

Petrophysical “Big Data” - case study from the Stavely Project, western Victoria

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SUMMARY

The application of recent technological advances to the acquisition of petrophysical datasets has significantly increased the amount of quality, systematic physical rock property measurements that can be captured efficiently and cost effectively. These large datasets provide a more comprehensive understanding of petrophysical values and, as importantly, their statistical distribution – particularly when encompassing a diverse set of rock types and stratigraphy. To date, these types of comprehensive datasets are limited in the mineral exploration space, in both number and their spatial distribution.

This paper presents a case study from the Stavely Project area in western Victoria outlining the workflow from acquisition, compilation and analysis, to the application of a large, pre-competitive petrophysical dataset. These data, including gamma density, magnetic susceptibility, P-wave velocity, electrical resistivity and natural gamma, were acquired by scanning of diamond core from 21 stratigraphic and mineral exploration drill holes by Multi-Sensor Core Logger equipment, providing a combined final dataset of 216,699 petrophysical values. The pre-competitive data and subsequent analyses are available for download.

In developing a statistical analysis of the petrophysical values, the datasets were segregated into stratigraphic, lithological and spatial sub-populations, therefore giving a geological context for the data, and providing baseline values for regional geophysical interpretations, forward modelling and inversions, and the identification of regions of anomalous petrophysical values potentially associated with hydrothermal mineralisation. Cross-correlation of various petrophysical properties highlights important relationships within the data, thus maximising its value. In western Victoria these data have been important in the delineation of prospective volcanic belts of the Stavely Arc beneath cover, and the development of a 3D model displaying the regional geometries and distributions of the belts at depth.

Key words: petrophysics, physical rock properties, Stavely Arc, geophysics, geophysical modelling, 3D modelling, cross-correlation, density, magnetic susceptibility, P-wave velocity, electrical resistivity and natural gamma.

INTRODUCTION

An increasingly important area of geoscience research and mineral exploration is the integration of petrophysical properties with geophysical datasets to maximise value from local- and regional-scale geophysical surveys, which can be expensive and time consuming to acquire. This approach provides an important link between geology and its geophysical response. Knowledge of petrophysical properties in the context of lithological, stratigraphic and spatial relationships enables a more informed interrogation of associated geophysical datasets, and interpretation of the geological information they contain. The development of regional pre-competitive petrophysical datasets also provide a baseline that has the potential to highlight anomalous rock property values which, particularly in combination with other geoscience datasets, can improve mineral exploration targeting.

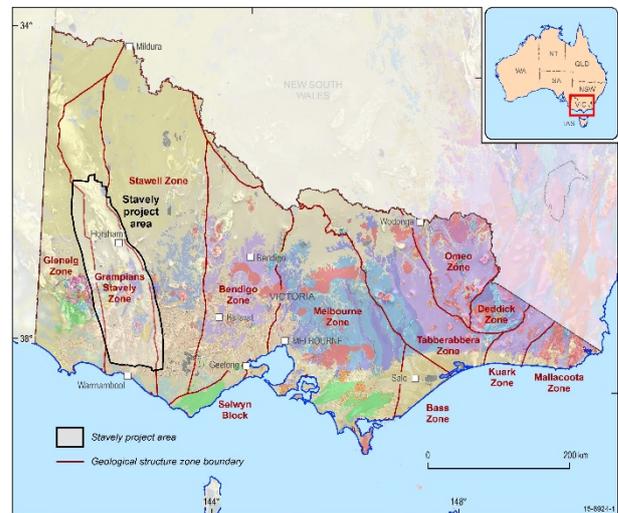


Figure 1. Location of the Stavely Project area shown with Victorian structural zones, underlain by 1:1 000 000 geology of Victoria, 2012 edition (courtesy Geoscience Australia).

Density and magnetic susceptibility field measurements are commonly collected as part of mineral exploration and government mapping programs. These data may be biased by limited point measurements of selective drill hole intervals or sequences. The recent development of multi-sensor petrophysical scanning technology has enabled the efficient and systematic acquisition of multiple petrophysical datasets at regular, closely spaced intervals from drill core, delivering a substantial increase in the amount of available data, which has the potential to better characterise complete petrophysical property distributions and increase their practical application.

In addition to density and magnetic susceptibility, properties including electrical resistivity, natural gamma and P-wave velocity (sonic velocity) can be acquired concurrently, as in this study. This paper outlines the compilation, statistical analysis and application of petrophysical (rock property) data for the Stavely Project in western Victoria (Figure 1), a collaborative project between the Geological Survey of Victoria (GSV), Geoscience Australia (GA) and AuScope (Schofield et al., 2015). The petrophysical data have been collated and statistically analysed, providing constraints for the interpretation of geophysical datasets.

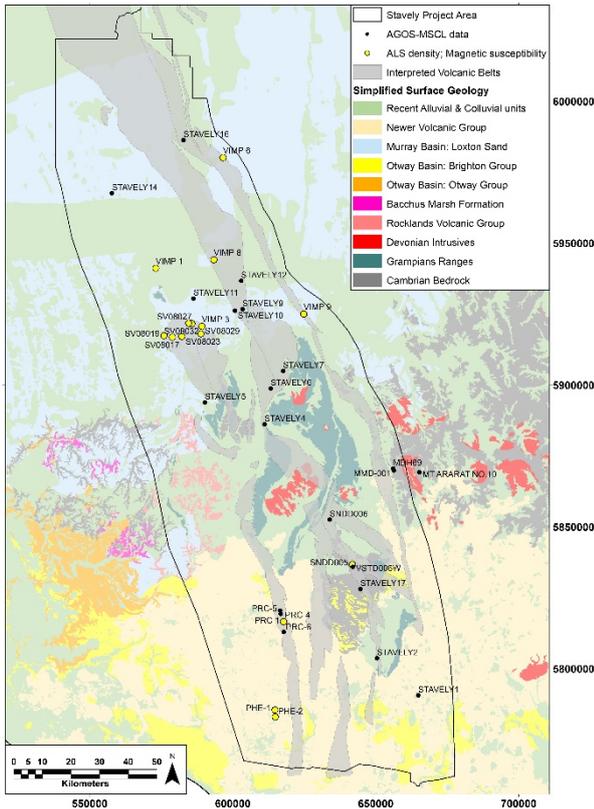


Figure 2. Locations of diamond drill holes with petrophysical MSCL measurements (black dots), showing spatial relationships to volcanic belts of the Stavely Arc and surface geology, including cover. Traditional measurements of core samples for density and magnetic susceptibility are indicated by yellow dots.

Understanding the value and distribution of petrophysical properties of various lithology, stratigraphy and potential hydrothermal alteration in the Stavely region in western Victoria, is particularly important due to the extensive cover sequences that conceal (prospective) Cambrian bedrock (Figure 2). The cover places a greater emphasis and reliance on geophysical datasets to develop and inform the geological interpretation, the geodynamic and tectonic setting and mineral systems potential of the Cambrian-aged Stavely Arc. Further, knowledge of the petrophysical properties of the cover units enables: 1) their effect on the overall geophysical response to be moderated while enhancing bedrock signatures, and 2) more accurate cover thickness estimates from geophysical datasets. Statistical analysis of sub-populations of petrophysical data has provided robust rock property values and ranges used to constrain forward and inversion modelling of ground gravity and aeromagnetic data, thereby informing the regional geological interpretation and delivering a

framework for the development of a full crustal 3D geological model of the Stavely Project area (see Cayley et al., 2018). These data, tagged with metadata including lithology and stratigraphy, have been uploaded to the GA Rock Property Explorer (www.ga.gov.au/scientific-topics/disciplines/geophysics/rock-properties).

DATA ACQUISITION AND ANALYSIS

Data Acquisition

Two tranches of petrophysical diamond drill core scanning were undertaken using the Geotek Multi-Sensor Core Logger (MSCL) equipment (Figure 3) at AuScopes' Australian Geophysical Observing System (AGOS) at The University of Melbourne – a tranche of 13 (of 14) stratigraphic drill holes completed as part of the Stavely Project in 2014/15, and another tranche of eight historical mineral exploration drill holes held by the GSV in 2012. A total of 1,940 m of diamond drill core from 21 drill holes was scanned (Figure 2), resulting in a raw dataset comprising 259,040 measurements over the five petrophysical properties described above. Measurements were acquired at 2 cm intervals along the core for all properties except for natural gamma which was measured at intervals of either 2 or 10 cm. Compromised sections of core (e.g. fractured or incomplete core) were not scanned. Log plots of the measured raw petrophysical data, as well as core thickness were produced, providing a quick reference of property variations with depth (Figure 4). Final processed raw data were delivered in ASCII comma separated values (.csv) format. For a description of the MSCL sensors, scanning methodology and associated metadata see Skladzien et al. (2016).

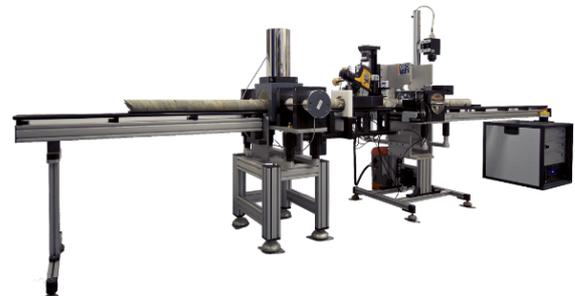


Figure 3. The Geotek Multi-Sensor Core Logger (www.geotek.co.uk)

Statistical Analysis and Data Presentation

Typically, petrophysical data are reported for lithologies of interest, with little consideration given to their relationship with the encompassing geological environment. Together with the lithological context, an important consideration when developing a statistical analysis of petrophysical data is the geological context of the sample population (Dentith et al., 2018) – for example, the geodynamic and tectonic setting, metamorphism, hydrothermal alteration, etc. The use of stratigraphy, geographic location (i.e. Victorian structural zones - see Figure 1), geochronology (i.e. cover unit vs. bedrock), etc., can be applied as proxies to enable the separation of petrophysical values into discrete populations reflecting these geological environments.

MSCL petrophysical data were cleaned, verified and correlated with lithology and stratigraphy before being segregated into sub-populations and being subject to statistical

analysis. Of the total 259,040 raw data values, a final dataset of 216,699 measurements were used for analysis. Descriptive statistics of property values were generated for sub-populations of cover, bedrock and structural zone, with further sub-populations of 18 stratigraphic units comprising 40 lithological units. A further break-down of data based on hydrothermal alteration has not been attempted in this regional analysis, however, this would be an important consideration for mineral explorers when collecting, compiling and interpreting petrophysical data, especially at the camp/district and prospect/deposit scale. Tables containing petrophysical descriptive statistics for the above mentioned sub-populations can be found in Skladzien (2018).

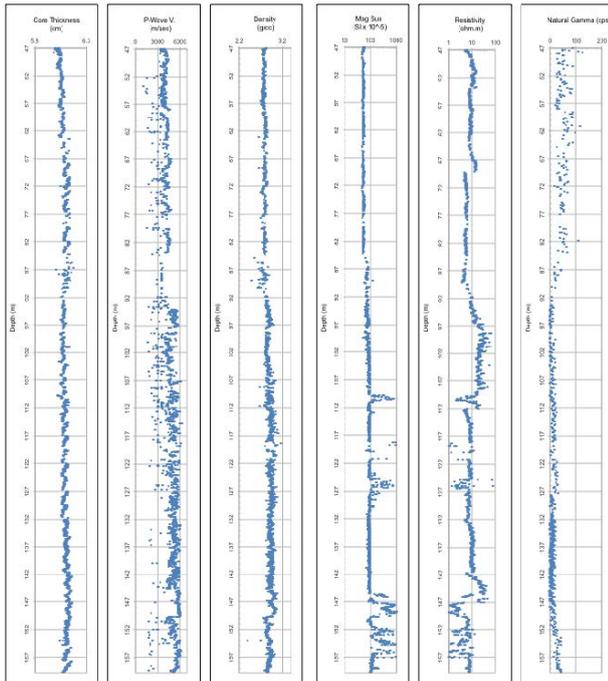


Figure 4. MSCL scan log plots of drill hole STAVELY02 (47.45–159.5 m). Plots include core thickness, P-wave velocity, gamma density, magnetic susceptibility, electrical resistivity at 2 cm sample intervals, and natural gamma alternating between 2 cm and 10 cm sample intervals. Note the localised inverse correlation between magnetic susceptibility and electrical resistivity. From Skladzien et al., 2016.

Frequency histograms provide a visual representation of the distribution of petrophysical properties and can highlight information contained within the data which may be of relevance when assigning petrophysical values, but may not be evident from the descriptive statistics alone – for example the identification of a bi-modal distribution (Figure 5).

DATA APPLICATION

The results of these analyses provide baseline values for regional geophysical interpretations, modelling and inversions, and the identification of anomalous values potentially associated with hydrothermal alteration.

The spatial distribution of density or magnetic susceptibility data, in relation to regional gravity and magnetic potential field datasets (Figures 6), provides constraining information when developing a quantitative geophysical interpretation (Figure 7). Furthermore, knowledge of the petrophysical

attributes of the subsurface geology allows its correlation with geophysical anomalies or characteristic geophysical signatures to be extended away from areas of control (e.g. drilling), and across different geophysical datasets.

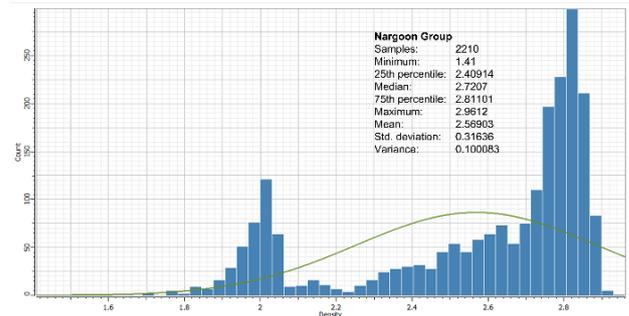


Figure 5. Frequency histogram of the density of Nargoon Group metasediments, showing a bi-modal distribution. Descriptive statistics are also shown. Green line is the normal curve, density is given in g/cm³.

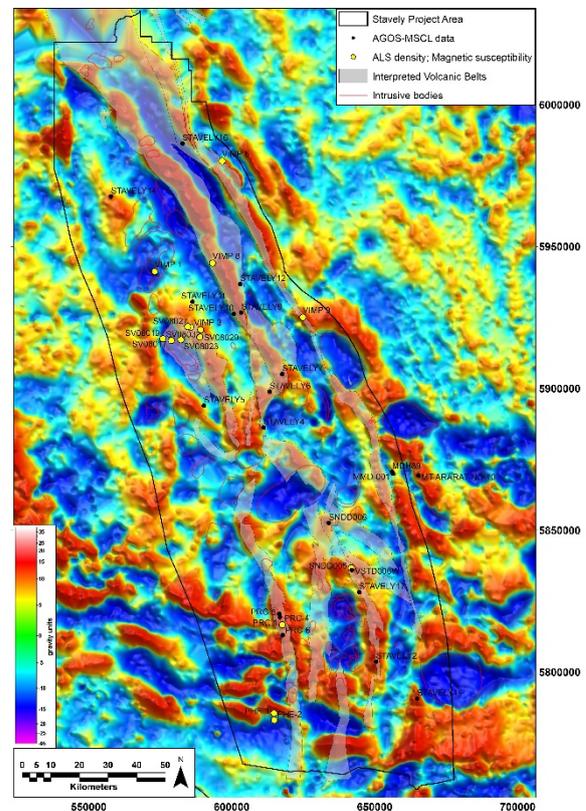


Figure 6. Locations of drill holes with petrophysical measurements, showing spatial relationships to volcanic belts of the Stavely Arc and intrusions, overlain on an image of high-pass filtered gravity data.

These data fusion techniques have been important in the delineation of prospective volcanic belts of the Stavely Arc beneath cover, and the development of a 3D model, informed by geophysical datasets, displaying the regional geometries and distribution of the belts at depth (Figure 8) (see Cayley et al., 2018).

Electrical property data (e.g. electrical conductivity and resistivity) are essential for inverting airborne electromagnetic and magnetotelluric data and can provide valuable information

for interpretation of electrical geophysical ground surveys (e.g. electromagnetics and induced polarisation) commonly employed at the district/camp- and prospect/deposit scale. Natural gamma property data can assist in "ground truthing", correlation and interpretation of airborne radiometric datasets while P-wave velocity data are useful in seismic depth conversion and in modelling of cover thickness using both passive and active seismic methods. The systematic acquisition of these properties has rarely been undertaken as part of mineral exploration programs in the past but is now feasible with equipment such as the MSCL.

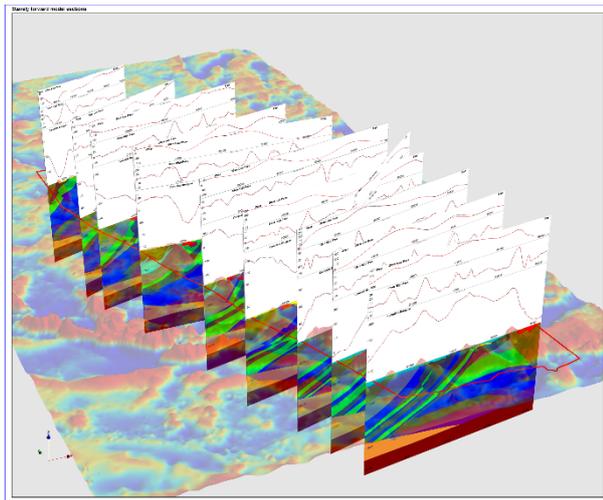


Figure 7. Forward gravity modelled, full crustal serial cross-sections over the Stavely Project area. Assigned density values have been constrained by MSCL density measurements where available. Background image is of high-pass filtered gravity data.

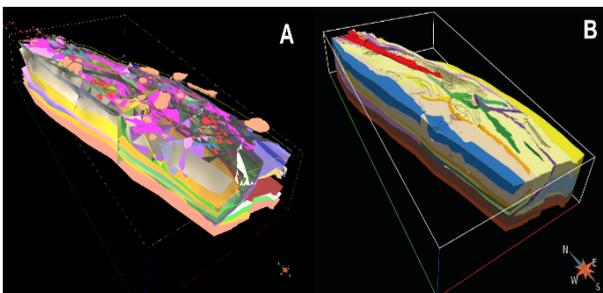


Figure 8. Stavely 3D geological model showing modelled A) surfaces and intrusives, and B) volumes. Spatial distribution and geometries have been informed by geophysical data, the interpretation of which has been constrained by petrophysical property values and their distributions.

Additionally, the ability to now acquire large volumes of multiple properties simultaneously over coincident core intervals provides the opportunity to maximise the value of these petrophysical datasets by investigating the relationships between different properties (i.e. cross-correlation - see Figure 9 and Figure 10). These large datasets now allow a probabilistic rather than deterministic description of a particular units' petrophysical property. This potentially provides a predictive tool for the estimation of a property where a relationship with one or more other properties has been identified, as in the examples shown in Figures 9 and 10. The cross-correlation of petrophysical data with

complimentary geological datasets such as geochemistry and mineralogy, would also be an exercise worth exploring.

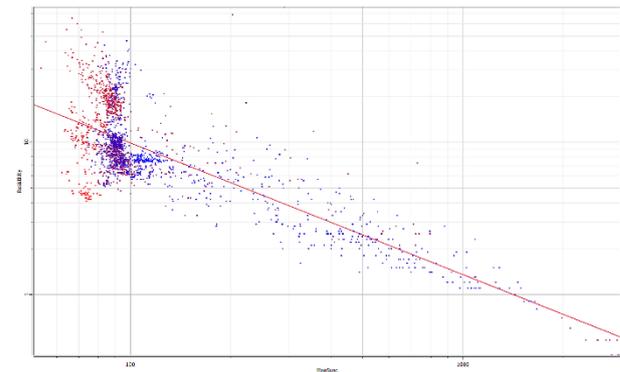


Figure 9. MSCL data for Mount Stavely Volcanic Complex rocks intersected in drill hole STAVELY02, showing an inverse correlation between magnetic susceptibility ($SI \times 10^{-5}$) (X-axis) and electrical resistivity (ohm.m) (Y-axis). Colours indicate depth from shallow (red) to deep (dark blue). Both axes are shown as log scale.

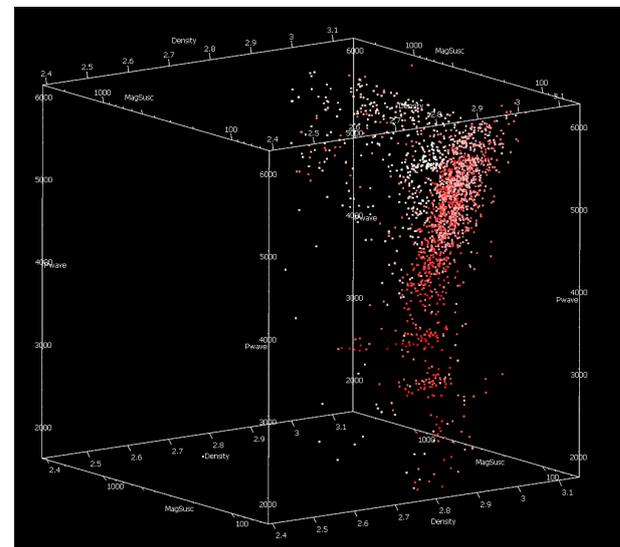


Figure 10. MSCL data for Mount Stavely Volcanic Complex rocks intersected in drill hole STAVELY02, showing the relationships between magnetic susceptibility ($SI \times 10^{-5}$), density (g/cm^3) and P-wave velocity (m/s). A positive correlation is evident between density and P-wave velocity for velocities above 4000 m/s. Colours indicate depth from shallow (red) to deep (white).

CONCLUSIONS

The acquisition of petrophysical data using the MSCL equipment on diamond drill core has significantly increased the amount of quality, systematic physical rock property measurements that can be captured efficiently. These large datasets provide a more comprehensive understanding of petrophysical values and, as importantly, their statistical distribution – particularly when encompassing a diverse set of rock types and stratigraphy. This understanding can increase the value of geophysical datasets by providing constraining information to inform interpretation. Furthermore, understanding the behaviour of petrophysical data in relation to various geological environments can identify anomalous values and trends when compared with robust baseline data,

which may aid mineral exploration targeting. Cross-correlation of spatially coincident petrophysical datasets can highlight useful relationships between different properties, potentially providing a predictive tool for further petrophysical analyses.

The petrophysical data compiled and presented here has vastly increased the existing number of petrophysical measurements in western Victoria, albeit limited in their spatial extent. Statistical analysis of lithological and stratigraphic populations of these data offers a better understanding of the distribution and characteristics of petrophysical values. The continued acquisition of these types of datasets by government, industry and academia will further improve their value and application, as well as value-adding to existing geophysical datasets.

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