# Near-surface geophysics for informed water-management decisions in the Anangu Pitjantjatjara Yankunytjatjara (APY) lands of South Australia

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## Abstract

The Aboriginal population of the Anangu Pitjantjatjara Yankunytjatjara (APY) lands in South Australia is dependent on groundwater for nearly all water needs. In that region, placement of wells in productive aquifers of appropriate water quality is challenging because of lack of hydrologic data and variable aquifer properties. It is desirable to have an improved ability to identify and evaluate groundwater resources in this remote region with cost-effective methods that make minimal impact on the environment. A project supported by the Society of Exploration Geophysicists program Geoscientists *Without* Borders tested a combined geophysical approach with airborne and ground-based data sets to locate a potential aquifer, confirm water content, and estimate the subsurface extent of the water-bearing zone. This hydrogeophysical approach was an effective means for exploration and evaluation of groundwater resources in APY lands generally, and it characterized a specific aquifer as a case study.

## Introduction

The Anangu Pitjantjatjara Yankunytjatjara (APY) lands encompass a region of more than 110,000 km$^2$ in the arid northwestern corner of South Australia. Dozens of small communities with fewer than 400 inhabitants each are scattered throughout the remote landscape that spans the Musgrave and Officer Creek provinces. Precipitation is scarce, averaging only about 250 mm each year, and meteoric water falls in sparse, episodic events. Groundwater is an essential resource for the Aboriginals of APY lands, fulfilling all basic needs required to sustain human life and enabling pastoral agriculture that provides critical income.

Adding to the challenge of water scarcity, poor water quality resulting from high salinity (Watt and Berens, 2011; Varma, 2012) means that not all groundwater resources are viable to meet the needs of communities. It is estimated that only about half the wells in APY lands attain Australian drinking-water standards for salinity (Varma, 2012). Those communities historically are disadvantaged (socially and in terms of economics, health, and education) and typically are among the lowest-income groups in Australia, at less than half the national median (Biddle, 2013).

## Need for this project

Hydrogeologic data in the region are limited. Relatively little is known about local aquifer systems beyond what can be gleaned from drillers' logs of existing wells and large-scale mapping efforts. This paucity of information leads to challenges when making informed water-management decisions such as where to locate new wells. This approach historically has been largely hit and miss. Recent reports on the large-scale mapping of paleovalley groundwater systems in Australia highlight the need for improved characterization of aquifer geometry and hydrostratigraphy (English et al., 2012). General geologic interpretations are used to guide auspicious well placements, targeting fracture systems and paleovalleys (Varma, 2012).

However, even when water is encountered, quality might not be adequate. Given the remoteness of the settlements, difficulty of access, and expense of drilling, there is a need for improved guidance that would result in fewer dry holes and higher success with producible water that meets standards for use. Furthermore, drilling or other destructive sampling activities risks disturbance or damage to a landscape that has significant cultural value to Aboriginal residents.

## A geophysical solution

Geophysical methods meet the need to characterize the subsurface on the scale of aquifers and without the need for invasive investigation. Although geophysical measurements have been tested in this (Dodds and Clarke, 2003) and other Aboriginal regions of South Australia (Inverarity et al., 2011), a multiscale approach with explicit sensitivity to groundwater has not been piloted until now.

To ensure the continued sustainability of these remote communities, we have developed and demonstrated a geophysical-measurement protocol to locate and verify potential freshwater aquifers by using a combination of airborne and ground-based geophysics. First, airborne magnetic survey data are analyzed to investigate large regions and locate potential aquifer systems based on anomalies in the first derivative of the magnetic field. We presume that the magnetic lineaments can be used to indicate likely sedimentary units that are relatively thicker than the surrounding overburden.

Next, we can rapidly acquire kilometer-scale ground transient electromagnetic (TEM) measurements to evaluate the conductivity structure of the possible aquifer. Finally, surface nuclear magnetic resonance (NMR) — a measurement that is directly sensitive to water presence — is used along the TEM transect to estimate aquifer properties.

The two ground-based measurements complement each other. TEM is a relatively fast measurement that can be used to perform a 2D survey to determine aquifer geometry and extent. TEM measurements provide an image of the subsurface electrical-conductivity structure. This information is necessary for surface NMR inversions, but the TEM hydrologic interpretations are nonunique given that factors besides water content might influence conductivity.

To eliminate this ambiguity, we use surface NMR, the only geophysical measurement that provides direct sensitivity to water content. Surface NMR measures the quantity of free water in soils and rock and provides insight into aquifer properties such as pore size and permeability.

Surface NMR measurement is much slower than TEM and as such is performed at fewer locations. TEM measurements are used to infill the regions between surface NMR measurements, thereby providing a basis for extrapolating aquifer characteristics over a larger area.

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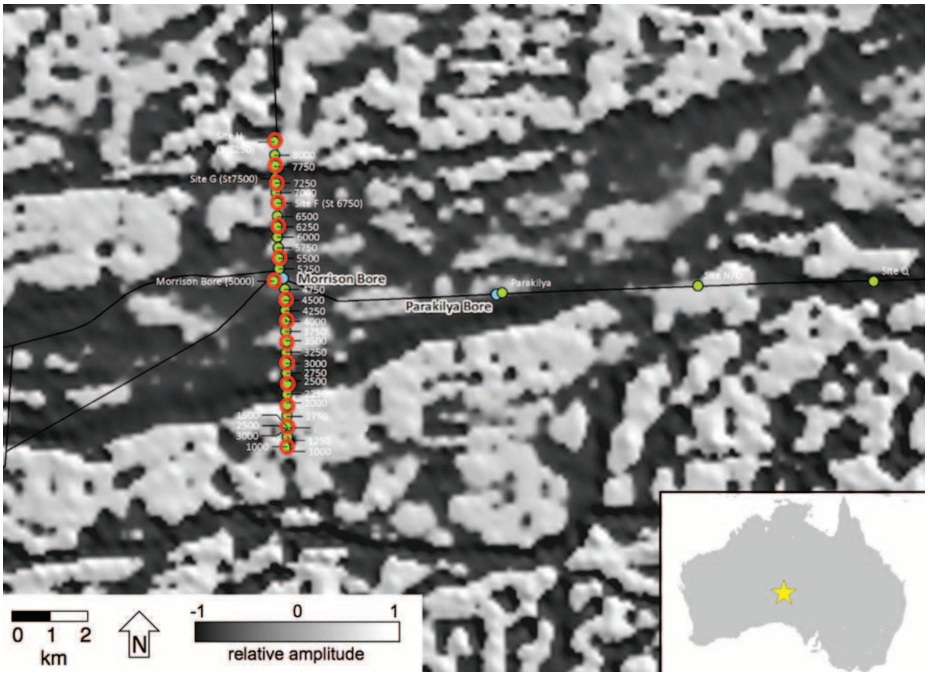


**Figure 1.** A first-vertical-derivative map of the total magnetic field 15 km northeast of Kaltjiti (Fregon). Green dots indicate locations of TEM measurements; red circles indicate surface NMR at the same position. Existing bores that supply livestock are indicated in blue. Inset map shows survey location in southern Australia.

## Objectives of the project

Our specific goals were to use the information derived for the local aquifer system (1) to demonstrate a multiscale geophysical-characterization approach that could be used to guide informed decisions regarding water management, (2) to characterize an aquifer in the APY lands and assess water resources, and (3) to suggest sites that have potential for future wells. This project, supported by funding from the Society of Exploration Geophysicists program Geoscientists *Without* Borders, aimed to characterize a local aquifer system near the township of Kaltjiti (Fregon), South Australia. The goal was to provide additional information on a potential water source for nearby communities to be used for emergency water needs, to expand pastoral opportunities in the region, and to help foster economic growth.

## Field study

The field study was conducted near the township of Kaltjiti (Fregon) in the APY Lands of South Australia, approximately 1400 km northwest of Adelaide (Figure 1, inset). Analysis involving calculation of derivatives of existing regional airborne magnetic data was used to highlight potential fractures, shears, and fault zones and areas of thicker transported cover on basement rocks. This work targeted localized wrench grabens, resulting from Mesoproterozoic faulting, which are known to contain sedimentary units — i.e., potential aquifers (Watt and Berens, 2011). An anomalous magnetic response in the first vertical derivative of the magnetic field, approximately 15 km northeast of the township, was identified as a possible aquifer.

Figure 1 illustrates a first vertical derivative in the study area and the location of the high-resolution geophysical transect undertaken in the area. A northeast-striking lineament across the center of the map defined by gray values (i.e., muted amplitude relative to the maxima and minima) corresponds to a region of greater depth to bedrock. The lineament likely is caused by a northeast-striking extensional fault zone that results in locally depressed bedrock (a graben) that likely has been infilled with transported sediments. As such, this site was recognized as a potential target aquifer, given the possibility of a thick sediment package and high permeability associated with deposited consolidated and unconsolidated sediments in contrast to surrounding bedrock.

To verify this potential aquifer, ground-based measurements consisting of TEM and surface NMR measurements were performed along the transect shown in Figure 1. Because no drillers' logs were available along the transect, we also made TEM and NMR measurements at other nearby wells for which logs are available (Dodds and Clarke, 2003) to validate the geophysical measurements for the area.

Surface NMR measurements were conducted using the Vista Clara GMR system (Figure 2a), and TEM measurements were conducted using a Zonge NanoTEM system (Figure 2b). The 8-km north-south transect that intersected the graben consisted of surface NMR measurements acquired at 500-m spacing and TEM measurements at 250-m spacing along the length of the line. The remote location of the sites, away from anthropogenic sources of electromagnetic noise, provided high-quality surface NMR data (signal-to-noise ratio ~ 50).

## Results

Figure 3 shows conductivity-depth section and water-content profiles calculated from the 8-km transect that crosses the inferred graben. The conductivity section shows a thicker, more conductive zone at depth, elevation 470 to 510 m, extending from the 1000-m mark to the 4500-m mark. We interpret this conductive high as transported sedimentary-fill material that occupies the graben structure. This interpretation is consistent with other observations made in APY lands where paleovalley fill is relatively conductive (Munday, 2013). The surface NMR-estimated water content is illustrated as gray sounding curves.

Each surface NMR measurement results in an estimated 1D water-content profile. The water table in the region is observed to be at a depth of > 10 m across the transect. Starting at the southern end of the transect (left in Figure 3) and to the south of the graben, we interpret a single water-bearing unit approximately 15 m thick. In the central part of the transect (crossing the graben), the depth to the bottom of the water-bearing unit increases, consistent with greater basin depths in that region. In the center of the transect, water-content data indicate a thicker, deeper aquifer, extending to ~ 45 m below the surface. At depths greater than 45 m, water-content profiles predicted using surface NMR become less reliable, and we do not interpret NMR results below that depth.

One concern prior to field deployment was that magnetic materials in the area might make NMR measurement difficult (Grunewald and Knight, 2011). Therefore, one objective of our study was a comparison of TEM and NMR results with available boring logs to verify measurement performance. We acquired two NMR profiles at borehole locations ~ 20 km from our primary transect as a comparison survey.

As can be seen in Figure 4a, at the Fregon 64 bore, the measured static water level (SWL) is coincident with depth, where we interpret elevated water content from surface NMR measurements. This higher water content is in a sand aquifer (shaded blue) that extends to shale bedrock. The sand aquifer contains volumetric water content in excess of 10%.

At the Fregon 65 bore (Figure 4b), we identify an aquifer below a clay layer (shaded green), and the aquifer is mostly silty sand (shaded magenta). In this case, bedrock was not encountered during drilling, and the NMR result indicates that there is likely a water-bearing unit that extends even beyond the bottom of the bore. Measurement also detects a clay-rich layer at 20 m with a drop in water content. These validation measurements add confidence to the interpretation of measurements along our target transect.


**Figure 2.** (a) Student project participants Denys Grombacher (brown shirt) and Brady Flinchum (blue shirt) make NMR measurements in the field while Andy Parsekian (seated) looks on. (b) Denys Grombacher watches while Aaron Davis conducts TEM measurements. (c) Reviewing maps, the field team discusses measurement locations. (d) Field team: upper row, from left: Tim Munday, Andrew Parsekian, Aaron Davis, and Denys Grombacher; bottom row, from left: Kevin Cahill and Brady Flinchum. Missing from photo: Michael Hatch and Rosemary Knight.

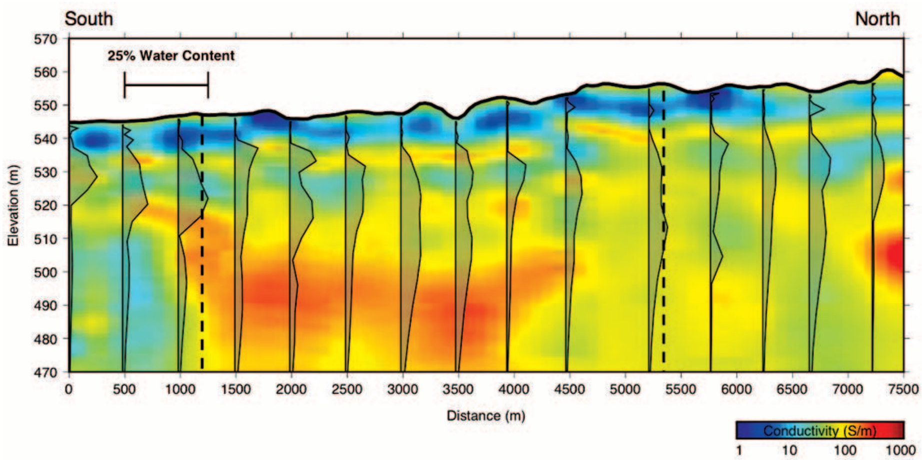


**Figure 3.** A stitched conductivity-depth section with water-content profiles (in gray) overlain along an 8-km transect spanning the interpreted wrench graben. The surface NMR water-content profiles are scaled to the bar on the top left. Dashed black lines indicate approximate extent of graben, as interpreted from Figure 1.

## Development of a protocol for identifying aquifers in remote conditions

Ongoing geologic and geophysical efforts to assess groundwater resources in Australia have demonstrated the level of interest and need for effective measurement approaches. Although surface NMR is a well-proven, reliable technology in research circles, we are sensitive to the fact that it is still emerging as a tool in industry and larger-scale water-exploration efforts. It is understandable that investigators who are not familiar with the method might be skeptical until it is demonstrated successfully on-site. This project goes some way in addressing that need and shows the benefits of an integrated approach in the broader context of groundwater exploration in APY lands.

Although we focus on a specific area, we suggest that this protocol could be expanded for use in other regions of Australia, given the ubiquitous availability of existing magnetic surveys nationwide. Our approach is not a direct technology transfer to the end users of water resources, but in a sense, we hope use of this technology and protocol can become even more widespread for groundwater exploration in APY lands and other regions.

## Communicating with local stakeholders

Interaction with local stakeholders was invaluable in helping us to understand how the community relies on groundwater and what drives the need for an enhanced knowledge of aquifer characteristics. In the field, we met with local managers, anthropologists, and Aboriginal ranchers and artists to discuss water and the potential impact of this project on water resources in the region. They were unanimous in indicating that groundwater was critical to survival in APY lands and that obtaining a reliable groundwater source was always a challenge.

Meeting with local Aboriginal artists was enlightening because they told the story of how, before the introduction of mechanical well boring, groundwater was obtained through hand-dug "rock holes" — a prominent feature in current and past artwork. The widespread depiction of groundwater resources in artwork highlights the importance of this resource to these communities through time.

Since completion of field activities, we have begun to communicate preliminary results to stakeholders in APY lands who are concerned with water. The South Australia Department of Environment, Water and Natural Resources (DEWNR) and South Australia (SA) Water have shown interest in the study, particularly as a potential means for identifying new well locations.

The next steps include production of brief materials to circulate among regional and national water-management offices to make an example of these successful measurements and to suggest more widespread use when planning well installation in APY lands. We see the possibility for drawing from the regional paleovalley analysis (English et al., 2012) to inspire more locations to apply our measurement protocol and fill the stated need for enhanced, detailed aquifer characterization.

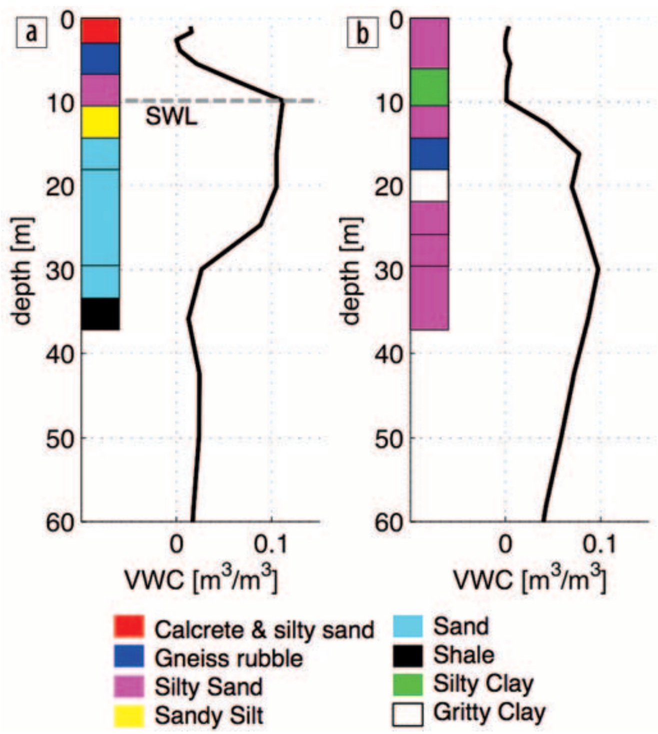


**Figure 4.** Surface NMR measurements (black curves) compared with nearby boring logs (color bars after Dodds and Clarke, 2003): (a) Fregon 64 and (b) Fregon 65. Static water level (SWL) was not reported for Fregon 65.

## Student contributions

Inspiration and training of the next generation of geoscientists were fundamental components of this project. The fieldwork involved participation of two geophysics Ph.D. students, Denys Grombacher of Stanford University and Brady Flinchum of the University of Wyoming, who were integral to the outcomes. They assisted and led data collection, carried out data processing, and contributed significantly to interpretation. Their being part of the field effort generated enthusiasm about the humanitarian goals of this project and helped these students to learn the importance of water resources to other cultures and to gain experience in an international research environment.

## Conclusions

Using reliable, proven geophysical methods, we have demonstrated a multiscale approach for evaluation of groundwater resources in APY lands of South Australia. We suggest that using airborne surveys to target potential aquifers and ground-based geophysics to image subsurface architecture and verify aquifer properties can enhance efficiency for water-resource decision making so as to have the slightest impact on culturally important lands. Discussions with stakeholders highlighted the importance of this work, and our results are clearly compatible with existing water-resource exploration efforts ongoing in Australia. TLE

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