Improving Exploration Efficiency by Predicting Geological Drill Core Logs With Geophysical Logs

Killeen, P.G.[1], Mwenifumbo, C.J.[1], Elliott, B.E.[1], and Chung, C.J.[1]

1. Geological Survey of Canada, Mineral Resources Division, Ottawa, Ontario, Canada

INTRODUCTION

Borehole geophysical data can provide an objective geologically-related interpretation of the lithology intersected by a drillhole. In mineral exploration projects in greenstone belts, geological logging of the drill core is difficult because different volcanic and volcaniclastic rocks are often visually similar. More rapid and efficient geological logging of core is possible by enlisting the aid of geophysical logging tools which measure physical and chemical properties that are not visible and therefore complement observations made in geological logs.

To interpret geology from geophysical logging data one must understand the physical rock properties to which each of the geophysical parameters respond (Killeen, 1991; Killeen *et al.*, 1995a,b; Mwenifumbo *et al.*, 1993; Pflug *et al.*, 1994). For example, the magnetic susceptibility (MS) of a volume of rock is a function of the amount of ferromagnetic minerals (magnetite and pyrrhotite) contained within the rock. In time domain induced polarization (IP) the chargeability is an indication of metallic sulphides and oxides. Resistivity relates to porosity and salinity of the pore fluids and conductive minerals such as base metal sulphides, oxides and graphite. Natural gamma rays originate from the radioactive elements potassium, uranium and thorium which may be preferentially concentrated in certain lithologic units. The spectral gamma-gamma probe measures the density of the rock around the borehole and provides information (the spectral gamma-gamma ratio) on the effective atomic number (Zeq) of the rock.

LOG CORRELATION AND THE 'PSEUDO-GEOLOGICAL' LOG

Figure 1 shows a text-book case of correlation between geological and geophysical logs in volcanic rocks: the natural gamma-ray logs from the Mudhole Prospect near Buchans, Newfoundland (Mwenifumbo and Killeen, 1987). However, usually two or more physical rock property measurements are necessary to yield a unique signature for any given rock unit.

In November 1993, a suite of more than ten logs was recorded in a 600 m deep hole, immediately after it was drilled, in the Kam-kotia mine area, west of Timmins. It was determined that the geophysical parameters that most closely reflected the changes in the geology were the gamma-ray, density and MS logs. Figure 2 shows the gamma-ray, density and MS logs on the left. Subjectively, by observation of the geophysical logs, pseudo-geological boundaries were chosen, as shown on the three logs in the centre of Figure 2. Zones which appeared to be homogeneous, with similar amplitudes in the logs, were assigned the same cross-hatched patterns, as shown on the right. Thus, based strictly on the variations in physical properties, a pseudo-geological log was produced as shown on the three logs on the right in Figure 2, before the geologist had logged the drillcore. The pseudo-geological log was determined to contain five different geophysical units.

Figure 3 (left) shows the three logs plotted with the area under the log-trace filled with the different geophysical unit patterns. The three logs illustrate how one parameter may change within a single unit, while the others are relatively constant. For example, in unit 1 between 130 and 220 m the gamma-ray log and density log are fairly homogeneous, but the MS log shows large variations indicating this unit has 'magnetic' sections (increased magnetite content). For comparison, Figure 3 (right) shows the geological log which was produced from observation of the core. Based on the use of multiple geophysical logs, about 90% of the geological units were picked correctly by the pseudo-log. The derivation of the pseudo-geological log was subjective, but the experience gained would be invaluable in formulating an algorithm for objective production of the pseudo-geological log by a computer.

Figure 4 illustrates an early attempt to computerize the picking of boundaries and geological units or zones, using geophysical logs from hole 78928 in the McConnell Nickel Deposit. Here, a zone-picking algorithm has been used to process a density log to locate significant changes in the density which could represent a change in rock type. Essentially the algorithm analyzes a sample interval (with, say, 20 data points) to determine if it is statistically different from the next sample interval. The variables to be considered are the number of data points in a sample interval (SI), and the probability level (PL) used to determine if the intervals are different. Nine different computer picks of a density log are shown in Figure 4. On the left are three density logs showing computer picks of different zones for SI of 20, 50, and 100 samples, all with a PL of 0.7. It is easy to see that as the SI increases, the number of zones picked

In "Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration" *edited by* A.G. Gubins, 1997, p. 713–716

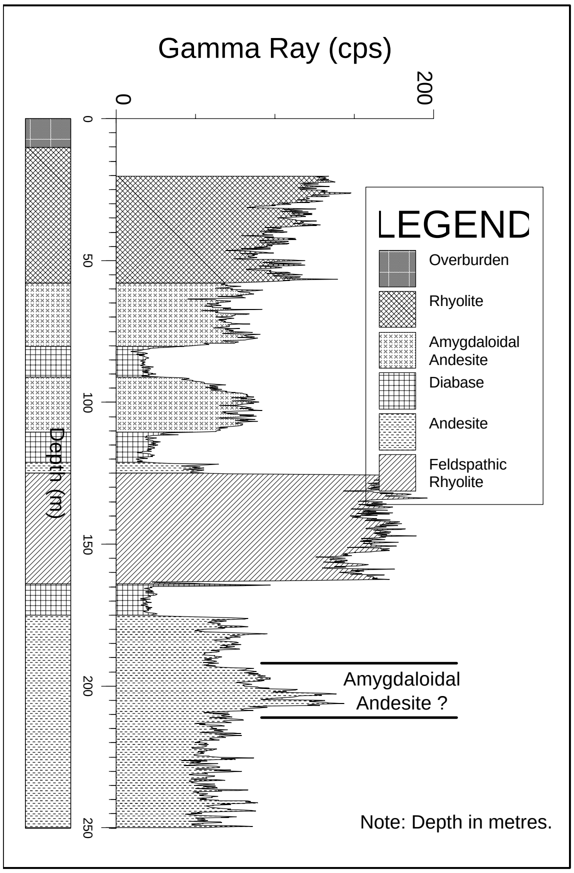
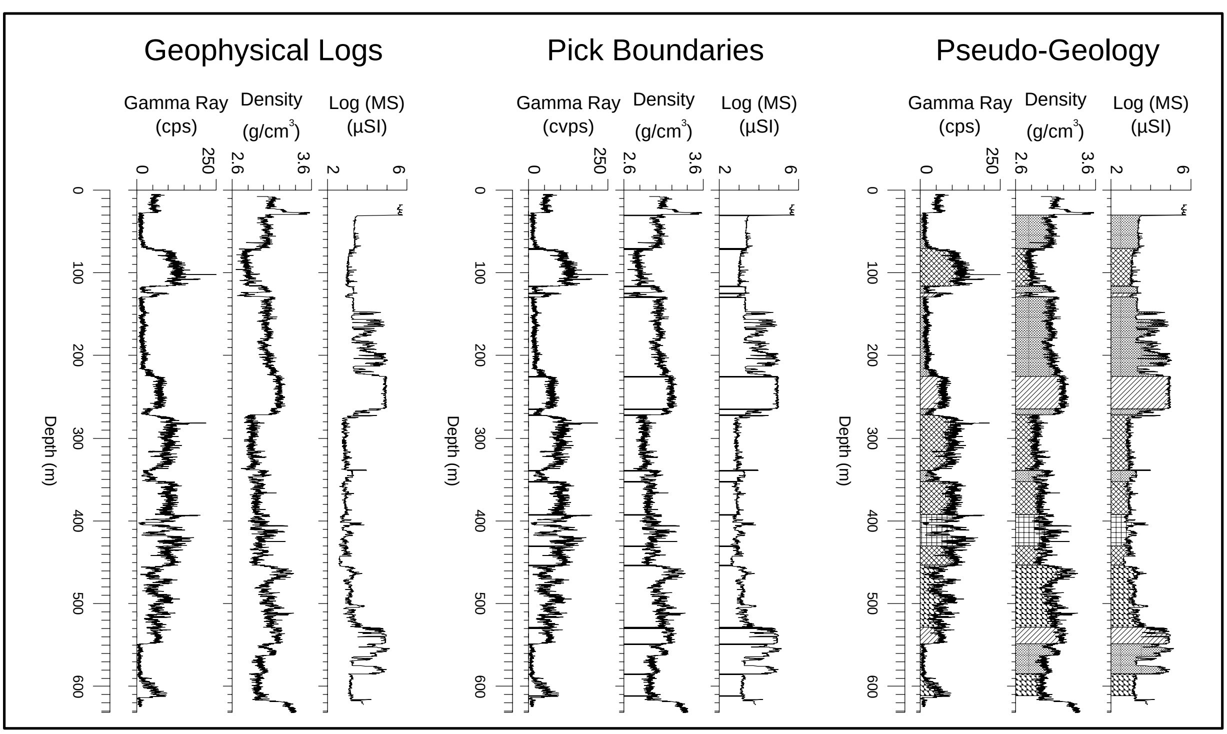


Figure 1: *Geological and gamma-ray logs from hole MH2572, Buchans Mine Area, Newfoundland. Contacts between major volcanic units are well defined on the gamma-ray log, and the thickness of individual units can be easily determined. Changes ot easily seen in the geological log are identifiable in the gamma-ray log, such as the amygdaloidal andesite at 200 m.*

Figure 2: *Gamma-ray, density and magnetic susceptibility logs from hole R5603 in the Kam-kotia Mine Area, Ontario. To produce a pseudo-geological log, boundaries between homogeneous zones on the geophysical logs (left) are selected and shown in the centre of the figure. Then zones with similar amplitudes are assigned similar patterns to produce the pseudo-geology on the right.*



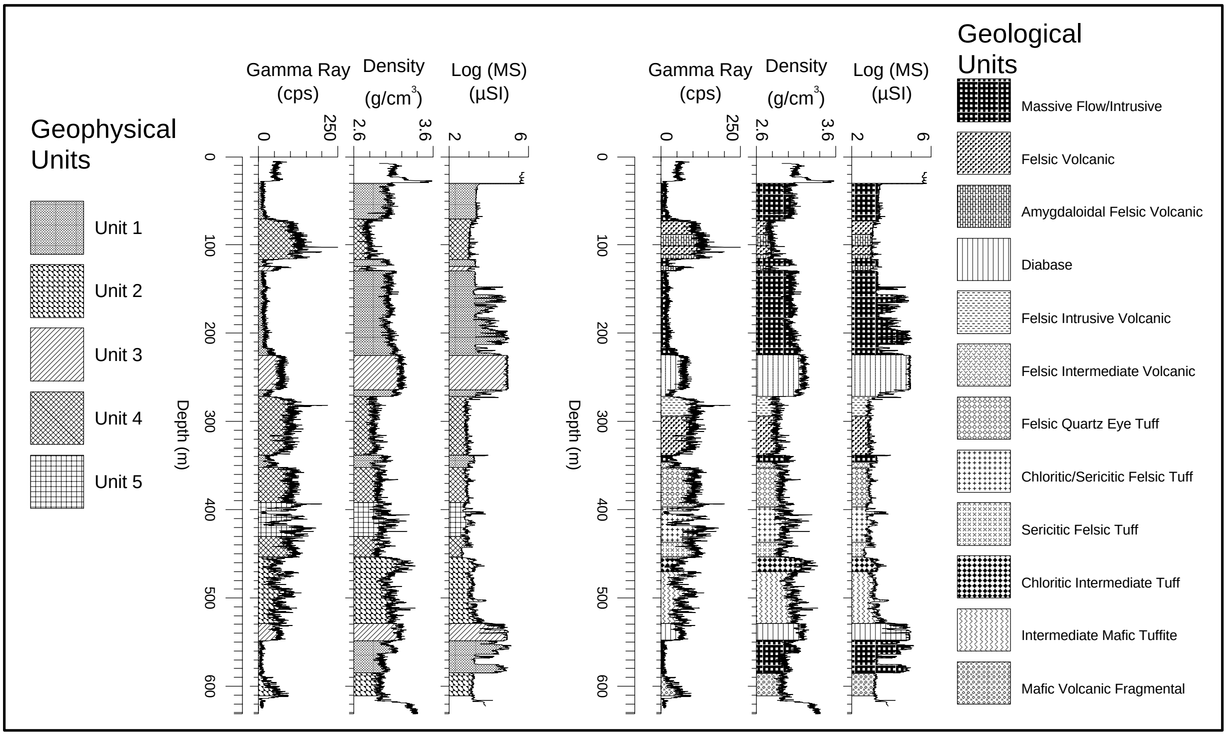


Figure 3: *Geophysical logs from the Kam-kotia Mine Area, Ontario, showing the geophysical units of the pseudo-geological log on the left compared to the geological units based on drill core observations on the right.*

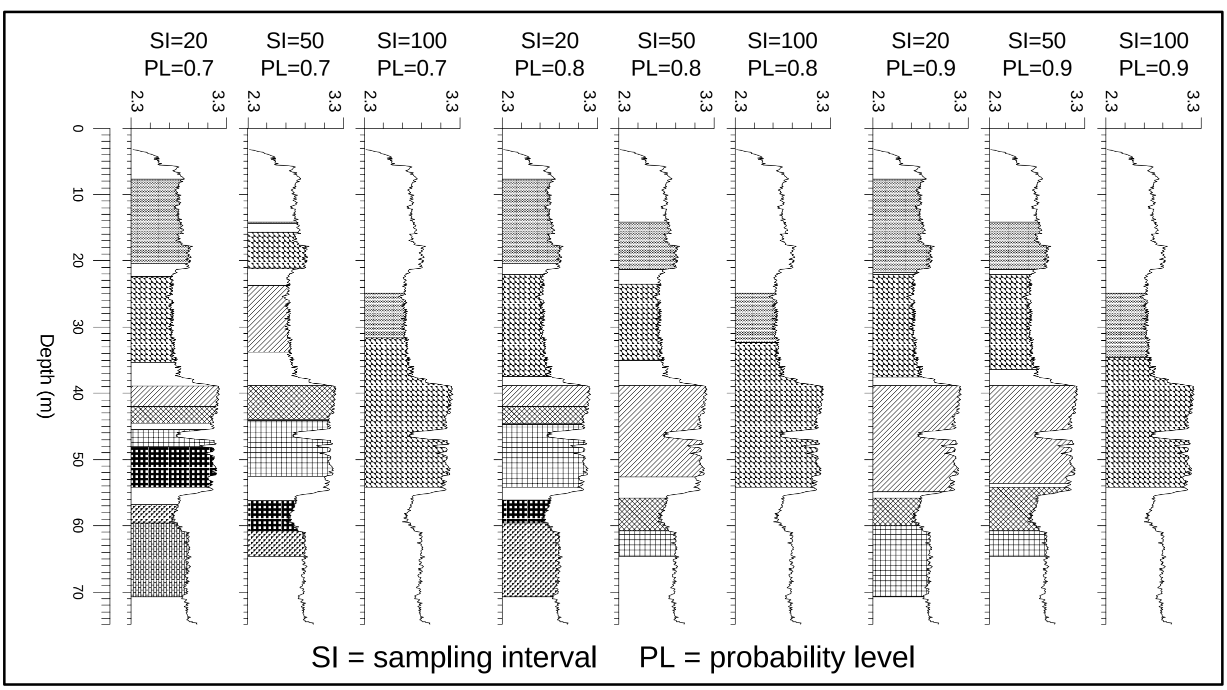


Figure 4: *Nine different computer picks of zones in a density log for hole 78928 in the McConnell Deposit, Ontario. The three density logs on the left show computer picks of zones based on 20, 50 and 100 data points in a sample interval (SI), all with a probability level (PL) of 0.7. For the three logs in the centre the PL was raised to 0.8, and for the three logs on the right to 0.9.*

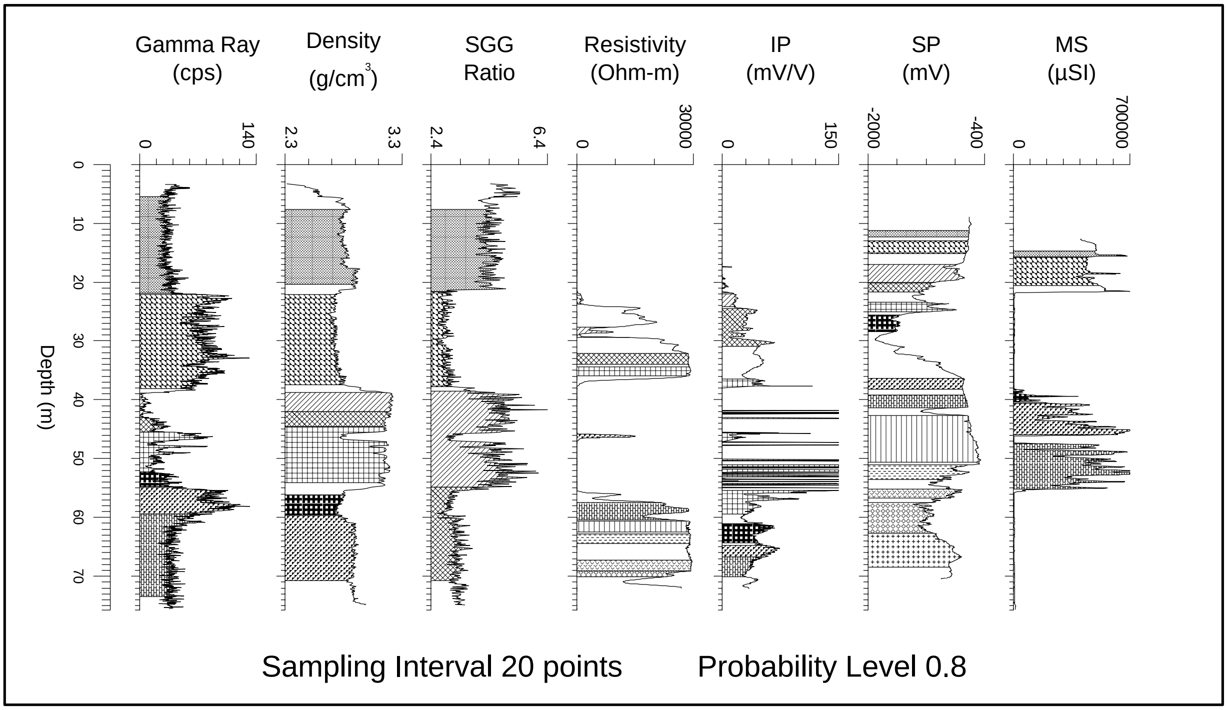


Figure 5: *Multiparameter geophysical logs of hole 78928, McConnell Nickel Deposit, Ontario, processed with the zone picking algorithm using a SI of 20 and a PL of 0.8. Each geophysical log provides its own pseudo-geology log. A final pseudo-geology log would be produced by combining the information on zones picked in each geophysical log.*

goes down. Also, there is a loss of data at the beginning and end of the log where there aren't enough points to do the computation. In the centre three logs, the PL is increased to 0.8 and on the right three logs it is increased to 0.9. Increasing the PL means that only the most guaranteed different zones will be picked (i.e., those with a high probability (confidence level) of being truly different).

This analysis was done on all of the geophysical logs available for hole 78928 in the McConnell deposit, and it was determined that a SI of 20 and a PL of 0.8 gave the best results. Figure 5 shows all of the geophysical logs processed with these SI and PL values, and the resulting pseudo-geological log for each parameter. It is apparent that some logs, such as the IP log, are not very helpful in this particular case. A final pseudo-geological log would have to be some combination of all of the zones based on the different geophysical logs. A new mathematical approach in the zone-picking procedure, combining the data from all of the geophysical logs, is now being investigated.

It is entirely feasible to develop computer software to produce the pseudo-geological log objectively, in real-time in the field. Its accuracy would be dependent on the number of parameters it had to work with, as well as previous training from other holes in the area. Various approaches to this problem have been tried, such as the work by Hoyle (1986), and Wu and Nyland (1987).

ACKNOWLEDGEMENTS

We thank Alan King of Inco, Ray Band and John Pattison of Falconbridge, and ASARCO Inc. and Abitibi-Price Inc. for their collaborative support of this work, as well as permission to publish the results.

REFERENCES

Hoyle, I.B., 1986, Computer techniques for the zoning and correlation of well-logs; *in* Geophysical Prospecting 34, p. 648-664.

Killeen, P.G., 1991, Borehole geophysics: Taking geophysics into the third dimension; *in* GEOS, Vol. 20, No. 2, 1991, p. 1-10.

Killeen, P.G., Elliott, B.E., and Mwenifumbo, C.J., 1997, Towards prediction of geological drill core logs using geophysical logs in volcanic stratigraphy; *in* Proceedings of the 10th annual symposium on the application of geophysics to engineering and environmental problems (SAGEEP); Reno, Nevada, 23-28 March 1997.

Killeen, P.G., Mwenifumbo C.J., and Elliott, B.E., 1995a, The Pseudo-geological log: using geophysical logs as an aid to geological logging in volcanogenic massive sulphides; *in* Current Research 1995-E; Geological Survey of Canada, p. 321-330.

Killeen, P.G., Mwenifumbo C.J., and Elliott, B.E., 1995b, Borehole geophysical logs from massive sulphide deposits in the cordillera, British Columbia; GSC Open File 2610.

Mwenifumbo, C.J., and Killeen, P.G., 1987, Natural gamma ray logging in volcanic rocks: the Mudhole and Clementine base metal prospects; *in* Buchans Geology, Newfoundland: 1982–1984, Kirkham, R.V., ed., Geological Survey of Canada, Paper 86-24, p. 263-272, Report 16.

Mwenifumbo, C.J., Killeen, P.G., Elliott, B.E., and Pflug, K.A., 1993, The borehole geophysical signature of the McConnell Nickel Deposit, Sudbury area; *in* Proceedings of the 5th Int'l. Symposium of the Minerals and Geotechnical Logging Society, Tulsa, 24-28 October 1993.

Pflug, K.A., Killeen, P.G., and Mwenifumbo, C.J., 1994, Acoustic velocity logging at the McConnell nickel deposit, Sudbury area, Ontario: preliminary in situ measurements; *in* Current Research 1994-C, Geological Survey of Canada, p. 279-286.

Wu, Z., and Nyland, E., 1987, Automated stratigraphic interpretation of well-log data; Geophysics, vol. 52, no.12, December, 1987, p. 1665-1676.