Facies probabilities from seismic data in Mamm Creek Field, Piceance Basin, Colorado

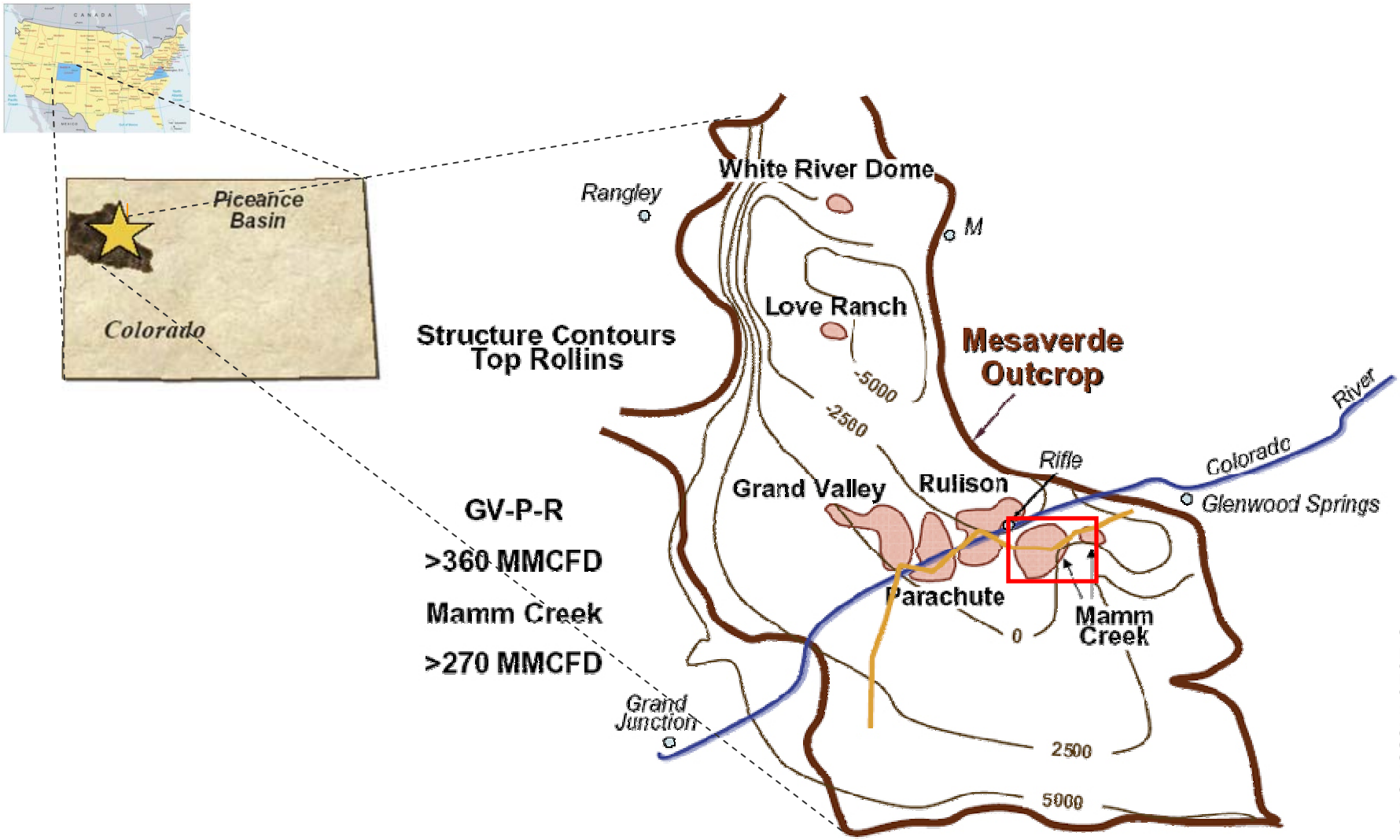
Reinaldo J Michelena
Kevin S Godbey
Patricia E Rodrigues
Mike J Uland

July, 2010

Mamm Creek Field: details

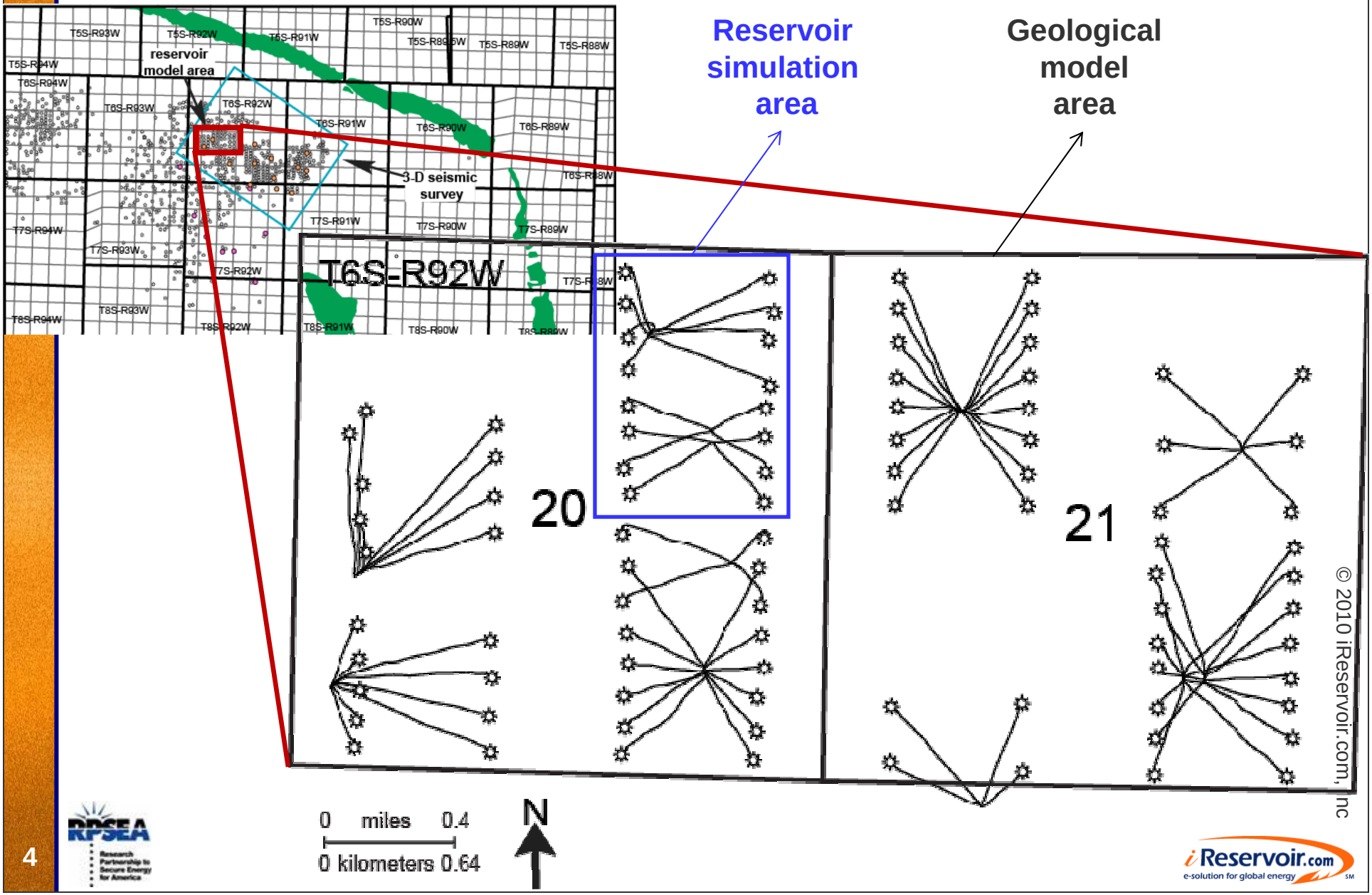
- Complex reservoir architecture: high degree of vertical and lateral compartmentalization, particularly in fluvial Williams Fork Formation
- OGIP estimated in more than 1 TCF
- Ultra tight reservoir: median permeability ranges from of 0.02 to 0.04 mD and median total porosity of 9%.
- Multi-stage hydraulic fracture stimulation and well density of at least 1 well/10 acres have become standard practices in the field

Location of Piceance Basin

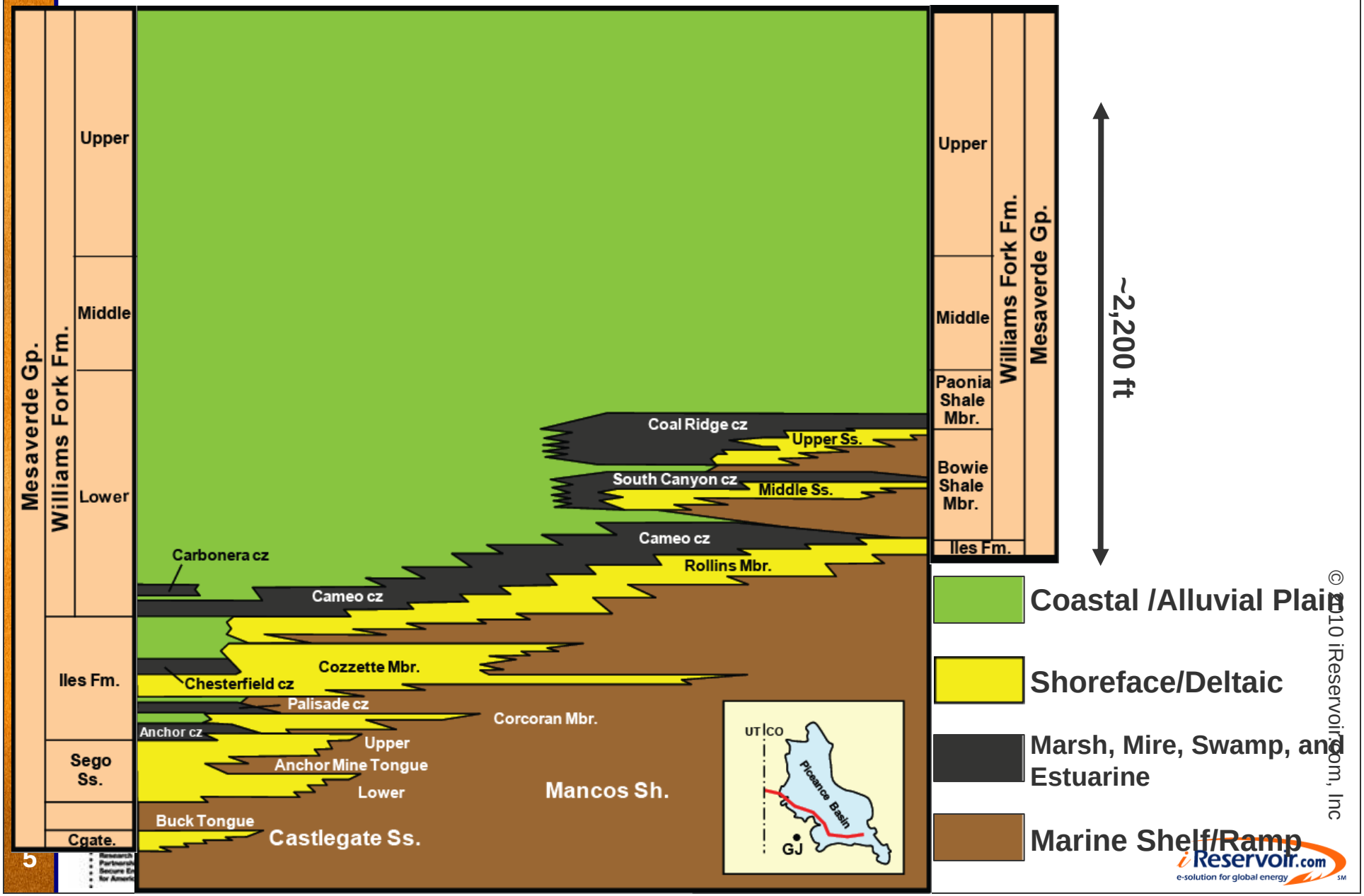


Modified from Law and Johnson (1989)

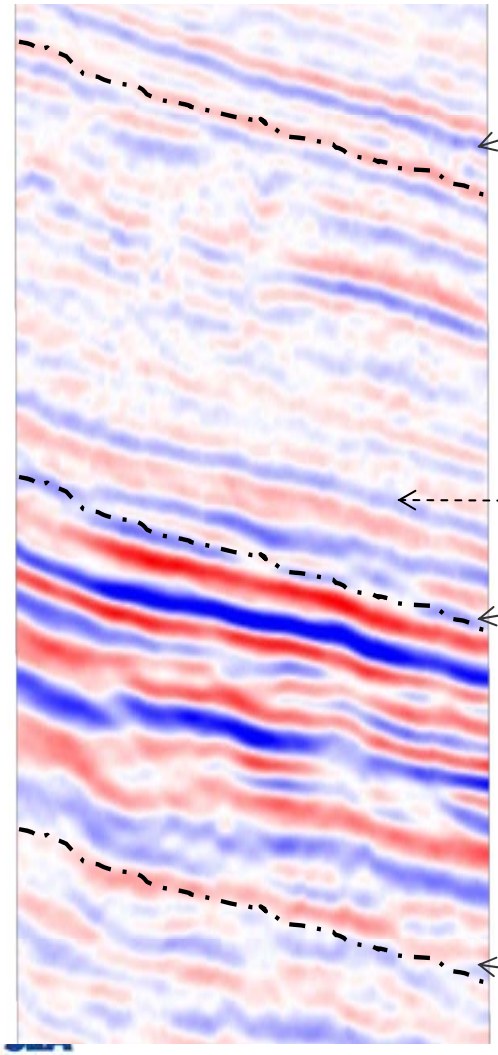
Area of interest in Mamm Creek Field



Stratigraphic column



Intervals of interest for seismic analysis



Seismic amplitudes

density log

seismic trace

Price Coal

UMV

Lower amplitudes (fluvial)

beginning of coal interval

MiddleSS

Higher amplitudes (transitional and marine)

Rollins

Cozette

Mancos

Reservoir characterization at Mamm Creek

MOTIVATION

- Effective development of Mamm Creek field requires detailed understanding of all geological features that control gas accumulation and connectivity

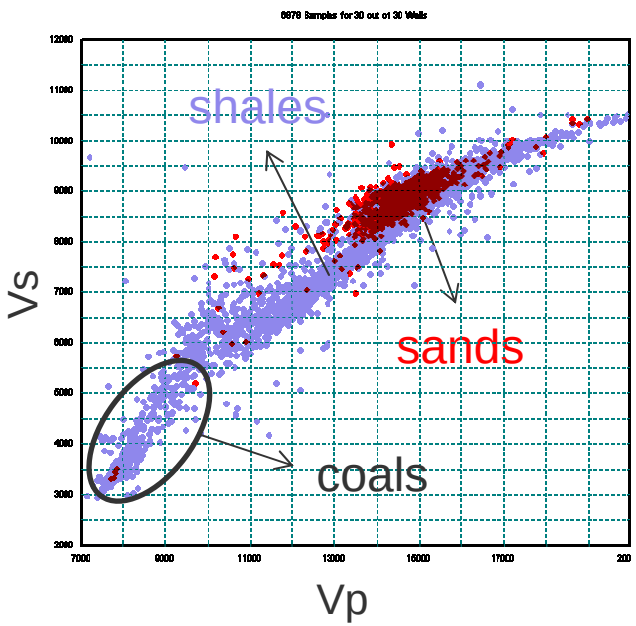
GOAL

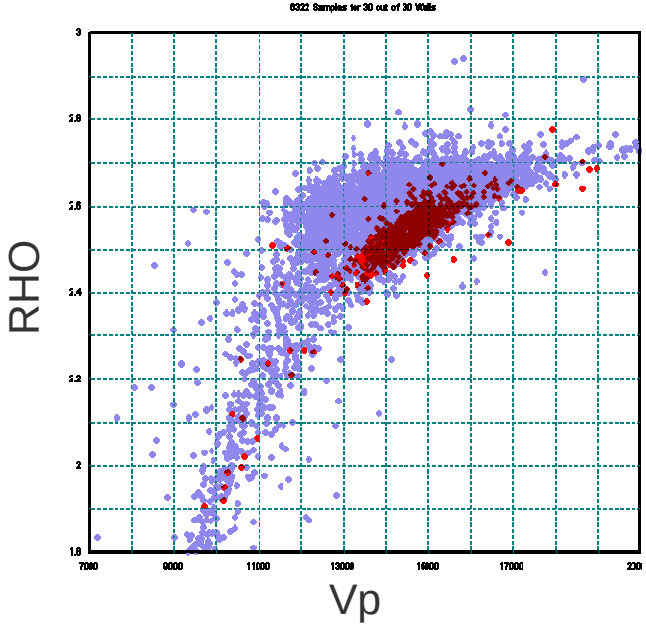
- Build geological models that capture the main geological complexities of the field

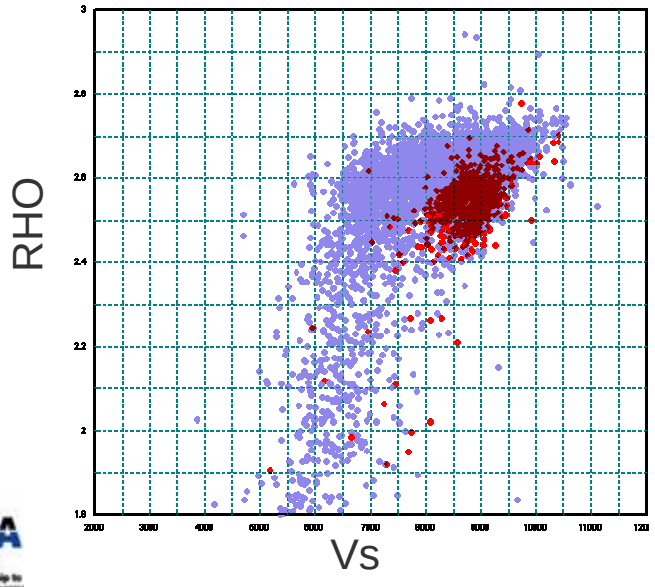
Show how seismic data can be used to help mapping sand distribution in Mamm Creek field

this presentation

Challenges from rock physics diagnostics







Potential difficulties:

1)Sands and shales show significant overlap in log scale crossplots of elastic properties

2)Presence of thin coal layers may mask “real” seismic response from surroundings sands and shales.

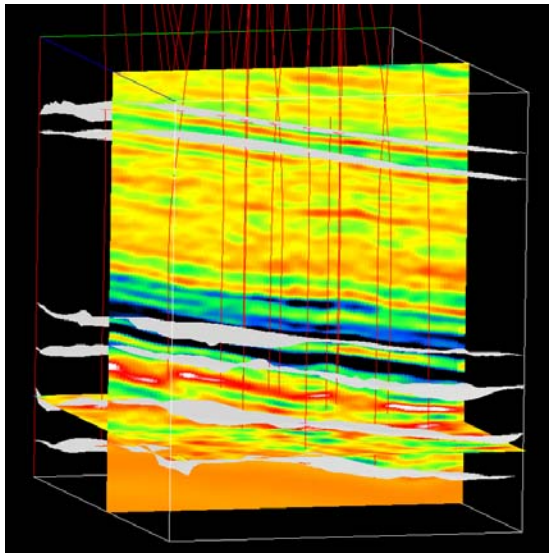
Data inventory

- **Seismic:**
  - 3D, PP pre-stack, NMO corrected gathers
  - 3D PS_fast and PS_slow stack volumes (not part of same survey as PP data)
- **Well:**
  - 102 density logs. Most wells with Gamma Ray, Neutron Porosity and Resistivity
  - 3 sonic logs
  - 2 dipole sonic logs (one of them crossdipole)
  - Formation tops from Bill Barrett Corporation
  - 8 cores
  - 12 FMI logs

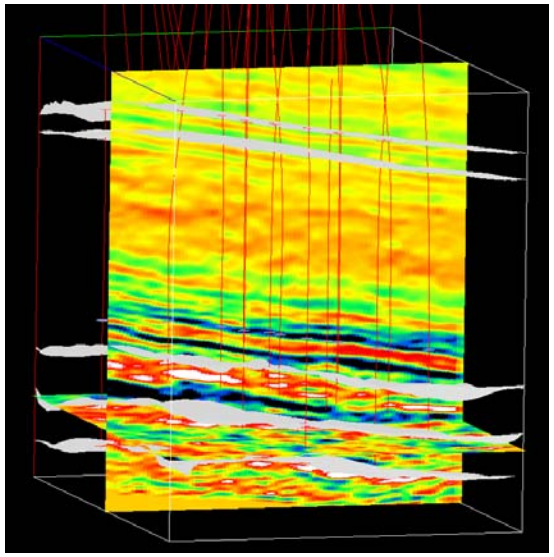
Summary of seismic workflow

- Perform petrophysics/rock physics diagnostics
- QC seismic data
- Precondition pre-stack gathers for AVO analysis
- Interpret PP data
- Interpret PS data (consistent with PP interpretation)
- Invert PP pre-stack data for Vp, Vs and density
- Invert PS stack data for pseudo shear impedance (Zps)
- Generate velocity model that honors all marker and horizon information in PP and PS time
- Perform time to depth conversion of seismic derived information

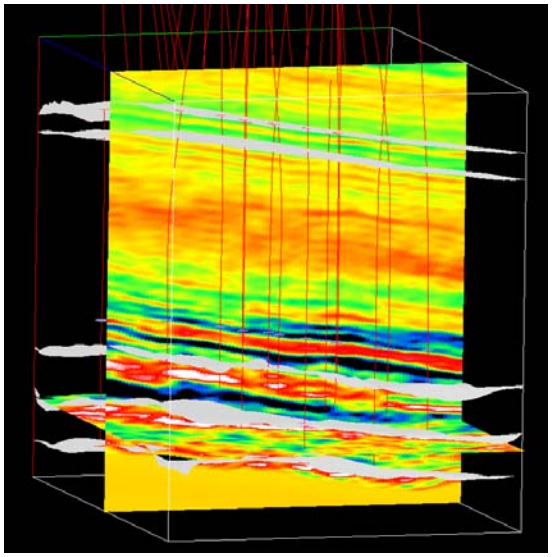
Inverted seismic volumes in depth



RHO



Vp

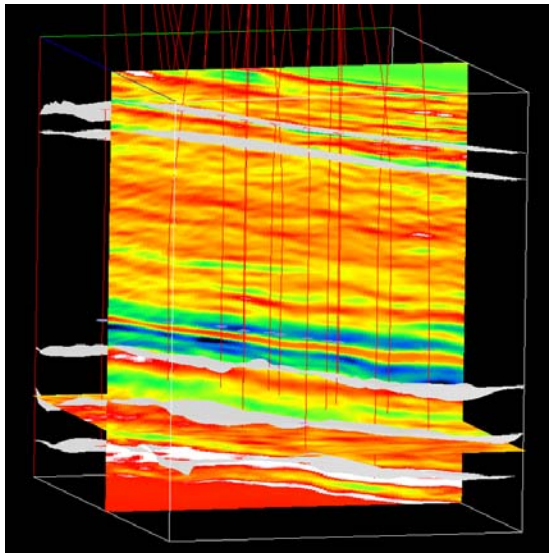


Vs

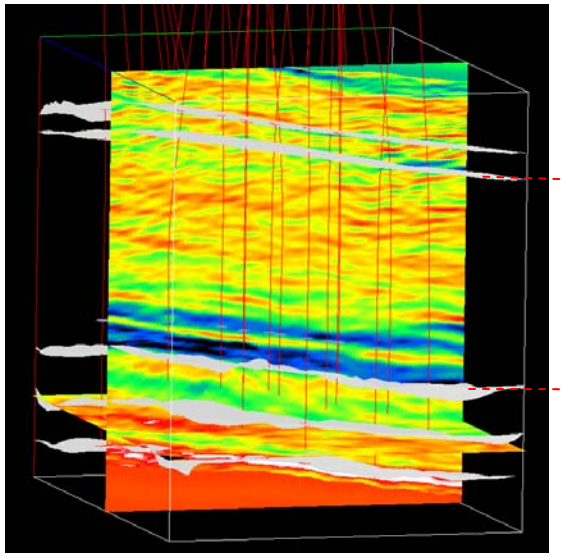
Z

high

low



Zps_fast



Zps_slow

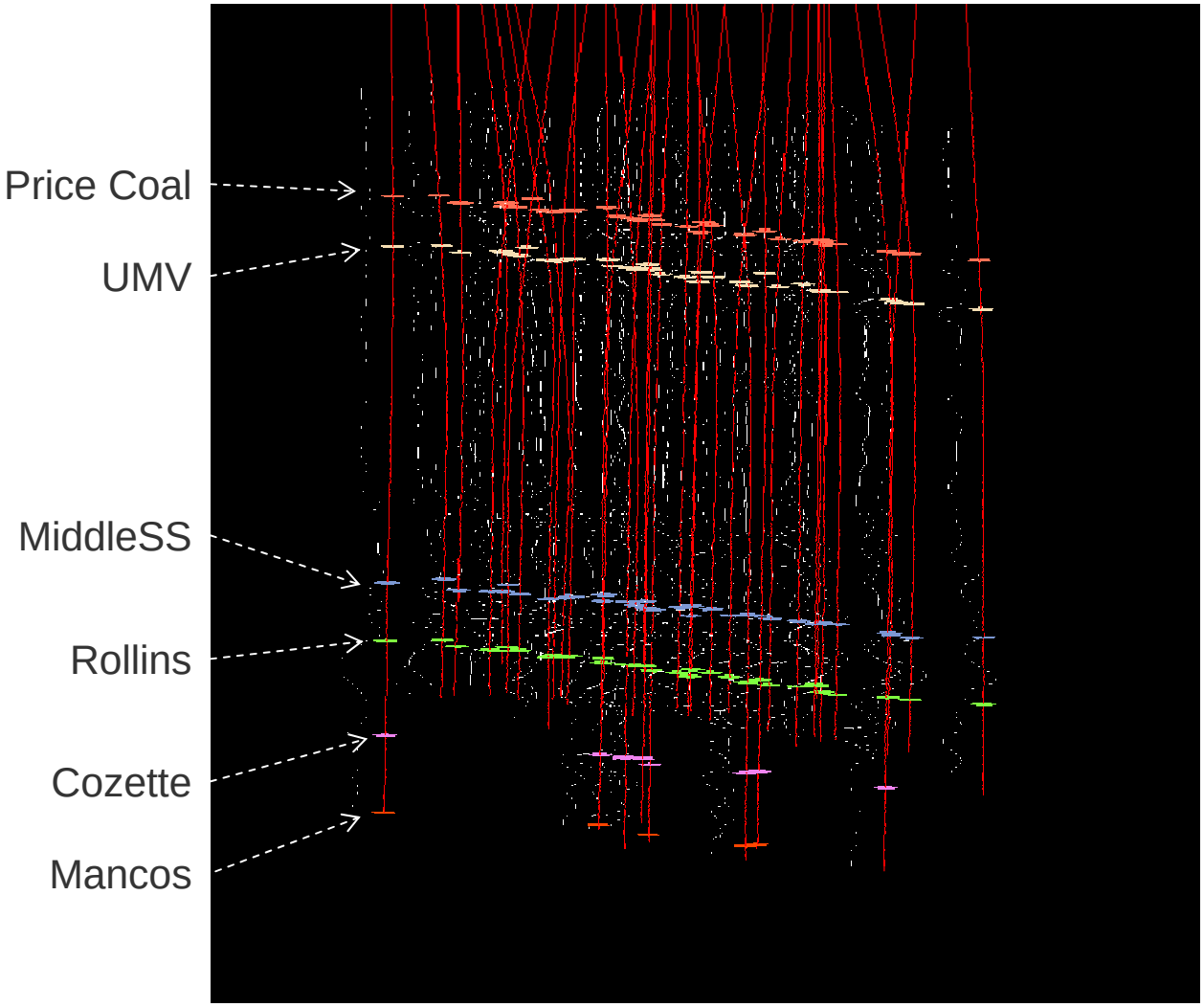
UMV

MIddleSS

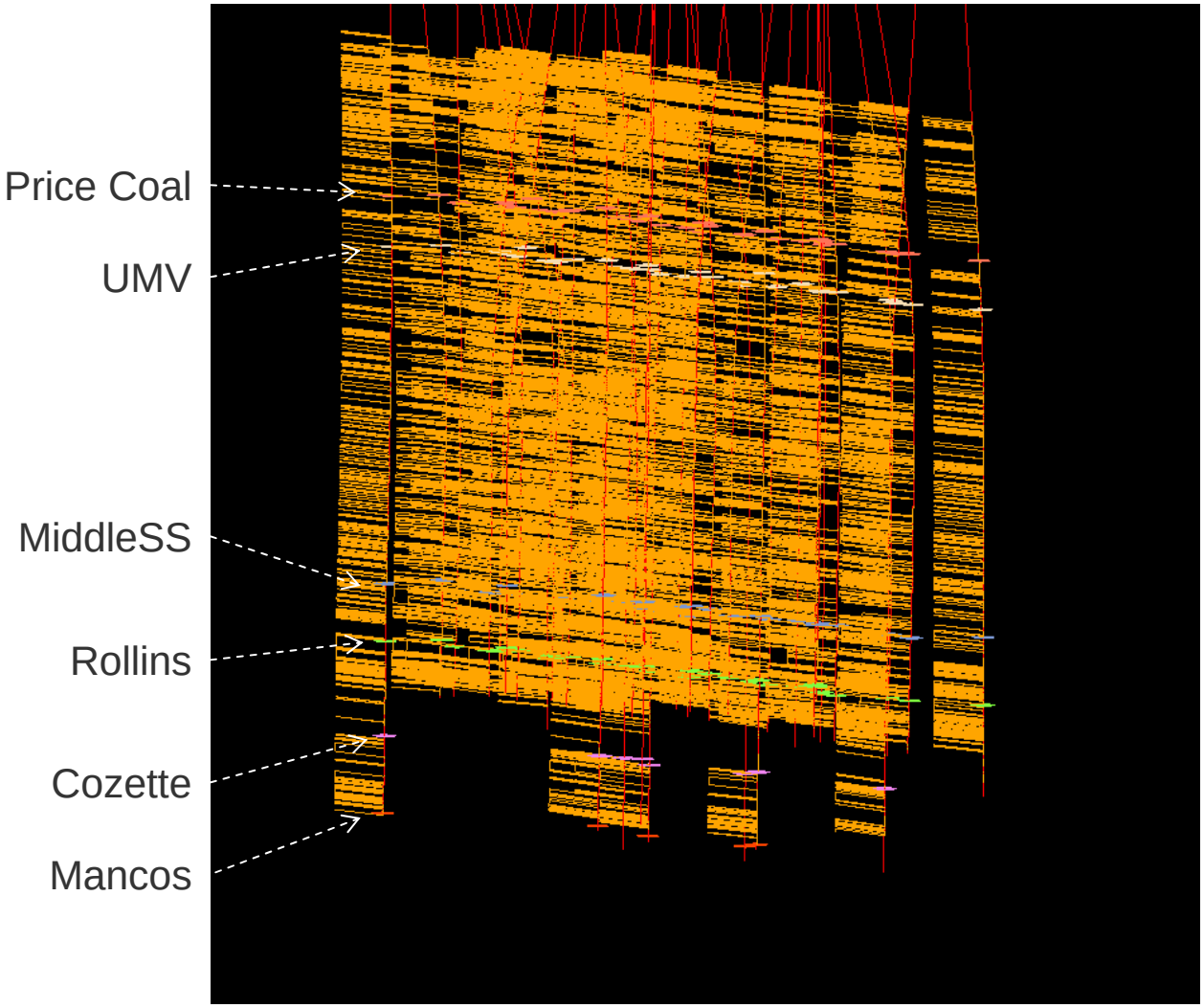
Attribute crossplots

- Inverted seismic attributes (3 from PP and 2 from PS) can be cross plotted in many different ways
- After examining various combinations of these five attributes, we decided to focus only on 6 of such combinations and assess the contribution of each attribute:
  - **Vp** vs **Vs**
  - **Vp** vs **RHO**
  - **Vs** vs **RHO**
  - **Zps**$_{fast}$ vs **Zps**$_{slow}$
  - **Vp** vs **Vs** vs **RHO**
  - **Vp** vs **Vs** vs **RHO** vs **Zps**$_{fast}$ vs **Zps**$_{slow}$

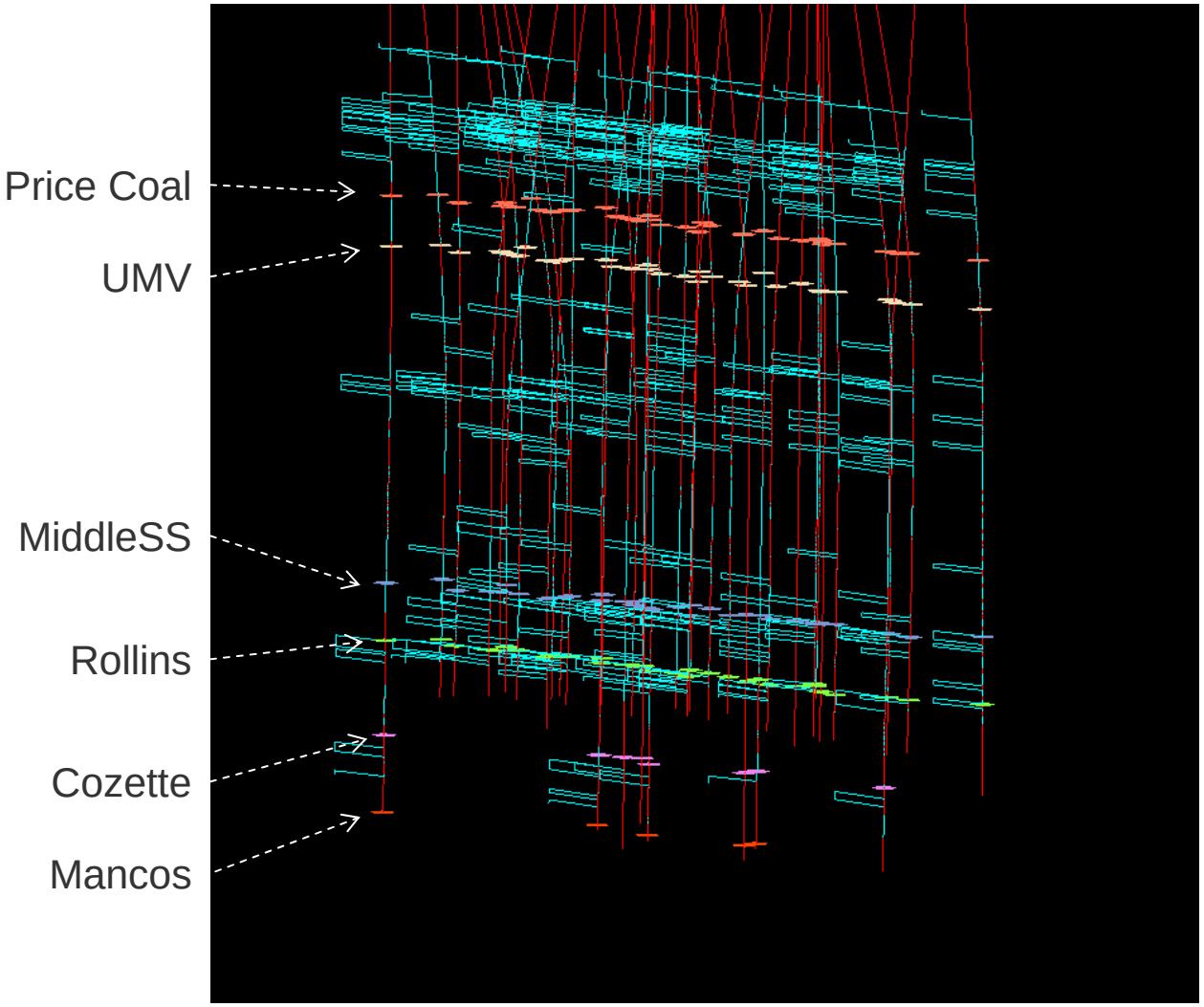
Seismic attribute extracted at well locations



Sand flags based on lithology rules

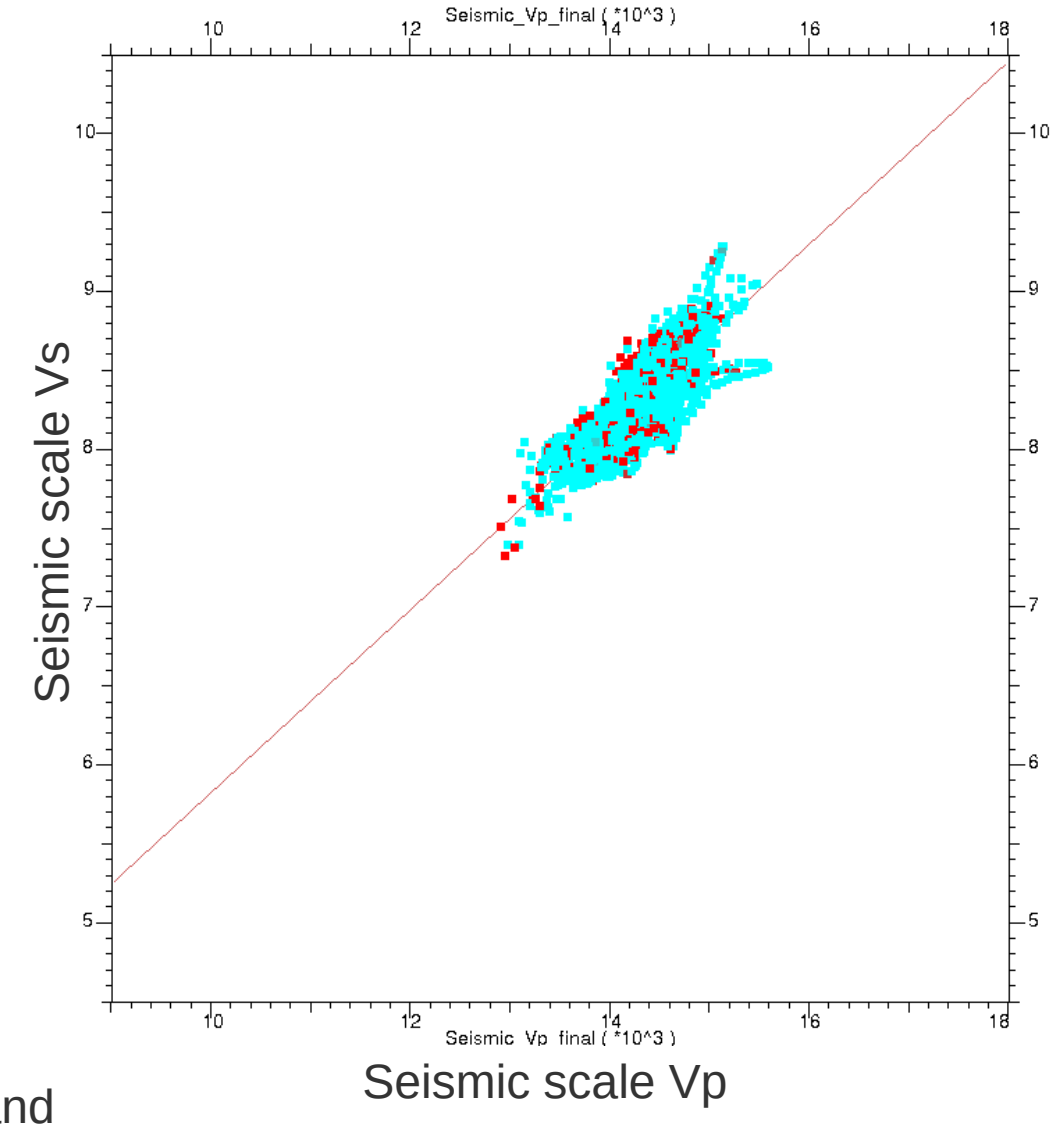


Thick sands facies (~> 15 feet) from sand flags



Thick sand flags created using “most likely class” moving window of 20 samples

Seismic scale Vp vs Vs (fluvial interval)



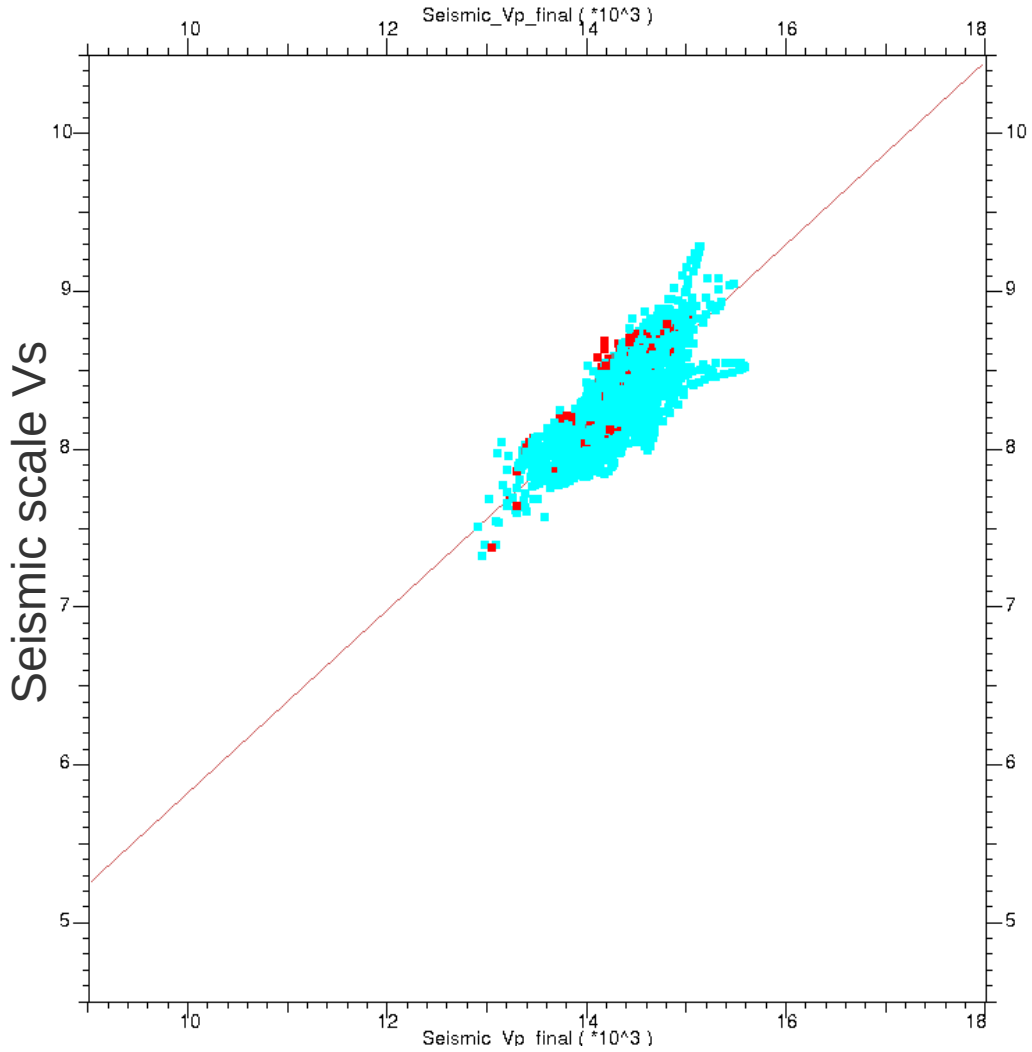
Sand

Background

Flag = Sand

Interval = UMV-Marker1

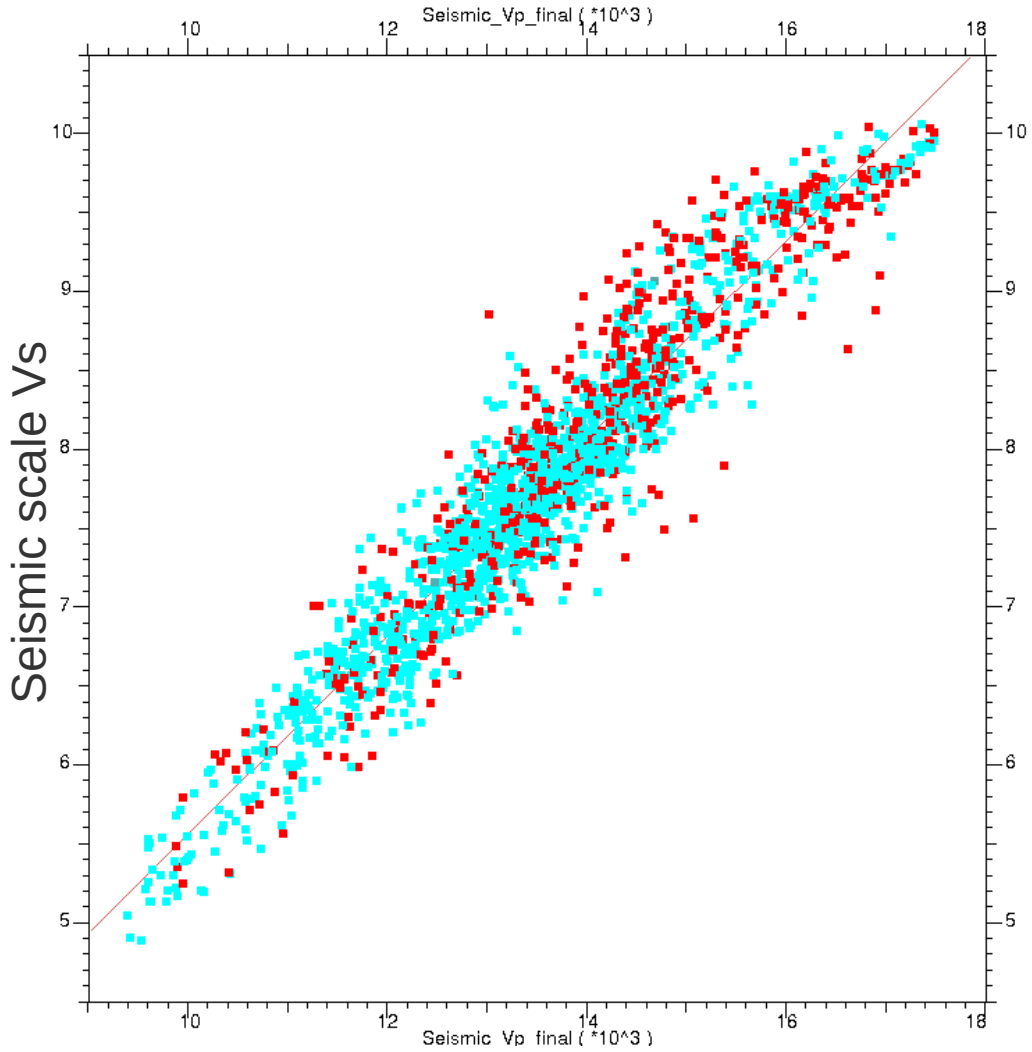
Seismic scale Vp vs Vs (fluvial interval)



Flag = MS channel (15 ft)
Interval = UMV-Marker1

Thick sand
Background

Seismic scale Vp vs Vs (marine interval)



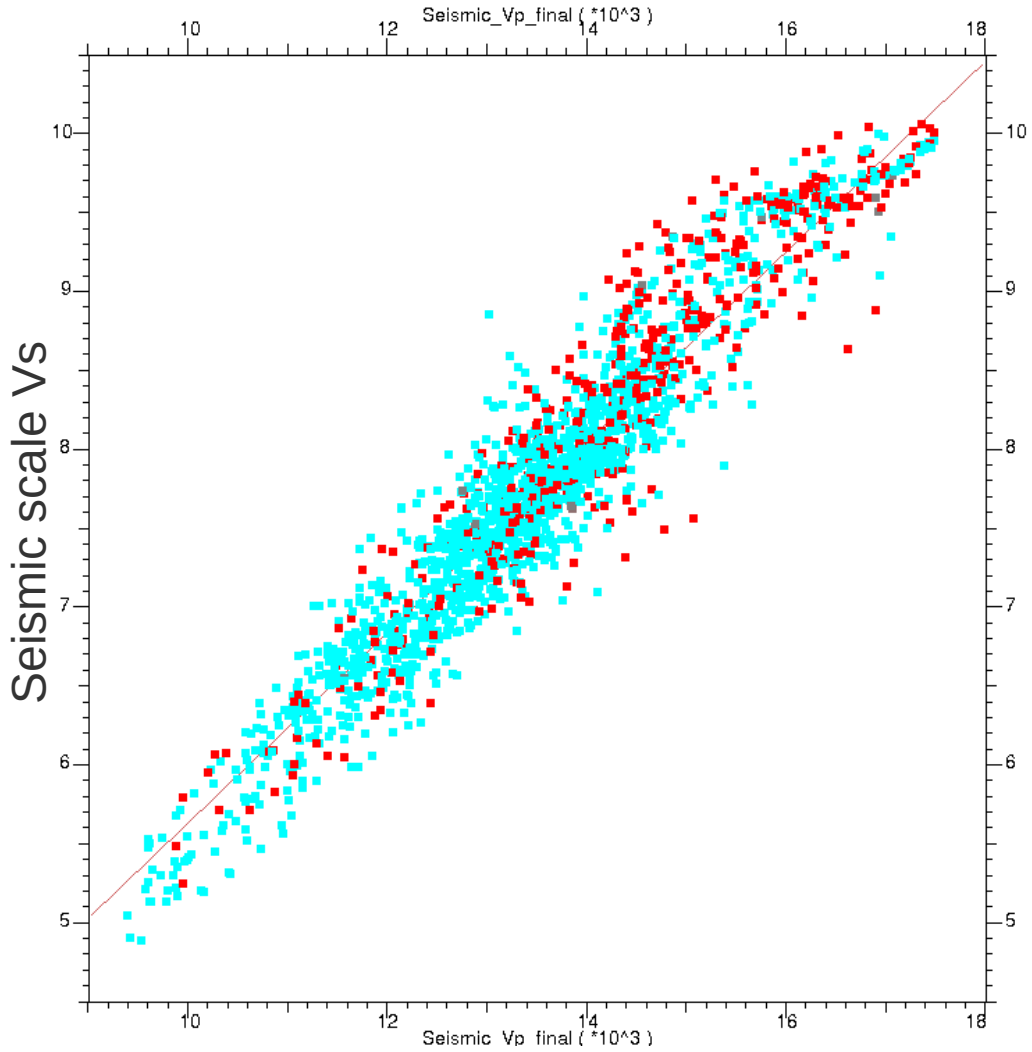
Sand

Background

Flag = Sand

Interval = Marker1-TD

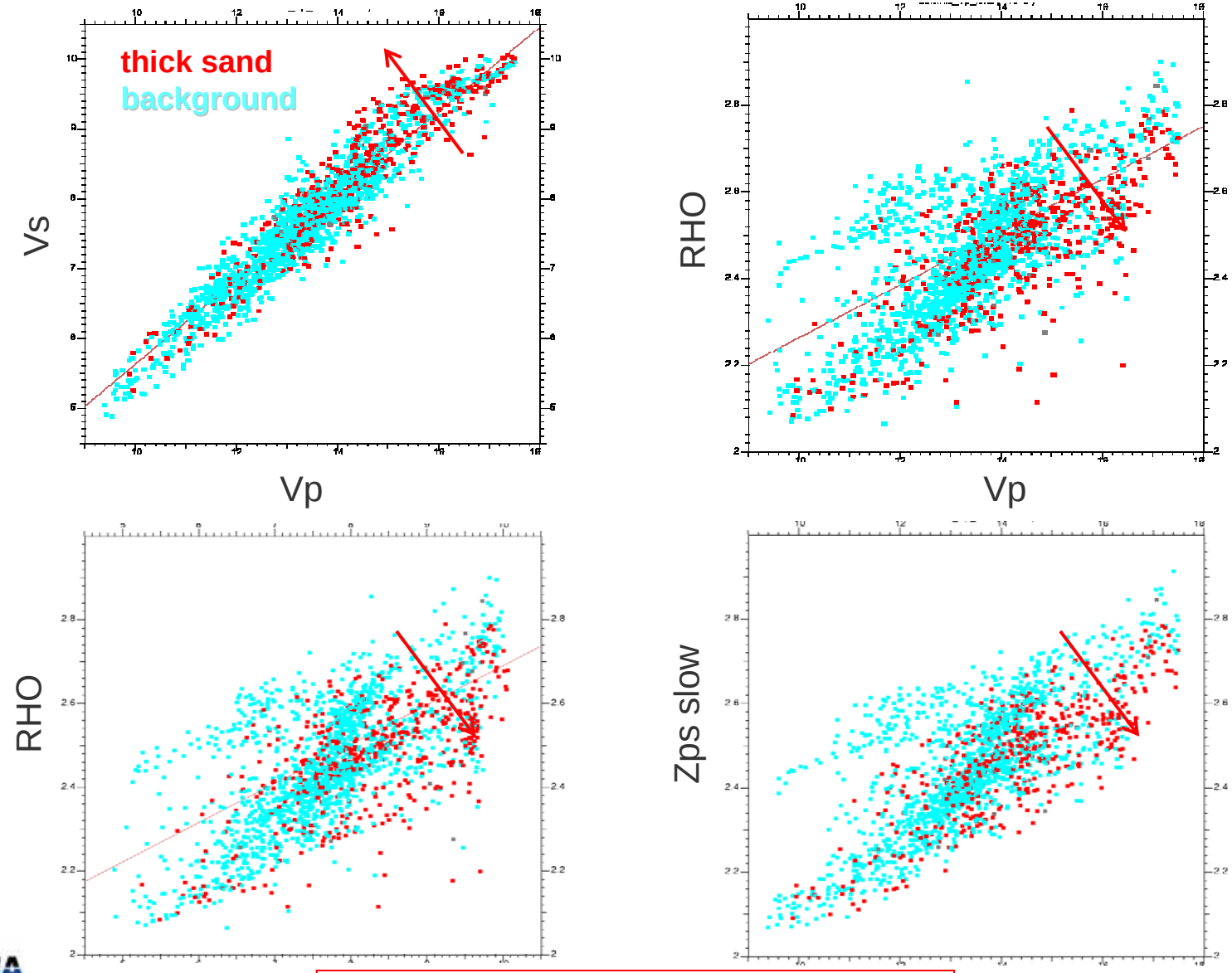
Seismic scale Vp vs Vs (marine interval)



Flag = Thick sand (15 ft)
Interval = Marker1-TD

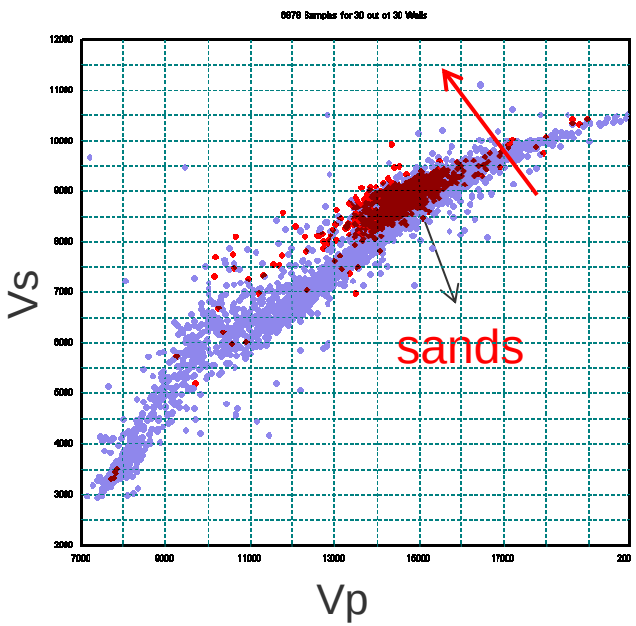
Thick sand
Background

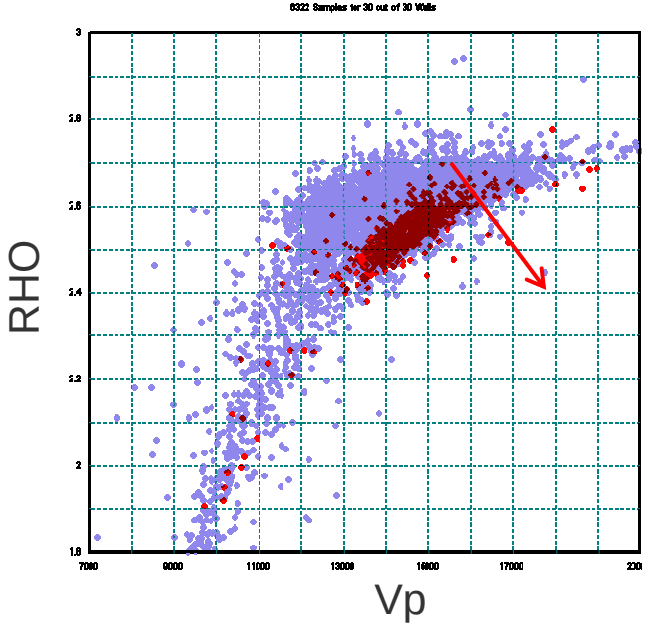
Seismic attributes at well locations (color = log scale facies)

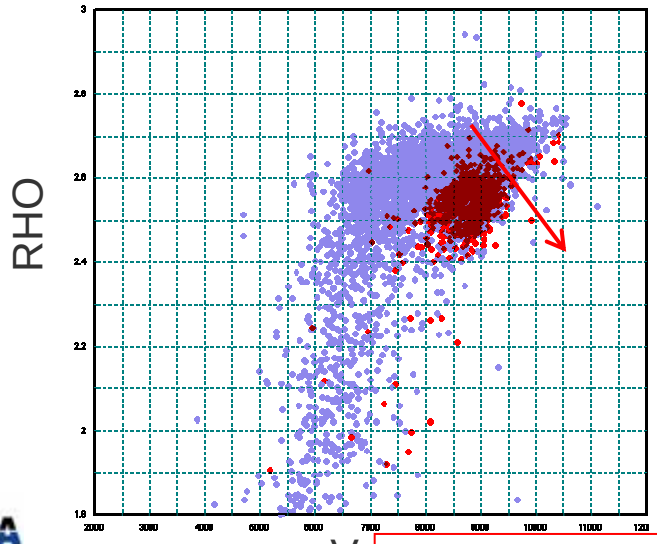


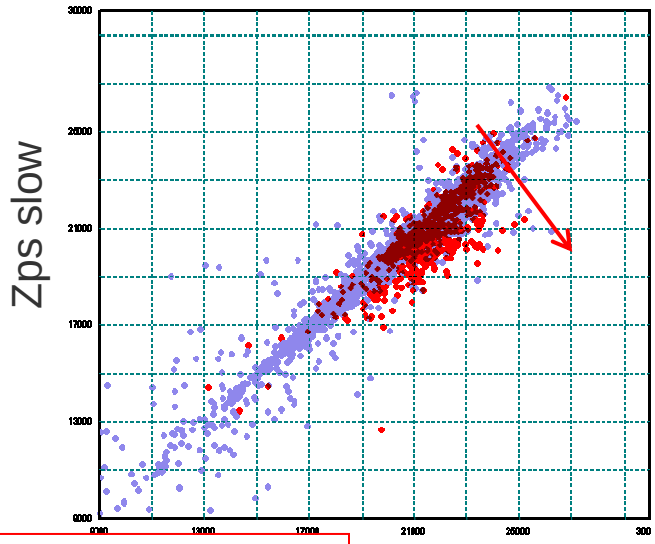
Transitional and marine interval

Log scale attributes (color = lithology)



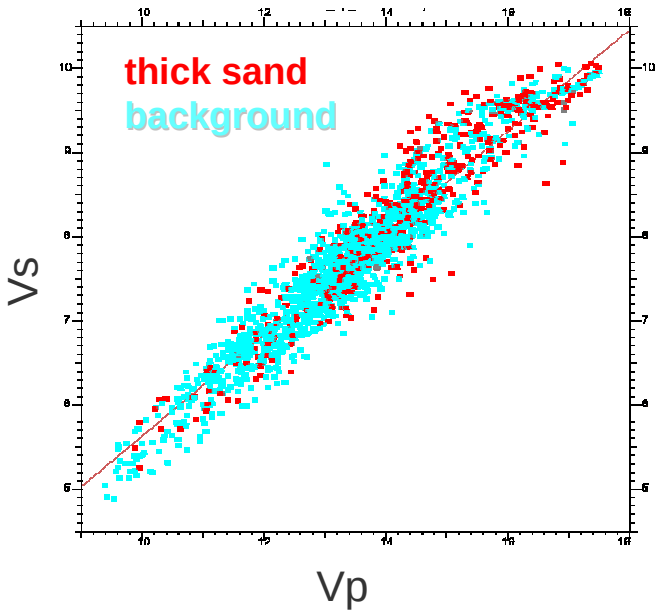


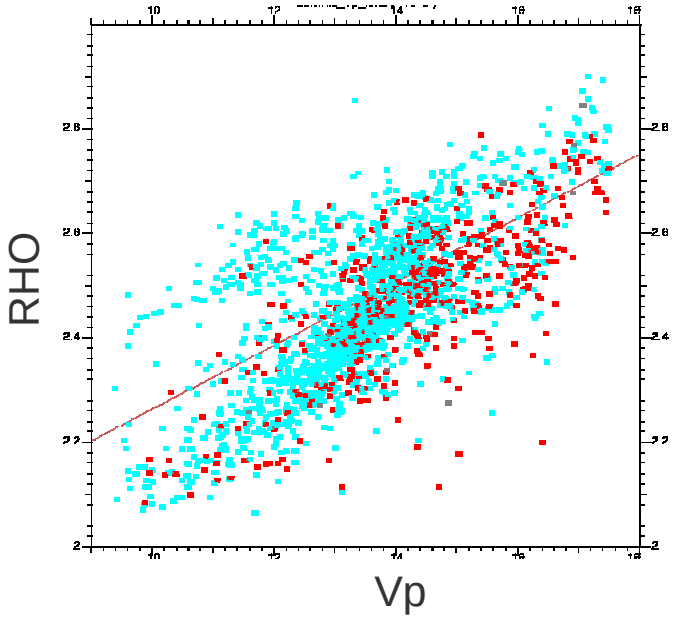


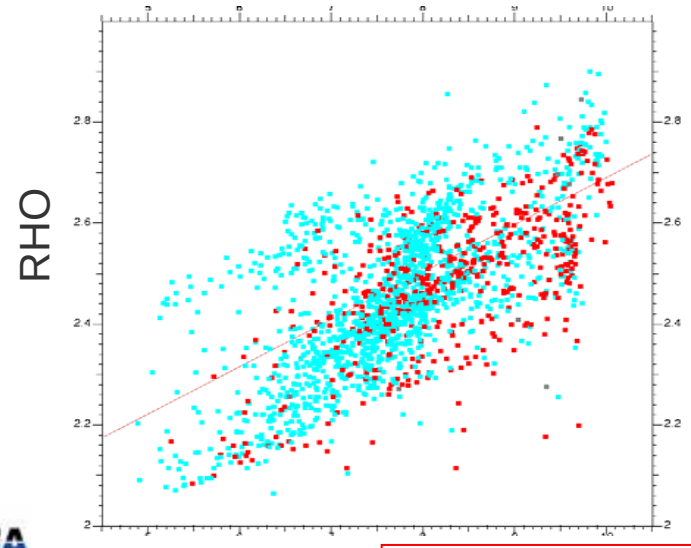


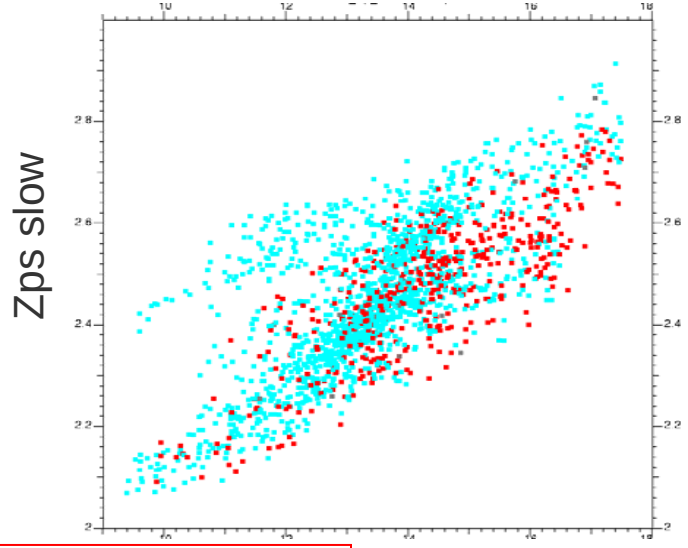
Transitional and marine interval

Seismic attributes at well locations (color = log scale facies)



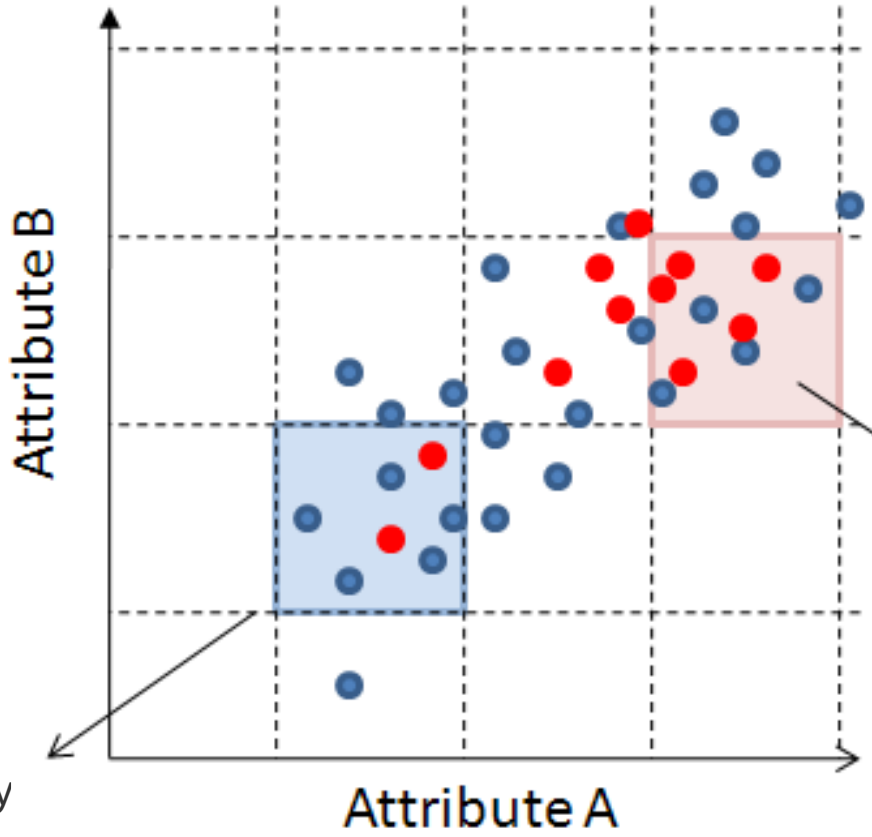






Transitional and marine interval

Probabilities from seismic attribute crossplots



Higher probability of red **(5/9)**

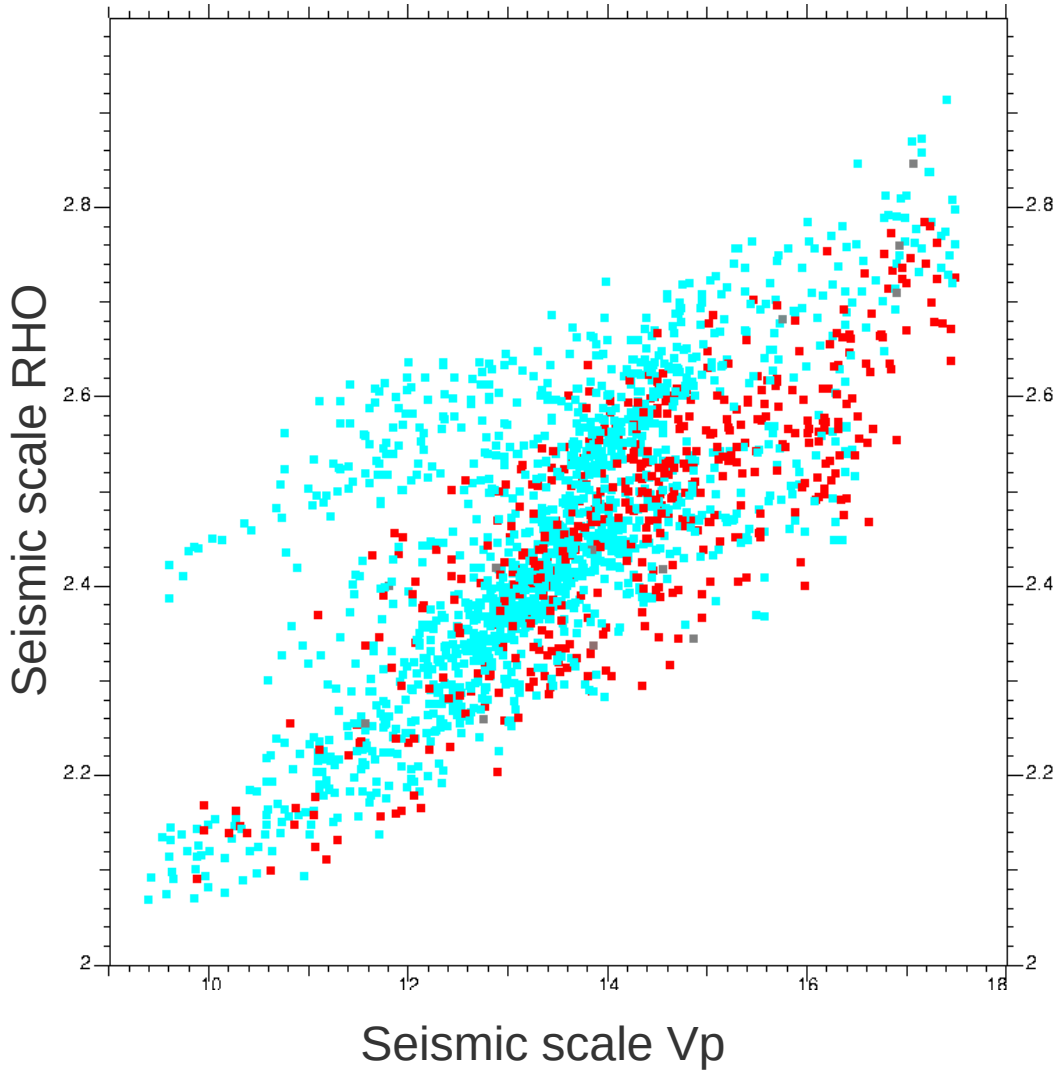
Lower probability of red **(2/7)**

Channel
No channel

Comments about facies probability estimation

- Based on simple probability definitions
- Bayes' formula could be also applied if a reliable prior can be built
- Can be used to analyze crossplots between any number of attributes. For practical reasons, we limit the number of attributes to be analyzed at the same time to five
- Estimates of uncertainty and thickness of target facie can be also extracted

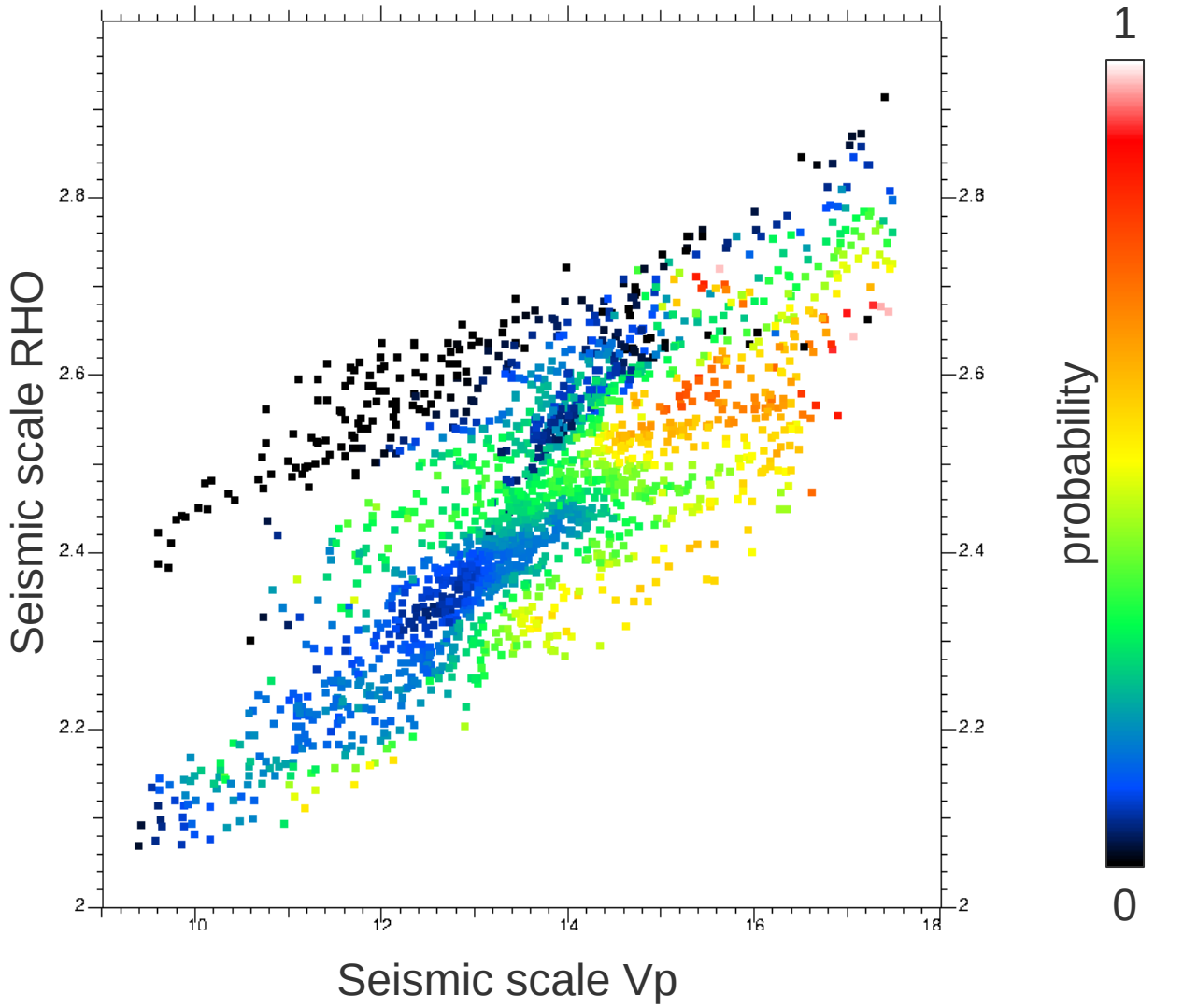
Seismic scale Vp vs RHO (color= log facies)



Thick sand

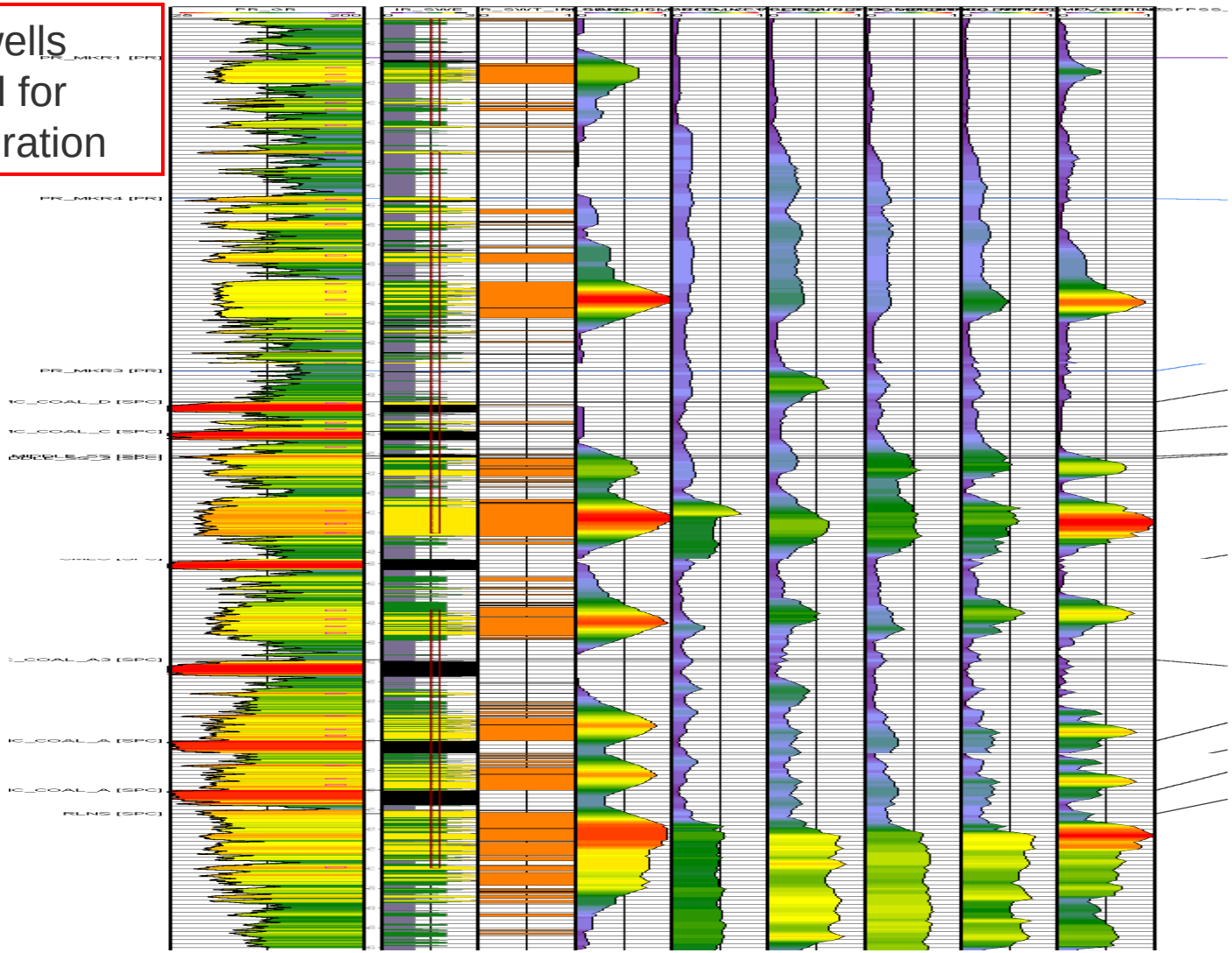
Background

Seismic scale Vp vs RHO (color= thick sand probability)



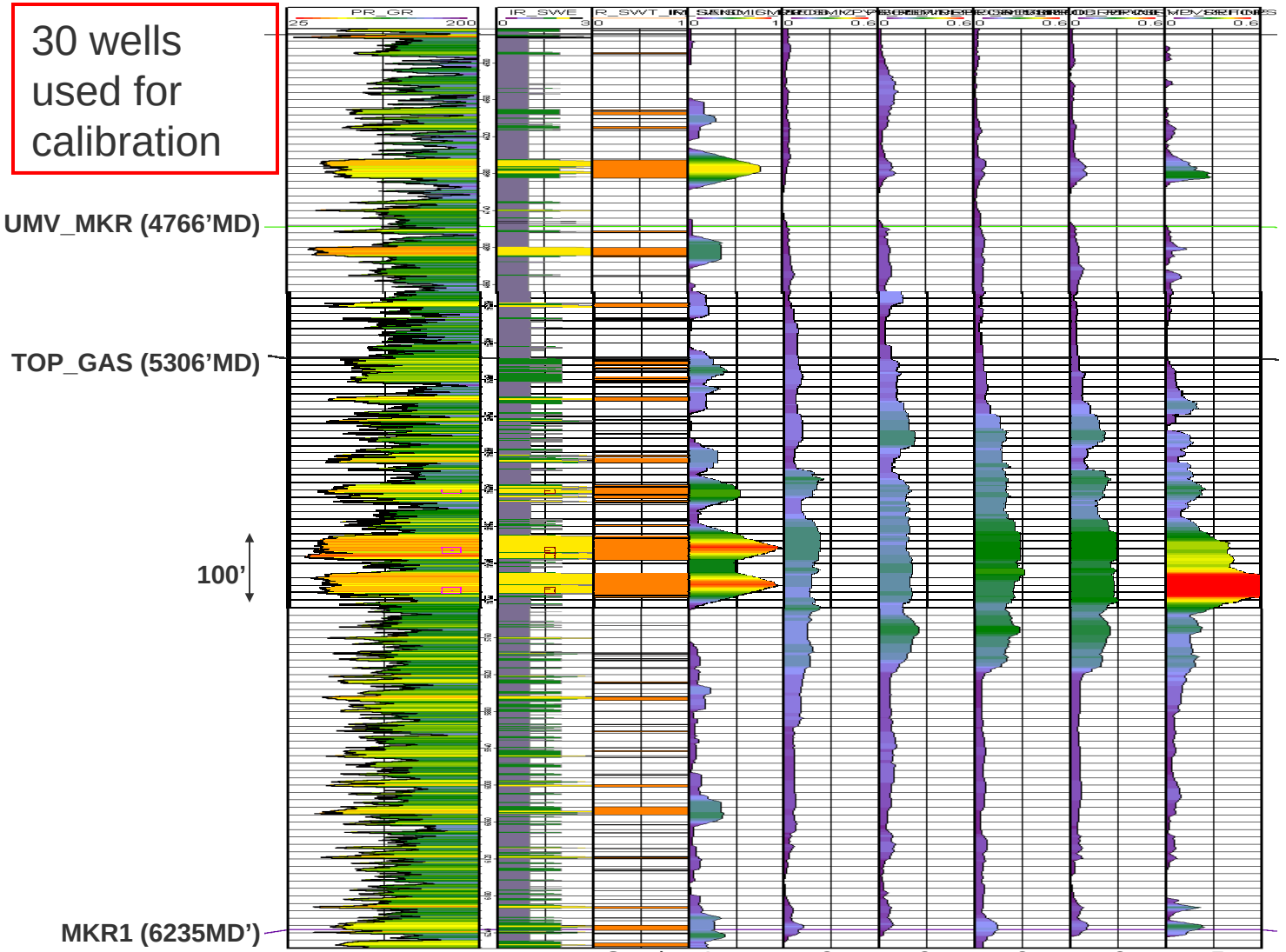
QC at well 21B-28 (marine)

30 wells used for calibration

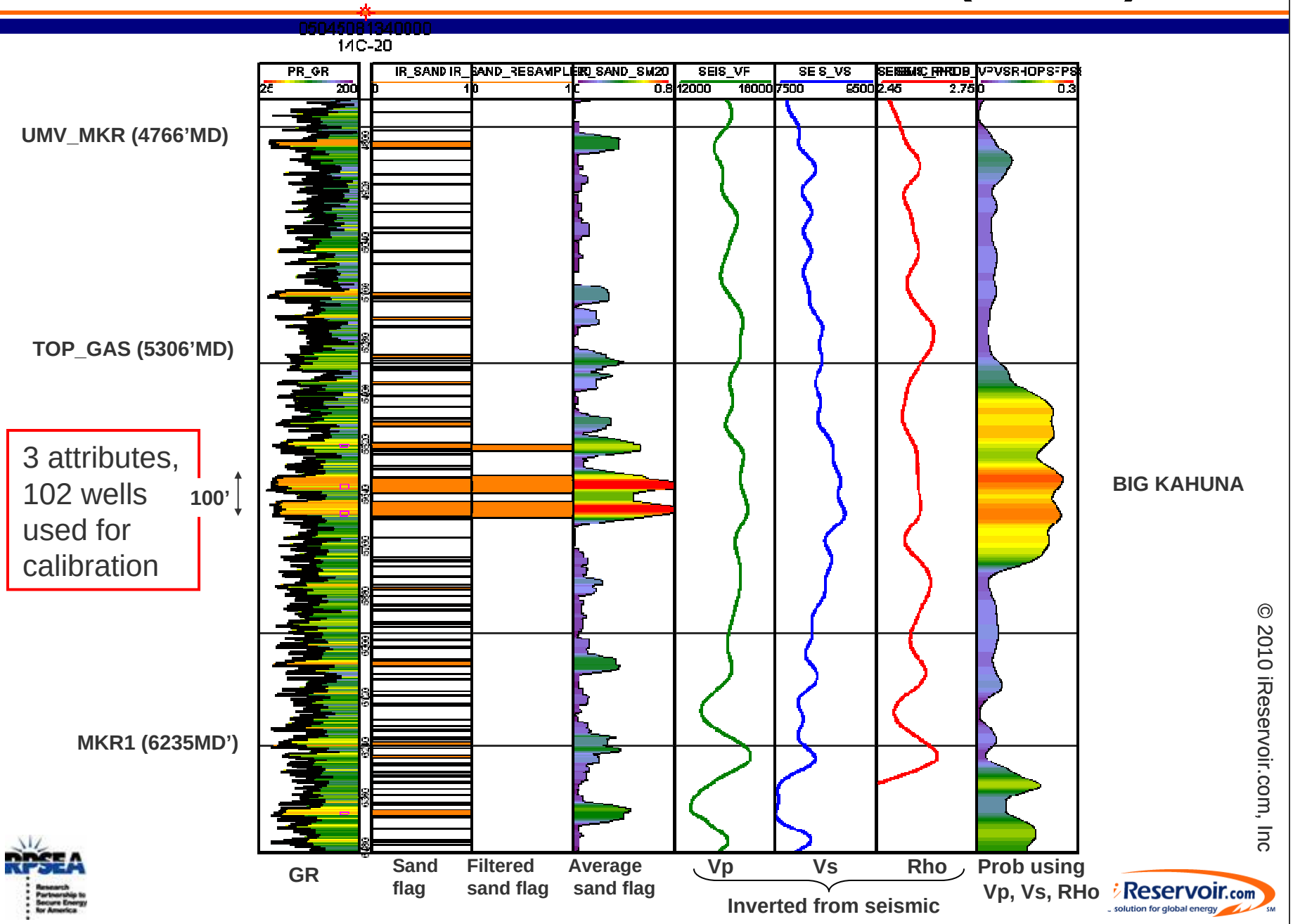


Probabilities extracted at well 14C-20 (fluvial)

30 wells used for calibration

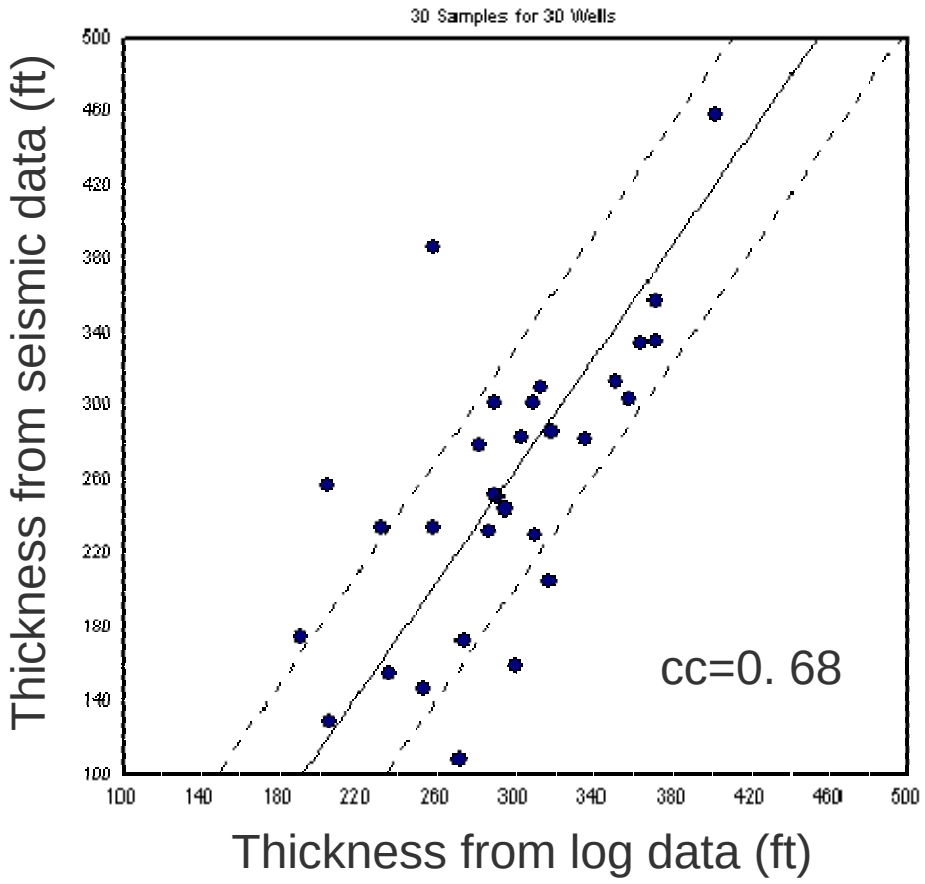


Probabilities extracted at well 14C-20 (fluvial)



Real vs estimated sand thickness (Vp, Vs, RHO and 3C)

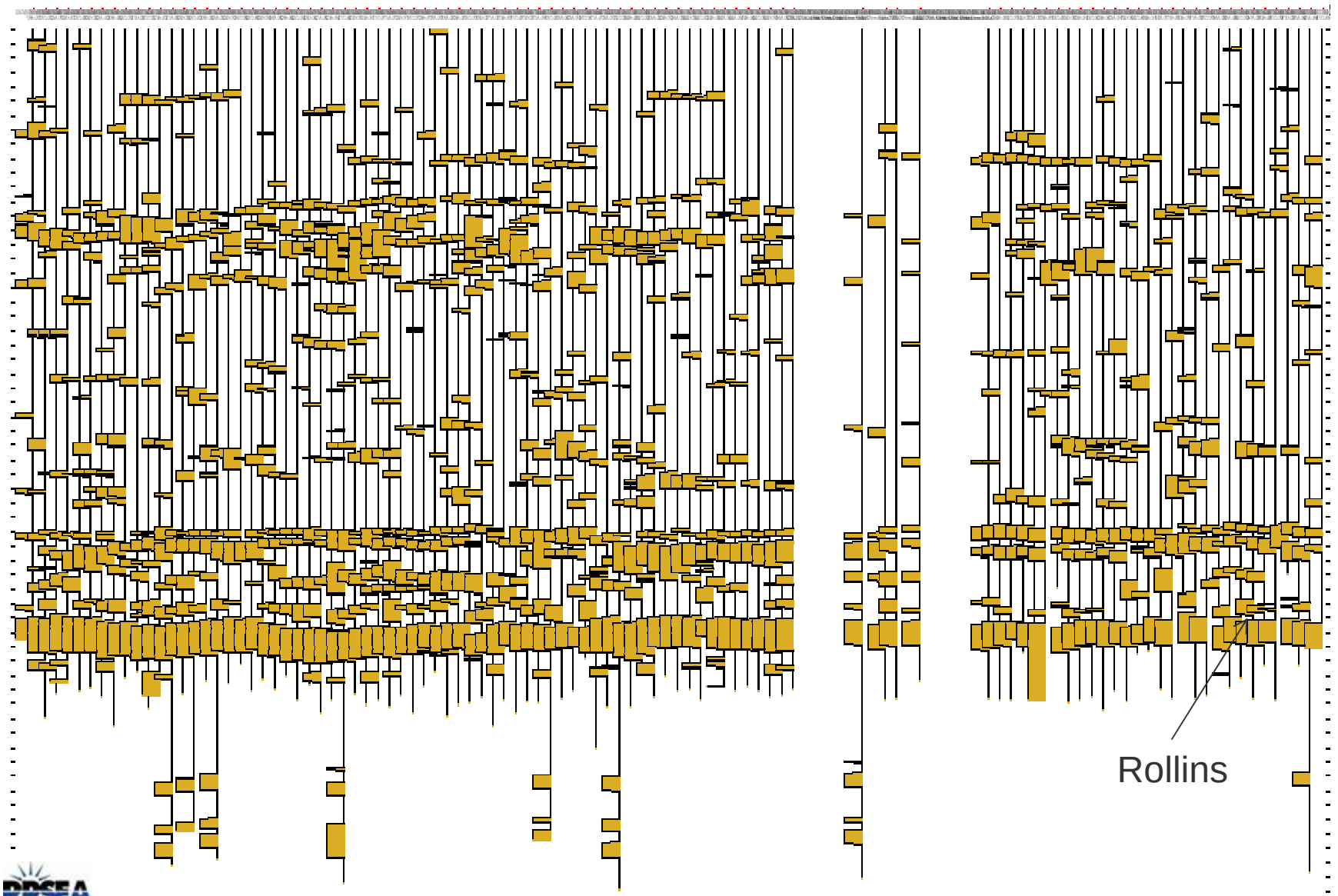
Fluvial interval



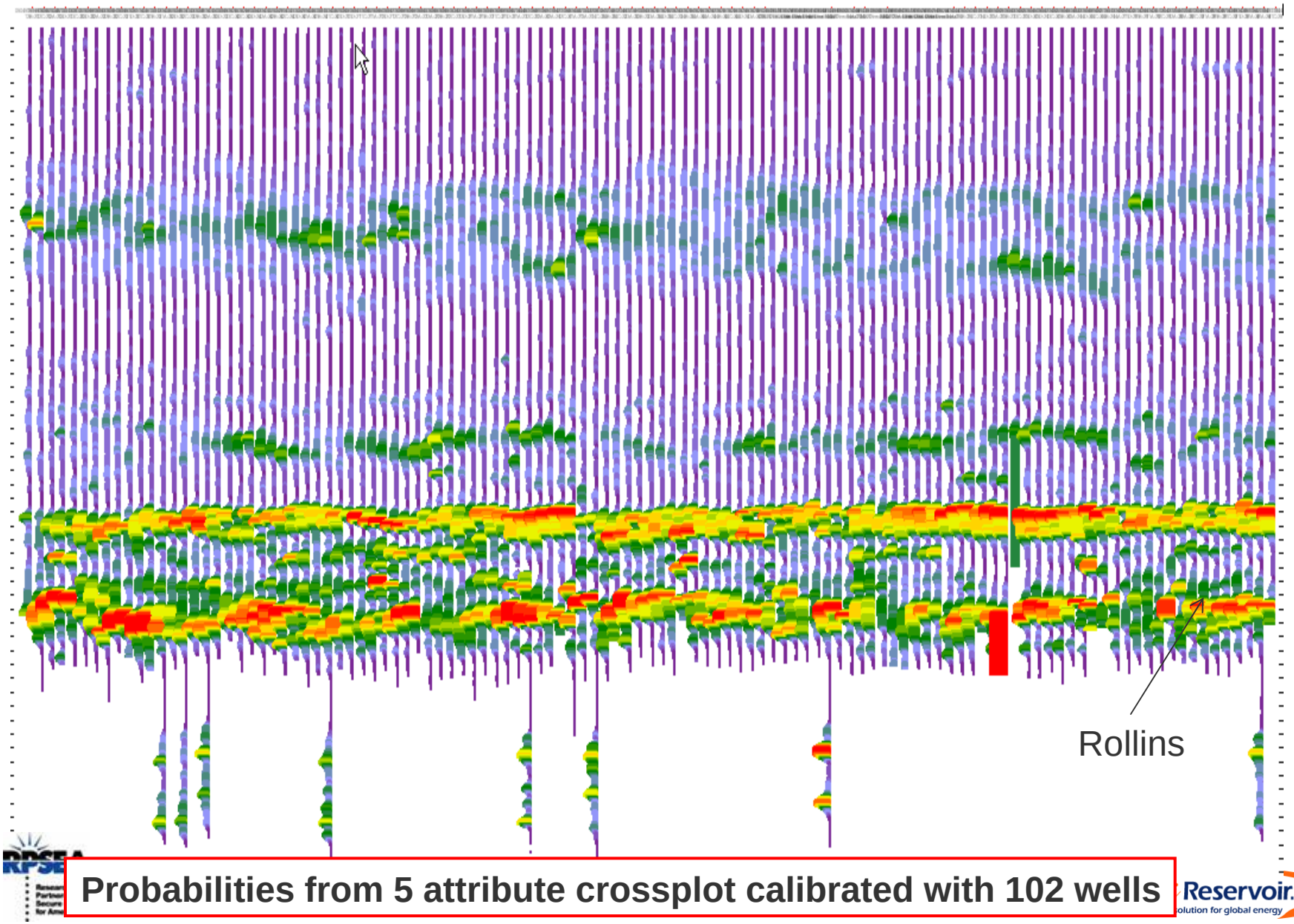
Prob cutoff = 0.18

30 wells used to calibrate seismic

Thick sand flags at well locations

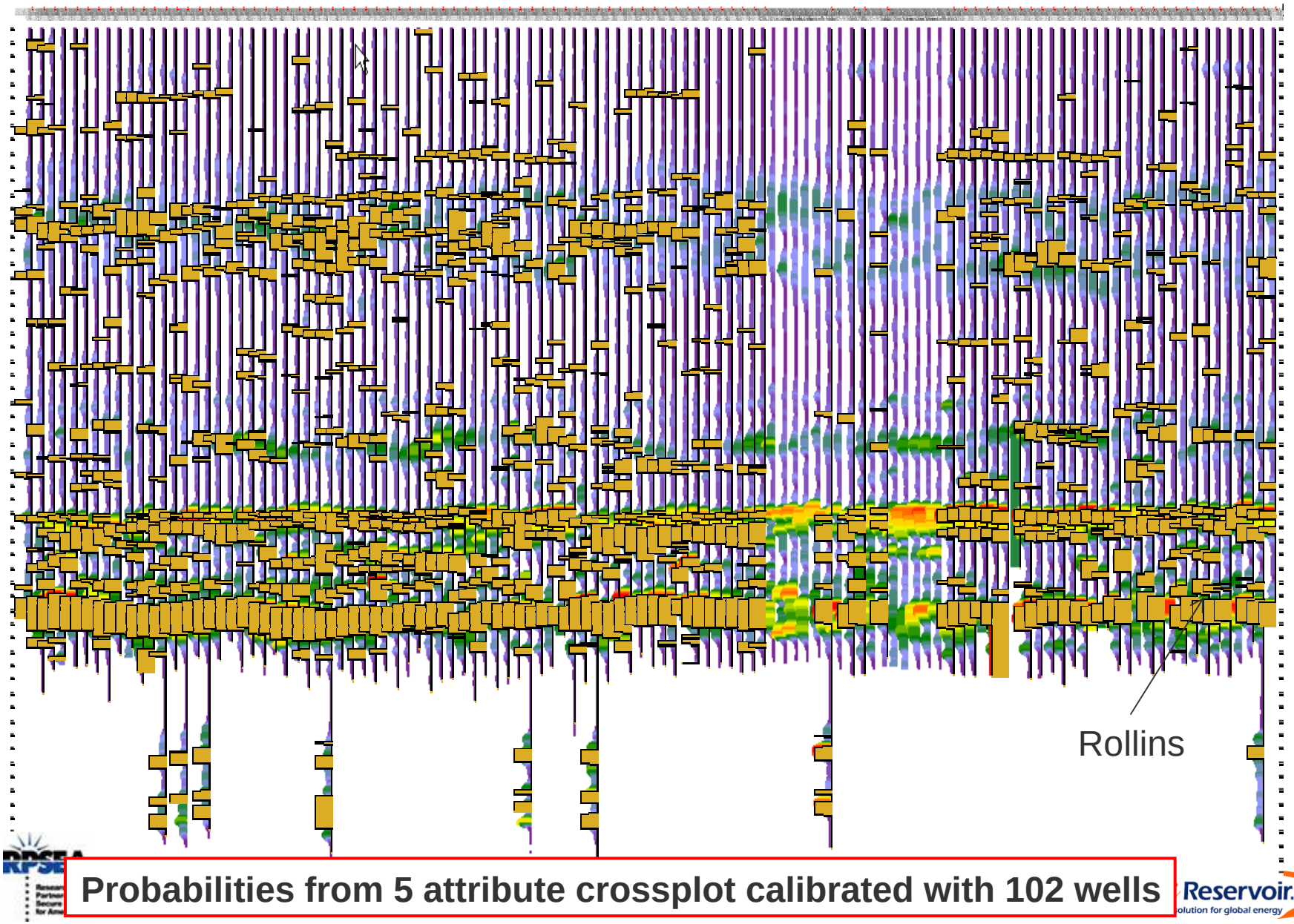


Seismic derived probabilities at well locations



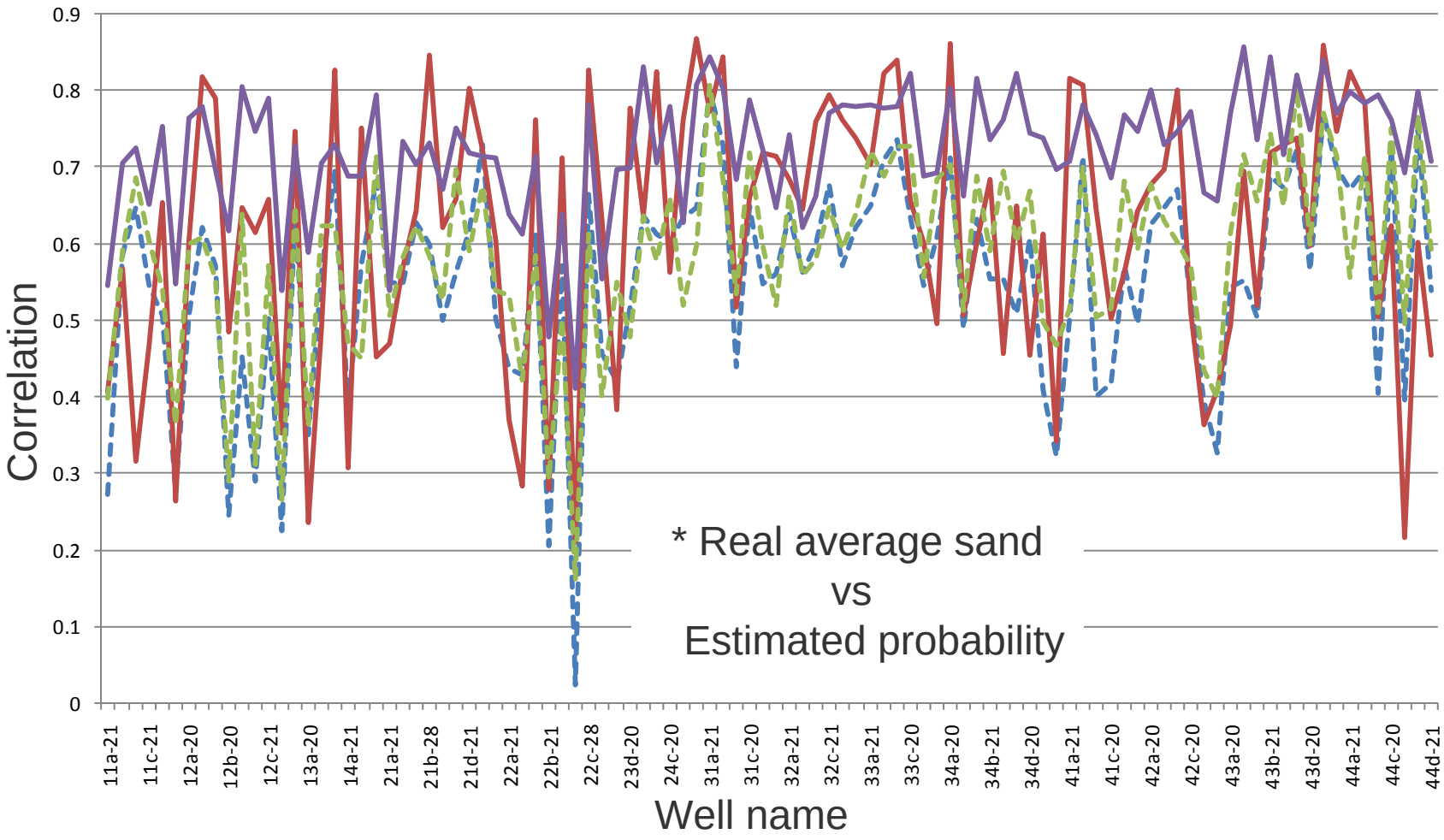
Probabilities from 5 attribute crossplot calibrated with 102 wells

Thick sand flags and probabilities at well locations



Probabilities from 5 attribute crossplot calibrated with 102 wells

Correlation coefficient* per well (marine)



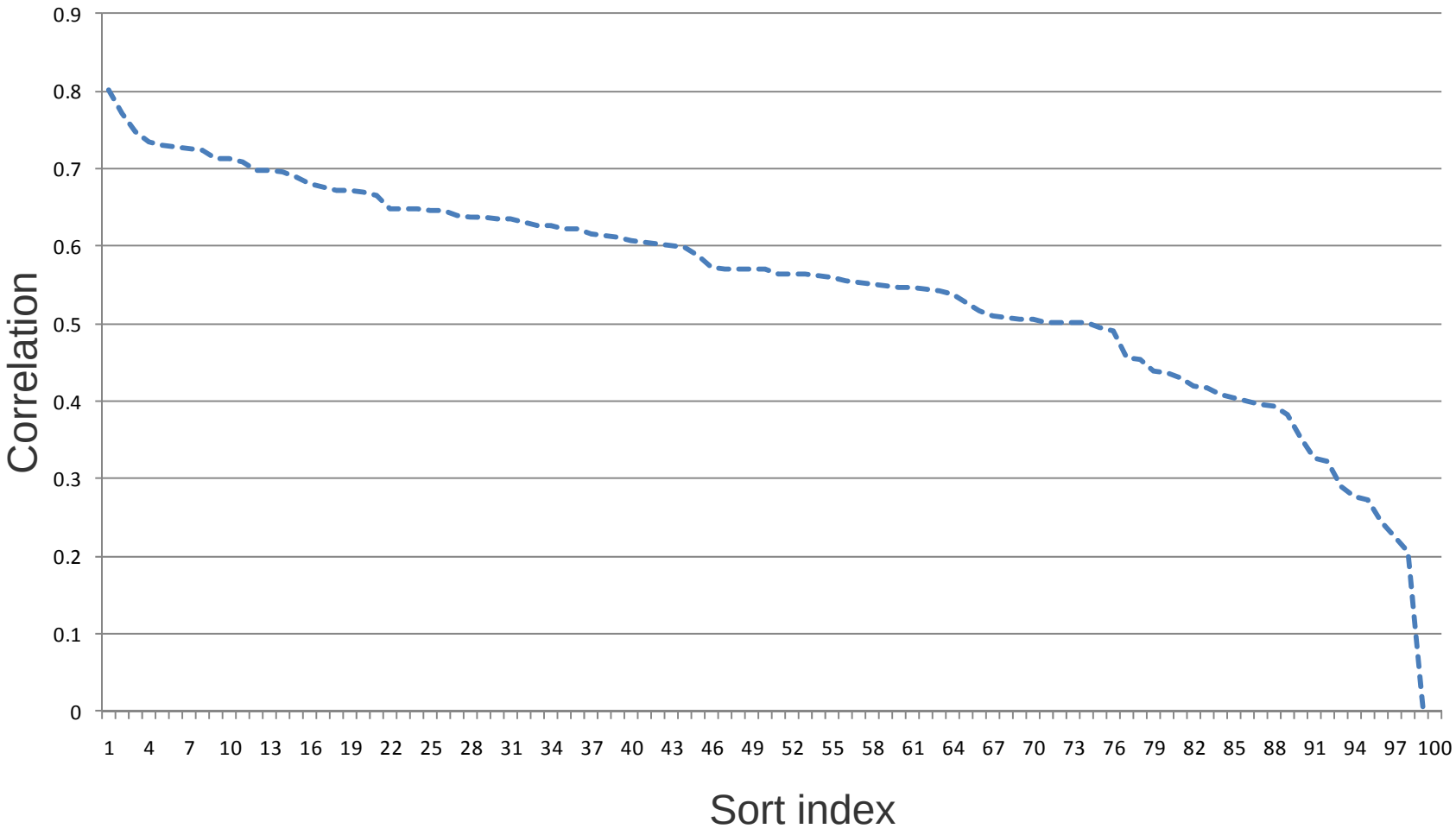
Vp, Vs, RHO, 30 calibration wells

Vp, Vs, RHO, 102 calibration wells

Vp, Vs, RHO, PS, 30 calibration wells

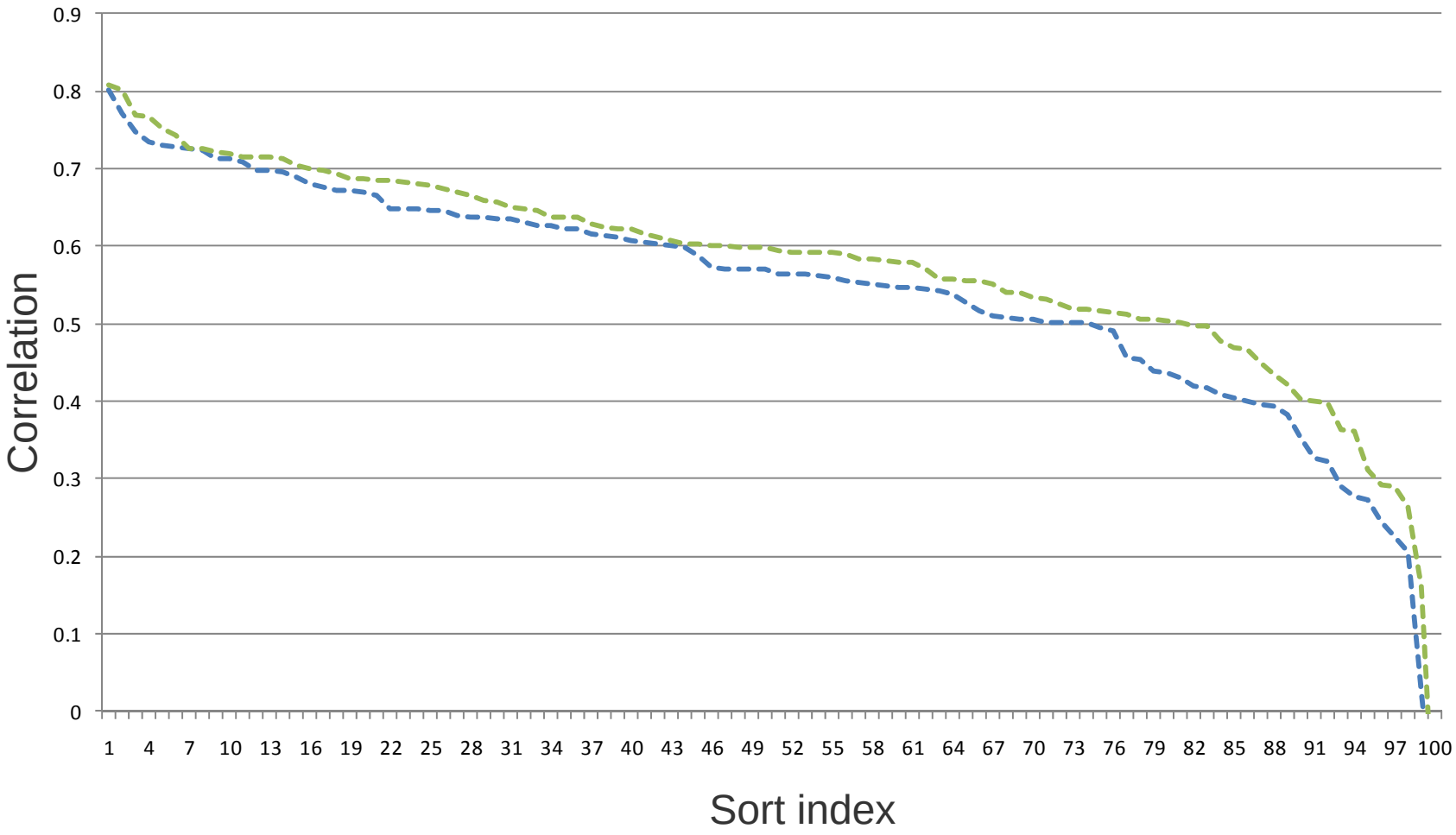
Vp, Vs, RHO, PS, 102 calibration wells

Sorted correlation coefficients (marine)



Vp, Vs, RHO, 30 calibration wells

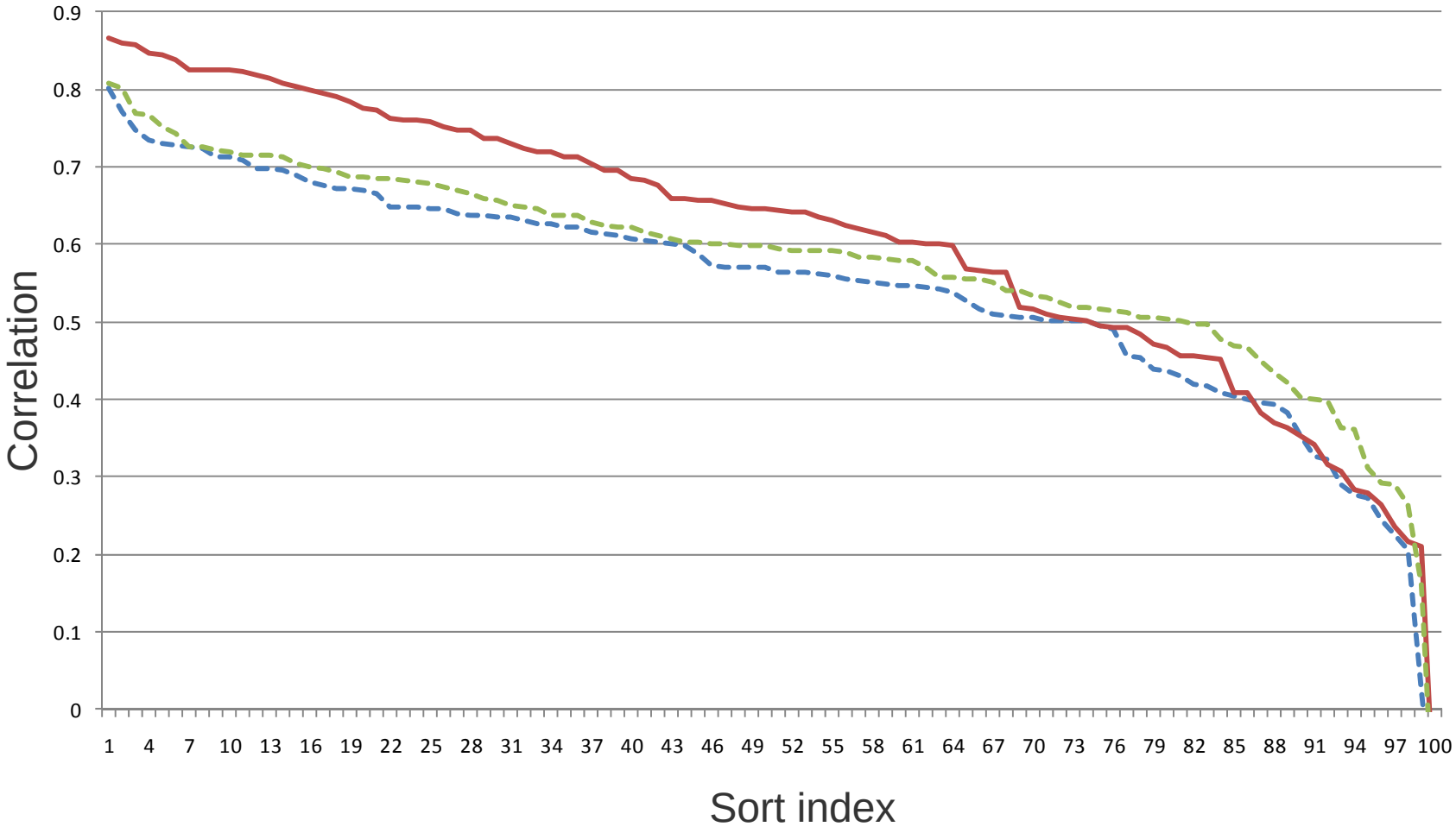
Sorted correlation coefficients (marine)



Vp, Vs, RHO, 30 calibration wells

Vp, Vs, RHO, 102 calibration wells

Sorted correlation coefficients (marine)

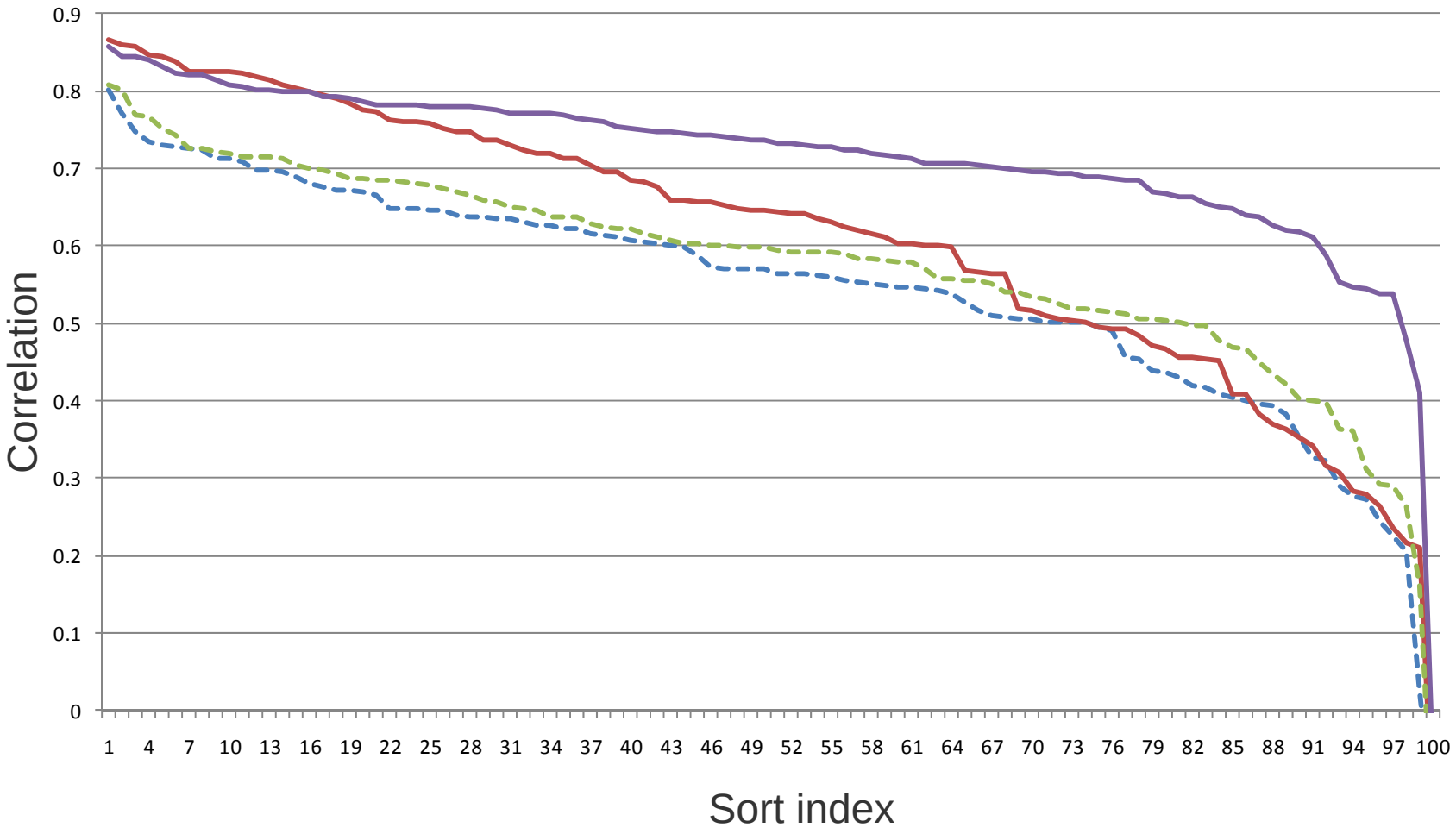


Vp, Vs, RHO, 30 calibration wells

Vp, Vs, RHO, PS, 30 calibration wells

Vp, Vs, RHO, 102 calibration wells

Sorted correlation coefficients (marine)



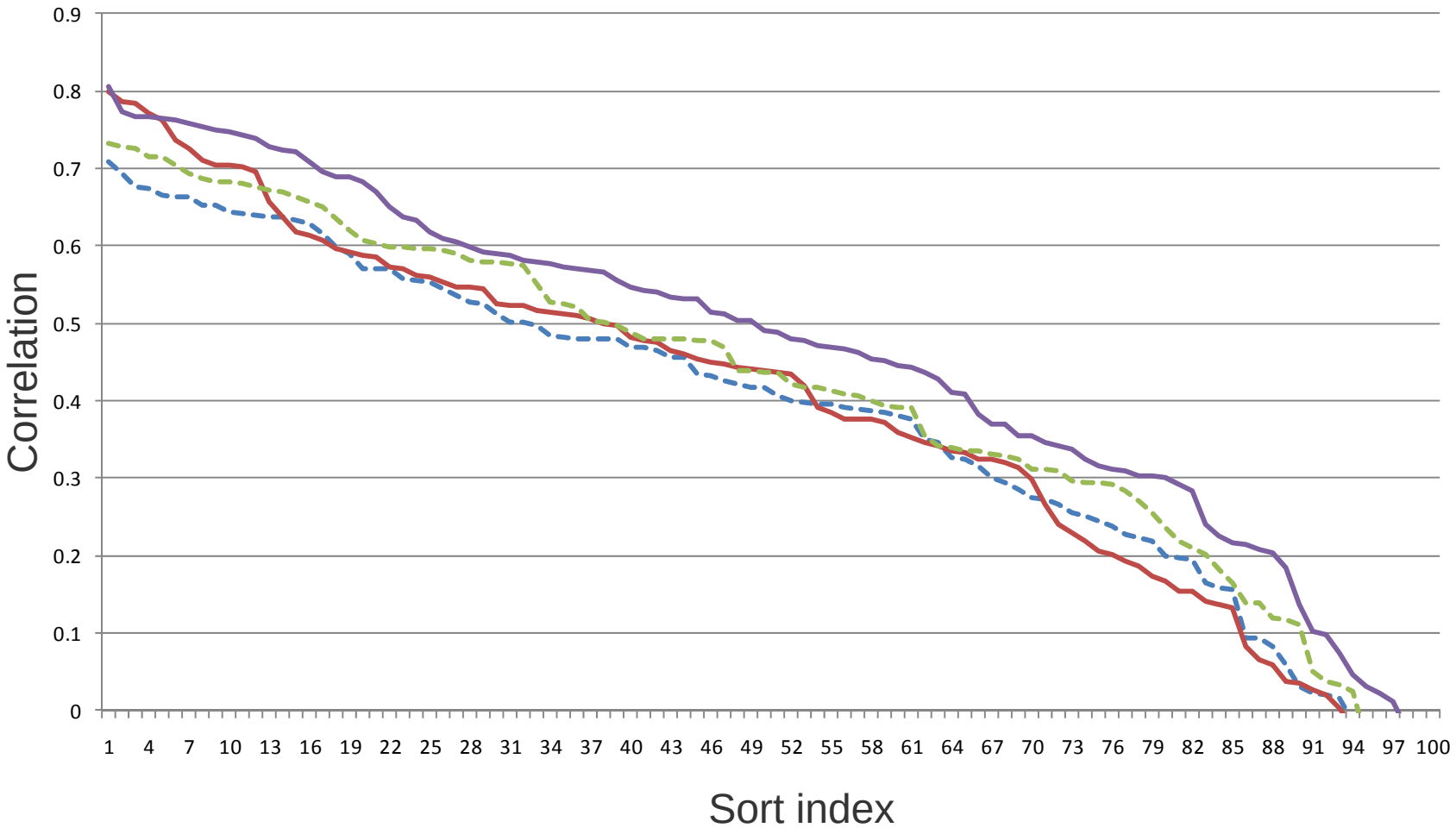
Vp, Vs, RHO, 30 calibration wells

Vp, Vs, RHO, 102 calibration wells

Vp, Vs, RHO, PS, 30 calibration wells

Vp, Vs, RHO, PS, 102 calibration wells

Sorted correlation coefficients (fluvial)



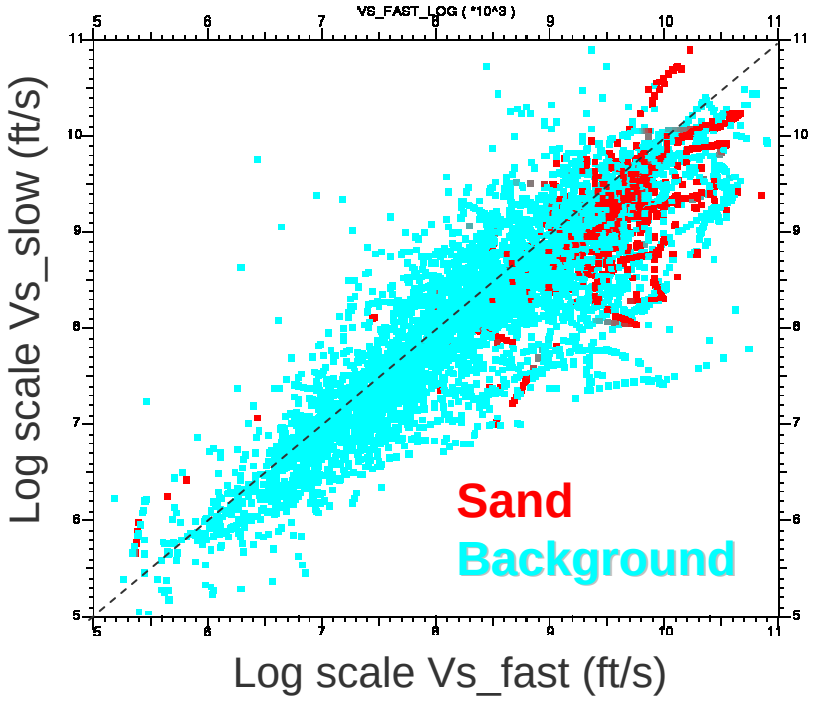
Vp, Vs, RHO, 30 calibration wells

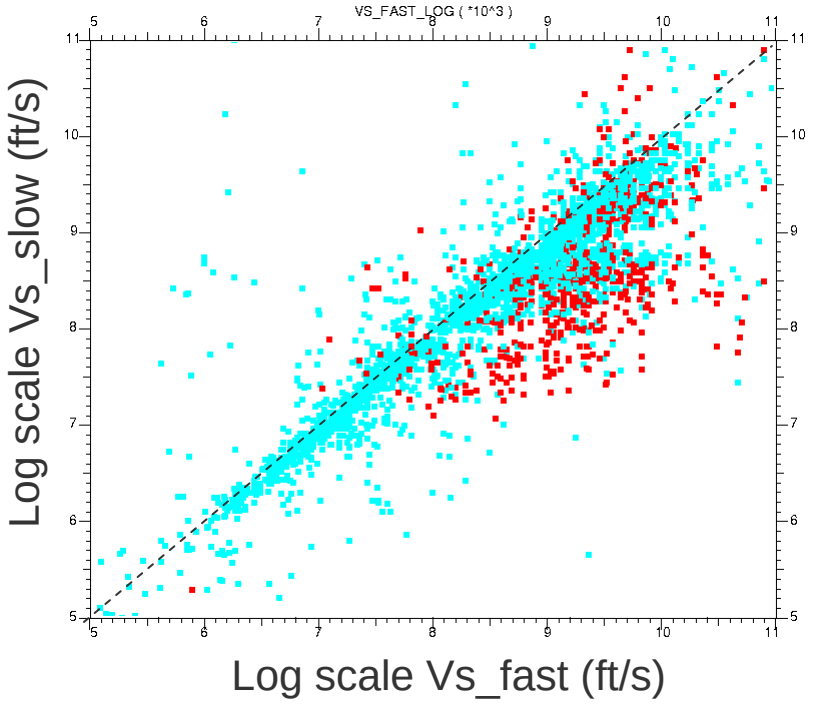
Vp, Vs, RHO, 102 calibration wells

Vp, Vs, RHO, PS, 30 calibration wells

Vp, Vs, RHO, PS, 102 calibration wells

Log scale Vs_fast vs Vs_slow (well 41A-28)





Fluvial interval

Marine interval

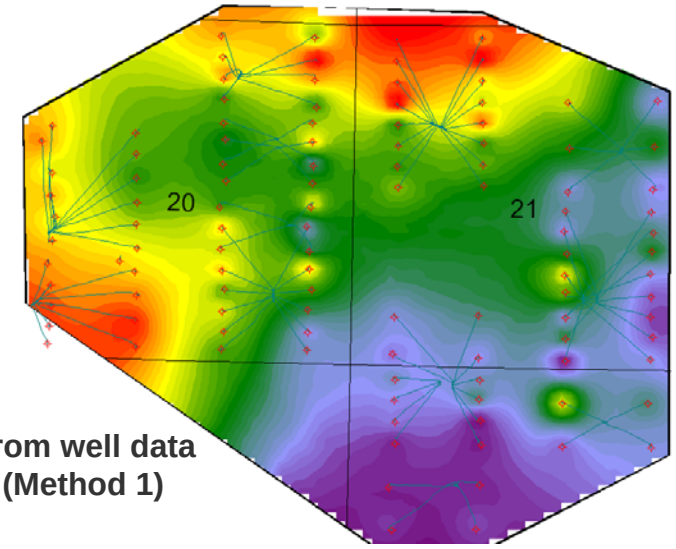
- Fluvial shales are more azimuthally anisotropic than marine shales
- Fluvial sands are less azimuthally anisotropic than marine sands

Net thickness maps – Big Kahuna (mid section ~140 ft)

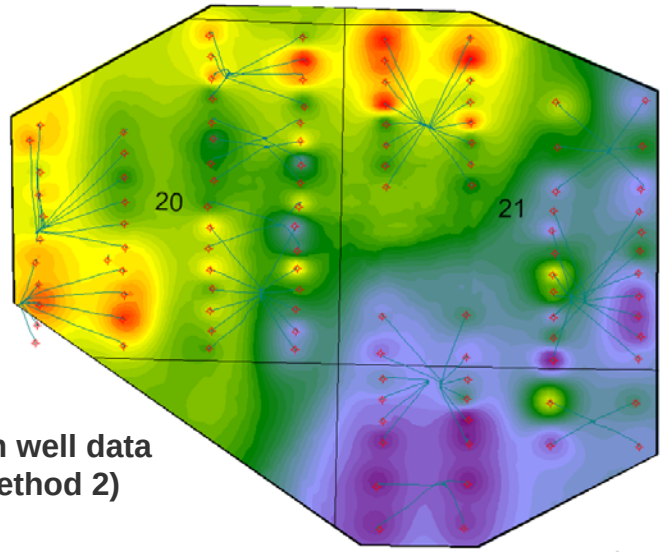
Net sand

High

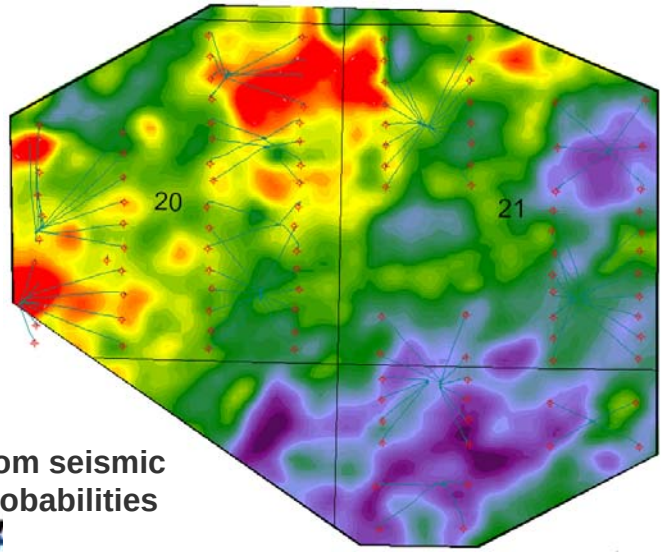
Low



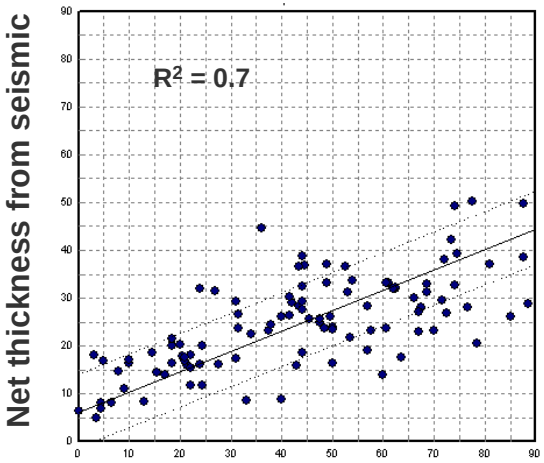
From well data (Method 1)



From well data (Method 2)



From seismic probabilities



Seismic probabilities underestimates net thickness due to:

-Limited seismic resolution

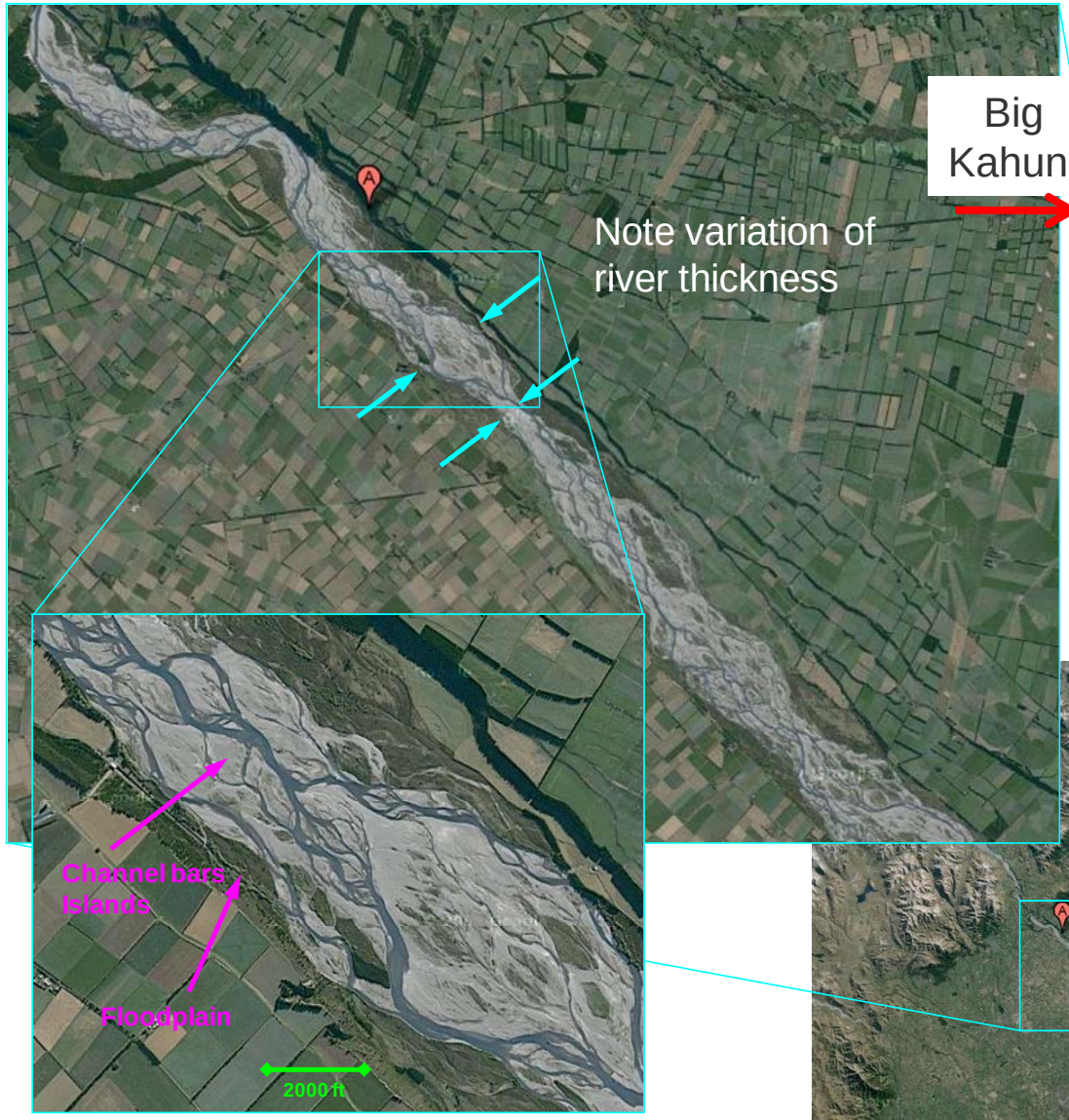
-Training on thick sands only

-Lack of contrast of elastic properties

-High heterogeneity (probabilities << 1)

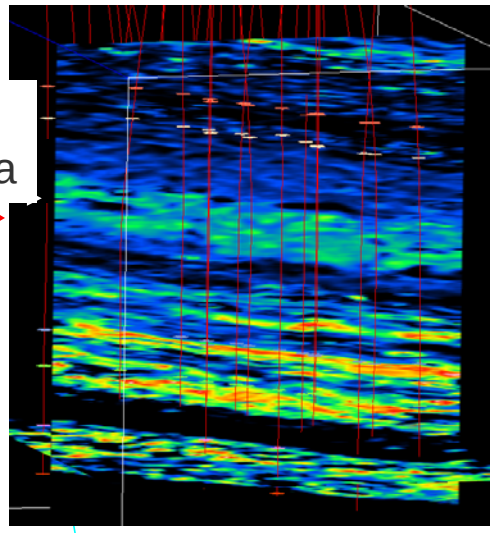
5 attributes, 102 wells used for calibration

Analog braided river system



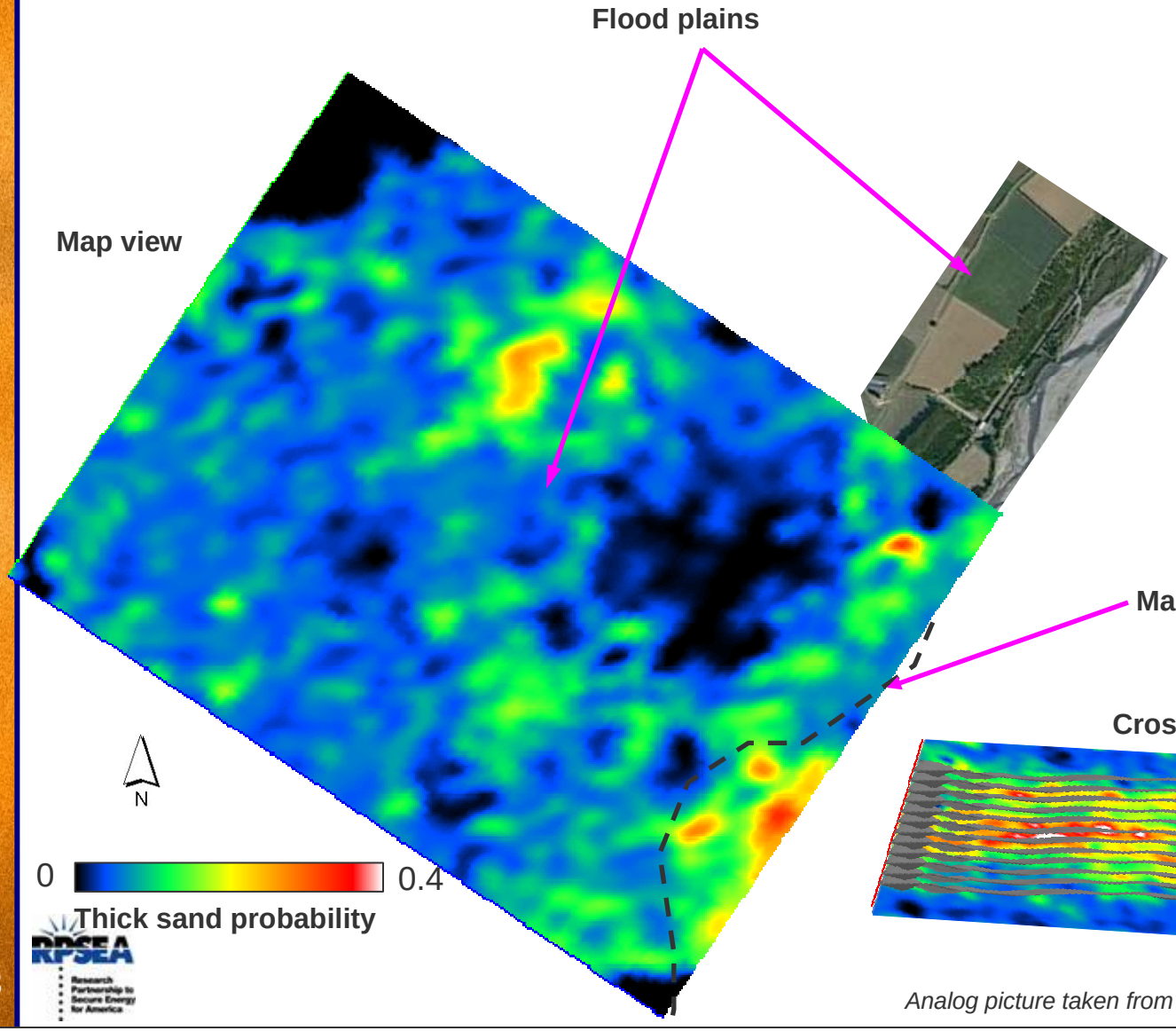
Google Earth, 2010

Big Kahuna



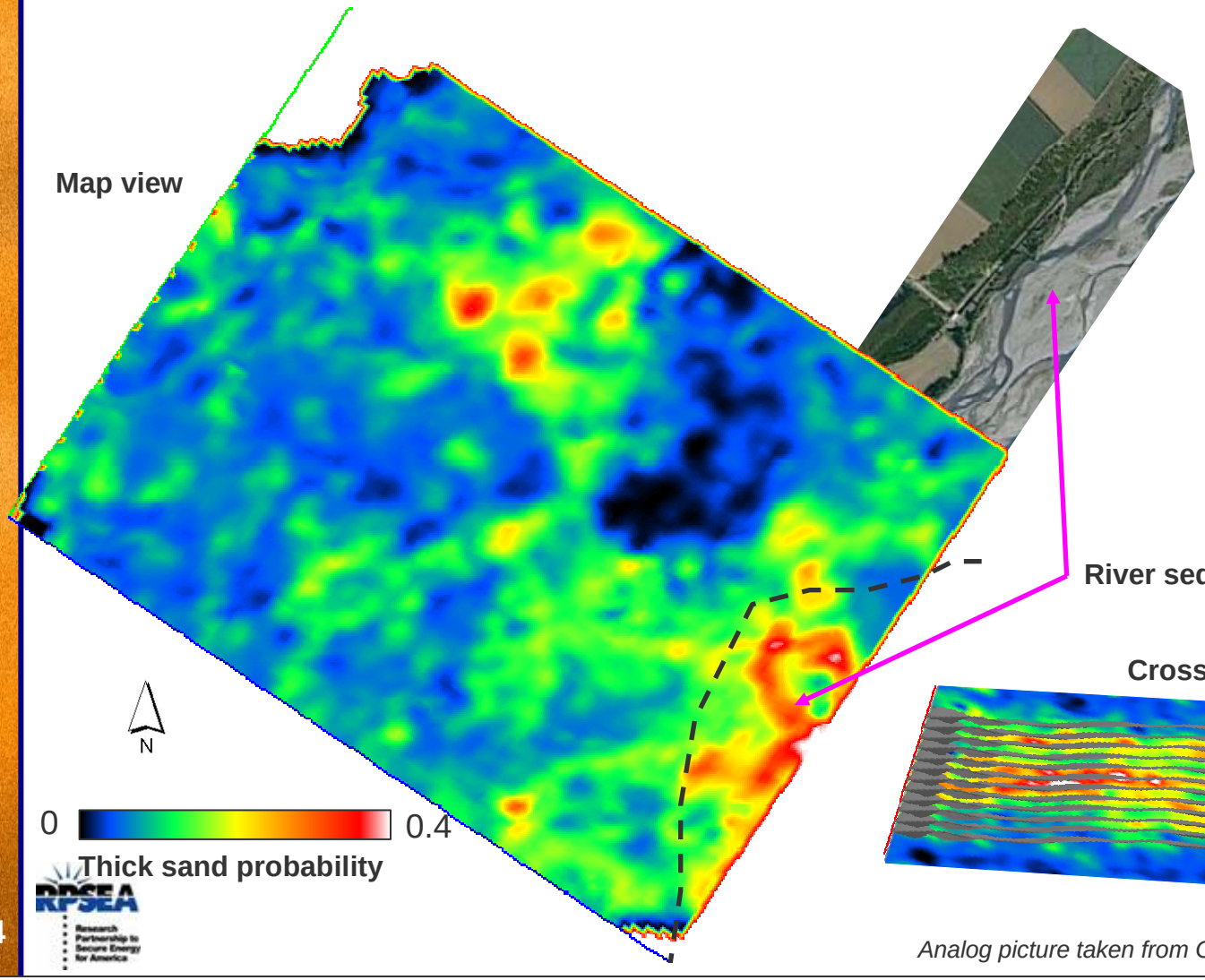
Rakaia River, South Island New Zeland

Base of Big Kahuna – Stratigraphic slide



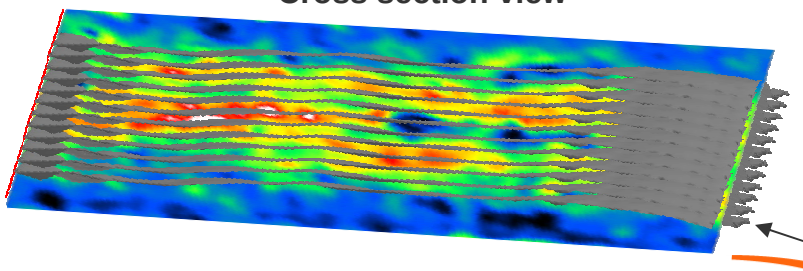
Analog picture taken from Google Earth 2010

Base of Big Kahuna minus 50 ft – Stratigraphic slide



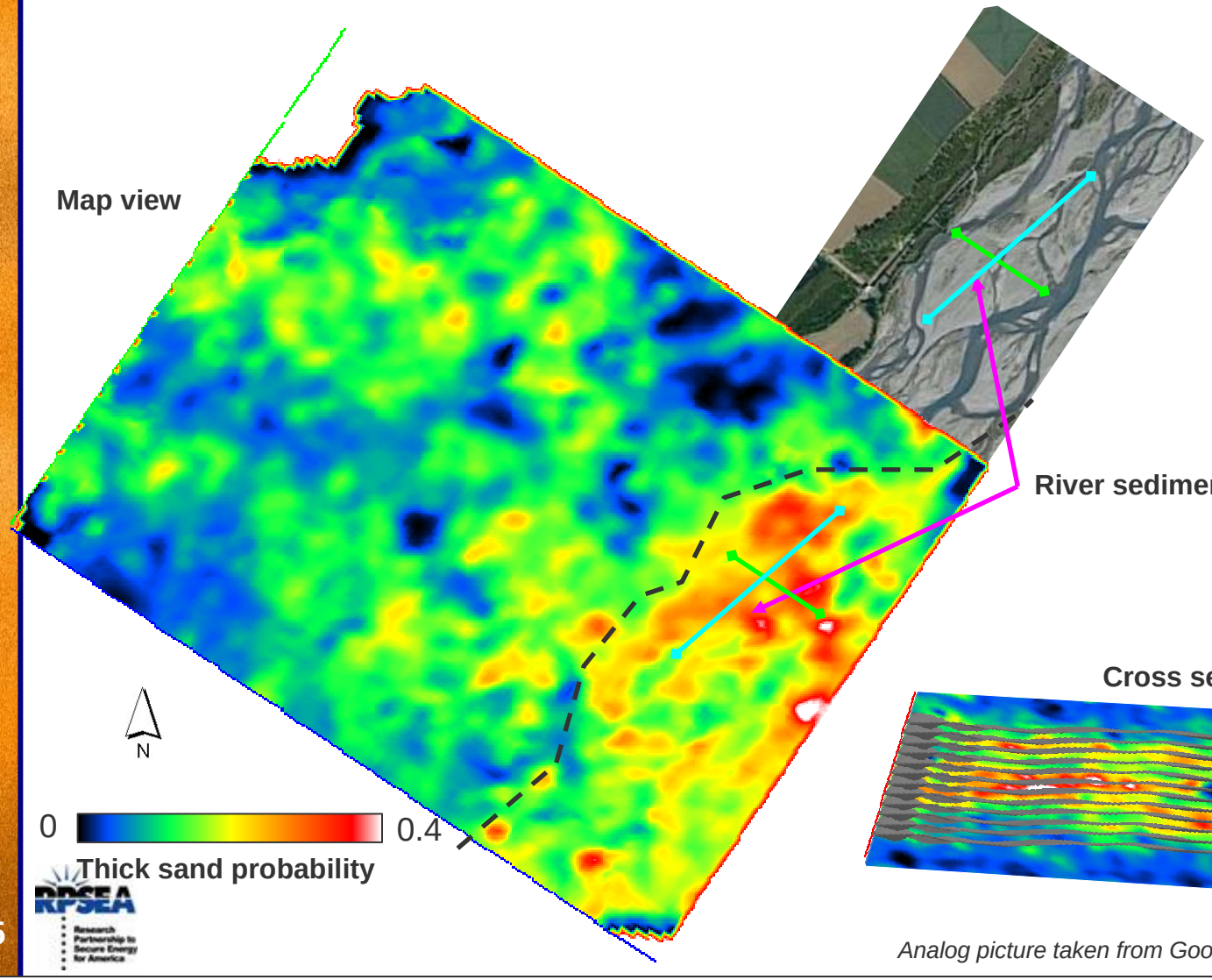
River sediments

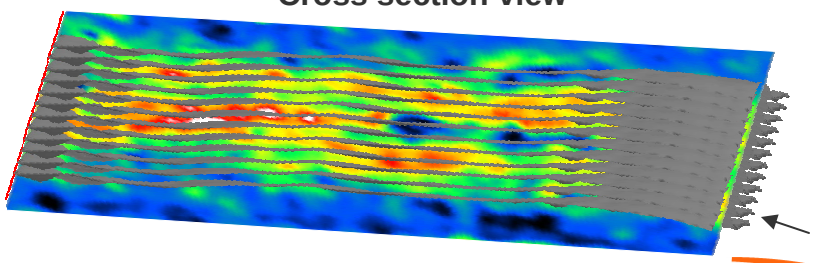
Cross section view



Analog picture taken from Google Earth 2010

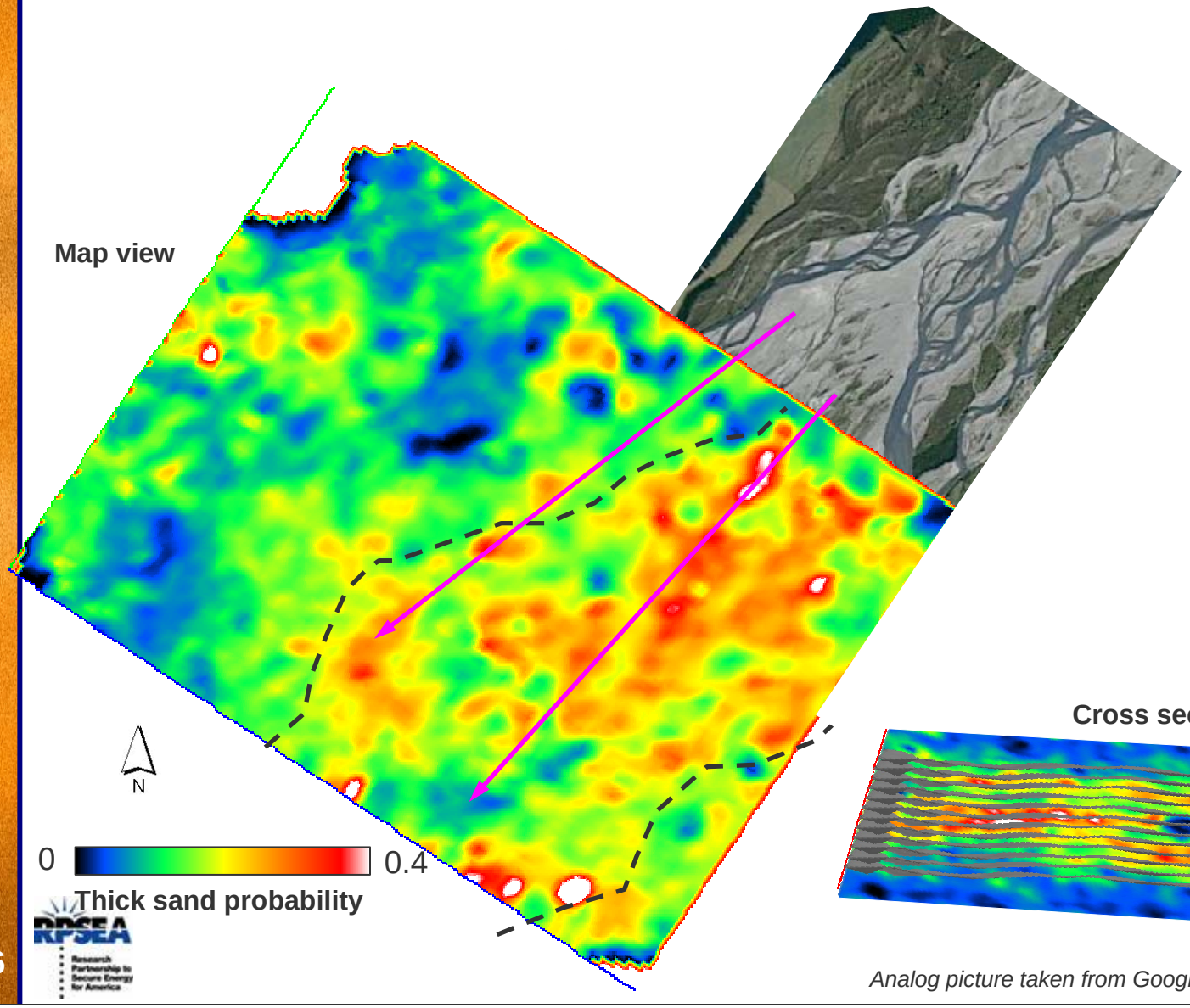
Base of Big Kahuna minus 100 ft – Stratigraphic slide





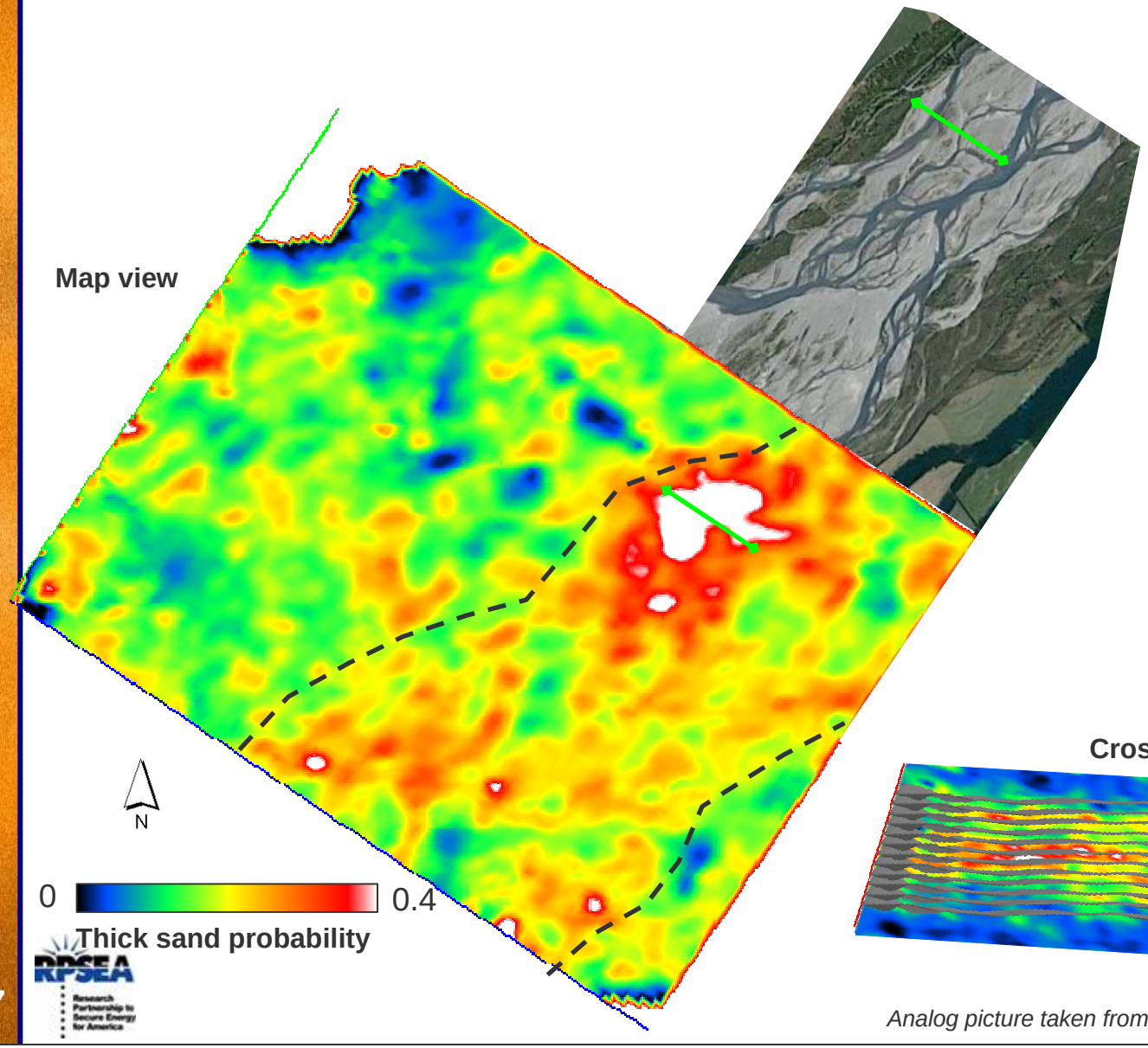
Analog picture taken from Google Earth 2010

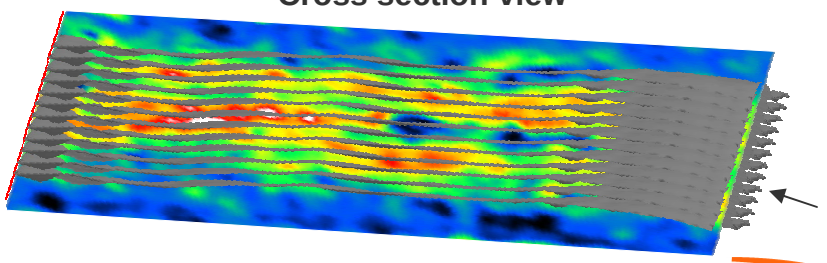
Base of Big Kahuna minus 150 ft – Stratigraphic slide



Analog picture taken from Google Earth 2010

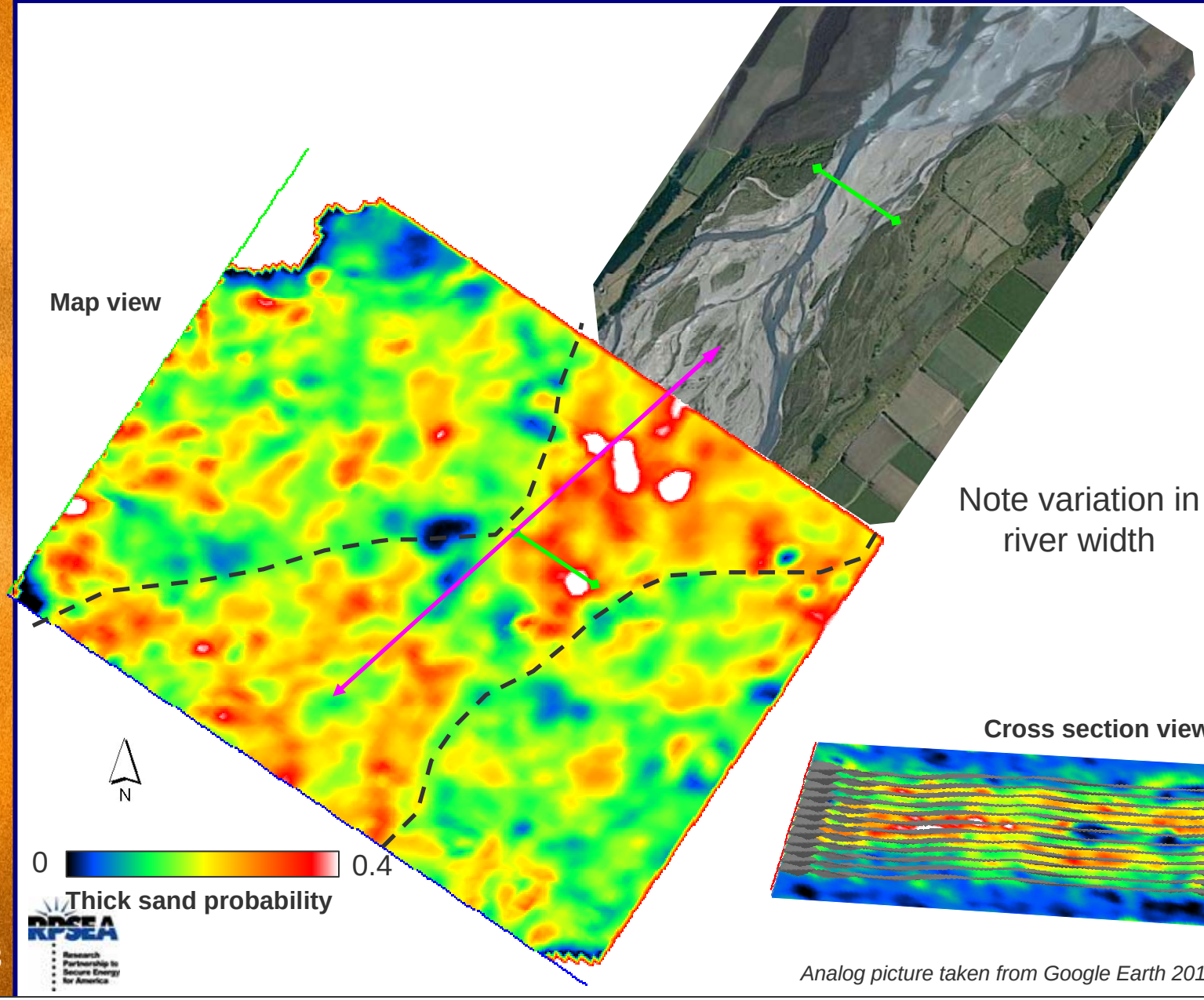
Base of Big Kahuna minus 200 ft – Stratigraphic slide





Analog picture taken from Google Earth 2010

Base of Big Kahuna minus 250 ft – Stratigraphic slide

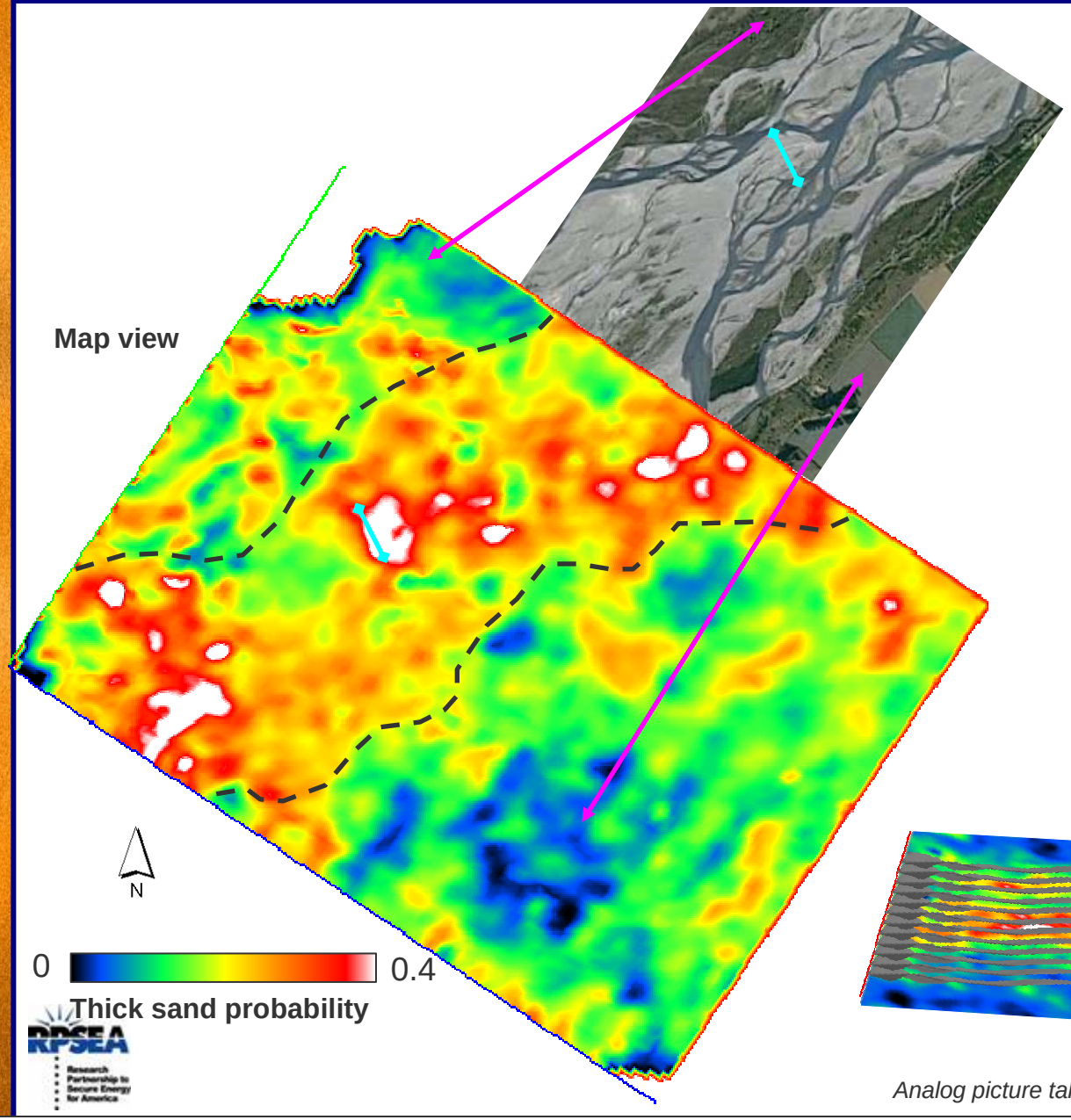


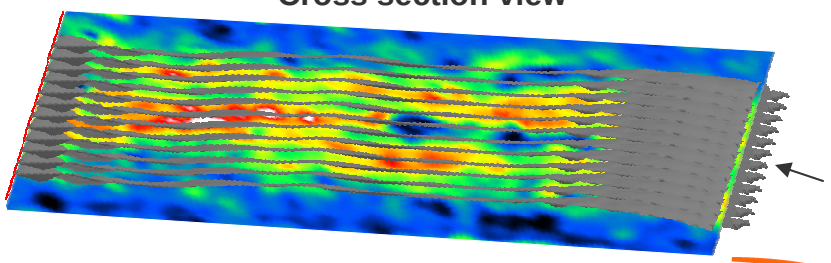
Note variation in river width

Cross section view

Analog picture taken from Google Earth 2010

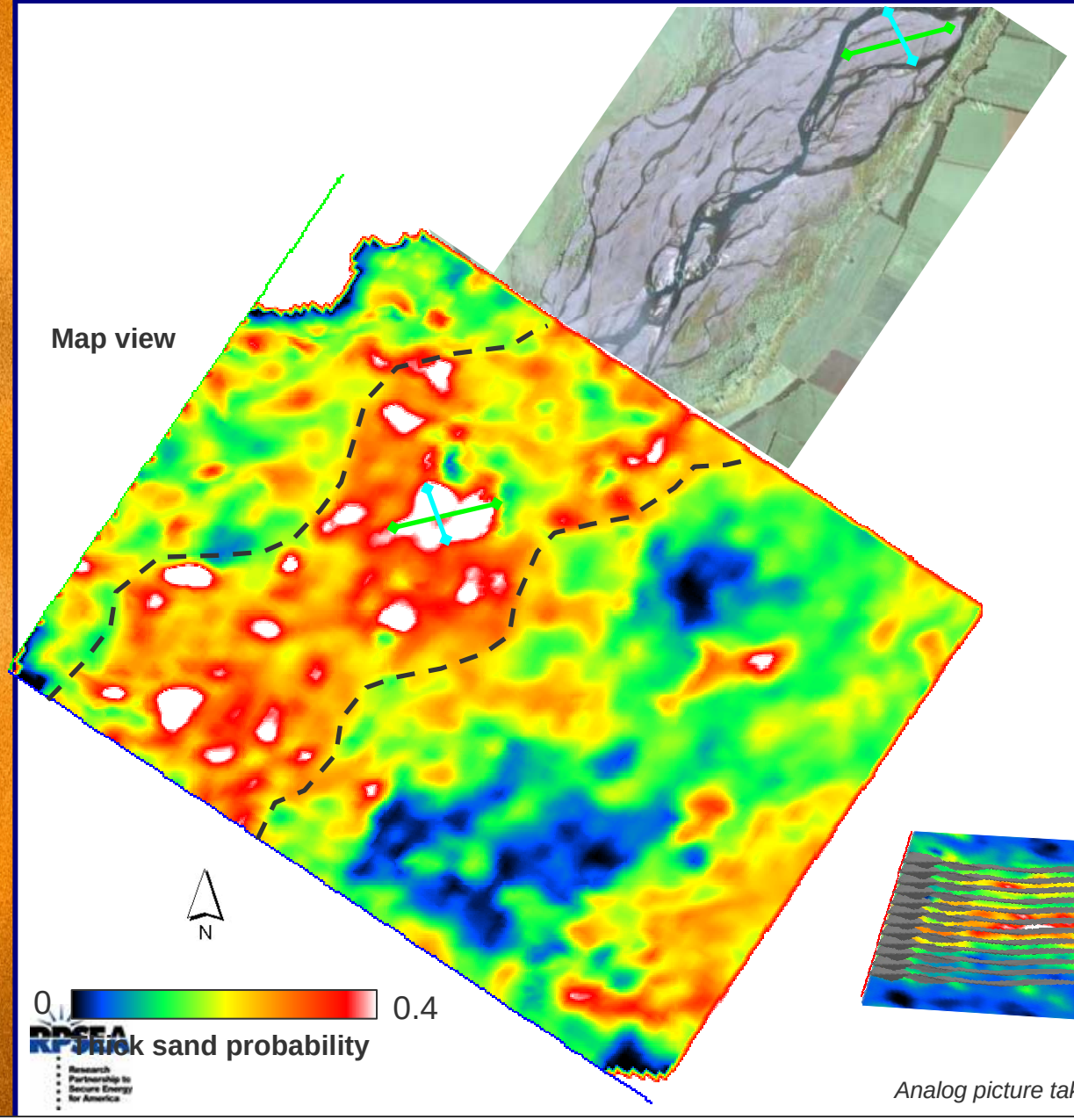
Base of Big Kahuna minus 300 ft – Stratigraphic slide

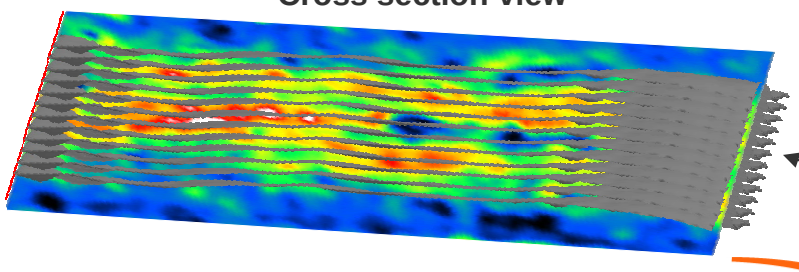




Analog picture taken from Google Earth 2010

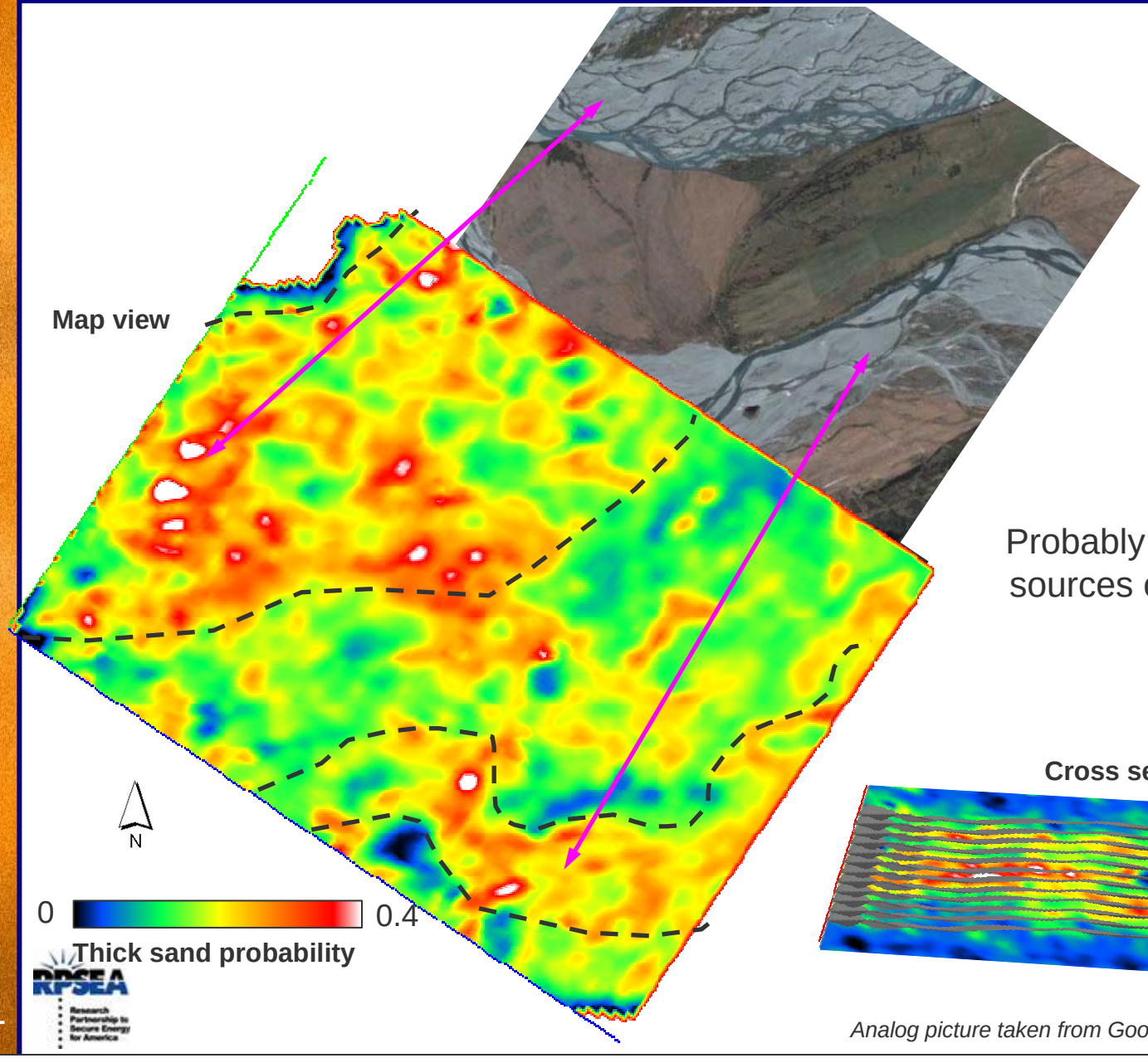
Base of Big Kahuna minus 350 ft – Stratigraphic slide





Analog picture taken from Google Earth 2010

Base of Big Kahuna minus 400 ft – Stratigraphic slide



Probably two different sources of sediments

Analog picture taken from Google Earth 2010

Conclusions

- Sand probability estimation using multiple seismic attributes yields useful results even when properties of sand and background facies overlap completely
- Seismic derived probabilities maps show expected geological behavior
- Predicted sand thickness from seismic probabilities have a high correlation coefficient with sand thickness from wells
- Analysis of different combinations of attributes show that when using PP data only, the best results are obtained when using Vp, Vs, and RHO simultaneously and the best results are obtained when using all five attributes (Vp, Vs, RHO, Zps_fast and Zps_slow)
- Using 35 or 102 wells to train the probability estimation give similar results indicating robustness in the methodology (the algorithm has been tested using as few as 4 wells for training)

Acknowledgments

- The authors acknowledge RPSEA (Research Partnership to Secure Energy for America) for financial support
- Thanks also to Bill Barrett Corporation for providing the data used for this study