

2 THE PHYSICAL PROPERTIES OF COAL

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CHAPTER OUTLINE

- ▶ Why are physical properties so important?
- ▶ The variability and unpredictability of physical properties
- ▶ Physical properties – to test or not to test?

This chapter explains why geophysicists usually want to know as much as possible about the physical properties of the different lithological units in an area before embarking on a geophysical survey. We also highlight some of the common pitfalls associated with predicting geophysical performance without reliable physical property information.

▶ Why are physical properties so important?

The physical properties of rocks – both the geophysical target and the surrounding host rocks – determine the applicability and performance of geophysical methods. Each geophysical method is based on one or more specific physical properties, and for a geophysical method to be applicable to a given geological problem the fundamental requirement is that there exists a measureable contrast in the relevant physical property between the target and host rocks. The contrast in physical properties may be related to factors such as changes in lithology, mineral composition, porosity, texture, and groundwater chemistry, amongst others. This contrast can then be exploited and used to detect, characterise or map the target of interest. **Table 2.1** below lists selected geophysical methods and the physical properties on which these methods are based:

Table 2.1 Geophysical methods with relevant physical properties

METHOD	PHYSICAL PROPERTIES
Magnetics (including ground and airborne magnetics)	Magnetic susceptibility
Gravity and micro-gravity	Density
Electrical methods (including direct-current (DC) resistivity profiling and soundings, and electrical resistance tomography (ERT))	Electrical conductivity
Induced polarisation (IP)	Polarisability (often referred to as chargeability)
Electromagnetics (EM) (frequency- and time-domain EM methods, including airborne EM)	Electrical conductivity
Ground-penetrating radar (GPR)	Dielectric constant and electrical conductivity
Seismics	Density and seismic wave velocities
Magnetotellurics (MT)	Electrical conductivity

From a practical perspective, knowledge of the relevant physical properties in a given survey area is important for the following reasons:

- The applicability of a geophysical method(s) can be assessed;
- It allows the geophysicist to predict the performance of the geophysical method(s) prior to the survey and to select optimum survey parameters; these critical steps in geophysical surveying are typically done through numerical modelling, which requires accurate estimates of physical parameters;
- It enables the geophysicist to make an improved interpretation of measured data; for example, in radar and seismic applications the conversion from measured travel-time to depth relies on accurate seismic and radar wave velocity information.

For any geophysical technique to work, the key requirement is a contrast in the relevant physical property.

► The variability and unpredictability of physical properties

There are currently only three known sources of physical property information for the South African coalfields:

1. The Council for Geoscience (CGS) maintains a physical property database, but this only includes information relating to a few tens of samples from various coal-mining areas. CGS typically records one or more of the following properties: electrical resistivity and chargeability, magnetic susceptibility, magnetic remanence, seismic wave velocity, density and, from 2011 onwards, also frequency-dependent dielectric properties. Lists of values for the various properties can be downloaded from the CGS website²².
2. The CSIR has acquired some coal-related physical properties over the last two decades, but this data is limited to approximately 10–20 coal-related samples and to electromagnetic measurements in the frequency band 0.5–64 MHz (traditionally used for radar and radio wave applicability studies). In recent years, the capability to measure spectral complex resistivity (resistivity and induced polarisation as a function of frequency) has also been developed.
3. Wireline logging represents the third and most abundant source of coal physical properties. Wireline results, however, are typically kept by individual mining companies and are not available to the public or for research purposes. Wireline logging is not necessarily done to assess the applicability or performance of other geophysical methods, but is considered a geophysical method in its own right. The basic principles and application of wireline logging will be discussed in more detail in the following chapters.

One of the products derived from the abovementioned CGS physical property database is a summary of the typical physical property ranges for the various rock types that have been studied over the years. Consider, for example, the ranges determined for electrical resistivity,

magnetic susceptibility and density shown in **Figure 2.1**. Note that these results relate to all rocks that have been tested by CGS’s physical property laboratory, and not only coal-related samples. To gain some insight into the properties of coal-related rocks one would have to focus on the results for specific lithologies expected in coal environments; for example, coal, siliciclastic sediments, unconsolidated sediment, sand, dolerite, etc.

Figure 2.2 presents the selected physical property results from a single site (Bank Colliery) – this data was extracted from the CSIR database and was the result of a joint study by CSIR, CGS and Coaltech.

As a final example, **Figure 2.3** shows the magnetic properties of various intrusions from different collieries.

Figure 2.1 Typical physical property ranges for South African rocks

Resistivity ranges for various rock types

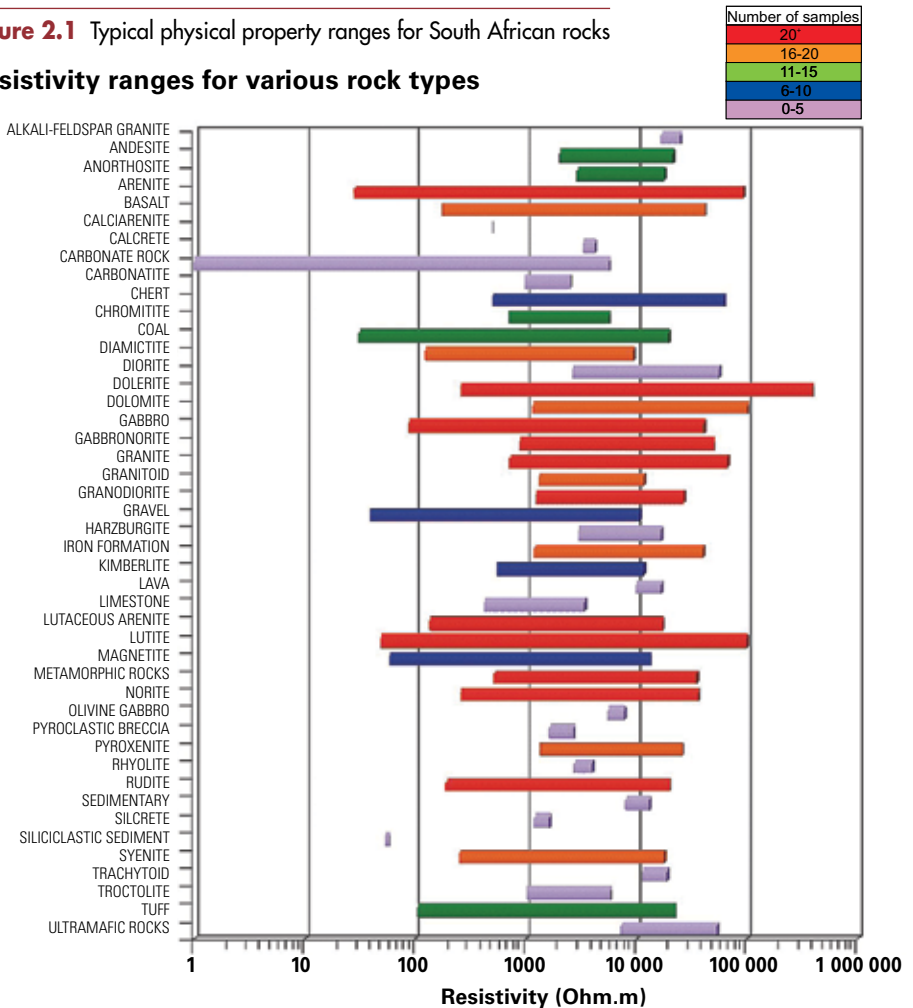


Figure 2.1 (continued) Typical physical property ranges for South African rocks

Number of samples
20
16-20
11-15
6-10
0-5

Susceptibility ranges for various rock types

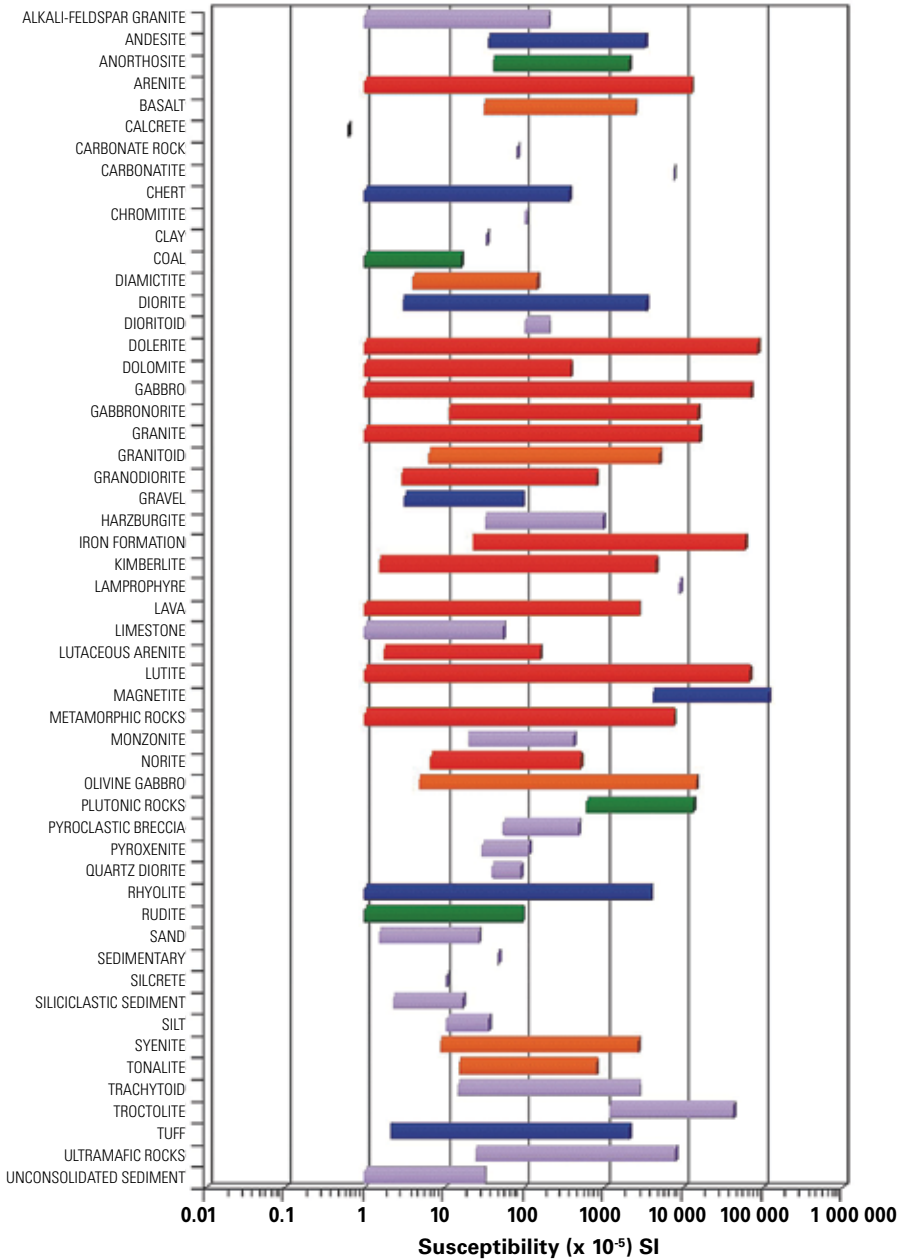


Figure 2.1 (continued) Typical physical property ranges for South African rocks

Density ranges for various rock types

Number of samples
20
16-20
11-15
6-10
0-5

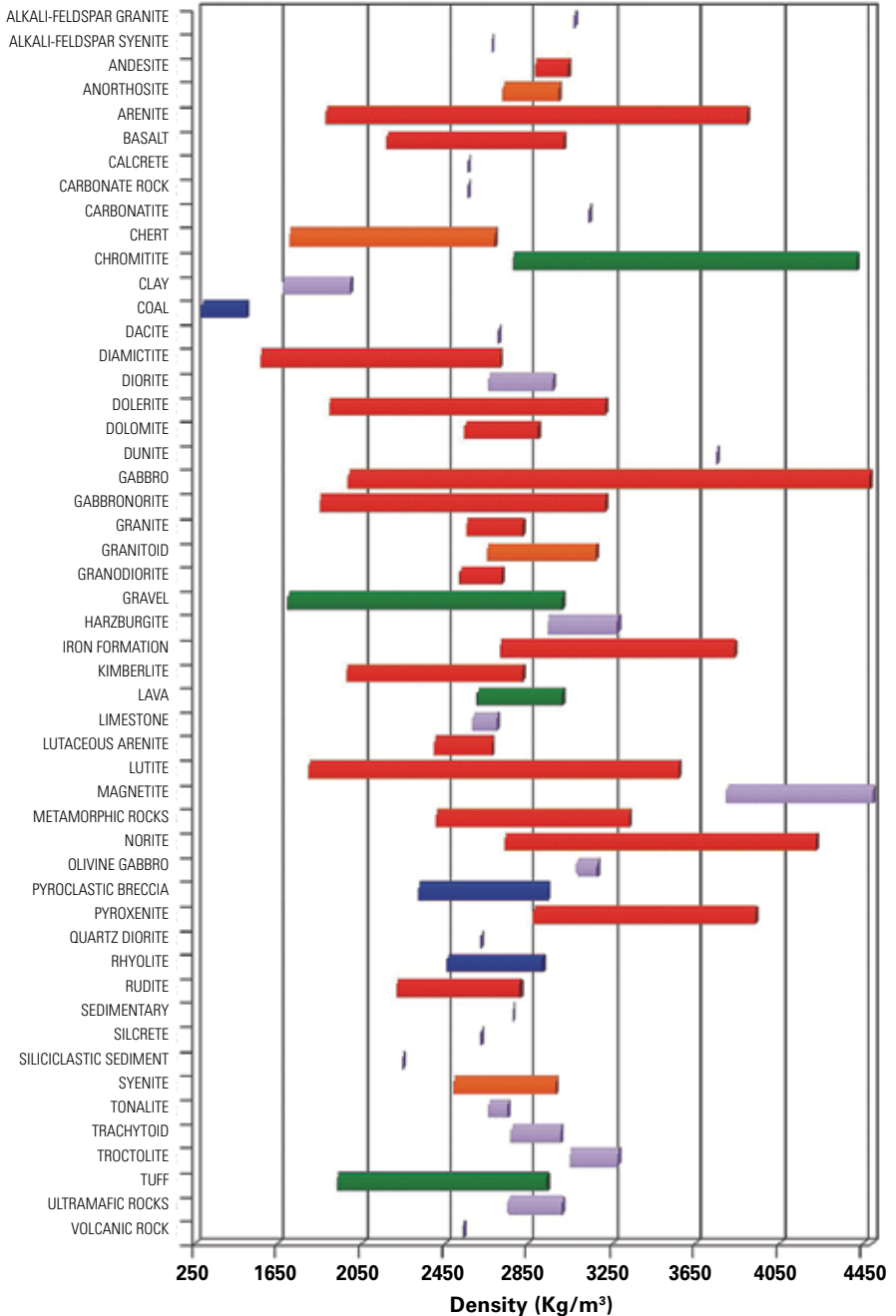


Figure 2.1 illustrates that it is not always possible to differentiate between different rock types based on a single physical property. This is because physical properties often span a broad range of values. Consider, for example, the resistivity and susceptibility of coal and dolerite; not only do these individual properties span a significant range for the respective rock types, but the respective ranges also overlap to some extent. Thus at some sites it may not be possible to differentiate between coal and dolerite based on the resistivity or magnetic susceptibility alone. This is why geophysicists often advocate the use of integrated geophysics – that is the use of two or more methods to address the same problem. By jointly interpreting multiple data sets, one is often able to reduce the ambiguity that may be present in single-method data sets.

Figures 2.2a–d (see pages 28, 29) further demonstrate some of the abovementioned pitfalls for rocks from a single colliery. From the scatter plots of resistivity versus IP (%) and magnetic susceptibility versus NRM presented here, the following observations can be made:

- Coal appears to be a bit more resistive than the typical host rock type. Coal resistivities vary from approximately 1 000 Ωm to 10 000 Ωm , while host rocks range from a few hundred to a few thousand Ωm .
- Coal appears to be a bit less chargeable than the surrounding host rocks. The range of IP values for coal is approximately 5–15%, while some host rocks attain values of 25–35%.
- The resistivity contrast between coal and host rocks can be as large as 10:1, but it is also possible to have little or no contrast; the same is true for the IP response.
- Coal generally has much lower magnetic property responses (susceptibility and NRM) than most of the host rocks, but coal from different seams cannot be differentiated based on these magnetic properties.
- There is great variation in the magnetic response among host rocks and within specific rock types; however, some host rock samples show little or no contrast with the coal samples.



Waterberg Coalfield (Bruce Cairncross)

Figure 2.2a Physical property scatter plots for selected samples from Bank Colliery

Resistivity vs IP (%) for selected coal samples

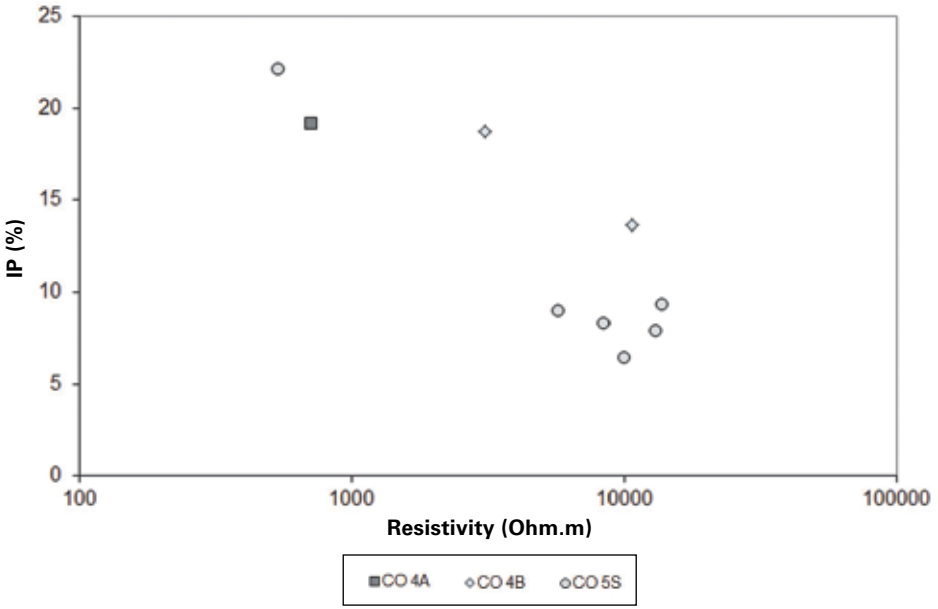


Figure 2.2b Physical property scatter plots for selected samples from Bank Colliery

Resistivity vs IP (%) for selected interburden samples

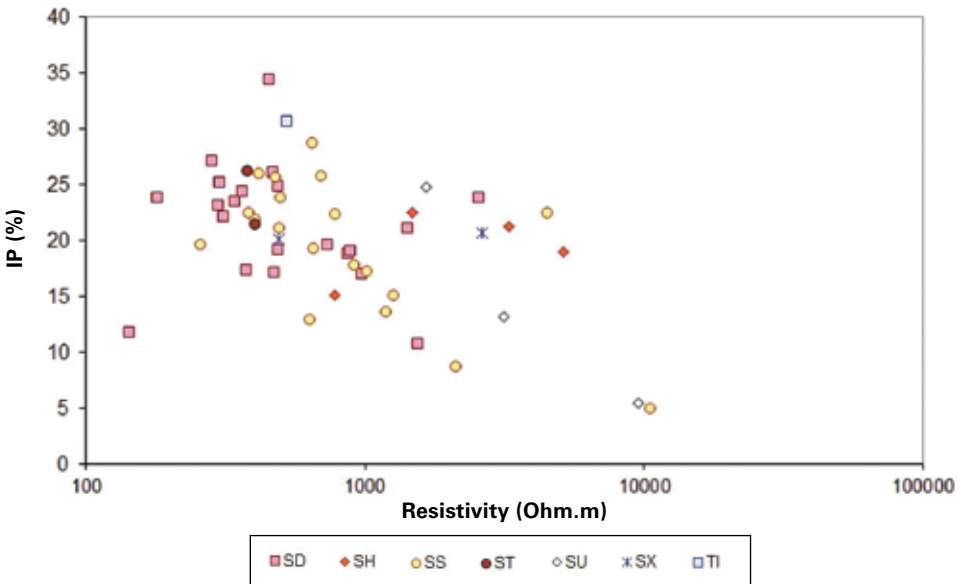


Figure 2.2c Physical property scatter plots for selected samples from Bank Colliery

Magnetic susceptibility vs NRM for selected coal samples

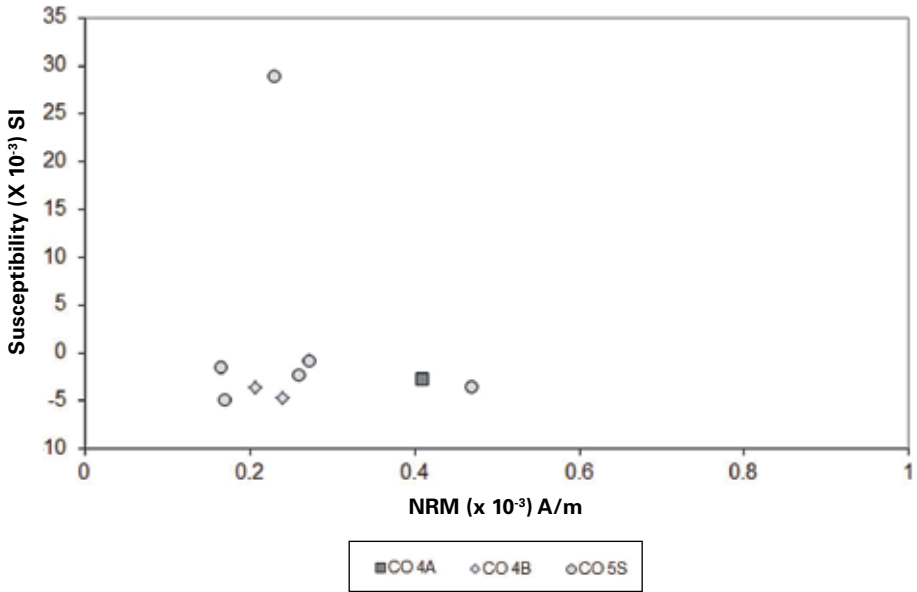


Figure 2.2d Physical property scatter plots for selected samples from Bank Colliery

Magnetic susceptibility vs NRM for selected interburden samples

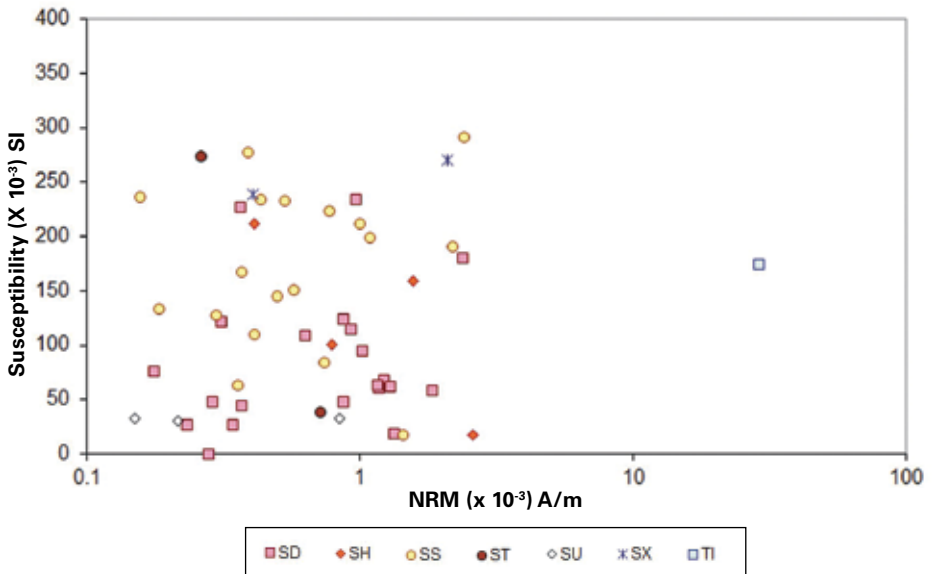


Figure 2.3 Magnetic properties of various intrusions

Magnetic properties of intrusions (by colliery and intrusion type)

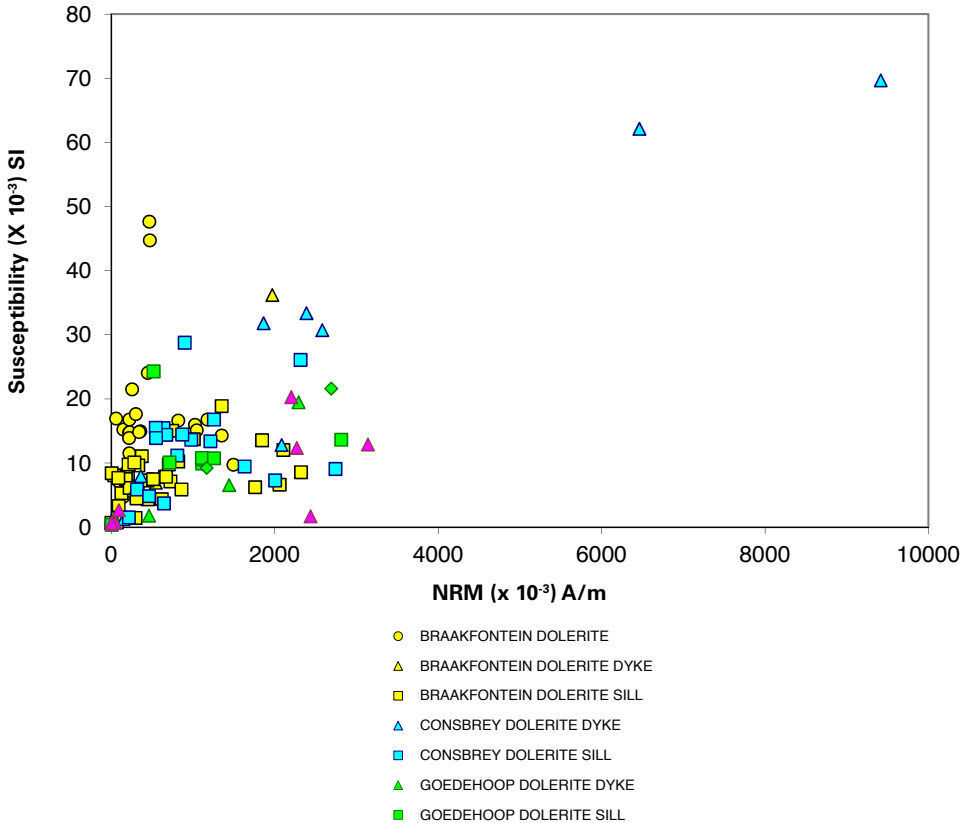


Figure 2.3 further illustrates the fact that it is usually not possible to associate a specific rock type with an exact or known physical property value.

Although the above examples may reflect general trends for the physical properties of coal versus host rocks, physical properties should always be considered site-specific. At one mine or site, a specific coal seam (or interburden layer) may be a good target for a given geophysical method. This relationship may, however, not be valid at other sites. It is therefore strongly recommended to characterise and gain a better understanding of the physical properties of an area before planning or executing geophysical surveys.

A distinction must be made between in situ physical properties and the properties determined in a laboratory using selected core or hand samples. Site-specific in situ parameters such as groundwater chemistry, degree of saturation, depth below surface, orientation of strata and subsurface temperature may be poorly estimated by laboratory-

determined values. Nevertheless, laboratory measurements do at least provide a good indication of some fundamental performance-related parameters such as target detectability, maximum expected range and depth of investigation, and resolution (mapping accuracy).

Coal and host rock physical properties and the relationships between them do not always follow the expected trends and are often highly site-specific; a rock property analysis is strongly recommended as a first step in any mapping or exploration study.

► **Physical properties – to test or not to test?**

The previous two sections highlighted the importance of obtaining as much information as possible about the rock properties at a site before commissioning a geophysical survey. In fact, the choice of geophysical method, and that method's chances of success, start with a good understanding of the expected rock properties in the area. In some cases the results from wireline logging (if available) may indicate whether methods like seismics and electrical methods are applicable; where no logging has been done, or where one is interested in a physical property not evaluated by the logging tools employed, one might have to resort to taking representative borehole core or hand samples and sending them to a laboratory for the relevant physical property analysis. The decision to proceed with rock property analyses should not be taken blindly, but in cases where the rock property information plays a role in survey parameter selection or in processing and interpretation, a rock property analysis is recommended. Where the proposed geophysical survey is relatively expensive, for example three-dimensional seismic or airborne geophysical surveys, the additional cost of a rock property study is only a fraction of the survey costs, and such a study is recommended as part of the applicability assessment. For small-scale and relatively inexpensive geophysical surveys, a phased field approach can be followed, where initial controlled trial surveys are used to give the user an indication of applicability and a better estimate of the local rock properties.