WELLBORE INTEGRITY MAPPING USING WELL-CASING ELECTRODES AND SURFACE BASED ELECTRICAL FIELDS

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INTRODUCTION

Well integrity is a major issue for older oil, water, and geothermal wells, affecting thousands of wells countrywide. Over time, many wells become damaged by casing corrosion caused by prolonged exposure to wellbore fluids, or may have mechanical failures from fluid drawdown and external forces such as ground subsidence. Methods to assess well integrity exist, but are invasive, expensive, and may require halting injection/production.

We address this problem by developing a new low-cost, non-invasive tool for evaluating well integrity. We attach a current source to a well casing and measure the resulting electric fields along the surface. By comparing these fields with modeling results, we can distinguish wells with significant corrosion or breakage. This method is ideal for diagnostic testing and can be done for multiple wells in a short amount of time.

FIGURE 1 Examples of well casing damage due to corrosion from wellbore fluids and other factors.

WELL CASING AS A CURRENT SOURCE

+ Current source attached to wellhead
  + Return electrode placed at far distance
+ Casing distributes the transmitted current along the well path.
+ Current within the casing (I_{cas}) modeled as:

$$I_{cas}(z) = I_0 \exp(-z/L_c)$$

+ L_c defined as conduction length,

$$L_c = \sqrt{\rho_{formation}\sigma_{case}A_{case}}$$

  + Length at which the current has been diminished by 1/3 due to leak-off (Schenkel and Morrison, 1994)

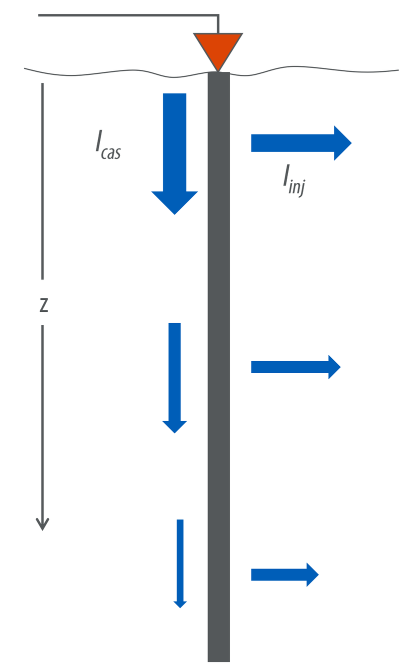


FIGURE 2 Depiction of the current within (I_{cas}) and leaking from (I_{inj}) a semi-infinite casing due to a surface source as a function of depth z.

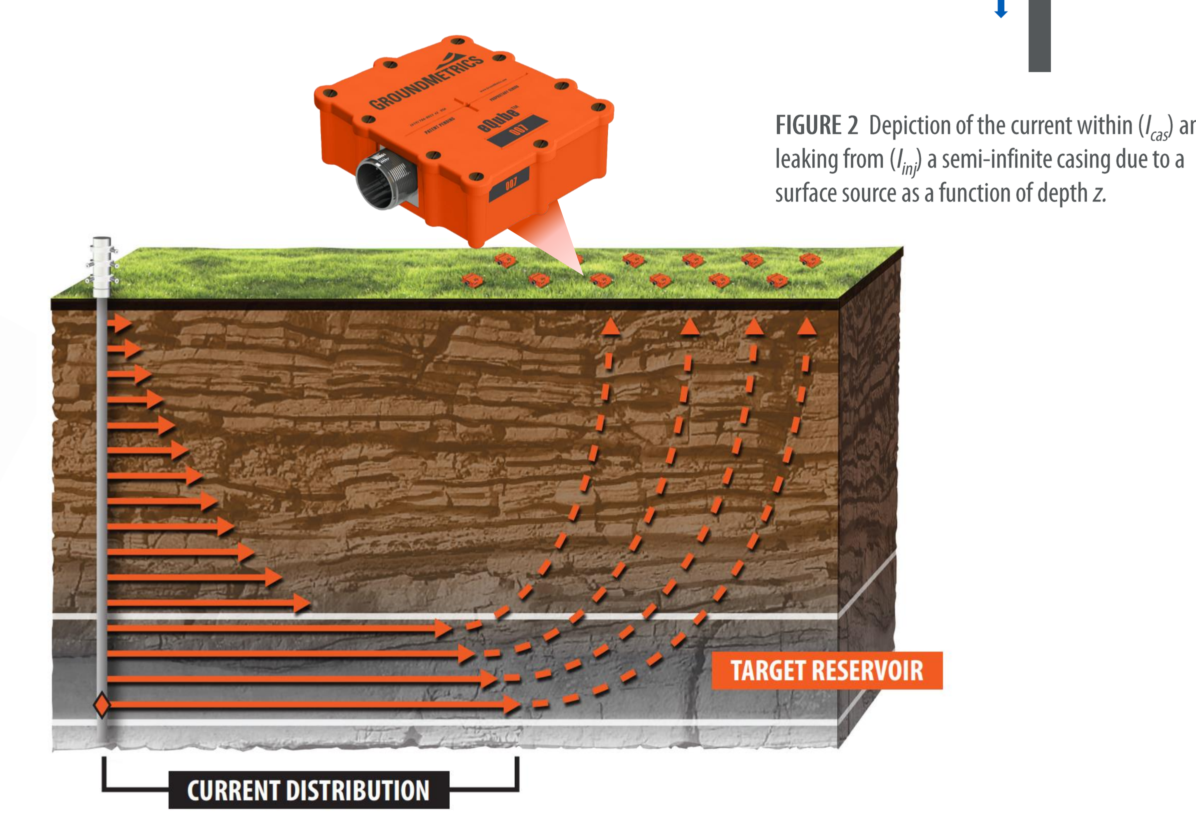


FIGURE 3 Current leaks from energized casing (source connected to casing at depth) and travels through subsurface, creating electric fields. Fields are measured at the surface by GroundMetrics eQube sensors. eQube sensors use capacitive coupling to collect highly accurate measurements (20x SNR of standard porous pot sensors) of the electric field at the surface with minimal ground disturbance (Hibbs et al., 2012).

MODELING WELL INTEGRITY EFFECTS

+ Length of casing affects measured fields
  + Field from a shorter casing will be larger than one from a longer casing at distances near the well.
+ Electrical current is discontinuous where there is a break or corroded interval
  + Alters effective length of casing

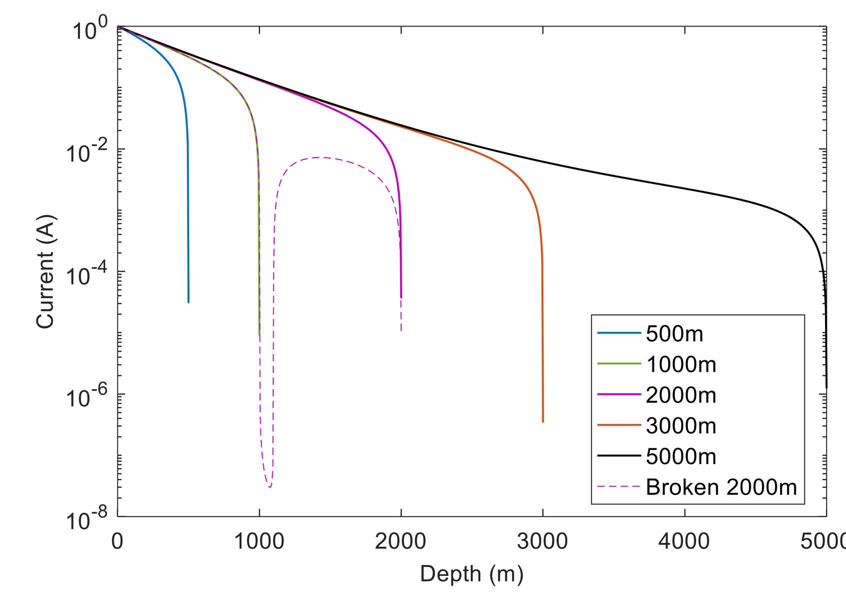


FIGURE 4 Current as a function of depth within an energized casing. A longer casing (2000 m) with a 50 m long break at a depth of 1000 m shows a profile similar to that of a 1000 m long casing.

FIGURE 5 Effects of varying the conductivity of a 5 m long segment in a 1000 m long casing, with a half-space background of 10 Ωm. The segment is modeled at two different depths.

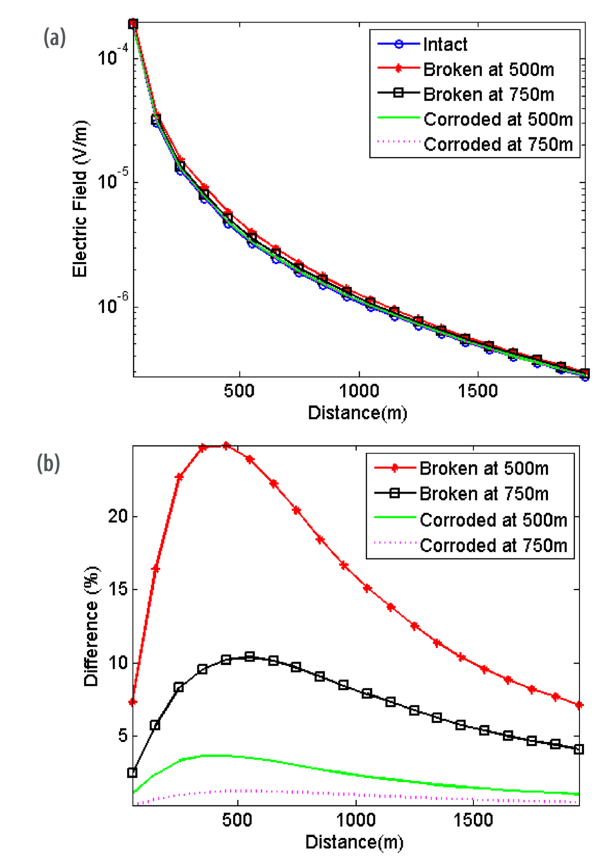
$\sigma_{intact} = 5.5\text{x}10^6$ S/m

$\sigma_{corroded} = 5.5\text{x}10^3$ S/m

$\sigma_{broken} = 0.01$ S/m

(a) Electric fields along the surface due to casing in different states of damage.

(b) Percent difference in electric field between intact casing and corroded or broken casings.



+ Lower casing conductivity results in larger electric field
  + More current leaks out into formation at shallow depths
+ Higher contrast in casing conductivity results in larger % difference
+ Shallower damage produces larger fields than deeper damage
  + Damage at shallow depths may mask damage at deeper depths
+ Peak difference in electric fields occurs at distance less than depth of zone of weakness in casing

EVALUATION AND INTERPRETATION

+ Fit observed data to numerical model
  + Known background resistivity, given well completion
+ If fit between observed and modeled data very poor, well casing may be damaged
+ Can also use inverse methods to quantify further where well is damaged, at what depth, and to what extent
  + Start with known well completion and background
  + Divide casing into segments of variable conductivity
  + Adjust conductivity of various segments with appropriate weighting until data fit achieved

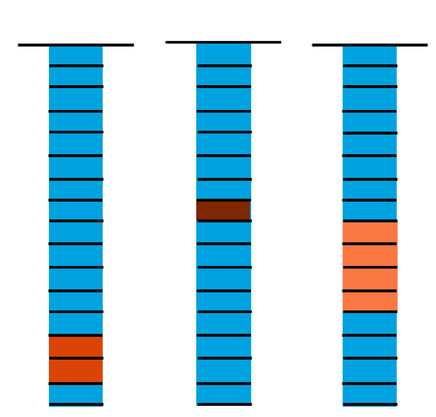


FIGURE 6 Representations of various possible 1D inversion models for casing conductivity.

FIELD DEPLOYMENT

+ Capable of testing multiple wells in a short amount of time
  + Sequential deployment on each well
  + Cable extends out from each well in consistent direction
+ Single cable, multiple take-outs for receivers and ground references
+ Data acquisition unit (DAQ) collects for all receivers on a cable
  + In-field processing of the collected data
+ Additional data acquisition units and sensors placed at farther distances to capture far-offset data for all wells tested

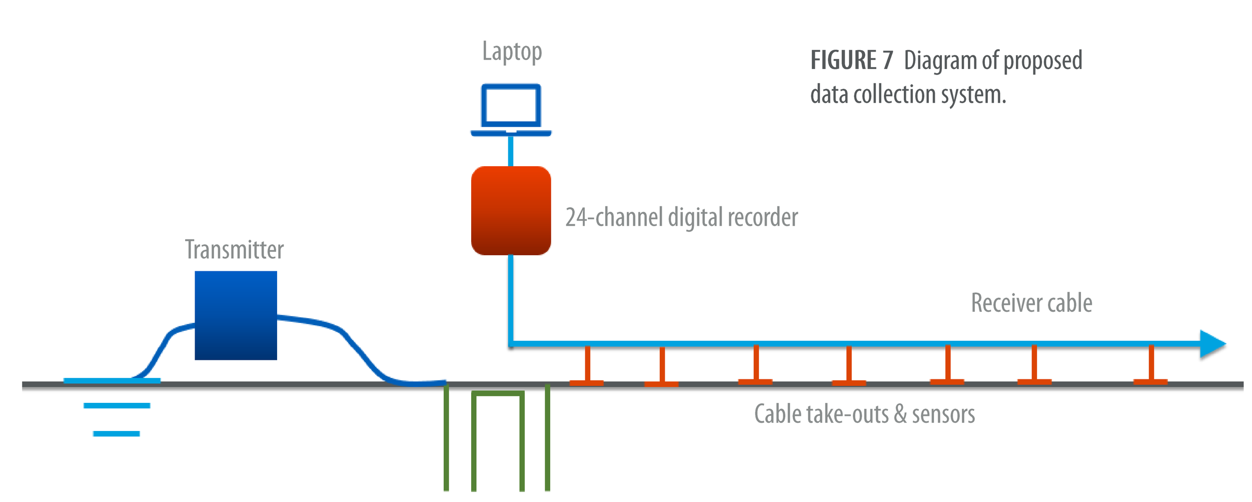


FIGURE 7 Diagram of proposed data collection system.

FIELD TESTING

+ Hastings Field in southern Texas, February 2017
  + CO_2 injection for enhanced oil recovery

FIGURE 8 Hastings Field, where field survey was carried out. The field is actively undergoing CO_2 injection and production for enhanced oil recovery.

+ Transmitter grounded on wellhead
+ E-field measurements made along profile from 5 m to > 1 km
  + Compared to modeled data using known well completion diagram

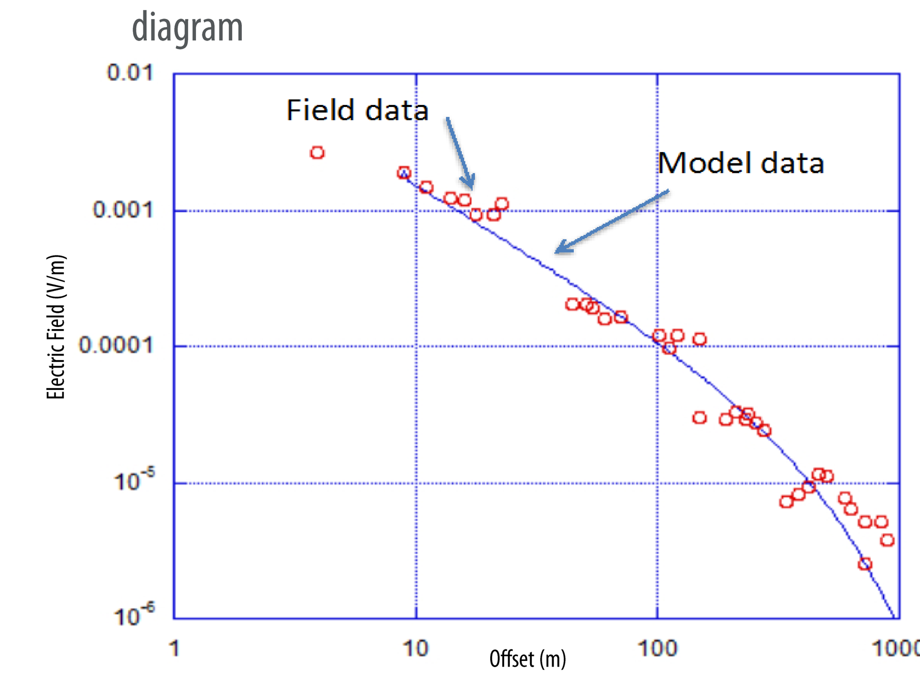


FIGURE 9 Normalized electrical field profile over well 7613 at Hastings field. Red circles indicate observed data, while the solid blue line is a 2.5D model using the known well completion and the average background resistivity. Data are normalized by transmitter current. Good match between model and data indicates well is likely intact and uncorroded.

ADDITIONAL GEOTHERMAL APPLICATIONS

+ Well-casing electrode systems useful to map reservoir resistivity
  + Significant sensitivity increase compared to surface-based EM methods
  + Ideal to see below conductive overburden/clay cap formations
+ Sensitive to connected fluids
  + Monitor status of hydraulic fracturing within EGS reservoirs
  + Possible to see status of reservoir prior to stimulation

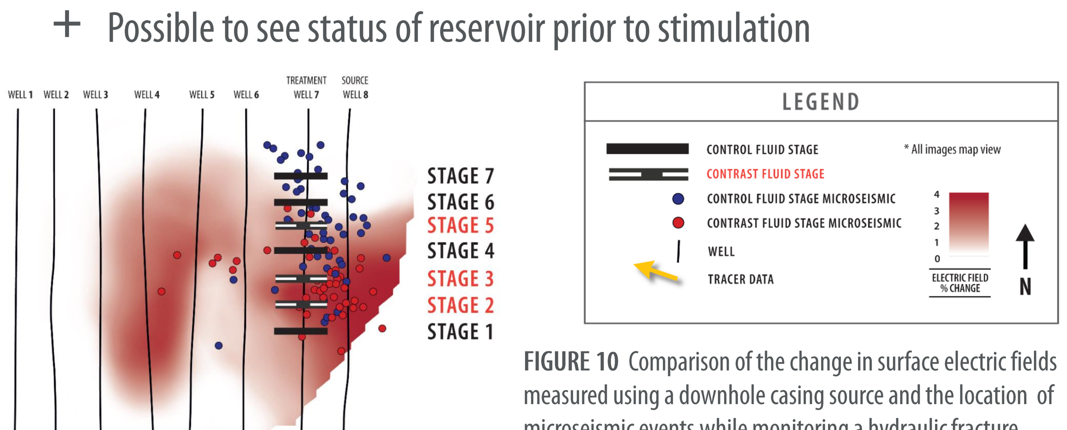
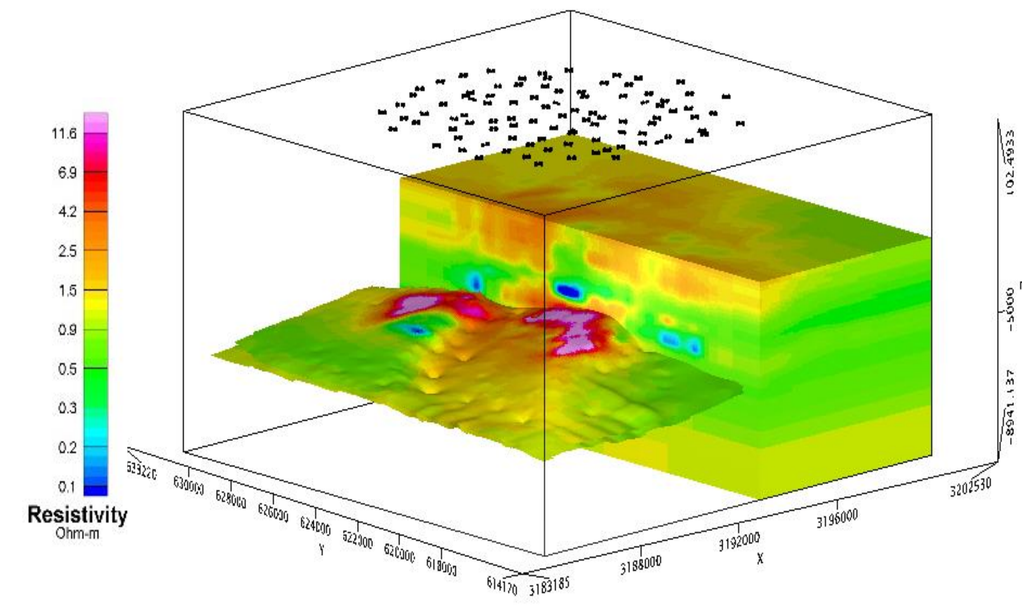


FIGURE 10 Comparison of the change in surface electric fields measured using a downhole casing source and the location of microseismic events while monitoring a hydraulic fracture event. The two data sets show positive correlation.

FIGURE 11 Inversion model of resistivity at reservoir depth using surface and downhole casing sources in an area where both the overburden and near surface are conductive.



SUMMARY

+ Casing integrity is a vital part of risk assessment and well maintenance in the geothermal and hydrocarbon industries
  + Simple, low-cost and non-invasive tool needed to diagnose potentially damaged well casings
+ Method passes current down a well casing and observes the resulting electric fields at the surface to determine the status of the casing
  + Swiftly identify wells damaged by corrosion, pressure, and mechanical failure
+ Tested both numerically and in field surveys
  + Field data good match with modeled data
+ Future work will develop interpretation and inversion software for rapid data evaluation

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