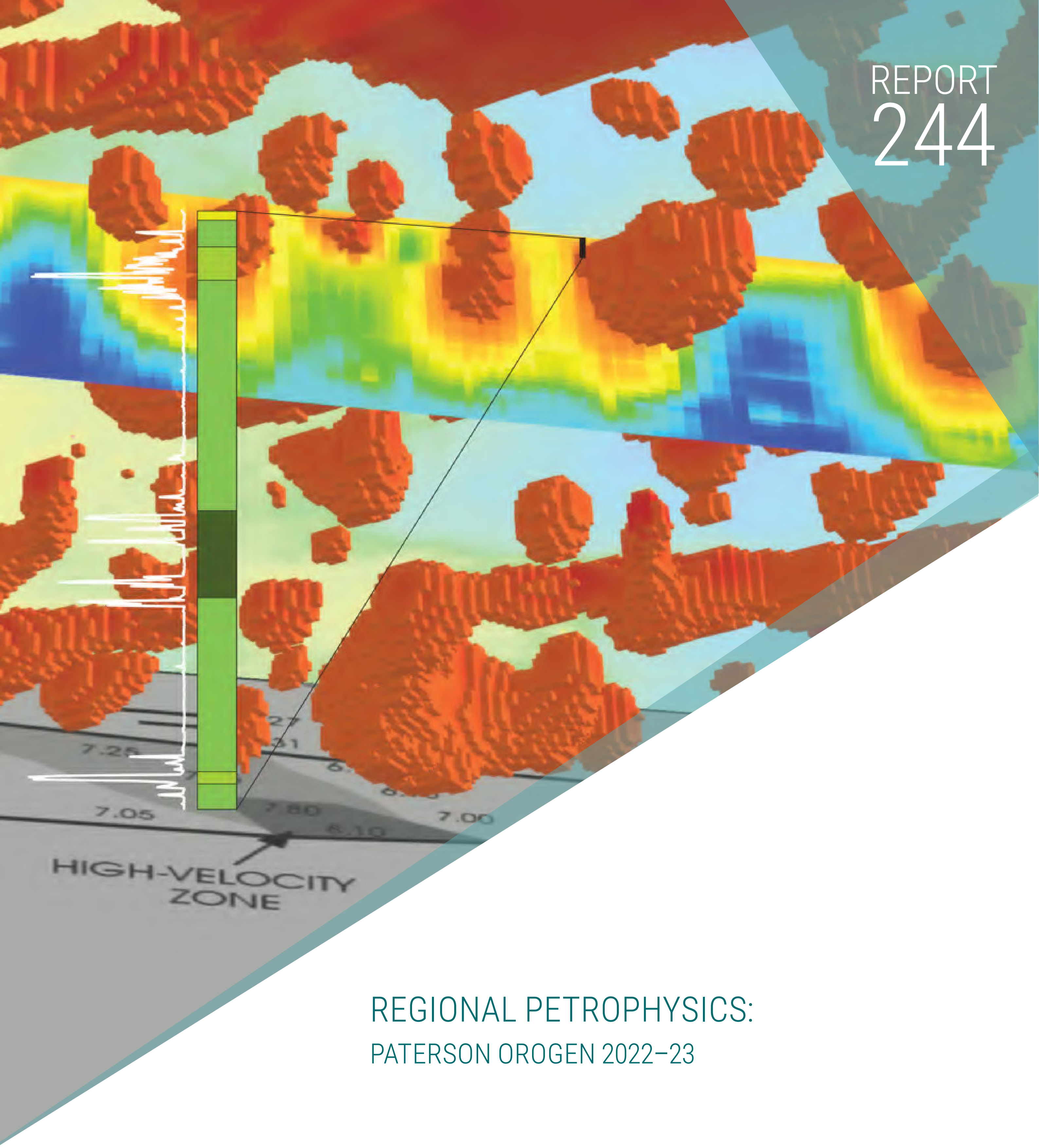


REPORT 244

# REGIONAL PETROPHYSICS:
## PATERSON OROGEN 2022–23

M Markoski and B Bourne

Government of Western Australia
Department of Mines, Industry Regulation and Safety

Geological Survey of Western Australia

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REPORT 244

# REGIONAL PETROPHYSICS: PATERSON OROGEN 2022–23

M Markoski* and B Bourne*

* Terra Petrophysics Pty Ltd, Unit 5/51 Forsyth Street, O'Connor Western Australia 6163

PERTH 2023

**Geological Survey of Western Australia**

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**About this publication**
Terra Petrophysics Pty Ltd carried out petrophysical measurements under contract to the Geological Survey of Western Australia, funded by the Exploration Incentive Scheme.



**Acknowledgement of Country**
We respectfully acknowledge Aboriginal peoples as the Traditional Custodians of this land on which we deliver our services to the communities throughout Western Australia. We acknowledge their enduring connection to the lands, waterways and communities and pay our respects to Elders past and present.

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**Cover photograph:** Down core petrophysical data shown in relation to crustal scale density and velocity models

# Introduction

The Geological Survey of Western Australia's (GSWA) regional petrophysics project provides high-quality petrophysical measurements to assist with the interpretation of geophysical data. The project commenced in 2021, in collaboration with Terra Petrophysics, and is funded by the Exploration Incentive Scheme (EIS). Petrophysical data were collected from EIS co-funded drillcore, company drillcore, and GSWA stratigraphic drillcore. All cores sampled for petrophysics have, or will have, HyLogger data and most have open-file company assay data available through the Mineral Exploration reports database (WAMEX).

Terra Petrophysics conducted petrophysical analyses on 1180 samples from 18 diamond drillholes (Fig. 1, Table 1) drilled into the Paterson Orogen. Samples comprise both partially mineralized and unmineralized metasedimentary and igneous rocks from the Paterson Orogen to a depth of up to 827 m below the surface. Where drillcore samples from the weathering profile and sedimentary units were competent enough, they were submitted for petrophysical analysis.

Physical properties measured include:

- Induced Polarization (Chargeability) and Galvanic Resistivity
- Inductive Conductivity
- Magnetic Susceptibility
- Remanent Magnetization: the ratio of induced- to remanent-magnetization intensity of the sample (known as the Koenigsberger Ratio, Q), as well as an estimate of the total remanent vector (relative to drillhole)
- Dry Bulk Density
- Apparent Porosity
- P-wave Sonic Velocity
- Spectral Radiometrics.

GSWA provides a datasheet (with petrophysical measurements, lithological information, and supplementary material), a photo of each sample, and a description of the methods. Terra also produces a report with an analysis of the petrophysical data for drillholes located within common geological terranes. All of these datasets and reports can be downloaded from **MAGIX** and the **eBookshop**, respectively.

## GSWA drillholes and reporting

Fifteen of the 18 drillholes sampled for petrophysics in this Report are located at the Perth Core Library. These holes were either donated to GSWA or formed part of an EIS-funded drilling program. Open-file data and reports for these drillholes are available from the department's WAMEX online database under the file names in Table 1.

This Report builds on previous petrophysical reporting by GSWA. Five drillholes in this Report were previously reported in September 2021; available from the department's **eBookshop**:

- Report 217 Regional petrophysics: Paterson Orogen 2020–21 *by* M Markoski, J Trunfull and B Bourne

## Non-GSWA drillholes

Metals X Limited supplied three drillholes for HyLogger and petrophysical analysis:

- 17NNMD001 is a surface drillhole drilled between September 2016 and March 2017
- NUG0453 was drilled from the Nifty underground operations in July 2018
- UGD063 was drilled from the Nifty underground operations by Birla Nifty Pty Ltd in December 2006 (prior to Metal X Ltd acquisition of Birla Nifty Pty Ltd).

The drillhole reports compiled as a statutory requirement are available in WAMEX under the file numbers in Table 1.

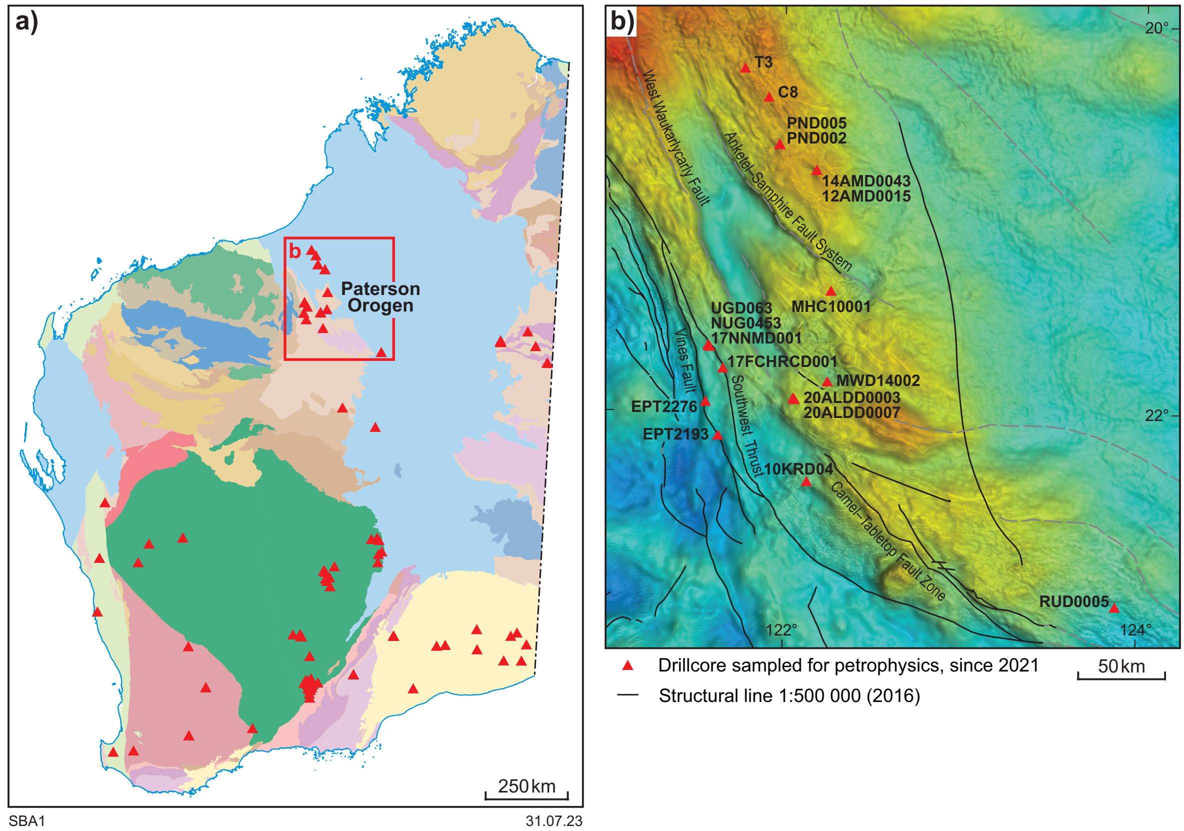


Figure 1. Drillcore locations sampled for petrophysics: a) statewide drillcores sampled since 2021, shown on tectonic units map (2021) with major crustal boundaries; b) location of 18 drillholes sampled for petrophysics (this Report) shown on a first vertical derivative of the reduced-to-pole total magnetic intensity data (grey scale, 80 m cell size) draped with Bouguer gravity anomaly data (colour, 400 m cell size)

Table 1. Drillcore identification names/numbers, collar details, MAGIX reference numbers, and WAMEX report numbers for the drillcores sampled for petrophysics in this Report

| Drillhole ID | Latitude | Longitude | Elevation (m) | Azimuth (degrees) | Dip (degrees) | Depth (m) | Number of petrophysical samples | Source of core | MAGIX registration number | WAMEX file number |
|---|---|---|---|---|---|---|---|---|---|---|
| 12AMD0015 | −20.7579 | 122.1757 | 260.00 | 210 | −55 | 550.20 | 90 | EIS | 72014 / 72482 | A96042, A96872, A110191 |
| 14AMD0043 | −20.7574 | 122.1752 | 263.00 | 200 | −60 | 300.02 | 43 | EIS | 72014 / 72482 | A103692, A104366, A109946 |
| C8 | −20.3802 | 121.9078 | 201.00 | 000 | −90 | 252.20 | 31 | EIS | 72014 / 72482 | A97188, A97642 |
| PND002 | −20.6263 | 121.9695 | 229.00 | 055 | −60 | 517.40 | 36 | Company – donated* | 72014 / 72482 | A115331, A122049, A127434, A134589 |
| PND005 | −20.6224 | 121.9684 | 121.00 | 058 | −60 | 510.50 | 74 | EIS | 72014 / 72482 | A119418, A134589 |
| 17FCHRCD001 | −21.7810 | 121.6580 | 290.00 | 024 | −65 | 694.20 | 120 | EIS | 72201 / 72482 | A115155, A116880, A132423 |
| 20ALDD0003 | −21.9338 | 122.0528 | 317.79 | 050 | −70 | 548.70 | 48 | EIS | 72201 / 72482 | A126600 |
| 20ALDD0007 | −21.9422 | 122.0601 | 320.17 | 230 | −70 | 439.00 | 105 | EIS | 72201 / 72482 | A126600 |
| T3 | −20.2304 | 121.7756 | 172.00 | 000 | −90 | 269.90 | 36 | EIS | 72201 / 72482 | A97188, A97642, A110191 |
| 10KRD04 | −22.3647 | 122.1314 | 320.00 | 050 | −60 | 150.40 | 42 | EIS | 72201 / 72482 | A91026, A91525 |
| EPT2193 | −22.1277 | 121.6314 | 354.14 | 270 | −60 | 398.90 | 78 | EIS | 72201 / 72482 | A104967, A105177 |
| EPT2276 | −21.9532 | 121.5605 | 352.94 | 000 | −80 | 783.80 | 88 | EIS | 72201 / 72482 | A109408, A114039 |
| MHC10001 | −21.3809 | 122.2605 | 500.00 | 240 | −60 | 828.60 | 182 | EIS | 72201 / 72482 | A89687 |
| MWD14002 | −21.8495 | 122.2433 | 314.00 | 030 | −60 | 528.50 | 93 | EIS | 72201 / 72482 | A104970 |
| RUD0005 | −22.9960 | 123.8781 | 390.00 | 050 | −70 | 237.00 | 33 | EIS | 72201 / 72482 | A115833, A118941 |
| 17NNMD001 | −21.6695 | 121.5834 | 300.00 | 019 | −72 | 642.80 | 37 | Company – loaned | 72383 / 72482 | A115155, A134495 |
| NUG0453 | −21.6651 | 121.5767 | -87.53 | 066 | −28 | 257.00 | 24 | Company – loaned | 72383 / 72482 | A134495 |
| UGD063 | −21.6623 | 121.5742 | -57.15 | 232 | −65 | 108.00 | 20 | Company – loaned | 72383 / 72482 | A134495 |

* Stored at the Perth Core Library

# TERRA PETROPHYSICS PTY. LTD.

**(ABN 71 613 484 807)**

**GEOLOGICAL SURVEY OF WESTERN AUSRTRALIA**

**PATERSON OROGEN**

**WESTERN AUSTRALIA**

**TECHNICAL REPORT NO. 23_024**

GDA94 / UTM Zone 51

**DISTRIBUTION**

1. GSWA – Charlotte Hall
2. Terra Petrophysics – Barry Bourne

Mila Markoski
Geoscientist
June, 2023



TERRA PETROPHYSICS

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# 1. INTRODUCTION

Terra Petrophysics have performed petrophysical analysis of 1180 core samples for the Geological Survey of Western Australia (GSWA) from the Paterson Orogen in Western Australia. These samples have been provided by GSWA to develop an understanding of physical properties of rocks in the region and to assist with the interpretation of geophysical field data. Petrophysical analysis includes measurement of the following physical properties:

- Induced Polarisation (Chargeability) and Galvanic Resistivity
- Inductive Conductivity
- Magnetic Susceptibility
- Remanent Magnetisation; the ratio of induced- to remanent-magnetisation intensity of the sample (known as the Koenigsberger Ratio, Q), as well as an estimate of the total remanent vector (relative to drill hole).
- Dry Bulk Density
- Apparent Porosity
- P-wave Sonic Velocity
- Spectral Radiometrics

During analysis, Terra Petrophysics utilises standards and reference samples to ensure precision and accuracy.

# 2. PETROPHYSICS

## 2.1 Sample Preparation

Samples for physical property measurements should be carefully selected for quality and representation of geology and/or alteration. Terra recommends samples between the sizes of 10cm to 15cm. In this study all samples were of adequate size and quality. The size and shape of the sample need to be determined for most physical property measurements (e.g., geometric and core size correction factors). All samples and cores are returned to the client.

All samples are photographed and marked with Terra sample numbers. Samples for which magnetic remanence vector measurements are requested should be oriented in space. All samples should be accompanied by a project name, a brief description of each sample, requested physical property procedures and final disposal requirement for the samples.

Physical property determinations are non-destructive procedures; however, sample preparation requires the sample to have flat/square ends and sometimes requires them to be cut with a rock saw. In addition, samples are required to be submerged in water for 24 hours before being measured. Samples containing clays can absorb water and break. Extra caution is taken with these samples.

## 2.2 Inductive Conductivity

The inductive conductivity measurement is made in the frequency domain at 10,000 Hz via an external magnetic field inducing a small current in the sample. The measurement is most influenced by sample material at the receiver coil and within a 10 cm radius from the centre of the sample.

Inductive conductivity is calculated from the difference in amplitude between the sample and free air measurements. The limits of detectability are 0.1 S/m (maximum 100,000 S/m) and resulting data are presented in S/m. Several inductive conductivity measurements will be made and reported when the sample size permits.

## 2.3 Induced Polarization and Resistivity

The apparent resistivity and induced polarization (or chargeability) determinations are measured in time domain. The resistivity and chargeability values are measured by passing a constant current through the sample and then switching it on and off at 2 second intervals. While the current is flowing through the sample, the resistivity (ohm-m) is calculated. When the current is switched off, the voltage across the sample drops and a decay curve is measured. The induced polarization (mV/V) is calculated from this decay between 450-1100 milliseconds after turn off (Newmont Standard). Resistivity and induced polarization values are stacked and averaged a minimum of 10 times for one reading. Terra provide the average results for two readings (minimum).

Some samples (for example, silica rich samples) can be so resistive as to act dielectric. Electricity does not flow through the sample as if it were conductive, but charged particles are shifted minutely from their original position. When the current is removed the charged particles slowly (due to the high resistivity of the sample) relax to their original state. Therefore, samples are measured to be more chargeable than would be recognised by a field IP survey.

## 2.4 Wet/Dry Bulk Density and Porosity

The density determinations are calculated using Archimedes Principle. Dry bulk densities are determined by dry weight divided by the buoyancy determined volume of each sample. Porosities are calculated from water saturated weights, dry weights, and the buoyancy-determined volume. All sample are soaked for at least 24 hours after dry weights are measured.

The accuracy of the buoyancy technique of density measurement is 0.01 grams per cubic centimetre ($g/cm^3$). The results of the laboratory density determinations are reported in grams per cubic centimetre. Density measurements can be made on grab samples or drill core. Very large or heavy samples (>1 kg) require coring or breaking prior to the density determination.

## 2.5 Magnetic Susceptibility and Remanence

Magnetic susceptibility is measured by using a magnetic susceptibility meter to apply an external magnetic field to the sample at an operating frequency of 8 kHz. Magnetic susceptibility is calculated from the frequency difference between the sample and free air measurements. The limits of detectability are approximately 1 × 10-7 SI units and resulting data is presented in SI (×10-3) units. The measurement is most influenced by sample material at the receiver coil and within a 10 cm radius from the centre of the sample. Magnetic susceptibility measurements can be made on core, hand and surface samples.

For magnetic samples (>5 × $10^{-3}$ SI) the magnetic remanence can be measured. The measurement of remanence (Jr) in the field and the ratio of remanence to the induced magnetization ($J_{rem}/J_{ind}$ = Q) has in the past been problematic. The induced magnetization can be estimated using the susceptibility (k, where $J_{ind}$ = kH and typically H = 40-50 $Am^{-1}$) which can be measured using a handheld meter, but magnetic remanence is more difficult.

A recent development in field instrumentation uses a miniature fluxgate magnetometer and a pendulum arrangement in which a magnetic rock may be swung generating a transient signal at the fluxgate which is converted to a magnetic moment and magnetization.

## 2.6 Velocity

Terra Petrophysics can acquire P-wave velocity measurements on samples with a minimum length of 15 centimetres. Measurements are taken at 50,000 Hz. The velocity measurement range is between 1500-9999 m/s.

## 2.7 Spectral Radiometrics

Terra Petrophysics reports on the following radionuclides: Potassium (K-40) %, Uranium (U) ppm and Thorium (Th-232) ppm. The measurements are acquired using a 256 and 1024 channel spectrometer with a 3”x3” (21ci – 0.35L) Sodium-Iodide (NaI) gamma detector which is operated within the confines of a lead laboratory shield.

The minimum detection sensitivities of the instrument are 0.3% K, 0.9 ppm U, and 1.5 ppm Th; and the gamma ray sensitivity is (1MBq Cs-137 1 m) 386 cps.

## 3. RESULTS

A total of 1180 samples have undergone petrophysical analysis, the results table of which is included as APPENDIX 1 – DATA TABLES. Each sample is assigned a Terra ID, and photographs of the samples are included as APPENDIX 2 – SAMPLE PHOTOS. Raw data files for the induced polarization/resistivity and spectral radiometric measurements are included in the datasheet. Cross plots of the various petrophysical data are given in Figure 2 to Figure 14.

The data points are classified by Au content (ppm), using cool to warm colours, lithology, which is represented by shape and Cu content (ppm) which is represented by symbol size (Figure 1).

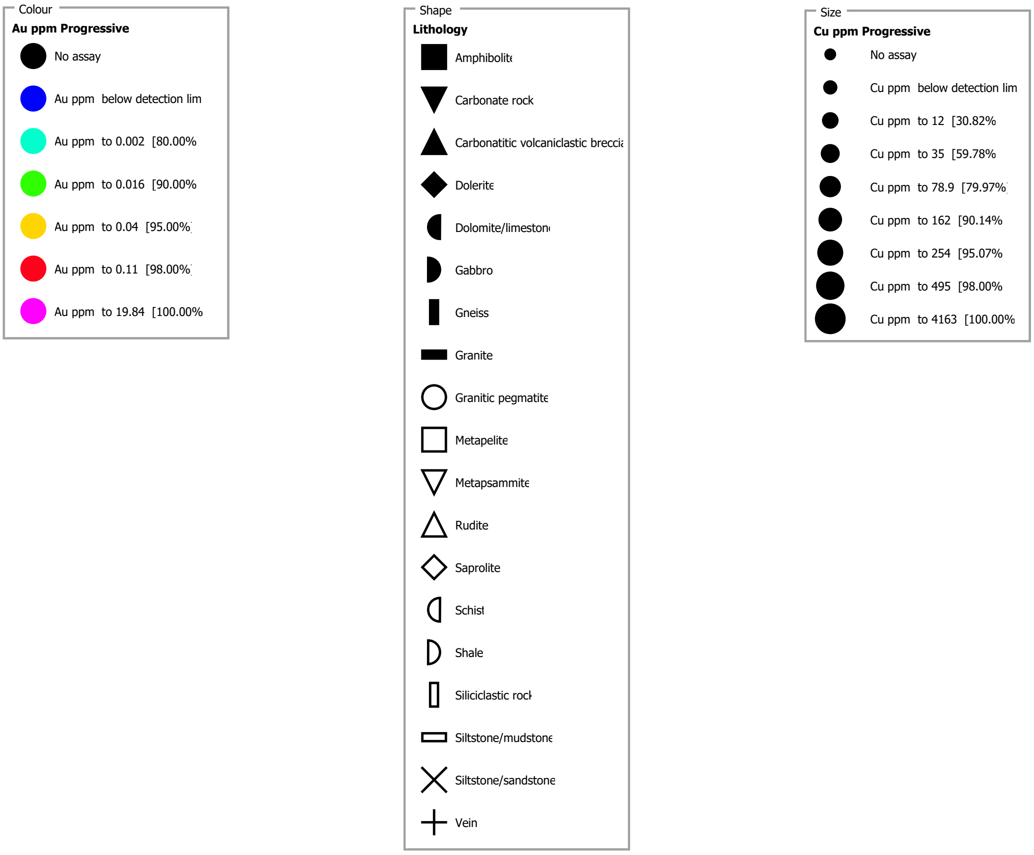
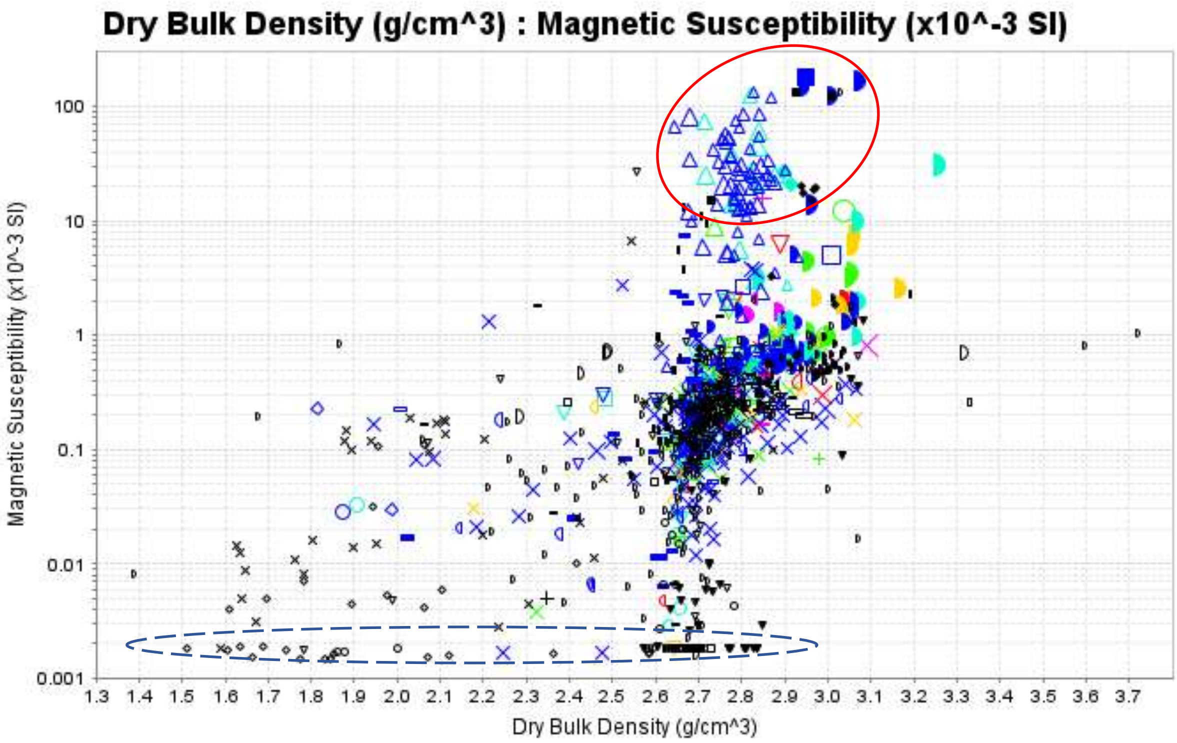


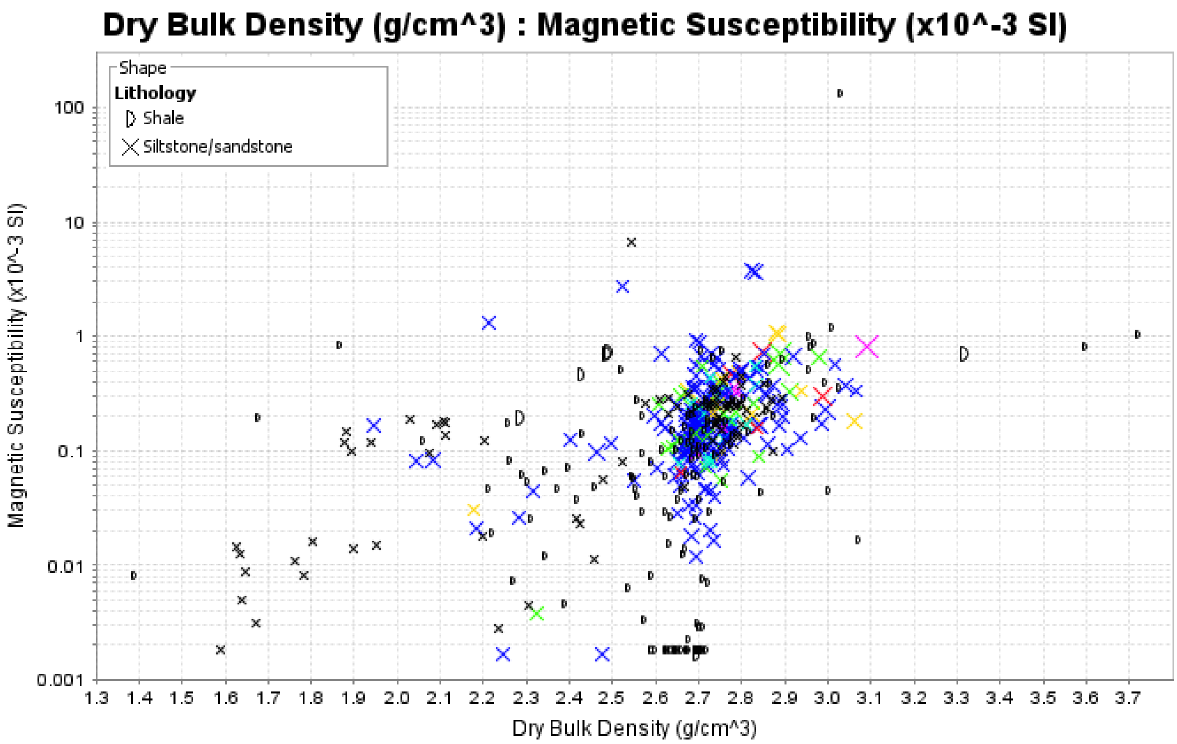

**Figure 1. Legend corresponding to Figure 2, and Figure 5 to Figure 12.**

A cross-plot of dry bulk density (DBD) and magnetic susceptibility data is given in Figures 2 a-e. Dry bulk density values range from 1.39 to 3.72 g/cm$^3$, but the majority of the samples cluster between 2.65 and 2.95 g/cm$^3$. Magnetic susceptibility values range from 0.001 to 178.292 ($\times 10^{-3}$) SI. The following observations were made from the plot:

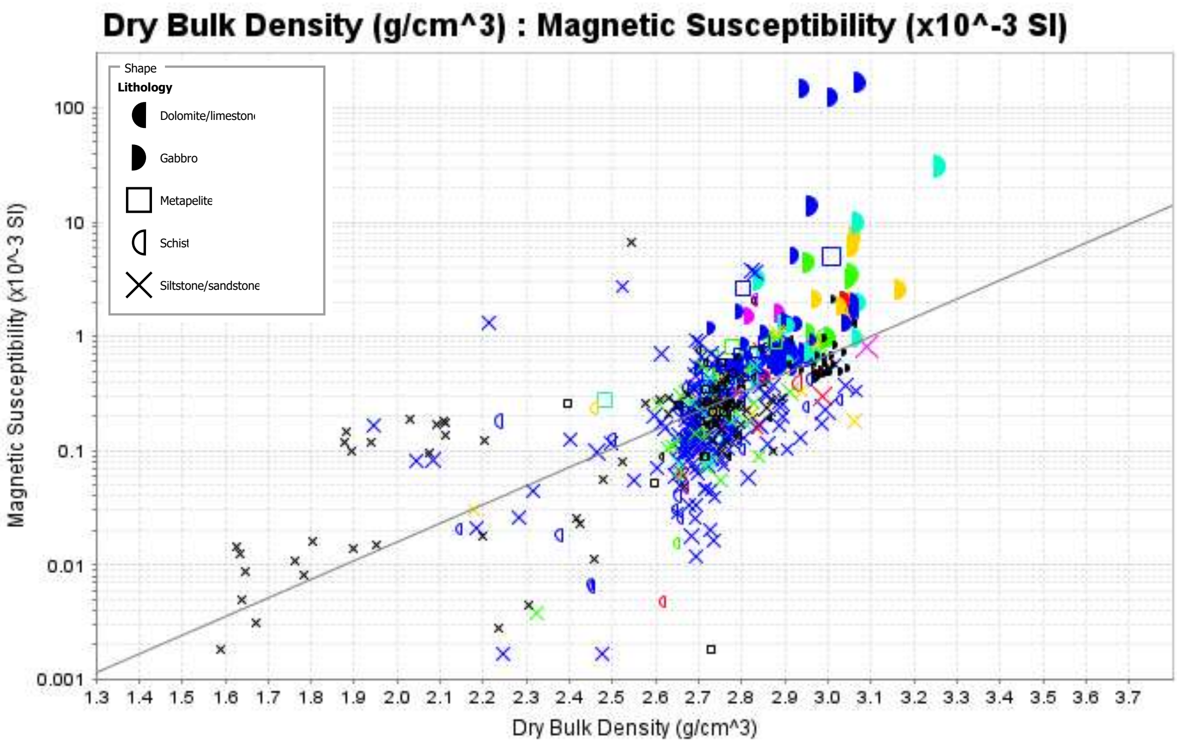
- The majority of the samples exhibit low magnetic susceptibility $< 1 \times 10^{-3}$ SI.
- Amphibolite, rudite and a few gabbro and dolerite samples exhibit high magnetic susceptibility ($(5 – 178.292) \times 10^{-3}$ SI, circled in red in Figure 2 a).
- Circled in blue is a group of samples with anomalously low magnetic susceptibility ($< 0.002 \times 10^{-3}$ SI, Figure 2 a), which consists of saprolites, shales and carbonate rocks.
- Shales exhibit a wide range of dry bulk density (DBD) values (1.39 – 3.72 g/cm$^3$, Figure 2 b).
- Siltstone/ sandstone samples exhibit a wide range of DBD values (1.59 – 3.09 g/cm$^3$), however, the majority of these cluster between 2.65 and 2.90 g/cm$^3$ (Figure 2 b).
- There is a positive correlation between the properties observed in gabbro, metapelite, schist, siltstone/sandstone and dolomite/limestone samples. This is indicated by the grey trendline in Figure 2 c (Spearman correlation coefficient r= 0.72).
- Saprolite samples exhibit low – medium DBD (1.51 – 2.61 g/cm$^3$) and low magnetic susceptibility values ($< 0.01 \times 10^{-3}$ SI, Figure 2 d).
- Sample 22TR0909 (siltstone/ sandstone) has the highest Au content (19.84 ppm) and shows a DBD of 2.79 g/cm$^3$ and low magnetic susceptibility of $0.352 \times 10^{-3}$ SI.
- Sample 22TR1063 (siltstone/ sandstone) has the highest Cu content (4163 ppm) and exhibits a DBD of 3.09 g/cm$^3$ and low magnetic susceptibility of $0.819 \times 10^{-3}$ SI.
- The majority of Cu mineralised samples (> 254 ppm) corresponds with magnetic susceptibility $> 1 \times 10^{-3}$ SI (Figure 2 e).



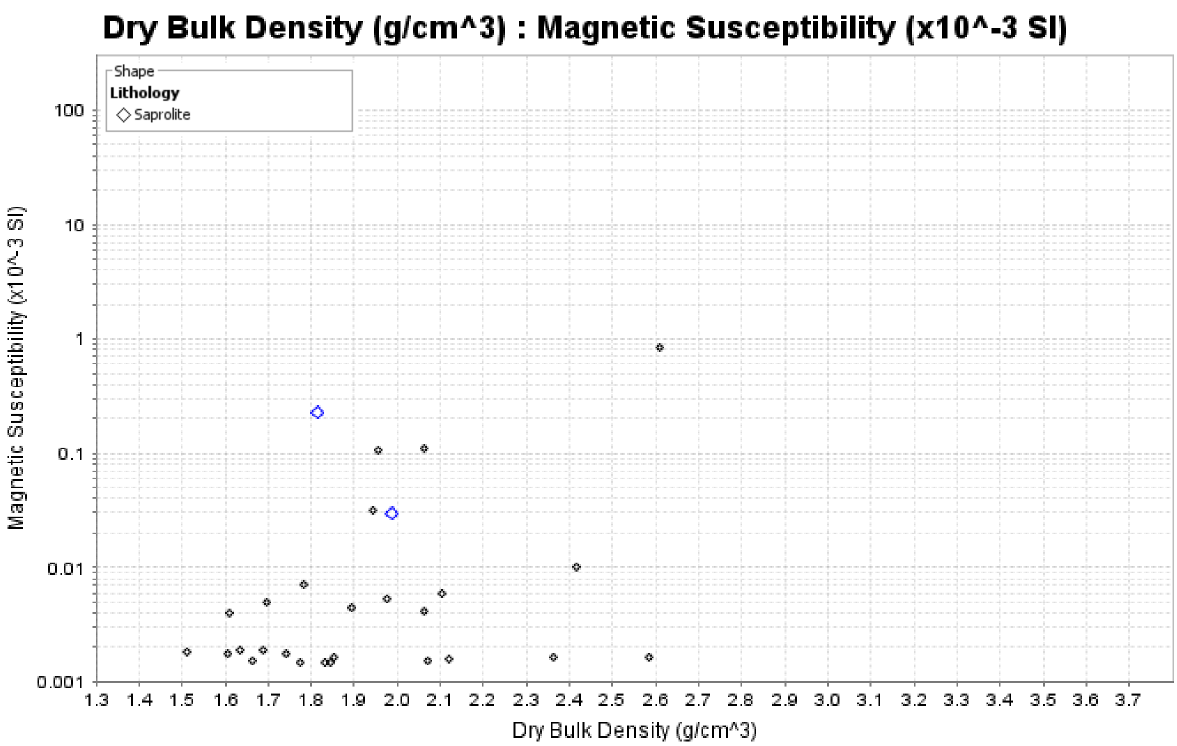

**(a)**


Dry Bulk Density (g/cm^3) : Magnetic Susceptibility (x10^-3 SI)
Shape
Lithology
Shale
Siltstone/sandstone
Magnetic Susceptibility (x10^-3 SI)
Dry Bulk Density (g/cm^3)

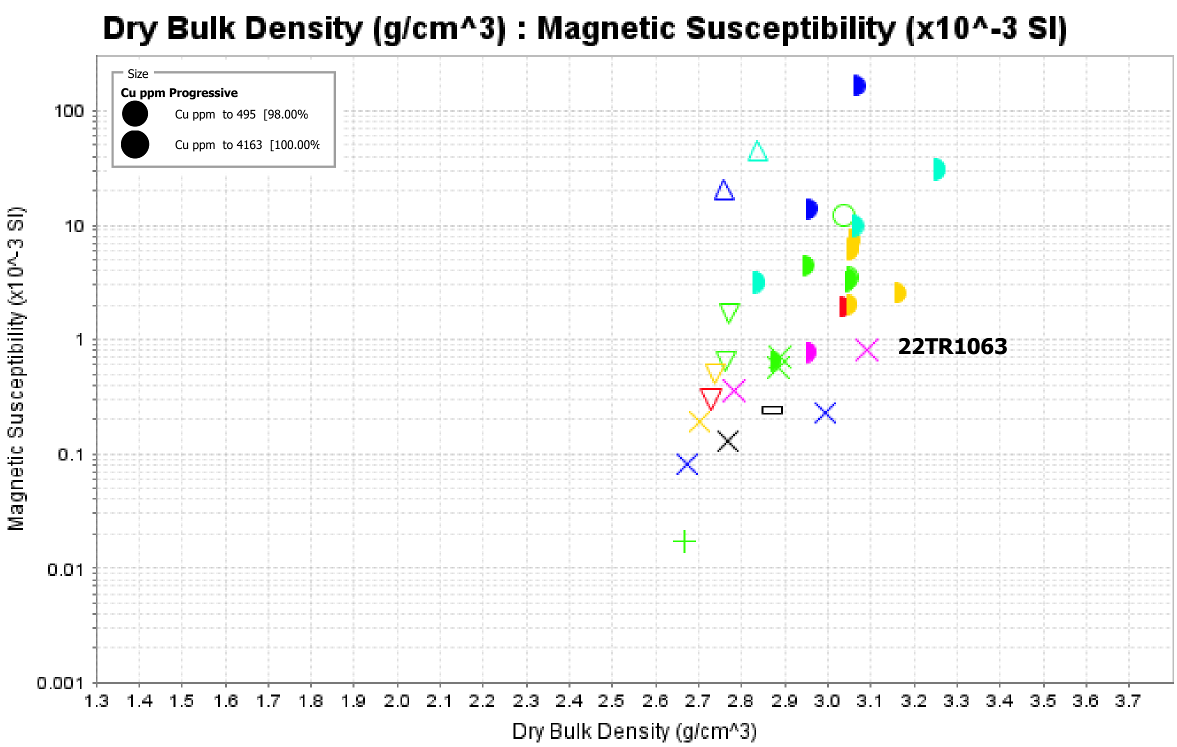
**(b)**


Dry Bulk Density (g/cm^3) : Magnetic Susceptibility (x10^-3 SI)
Shape
Lithology
Dolomite/limestone
Gabbro
Metapelite
Schist
Siltstone/sandstone
Magnetic Susceptibility (x10^-3 SI)
Dry Bulk Density (g/cm^3)

**(c)**




**(d)**




**(e)**

**Figure 2. Cross-plots of dry bulk density against magnetic susceptibility data. (a) shows all data, (b) shows shale and siltstone/mudstone/sandstone samples, (c) shows dolomite/limestone, gabbro, metapelite and schist samples, (d) shows saprolites and (e) shows samples with Cu content > 254 ppm.**

A method of estimating magnetic mineral content from magnetic susceptibility via a simple relationship was devised by Emerson (1997) and is shown in Figure 3. Sample 22TR1987 has a magnetic susceptibility of 0.178 SI, and correspondingly is estimated to contain approximately 4% magnetite (red line) and/or 45% monoclinic pyrrhotite (blue line).

Figure 4 shows ranges of density values for common rocks and minerals (Emerson, 1990). From this diagram, it can be noted this project shows a "very low to high" range of densities within the samples.

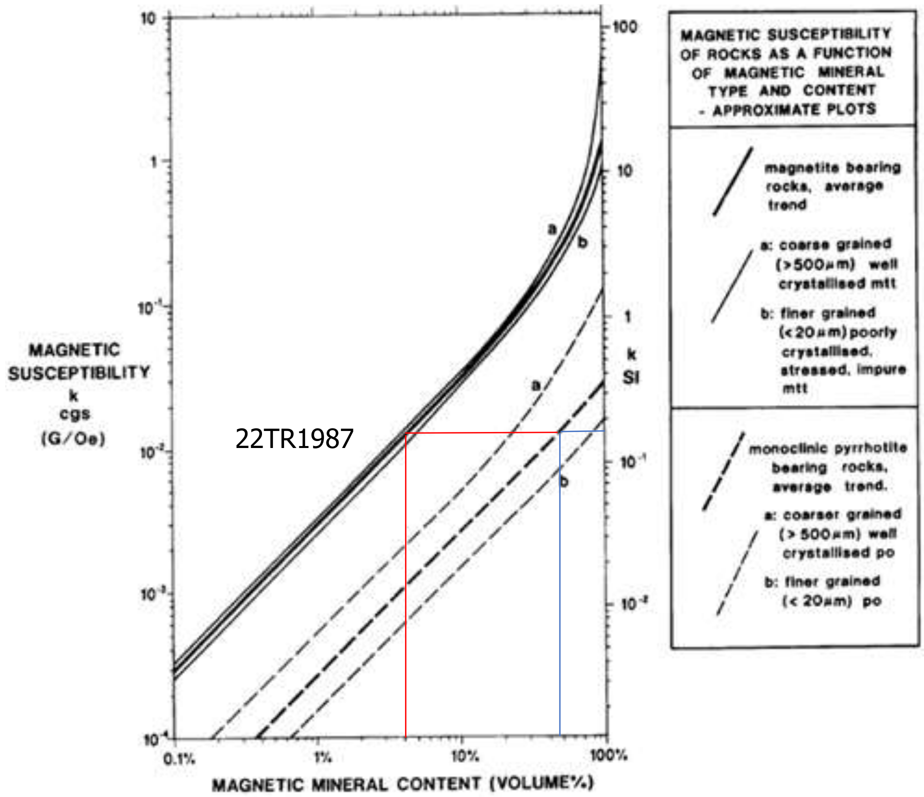



**Figure 3. Theoretical magnetic mineral content (magnetite – solid lines; pyrrhotite – dashed lines) as a function of measured magnetic susceptibility (Emerson, 1997)**

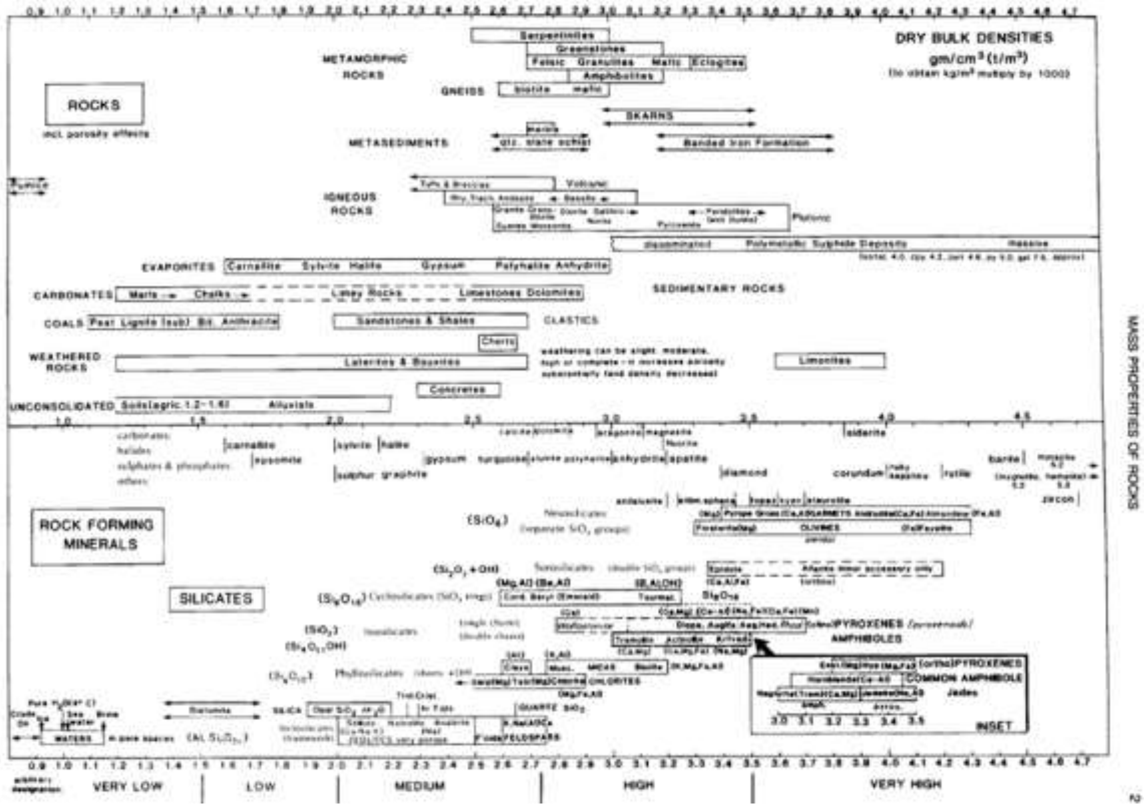



**Figure 4. Dry bulk density ranges for common rock types (Emerson, 1990).**

A cross-plot of dry bulk density and galvanic resistivity data is given in Figure 5. Galvanic resistivity values range from 1.5 to > 1,000,000 Ωm. The following observations are made from the figure below:

- The majority of the samples appear to cluster between 1,000 and 1,000,000 Ωm.
- Saprolite, schist and shale samples, as well as, some siliciclastic rock, siltstone/ sandstone and siltstone/mudstone samples appear conductive (< 100 Ωm) and exhibit low DBD (< 2.60 g/cm$^3$). This is likely due to weathering and increased clay content. An exception to this trend is a group of shales and a few siliciclastic rocks circled in red, which exhibit low galvanic resistivity, but higher density (> 2.60 g/cm$^3$).
- Two groups of samples vertically extend across a range of resistivity values (2,000 – 1,000,000 Ωm): one at DBD of 2.69 g/cm$^3$ and another one at 3.05 g/cm$^3$. The group with higher DBD consists of Cu-mineralised gabbros.

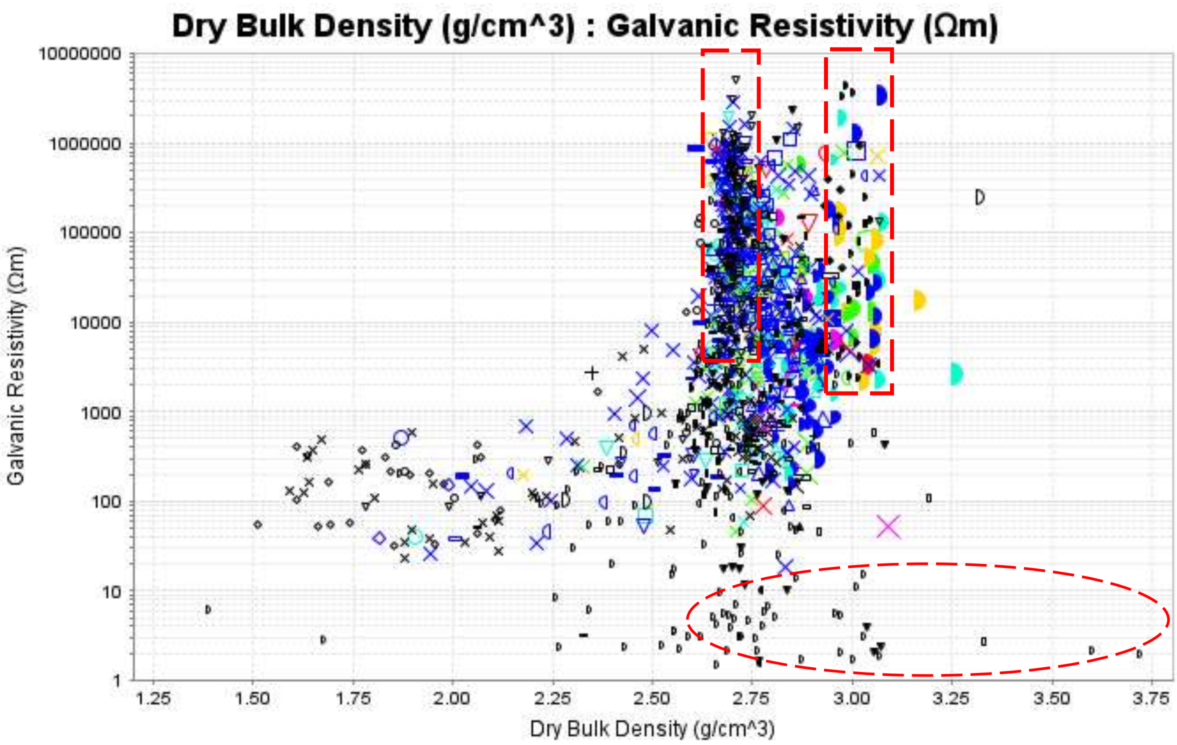



**Figure 5. Cross-plot of dry bulk density against galvanic resistivity data.**

A cross-plot of magnetic susceptibility and galvanic resistivity data is given in Figure 6.

Cu mineralised samples exhibit magnetic susceptibility > 1 × $10^{-3}$ SI and correspond to high resistivity values (1,000 – 1,000,000 Ωm).

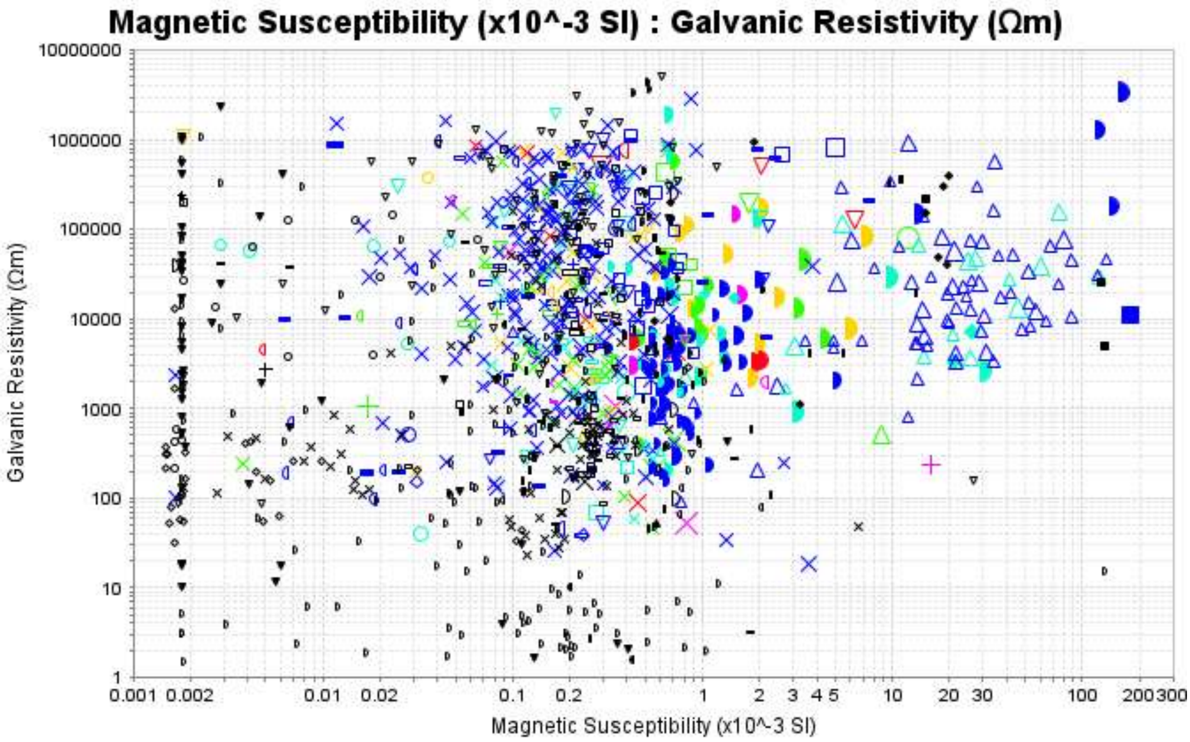
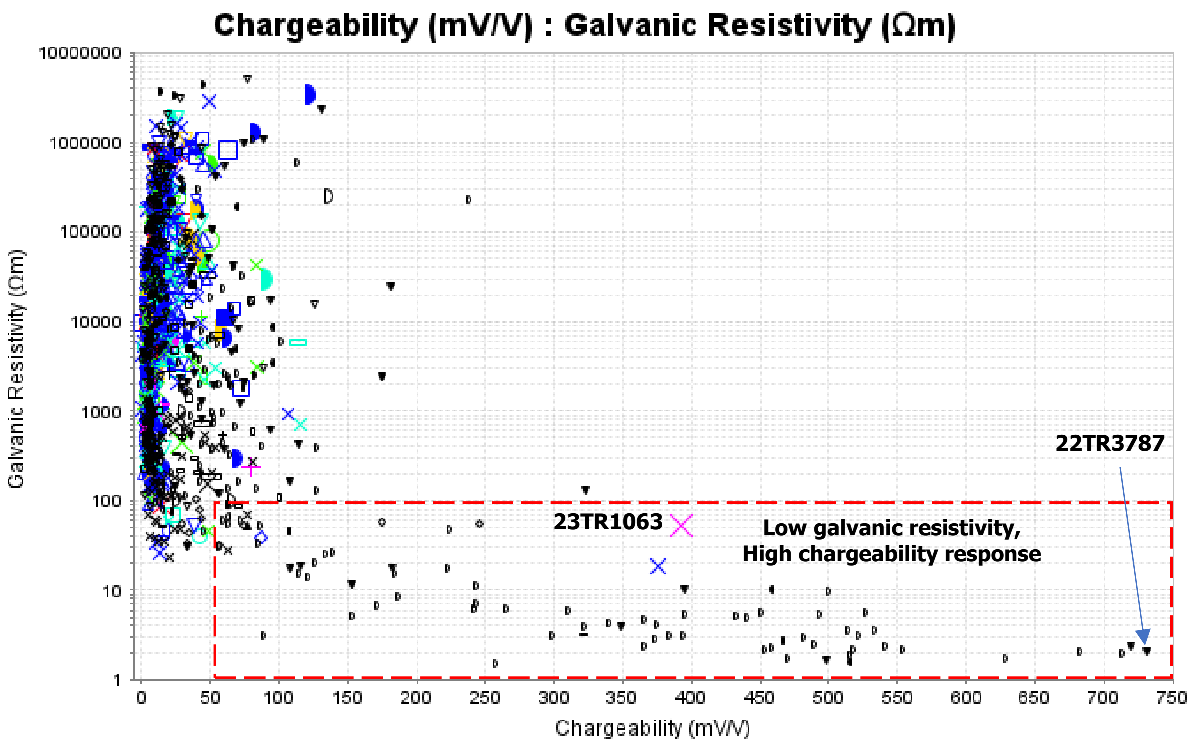


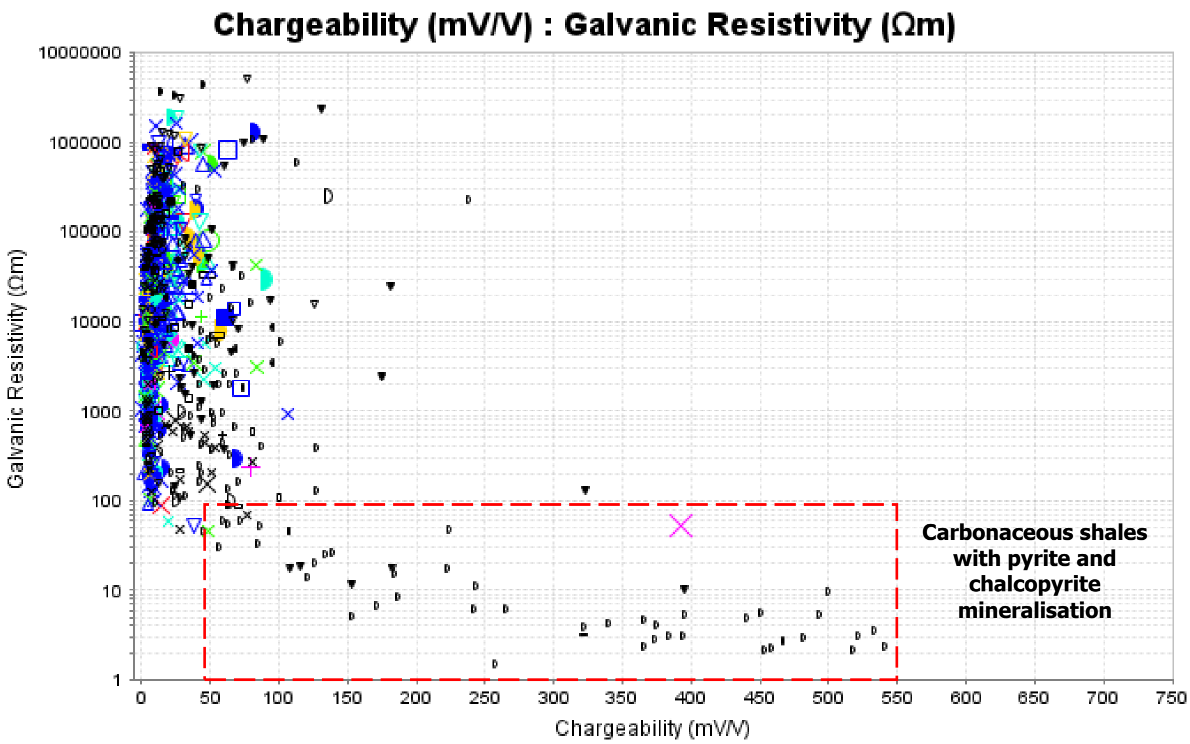

**Figure 6. Cross-plot of magnetic susceptibility against resistivity.**

A cross-plot of chargeability and galvanic resistivity data is given in Figure 7 a-e. Chargeability values range between 0.7 and 731.5 mV/V. The following observations are made from the figures below:

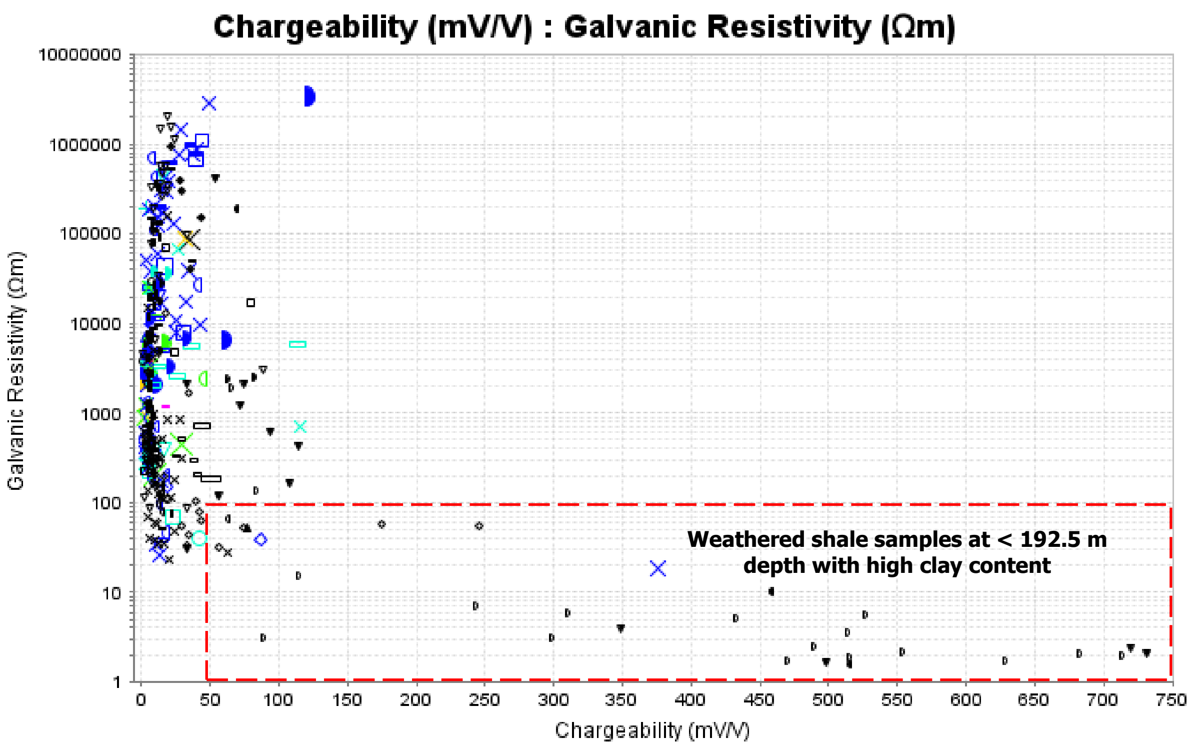
- The red square in Figure 7 (a) shows shale, carbonate rock and carbonaceous shales which exhibit low galvanic resistivity (< 100 Ωm) and anomalously high chargeability (up to 731.5 mV/V). The high chargeability response in the carbonaceous shales is due to sulfide mineralisation and increased carbon content (Figure 7 b) and the high chargeability response in the shales and carbonate rocks is due to higher clay content from weathering (Figure 7 c).
- Sample 22TR3787 (carbonate rock) exhibits the highest chargeability value of 731.5 mV/V and corresponds to a low galvanic resistivity of 2 Ωm.
- Sample 23TR1063 (siltstone/sandstone) has the highest Cu content (4136 ppm) and exhibits an anomalously high chargeability (392 mV/V) and low galvanic resistivity of 53 mV/V.
- There is a negative correlation (Spearman correlation coefficient r=-0.59, Figure 7 c) between the properties in: carbonate rocks, dolomite/limestones, saprolites, shales and siliciclastic rocks. This is due to increased clay content and weathering.



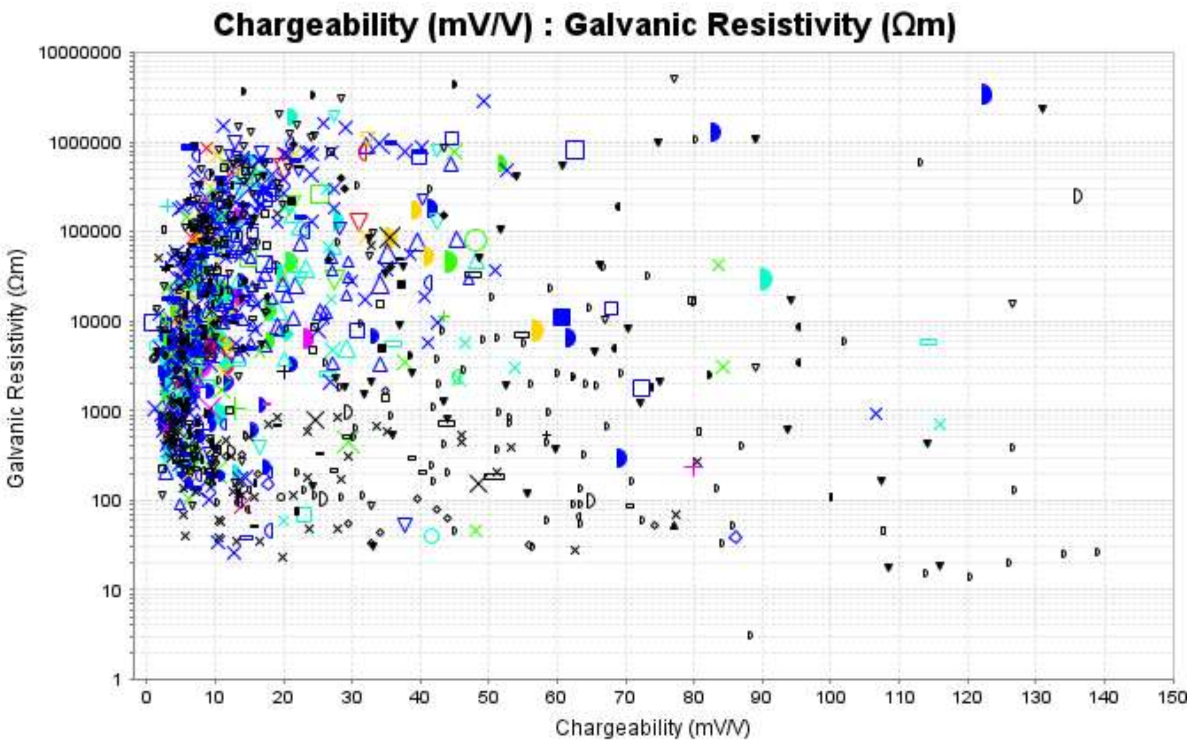

**(a)**


Chargeability (mV/V) : Galvanic Resistivity (Ωm)
Galvanic Resistivity (Ωm)
Chargeability (mV/V)
Carbonaceous shales with pyrite and chalcopyrite mineralisation

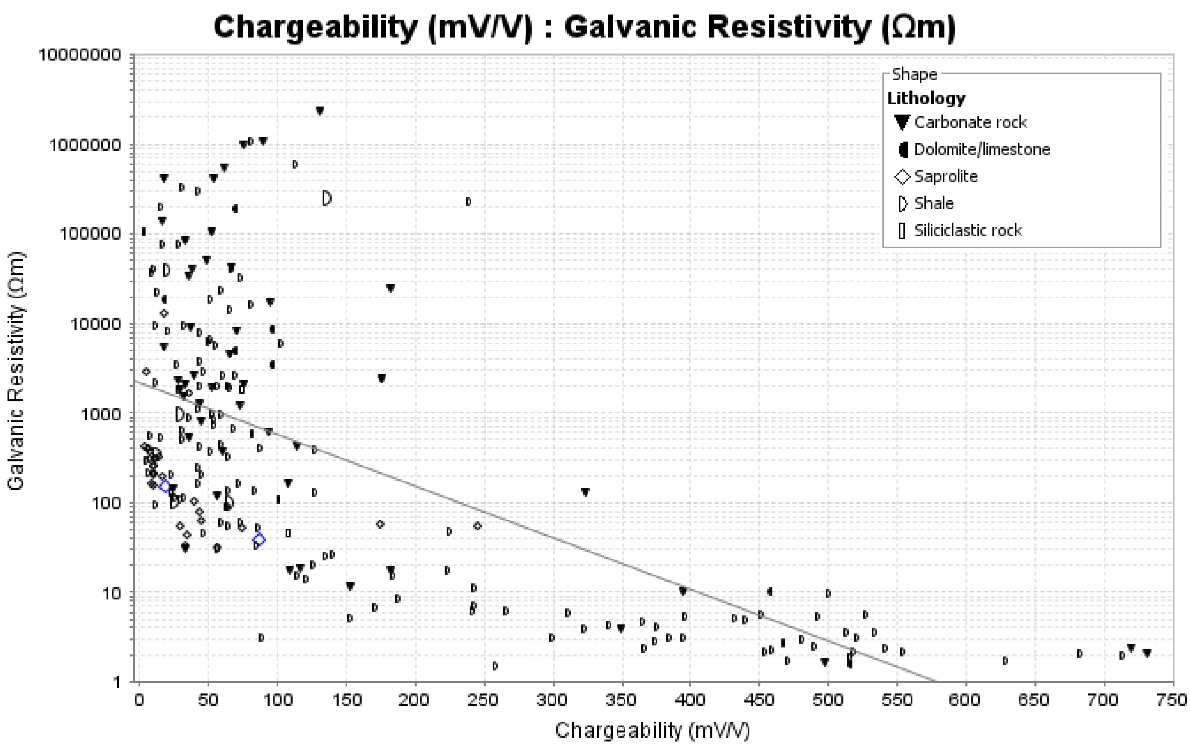
**(b)**


Chargeability (mV/V) : Galvanic Resistivity (Ωm)
Galvanic Resistivity (Ωm)
Chargeability (mV/V)
Weathered shale samples at < 192.5 m depth with high clay content

**(c)**




(d)

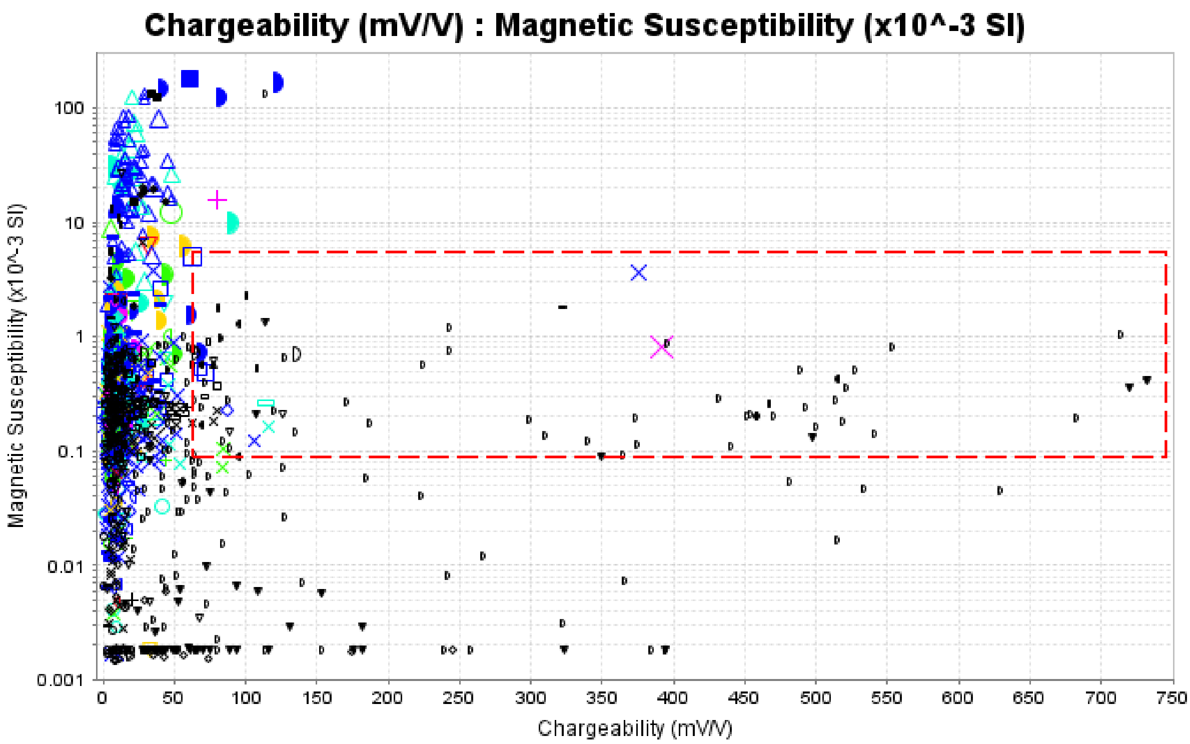



(e)

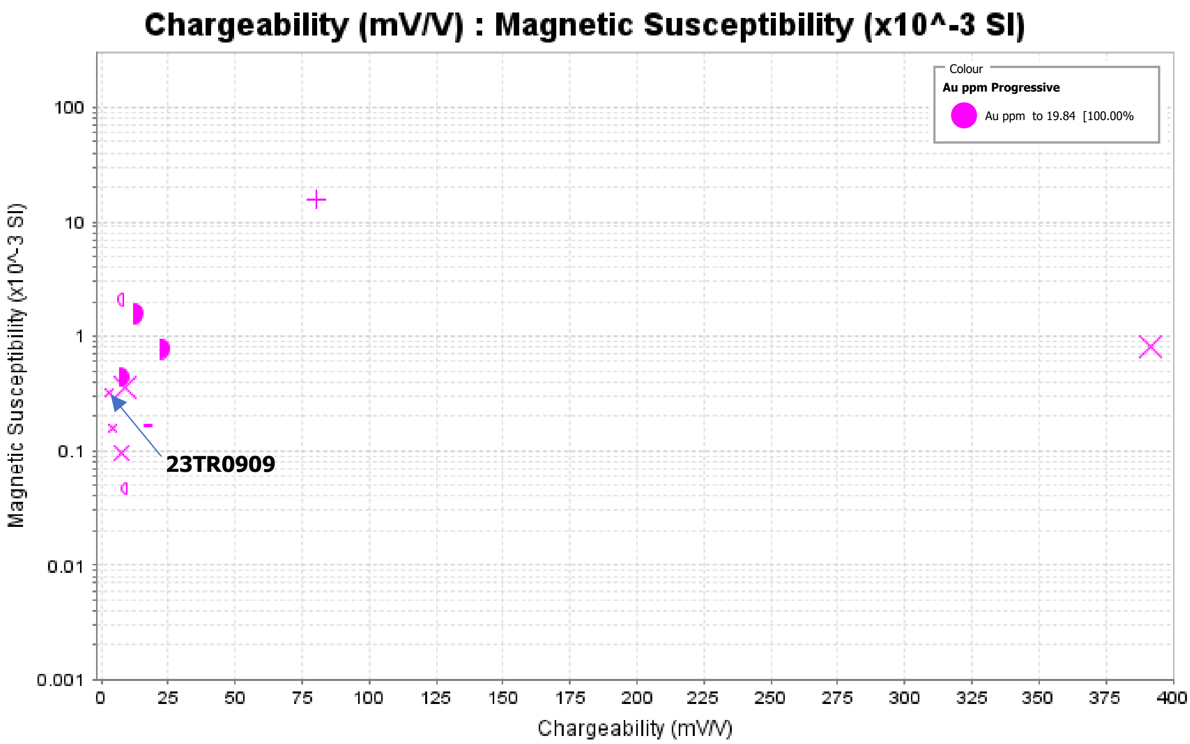
**Figure 7. Cross-plots of chargeability against resistivity. (a) shows all data, (b) shows all samples with depth > 192.5 m, (c) shows all samples at depth < 192.5 m, (d) shows chargeability on a reduced axis and (e) shows carbonate rocks, dolomite/limestone, saprolite, shale and siliciclastic rocks.**

A cross-plot of chargeability and magnetic susceptibility data is given in Figure 8 a-c. The following observations are made from the figures below:

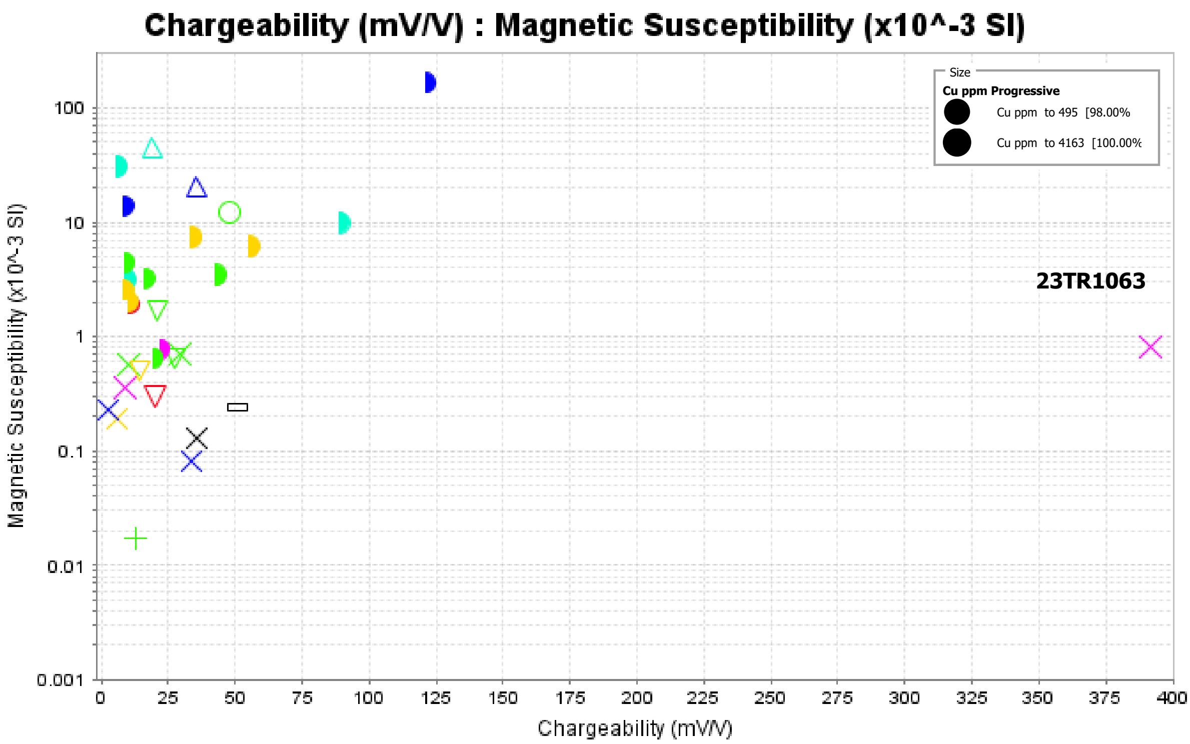
- The red square represents a group of shales which produce anomalously high chargeability and correspond to magnetic susceptibility of < 1 × $10^{-3}$ SI (Figure 8 a).
- The majority of Au-mineralised samples exhibit chargeability < 15 mV/V (Figure 8 b). Sample 22TR0909 (siltstone/sandstone) has the highest Au content (19.84 ppm) and shows both, a low chargeability and low magnetic susceptibility (2.8 mV/V and 0.325 × $10^{-3}$ SI).
- Some Cu-mineralised samples appear to produce a higher chargeability response (> 15 mV/V, Figure 8 c). Sample 23TR1063 (siltstone/sandstone) has the highest Cu content (4136 ppm) and exhibits an anomalously high chargeability (392 mV/V) and low magnetic susceptibility of 0.819 × $10^{-3}$ SI.




**(a)**




(b)




(c)

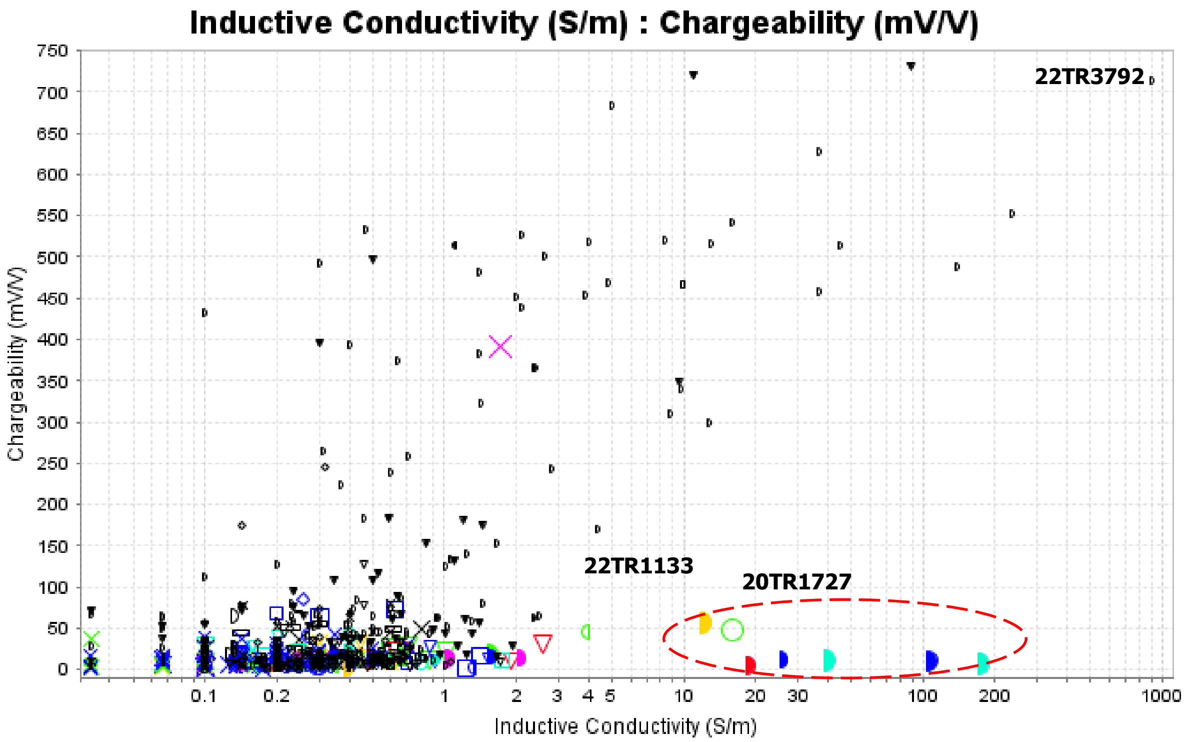
**Figure 8. Cross-plots of chargeability against magnetic susceptibility. (a) shows all data, (b) shows samples with Au amount > 0.11 ppm and (c) shows samples with Cu amount > 254 ppm.**

A cross-plot of inductive conductivity and chargeability data is given in Figure 9 a-b. Only samples with a non-zero inductive conductivity value are included.

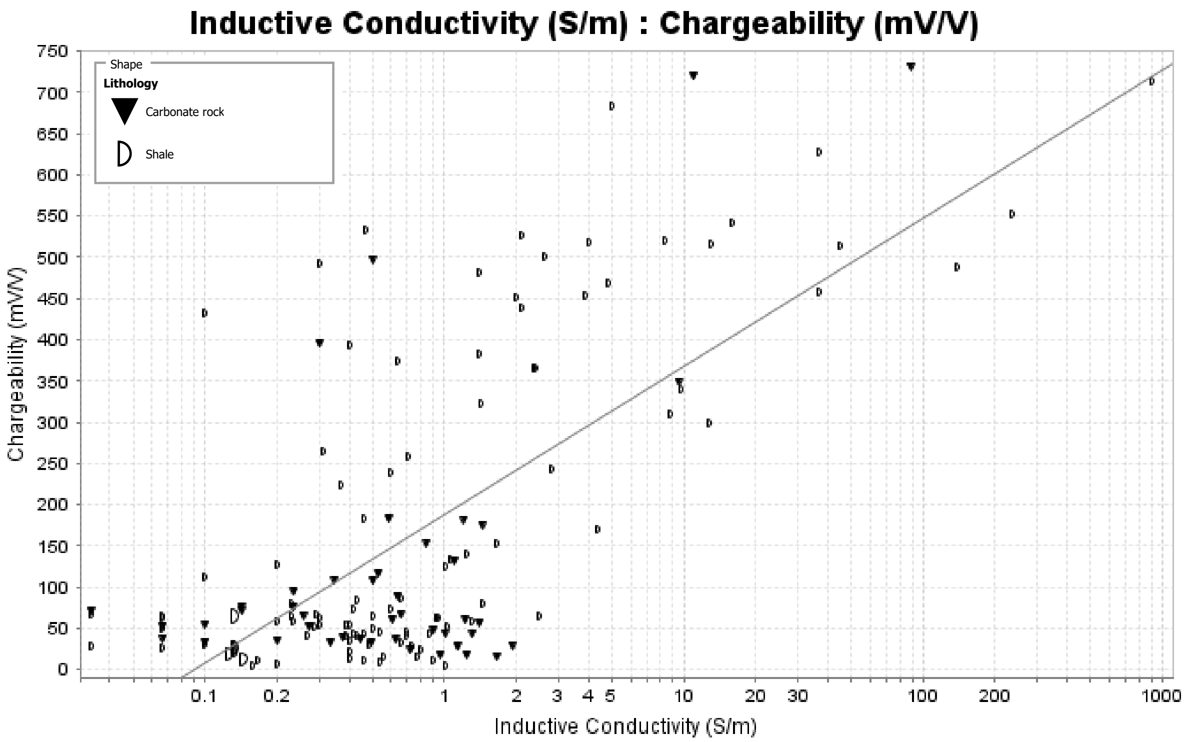
Chargeability of a material is dependent on 4 major factors: the degree of sulphide or metallic mineralisation, presence of clays, the pore-water salinity, and the overall tortuosity of the pore-space network within the rock. Both a high inductive conductivity and a high chargeability may be indicative of the presence of sulphides within the sample, although conductivity tends to better respond to massive (connected) sulphides, while chargeability responds better to disseminated (disconnected) sulphides.

The following observations are made from the figures below:

- Inductive conductivity ranges up to 903 S/m for this dataset, which is very high.
- A few Cu-mineralised gabbros and a granitic pegmatite (circled in red, Figure 9 a) produce a high inductive conductivity response (10 – 200 S/m) and correspond to low chargeability values (< 10 mV/V), with the exception of gabbro sample - 22TR1133 and granitic pegmatite -20TR1727, which exhibit chargeability values of 57.1 and 48.1 mV/V, respectively.
- There is a positive correlation between the properties visible in carbonate rock and shale (Spearman correlation coefficient r= 0.49, Figure 9 b).
- Sample 22TR3792 (shale) produced the highest inductive conductivity response (903 S/m), which corresponds to a high chargeability (712.9 mV/V).




(a)



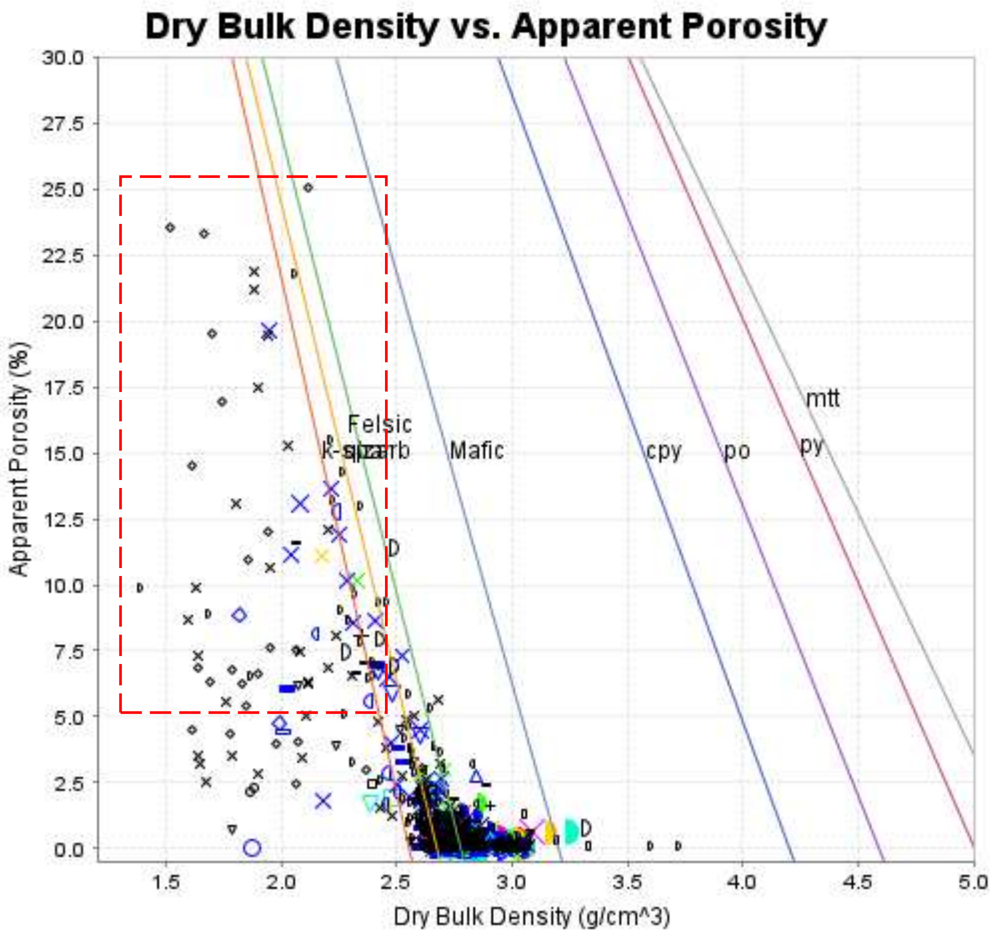

(b)

**Figure 9. Cross-plot of inductive conductivity against chargeability. (a) shows all data and (b) shows lithologies with a positive correlation.**

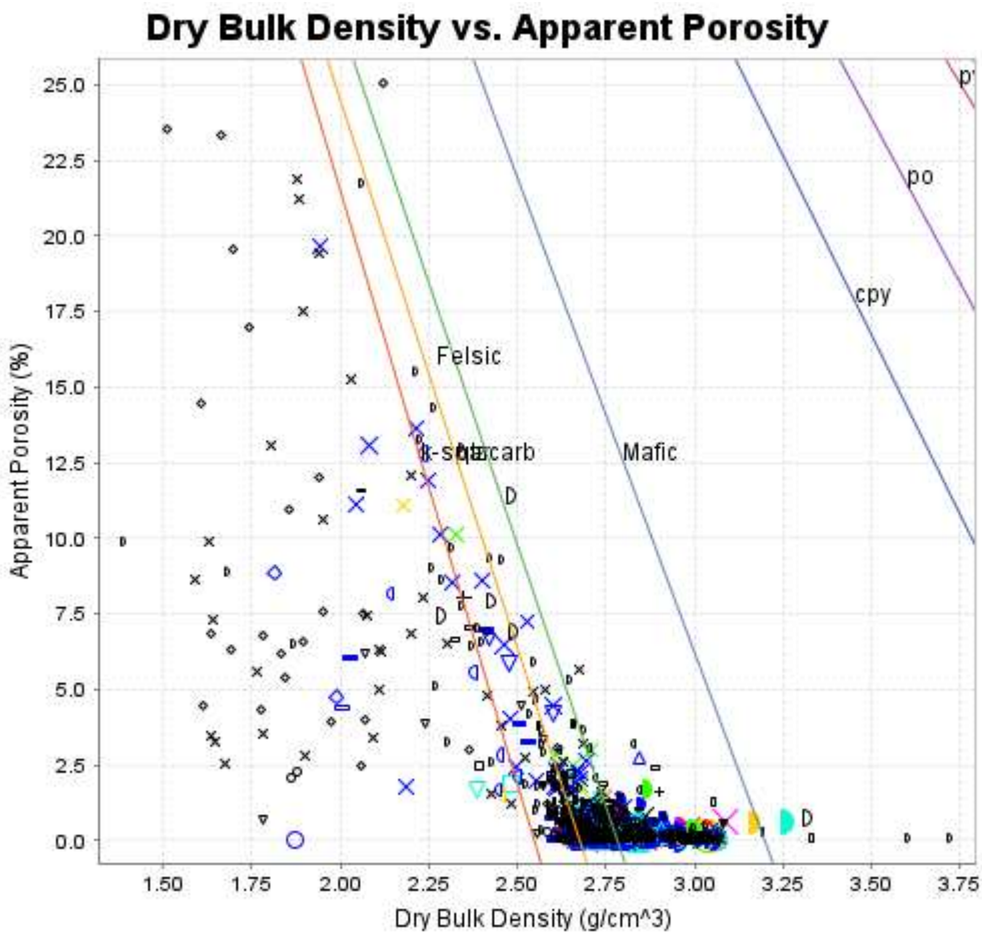
A cross-plot of dry bulk density and apparent porosity data against mineral trends (Emerson, 1997) is given in Figure 10.

Apparent porosity values for the project range up to 25%, however, the majority of the samples plot below 2.5%. The porosity of some samples may be slightly overestimated and the dry bulk density value slightly underestimated where the samples were extremely friable and could not be soaked without disintegrating, and as a result a saturated mass could not be obtained. These samples have been noted in the data sheet. Samples with high porosity (red square) correspond to DBD < 2.50 g/cm$^3$. This is due to increased weathering/alteration.

The majority of the samples plot between the 'qtz' and `mafic' mineral line — though this may be reflective of alteration and weathering, rather than based purely on lithology. Some Cu and Au mineralised samples plot with DBD higher than 2.67 g/cm$^3$.




**(a)**




**(b)**

**Figure 10. Cross-plot of dry bulk density against porosity; (a) shows the full diagram, (b) shows just the data range.**

A cross-plot of dry bulk density and P-wave velocity data, with contours of acoustic impedance, is given in Figure 11. The separation between the contours represents the contrast required to produce a minimum reflection coefficient (R=0.06) detectable by the seismic reflection method. The more contours the data overlaps, the more likely the seismic reflection method is to map geological and/or lithological contrasts. P-wave velocity was unable to be measured on 168 samples due to insufficient sample length (<15 cm).

P-wave velocity for this data range from 890 m/s to 6,710 m/s and spread over 8 acoustic impedance contours. This method may be able to distinguish between some cover and basement rocks.

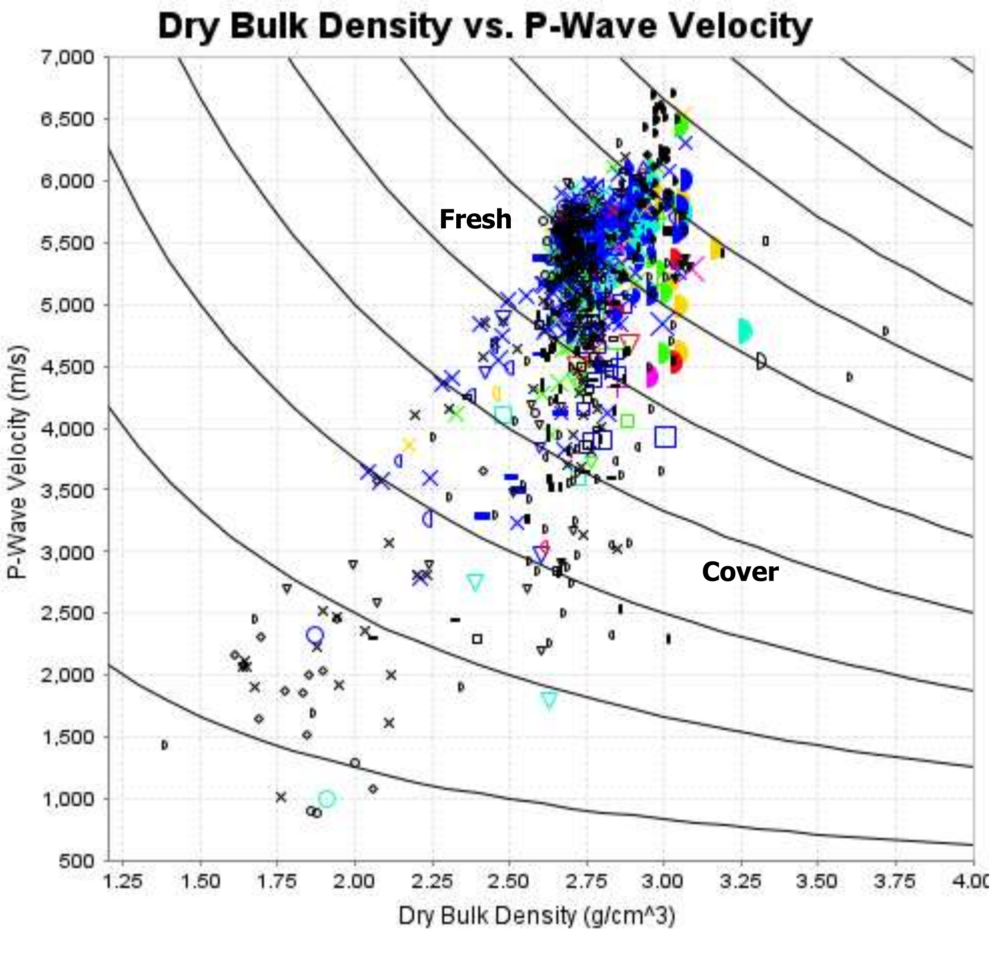



**Figure 11. Cross-plot of dry bulk density against sonic (P-wave) velocity.**

A ternary diagram of K, U and Th distributions is shown in Figure 12. Spectral radiometrics were only measured for 81 samples from 3 drillholes (UGD063, 17NNMD001 and NUG0453). Values range from below detection limit up to 17.88% for K, 54.39 ppm U and 56.93 ppm Th.

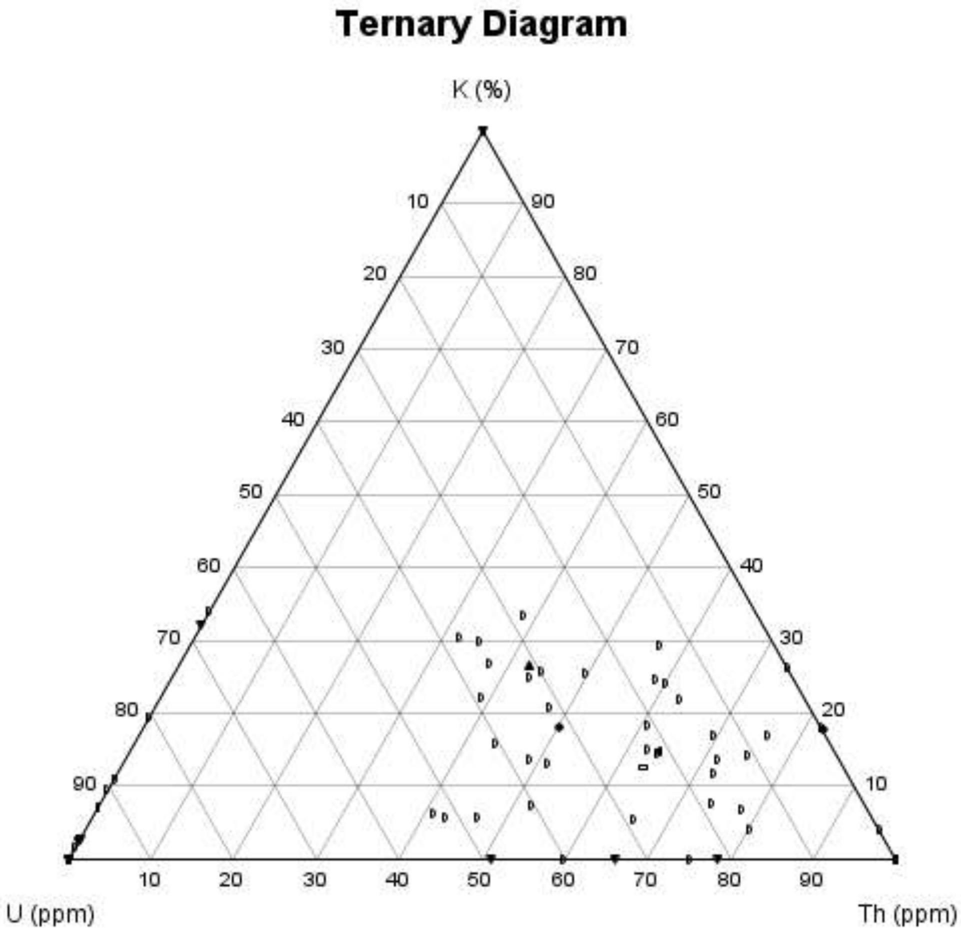



**Figure 12. Ternary diagram of K%, U ppm and Th ppm.**

A cross-plot of the intensity of the induced vs. remanent vectors ($J_{ind}$ vs. $J_{rem}$) is given in Figure 13.

The components of induced and remanent magnetism were measured for 229 samples. 96 samples are measured to be induced-dominant (Q<1) and 133 to be remanent-magnetisation dominant (Q>1).

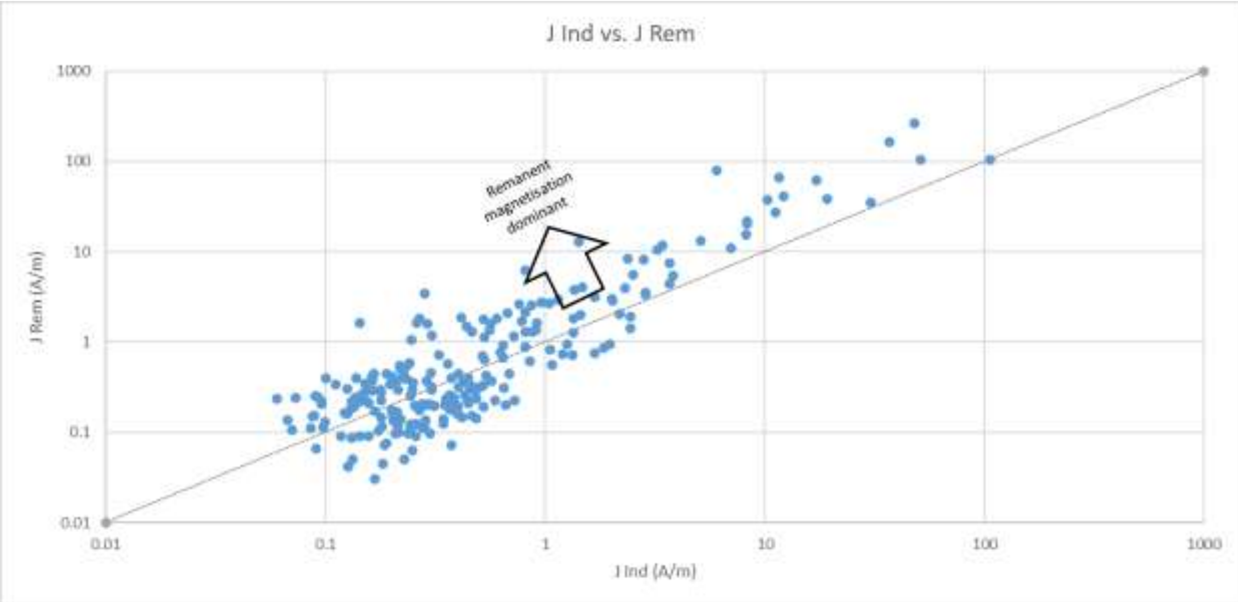



**Figure 13. Cross-plot of intensity of $J_{ind}$ versus $J_{rem}$. Samples above the trend line have Koenigsberger ratio (Q) greater than 1, indicating they are remanent-magnetisation dominant. Conversely, samples below the trend line have a Q value less than one, and are induced-magnetisation dominant.**

A theoretical magnetic susceptibility value has been calculated from the $J_{ind}$ vector intensity, and is compared with the measured magnetic susceptibility via a cross-plot (Figure 14).

Variation between the two values is expected. Samples with higher orders of magnitude differences between measured magnetic susceptibility and the calculated value may be attributed to remanent dominance and the associated cancellation of induced magnetisation. This is particularly observed in remanent magnetisation dominant samples with high pyrrhotite content. For this dataset, the trend is also observed in induced-magnetisation dominant samples.

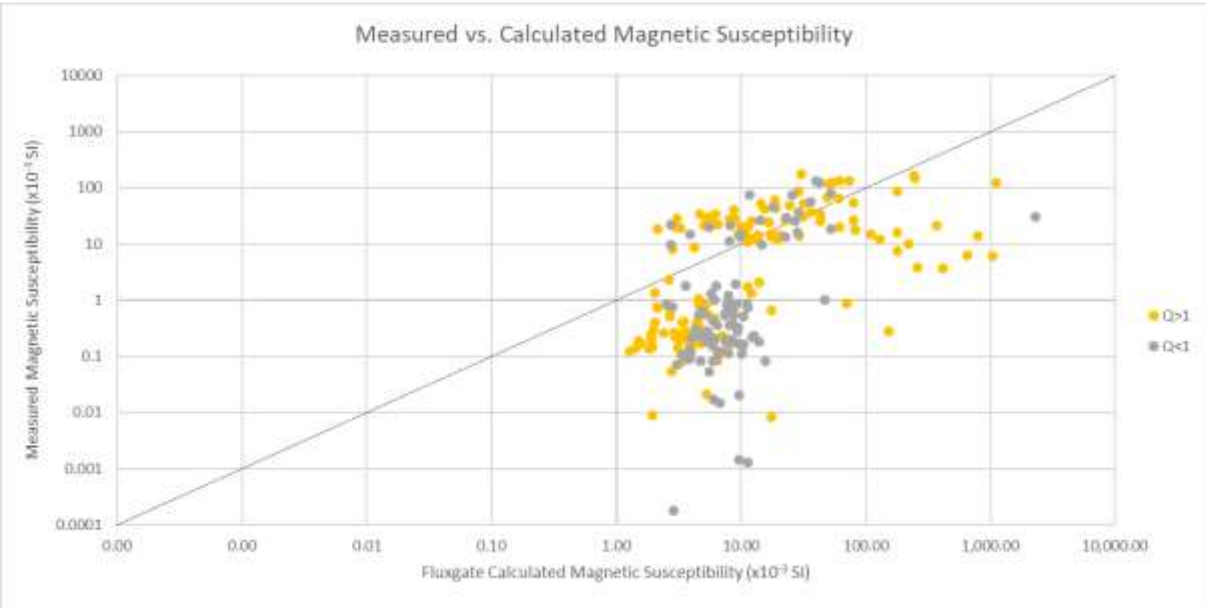



**Figure 14. Logarithmic plot of magnetic susceptibility derived from fluxgate against measured magnetic susceptibility.**

# 4. CONCLUSION

Terra Petrophysics has performed petrophysical analysis of 1180 core samples from the Paterson Orogen in Western Australia. Integration of the petrophysical data with geological logging and elemental assays has been performed to aid a better understanding and the potential implications of the physical properties of the data. A summary of the findings is given below.

- Dry bulk density values range from 1.39 to 3.72 g/cm$^3$ and magnetic susceptibility values range from 0.001 to 178.292 (× $10^{-3}$) SI.
- The majority of the samples exhibit low magnetic susceptibility < 1 × $10^{-3}$ SI, except for a group of amphibolite, rudite and a few gabbro and dolerite samples ((5 – 178.292) × $10^{-3}$ SI).
- Galvanic resistivity for this data set is high (1.5 to > 1,000,000 Ωm), with the majority of the dataset clustering between 1,000 and 1,000,000 Ωm.
- Chargeability values for the sample suite range between 0.7 and 731.5 mV/V, however most of the samples exhibit values less than 150 mV/V.
- Inductive conductivity values for majority of the data set ranges up to 903 S/m, but most of the samples plot with less than 40 S/m.
- Apparent porosity values for the project range up to 25% but most of of the samples plot below 2.5%.
- P-wave velocity values for the data set range from 890 to 6,710 m/s, acoustic impedance values are spread over 8 contours, indicating sonic velocity may be a useful tool in mapping the cover/basement contact and other major lithological contacts
- The induced and remanent magnetic vectors have been measured for samples that exhibit a magnetic susceptibility >10 × 10−3 SI, and samples with a chargeability >30 mV/V. 133 were remanent-magnetisation dominant and 96 were induced-magnetisation dominant.
- Spectral radiometrics were only measured for 81 samples from 3 drillholes (UGD063, 17NNMD001 and NUG0453). Values range from below detection limit up to 17.88% for K, 54.39 ppm U and 56.93 ppm Th.
- Cu mineralised samples produce higher magnetic susceptibility response (> 1 × $10^{-3}$ SI) and correspond to higher chargeability (> 15 mV/V).
- Au-elevated samples produce low chargeability and low magnetic susceptibility response.

## 5. REFERENCES

Emerson, D.W., 1990, Notes on Mass Properties of Rocks – Density, Porosity, Permeability. Exploration Geophysics, 21, 209-216

Emerson, D.W., and Yang, Y.P. 1997, Insights from laboratory mass property Cross-plots. ASEG Preview, 70, 10-14.

## APPENDIX 1 – DATA TABLES

Please see attached document 'Appendix1_Petrophysics Datasheet'.

## APPENDIX 2 – SAMPLE PHOTOS

Please see attached document 'Appendix2_Sample Photos'.

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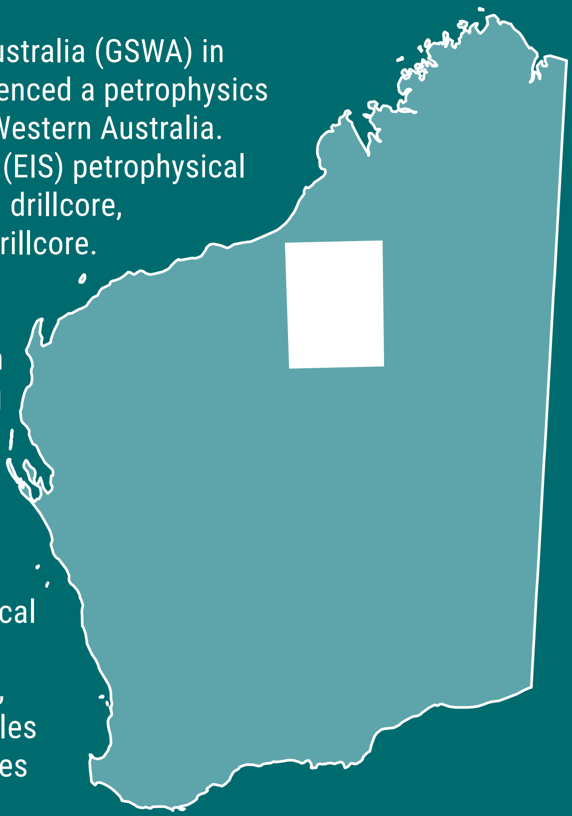
# REGIONAL PETROPHYSICS: PATERSON OROGEN 2022–23

M Markoski and B Bourne



In 2020, the Geological Survey of Western Australia (GSWA) in collaboration with Terra Petrophysics commenced a petrophysics project to sample diamond drillcore across Western Australia. Funded by the Exploration Incentive Scheme (EIS) petrophysical data have been collected from EIS co-funded drillcore, company drillcore, and GSWA stratigraphic drillcore. The aim of this project is to provide petrophysical datasets that can be used to assist with the planning and interpretation of geophysical data, including characterizing the physical property response of stratigraphic units, alteration and mineralization styles, and constraining geophysical models of the subsurface.

This Report provides a dataset of petrophysical analyses on 1180 samples from 18 diamond holes located across the Great Sandy Desert, in far northern Western Australia. The drillholes penetrate Phanerozoic sedimentary sequences (Canning Basin) and basement rocks of the Paleoproterozoic igneous and metamorphic units of the Paterson Orogen.

Further details of geoscience products are available from:

First Floor Counter
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Phone: +61 8 9222 3459 Email: publications@dmirs.wa.gov.au
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