Petrophysics and Exploration Targeting: Best Practice and Applications

by

Mike Dentith*, Cameron Adams* and Barry Bourne#

***Centre for Exploration Targeting, The University of Western Australia**

#Terra Resources

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 and testing targets and accurately mapping the geology are equally dependent on petrophysics which constitutes a link between the mineralogy, fabric and rock propertires at a particular scale. .
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 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 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 geophysics . The behaviour in the geological environment of the main 'geophysical minerals' (Fe Oxides, metal sulphides) is extremely complex and often not well understood in a petrophysical context, i.e. controls on magnetic properties.

All petrophysical data must be considered in the context of scale and sampling. Many properties, especially magnetism and electrical conductivity, 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.

Cost and logistical constraints mean there are often only a handful of measurements available. 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 measuring both geological and petrophysical together are now available. A consequence of this is that far data volumes are now practically achievable and there are multiple measurements on the same samples. This combination of circumstances warrants a reassessment of how petrophysical data can be integrated in to the exploration targeting process.

Petrophysical Data Types

The various petrophysical properties are fundamentally different with respect to their underlying geological controls and so there is no reason they should correlate with one another. A useful way to understand the relationship between different petrophysical properties is using a schematic ternary diagram with end members categorised as 'bulk', 'grain' and 'texture' properties (Fig.1). Properties of similar types are more likely to correlate. Bulk properties are the simplest to understand because the rock properties are a weighted average of the constituent mineral properties. Density and acoustic velocity are examples of bulk properties. Grain properties, 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 their shape and size, i.e. the texture of the grains. The most hard to quantify kind of physical property 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 bulk properties is much more likely than texture properties, for example. Also 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. This highlights serpentisation because of the associated increase in magnetism and decreases in density compared to the unaltered rock.

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 texture properties. Even with the relatively simple bulk properties 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 context of the rocks being measured. For example rocks such as iron formations, greywackes and komatiites (Fig.1) are inherently zones/layered and so simple probability density displays are not to be expected.

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 second 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.

Another important factor, especially in sedimentary rock types, is porosity. When significant porosity is present it usually dominates the physical properties, especially electrical properties. As porosity increases the property reflects that of the sample as a whole (Fig.1). Again, analysis of the data in the context of lithology only will not lead to an understanding of the controls on physical properties.

Two studies of this type, on ultramafic rocks from greenstone terrains and on dolomitisation processes in carbonate successions hosting base metal deposits are on-going and will be presented

Summary

The conceptual framework described above provides the basis for a work flow that can be used to analysis the increasingly large volumes of petrophysical data that are likely to become more available in the future.

References

Dentith, M. and Mudge, S.T., 2014. Geophysics for the Mineral Exploration Geoscientist. Cambridge University Press.

Figures and captions

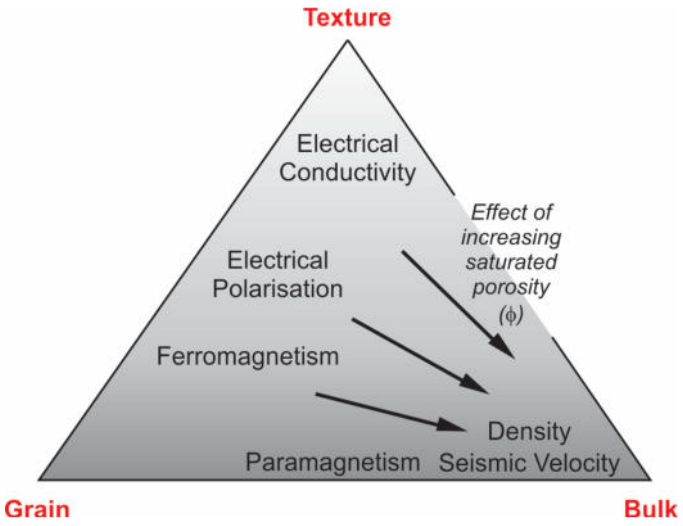

Figure 1. Ternary diagram showing the relative influence of texture, grains and aggregate effects on commonly measured petrophysical properties.

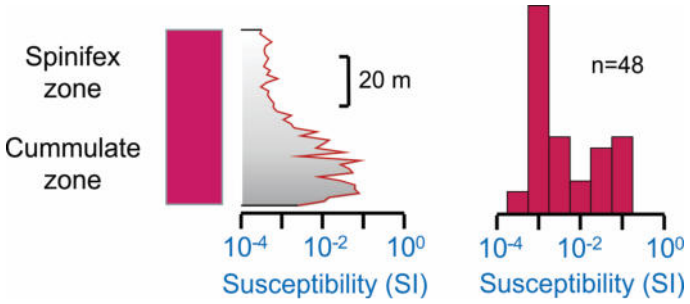

Figure 2. Susceptibility data from a single komatiite flow in the Eastern Gold fields. Simple averaging or range diagrams do not adequately represent the variation in magnetism.

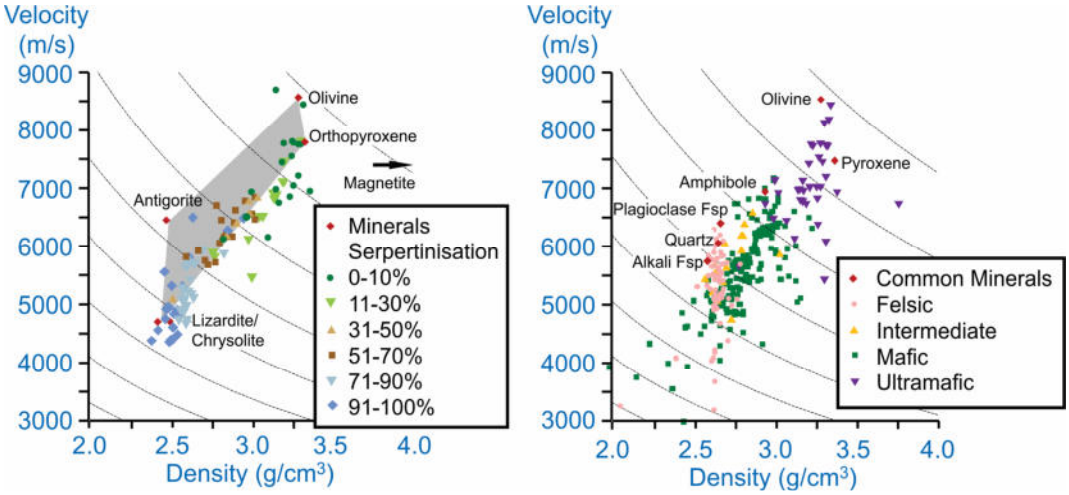

Figure 3. Effect of serpentinisation on the seismic properties of mafic and ultramafic rocks compared to the effects of changes in lithology. The alteration has a greater influence than the change in rock type.