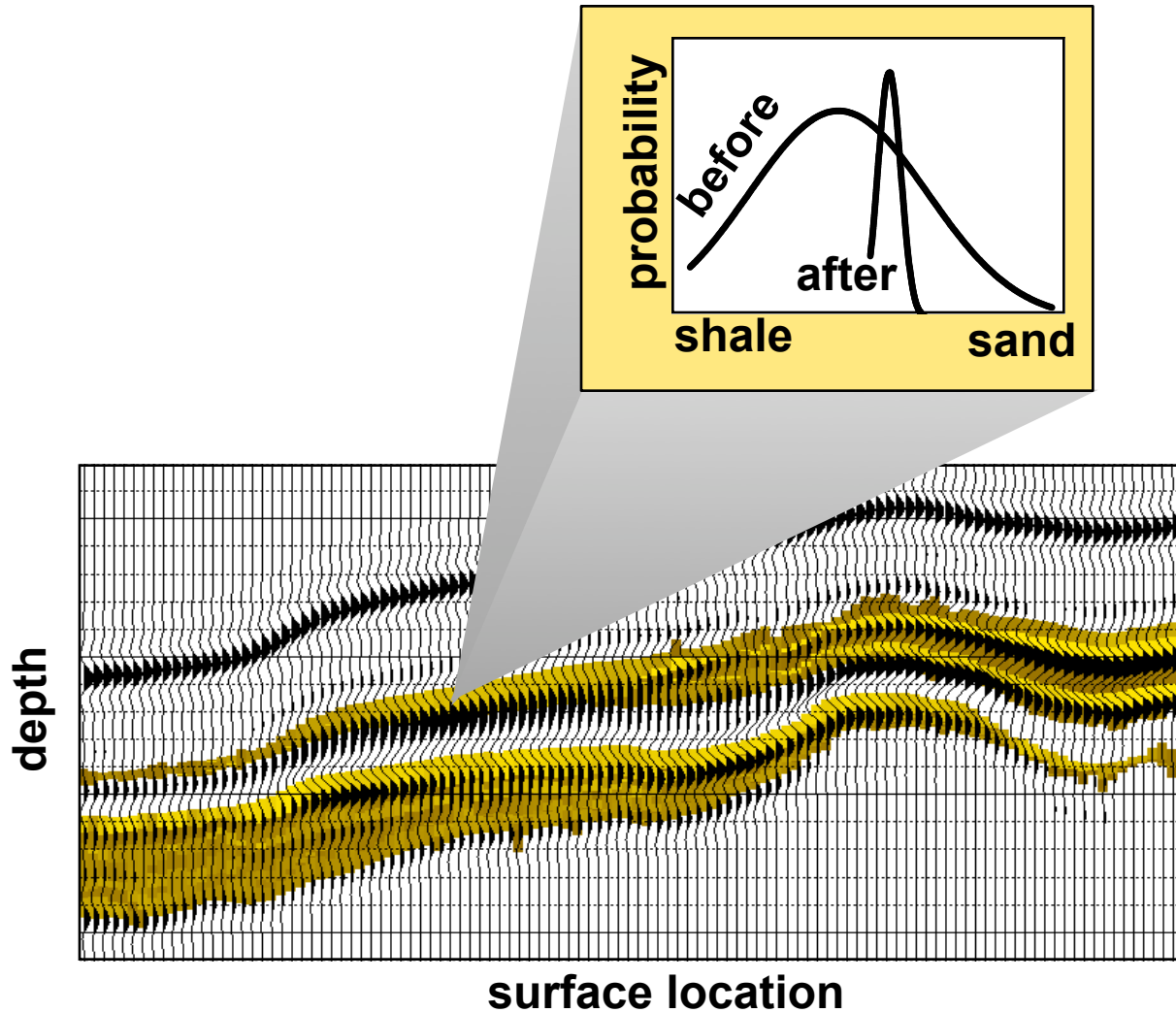
far stack and wavelet



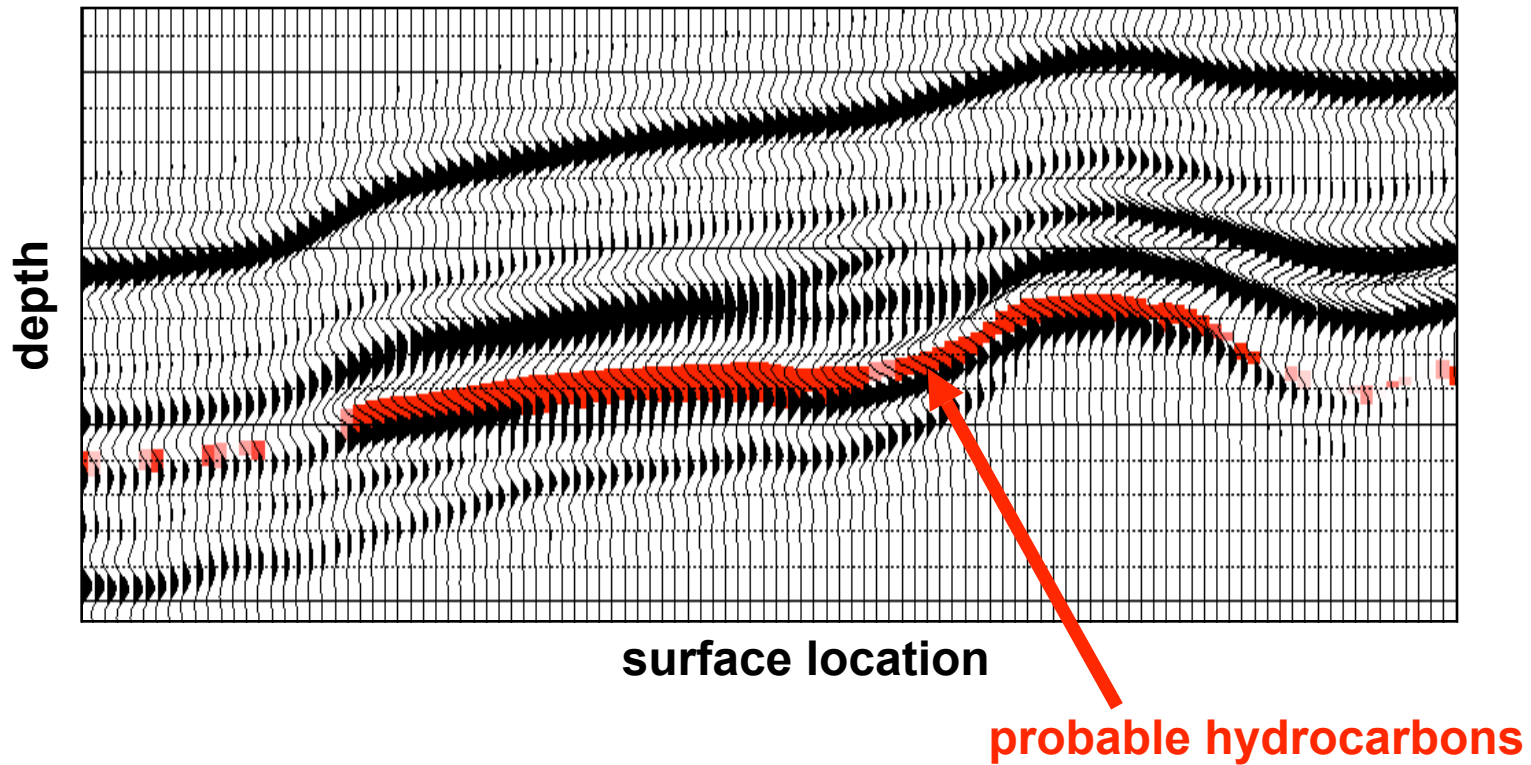
rock properties



Inversion includes seismic information, improving accuracy of model



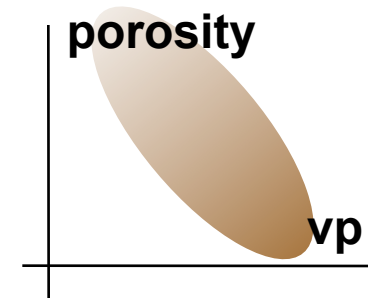
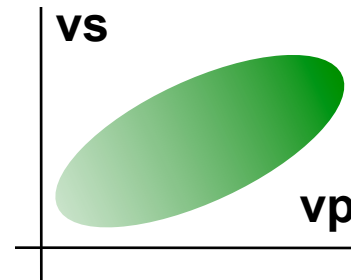
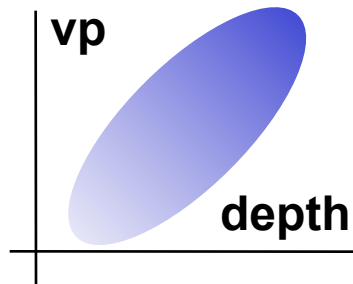
Inversion also locates hydrocarbons



GOM petrophysical end member trends used in prior probability

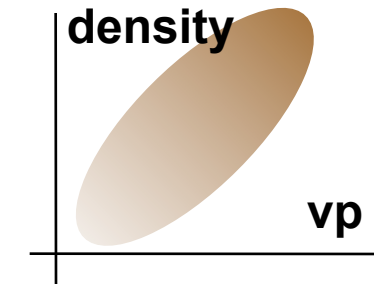
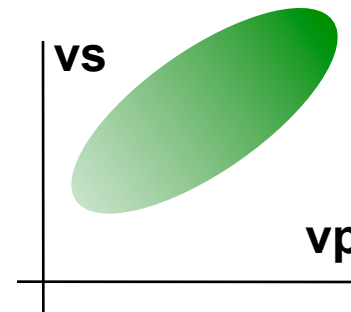
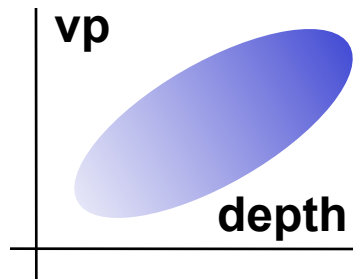


wet
sand



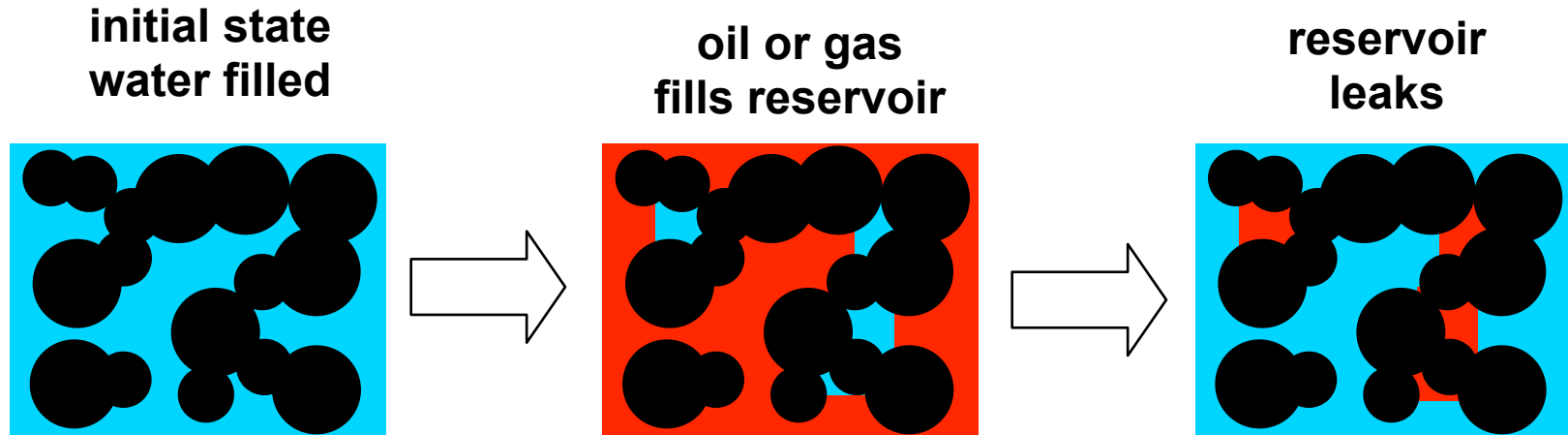
mix with net/gross $\pm \sigma$

mud-
stone



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

General information about Ram/Powell

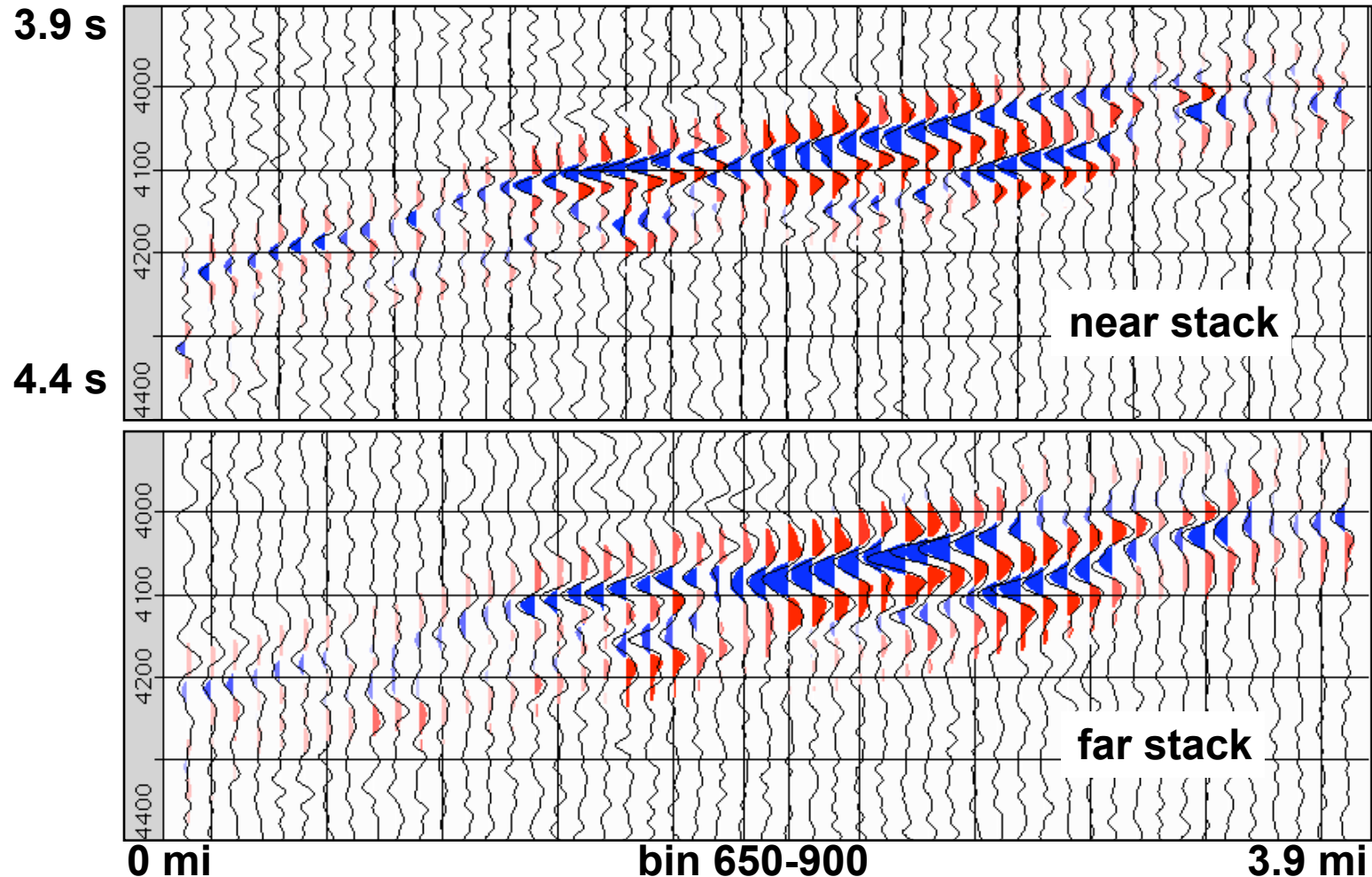


- **stratigraphically trapped unconfined turbidites in Eastern Gulf of Mexico**
 - J-sand is an amalgamated channel sheet sand complex
 - L-sand is channel levee
 - M-sand is channel levee to amalgamated channel
 - N-sand is massive channels
- **in 2500 to 4000 ft of water**
- **250 MMBBL equivalent**

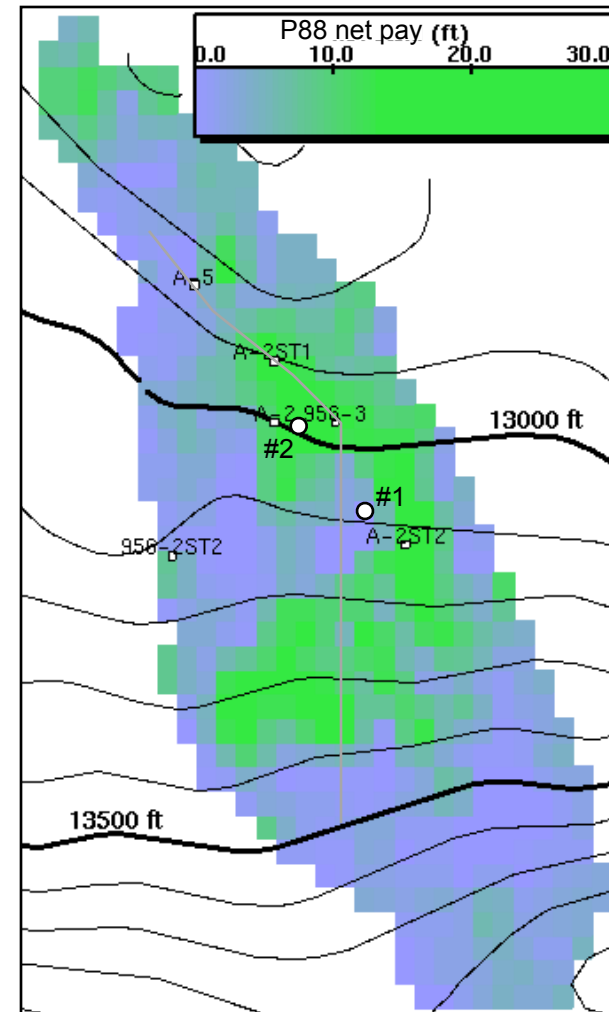
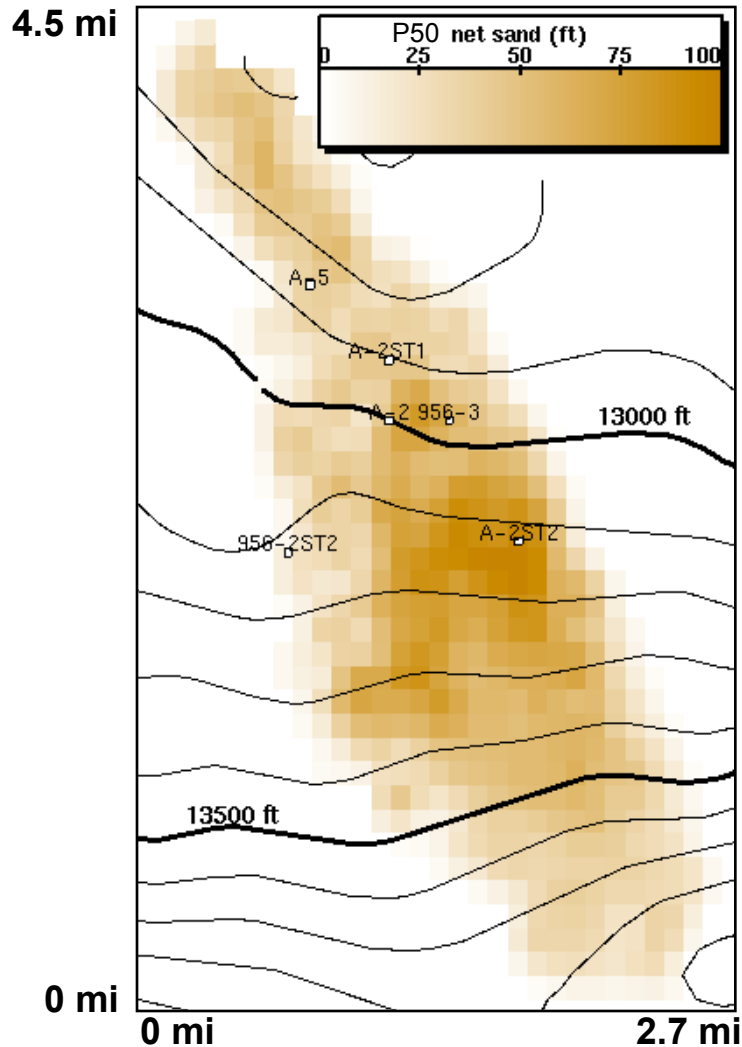
Synthetic data after inversion (red-blue) compared to seismic runsum data (trk 8575)



956-2ST2 ●



Inversion results of N sand shows perched water levels



net pay = thickness * N/G * porosity * pay probability

Geology lunchtime talk

07/19/2008

11

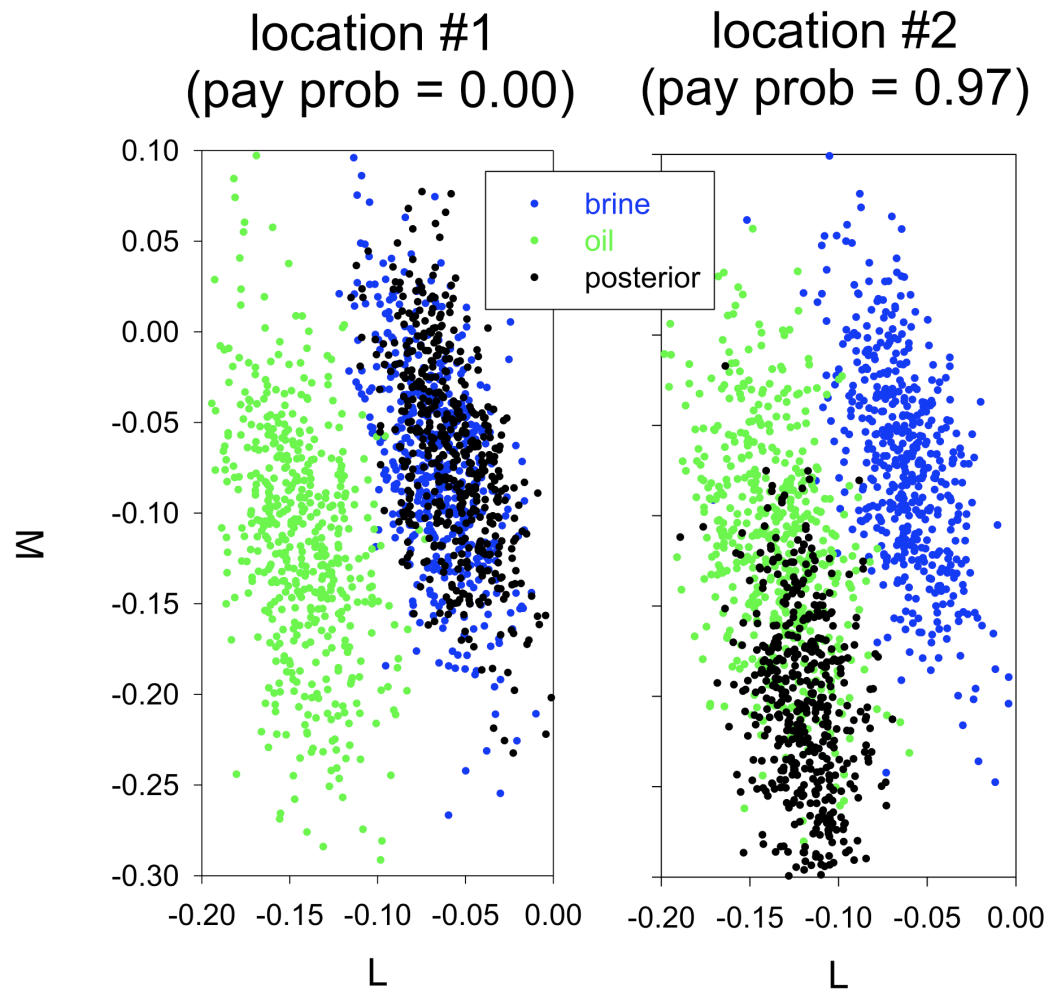
Inversion is consistent with well information



- **A5 wet**
- **A2 OWC**
- **A2ST1, 956-3, A2ST2, 956ST2 oil**
- **956-3 and A2ST2 in pressure communication**
- **mass balance gives 32 MMBBL connected to A2ST2**

pore volume (MMBBL)	inversion with infinite correlation length	inversion with 2000 ft correlation length
P12	14	26
P50	36	36
P88	82	48

View of the inversion results in L-M space



Multiple stack inversion adds value at location #2 (oil in N sand)

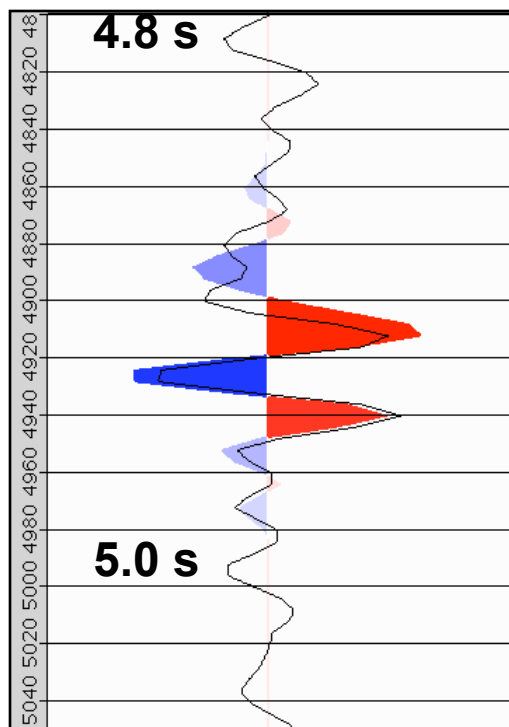


fluid prediction	with AVO	without AVO
oil	65%	41%
gas	32%	38%
residual gas	3%	3%
brine	0%	18%

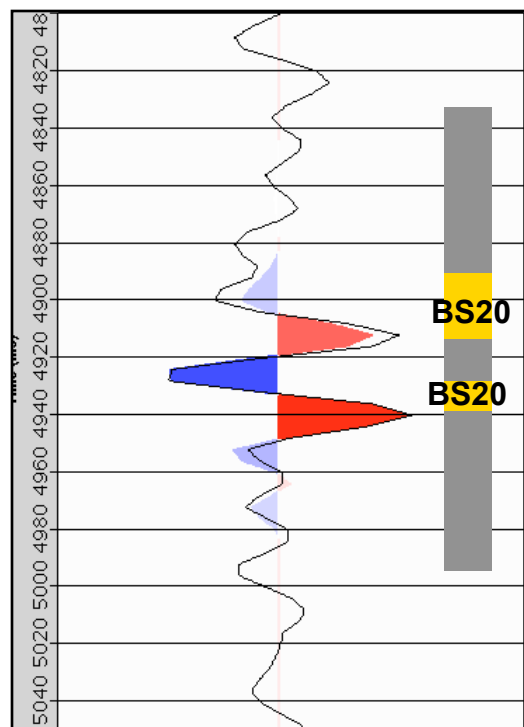
Fourier BS20 inversion at the well (522-1)



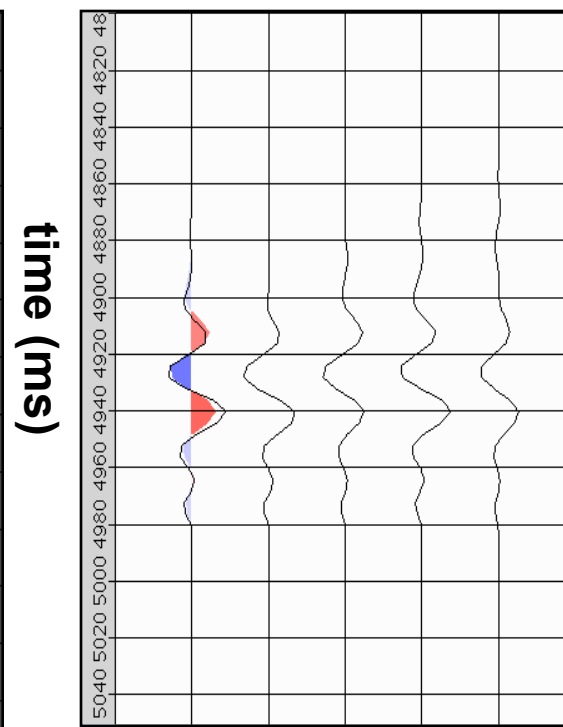
before inversion



after inversion



individual models

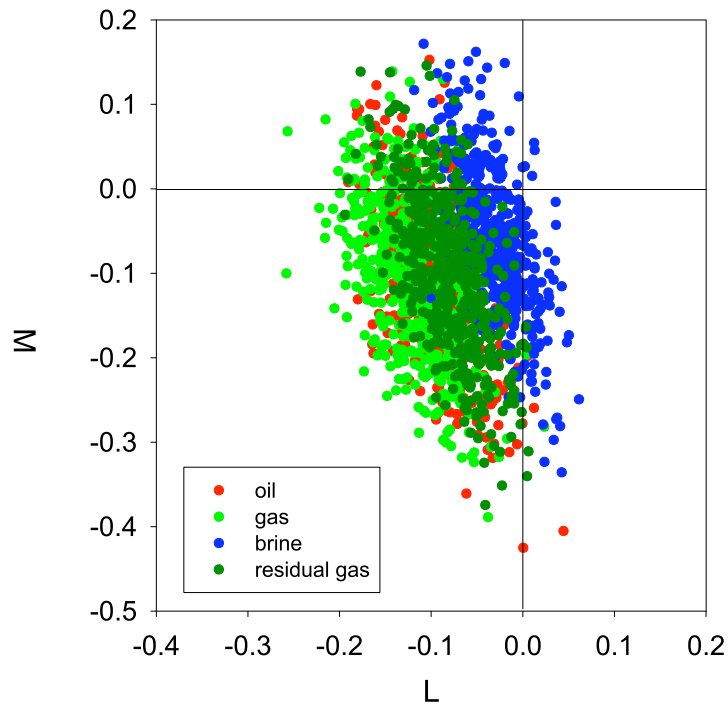


note: rfc data

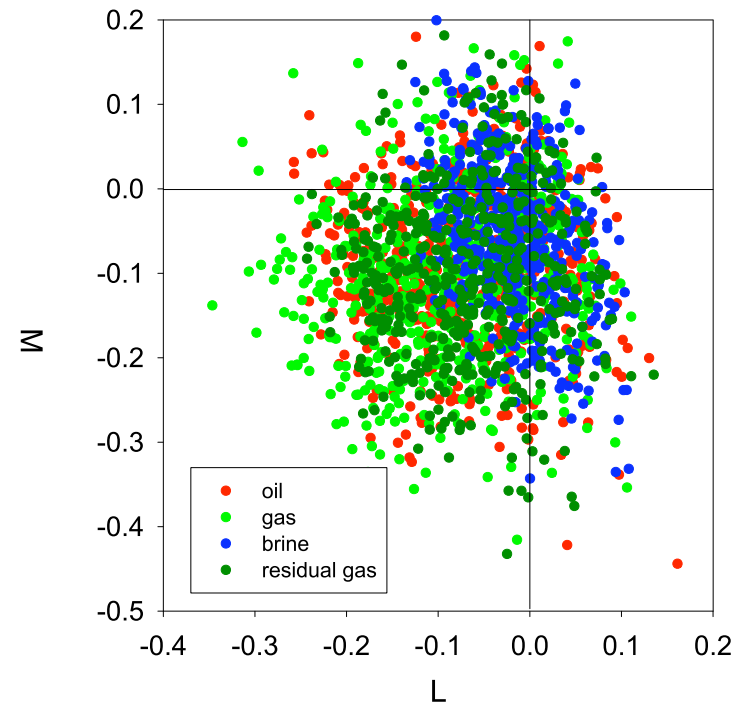
Lack of knowledge of N/G schemers clouds in L-M space



**N/G well known
N/G = 0.50(1)**



**N/G uncertain
N/G = 0.4(4)**



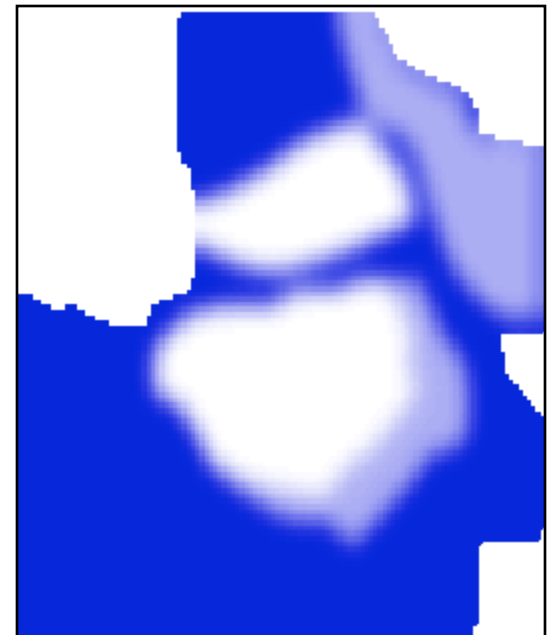
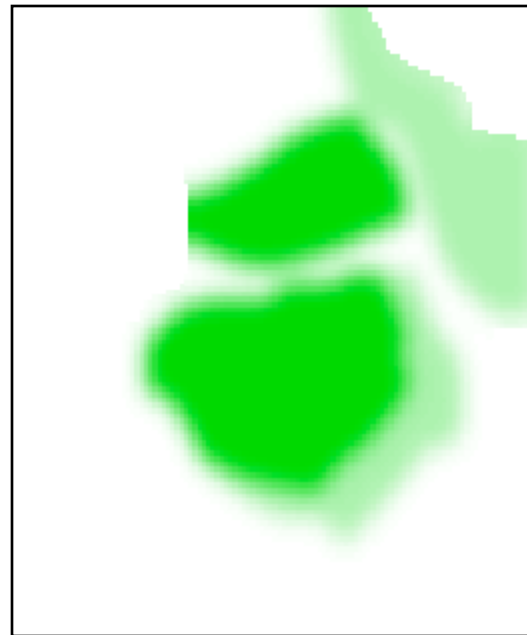
Prior probabilities of fluids are assigned



oil

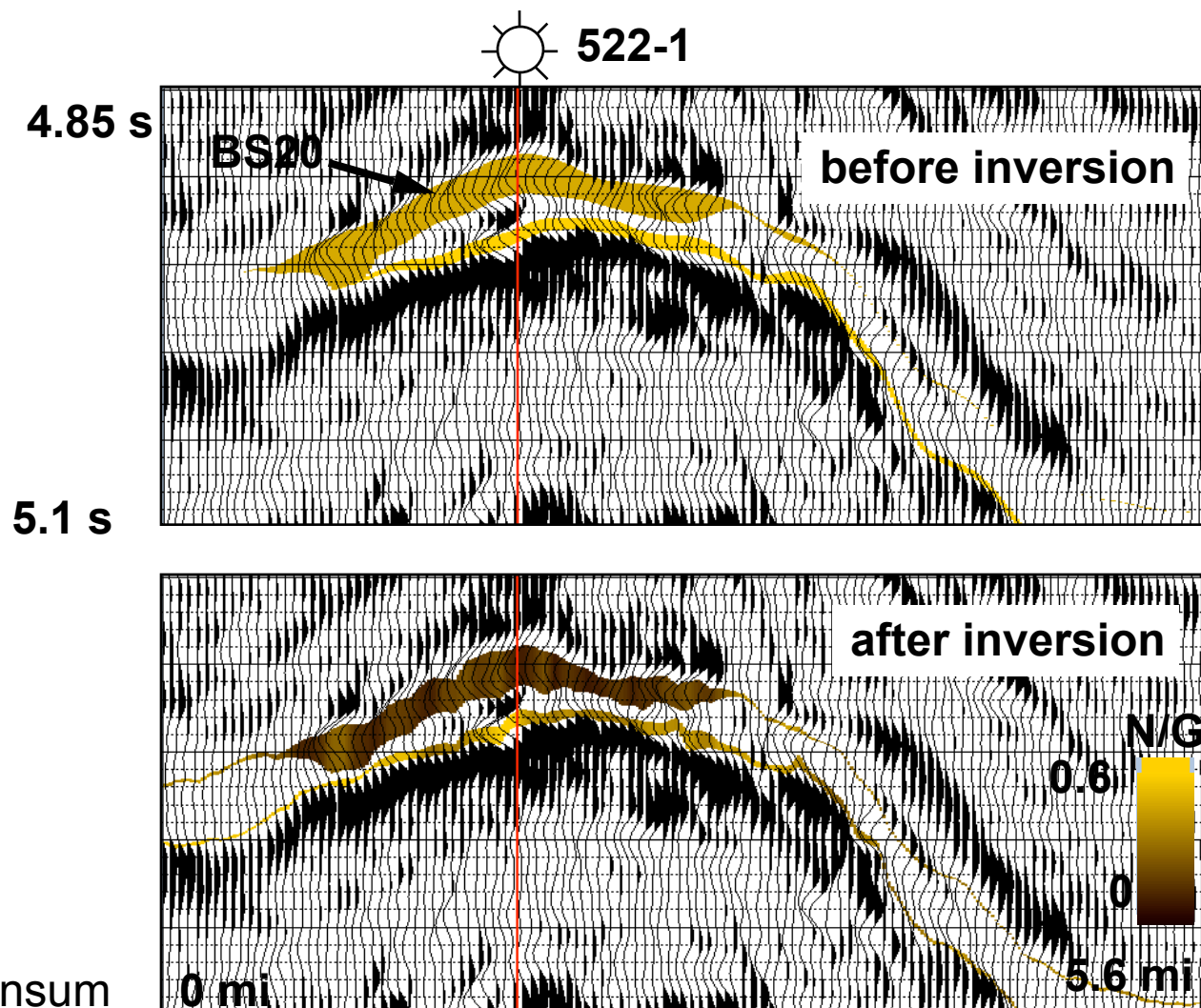
gas

water

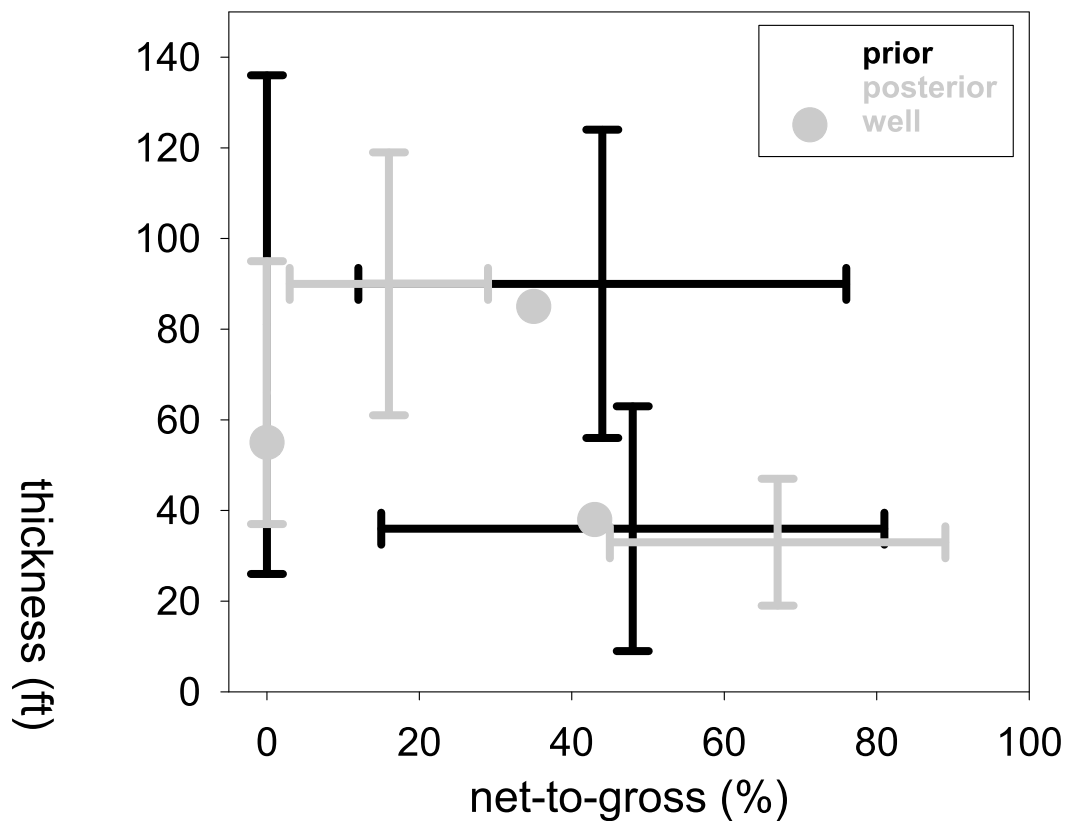


upper BS20

PROMISE inversion updates P50 model

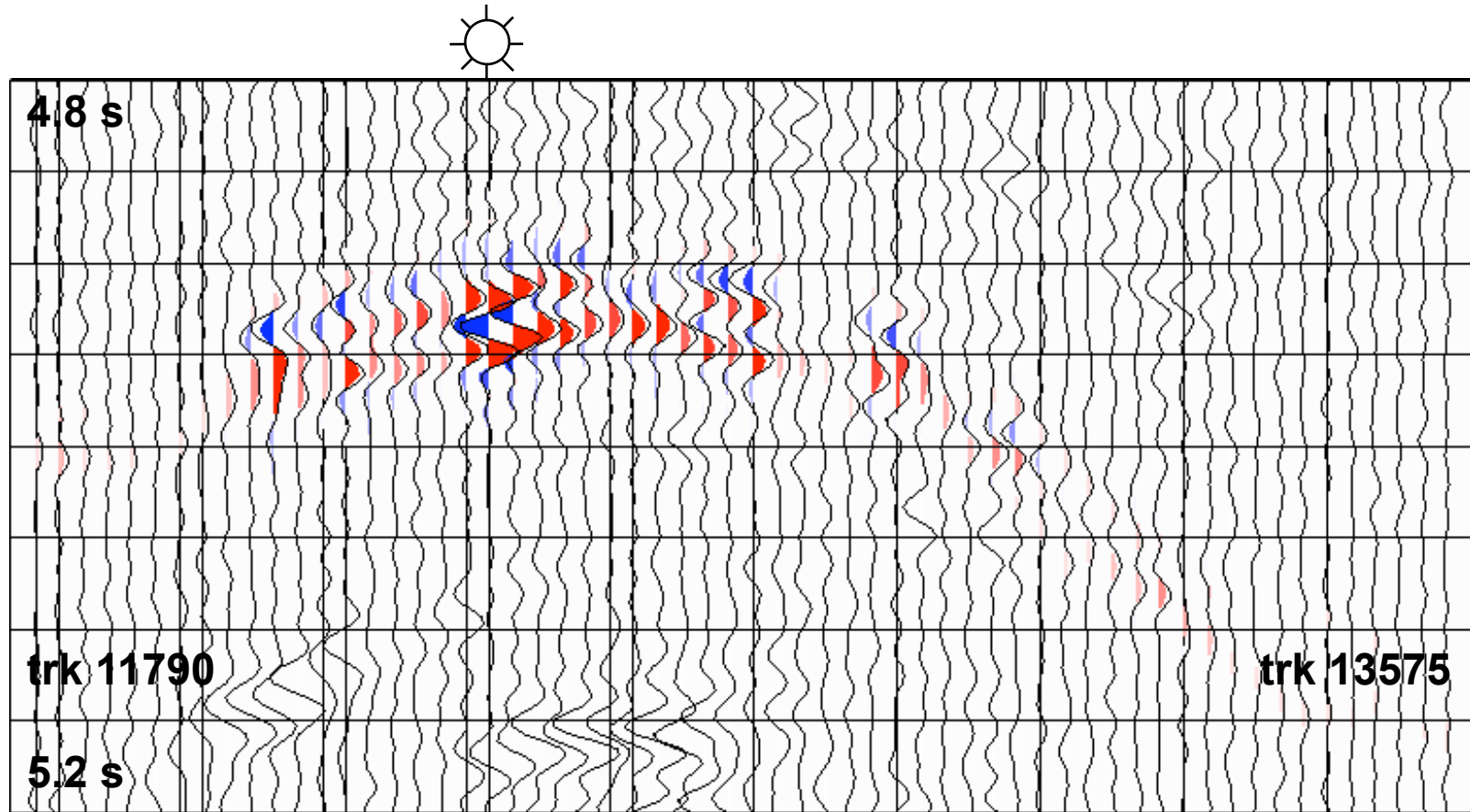


Fourier BS20 inversion at well 522-1

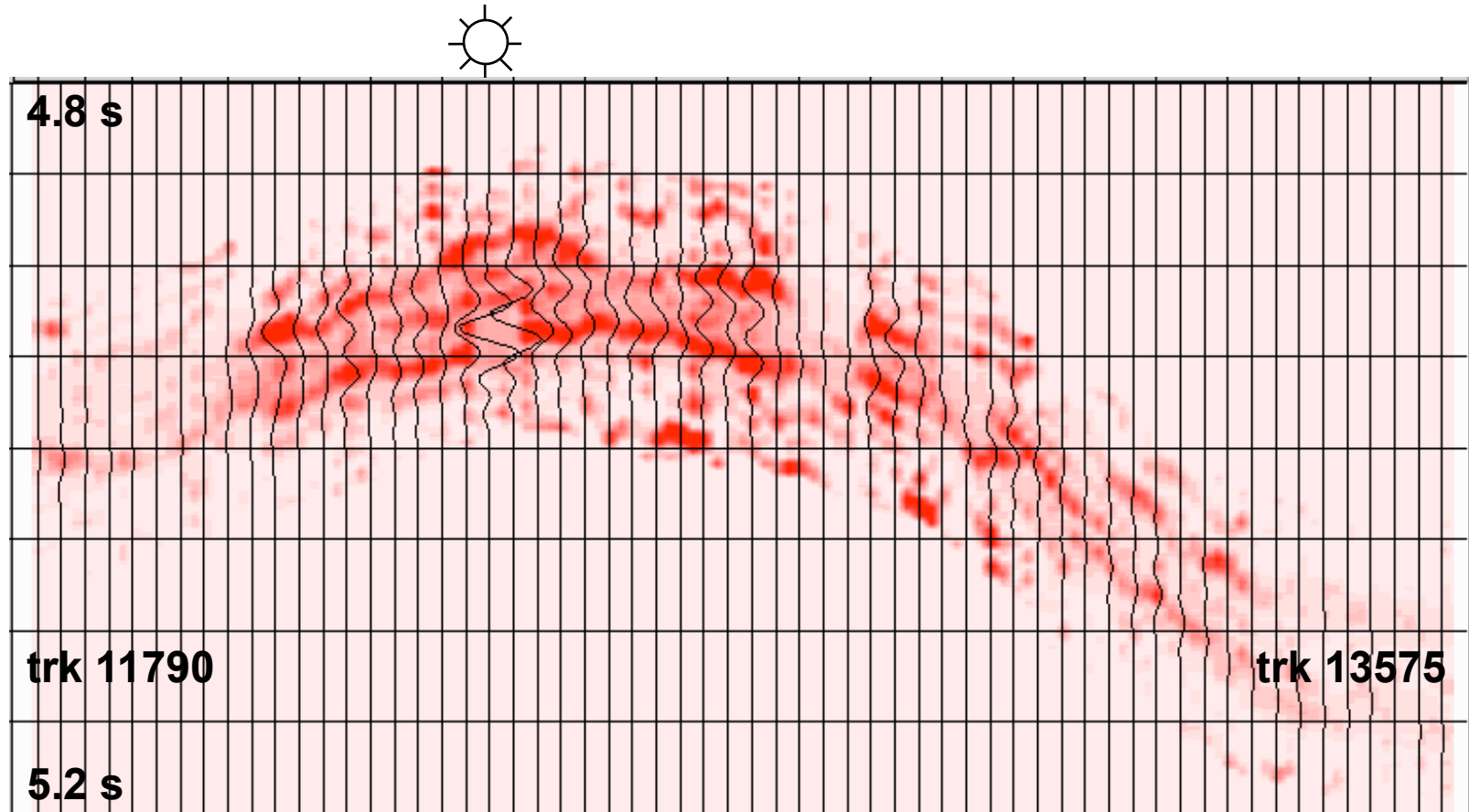


note: error bars show standard deviation

Synthetic data after inversion (red-blue) compared to seismic rfc data (bin 1846)



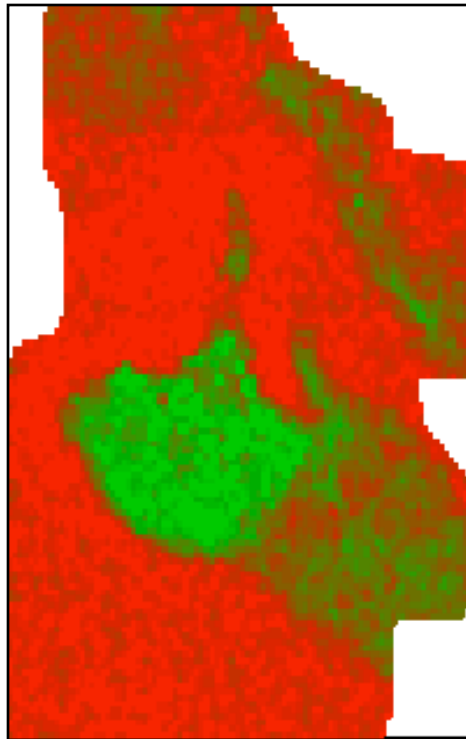
Chi-squared (0=white,1=red) shown in reference to synthetic rfc data after inversion



What properties are determined by seismic and where?

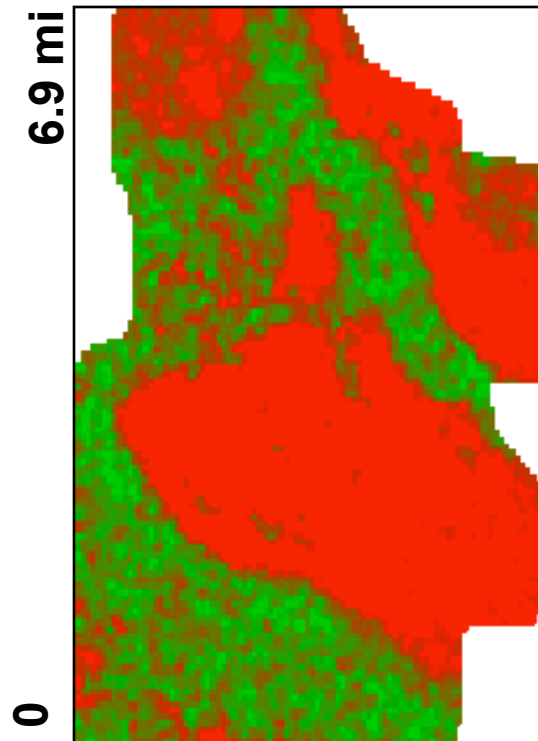


net/gross determined
where sand is thick



upper BS20

thickness determined
where sand is thin

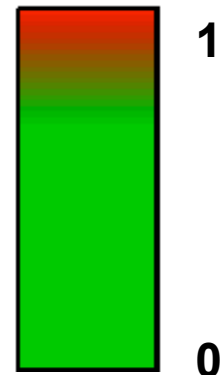


1.4 mi

5.9 mi

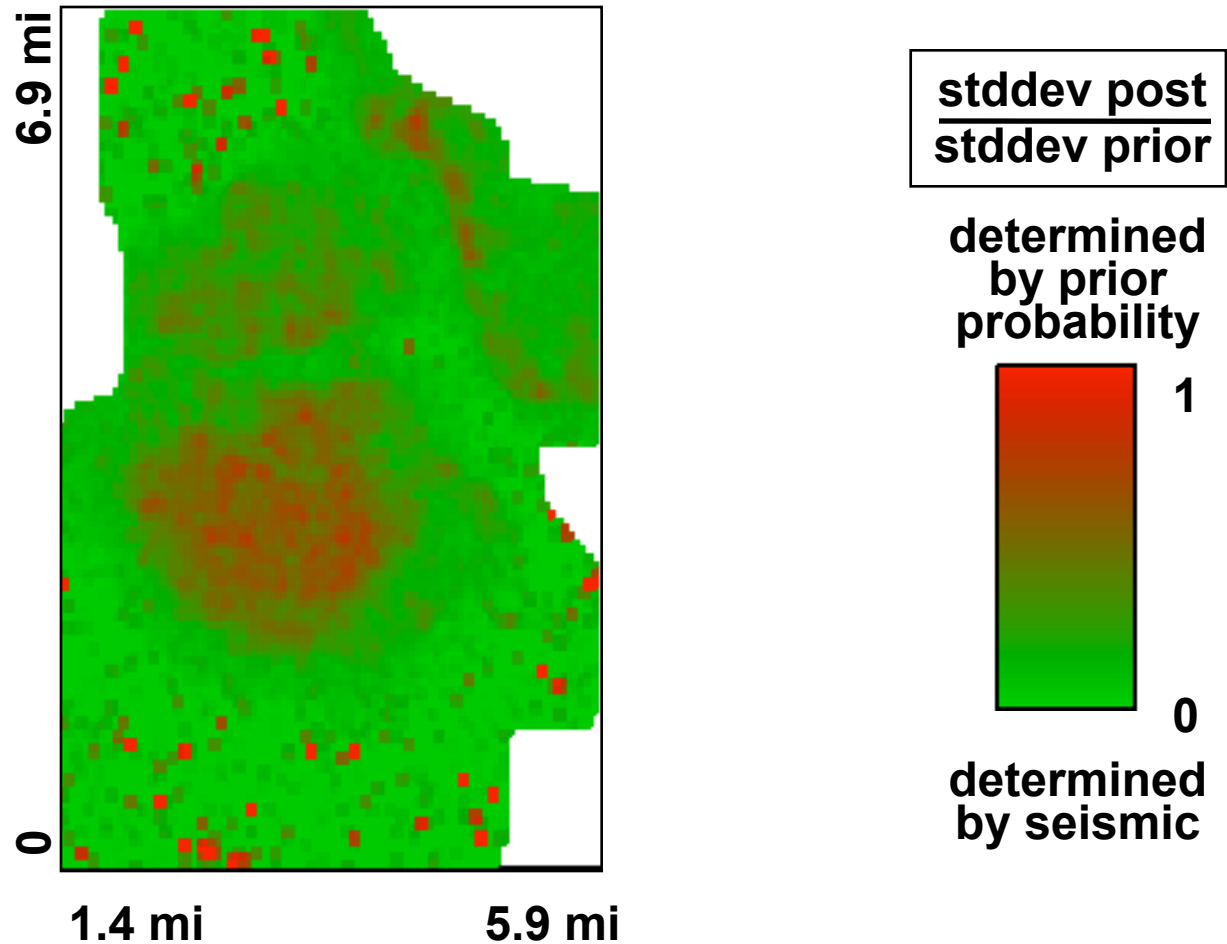
$\frac{\text{stddev post}}{\text{stddev prior}}$

determined
by prior
probability

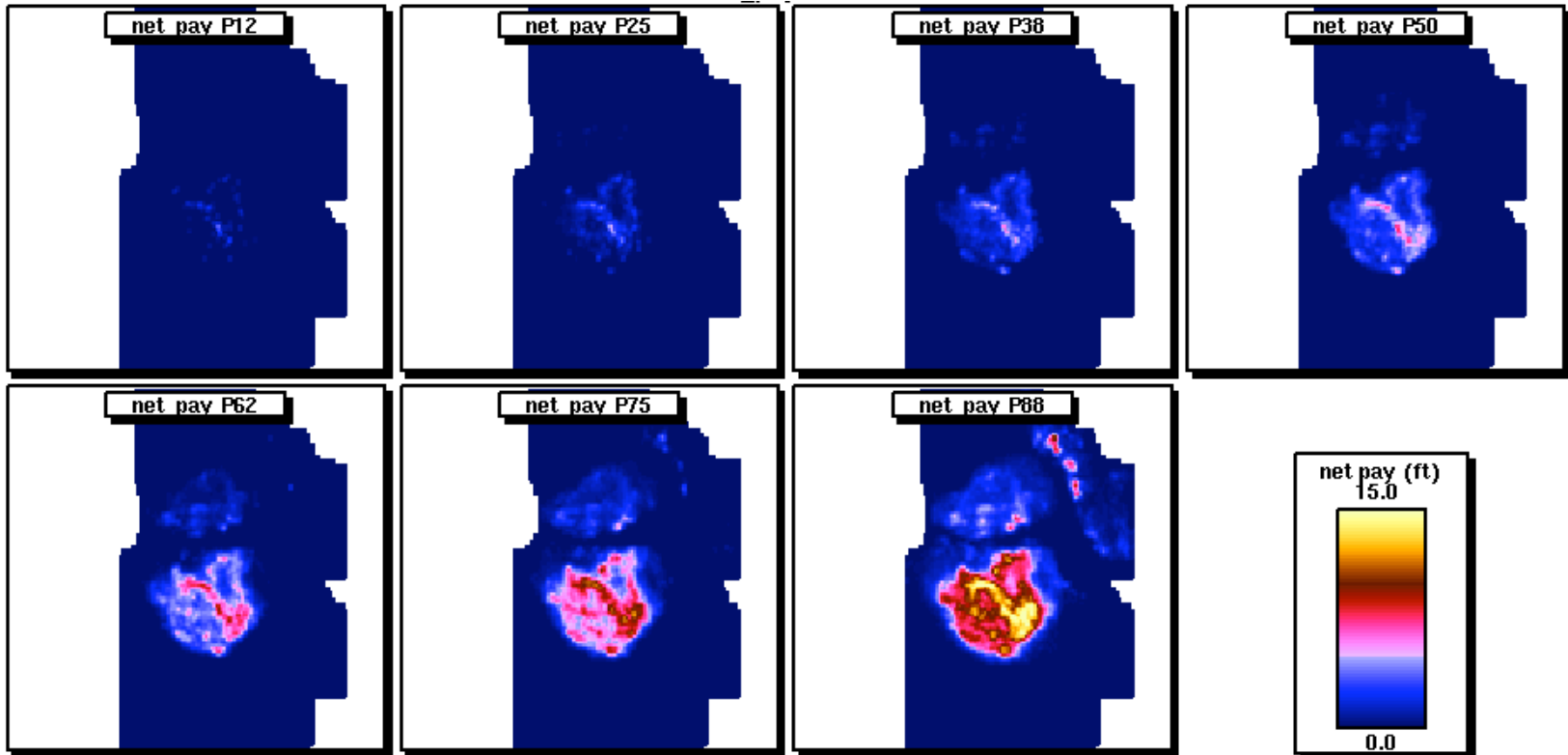


determined
by seismic

Where does seismic help determine net pay?

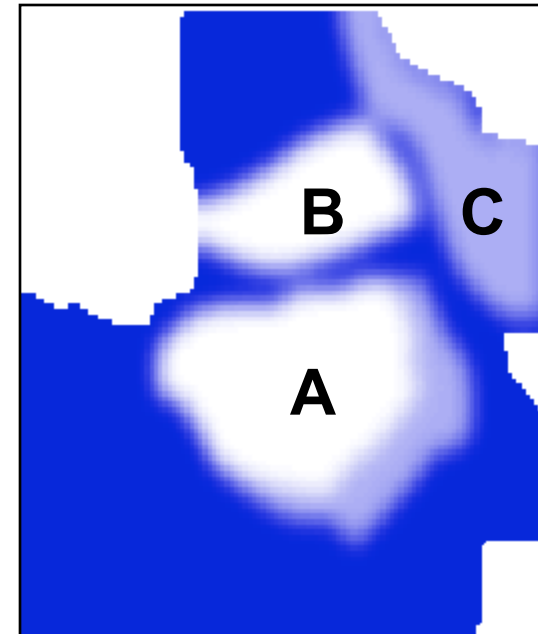
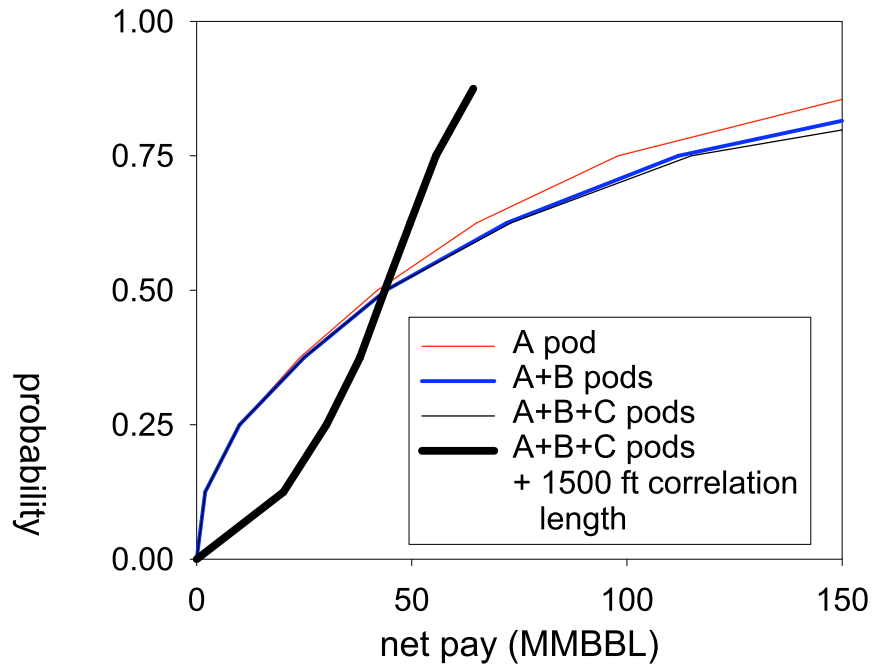


Probabilistic inversion gives distribution of net pay maps



note: assumes long correlation length

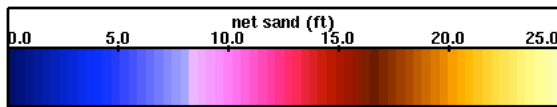
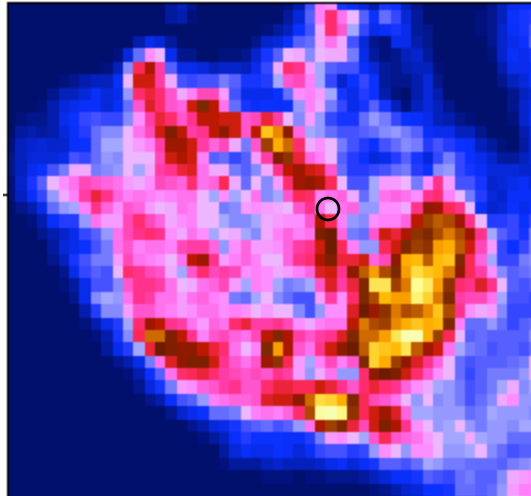
Different pods contribute to different parts of the distribution of net pay



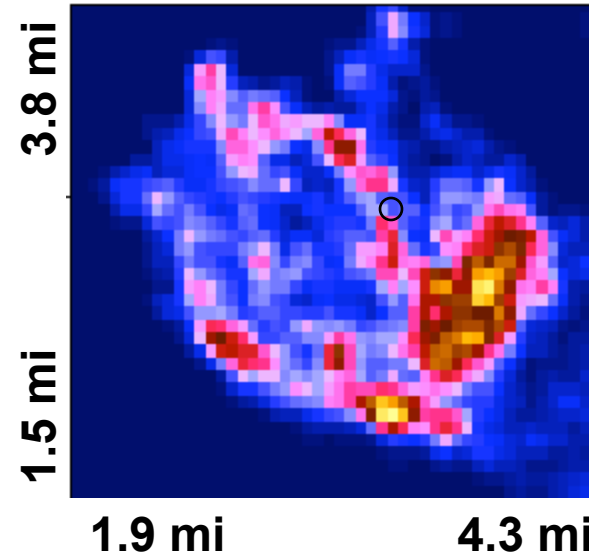
Seismic correlation of N/G and thickness reduces estimate of net sand by 60%



median N/G * median thickness
(with no correlation)



median net sand
(with correlation)



○ = well 522-1

$$\langle \text{net sand} \rangle = \langle \text{N/G} \rangle \langle \text{thickness} \rangle + \langle (\delta \text{N/G}) (\delta \text{thickness}) \rangle$$

Probabilistic inversion changes volumetric uncertainties



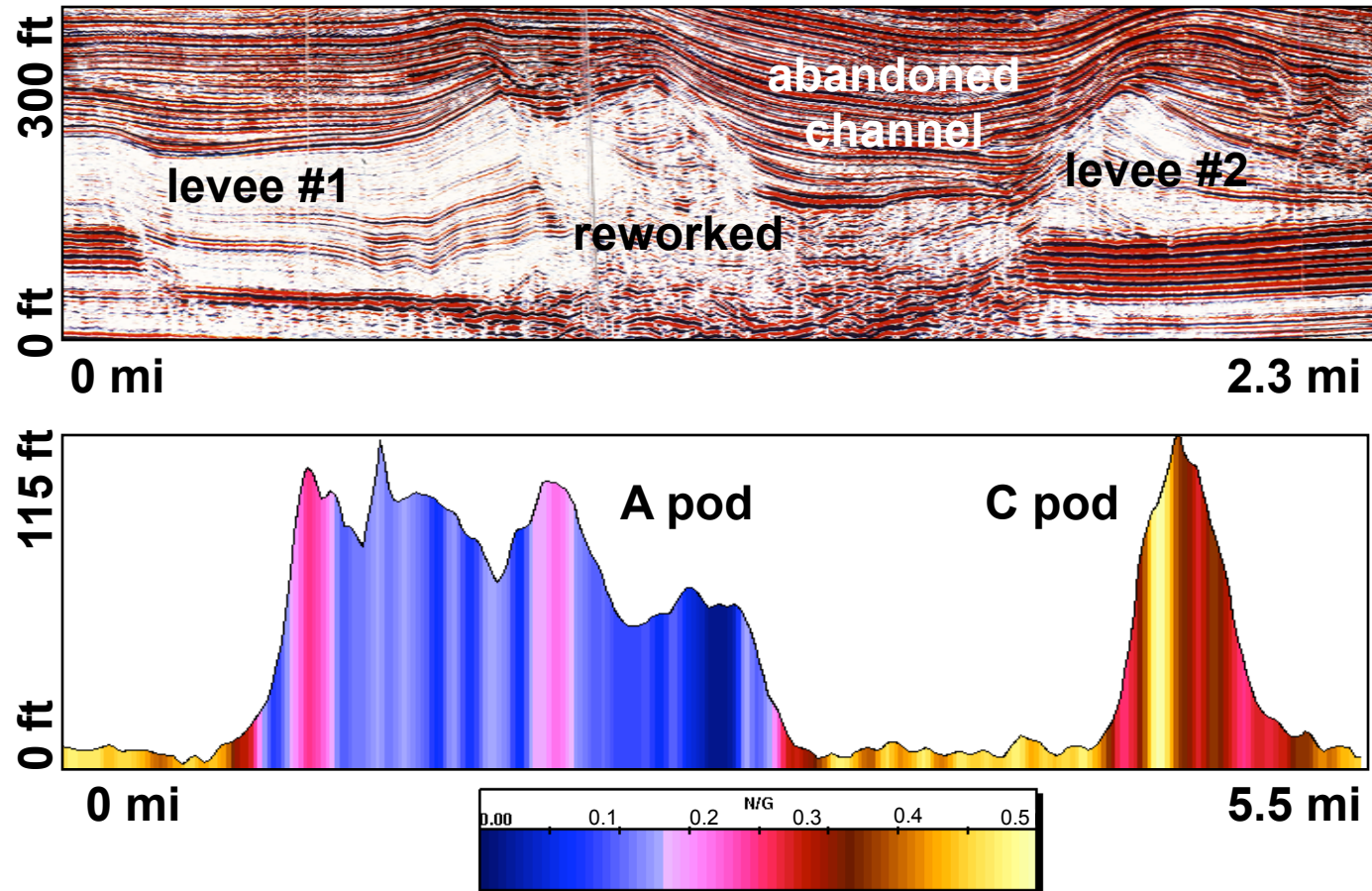
- N/G of upper BS20 is reduced (factor of 2.1)
- correlation of N/G and thickness reduced net sand (factor of 1.7)
- high spacial variation in upper BS20 (net sand can change by a factor of 3 within 100 ft) -- maybe a reworked levee

gas pore volume in upper BS20 A pod (MMBBL)	estimate before inversion	probabilistic inversion estimate	with 1500 ft correlation length
P12	34	1	10
P50	79	22	22
P88	156	180	37

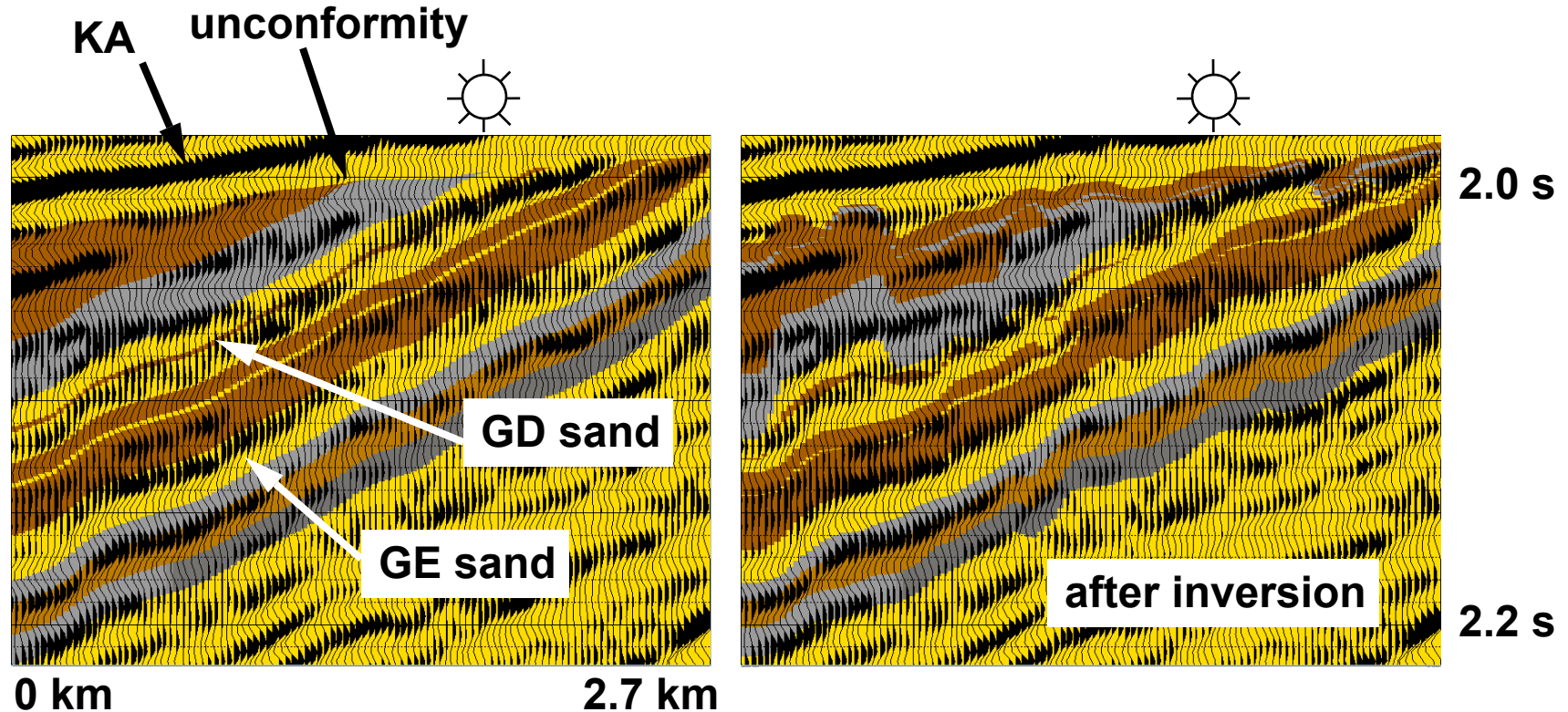
Upper BS20 as a levee



Einstien shallow seismic data (GOM turbidite)



Goodwyn inversion updates P50 model

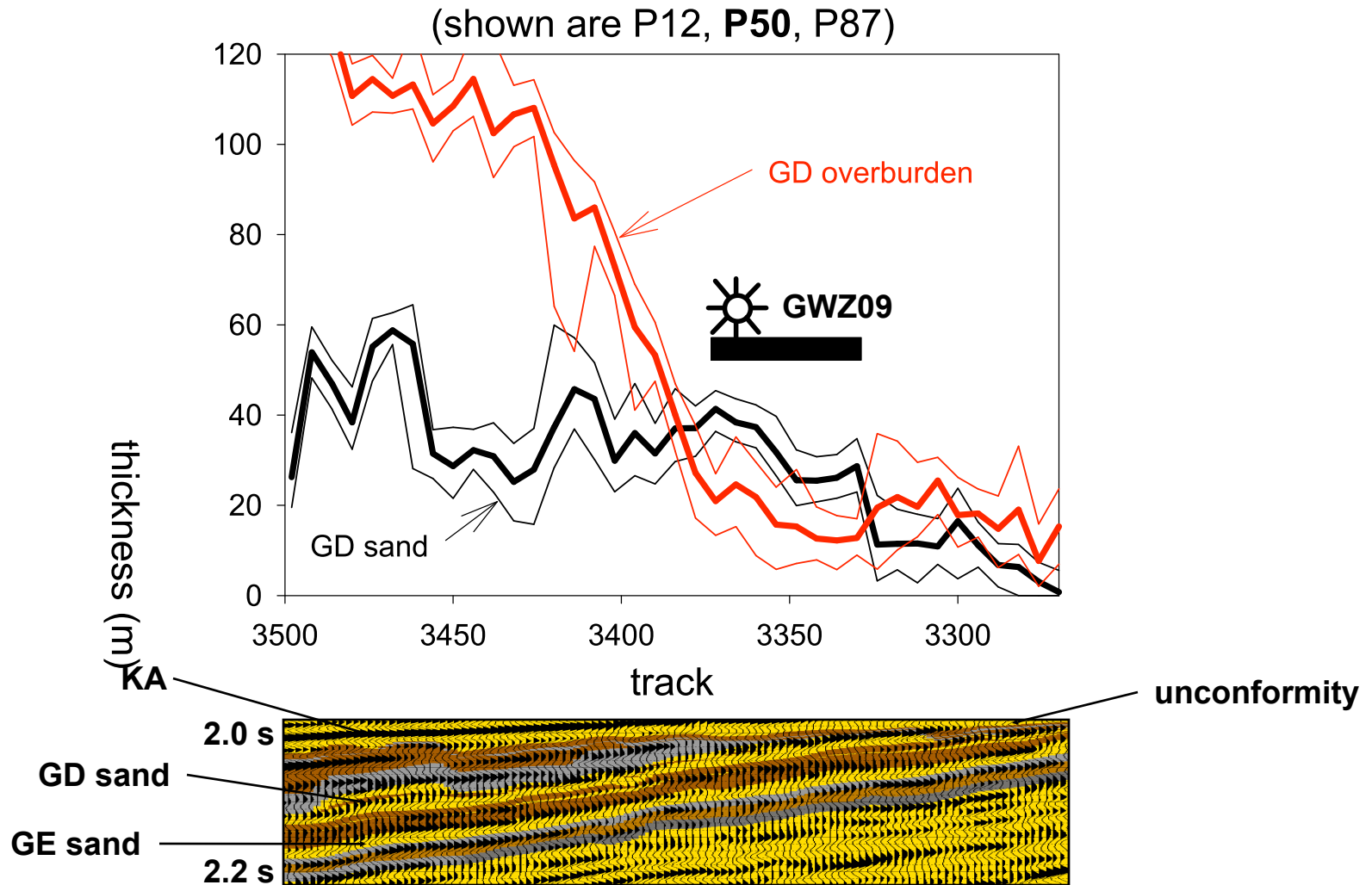


KA, unconformity, and base GE sand constrained to 4 ms

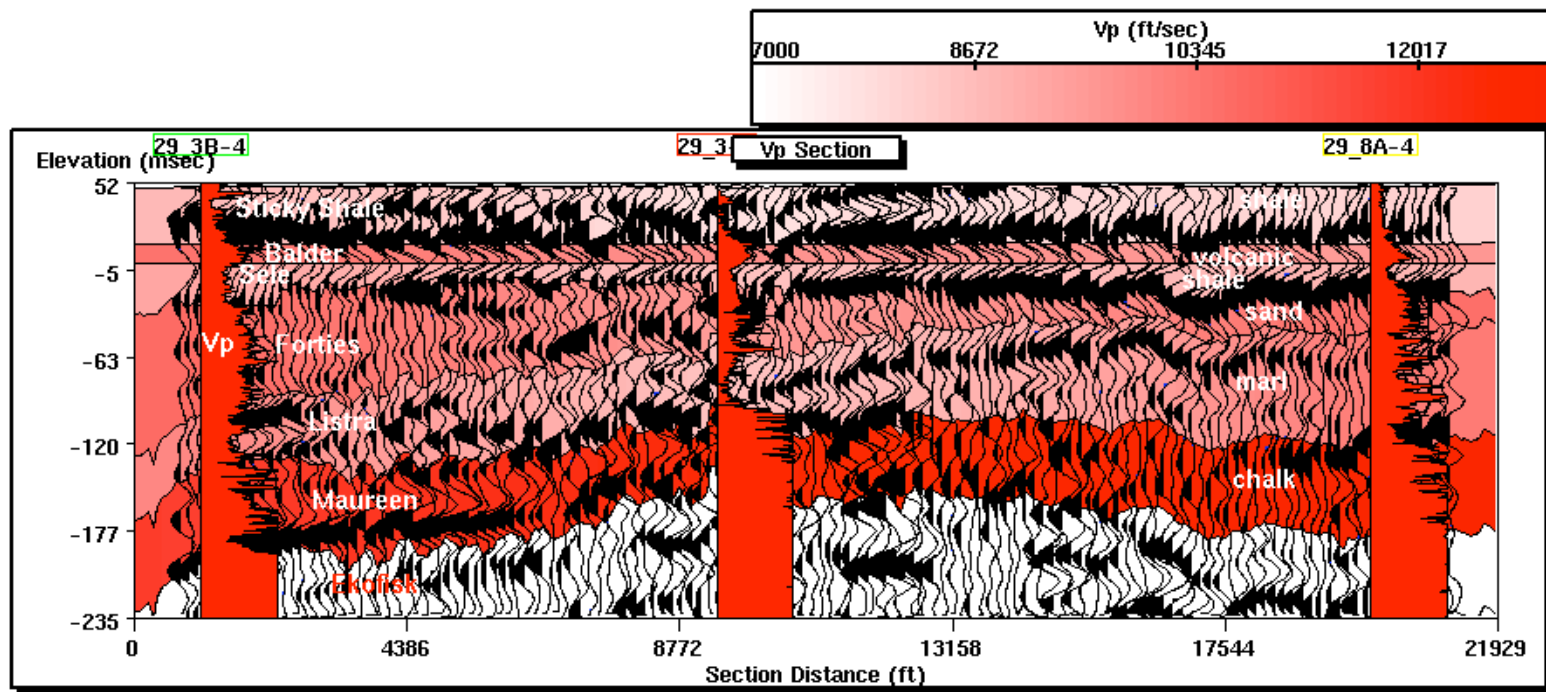
$\sigma_{vp} = 100$ m/s, $\sigma_{\rho} = 0.03$ gm/cc, $\sigma_{thickness} = 6$ m / layer

(each layer allowed to go to 0 thickness)

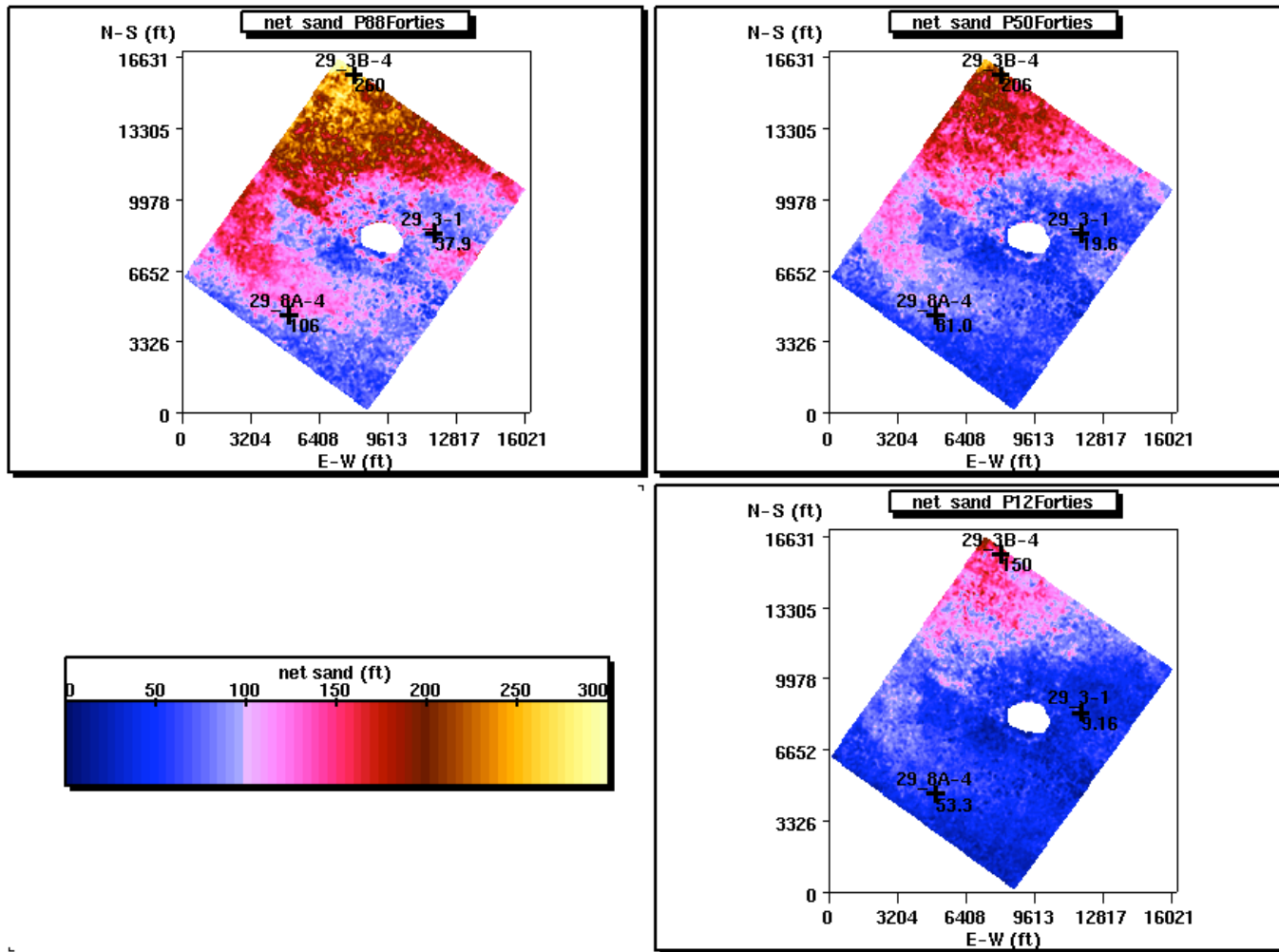
PROMISE estimates location of Goodwyn GD sand subcrop



FRAM (North Sea Forties)



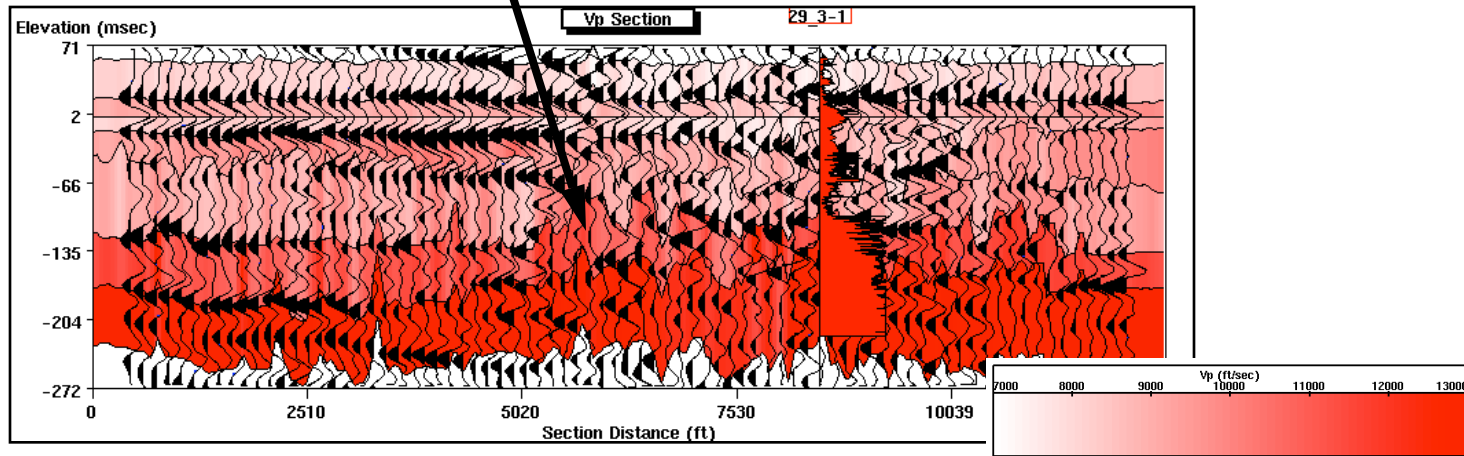
Uncertainty in the net sand estimation



Inverted velocity section shows “loop skipping” near slumps in marl



slumps in marl due to slope near salt dome



marl beneath
Aren sandstone
(Tresp basin)
slumping due to
uplift

Unique Shell capabilities exist to quantify subsurface geology



- **estimates of parameters and uncertainties**
 - petrophysical uncertainties integrated with seismic
 - parameters that matter estimated
 - N/G
 - saturations
 - porosity
 - etc.
- **multiple stack AVO/4D inversion**
 - one model fits multiple stacks
 - reduces uncertainty
- **probabilistic inversion done on business relevant time scale**
 - DepSim model built, petrophysics analyzed, and PROMISE inversion done in 8 calendar days (FRAM, North Sea Forties)