Borehole Correlation in Mineral Deposits Using Geophysical Parameters: Duck Pond, Newfoundland

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ABSTRACT

Correlation of geophysical well logs is an exploration technique that has been employed for many years in oil exploration. Over the past decade, a number of new slimline tools have been introduced advancing the application of logging to the smaller diameter mineral exploration boreholes. Interpretation of this data may follow a number of paths. Through the collaborative use of procedures such as: a) univariate, bivariate, or multivariate statistical methods, it is often possible to characterise some lithologies that are defined by distinctive physical property signatures; and b) the correlation of distinctive geophysical signatures between adjacent boreholes can be used to establish structural features of the subsurface. In this paper we show that gridding of geophysical parameters as conventionally applied to both ground and airborne surveys can also be applied to a suite of borehole data to produce an image of the subsurface which contains information on both structure and lithology. In this example we present results from a multi-well and multi-parameter survey of the volcanogenic massive sulphide deposit from Duck Pond, Newfoundland.

LOCAL GEOLOGY

The Duck Pond deposit is a 4 million tonne massive volcanogenic sulphide deposit located in the Dunnage Zone of central Newfoundland (Figure 1). Regionally, the deposit area is underlain by the Tally Pond volcanics. This belt of Upper Cambrian, arc-related volcanics constitutes part of the Victoria Lake Group. The local geology of the Duck Pond deposit has been divided into three stratigraphic sequences. In decreasing stratigraphic order these three sequences are: the Upper Unmineralised Block, the Duck Pond/Tally Pond Mineralised Block, and the Lower Sedimentary Block.

The Upper Unmineralised Block is comprised of a thick (>500 m), shallow dipping assemblage of submarine cyclic mafic and felsic flows and pyroclastics. These units are intercalated with both graphitic sediments and reworked tuffs. The base of the unit is highly deformed and defines the trajectory of the Duck Pond Thrust which dips to the south at 45° (Squires *et al.*, 1991).

The fault bounded Duck Pond/Tally Pond Mineralised Block has a crude wedge like shape. This sequence consists mainly of flat lying felsic flows which have a maximum thickness of 500 m. It is the felsic portion of the block that hosts significant accumulation of both barren and ore grade exhalative massive sulphides. This sequence is highly altered and the degree of mineralisation (mainly consisting of pyrite) ranges from 5% to locally massive sulphide.

The Lower Sedimentary Block located stratigraphically below the mineralised zone is composed of complexly folded interbedded graphitic and argillaceous sediments. The Terminator Thrust marks the boundary between the Mineralised and the Lower Sedimentary Block.

BOREHOLE SURVEY

A series of twelve boreholes, approximating a plane through the Duck Pond deposit, were logged with a multi-parameter probe measuring total magnetic field, magnetic susceptibility, 48″ resistivity, 16″ resistivity, single point resistivity, and temperature. The holes selected were logged to an average depth of approximately 400–500 m. This was sufficient to intersect all three Blocks that comprise the Duck Pond stratigraphy.

A lithological section compiled by Noranda (pers. comm.) was constructed on the basis of detailed core logging (Figure 2). From the above local geology five major lithological units are defined: gabbro, rhyolite, mafic flows, felsic porphyritic intrusions, and massive sulphides. Minor units of lapilli tuff and graphitic sediment lenses are also noted. As well, structural features such as the two major thrusts were identified and correlated between boreholes.

The geological features correlated between holes using this process defined a subsurface stratigraphy based on silicate mineralogy. The geophysical signals often record parameters that do not form the bulk

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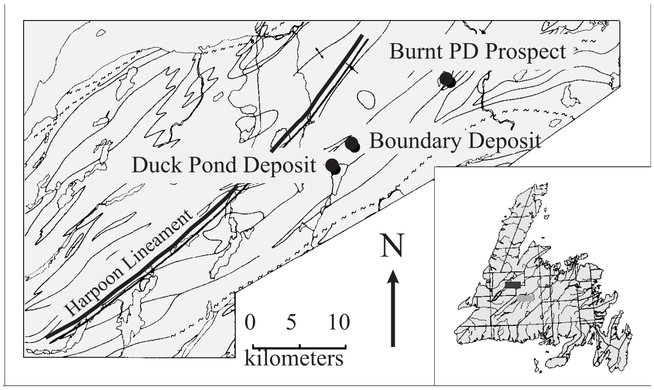


Figure 1: *Location map of the Duck Pond Deposit. Map is denoted by shaded box in large scale map of Newfoundland, Canada.*

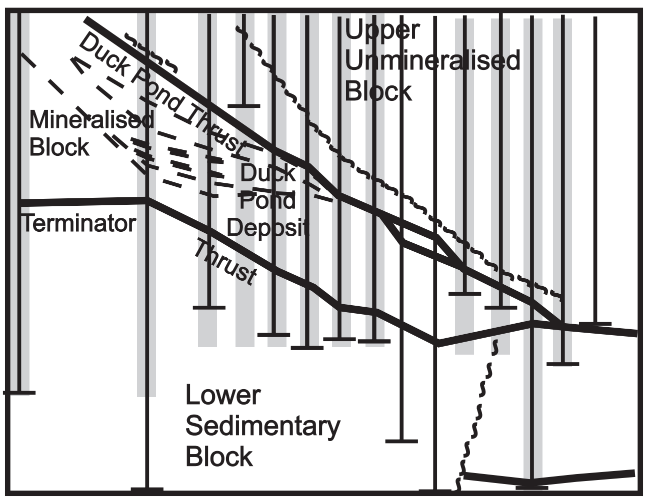


Figure 2: *Vertical lithological section along mine grid 9200N produced by Noranda from logged core.*

composition of the rock. For example, magnetics signals are controlled by the percentage of magnetic minerals present in the rock. These rarely occur in any great concentration. Rather, we assume just as in airborne magnetics surveys that the detailed variations in these trace minerals provides a (complex) proxy of the silicate based variations. Often the greatest challenge is understanding the significance of the relationship between the magnetic and silicate based observational systems.

Each of the 12 holes was surveyed as the probe travelled down and up the hole. As the sampling was based on a time interval, the first step in data reduction involved splining the uphole and downhole data to a common depth interval. At this point we rejected a number of logs because of their poor quality. After this, base level shifts were applied to bring individual logs to a common level, and polynomial trends were removed to eliminate the effects of instrumental drift. Spikes and steps were eliminated using a fourth difference approach. Finally, where possible the two up and down logs were combined to provide a single log for each parameter for each hole.

BOREHOLE CORRELATION

Traditional well log correlation identifies similar geophysical signatures in adjacent boreholes leading to a framework for subsurface morphology mapping. This process is highly evolved in laminated sedimentary terrain. Detailed correlation of resistivity and spectral gamma logs forms one of the basic tenets behind the concepts of sequence stratigraphy and has been used extensively in the Phanerozoic Alberta Basin. In addition to defining subsurface structure, borehole logs have also been used in sedimentary terrain to identify individual lithological units. The limited variability of constituent minerals in sedimentary terrain can be used to advantage in that crossplots of physical property responses often provide insight into possible lithologies. Similar approaches are not as common in the mining environment; until recently the potential for detailed correlation using geophysical signals has rarely been realised. This resulted in part from a limited number of slimline probes for the smaller diameter boreholes, together with a much more heterogeneous geological environment.

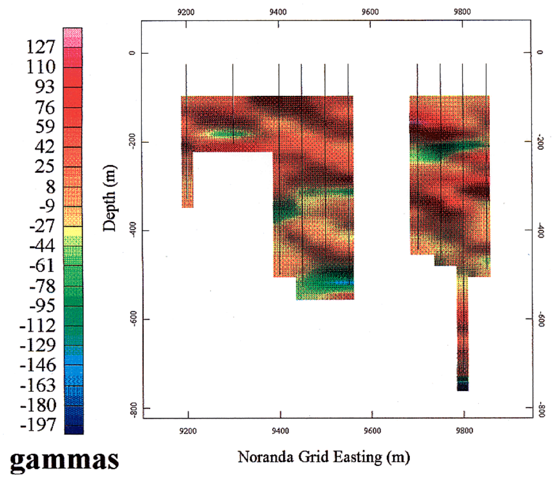
Taking this traditional approach, logs from the Duck Pond deposit were examined to address two questions:

1. is it possible to identify specific units on the basis of their geophysical response and do these boundaries correspond to a particular lithology as identified in the Noranda section; and
2. is it possible to identify features that can be correlated between holes.

Univariate and multivariate distributions of the geophysical parameters were used to determine if particular lithological units could be discriminated on the basis of one or more sensor responses. For example, all of the rhyolites form a tight cluster in a plot of 16″ resistivity vs. magnetic susceptibility. Also, the gabbro and rocks from the shear zone of the two thrust faults show similar correlations. However, some units such as the mafic flows and graphitic sediments do not exhibit any diagnostic signature. This method then permits the recognition of only a few distinctive lithologies. For the majority of the lithologies there is too much overlap between physical responses to provide a diagnostic response. In most cases the boundaries between the geophysical response corresponded to the geological boundary within the accuracy limits of the borehole and the borecore depth estimates.

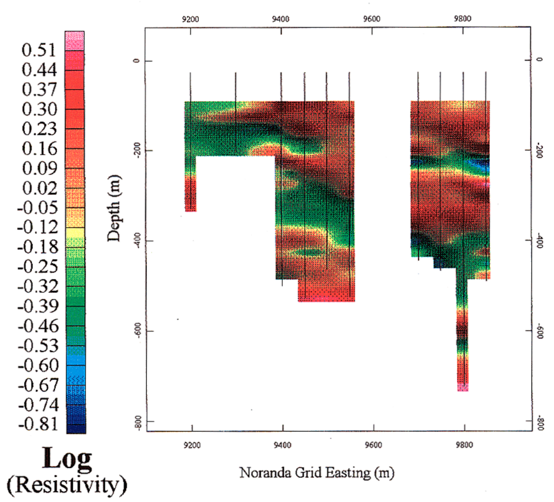
The traditional approach outlined above only leads to a limited resolution of lithology and structure. The borehole geometry of this survey, together with the digital data acquisition, permits testing an alternative approach to subsurface mapping using borehole logs. The boreholes logged in this survey were part of an ore delineation drilling exercise: holes were drilled on a 100 m grid. The orientation of the boreholes was near vertical with little deviation. The trajectories of the boreholes then fall on a common planar surface that is trending north-south and vertical. The digital probe sampled every 0.25 seconds giving a depth resolution of better than 1 m. In its broadest terms this closely resembles the standard database that one might expect from an airborne survey. That is, data are acquired on a series of flight lines at either a constant elevation, or a constant ground clearance. The spacing between lines is much greater than the along line spacing between observations. The major differences between these two types of surveys are that the plane of the borehole survey is vertical, and the along line (downhole) spacing between observations in the borehole is much smaller.

Treating the digital data as a standard airborne survey leads to the production of grids for each of the individual geophysical parameters



Duck Pond Borehole Correlation
Total Magnetic Field : Nyquist Removed and Downhole Directional Filtered

Figure 3: *Gridded total magnetic field section.*



Duck Pond Borehole Correlation
16 Inch Resistivity : Nyquist Removed and Downhole Directional Filtered

Figure 4: *Gridded 16″ resistivity section.*

measured (Figures 3 and 4). The resultant grids were derived using standard Geosoft Bigrid gridding routine and then were filtered to remove instrument artefacts just as one would do in a standard airborne survey. Additional directional filtering was applied to the data using directions obtained from the geological approach, and also some details obtained from the Noranda geological section. Based on correlations identified by the variance analysis, various parameters were superimposed to provide higher resolution of lithological and structural boundaries. This method was much more successful than the traditional individual horizon approach. On the composite sections it is possible to recognise the spatial location and extent of the mineralised zones as well as the rhyolite, gabbro, mafic flows, and graphitic sediments (Figures 3 and 4). The image processing approach to borehole correlation also provides much more detail on subsurface structural variations. The trend of the Duck Pond and Terminator Thrust zones was very strongly defined, especially in the resistivity signal. Plus it is also possible to identify lithological structure within the Upper Unmineralised Block.

CONCLUSIONS

Using a variety of interpretation procedures on a suite of borehole geophysical parameters it is possible to derive detailed information on the subsurface morphology. This example reports results from a combined total magnetic field, susceptibility, and resistivity survey of the Duck Pond volcanogenic massive sulphide deposit. Crosswell correlation provided a generalised picture of the boundaries of lithological packages in the study area and also an initial look at which units possessed characteristic signatures. Scatter crossplots of data from selected depth ranges of total magnetic field, susceptibility, and resistivity made it possible to begin discrimination of individual lithological packages on the basis of their geophysical signature. Finally, the process of gridding individual parameters and parameter superimposition, detailed structures within the subsurface were defined.

REFERENCE

Squires, G.C., MacKenzie, A.C., and MacInnis, D., 1991, Geology and genesis of the Duck Pond volcanogenic massive sulphide deposit; *in* Swinden, H.S., Evans, D.T.W., and Kean, B.F., eds., Metallogenic framework of base and precious metal deposits, central and western Newfoundland, (Field Trip 1); Geological Survey of Canada Open File 2156, 56-65.