Petrophysics and Exploration Targeting: The Value Proposition

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SUMMARY

There is still much that needs to be understood about the physical properties of rocks in mineralised geological environments. This knowledge gap becomes more important as the transition to deeper exploration targets under cover occurs, with an associated greater reliance on geophysical exploration methods. The major challenge associated with understanding petrophysical data is not making the measurement, but rather understanding the results. The interpretation of the data is a cross disciplinary problem. Fundamentally it is necessary to understand the rock mineralogy and geochemistry to put the petrophysics in context with the geophysical results. Several case studies are presented where the petrophysics have determined not only which geophysical techniques to apply but whether a geophysical target has indeed been tested.

Drill testing EM plate approximations for nickel sulphide and volcanogenic massive suphide (VHMS) ore deposits can benefit from inductive conductivity measurements on core as it can determine whether an EM conductor has been intersected. Chargeability highs associated with porphyry copper mineralisation is indicative of disseminated pyrite in the propylitic and pyrite +/- chalcopyrite +/- bornite in the potassic alteration zones and higher chargeability does not necessarily mean more copper. In most porphyry systems magnetite is coarse-grained, therefore a world class porphyry deposit should not have dominant remanent effects and the only likely source of remanence features in younger terrains are oxidised mafic intrusions and skarns. Furthermore, porosity and specific types of alteration (argillization) display the strongest correlations with resistivity and can be tied to gold distribution in Carlin Type Deposits.

Key words: petrophysics, nickel, copper, porphyry, gold, Carlin, alteration, porosity, IP, magnetics, remanence, EM

INTRODUCTION

There is still much that needs to be understood about the physical properties of rocks in mineralised geological environments. This knowledge gap becomes more important as the transition to deeper exploration targets under cover occurs, with an associated greater reliance on geophysical exploration methods. The major challenge associated with understanding petrophysical data is not making the measurement, but rather understanding the results.

Petrophysical data links the geologists' view of the world with the geophysicists view. A fundamental understanding of rock chemistry and mineralogy lead to better understanding of lithology, the same way physical rock properties such as density, magnetism and conductivity lead to a better understanding of the geophysical response.

Dentith et al. (2017) discuss petrophysical properties for mineral exploration by using a conceptual framework whereby porosity and alteration, and not purely lithology, are dominant controlling factors on rock physical properties (Figure 1). This schematic ternary diagram uses end members to categorise behaviours such as "bulk", "grain" and "texture" in order to correlate similar behaviours with one another.

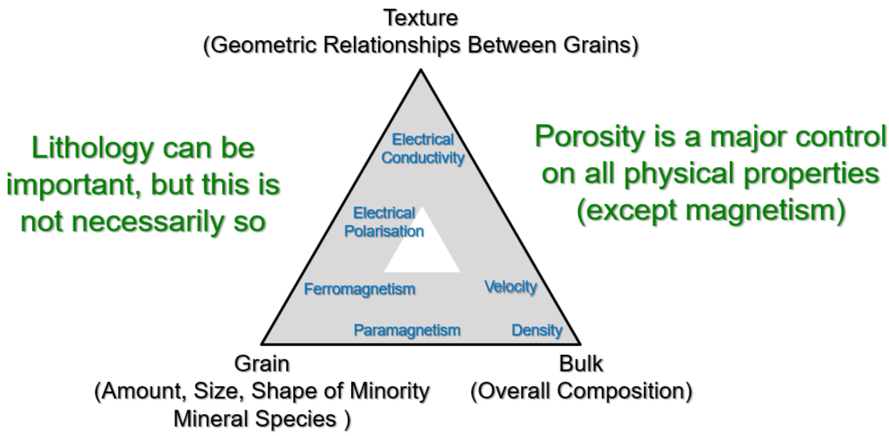

Figure 1: Ternary diagram showing the relative influence of texture, grains and bulk behaviours on commonly measured petrophysical properties (Dentith et al., 2017).

THE VALUE PROPOSITION

The interpretation of geophysical data is a cross disciplinary problem. Fundamentally it is necessary to understand the rock mineralogy and geochemistry to put the petrophysics in context with the geophysical results. Several case studies are presented where the petrophysics have determined not only which geophysical techniques to apply, but whether a geophysical target has indeed been tested.

NICKEL

The Nova Bollinger Deposit is located within the Fraser Zone of the Proterozoic Albany-Fraser Orogen and is considered to be a magmatic nickel sulphide deposit. The host rocks consist of a suit of meta-gabbroic to meta-picrite cumulates which have undergone lower granulite grade metamorphism. These rocks are interpreted to have been emplaced as layered sills in an extensional sedimentary basin during the late stages of the breakup of continental crust and formation of a volcanic margin (Figure 2).

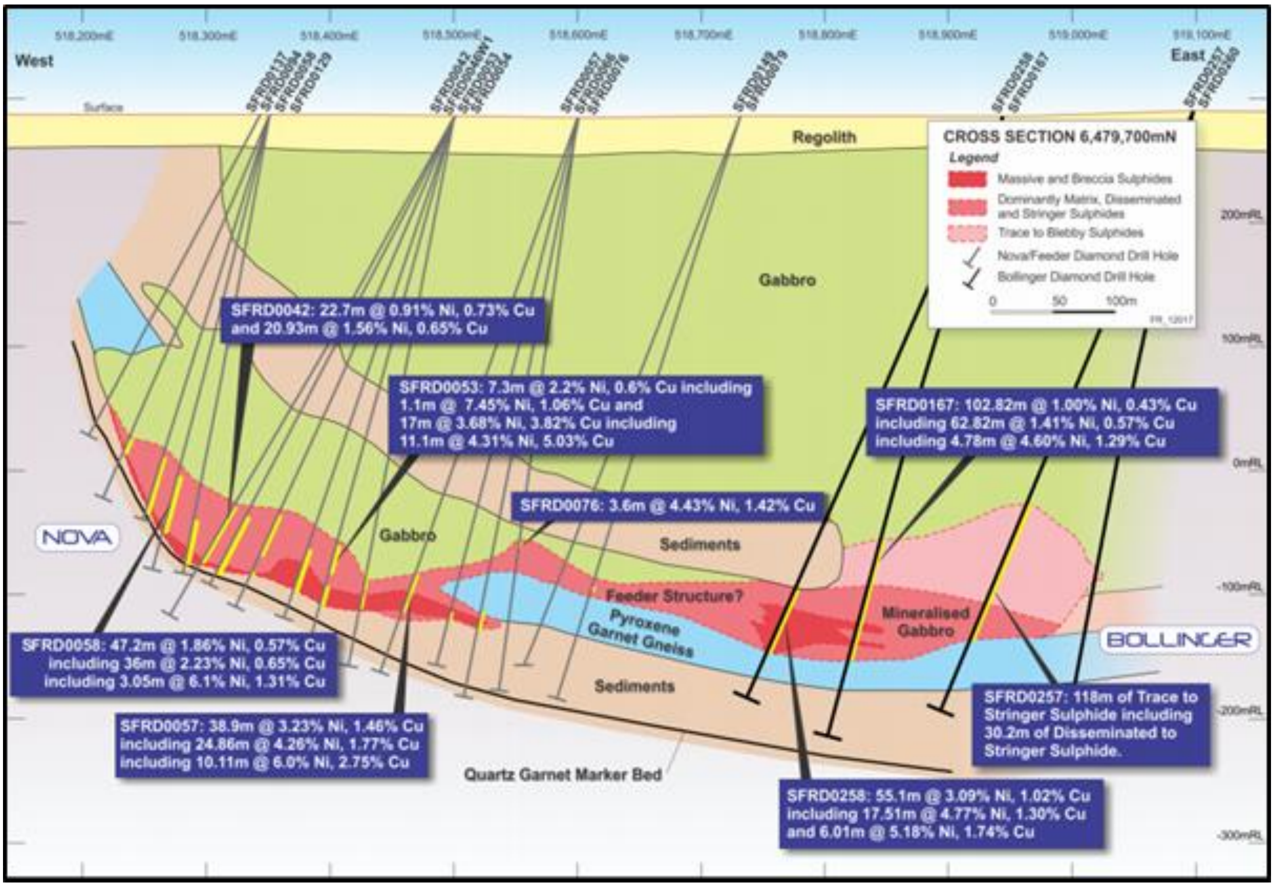

Figure 2: Nova-Bollinger Ni-Cu deposit cross-section showing geological setting and mineralisation (Bennett, 2013)

The gabbro can be divided into two main types: 1) abundant non-cumulate gabbro sills intruding metasedimentary sequence and; 2) minor gabbroic to ultramafic cumulate bodies (centre of thicker gabbro sills and lower part of larger bodies (e.g. Nova-Bollinger). The nickel-copper mineralisation occurs as disseminated and massive sulphides. The sulphides consist of 80-85% pyrrhotite, 10-15% pentlandite and 5-10% chalcopyrite.

As part of the co-funded drilling initiative by the Western Australian Department of Minerals and Energy, drill hole SRFR0017 into Nova was made available the public. Limited petrophysical analysis via hand held magnetic susceptibility measurement has shown the susceptibility range for gabbroic to ultramafic cumulate bodies to be 0.01×10^{-3} – 13.2×10^{-3} (average 2.2×10^{-3}) SI. This goes part the way in explaining why a relative magnetic low is associated with the gabbroic/ultramafic intrusives, which is typical in the Albany-Fraser Orogen. Metamorphosed ultramafic rocks in the Archean are often serpentinised and form magnetite. Within the Fraser Zone there are still some uniformed explorers looking for magnetic highs.

With additional information, such as inductive conductivity and IP/resistivity, the cover/regolith, host and mineralisation can be characterised. Practical exploration questions such as, "What is the effective depth of investigation for commercially available EM systems?" and, "Is IP an effective exploration method for massive sulphides at depth?" can only be answered with petrophysical data.

COPPER

Porphyry deposits are among the world's major accumulations of copper and gold mineralisation. Porphyries form in various settings, usually at convergent plate margins. Gold rich copper porphyries are typically associated with the following characteristics: potassic-silicate core – magnetic and chargeable and phyllic alteration – chargeable, propylitic alteration – chargeable (Figure 3). The sulphides associated with the porphyry alteration can be either conductive or resistive, depending on the geometry/size of the alteration and the host (sediment versus volcanic). Near surface weathering of porphyries can form conductive lithocaps.

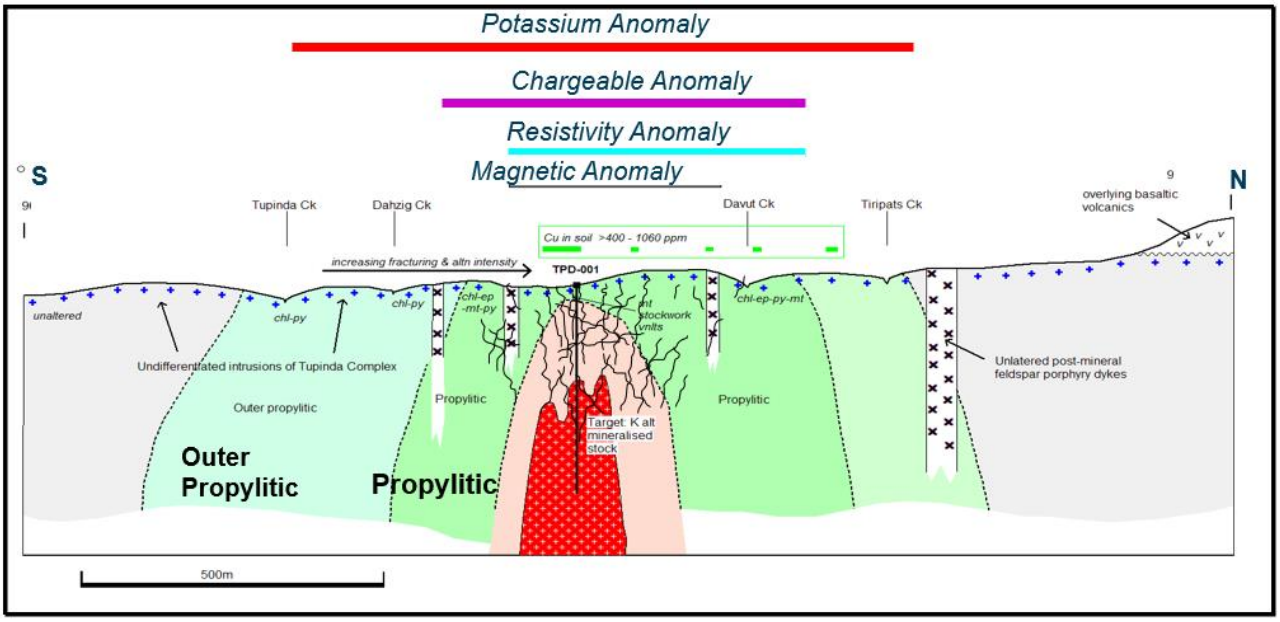

Figure 3: Various geophysical responses over a typical porphyry Cu-Au system (Howe and Kroll, 2010).

The dominant sulphide species in the porphyry environment is pyrite and chalcopyrite. Other gangue minerals include bornite and molybdite. Pelton in 1977 showed via petrophysical analysis that that there was little difference in the IP response of disseminated pyrite and chalcopyrite in porphyries. Explorers continue to not fully understand the IP response in the porphyry environment by drilling the highest chargeability values. IP standards such as the Newmont Standard (450-1100msec) or the 3-pt decoupled (0) frequency response should be used to determine the sulphide response of the entire porphyry system. Often IP surveys are not large enough to map the sulphide alteration (often >1km) and smaller surveys within the alteration are entirely anomalous.

The different types of magnetic responses for the porphyry environment can be explained by petrophysical analysis. Magnetite associated with porphyry alteration is coarse-grained, therefore remanence < induced so the dominant magnetic response from any world class porphyry deposit is induced. The only likely source of remanence features in younger terrains are oxidised mafic intrusions and skarns.

GOLD

Carlin type deposits are sediment-hosted disseminated gold deposits characterized by invisible (typically microscopic and/or dissolved) gold in pyrite and arsenopyrite. The vast majority of these deposits typically occur in north-eastern Nevada within or in close proximity to two narrow sub-parallel corridors: The Carlin trend and the Cortez or Battle Mountain Eureka trend. This Nevada host spot plays host to +250 Moz Au within a 200 by 400 km area which produces approximately 5% of the world's gold.

At the Getchell/Turquoise Ridge deposit, gold bearing ore is predominantly hosted within fine-grained, variably metamorphosed, calcareous rocks of the Ordovician Comus Formation. The gold is microscopic in scale and forms on the rims of arsenian pyrite (Tosdal et al, 2003). Main controls on mineralisation include high and low-angle faults or folds intersecting with the favourable host rock of the Comus Formation. Characteristic Carlin style alteration is present including decarbonatization, argillization and variable silicification (Cline et al., 2005).

Magnetotelluric (MT) data acquired over the Getchell/ Turquise Ridge deposit show a prominent resistivity low coincident with the known mineralisation (Figure 4). Petrophysical analysis on 352 samples located throughout this deposit showed that lithology has little correlation with variations in the overall resistivity response (Patraskovic, 2012). Instead, a combination of secondary processes dominated by alteration (argillization) and structural deformation display stronger correlations with the resistivity response (Howe et. al., 2014).

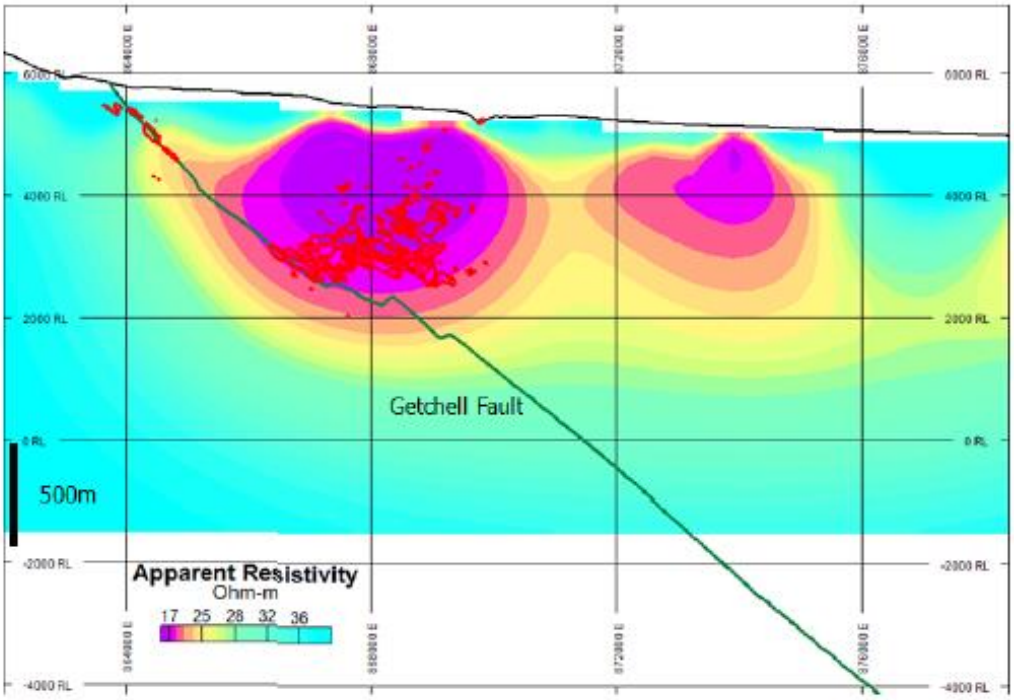

Figure 4: Magnetotellurics cross-section with Getchell/Turquoise Ridge (26Moz Au) deposit location (red) and the Getchell Fault (green) overlain (Howe et al., 2014).

Comparison of the geological and petrophysical datasets demonstrate that no single variable can be invoked as a control on resistivity. Rather, multiple factors contribute to the apparent resistivity of any given volume of rock within the model. Furthermore, porosity (affected by structural deformation?) and specific types of alteration (argillization) display the strongest correlations with resistivity and can be tied to gold distribution.

CONCLUSIONS

There is still much that needs to be understood about the physical properties of rocks in mineralised geological environments. This knowledge gap becomes more important as the transition to deeper exploration targets under cover occurs, with an associated greater reliance on geophysical exploration methods. The major challenge associated with understanding petrophysical data is not making the measurement, but rather understanding the results.

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ACKNOWLEDGMENTS

The authors acknowledge the Centre for Exploration Targeting at UWA, Terra Petrophysics Pty Ltd and Barrick Gold Corporation.

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