OPTIMIZING RESERVOIR CHARACTERIZATION

AND BUILDING

MECHANICAL EARTH MODELS

USING

MACHINE LEARNING

Challenges and Limitations

RESERVOIR CHARACTERIZATION

- Seismic Contribution
  - 3D has good spatial coverage
  - Proxy to subsurface characteristics
- Well data Contribution
  - Down hole mearuements of subsurface
  - Quite sparce compared to 3D seismic
- Machine Learning
  - Integrate Seismic and Well data
  - Build Data Driven Models
  - Predict at every seismic trace in 3D seismic

BROWNFIELD REJUVENATION

SEISMIC CONTRIBUTION

RECOMMENDED APPROACH

- Time Lapse (4D surveys)
  - Pros
    - Offshsore -> OBC/OBN
    - Repeatability and imaging
    - Depends on project economics and remaining reserves
    - Can monitor produced fluids.
  - Cons
    - Costly
    - Time consuming

MACHINE LEARNING CONTRIBUTION

- Data Driven
  - Well log curves and seismic segy (3D)
  - Petrophysical zone properties and seismic horizons (2D)
- Traditional or Deep ML
  - Numerous models either individually or stacked
- Challenges
  - Non Stationarity
  - Bias Variance trade off
  - Continuous updates with new data

AVAILABLE DATA SETS

- Sparse Data
  - Well logs, cores, images, etc…
  - Hard Data
- Pervasive (Dense) Data
  - Seismic
    - Lower temporal resolution than logs
    - High spatial resolution
    - Non unique
  - Soft Data
  - Interpreted Horizons

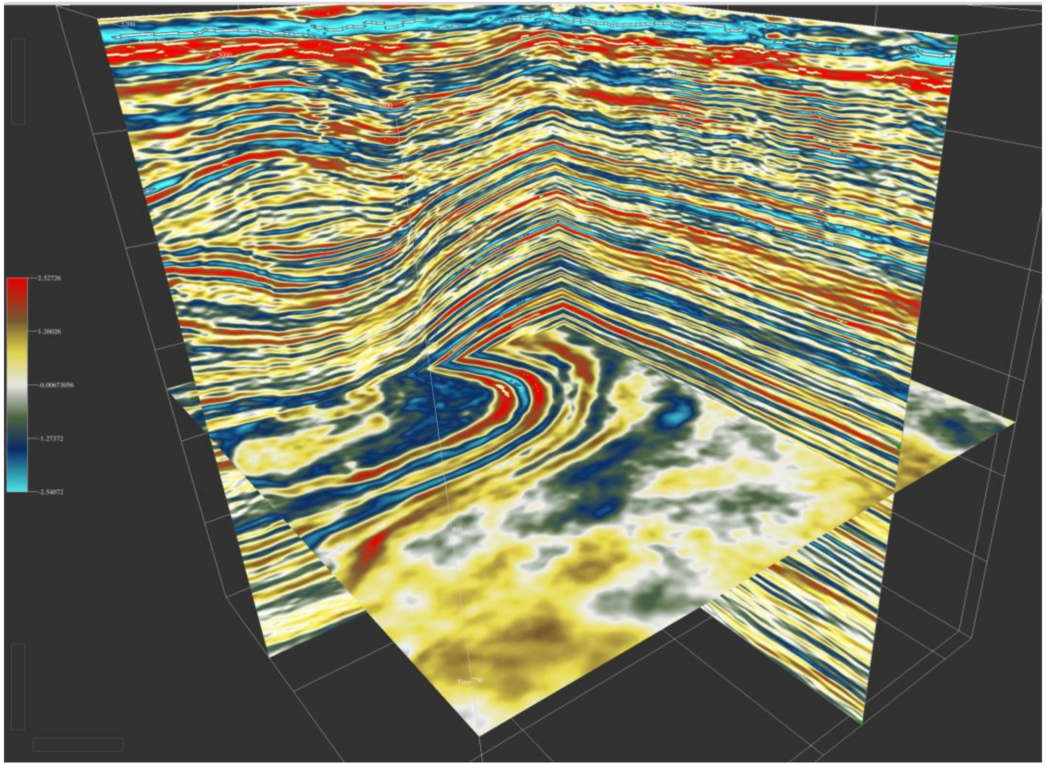
MACHINE LEARNING VS DEEP LEARNING

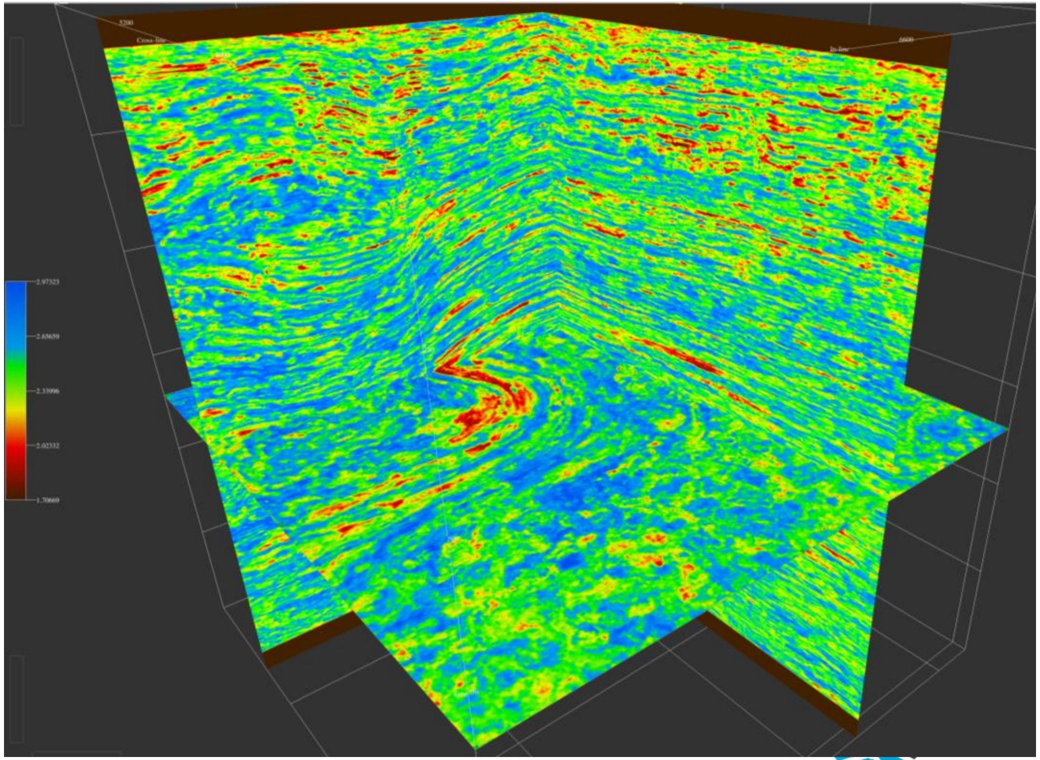
Traditional ML	Deep Neural Network
Can handle non linearity	Can handle non linearity
Broad range of models	Neural Network based (with different designs)
Needs humble amounts of data	Needs a lot of data to build models
Small set of parameters to tune	A lot of parameters to tune
Interpretable	Black box
Reasonably fast model building	Can be excessively long

REGRESSION VS CLASSIFICATION

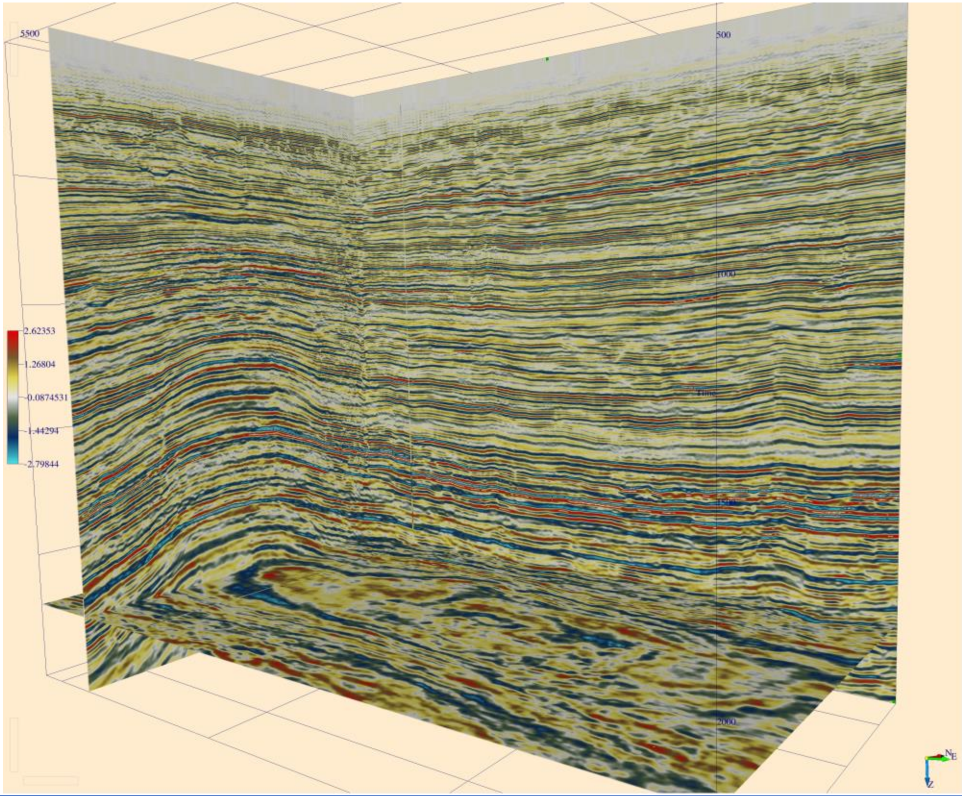
- Framing the data set as ***classification*** problem
  - Predicting sand vs shale
  - Or gas vs oil vs water
- Framing the data set as a ***regression*** problem
  - Predicting a GR log values
  - Predicting Rhob log values

SEISMIC AMPLITUDES/ML RHOB

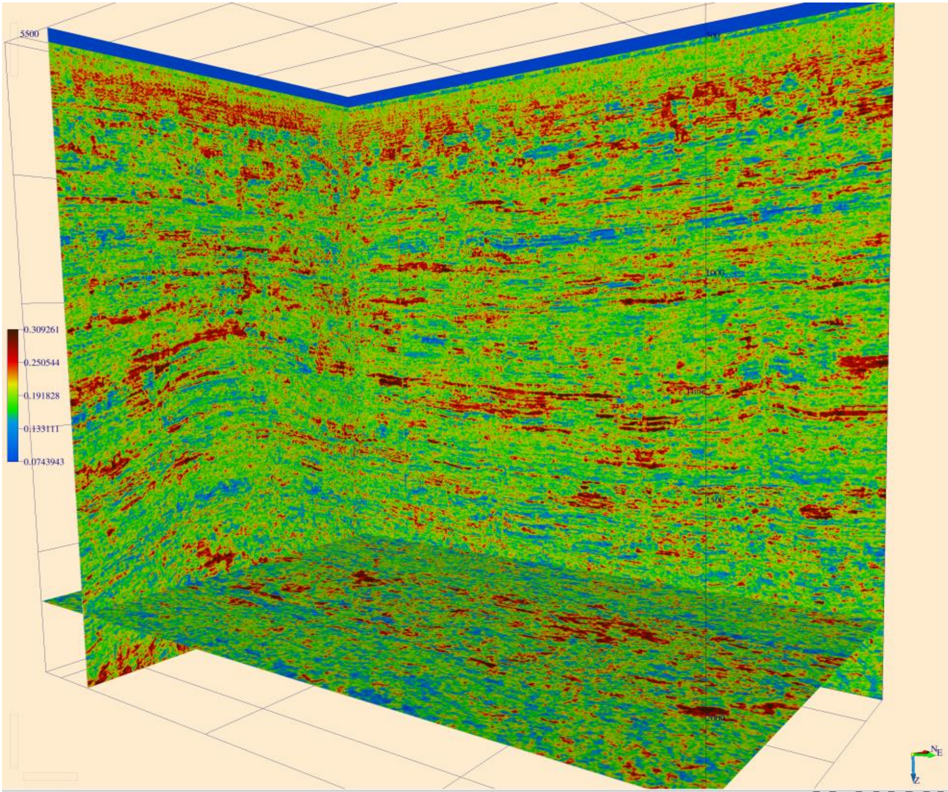




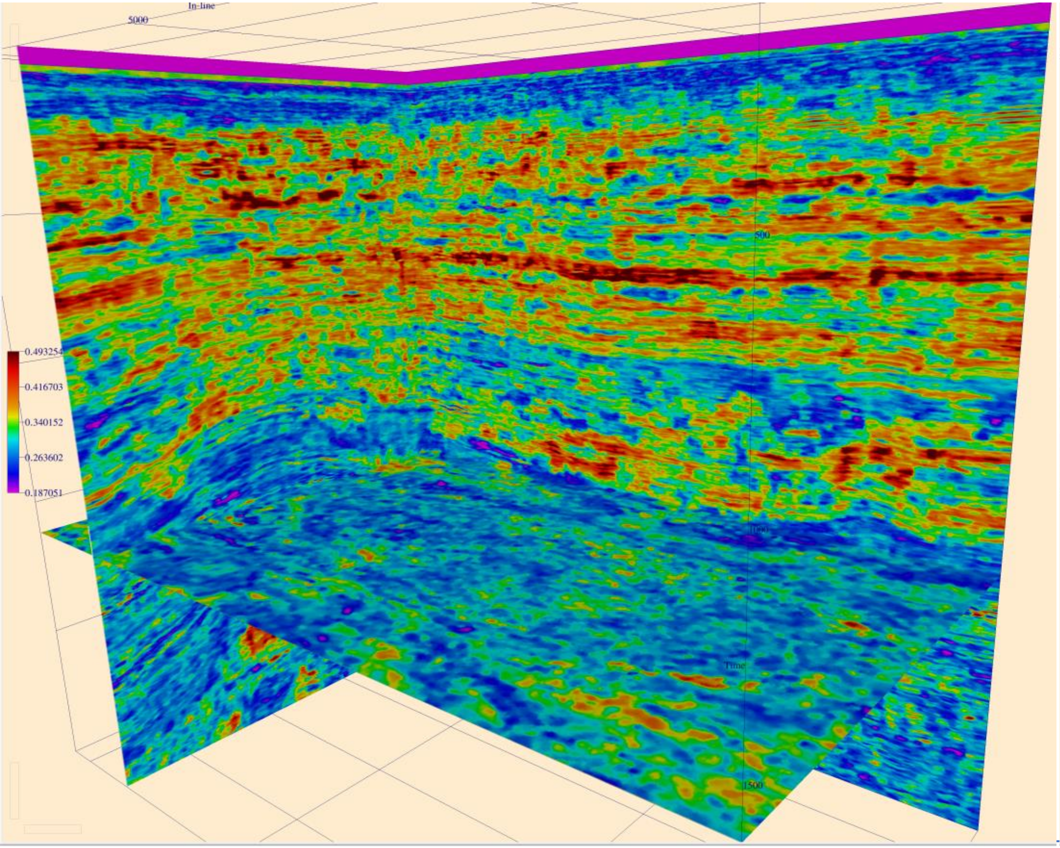
SEISMIC AMPLITUDE



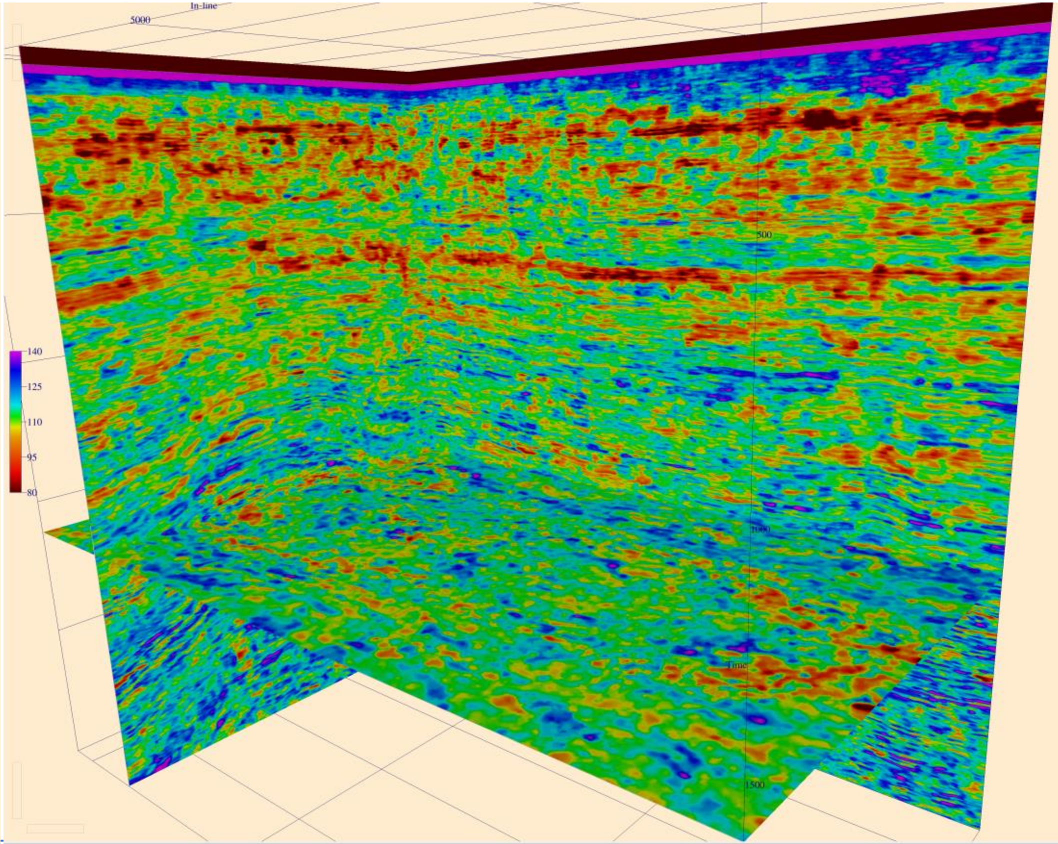
PSEUDO POROSITY



PSEUDO NPHI



PSEUDO GAMMA RAY



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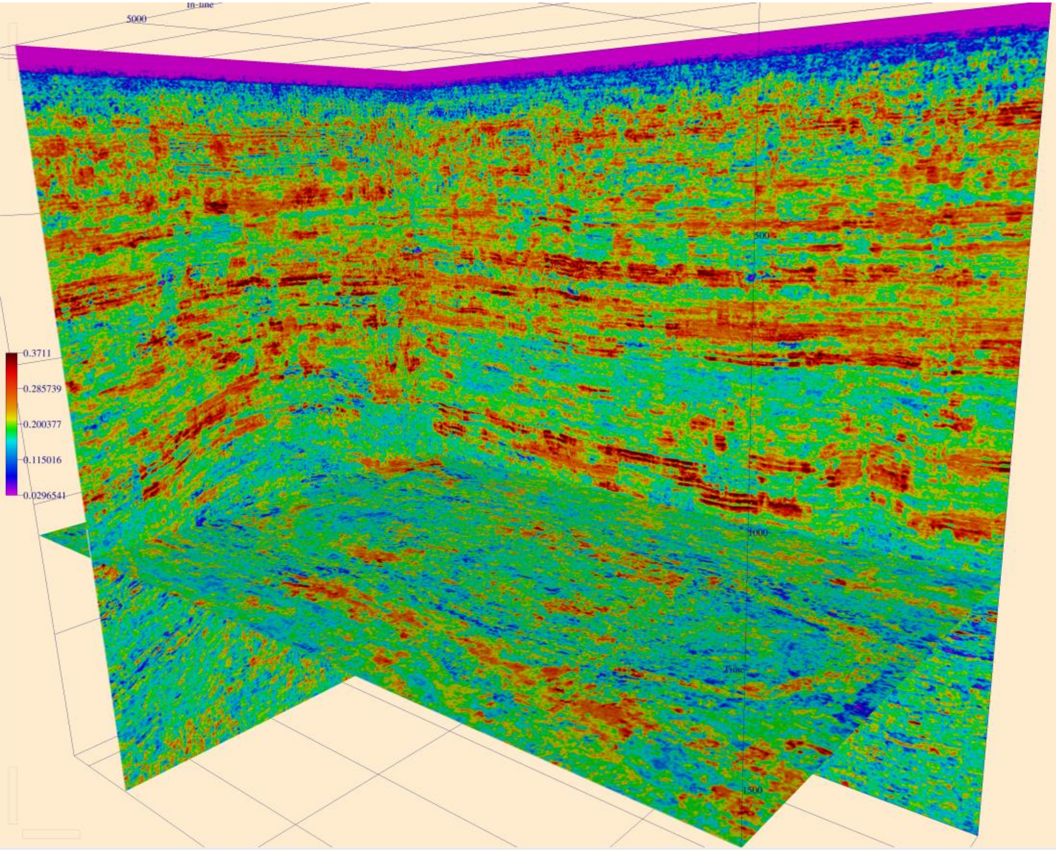

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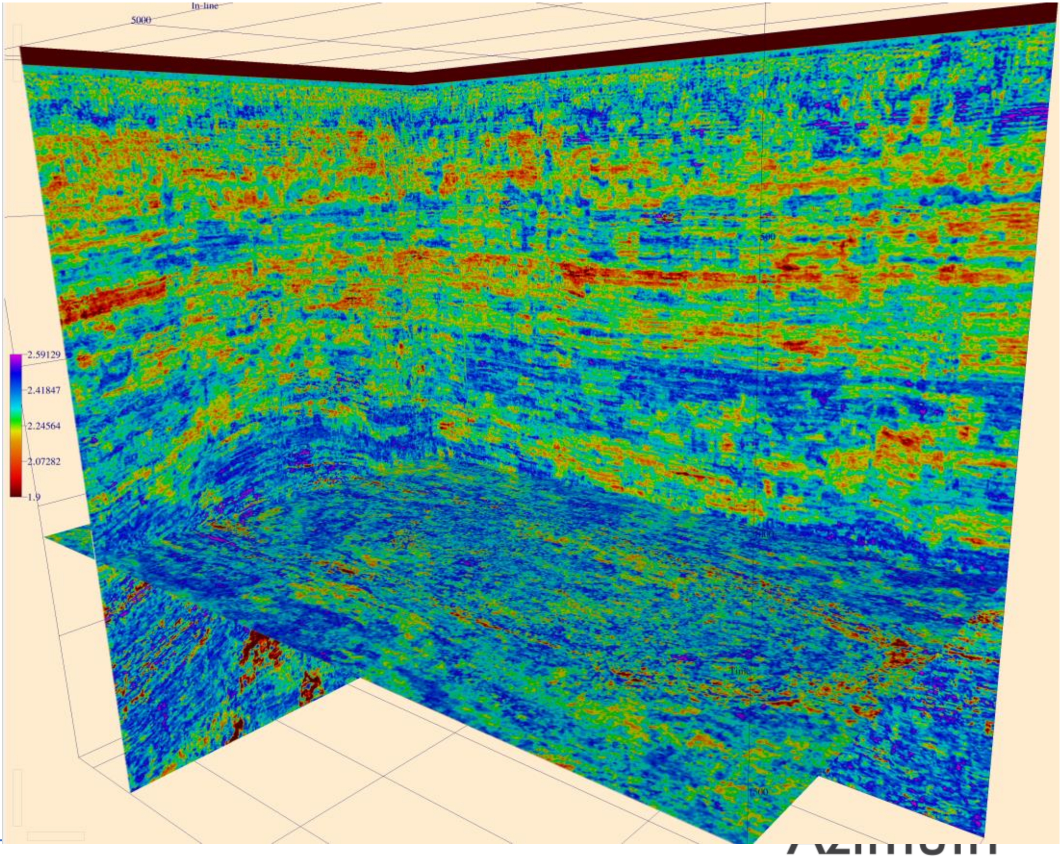

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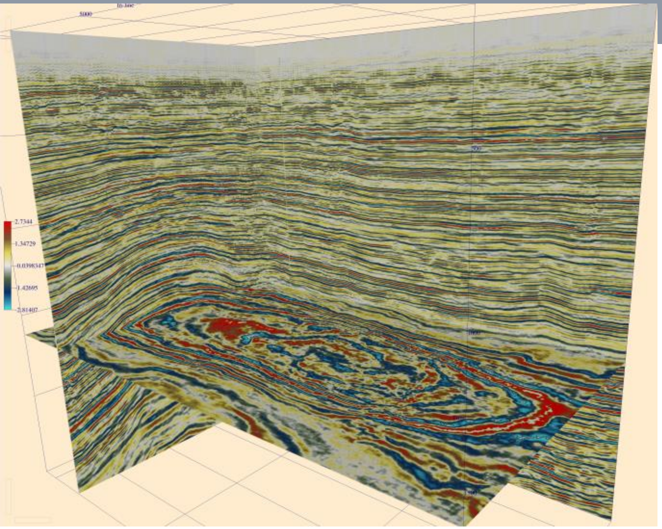
Azimuth GeoSolutions

SEISMIC AMPLITUDE



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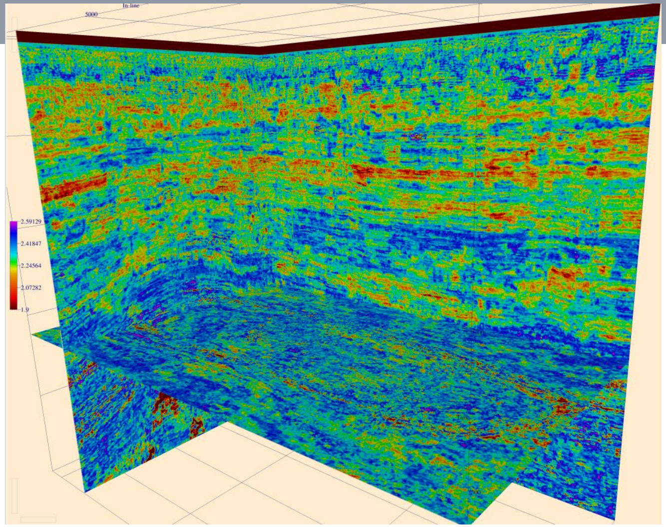

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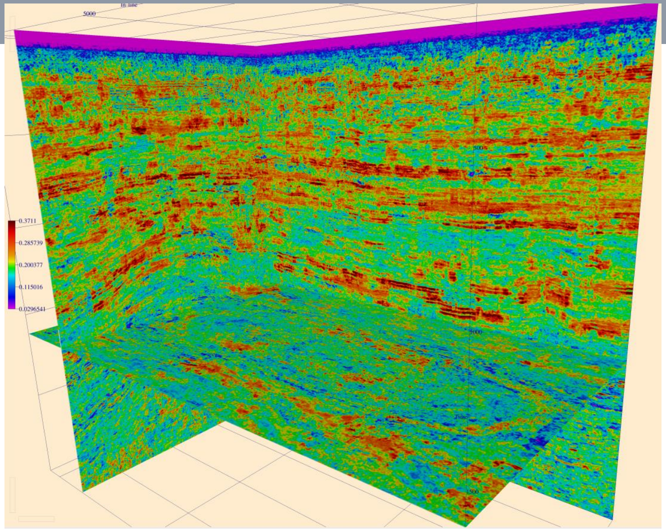

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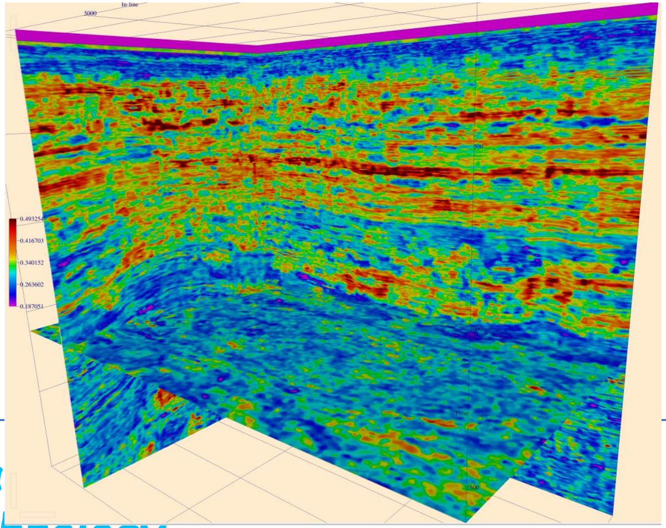
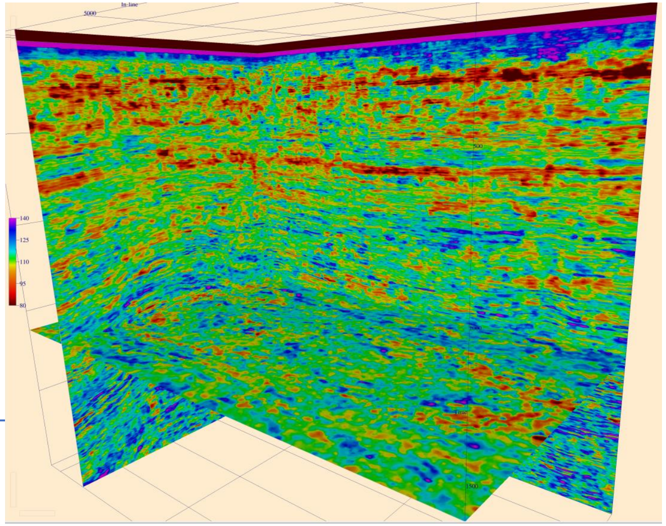


PSEUDO GR



Qua

SEISMIC DATA LIMITATIONS

- Amplitude manipulation
  - Processing focused on structural interpretation
- Frequency loss
  - Anelastic attenuation, Q
- Multiple content
  - Still not fully resolved
- Temporal resolution
  - 2 ms sampling interval not comparable to 0.5 ft log interval
  - @10,000 ft/s:
    - 2 ms = 30 ft
    - 0.5 ft = 0.033 ms

TEMPORAL RESOLUTION

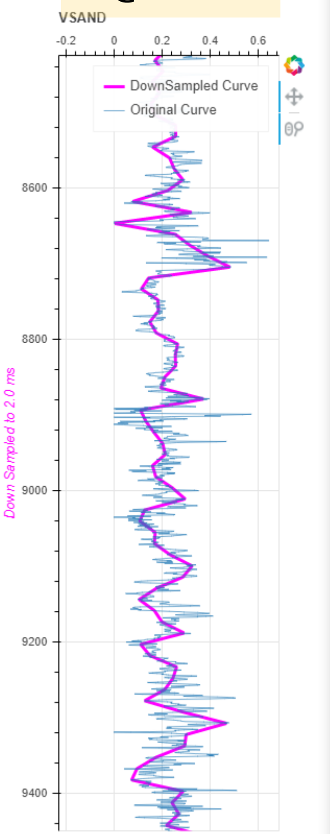
- Seismic has a lower vertical resolution than logs
- Theoretically we are limited by Ricker/Widess criteria
  - $\lambda/4$ or $\lambda/8$
- With ML we can go to log resolution
  - *Run time constraints*
  - *Storage constraints*
  - *Same approach used by QI for stochastic Inversion*

SAMPLING: A CRITICAL ISSUE

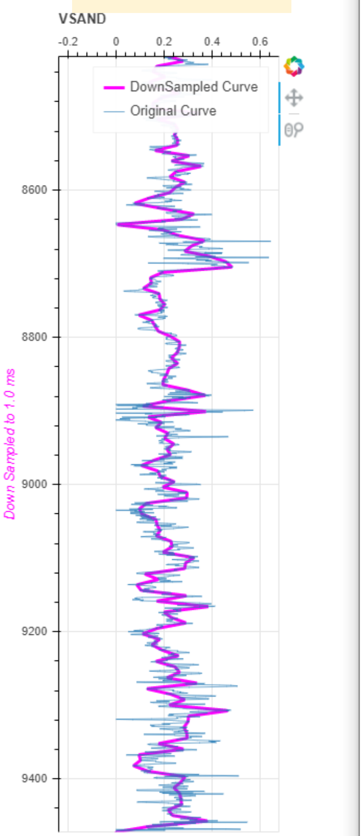
- Capturing log details with seismic sampling
  - Dependent on temporally varying velocities
  - Some log features might be totally missed with choice of sample interval
- Up Sampling (or Down Scaling) of seismic
  - Create a container of interpolated samples
  - Fill these extra samples by ML from highly sampled logs
- Recommendation
  - Sampling needs to be tested per area
  - 0.5 ms might be a reasonable option to capture log details

THE NEED TO UPSAMPLE

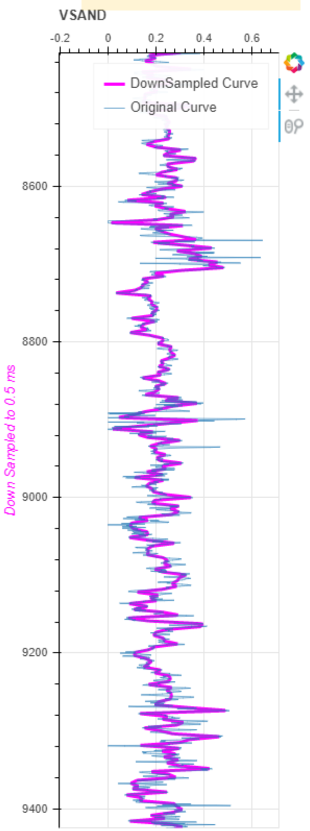
@ 2 MS



@ 1 MS



@ 0.5 MS



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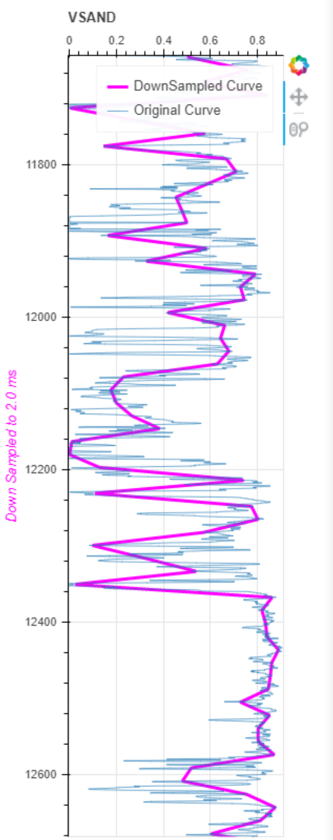
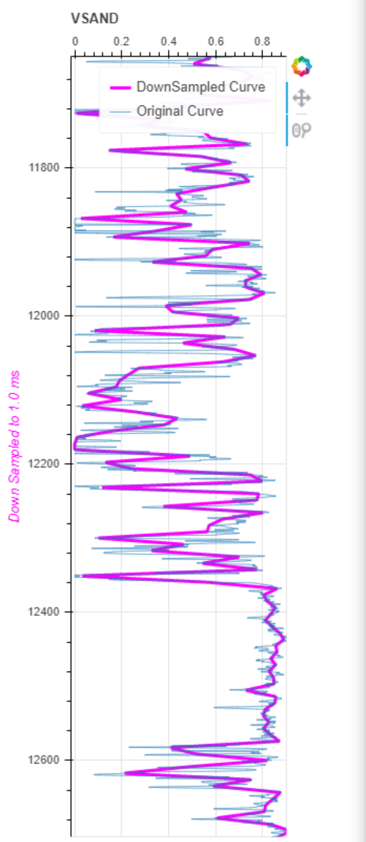
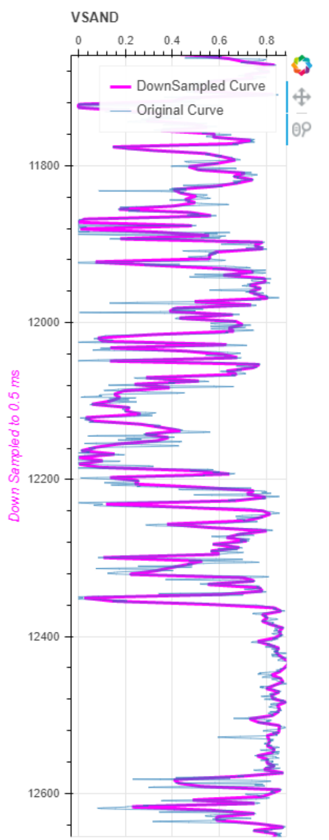


@ 1 MS



@ 0.5 MS



SHALLOW INTERVAL

DEEP INTERVAL

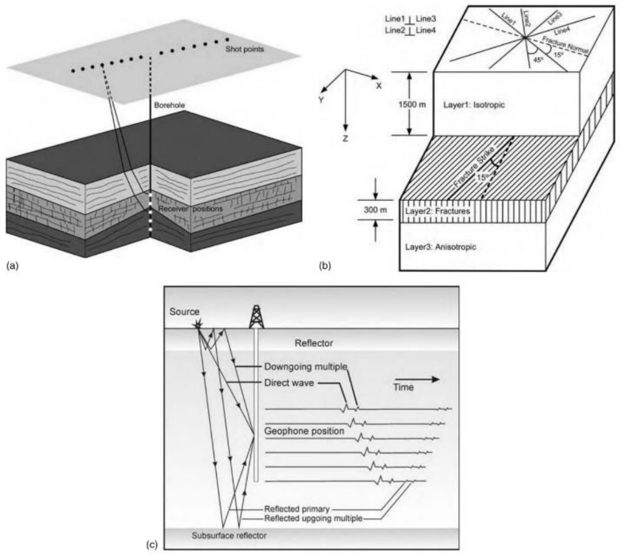
ANELASTIC FREQUENCY ABSORPTION

- Q Estimation
  - From seismic spectral ratios
    - Quick but inaccurate
  - From Well Logs
    - Not accurate due to a lot of simplifying assumptions
  - From VSP’s
    - Definitive approach
- Q compensation
    - Will restore lost frequencies with depth/time
    - Improve resolution
    - Reprocess seismic applying inverse Q

BROWNFIELD REJUVENATION:

PROPOSED APPROACH I

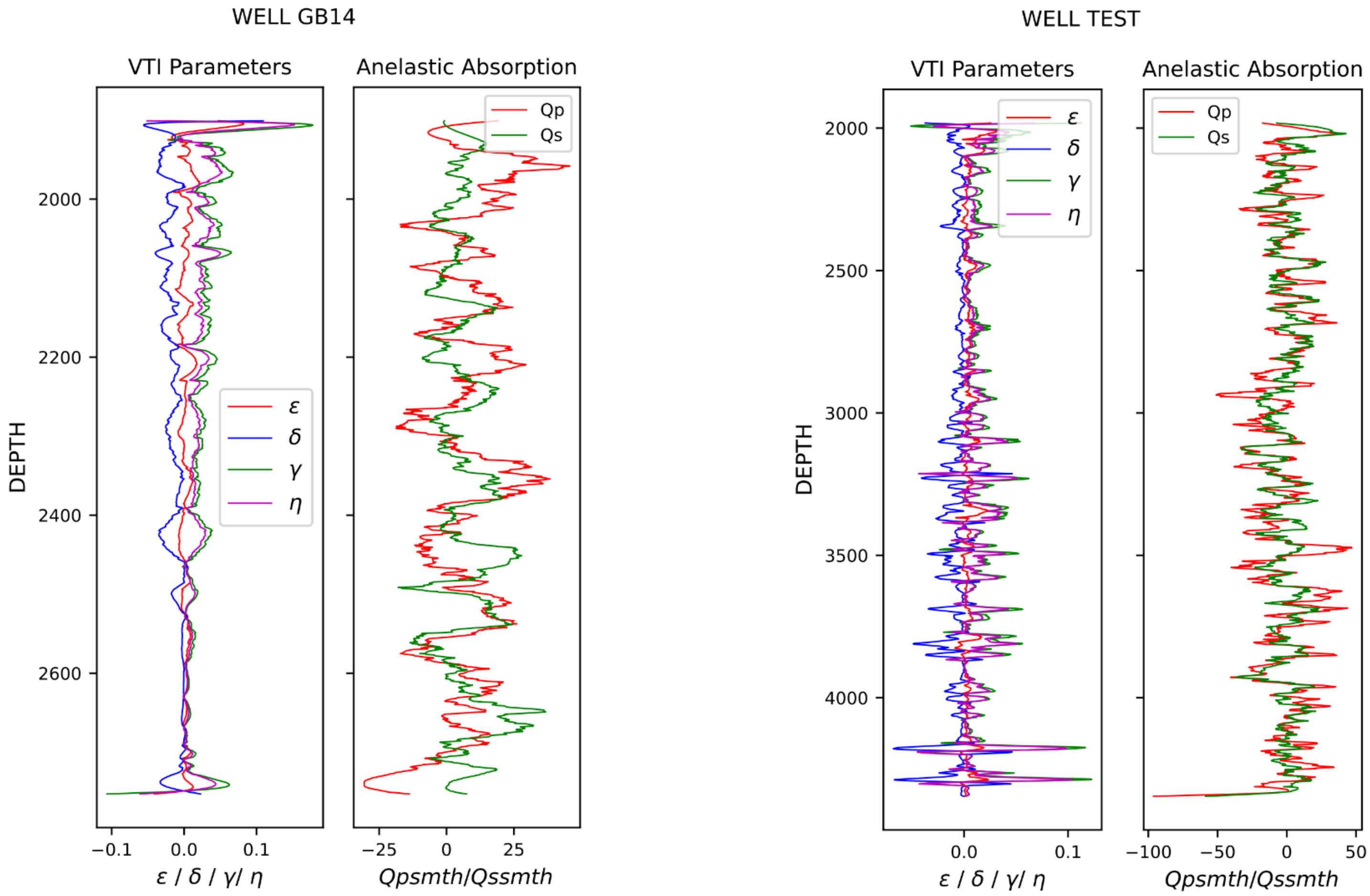
- **WAVSP**
  - ***Multi Azimuth*** walk away VSP
  - ***Azimuthal anisotropy*** (HTI)
    - causes P waves to be faster parallel to fractures
  - ***Attenuation anisotropy*** (VTI and HTI)
  - ***Multi mode*** (P, PS)
  - ***Q extraction***
    - ***Q profile from Zero Offset and WA VSP***
    - Q is lowered for P waves perpendicular to fractures



BROWNFIELD REJUVENATION:
PROPOSED APPROACH II

- ML Propagation
  - Build ML Q model
  - Generate SEGY of Q -> Q from logs/Zero offset VSP
  - Generate horizons -> Q from WAVSP
  - ***Interpret low Q as proxy for good permeability***

ANISOTROPY AND Q FROM WELL LOGS



Q EXTRACTION: *WELLS VS VSP*

- **Q from wells**
  - KHz frequencies
  - Have negative values -> amplification
  - Extracted over the full range of well depths
  - Isotropic assumption
- **Q from ZO/WA VSP**
  - Hz range of seismic frequencies
  - Physcially realizable values, no negatives
  - Limited by acquisition depths
  - Multi level spectral ratio averaging

QUALITY FACTOR (Q) INTERPRETATION

- Q_{seis}/V_p Ratio
  - High values correlate with most porous and most permeable
  - Low values correlate with reduced flow, e.g. shale rich layers
  - *Could* delineate unconsolidated sands & jointed sandstones
  - ***Low seismic velocity and Q values ->***
    - ***permeable or hydraulically transmissive fracture zones***

MECHANICAL EARTH MODELS

- Pore Pressure prediction
  - Compute Overburden Pressure
  - Overburden Stress Gradient
- Elastic coefficients
  - Poisson’s Ratio, Young’s Modulus, etc…
  - Quite sparce compared to 3D seismic
- Machine Learning
  - Integrate Seismic and Elastic Coefficients
  - Build Data Driven Models
  - Predict at every seismic trace in 3D seismic

Thank you