Typical and exotic rock physical property distributions

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ABSTRACT

Rock physical properties are controlled by mineral identities, concentrations and textures. Knowledge of typical rock physical property distributions assists simple geophysical interpretation, and highlights rocks or geophysical inversions which do not follow these typical distributions.

1. INTRODUCTION

Geological interpretation of geophysical surveys can only be accomplished through understanding the influence of lithology, mineralogy, texture, and alteration on the rock physical properties. In this abstract, the Canadian Rock Physical Properties Database is described and analyzed to familiarize practitioners on typical and exotic rock physical property distributions for mineral exploration.

2. THE CANADIAN ROCK PHYSICAL PROPERTIES DATABASE

As of October 2017, the Canadian Rock Physical Properties Database (CRPPDB) is 20160 rows long. The name is, for now, rather ambitious as the database is far from representative of all of Canada. At least an order of magnitude (maybe two) more measurements have been done in Canada in various government, academic and industry labs, and it is our intention to build up the compilation. Nevertheless, the sample size is large enough to make some interesting and important observations.

Due to the history of the Paleomagnetism and Petrophysics Laboratory at the Geological Survey of Canada – Pacific Division, the database is heavily weighted towards the Canadian Cordillera, and dominantly the southern Intermontane Belt. There are important collections from other sources, either publically available in publications or from the Geological Survey of Canada archives. A large number of samples (2163) were measured around three specific deposits (Canadian Malartic in Quebec, the McArthur-Millenium trend in Saskatchewan, and Highland Valley Copper in British Columbia) as part of the Canadian Mining Innovation Council Footprints Project.

Petrophysical measurements are not all done using identical sample collection strategies, sample sizes, and lab methods. Good Quality Control / Quality Assurance (QC/QA) practices are applied to the data, but there are certainly errors which have not been detected. A key aspect of the database is the lithological descriptions. One tries to be as faithful as possible to the original descriptions of the samples, but given the variety of geological applications for which the samples were collected, and the variety of geologists who produced the collections, it is difficult to produce a simple yet complete lithological description. Parsons et al. (2009) provide examples of the types of decisions the compiler must make when fitting geological descriptions into a simple lithological scheme.

Petrophysics has three major applications. For hydrocarbon exploration, seismic properties and porosity are the most important. Geotechnical applications mostly require strength measurements. Such measurements are less important for mineral exploration. The set of properties compiled for the Canadian Rock Physical Properties Database are:

Grain Density
Dry Bulk Density
Saturated Bulk Density
Porosity
Magnetic Susceptibility
Natural Remanent Magnetization,
Koenigsberger Ratio,
Electric Resistivity
Electric Chargeability

These terms are defined in the companion paper, “Rock physical properties measurements in the laboratory”, and Enkin et al., 2012.

3. DENSITY AND MAGNETIC SUSCEPTIBILITY

Often the first geophysical surveys in a prospective region are magnetic and gravity surveys. The main physical properties influences on anomalies are based on density and magnetic susceptibility (Fig. 1). Henkel (1991; 1994) was the first to describe and interpret the joint distributions of these two properties.

The most important features are that density in unimodal with the mode around 2.7 g/cm^3, while magnetic susceptibility is bimodal with modes around 3×10^{-4} SI (the Paramagnetic Trend) and 3×10^{-4} SI (the Magnetite Trend). Every sufficiently large and litholgically diverse petrophysical compilation from any region of Earth displays a similar distribution. It is against this “Typical Distribution” that “Exotic Distributions” are to be compared.

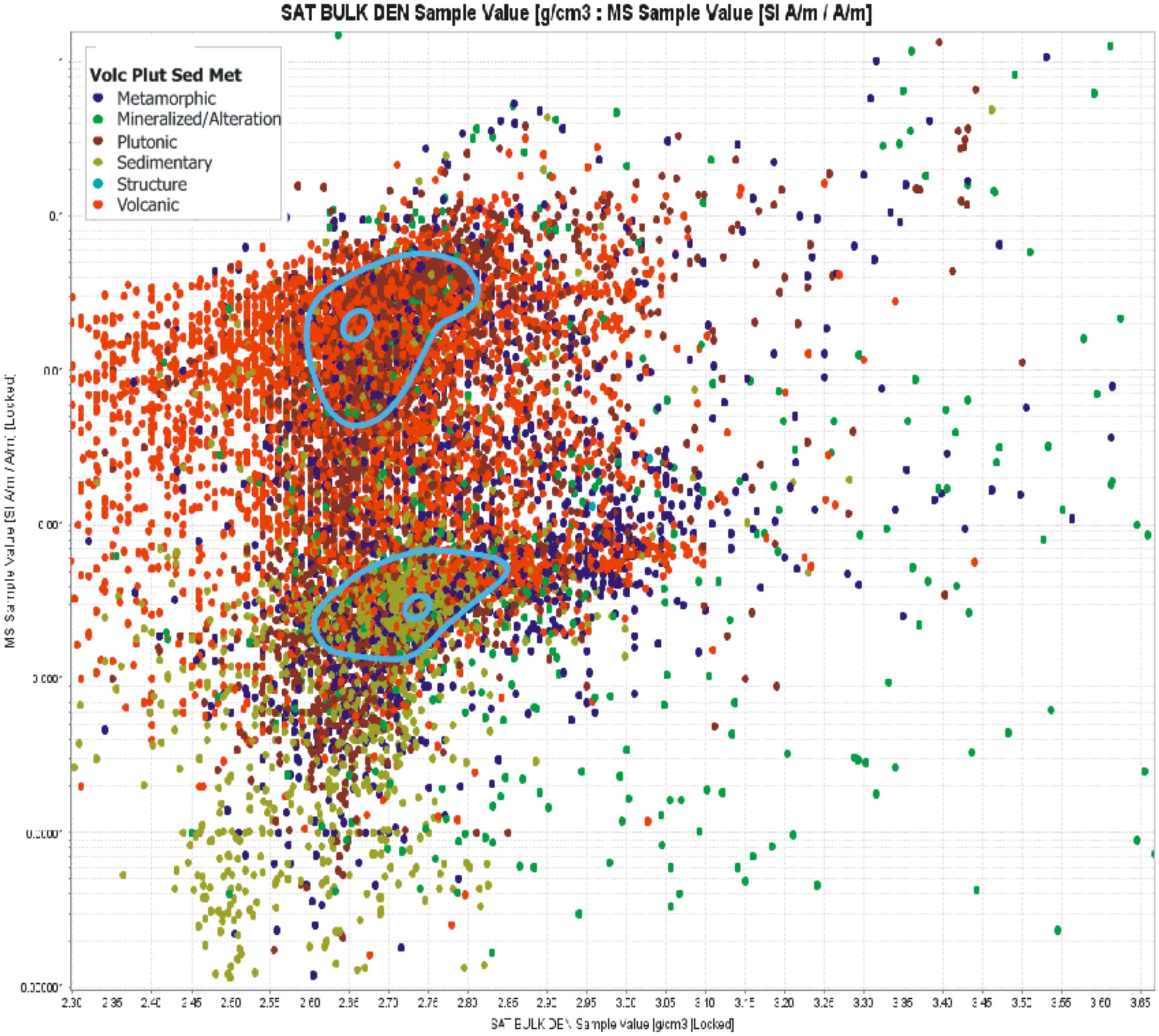

Figure 1: Density-Susceptibility biplot of the CRPPDB, with contours of the two modes

The 2.7 g/cm^3 density mode is a reflection of quartz and feldspar being the dominant minerals of most rocks (Fig. 2). Less density is almost always the result of increased porosity. Slightly higher densities usually indicates increased contributions of the mafic minerals: pyroxines, amphiboles and olivine. The much more dense samples are very often mineralized with oxides and sulfides.

The two modes of susceptibility likely result from primary mineralization in magma chambers with different oxygen fugacities. When oxygen is controlled by the quartz-fayalite-magnetite (QFM) buffer, then magnetite is produced with concentrations measured in percent. Otherwise, most iron is partitioned into silicates with the result that magnetite concentrations are measured in PPM. It is interesting that magnetic susceptibility in the 10^{-3} SI range is so rare, but it is an extremely useful property, as researchers are surprisingly sloppy concerning providing the units of their magnetic susceptibility measurements. It is often possible to verify the units (CGS or

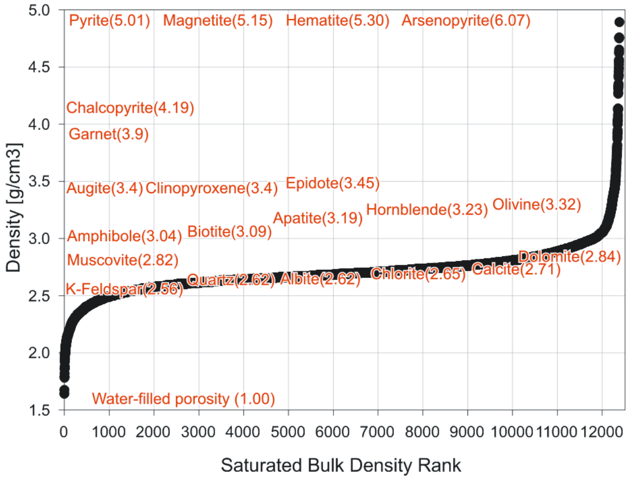

Figure 2: Mineral densities, and the cumulative distribution of the Canadian Rock Physical Properties Database

SI) and the exponent by fitting published results to the typical distribution.

A notable rock formation for violating the 10^{-3} SI susceptibility distribution valley is the Chilcotin Basalts of central British Columbia (Enkin et al., 2014). The interpretation is that these dry intracratonic basalts did not form in QFM oxygen buffer, such that less of the iron was partitioned to magnetite, compared to other basalts.

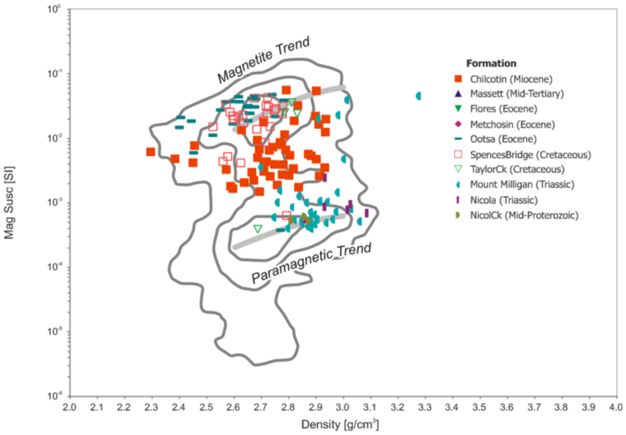

Figure 3: The Chilcotin Basalts have 10-3 SI magnetic susceptibility, unlike other basalts

4. POROSITY

The CRPPDB currently focusses on mineral exploration applications. As such, the compiled rocks tend not to come from sedimentary basins where hydrocarbon exploration focusses on high-porosity reservoir rocks. Indeed, in the CRPPDB, only about a quarter of the samples have porosity > 1% (Fig. 4). Rocks with porosity > 1% display a rough anticorrelation between density and porosity because "Saturated Bulk Density" include the density of water in the pore space. The same effect is not apparent with "Grain Density". The surprising straight line of sedimentary samples (gold dots) around density = 2.5 g/cm3, porosity = 10%, are from a single collection from the Athabasca Basin (Saskatchewan), which hold a similar lithological composition.

5. ELECTRIC PROPERTIES

Electric resistivity and chargeability depend on rock texture as well as mineralogy. Thus measured resistivities are high with respect to in situ measurements, as competent samples can not represent fluid pathways through less competent rocks. Still it is possible to place constraints on geophysical models using insights from laboratory measurements. Two examples are offered from the study of six porphyry deposits in British

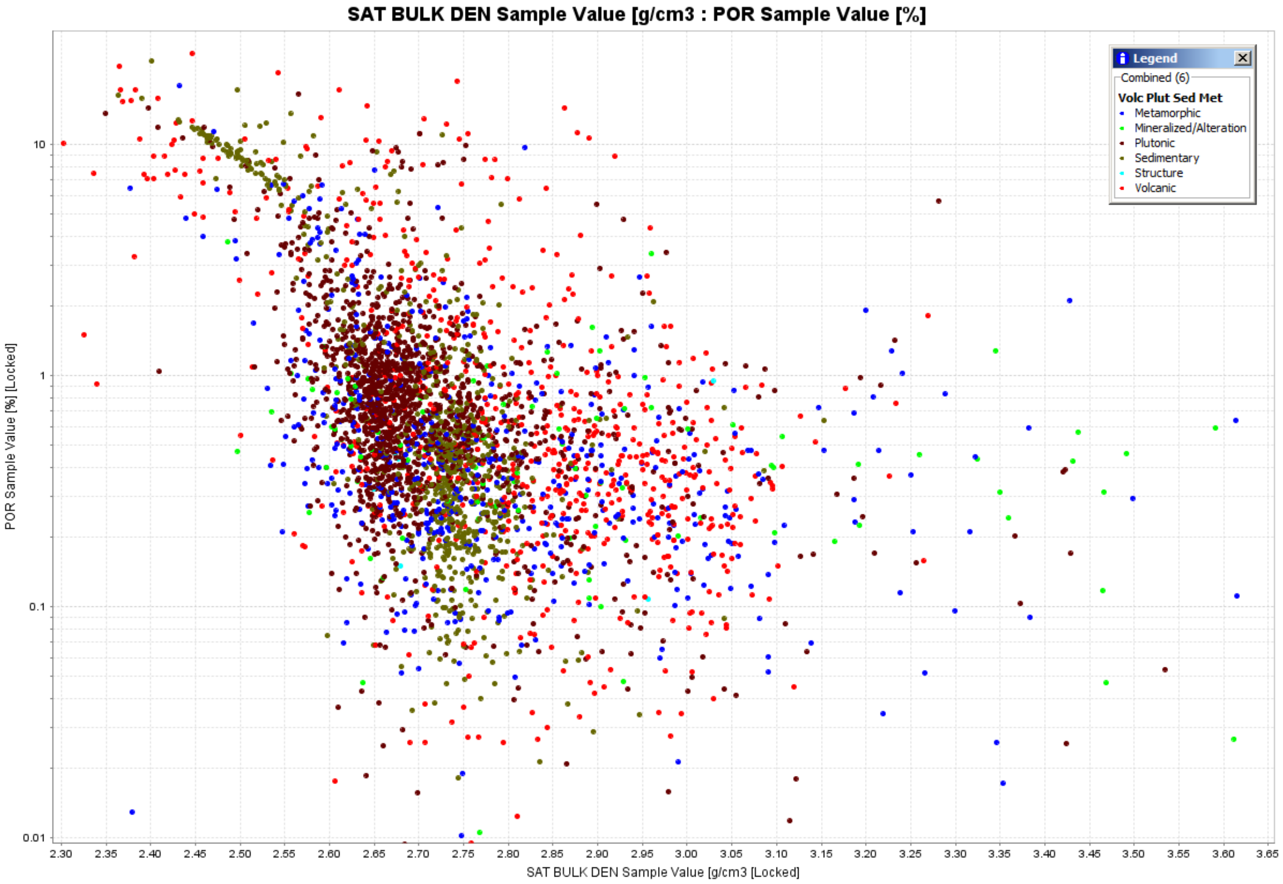

Figure 4: in the CRPPDB, only 28% of the samples have porosity > 1%

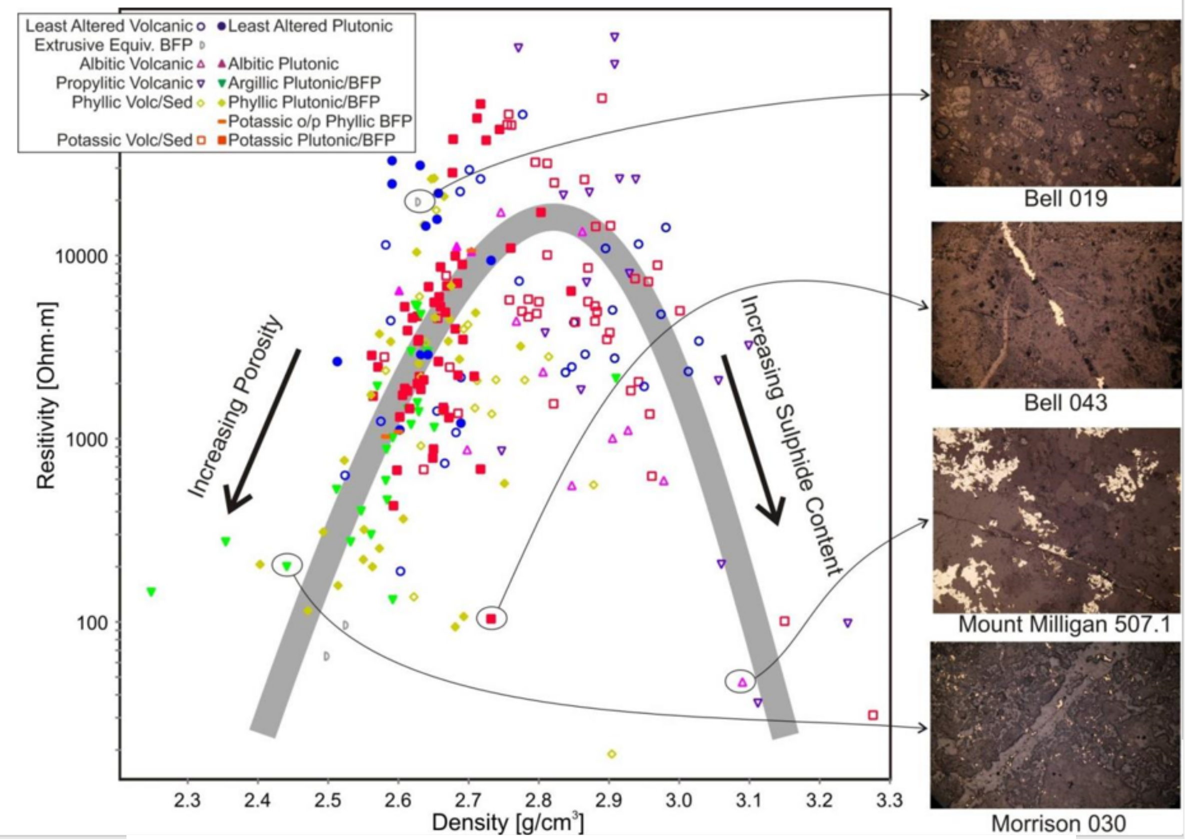

Figure 5: Resistivity is controlled by porosity and by conductive (dense) minerals (Mitchinson et al., 2013)

Columbia (Mitchinson et al., 2013). We present reflected light images of polished thin sections to demonstrate how the conductive opaque minerals control these properties. In Fig. 5, the conductive (low resistivity) samples are either low density, due to high porosity and permeability, or are high density due to conduction through networks of high density sulfide and oxide minerals. In Fig. 6, the high chargeable samples have opaque minerals that produce the equivalent of capacitors in the conductivity pathways.

6. ACKNOWLEDGEMENTS

The Canadian Rock Physical Properties Database has been a work in progress for decades. Carmel Lowe was the first compiler of these measurements at the Geological Survey of Canada – Pacific. At the urging and with the assistance of Judith Baker, I took over the role. The database began as a complementary compilation of the Rock Properties Database System set up by Sharon Parsons of Mira Geoscience, under the direction of John McGaughey. Particular thanks are due to Tark Hamilton, for collaboration on the lithological descriptions and geological interpretations.

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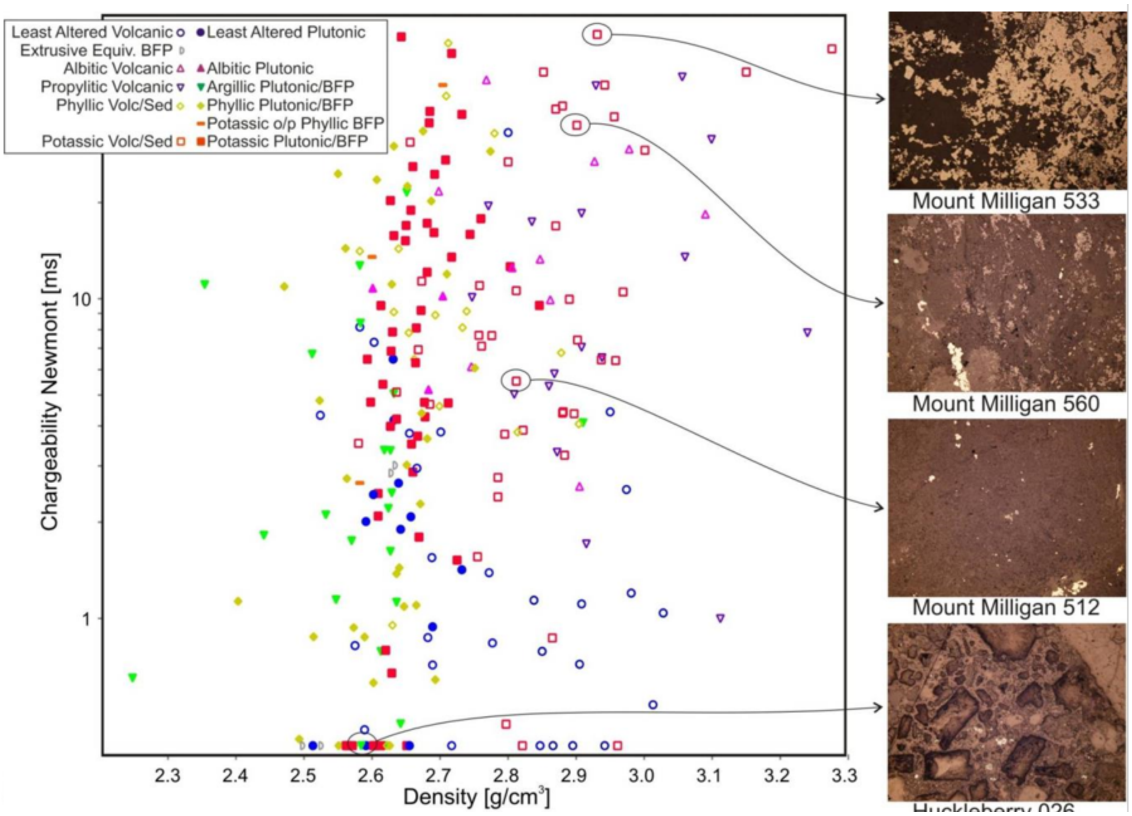

Figure 6: Chargeability is controlled by the concentration and connectivity of conductive (dense) minerals (Mitchinson et al., 2013)

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