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Evaluation of Banded Iron Formation using Magnetic Susceptibility

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SUMMARY

In a banded magnetite deposit where assays gave no indication of concentrate yield, information required for process plant design was derived from downhole magnetic susceptibility logs.

Early analysis showed poor correlation between Davis Tube Recovery (DTR) and downhole magnetic susceptibility. The role of anisotropy in this relationship was identified and a correction factor applied to bring all data to an equivalent core to bedding angle. The result was a very high definition measure of in-situ magnetite distribution from which product yield estimates could be made.

The definition of ore type according to magnetic susceptibility profile enabled the content of potential Run of Mine ore to be characterised. Information required for front end plant design relating to economic cut-off grade, magnetic separator configuration and waste rock volumes could be estimated at an early stage of project development.

The use of geophysical data has now been applied successfully to other banded formations where conventional mining block models fail to deliver the resolution of data required by process engineers.

Key words. Magnetic susceptibility, banded iron-formation, anisotropy, mining yield, magnetite

INTRODUCTION

The resource in this Australian iron ore project consists of magnetite banding separated by iron magnesium silicate and primary silica. This sub-vertical package with typical thickness around 40m to 60m is made up of banded magnetite separated by strata of amphibolite waste rock. Assays taken during exploration drilling showed little or no variation in iron content on moving through the magnetite and amphibolite layers. The process of using DTR tests to establishing a JORC resource by sampling drill core at 4m to 6m intervals had been established

This Banded Iron Formation (BIF) most likely originated as a sedimentary deposit which was later modified by heat and deformation. In this geological metamorphic process, the ore body has undergone folding and twisting as well as displacement by faulting and shear. As a result, the BIF ore body presents at various angles of dip, ranging between 20° and 90° to the horizontal. Due to the combination of variable dip angle and the hilly regional terrain, resource drilling has intersected the orebody at various angles ranging from down-dip holes at 0° up to true thickness holes intersecting at 90°.

The angle of intersection of the drill with the BIF horizon was indicated by the angle of banding of the core. This angle (α) was measured and entered into the geological logs with a high degree of interval resolution. Various presentations and banding angles together with density and magsus (magnetic susceptibility) traces are illustrated in Figure 1.

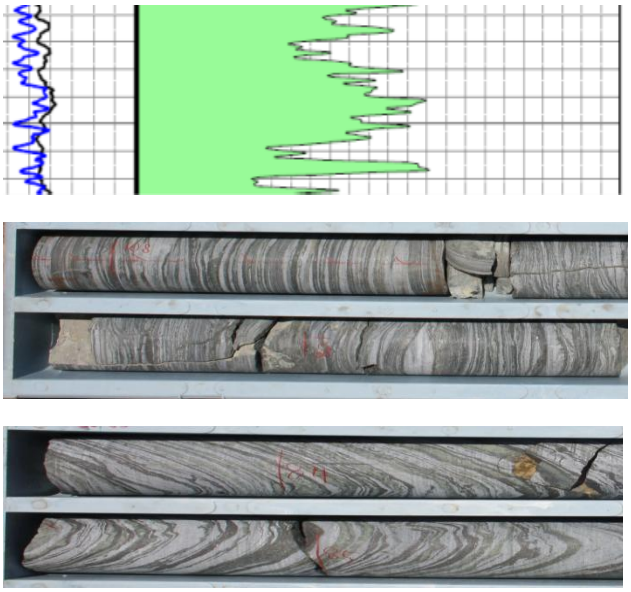

Figure 1. Illustration of magnetite banding and the variation in core to bedding angle. The magnetic susceptibility and density traces of this lower grade ore type are shown above.

By far the majority of exploration drilling had been carried out using NQ2 diamond drilling. When focus shifted to the metallurgical program, drill diameter was increased to PQ size. The wireline data supplied for the larger diameter format was therefore converted to the NQ2 size using guidelines supplied by the probe manufacturer. The resulting conversion to PQ shifted the magnetic susceptibility data off-scale. A cross calibration exercise was therefore carried out using twinned PQ and NQ2 holes which conformed to within 1m separation for their entire depth. The magsus traces from the

twinned holes were matched and the SI values of peak and trough recorded and plotted in Figure 2.

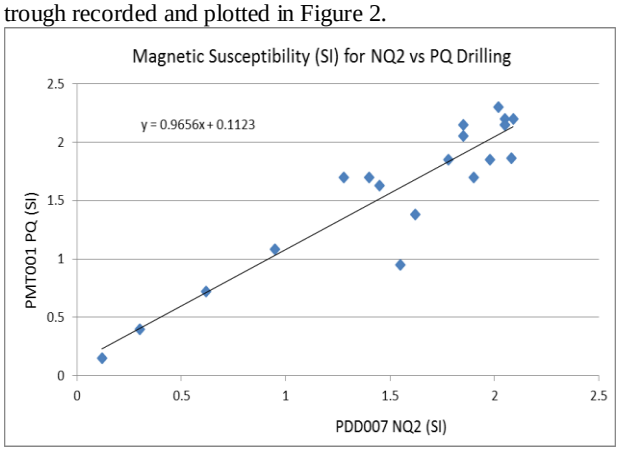

Figure 2. A plot of downhole magnetic susceptibility values at matching peaks and troughs from twinned PQ and NQ2 drill holes.

The magnetic response of the probe to drill diameter was not greatly affected. However, the correction value determined in this test was applied to all subsequent diamond drilling.

A similar test was carried out on twinned RC (Reversed Circulation) and diamond drilling. The consistency of magnetic response in the RC hole was very poor, a factor attributed to surface roughness and irregularity of diameter. However, due to issues with ground conditions and near-surface rock stability the RC drill program was shelved.

THE DTR / MAGNETIC SUSCEPTIBILITY RELATIONSHIP

The magsus data from resource drilling was measured at 0.01m intervals during the logging process and stored in the database. A representative magsus value was then taken by averaging 0.01m values over intervals corresponding to the DTR samples. These magsus values, extracted from 22 drill hole logs were plotted against %DTR in Figure 3.

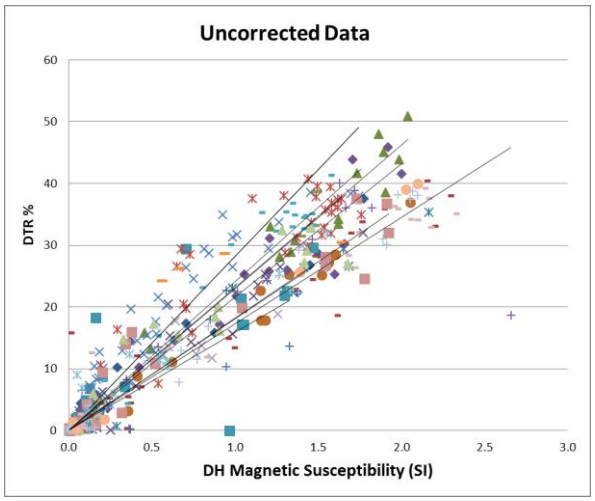

Figure 3. Uncorrected downhole magnetic susceptibility data plotted against the corresponding %DTR recovery measured on 4m-6m core intervals.

There was a considerable data scatter in this plot with DTR values ranging from 25% to 40% recorded at a magsus value of 1.5. The trend lines of individual drill holes showed a large spread in gradient which was largely indicative of the variable angle of intersection with the BIF.

The subject of anisotropy of susceptibility was investigated and options for its measurement reviewed in discussions with the Geophysics team at CSIRO, Earth Science & Resource Engineering. Their previous work on Hamersley Basin and Yilgarn BIF (Clark and Schmidt, 1994) indicated that effective susceptibility parallel to the bedding plane exceeds the susceptibility normal to bedding by a factor of 2-4. The anisotropy of remanence was also observed to display this type of behaviour. This was consistent with the degree of variation observed in the gradient of DTR plots as a function of bedding angle. The downhole probe registered higher magnetic susceptibility values as the angle of intersection with the BIF approached 90º.

A method of correction was adopted after merging the geological logs of banding angle, α into the resource model database. For calibration purposes, an average value for α was taken across each DTR sample interval. The magsus data from a drill hole which displayed the greatest alpha angle was selected as the true thickness (90°) reference point. The degree of shift required to bring all other magsus data into this reference position at 1.8 SI was determined. The relative shift applied at 38º and 65º is illustrated in Figure 4.

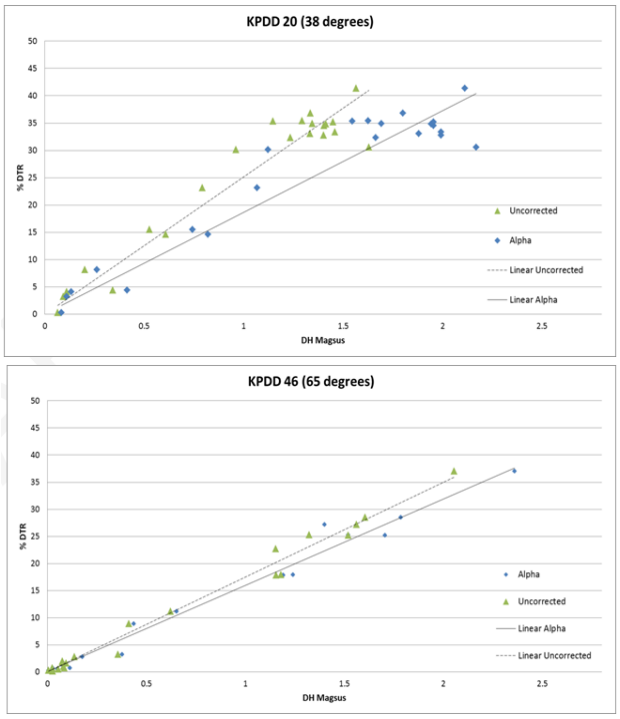

Figure 4. An illustration of the linear correction determined from the best line fit of %DTR values. The correction was applied to bring all magsus data to a 90º basis. Data scatter was seen to be greatest in the low angle intersections.

The linear correction values determined from the best line fit for each drill hole were applied to the drilling data and plotted in Figure 5.

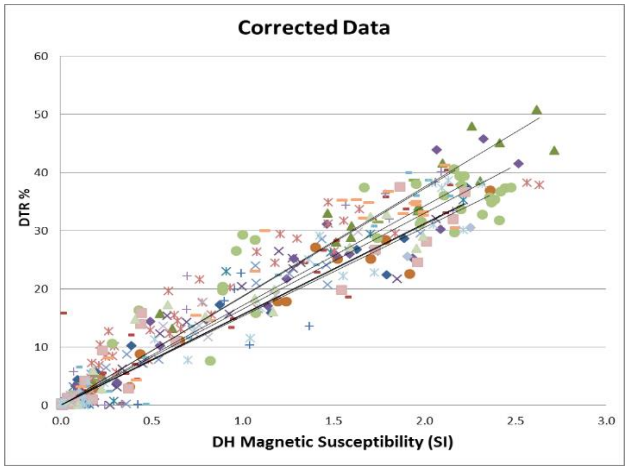

Figure 5. Corrected magnetic susceptibility values plotted for 22 drilling data sets. The gradient of the plot of magsus with Davis Tube Recovery reflects a bedding angle of 90º.

The shifting of magsus values gave an improvement in the alignment of data. An exception was to be found in the correction of the very high yielding intervals, say in excess of 55% DTR. Correction for low angle intersection of these intervals tended to produce magnetic susceptibility values exceeding the 2.5 SI saturation point of the detector. Examination of core structures of these members showed massive magnetite with no visible banding.

The correction of data produced a marked reduction in slope effectively giving a lower DTR for any given value of DH magsus. A relatively high degree of data scatter remained, however, particularly from drill holes with low angles of intersection with the BIF. This may be explained by the acknowledged error in sampling of down-dip holes. A consistent rule was applied in the selection of the quadrant of core taken for DTR tests despite large variations of magnetite distribution being visibly apparent.

The degree of correction, or % change required to bring the magsus data into the 90º format was plotted against the angle of intersection as shown in Figure 6.

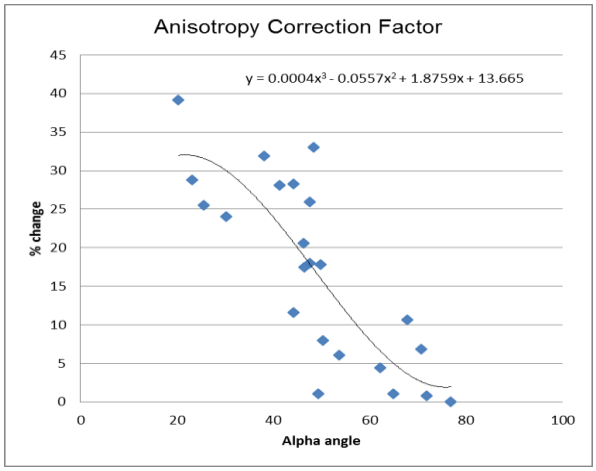

Figure 6. A plot of the individual linear correction required to bring magnetic susceptibility values for each drilling data set into the reference 90º format.

A polynomial function was chosen as being the most appropriate mathematical function to represent angular correction, i.e., a sinusoidal wave form describing the angular rate of change during rotation.
The anisotropy correction equation relating alpha angle to the percentage change in magsus data was given as:

$$\% \text{ change} = 0.0004x^3 - 0.0557x^2 + 1.8759x + 13.665$$

It was apparent from Figure 5 that a significant degree of error would remain in this approach to predicting DTR from downhole logs. These errors may be attributed to several sources, including:

- Localised deformation angles in the BIF
- Variable anisotropy due to band thickness
- Long core intervals used in DTR testing

Although the initial anisotropy correction was carried out using best line fit for each drill-hole, detailed information on core to bedding angle had been compiled in the database. This would give the potential to predict DTR outcomes over relatively short intervals.

The issues of variable thickness of magnetite banding and localised deformation of the BIF were examined by analysing the project on a regional basis.

The iron ore resource extends along a linear strike from District A in the SW to District C in the NE. This is separated by an intermediate strike running through District B. The formation in the NE contains more massive, undiluted magnetite sometimes devoid of banding. BIF in the SW tends to consist of limbs dipping from 20° to 50° in multiple ore horizons. Correction factors developed on a regional basis therefore gave DTR predictions more specific to ore structure.

However, before proceeding with any application of this approach, confidence in the accuracy of DTR prediction was required. This was provided in the approach taken to the design of the metallurgical testing program.

THE GEOMETALLURGY APPROACH

In support of the Definitive Feasibility Study an approach was taken to identify "pure forms" of the various lithologies and ore types present. These were selected according to the magnetic susceptibility profile with note taken of lithology. The inclusion of these parameters in the database would allow outcomes to be merged into the resource and mining models. This would provide details of processing yields for use in mine scheduling.

In the metallurgical test programme, a series of variability test samples were taken from PQ core. The physical properties including grinding hardness and strength were measured and the product yield (DTR) determined at 3 grind sizes on core intervals typically 2.5m in length.

The average DTR yield for the variability samples was determined and compared with the prediction made using alpha angle correction. The results are shown in Figure 7.

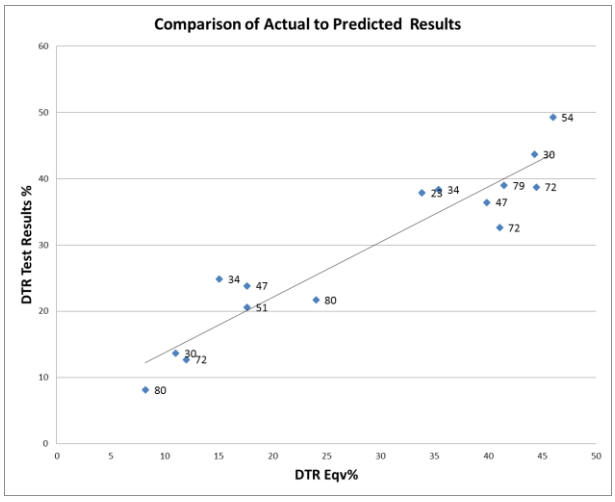

Figure 7. Predicted values (DTR Eqv) vs the actual DTR% reported in the metallurgical variability tests. The localised core to bedding angle for each test sample is indicated.

The prediction of DTR from DH magsus was considered to provide a useful degree of accuracy when considered over the full range of values. In this set of tests, non-conformance to prediction would not be attributed to sampling error as no quartering of core was used for DTR tests. No systematic error was attributed to either region or bedding angle.

As a result of this confirmation, the DTR Eqv values were imported into the mining model. A section through the deposit showing the distribution of high magsus values in the multi-limbed District A section is illustrated in Figure 8.

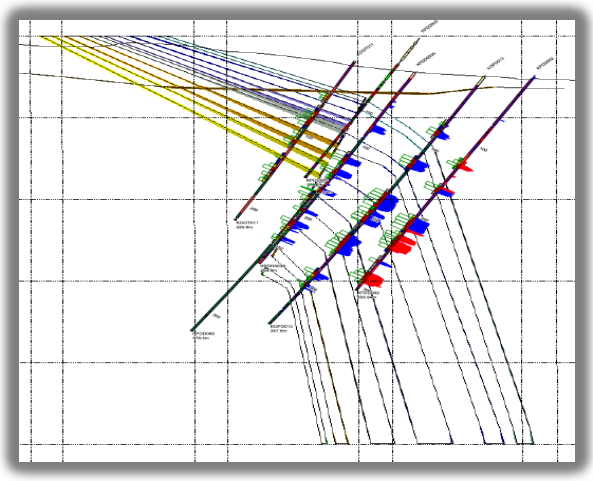

Figure 8. An illustration of a modelled section with line graphs through the multi-limbed structure in District A. High resolution DTR estimates would enable mining dilution and process plant yields to be estimated.

The high resolution data available in this type of 2D section would allow important mining and processing parameters including mining dilution and export yield to be estimated.

APPLICATION OF GEOPHYSICAL DATA

Where an ore body presents as a banded package, the adaptation of core sampling outcomes into the mining block model results in a significant loss of structural definition. At this point in project development, questions posed by process engineers relating to front end separator design need to be addressed.

In the case of this magnetite project high resolution susceptibility data presented as 2D sections provided the means to estimate mining and package dilution, economic cut-off grade and gave promising insight into the prediction of concentrate quality in terms of silica content.

In using a "geophysical pure forms" approach the outcome of the metallurgical program could be assembled to form a process yield model of the deposit. The use of small scale particulate tests such as MAGNASAT susceptibility measurement also provided additional correlation with DH data in tests used to determine the configuration of coarse magnetic separators.

Magnetic susceptibility provided a very useful measure of localised grade distribution in a project where density logs provided very little guidance. Application of this Geophysics approach to mining development has been used with great success in other banded iron deposits where density logs provided the best measure of grade distribution. However, it is clear that each deposit will present with a modifier that needs to be understood in order to make a useful interpretation of the data.

CONCLUSION

In banded, veined or otherwise complex ore deposits the use of downhole geophysical logs can provide the high resolution of physical properties that allows process plant outcomes to be predicted. The use of low cost, small scale particulate tests can provide the key to inversion of the geophysical information for engineering design purposes.

REFERENCES

Clark, D and Schmidt, W., 1994, Magnetic properties and magnetic signatures of BIFs of the Hamersley Basin and Yilgarn Block, Western Australia: ASEG Special Publications, Vol. 1994 No. 1 Pages 341 – 354