Improving grade control through Borehole Geophysics: Case study from Iron Ore Company of Canada

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Abstract

To better optimise mine performance geophysics in the mine environment can form an integral part of mine development and operation. In particular, borehole geophysics offers the mine operator the opportunity to maximise profitability through mine planning improvements.

In 1998, the Iron Ore Company of Canada began a multi-phase study at their Carol Operation mine site in Labrador. The objectives of the study were to evaluate the measurement of in situ grade parameters for quality control and planning. Excellent correlation of both susceptibility and magnetite and density and iron (Fe) that were, obtained in phase I, indicated that in situ measurements can be made to classify ore type and grade.

The benefits that are realised by optimising the mining process through the routine logging of bore holes at the I.O.C. mine include both improving downstream process efficiency (both concentrating and pelletising processes) and ultimately improve the final product quality. This paper will look at the approach applied by I.O.C. and the progress of this multi-phase project to date.

Introduction

Applications of physical property borehole analysis contributes directly to reduced costs in the mine environment. Physical property borehole analysis can; improve mine design, minimise dilution, provide valuable geotechnical information and resolve ore boundaries within centimetres. Through incorporation of physical property analysis at an early stage of mine development, such as delineation and site characteristic studies, a better mine model is derived which leads to improved mine design and more effective and efficient mining practices. Accurate ore/waste boundary definition will directly reduce unplanned dilution. The technologies that exist today are more advanced than they have ever been yet awareness and application remains low.

Physical Property Borehole Logging

Understanding the geological relationships between the mineral continuity and boundaries are essential in developing mine plans and to mine optimally. To properly and accurately map the deposit both geologically and geotechnically it is essential to fingerprint the physical characteristics of the deposit. The improved mine plan will result in decreased unplanned dilution through a better understanding of ore/waste contacts and will, through a better understanding of geotechnical problems, allow for the most efficient and cost effective mining method. Key advantages of in situ borehole analysis are; 1) the results are immediate, unbiased and continuous, 2) non- visual characteristics of the core can be identified, 3) repeatable results are digital and can be incorporated into mine modelling software. Additionally, on programs where non-coring drill methods are used, such as blast or percussion holes continuous quantitative results can be obtained where normally there would be none.

Proven Technology

Borehole geophysics in iron mines was first tested as early as 1971 at the Minntac iron mine in Minnesota results were reported in April 1974 Vol. 39 Geophysics. Later in 1982 a system was developed to measure magnetite content in large diameter blast holes and to and delineate ore/waste contacts. The system was quite cumbersome. Technology in this field has advanced at a rapid pace over the last ten years and more and more non oil industry applications for borehole technologies are being utilised globally.

The RTZ-CRA group of companies undertook experimental programs using high-resolution geophysics at several operating mines and advanced evaluation projects from 1991 to 1996. The application of these technologies at the Century zinc deposit evaluation documents just another example of the financial benefits of systematic geophysical logging of blast holes as an integral part of the ore extraction process in other mine environments. The objectives of borehole logging at the Century Zinc deposit were to:

1. Resolve ore boundaries within centimetres
2. Provide in-situ direct estimations of ore grade to a useable accuracy
3. Improve timeliness, accuracy, and quality of ore boundary data
4. Decrease ore dilution to optimise mill performance

Some of the work undertaken at the Century deposit included the geophysical logging of evaluation drill holes to quantify mineralogical, geotechnical and structural parameters of the ore and host rocks in situ. The use of standard suite petroleum tools such as density, sonic and dip-meter that have been adapted to the hard rock environment improved confidence and demonstrated that cost savings could be realised by the future use of non coring versus core drilling. Additionally, geophysical logging of blast holes defined ore/waste contacts to a few centimetres and in a number of cases was used to directly estimate ore grade. By applying this approach routinely to production blast holes several cost benefits were realised such as improved timeliness and accuracy of resource information, less dilution and finally, improved mill performance.

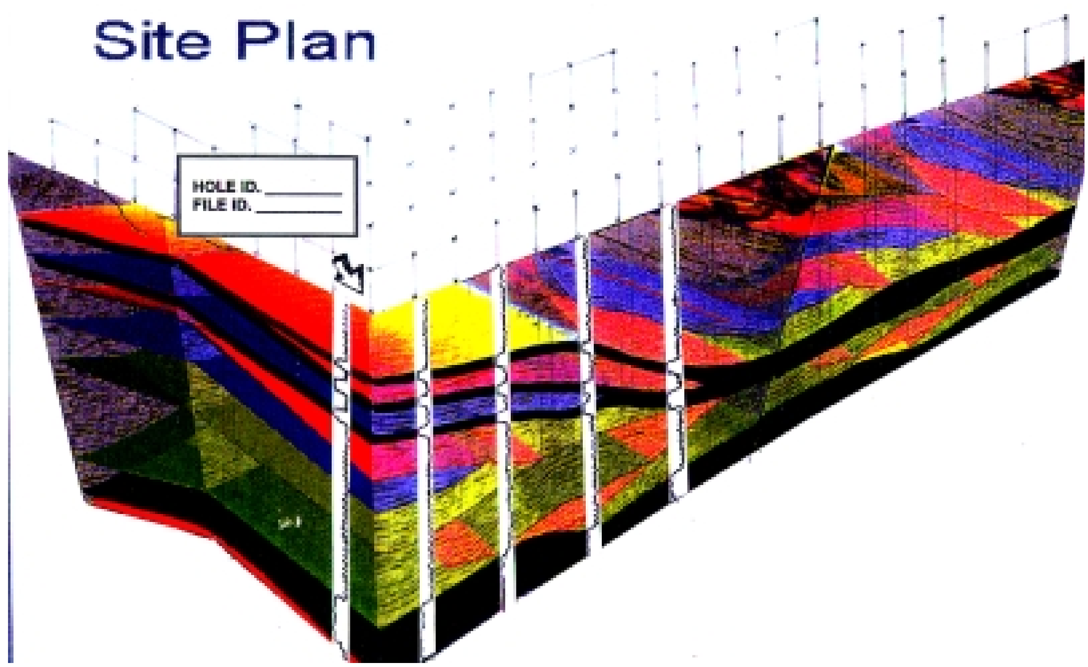
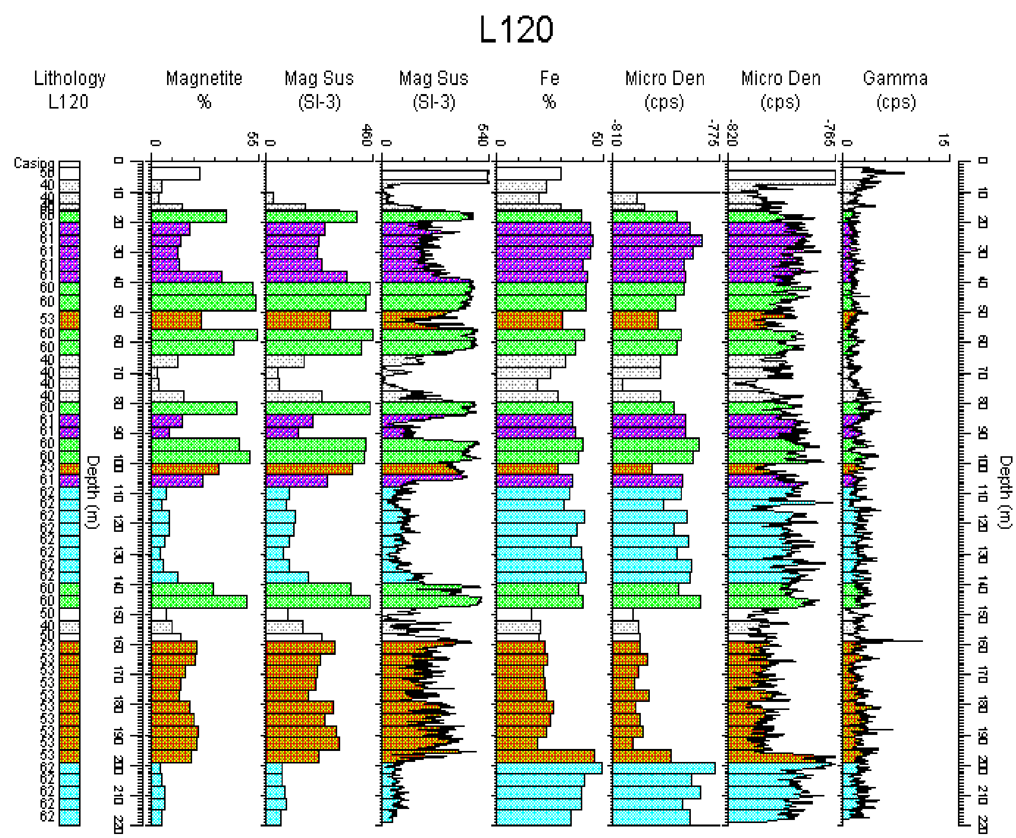


Figure 1. Theoretical application of borehole logging at the development stage

Iron Ore Company of Canada
Phase I – Mine site assessment

In 1998, the Iron Ore Company of Canada undertook a site assessment study at their Carol operation mine site in Labrador. The objectives of the study were to obtain physical properties of their deposit to assess the applicability of in situ borehole logging for improved resource definition and to evaluate the measurement of in situ grade parameters for quality control and planning. One of the main technical hurdles the mine had been faced with was that the blast hole samples of the drill cuttings gave a very unreliable result due to the bias nature of the sample. The unreliable grades from the blast hole sample hinders the ability to effectively plan and report ore quality for the mill.

The first phase of the program was a site visit to assess a variety of physical and chemical characteristics of the rock units associated with the deposit including the ore host and bounding rock types.
Four NQ delineation holes were surveyed with a small suite of borehole probes. Parameters measured for the study included; magnetic susceptibility, natural gamma, micro-density and calliper (Inductive conductivity and single point resistivity were also run in one hole). Sample intervals varied from 5 to 10 cm and hole depth varied up to 370 metres. Data quality was assessed by running the probe up hole as well as down hole where possible. Excellent repeatability was observed. Figure 2 and 3 represent data from two separate bore holes. Lithologic units are represented by a variety of shading.

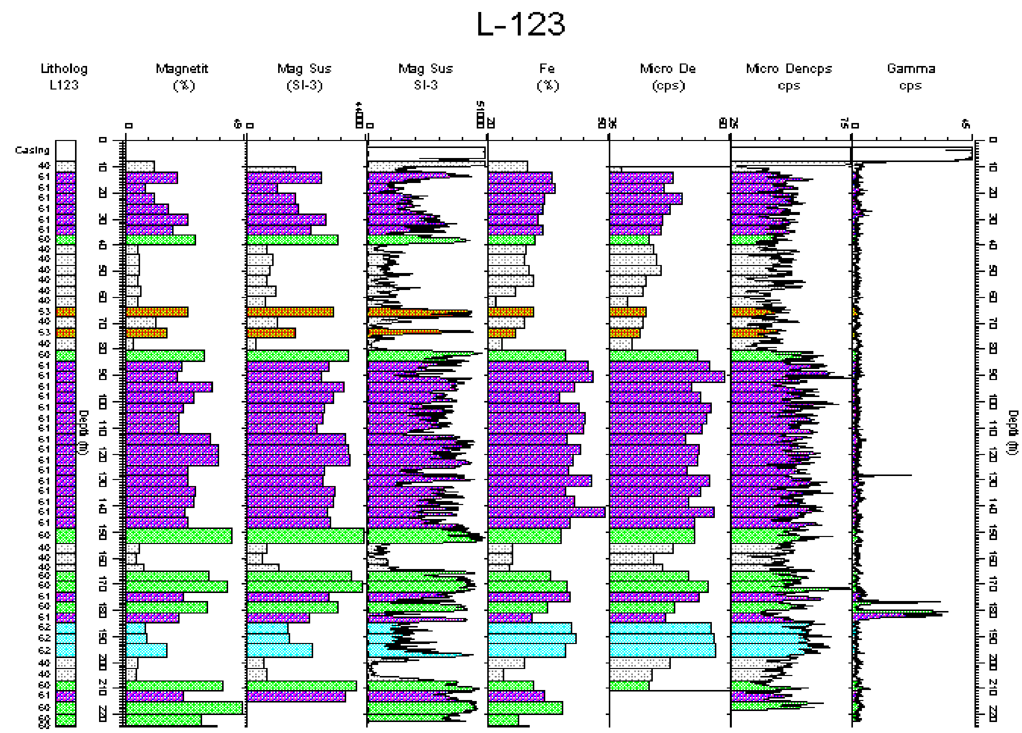


40 Quartz carbonate
50 Quartz carbonate magnetite
53 Quartz magnetite carbonate
60 Quartz Magnetite
61 Quartz Magnetite Specularite
62 Quartz Specularite

Figure 2. Borehole data from delineation hole at I.O.C. mine, Labrador.

The core from the holes was assayed for percent magnetite and the assays are represented in column one. Magnetic susceptibility data is presented in the fourth column and it has been downward averaged (3rd column) to allow direct comparison with the sample size of the assays. The noisy appearance of the data is in fact the accurate response of the tool. Visually the assays and the measured susceptibility are very similar indicating the strong correlation between the two. Preliminary statistical calculations revealed coefficient of determination factors (R) ranging from 0.96 to 0.98 (where R value of 1.0 is a perfect fit to the regression model.) See Figure 4.

The micro density probe also indicates quite good correlation with Fe determinations (R value of .90). Additionally, a calliper log for measuring variations in-hole diameter was utilised for fracture detection and competency.



40 Quartz carbonate
50 Quartz carbonate magnetite
53 Quartz magnetite carbonate
60 Quartz Magnetite
61 Quartz Magnetite Specularite
62 Quartz Specularite

Figure 3. Borehole log indicating actual assays and multiple in-situ physical parameters

In conclusion the site visit of phase I one demonstrated excellent digital data quality and repeatability. Gamma logs were able to identify marker beds associated with chemical anomalies in the assays. The excellent correlation of both susceptibility and magnetite, and density and iron (Fe) indicate that in situ measurements may be made to classify ore type and grade. Density data can be used to directly estimate ore grade and distinguish between ore and waste. In addition the accurate density information can be used to replace the assumed bulk densities in the tonnage calculations which could provide much more accurate information to the reserve database.

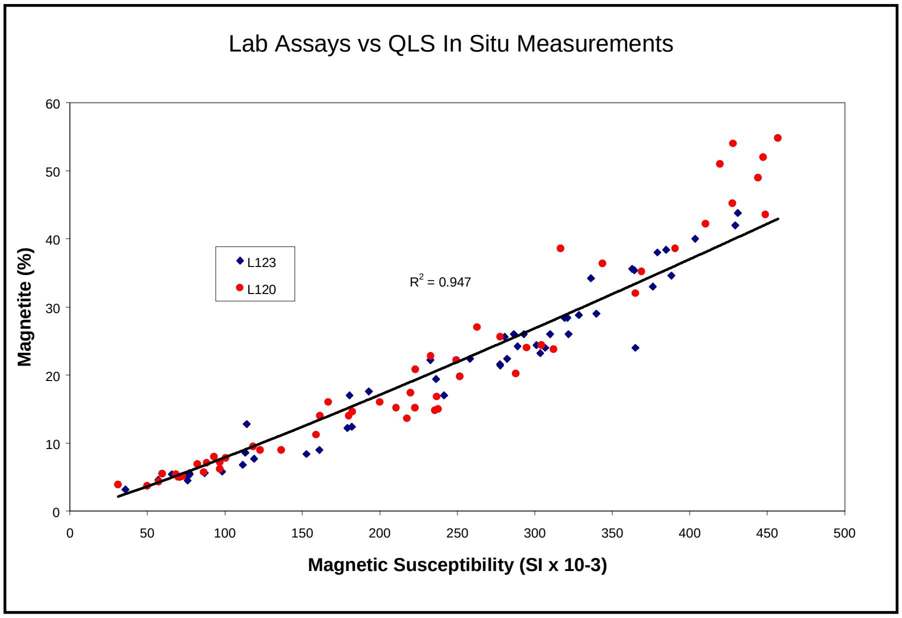


Figure 4. Statistical correlation of in-situ magnetic susceptibility measurements to actual magnetite assays

Phase II - Blast hole borehole measurements for In situ Ore classification and Potential Grade Determination

Building on the results from phase I mine site assessment, additional trials were warranted to determine the viability of routine logging of 16" blast holes for magnetite assays (ore classification) and to further test the application of density logging for grade determination.

Four representative test areas were established within one pit at the I.O.C. mine site. Each location one core and one 16" blast hole separated by 1 meter drilled to a depth of 17 metres was prepared. The core holes were to represent a base line for the project.

The data quality was excellent, demonstrating accurate repeatability where data was measured in both directions. Typically 2-4 passes were made in the core holes and 4-8 passes in the blast holes. The effect of hole diameter for the blast holes was monitored carefully. Multiple passes offset by 180° (i.e. North and South probe locations), were collected to identify any significant changes in the physical rock property responses with respect to the dip of the stratigraphy and spatial variations.

Figure 5. 16" Blast hole with side-walled borehole probe

Magnetic Susceptibility

As expected the magnetic susceptibility tool, provided excellent correlation with lab assays. The correlation functions range between R = 0.8709 and R = 0.9607, for each individual holes. As with the Density tool magnetic susceptibility measurements are affected by variation in geometry (hole diameter). Figure 6 and 7 represent cross plots of magnetic susceptibility vs. % magnetite assays. The correlation coefficient for the core holes is near perfect, R = 0.9808, while the blast holes show a correlation coefficient of R = 0.9701. The difference is attributed to the geometry of the hole. In an NQ hole the probe is predominantly surrounded by rock with minimal air/water. In a 16" blast hole, the % of rock surrounding the probe has diminished considerably resulting in lower rock counts. The change in the standard deviation from the NQ holes to Blast holes is in the order of < 0.03.

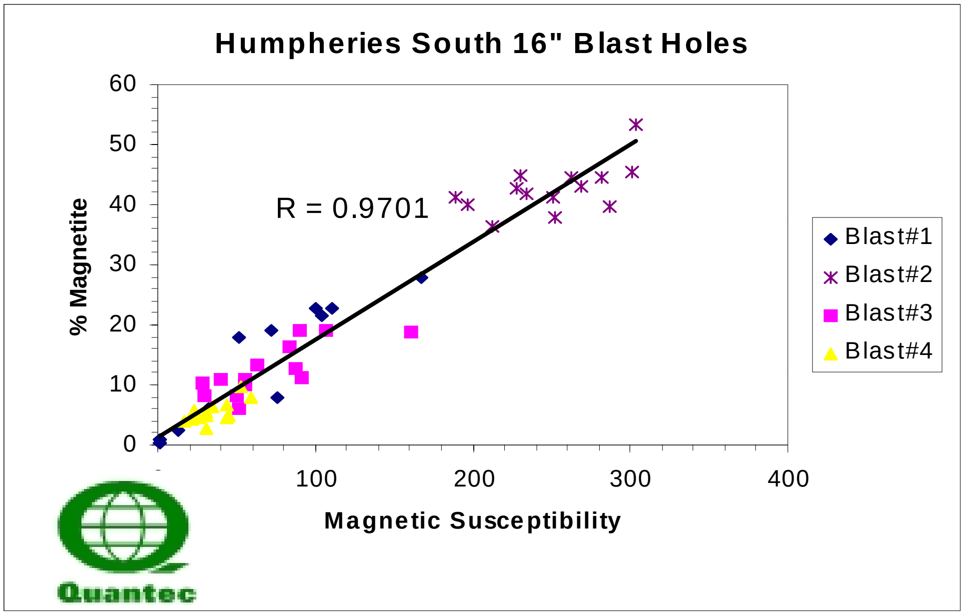


Figure 6: Correlation Coefficient for % Magnetite vs. Magnetic Susceptibility
16" Blast Hole

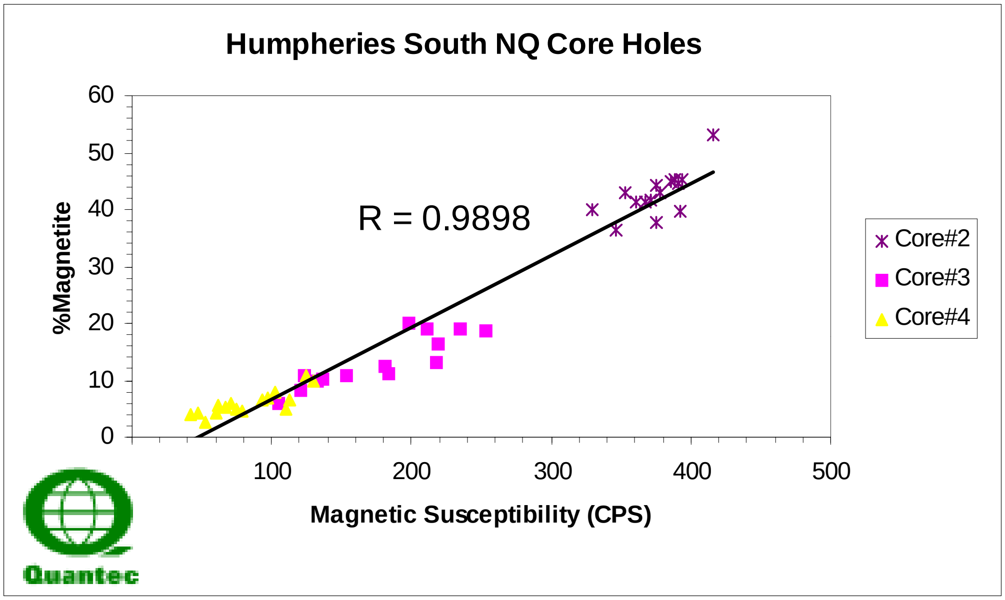


Figure 7: Correlation Coefficient for % Magnetite vs. Magnetic Susceptibility

NQ Core Hole

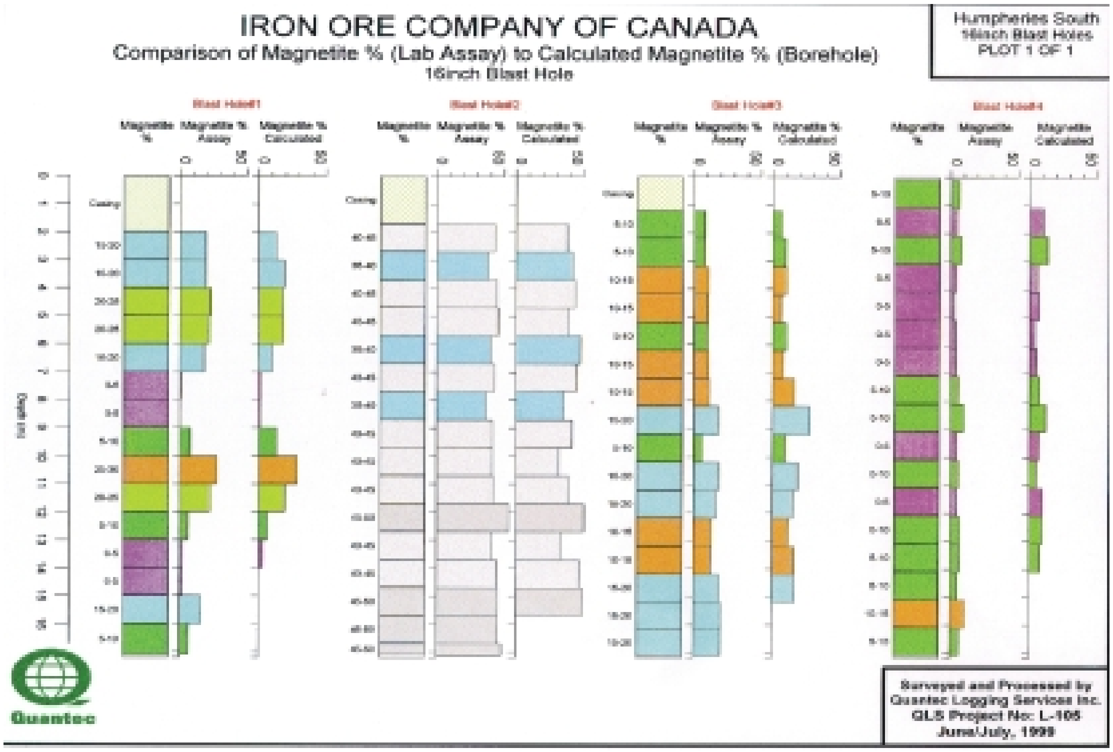


Figure 8: Comparison of the %magnetite lab assay results and the calculated %magnetite from the borehole logs, for all the blast holes. (*The borehole logs were calculated to emulate the one meter sample interval and are represented on a common scale. All the blast holes combined show good variability and correlation downhole. Of note is the diversity of magnetite content between the holes, in particular the elevated magnetite content of blast hole #2.)*

Calliper

The calliper log measured variations in hole diameter. This is often important for fracture detection and identifying relative rock hardness based on variation in hole diameter. Additionally where volumetric studies are important such as in kimberlites this information is essential. As hole diameter has an effect on the density measurements, the density tool includes a calliper for correction purposes.

Density

The composite plots comparing the %Fe lab assay results with Density (CPS) show very little correlation with individual borehole. This is due to the uniformity of the lithology and lack of variability of Fe in each hole. However, the variations from hole to hole can be readily distinguished when results are combined on one plot, (Figure 9). Furthermore, Figure 9 demonstrates that each blast hole was uniquely identifiable by individual clusters.

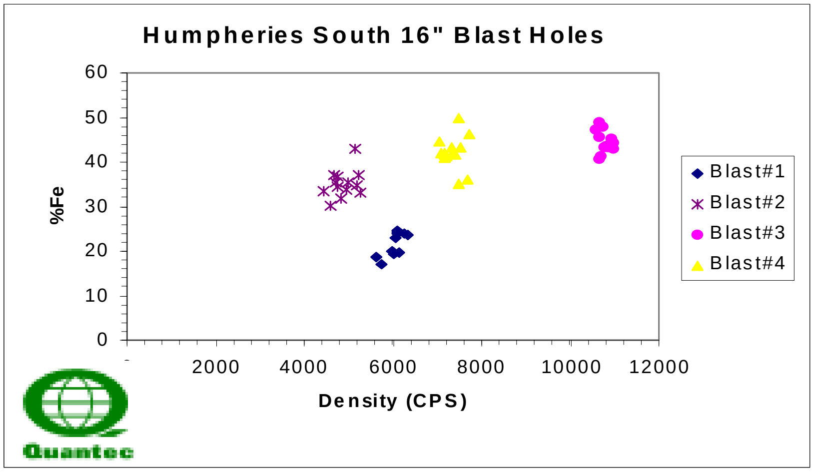


Figure 9: % Fe Lab Assay Results vs. Borehole Density Measurements (CPS)

Phase I demonstrated that the micro density log had a strong correlation to iron assays. The Phase II results indicate that there is a regional correlation between blast holes #1 to #4. Blast hole #1 represents an anomalous zone. Upon examination of the lab assay results for the core holes it was determined that Blast hole #1 encountered waste rock in a carbonate rich part of the iron formation.

Benefits

The phase II results have demonstrated that the magnetic susceptibility tool provides reliable and efficient magnetite assays for magnetite in the large diameter holes.

In situ density measurements made during phase I indicated good correlation with Iron. Information provided in real-time from blast holes yields significant benefits:

a) tonnage estimation.
b) direct correlation to iron grade.

Based on the information to date the direct correlation of density (cps) to iron grade could not be accurately established in the 16 inch blast holes. This is explained by extremely high iron concentration that surpassed the ability of the source utilised in the tool to obtain direct iron / density correlations. However the results were encouraging enough to warrant further investigations with respect to source size and activity including the use of the micro-density probe that was first utilised during phase I.

Routine logging of delineation holes can provide accurate in-situ data necessary for efficient mine planning. Thin marker beds can be identified for hole to hole correlation and assist in stratigraphic interpretation. Rock strength properties identified from density and sonic information will provide excellent geotechnical information such as Young's modulus and Poisson's ratio.

The cost benefits that can be realised by optimising the mining process through the routine logging of bore holes at the IOC mine are substantial. By collecting physical property information both at the delineation stage and in large diameter production blast holes I.O.C. can directly: reduce lab assay costs, increase timeliness, yield more efficient mine plans based on a higher level of ore grade and geotechnical information provided in real-time, and most importantly, optimise the downstream process of concentrating and pelletising. Ultimately I.O.C. will improve the product quality.

Discussion and Conclusion

The forward thinking of Iron Ore Company of Canada to carry out a mine site assessment for physical property determination of their deposit has lead to several benefits. Additional examples exist at the mine development stage where use of physical property analysis was utilised to effectively and more accurately delineate a body through increased use of percussion drilling. A Noranda study (McCreary, 1995) determined that there was an increase in ore body intersections of between 50-90% from redirecting 30% of a delineation drilling budget to percussion drilling and geophysical logging. Other studies by Noranda have indicated that at base and precious metal mines throughout the world 8 % of the ore was left in the ground and that an additional 20% of unplanned dilution was run through the mill, the potential cost savings were estimated at 54 million US dollars.

Mutton (1997) also documents the substantial positive benefits of this technology. But also comments that “the barriers that remain are largely related to acceptance by the mine operators and the integration of the technology with the mining process”. Effort by mine management should be made to become aware of these technologies in order to realise their cost saving benefits. Increased pressure from lower metal prices should encourage the integration and acceptance by new and existing mines of this proven technology.

The rapidly changing nature of the global economies makes it difficult for existing suppliers of natural resources to maintain consistent profitability and in some cases even viability. It has been recognised that diminishing metal prices necessitate the optimisation of mining operations. One of the crucial steps in the optimisation process is the integration of the information gathered by the respective disciplines of geology, geophysics, engineering and operations. Obtaining accurate quantified data pertaining to the variables associated with these disciplines is paramount to the optimisation process. Through the incorporation of borehole logging into the mining process, optimisation can be achieved. Adding essential knowledge will improve geologic models and mine plans that will directly lead to significant improvements in mine operations.

Today’s programs can provide routine logging of all bore holes, hole to hole evaluation, principal component evaluation and the integration of data into accurate 3D common earth models with programs such as GOCAD and mine planning software such as Vulcan. The concept of virtual logs is now a reality. Predictive logging coupled with the increased use of less expensive percussion and non-coring methods has already been contributing to improved efficiencies in mine operations.

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