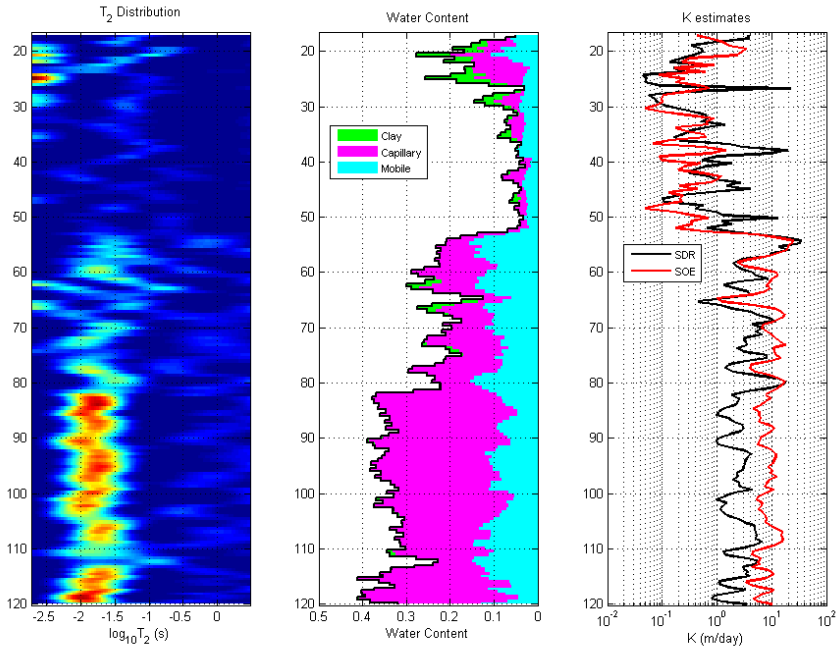
NMR Geophysics for Groundwater Investigations



Dave Walsh

October 13, 2016

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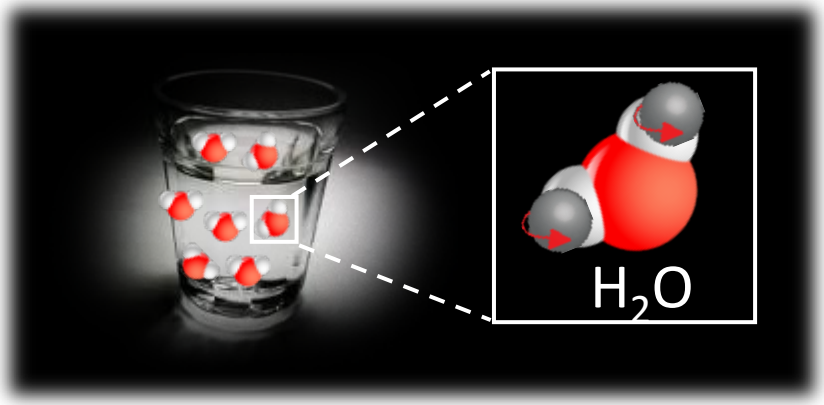
NMR GEOPHYSICS

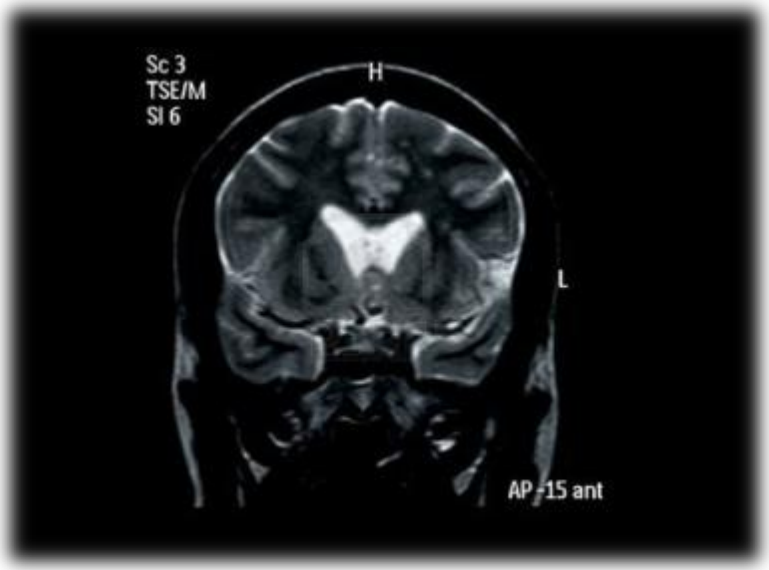
NMR Geophysics for Groundwater

- Traditional Geophysics Provides:
  - Acoustic Impedance (Seismic)
  - Electrical Resistivity (ERT/EM/MT)
  - Dielectric Constant (GPR)
  - *Hydrogeologic Properties are Inferred*

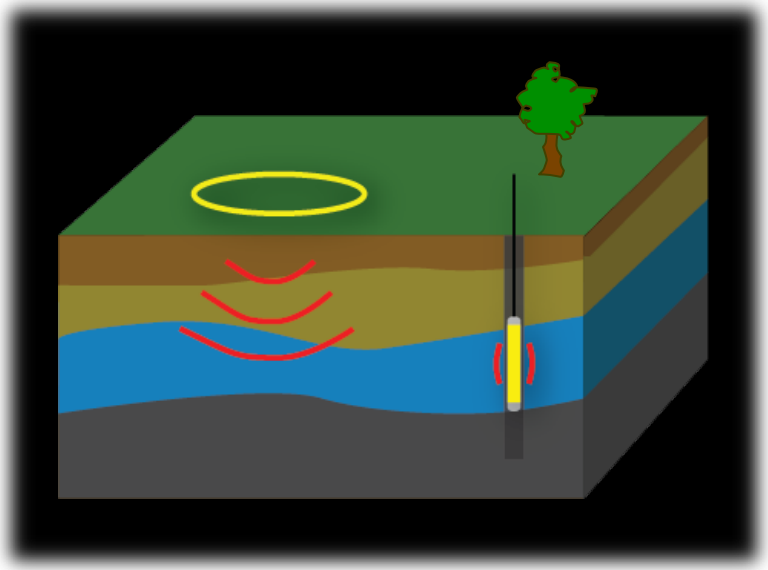
- NMR Geophysics Provides
  - Direct Quantification of Water Content
  - Sensitivity to Pore Size
  - Estimation of Permeability
  - *Hydrogeologic Properties are Directly Characterized*

Nuclear Magnetic Resonance (NMR)





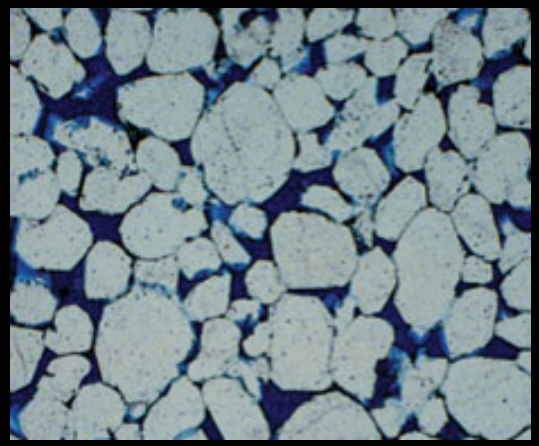
Medical MRI



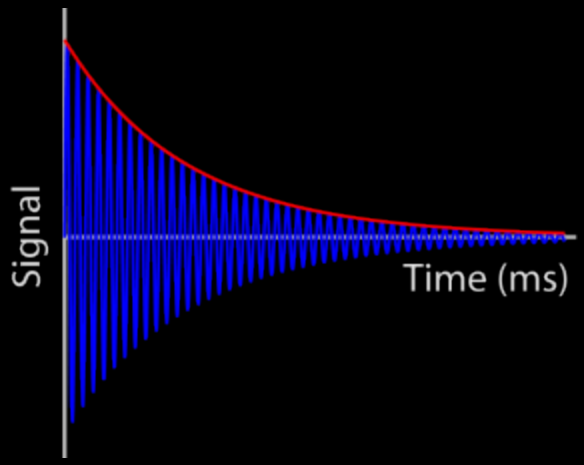
NMR Geophysics

Hydrologic Properties from NMR

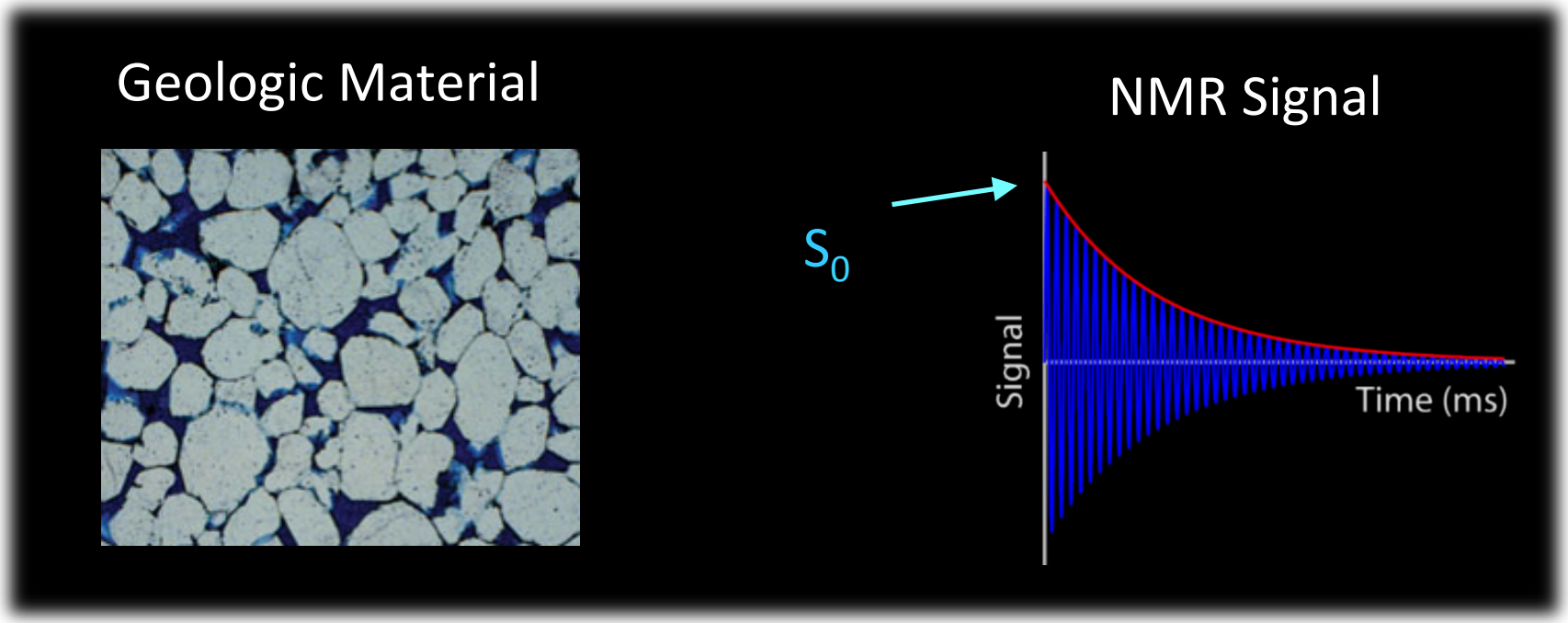
Geologic Material



NMR Signal



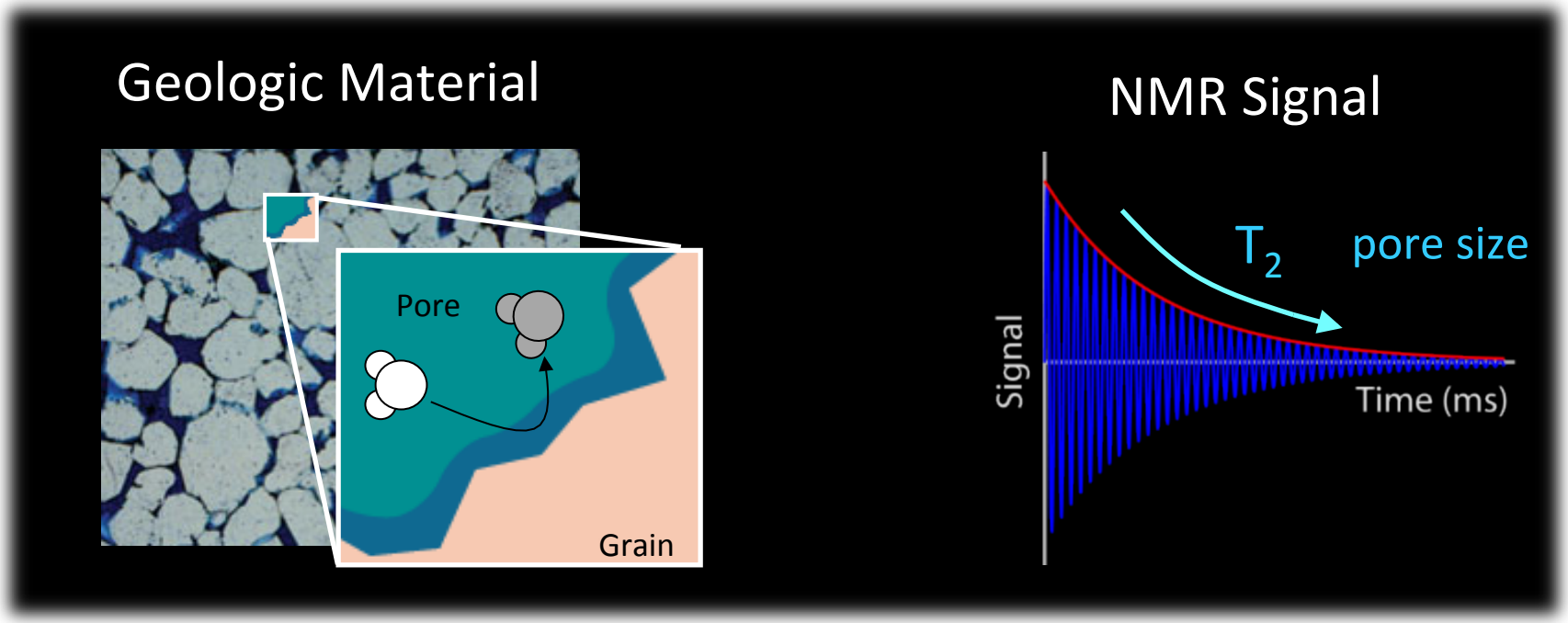
Hydrologic Properties from NMR



<u>NMR Provides</u>

- Water Content
- Porosity (Lithology Independent)

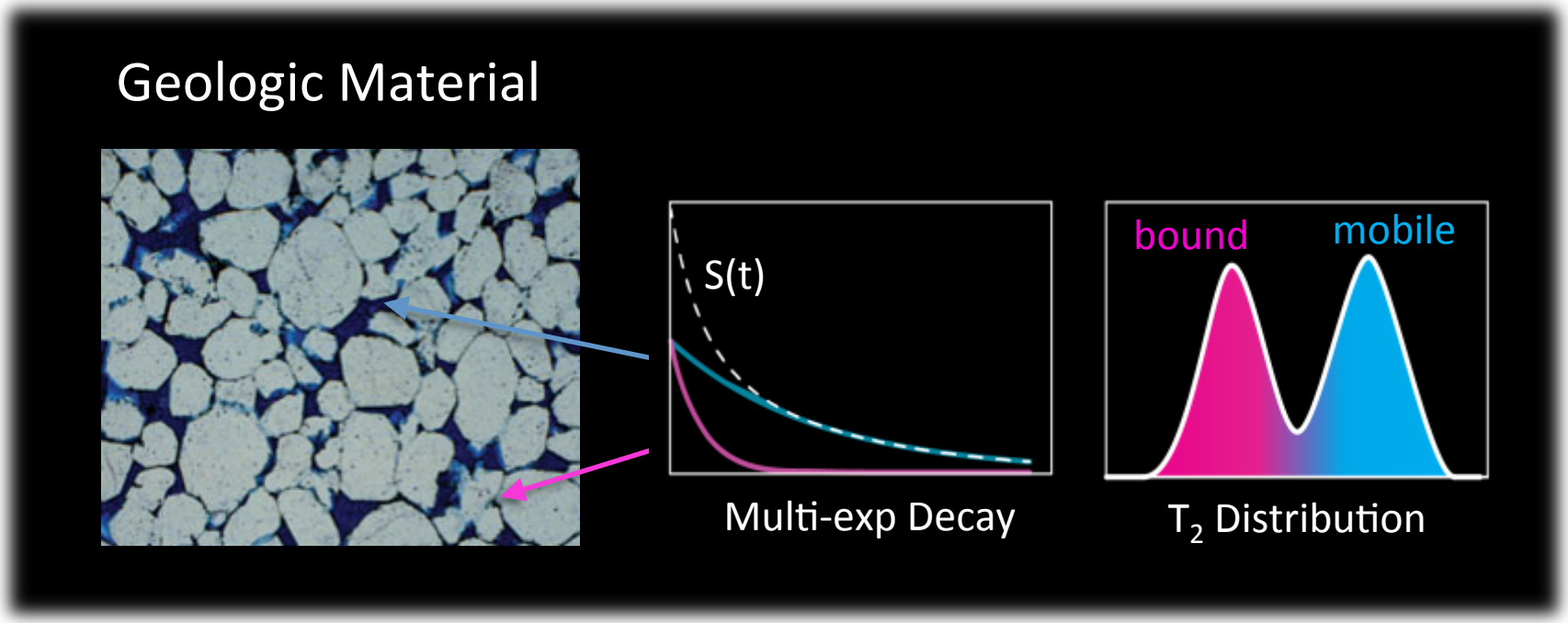
Hydrologic Properties from NMR



<u>NMR Provides</u>

- Water Content
- Porosity (Lithology Independent)
- Pore Size V/S

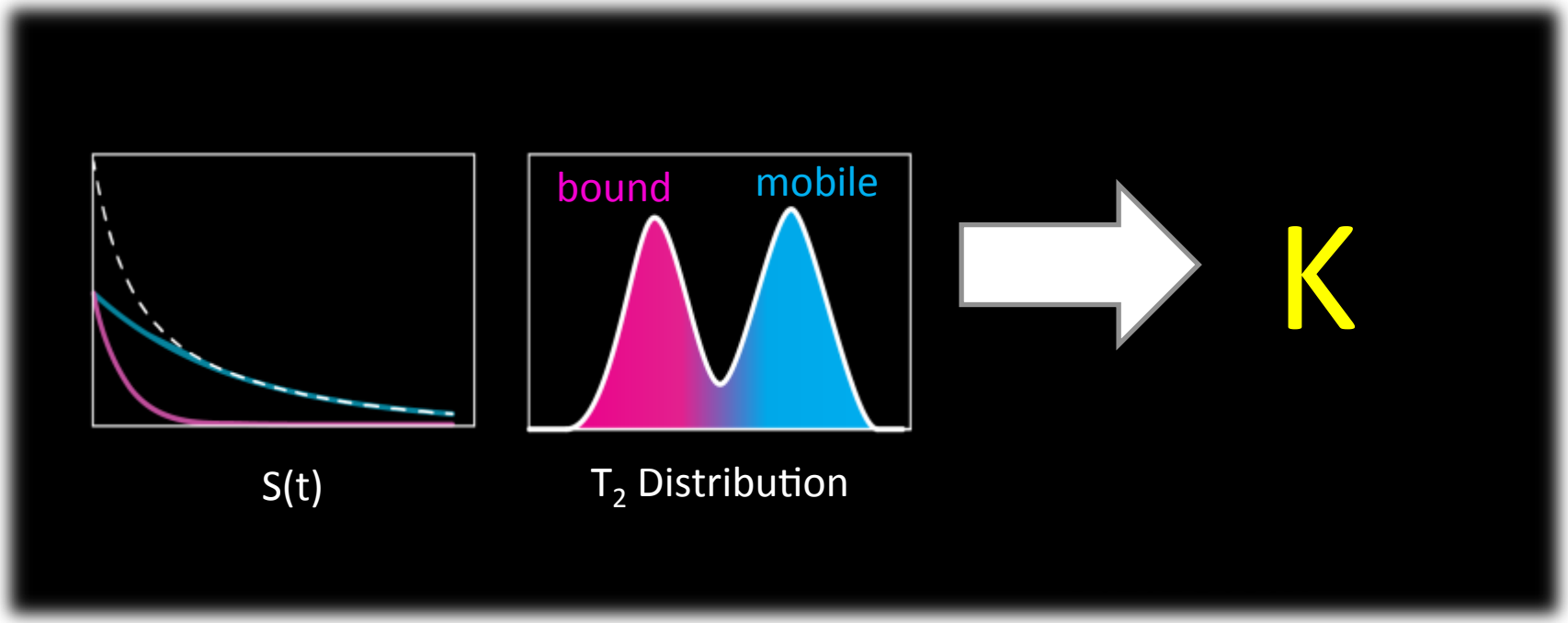
Hydrologic Properties from NMR



<u>NMR Provides</u>

- Water Content
- Porosity (Lithology Independent)
- Pore Size V/S
- Pore Size V/S Distribution
- Bound versus Mobile WC

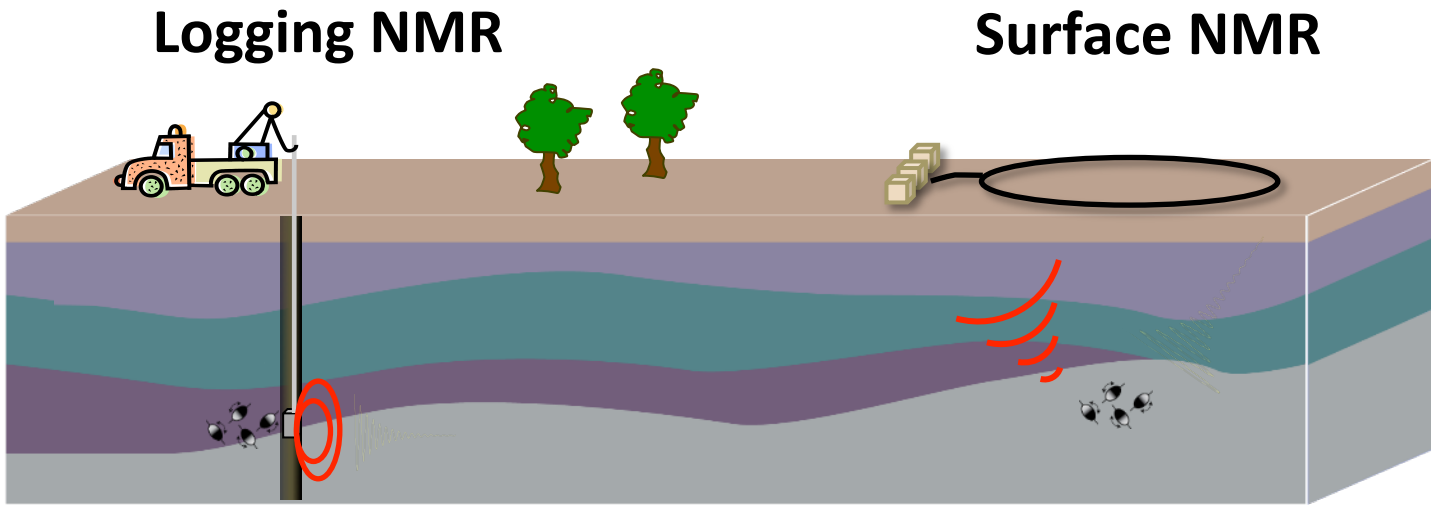
Hydrologic Properties from NMR



NMR Provides

- Water Content
- Porosity (Lithology Independent)
- Pore Size V/S
- Pore Size V/S Distribution
- Bound versus Mobile WC
- Permeability

Logging NMR vs. Surface NMR



Logging NMR:

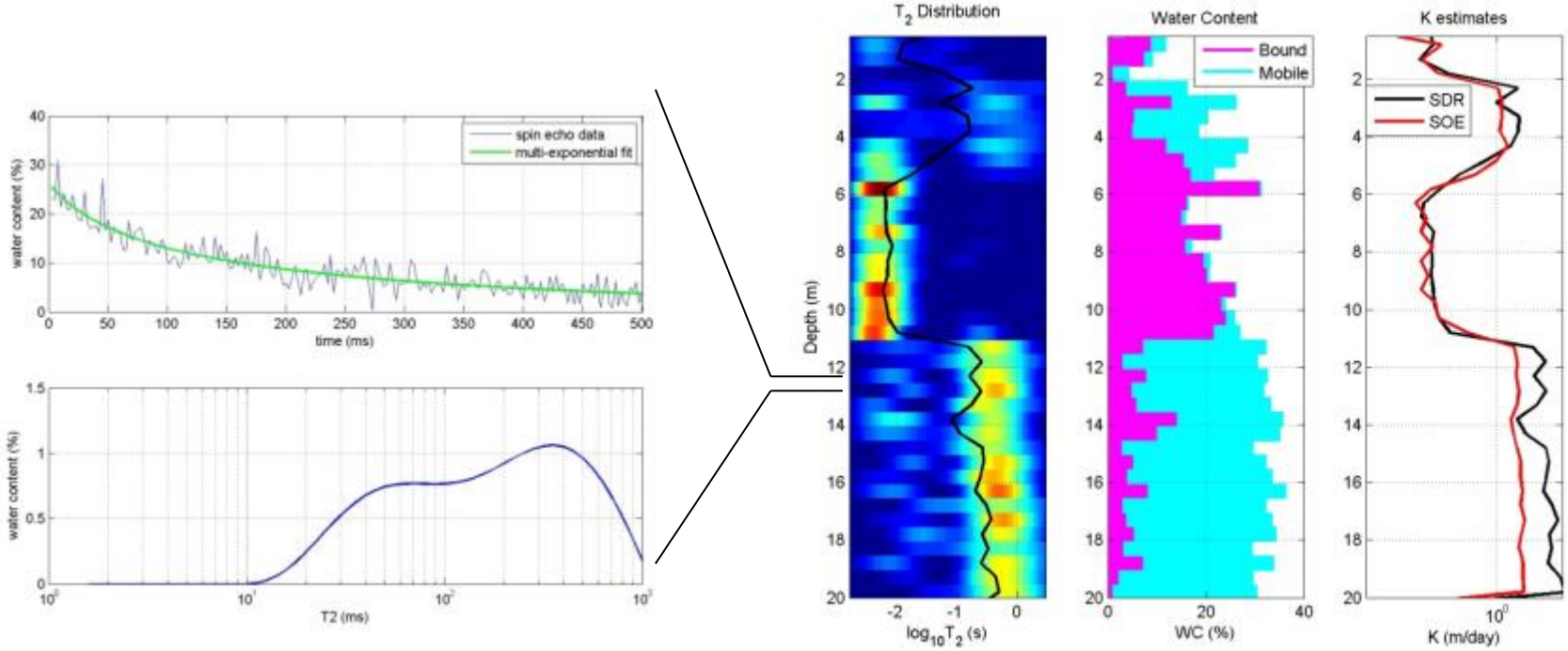
- Requires borehole (drilling cost)
- Depth range 1000s of meters
- Vertical resolution ~ 0.5m
- Data depends on borehole conditions
- Measures water in all pore sizes

Surface NMR:

- Non-invasive (no drilling cost)
- Max depth range 100 meters
- Vertical resolution ~ 2 – 20m
- Can't use in noisy urban areas
- Measures water in med-large pores only (not clay)

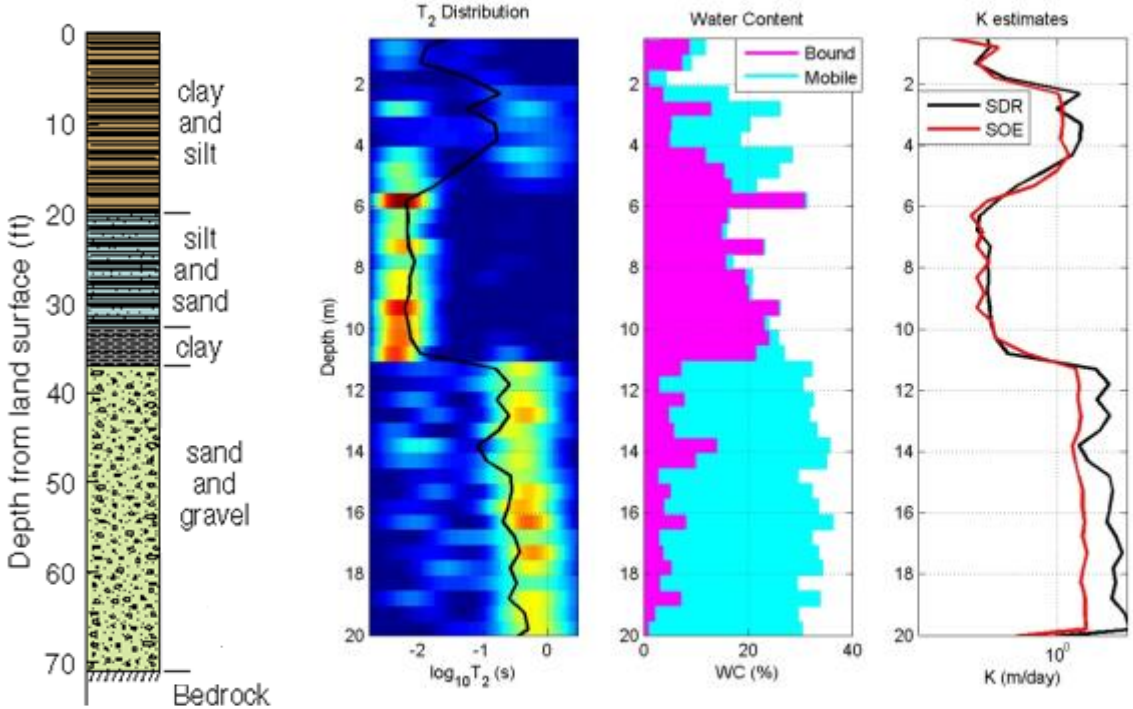
NMR Logging Data Interpretation

- Vertical resolution 0.5m (determined by length of coil in probe)
- Processing automated in packaged software
- Interpretation yields detailed characterization of aquifer structure and properties (bound/mobile water content, permeability)

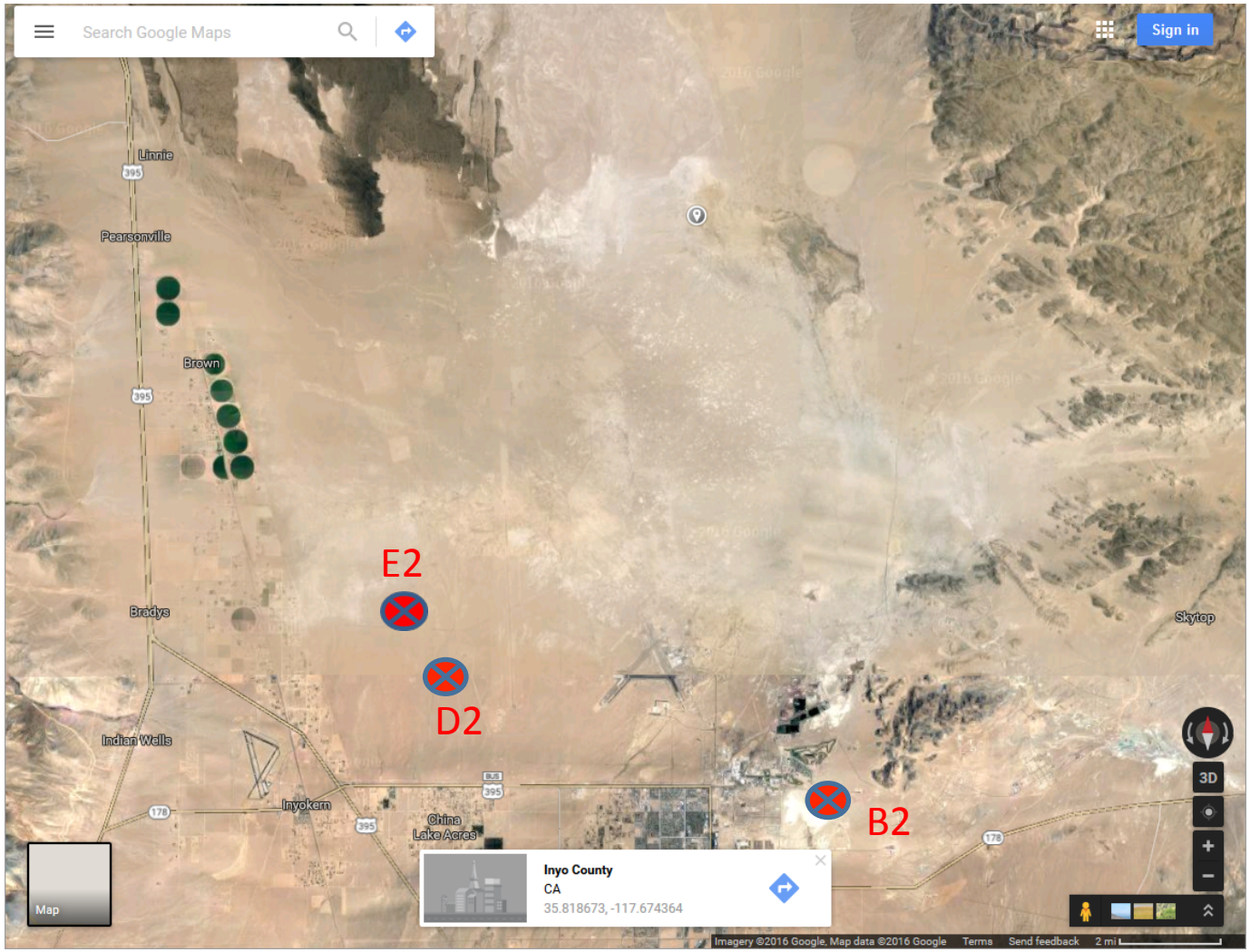


Straightforward Interpretation

- Vertical resolution 0.5m (determined by length of coil in probe)
- Processing automated in packaged software
- Interpretation yields detailed characterization of aquifer structure and properties (bound/mobile water content, permeability)



China Lake, CA 2016



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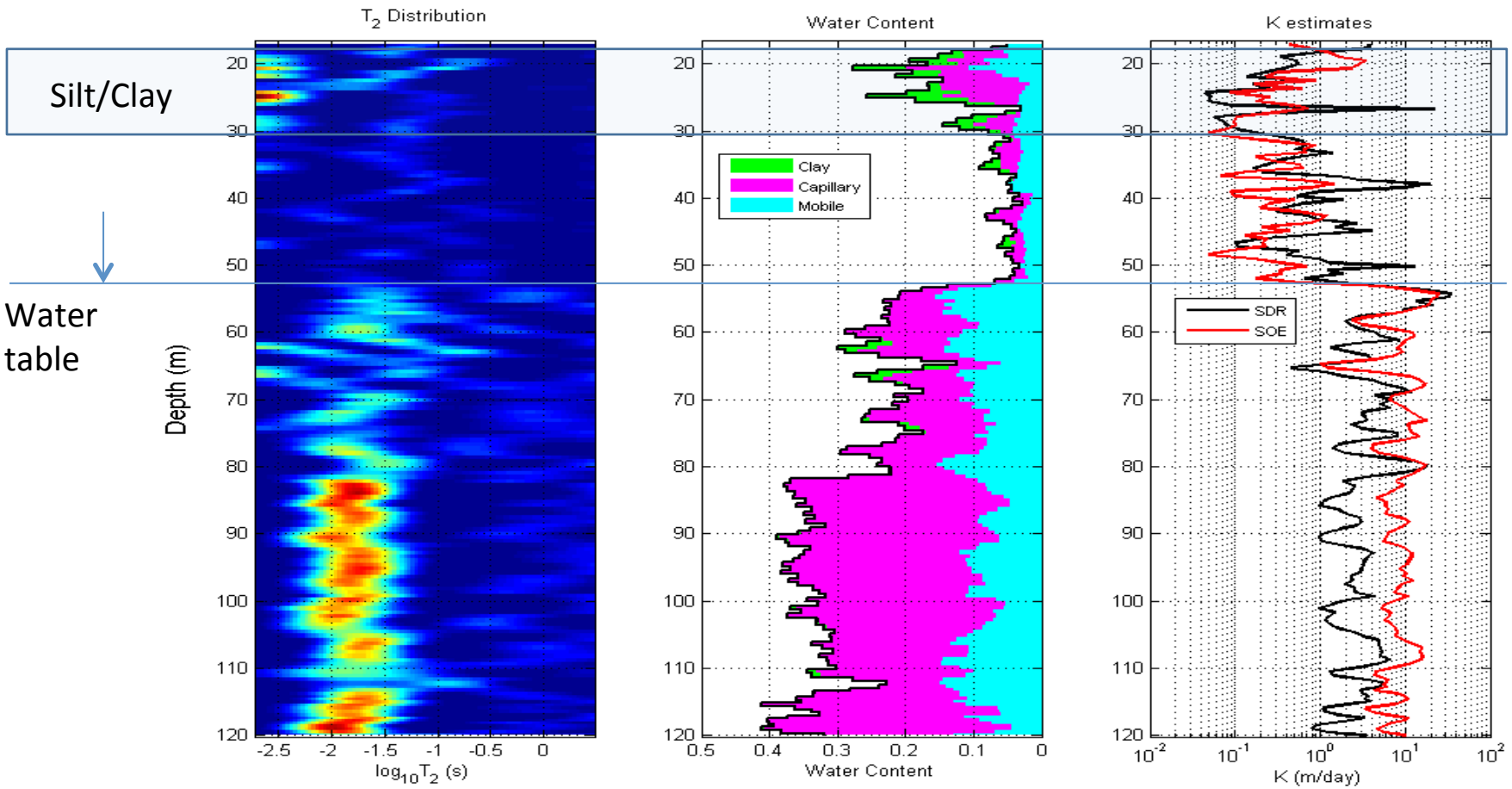
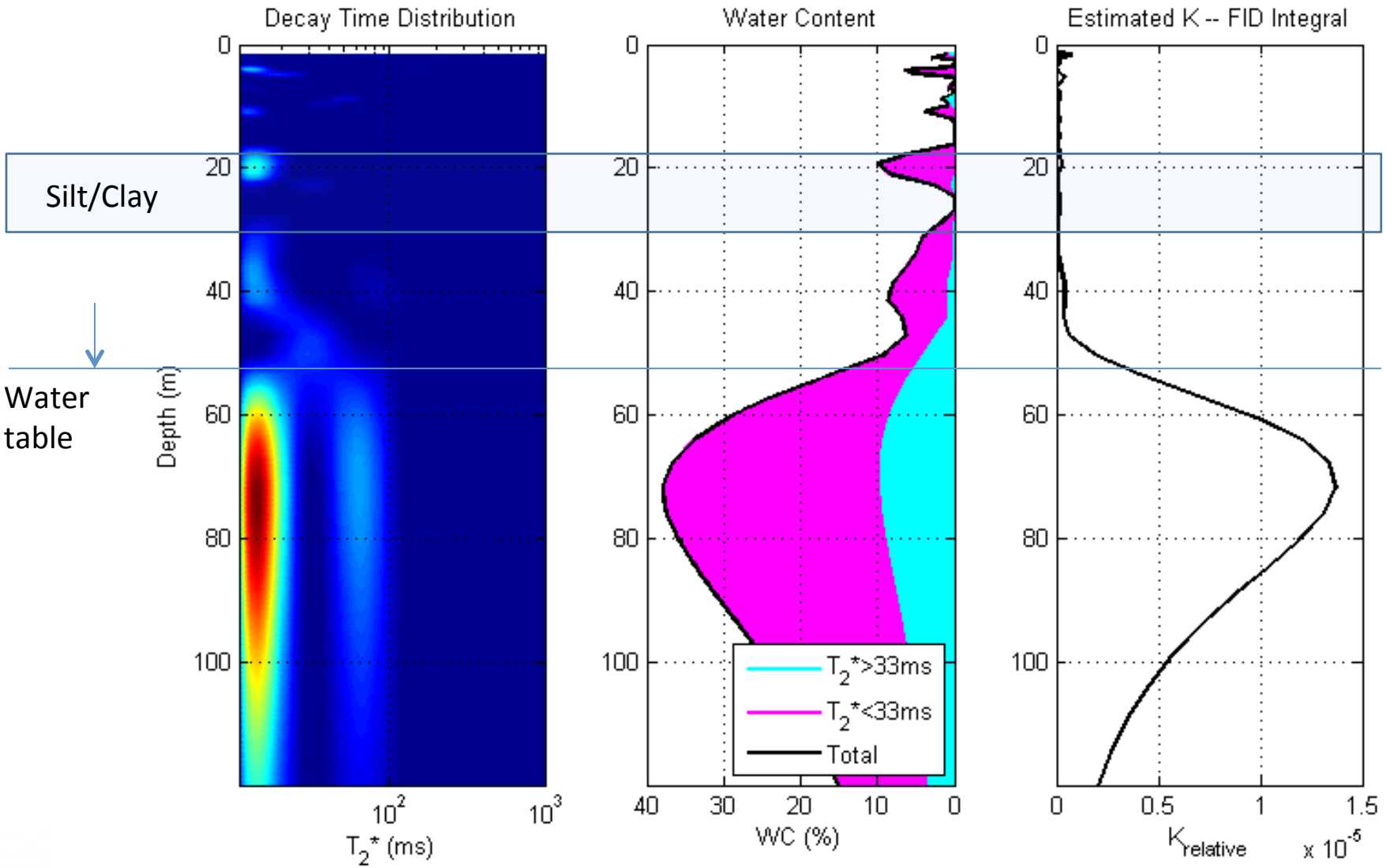
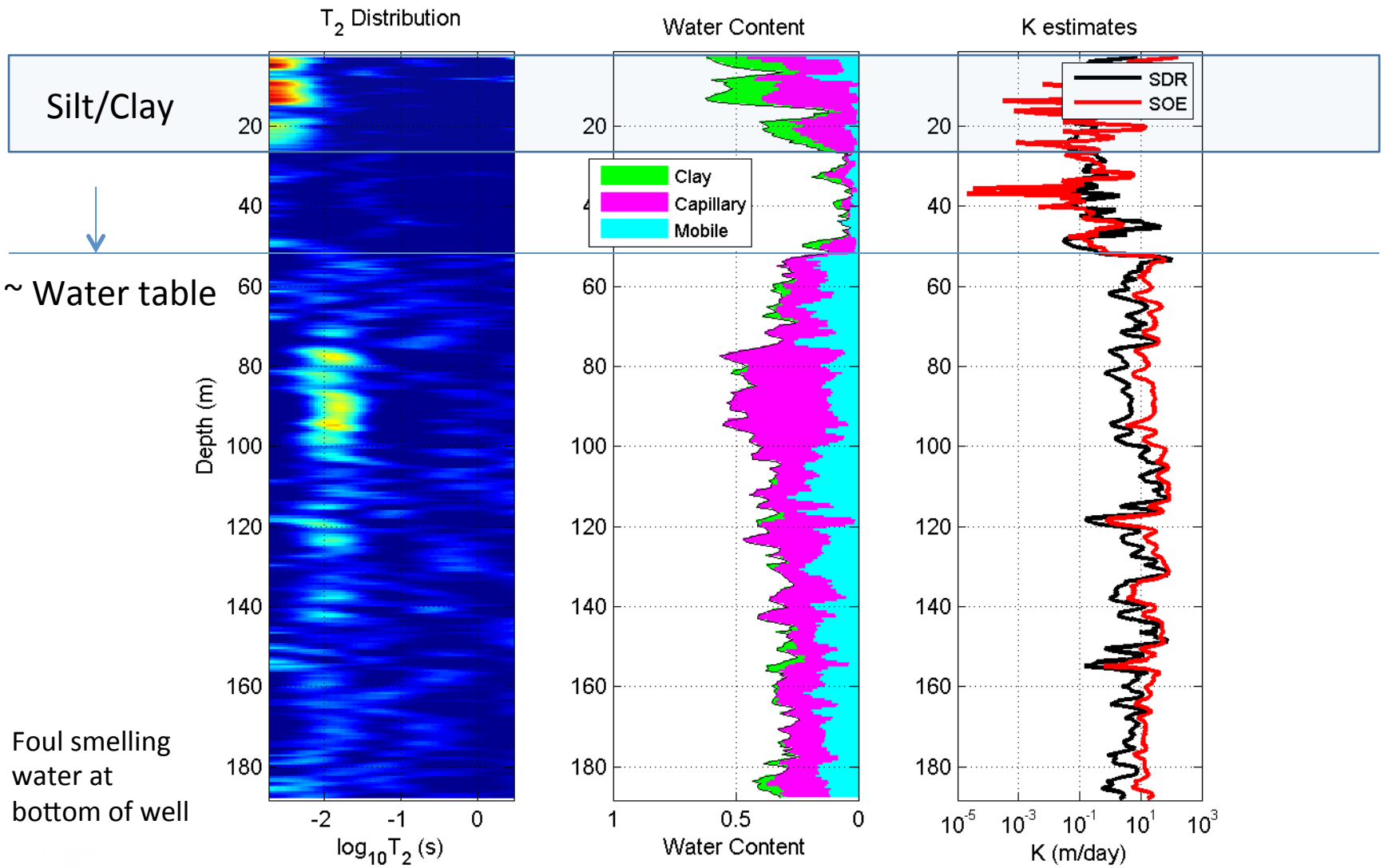
Navy Well D2, NMR Log



Navy Well D2, Surface NMR Inversion



Navy Well E2, NMR Logging



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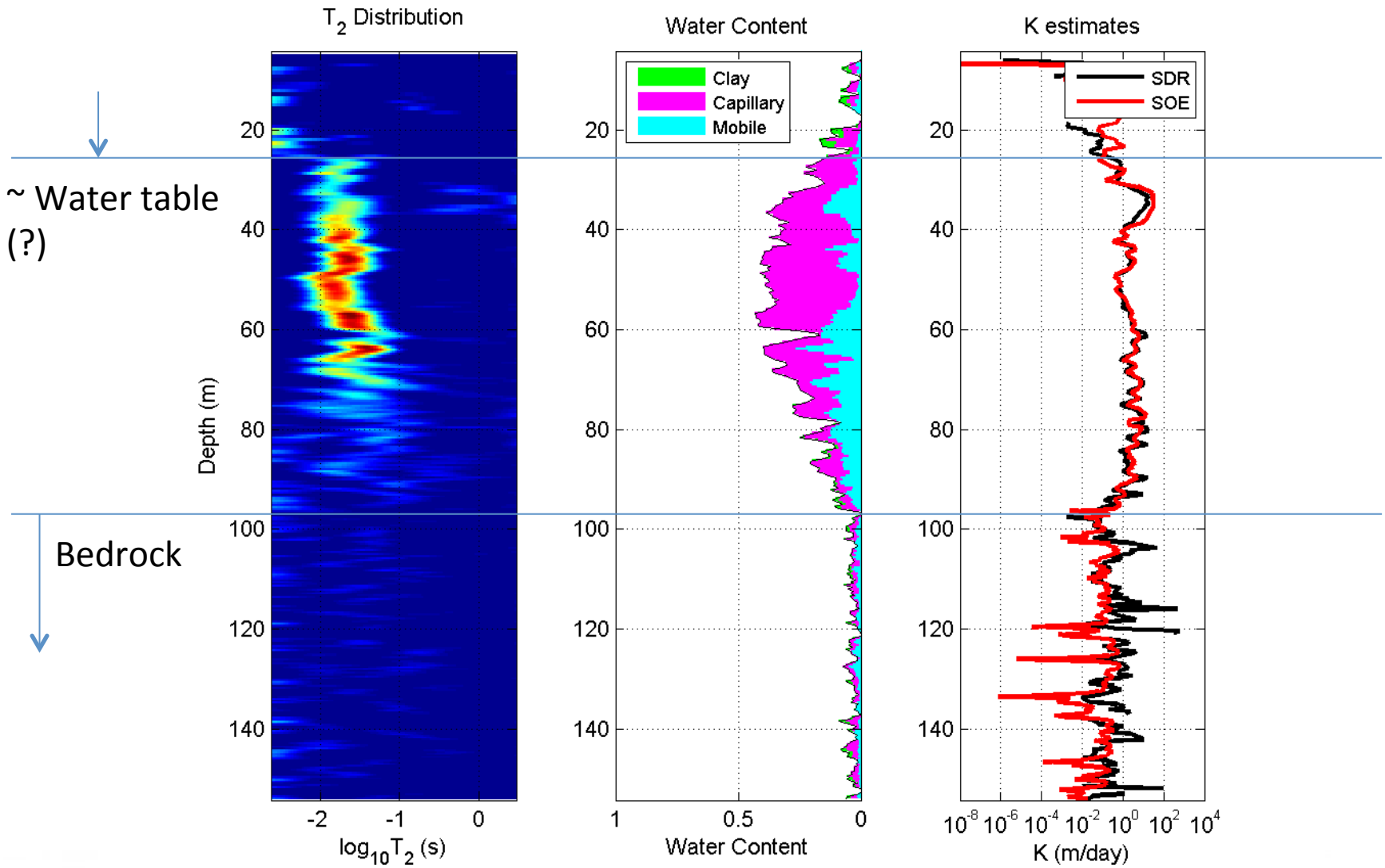
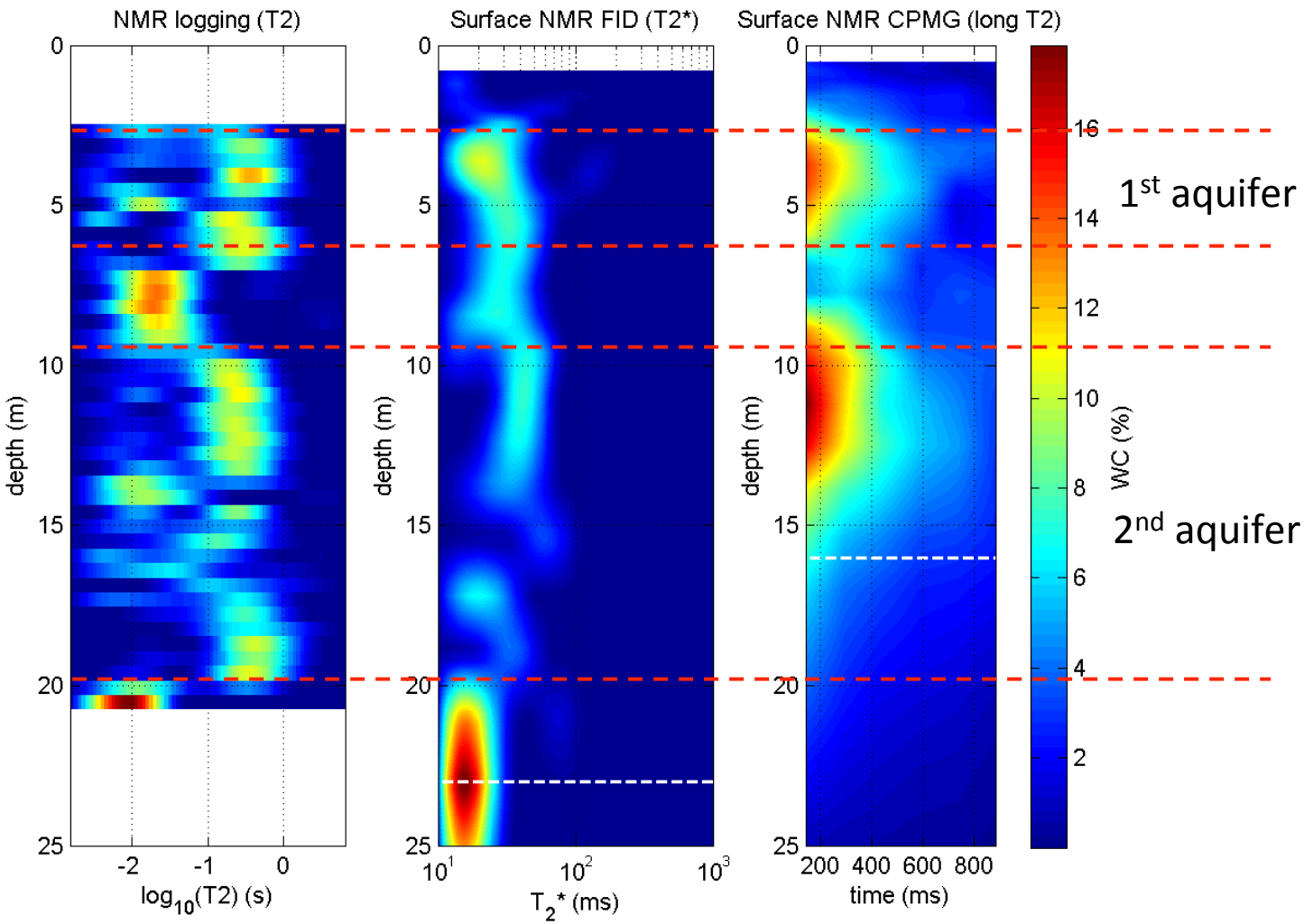
Navy Well B02, NMR Logging



Leque Island WA, DP NMR and Surface NMR



White dashed lines indicate maximum resolution depth for surface NMR data.

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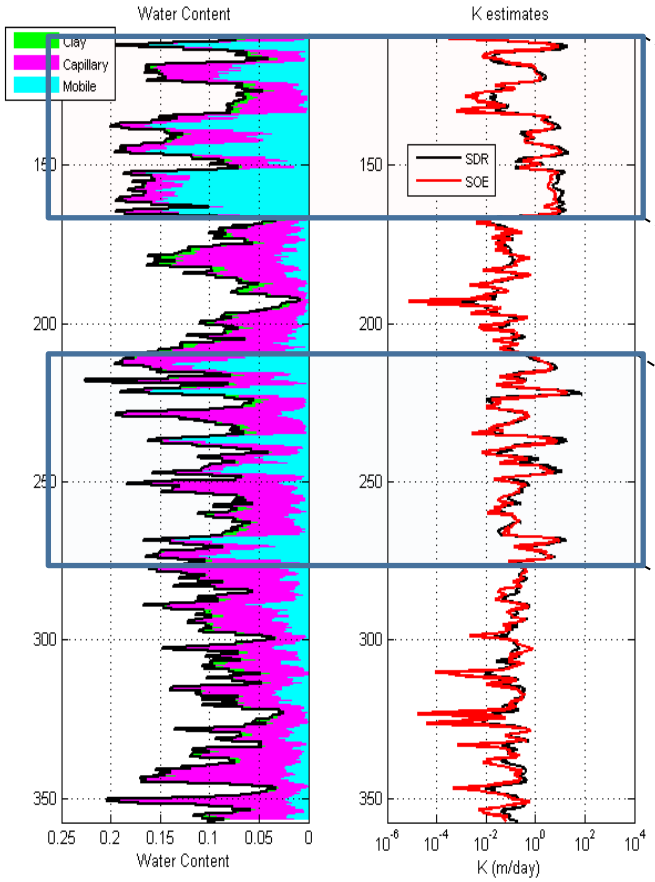
Denver Water ASR Pilot Study 2015

NMR Logging

40th & Colorado



Denver Formation

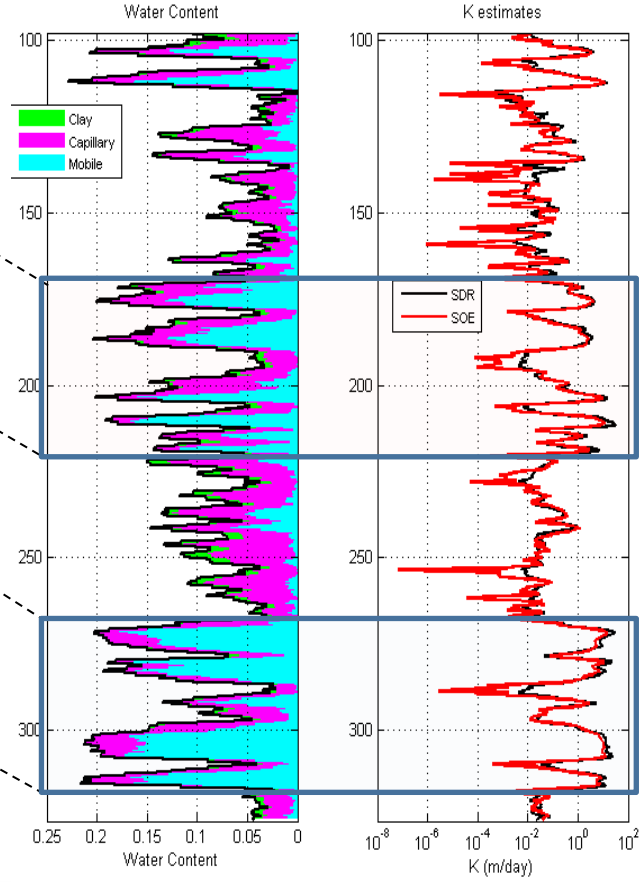
Upper Arapahoe

Low K

Lower Arapahoe

Low K

40th & Lima



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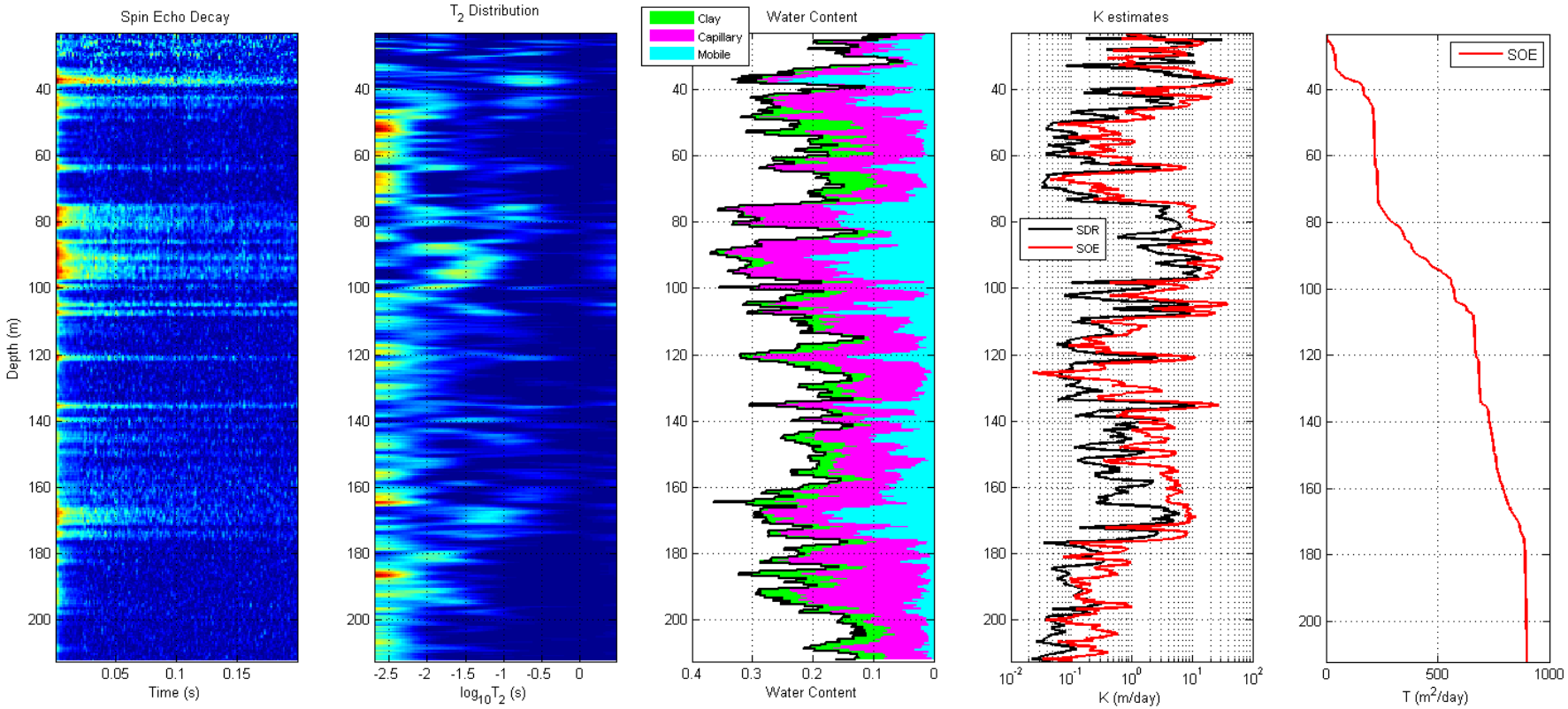
Chandler AZ, NMR Logging, 2016

Wireline NMR Tool Max Depth 1000m



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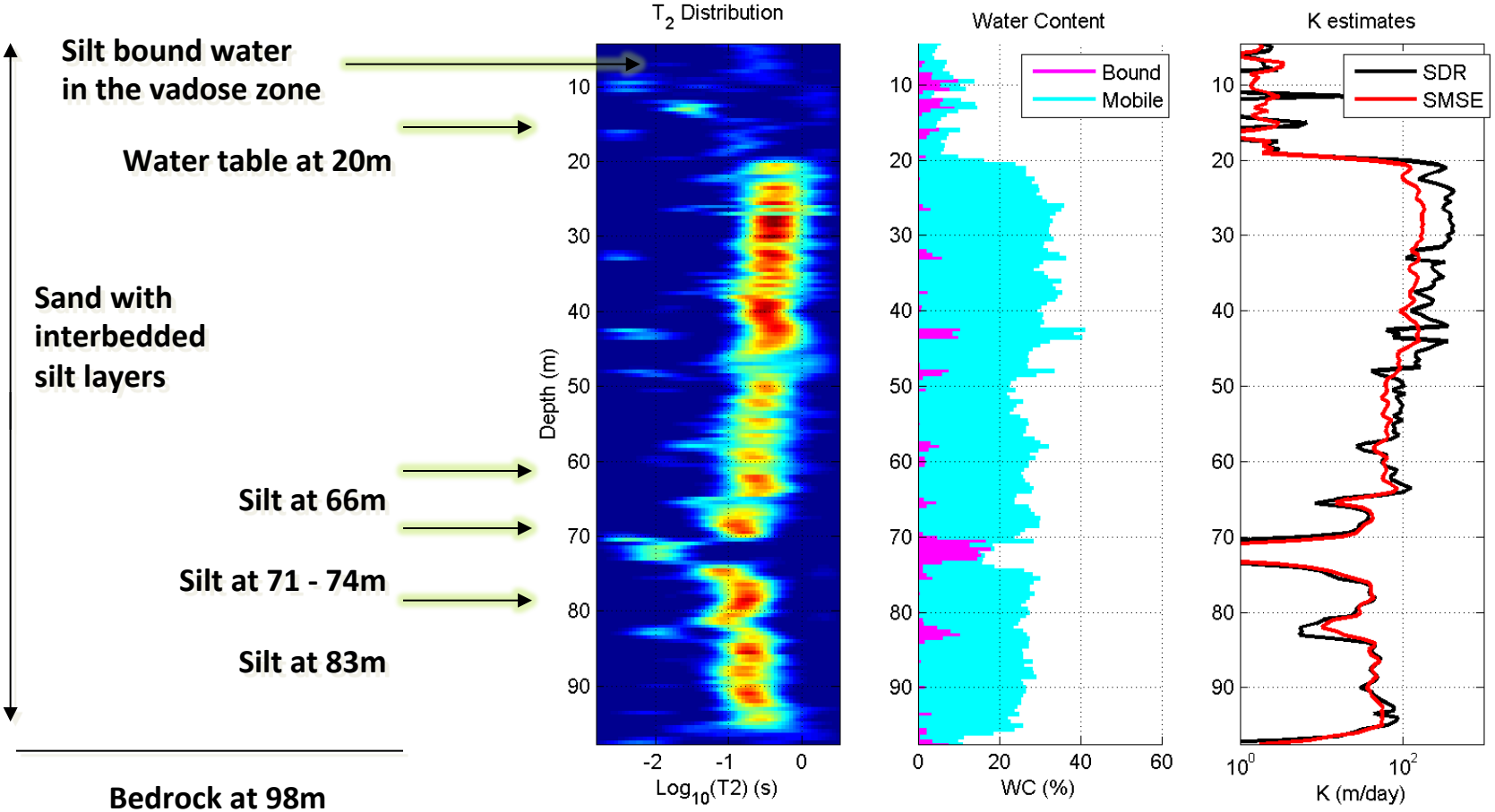
Identifying Low-K Bound Water Zones

NMR Logging



3.5" PVC well

Acknowledgements

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- Special thanks to:
  - Denver Water
  - Leonard Rice Engineering
  - Mike Gehrig
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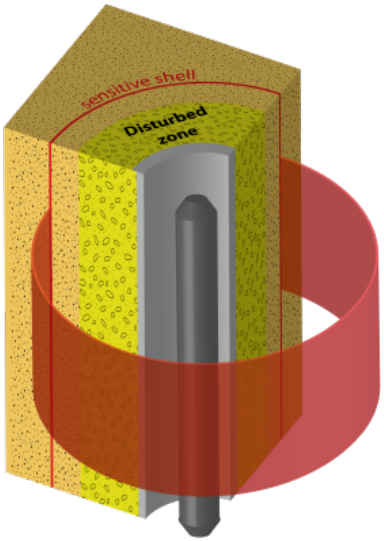
  - Kansas Geological Survey
  - Stanford University
  - Southwest Exploration Services

Javelin NMR Logging Tool



- Permanent magnets in probe polarize hydrogen
- Coils in probe transmit RF pulses to excite and measure NMR signal
- Sensitive zone is outside zone disturbed by drilling