NMR Geophysics for Groundwater Investigations

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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
Hydrologic Properties from NMR

NMR Provides

• Water Content
• Porosity (Lithology Independent)
Hydrologic Properties from NMR

NMR Provides

- Water Content
- Porosity (Lithology Independent)
- Pore Size V/S
Hydrologic Properties from NMR

Geologic Material

NMR Provides

- 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
Navy Well D2, NMR Log

- T2 Distribution
- Water Content
- K estimates

- Silt/Clay
- Water table

Depth (m)

log_{10} T_2 (s)

Water Content

K (m/day)
Navy Well D2, Surface NMR Inversion
Navy Well E2, NMR Logging

Silt/Clay

~ Water table

Foul smelling water at bottom of well

NMR GEOPHYSICS
Navy Well B02, NMR Logging

~ Water table (?)

Bedrock
Leque Island WA, DP NMR and Surface NMR

White dashed lines indicate maximum resolution depth for surface NMR data.
Denver Water ASR Pilot Study 2015

NMR Logging

40th & Colorado

Denver Formation

Upper Arapahoe

Low K

Lower Arapahoe

Low K

40th & Lima
Chandler AZ, NMR Logging, 2016
Wireline NMR Tool Max Depth 1000m
Identifying Low-K Bound Water Zones

NMR Logging

- Silt bound water in the vadose zone
- Water table at 20m
- Sand with interbedded silt layers
- Silt at 66m
- Silt at 71 - 74m
- Silt at 83m
- Bedrock at 98m

T2 Distribution

Water Content

K estimates

3.5” PVC well
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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