Decay-Curve Analysis for the Quantification of Data Error in Time-Domain Induced Polarization Imaging

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Delineation of Naturally Reduced Zones (NRZ)

- IP measurements can provide information about the accumulation of metallic minerals (e.g., FeS) accompanying the activity of iron-reducing microorganisms
  - Bio-stimulation
  - Microbiological “Hot-spots”

Flores Orozco et al., NSG 2013
Delineation of Naturally Reduced Zones (NRZ) at the Rifle site

• Estimation of lithological unit and NRZ based on IP imaging and wellbore data in a stochastic framework
• 65 IP profiles and 17 ERT profiles
• 171 wells

Wainwright et al., WRR 2015
Delineation of Naturally Reduced Zones (NRZ) at other DOE sites

- Former uranium-processing facilities
- Large scale
- High spatial resolution required
Shiprock site (New Mexico, USA)

• Dry surface with gravels $\rightarrow$ contact resistances $>30$ k$\Omega$
• Groundwater level at $\sim$2 m depth
• Mancos formation underlying aquifer at $\sim$6/7 m depth
Shiprock site (New Mexico, USA) TDIP Settings

- Electrode separation of 2m
- Dipole-dipole skip-0
- 2s pulse length
- Syscal Switch Pro (IRIS) and ARES II (GF Instruments)
- Normal and reciprocal measurements
- 7m depth of investigation
- 21 lines
- 10 days
Shiprock: Raw data (dipole-dipole)

• Agreement between normal and reciprocal readings for a maximum of 5 electrodes separation between current and potential dipoles

• Collection of multiple-gradient configurations to increase signal-to-noise ratio → Only normal readings
Shiprock: Data error quantification

• Statistical analysis of the normal-reciprocal misfit
  • Outliers removal

• Data error in phase measurements ($\varepsilon(\phi)$) as a function of associated resistances ($R$)

• Reciprocals only possible for Dipole-Dipole configurations!

• Artifacts in the inverted images $\rightarrow$ error underestimation for gradient measurements

$$\varepsilon(\phi) = aR^{-b}$$

Flores Orozco et al., GEO 2012
Analysis on the quality of the voltage decay curve in TDIP measurements

- Integral chargeability measurements
- CRTomo (Kemna, 2000) $\rightarrow$ linear conversion from chargeability to phase-shift
Decay-Curve Analysis in time-domain IP (TDIP)

Objectives:

• Evaluation of the quality of the voltage decay curve in TDIP to assess erroneous measurements (outliers)

• Quantification of the quality of the decay curve as an alternative to normal-reciprocal analysis?

• Quick assessment of data quality (and inversion)
  → needed to be performed on site during data collection
Fitting a power-law model to measured voltages in the decay curve

- Fitting parameters are computed for each decay curve
- Computed misfit between the measured and modeled decay curve for each IP window ($\Delta i$)

\[ m_{mod} = at^{-b} + c \]
First outlier definition

Analysis approach A

- $\Delta i := m$-misfit of window
- fit: $m(t) = at^{-(b)} + c$
- measured decay

Chargeability $m$ [mV/V] vs. Time [r]

Chargeability $m$ [mV/V] vs. Time [ms]
First outlier definition: no decay curves, but not enough....
Spatial comparison of the measured decay curves: Master curves

• A power-law model is fitted to all decay curves measured for each current injection
• The master curve is then shifted to fit the individual decay curves
• Removal of large misfits enhances spatial correlation in the data
Second outlier definition: comparison to the master curve
DCA with filtering after comparison with master decay curves seems to be particularly useful for noisy data.
Comparison between the decay-curve analysis (DCA) and the normal-reciprocal analysis (NRA)

• Misfit between modeled and measured voltage in the decay curves plotted as a function of associated transfer resistances

• Comparison with the misfit between normal-reciprocal misfit, as a function of the associated resistance
Data-error quantification

Slater & Binley, Geophysics 2006  
Flores Orozco et al., Geophysics 2012
Quantification of data error based on the proposed DCA

Error quantification for IP measurements ($\phi$) as a function of the associated resistance ($R$)

$$\varepsilon(\phi) = aR^{-b}$$
Inversion of the data following the DCA and the NRA
IP maps – 4 m depth

Clean anomalies with high IP response

Recovered sediments after drilling revealed no NRZ
IP maps – 4 m depth

Nitrate plume → modification of the biogeochemical conditions to the site?

→ Mechanisms underlying the IP response?
Conclusions

• The proposed analysis of the decay curve (DCA) permits the assessment of data quality in time-domain IP measurements
• Automatic detection and removal of outliers
• Quantification of data error comparable to normal-reciprocal analysis
• Permits to quantify data error without the collection of normal and reciprocal measurements

• Further studies are required to understand the interpretation of IP imaging results in complex environments