The use of petrophysical data in mineral exploration: A perspective

Mike Dentith*
Centre for Exploration Targeting
School of Earth Sciences
The University of Western Australia
Michael.dentith@uwa.edu.au

Cameron Adams
Centre for Exploration Targeting
School of Earth Sciences
The University of Western Australia
Cameron.dams@research.uwa.edu.au

Barry Bourne
TerraResources
Applecross
Western Australia
b.bourne@terraresources.com

SUMMARY

Using geophysical data for recognising targets for testing and accurately mapping the geology are equally dependent on petrophysics, which constitutes a link between the geologist's largely mineralogical 'view' of the Earth and the geophysicist's physics-based 'view'.

The availability of portable petrophysical instruments and spectral scanners allow co-located multiple geochemical, mineralogical and physical property measurements and allow larger volumes of petrophysical property data to be collected, and in a better geological context, than has been possible in the past.

Many rock physical properties are heterogeneous and a large number of data is required. Accurate interpretation of the data requires analysis of the data as populations and in the context of all of lithology, alteration, stratigraphy and spatial location. This requires close integration of the petrophysical data with the geochemical and mineralogical data.

A recommended interpretation workflow will be demonstrated using two examples: ultramafic rocks from greenstone terrains and carbonate successions hosting base-metal mineralisation.

Key words: Alteration, porosity, physical properties

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. Recognising targets for testing and accurately mapping the geology are equally dependent on petrophysics, which constitutes a link between the geologist's largely mineralogical 'view' of the Earth and the geophysicist's physics-based 'view'.

Petrophysical measurements may be made on hand specimens or in-situ via downhole logging. Measurements of density and magnetic susceptibility are most common, followed by measurements of electrical conductivity/resistivity and induced polarisation. Remanent magnetism, which cannot be measured downhole, is easily measured but the requirement for an oriented sample and laboratory-based equipment means comparatively few measurements are made, and often only the intensity of the magnetism is determined. The emergence of the seismic reflection method in the minerals industry has led to an increase in the measurement of acoustic velocity.

The major challenge associated with the analysis of 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. This is hindered by the behaviour in the geological environment of the main 'geophysical minerals' (Fe oxides, metal sulphides), which is extremely complex and often not well understood in a petrophysical context, i.e. controls on magnetic properties of magnetite and pyrrhotite.

All petrophysical data must be considered in the context of scale and sampling. Many properties are extremely variable even over distances of a few centimetres, and as such a few measurements from a small area are unlikely to be representative. At the larger scale, characteristics which are the dominant controls on petrophysical properties may have dimensions far exceeding the sample size, e.g. vuggy porosity. Cost and logistical constraints have meant there is often only a handful of petrophysical measurements available resulting in unreliable conclusions from their analysis.

The opportunity exists to address at least some of these problems. For example, the increased use of mineralogical scanners and portable XRF instruments means quantitative measures of the geological properties of a sample are now readily available for comparison with the petrophysical measurements. Also instruments to scan core, simultaneously measuring multiple geological and petrophysical parameters are now available. A consequence of this is that far larger data volumes are now practically achievable and there are multiple measurements made on the same samples. This combination of circumstances warrants a reassessment of how petrophysical data can be integrated in to the exploration process.

PETROPHYSICAL DATA

The various petrophysical properties relevant to mineral exploration have fundamental differences with respect to their underlying geological controls and so there is no requirement that they should correlate with one another. A useful way to understand the characteristics and relationship between different petrophysical properties is using a schematic ternary diagram with end members categorised as 'bulk', 'grain' and 'texture' behaviour (Fig.1). Properties with similar behaviour are more likely to correlate with each other.

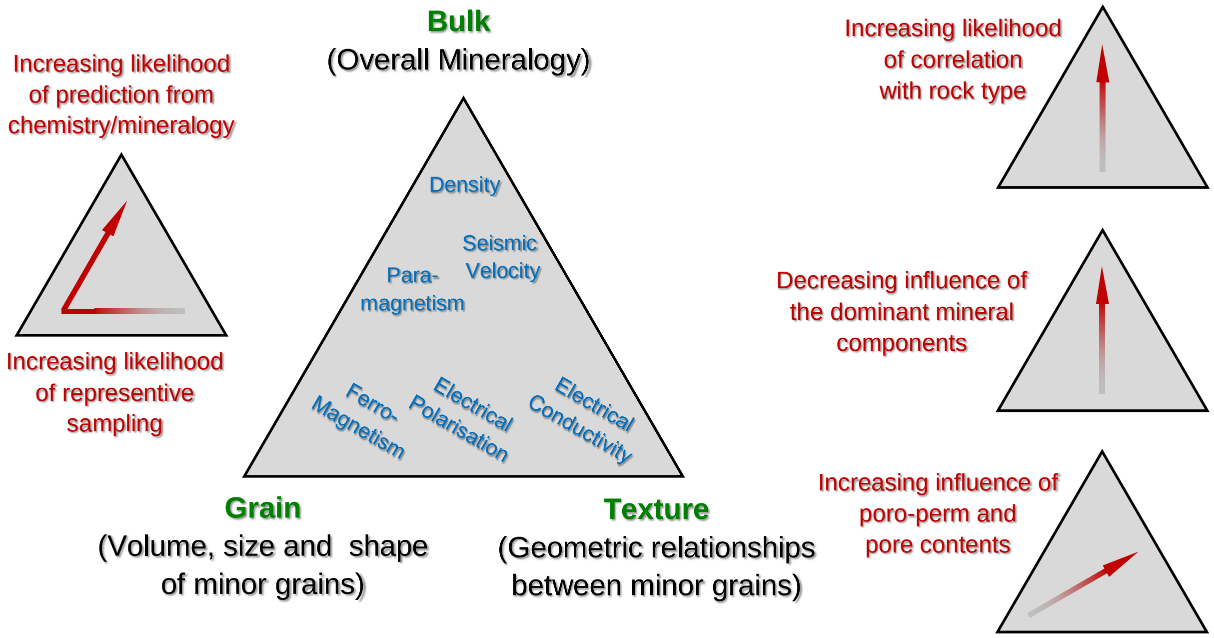

Figure 1. Ternary diagram showing the relative influence of texture, grains and bulk behaviour on commonly measured petrophysical properties.

Bulk behaviour is the simplest to understand because the rock properties are a weighted average of the constituent mineral properties. Density and acoustic velocity are examples of properties with largely bulk properties. Grain behaviour, of which ferromagnetism is the best example, depend on a minority component of the rock, which may make up only a few percent of the total mineralogy. Grain properties are not only controlled by the abundance of the relevant minerals, but also the shape and size of the mineral grains. The most hard to quantify kind of physical property behaviour is the texture property, of which electrical conductivity is the best example. The overall conductivity of a particular sample is in part controlled by the amount of conductive material present (which may be only minor and may be pore water) but the main control is the texture of the rock since this is the control on whether the conductive phases form the required inter connected network. Some properties, such as electrical polarisability have both grain and textural controls.

This categorisation of physical properties is useful when interpreting the datasets. Representative sampling of properties with bulk behaviour is much more likely than texture properties, for example. Also physical properties that plot closer together on the ternary diagram are more likely to correlate on cross plots. Regardless of particular correlations, the use of cross plots of different properties is especially useful for identifying 'anomalous' areas which may be associated with targets. Of particular use is the Henkel plot that compares susceptibility and density. For example, this highlights serpentinisation alteration because of the associated increase in magnetism and decrease in density compared to the unaltered rock.

DATA PRESENTATION

An important property of petrophysical datasets is that the distributions of physical properties are almost always complex, commonly skewed and multi-modal. This is a function of the extreme variability of some properties, especially the grain and texture controlled properties. Even with properties with the relatively simple bulk behaviour, presenting data as range charts or box plots or simply in tables with average, standard deviation etc. is not recommended. Individual populations of data need to be analysed accounting for such variables are geographic location, stratigraphic position and most important of all, the geological characteristics of the rocks being measured. For example rocks such as iron formations, greywackes and komatiites (Fig.2) are inherently zoned/layered and so simple probability density distributions are not to be expected.

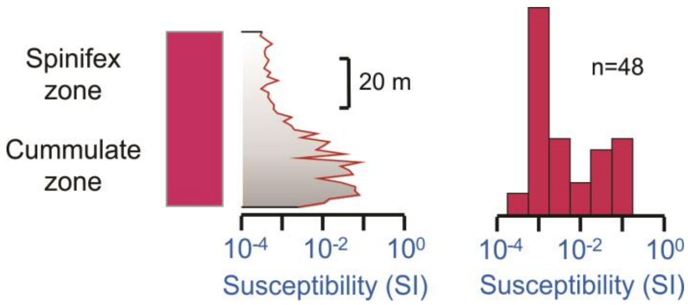

Figure 2. Susceptibility data from a single komatiite flow in the Eastern Gold fields. Simple averaging or range diagrams do not adequately represent the variation in magnetism.

Not Only Lithology is Important

Most compilations of petrophysical measurements categorise samples according to lithology. In some kinds of rocks, notably mafic/ultramafic rocks, lithology is a secondary control on most petrophysical properties, with alteration (serpentinisation (Fig.3), talc-carbonate alteration) being much more important. In fact there is a general lack of systematic studies (at least published) of the petrophysical characteristics of the types of alteration commonly encountered in mineral exploration. If mineralogical/geochemical data are also collected then samples can be classified by, for example, alteration index. This kind of approach is likely to significantly advance understanding of the petrophysical properties of common geophysical targets and perhaps suggest new ones (see Adams and Dentith, this conference).

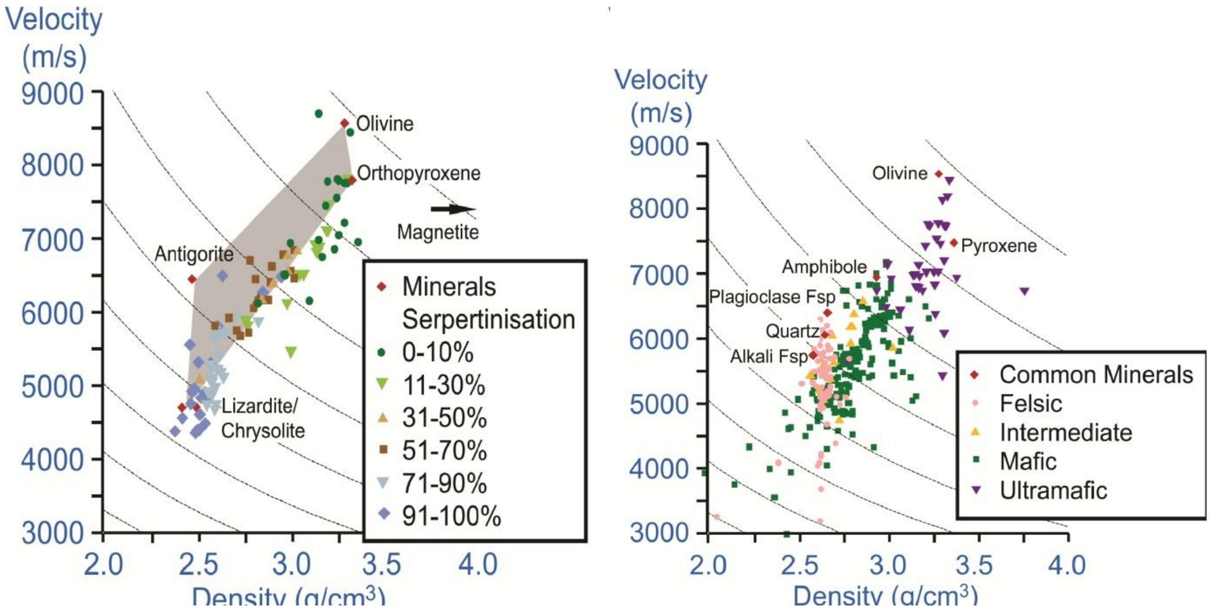

Figure 3. Effect of serpentinisation on the seismic properties of mafic and ultramafic rocks compared to the effects of changes in lithology. The alteration has a greater influence than the change in rock type.

Another important factor, especially in sedimentary rock types, is porosity. When significant porosity is present it dominates some physical properties, e.g. seismic and electrical properties. As porosity increases the shape of the pore space can also exert significant control on physical properties, for example the seismic properties of carbonates. That is seismic properties behave more like 'texture' properties. Again, analysis of the data in the context of lithology only will not lead to an incomplete understanding of the controls on physical properties.

CONCLUSIONS

The conceptual framework described above provides the basis for a conceptual understanding of the behaviour of petrophysical properties in the context of common geological processes, for example metamorphism and alteration. Available data clearly show that the current practice of analysing petrophysical data mainly in the context of lithology and in terms of averages and ranges is not fully accounting for all physical property controls and their behaviour. Petrophysical data must be analysed in terms of populations and factors such as alteration, geographic location and stratigraphy must be considered as well as lithology.

ACKNOWLEDGMENTS

Cameron Adams' research is supported by a grant from the ASEG Research Foundation