A new blasthole XRF probe for mining grade control.

P. J. Hawke *
Wireline Services Group
24 Sarich Ct
Osborne Park 6017
AUSTRALIA
philhawke@wirelineservices.com.au

J. Bachmann
J&C Bachmann
Im Stöckmädle 23/1
76307 Karlsbad
GERMANY
jba@jcbachmann.de

*presenting author asterisked

SUMMARY

Mining grade control is often based on geochemical sampling of blast cones. Limitations of this method include a single assay result representing the entire length of the hole, the requirement of an on-site lab to meet turn-around times, bias generated by sampling of the blast cones and the risk of physical injury during sampling.

A new XRF logging probe has been designed specifically for providing elemental analysis through wireline logging. This tool will provide a continuous geochemical log down the length of the blasthole, allowing composite samples to be generated for different sections of the hole, e.g. to provide more detailed grade control to support selective mining as several flitches within an open-pit bench. Once the system is calibrated, results can be delivered as soon as logging is complete.

This paper presents the results of a series of bench tests demonstrating the accuracy and precision of the prototype BHXRF probe as a potential new grade control tool for different types of bulk commodity or base metal deposits.

Key words: wireline, logging, XRF, grade control.

INTRODUCTION

Elemental analysis is a fundamental component of mining grade control. A mine is usually designed and long-term planned from a resource block model. These models of grade distribution are generally based on laboratory-grade assaying at one or two metre sample intervals of resource drillholes that are typically spaced between 25 and 50 metres apart. To assist with the short-term mine plan for individual mining benches, the block model geochemistry is often supplemented with additional data obtained from assaying of the cuttings cones from the holes drilled for the purpose of laying explosives for blasting (blast cones). As these holes are commonly drilled at an eight to ten metre interval, this additional information can be used to more accurately define the boundary between ore and waste, for instance, within a mining bench.

While this is a common practise at many mines, there are three main limitations with the sampling of blast cones for grade control in short-term mine planning;

(1) The ongoing operational expense of physically collecting the samples by a geologist or pit technician, with the possible associated risk of strain injury, and then geochemically assaying the samples.

(2) The capital expense of constructing an on-site assaying laboratory, which is often required to meet the demand of short turn-around times between the blast holes being drilled and subsequent mining of the bench.

(3) The fundamental problem in representative sampling of the blast cone to deliver, at best, a single assay value based on a very small volume of material which is considered the "average" grade for the entire length of the hole.

Problems associated with poor representation of traditional geochemical sampling of blast cones can be overcome by elemental analysis through wireline logging of the in-situ material surrounding the hole. By collecting a continuous element log of the hole, not only is the overall volume of material assayed increased but it is also possible to determine potential variability of grade within the hole. This allows mine planners to predict grade boundaries in three dimensions at a mining block scale, not just as surface plan offering greater options for planning selective mining of the resource, for example by dividing and mining a single bench as several flitches.

Currently, the most developed wireline logging tools for *in-situ* elemental analysis are based around the prompt gamma neutron gamma activation analysis (PGNAA) technology, in which fast neutrons generated by the tool interact with the nuclei of atoms in the formation that, in-turn, emit gamma rays of an energy which are characteristic to each element. Through analysis of the energy spectrum of the emitted gamma rays it is possible to predict both the presence and relative concentration of different elements surrounding the tool.

Early developments of this technology by the CSIRO using a small radioactive neutron source demonstrated the ability to map variations in the iron, silica and alumina content of iron ore blast holes (Eisler et al, 1977; Borsaru, et al, 2002) although the grades varied by up to four percent compared with laboratory analysis of material sampled from the same holes (Borsaru et al, 2002).

Current generation tools based on this technology utilise fast and thermal neutrons generated by an artificial source, thereby lowering the risks associated with using a radioactive source. Such a tool has been operating at BHP Mines to assist with grade control the Pilbara for the past few years, although the technology still reports a RMS error for iron estimates when compared with laboratory assays of about 3.6% (Sodern, 2017).

The main point of resistance in the uptake of this technology by the mining industry, however, is not the accuracy of the measurements nor its relatively large size but the high unit cost of the instrument.

This paper describes an alternative wireline elemental analysis tool based on x-ray fluorescence (XRF) technology which is intended as an inexpensive, fit-for-purpose tool to assist with grade control assaying of blast holes for short term mine planning.

X-RAY FLOURESCENCE

When materials are exposed to short-wavelength X-rays or to gamma rays, ionization of their component atoms may take place. Ionization consists of the ejection of one or more electrons from the atom, and may occur if the atom is exposed to radiation with an energy greater than its ionization potential. X-rays and gamma rays can be energetic enough to expel tightly held electrons from the inner orbitals of the atom. The removal of an electron in this way causes the electronic structure of the atom to get unstable, such that electrons in higher orbitals can "fall" into a lower orbital to fill the hole left behind. In falling, energy is released by the electron in the form of a photon of energy equal to the energy difference of the two orbitals involved. Thus, the material emits radiation, which has an energy characteristic of the atoms present. The term fluorescence is applied to phenomena in which the absorption of radiation of a specific energy results in the re-emission of radiation of a different, but characteristic, energy. This energy is generally lower than the energy of the exciting photon.

This principle can be used for elemental analysis. Material is irradiated with X-ray or gamma radiation and the excited radiation is detected. The wavelength of the fluorescence radiation tells exactly which element is present in the investigated material while the intensity of the radiation at this wavelength correlates with the concentration of the element in the sample. Although there are side effects which have to be regarded (matrix effects which influences specific intensities) this method is widely used in the laboratory for precise elemental analysis. There the measurement is performed on well prepared and fine ground subsamples which are representative of a larger bulk sample. Hand held devices utilizing this principle are also widely used, although these have a lower absolute accuracy.

This technique has been utilized by J&C Bachmann to construct a commercial for real-time elemental analysis of ore on moving conveyor belts named TEXAS (Bachmann, et al, 2015). In this system, an X-ray tube irradiates the material while an energy dispersive sensor monitors the fluorescence radiation. The generated spectrum is then analysed to determine elemental concentrations in the ore. The analyzer is mounted directly on a conveyor belt so that a strip of sample is continuously measured, resulting in a more representative measurement of the overall grade of the material over traditional "point sampling" by geochemical assay.

BLAST HOLE XRF PROBE

The principles used in the TEXAS analyser system has provided the basis for constructing a wireline tool to determine the elemental composition inside of a borehole (Bachmann et al, 2014). The main challenge in this application is in fitting all the components required for an XRF analyzer into the diameter of borehole probe. The main components of the XRF analyzer include the X-ray tube, a high voltage power supply, detection system, device control and uphole communications.

As all known standard XRF and power supply components exceed the allowed dimensions of a typical slimline wireline probe (50-60 mm outside diameter) we decided to construct a wider diameter probe (125 mm outside diameter) which will still be able to comfortably fit inside blast holes (Figure 1). In this configuration the probe is 112 cm long and weighs 22 kg, which is small enough to be able to be handled and used by a single operator.
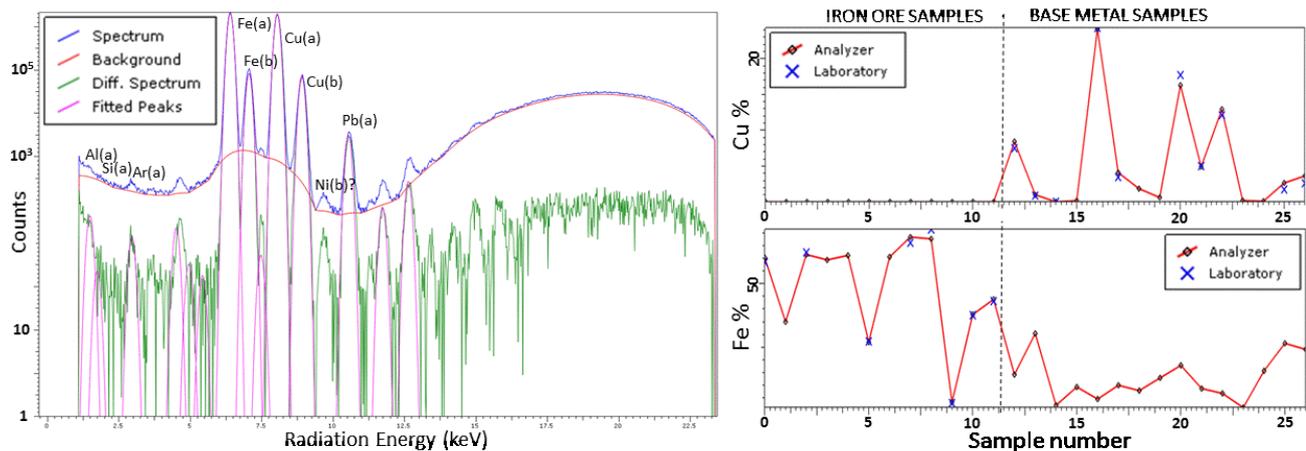

Figure 1: Prototype 125 mm blasthole XRF probe during bench testing.

While standard, commercially available components for the main XRF analyzer and power supply systems were able to be used in the construction of this new probe with only slight modification, the communications system to transmit information between probe and surface had to be re-designed from conventional logging systems. While the prototype XRF probe can be connected to a standard winch with 4 core logging cable for power and signal transmission, a modified version of ethernet communication over power cables is used for uphole telemetry.

The logging tool is designed to make measurements of the observed fluorescence spectra at 20 second intervals, which translates to an average grade estimate over an approximately 30_cm depth interval at a logging speed of one metre per minute.

TESTING AND RESULTS

From the observed fluorescence spectrum, a residual is taken to remove background response and the height of individual peaks corresponding to different element responses is measured. These peak responses are then placed into a calibration algorithm which determines a relationship with the elemental composition by comparison to a number of samples of known grade. This process is demonstrated in Figure 2, where the observed response of a multi-element metallic ore sample forms part of the calibration set for the prediction of iron and copper grades by the blast hole XRF probe.

Figure 2: Observed x-ray fluorescence spectra of known multi-element metallic ores (left) are used to create a calibration for converting measured peak response heights to a predicted elemental grade (right). Red lines show the predicted grades by the calibrated XRF probe against known laboratory assay values, shown as blue crosses.
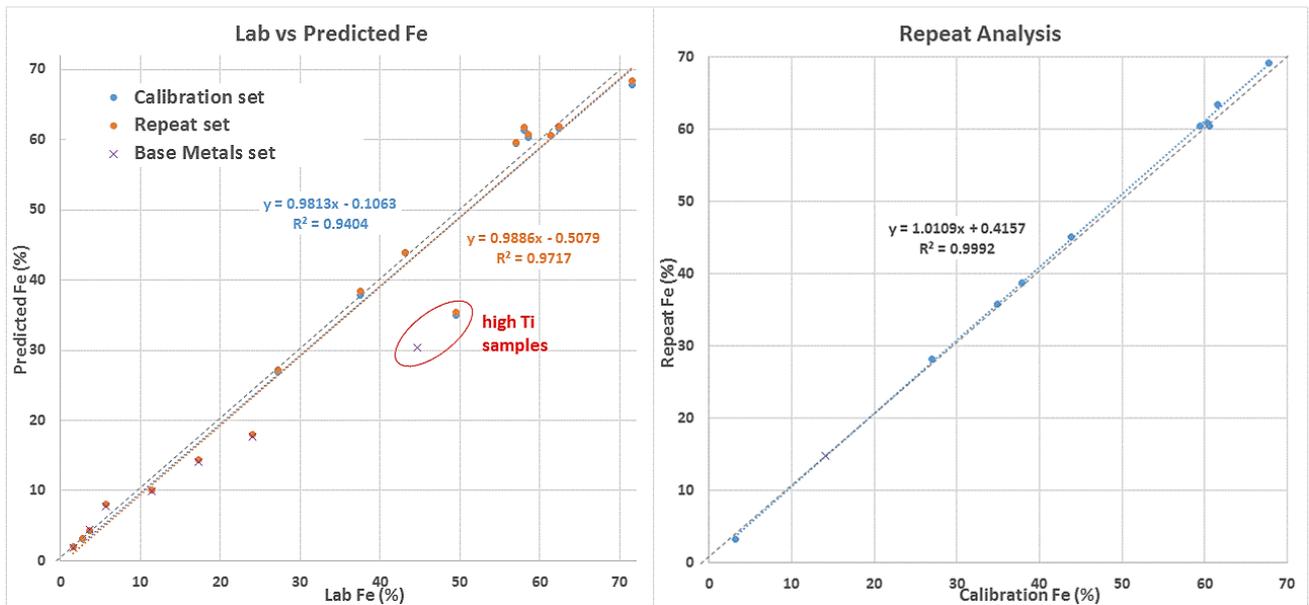
During June, a series of bench tests were conducted to test the nominal accuracy and precision of the blast hole XRF probe under ideal conditions. The instrument was calibrated against a series of commercial Certified Reference Material (CRM) standards for iron ore and base metal material. A sufficient amount of sample for each standard was used to fill a small zip-lock bag, which was then draped to fully cover the XRF window for the duration of each measurement.

XRF measurements were made with the tool for about three minutes per sample, resulting in 8 or 9 individual 20 second reading being collected. These were averaged to produce a composite spectrum for the sample, from which the peak heights were measured. The measurements from a selection of these samples, representing high, medium and low grade material, were then used to generate a calibration for predicting the percentage of iron, copper and nickel present within each sample.

By comparing the predicted grades of samples outside of the calibration data set, a fair estimate for the accuracy of the system can be established. The nominal precision of the tool was compared by comparing predicted grades from repeat measurements of the suite of samples. A second, but equally important, measure of instrument precision was established by comparing grade predictions made from each of the 20 second XRF readings with that obtained from the composite three minute spectra that was used for primary calibration.

The results of testing the predictions of iron grade made by the blast hole XRF are shown in Figure 3. A selection of the first round of measurement of the iron ore samples (calibration set) were used for the calibration of the tool. Predictions of the iron grade, using this calibration, were also made on a second round of measurements (repeat set) which were made several days later. While not included in the calibration for iron at all, grade estimates were also made on some of the base metal samples, also shown in Figure 3.

It was immediately noted that the XRF iron grades of (mafic derived) samples with a high titanium content were consistently difficult to predict compared with the main population of iron ore material, which was generally derived from banded iron formations and so were primary composed of iron, silica and alumina. The iron grades of these samples were consistently underestimated (Figure 3, left) and, consequently, were not used in the calibration of the tool.
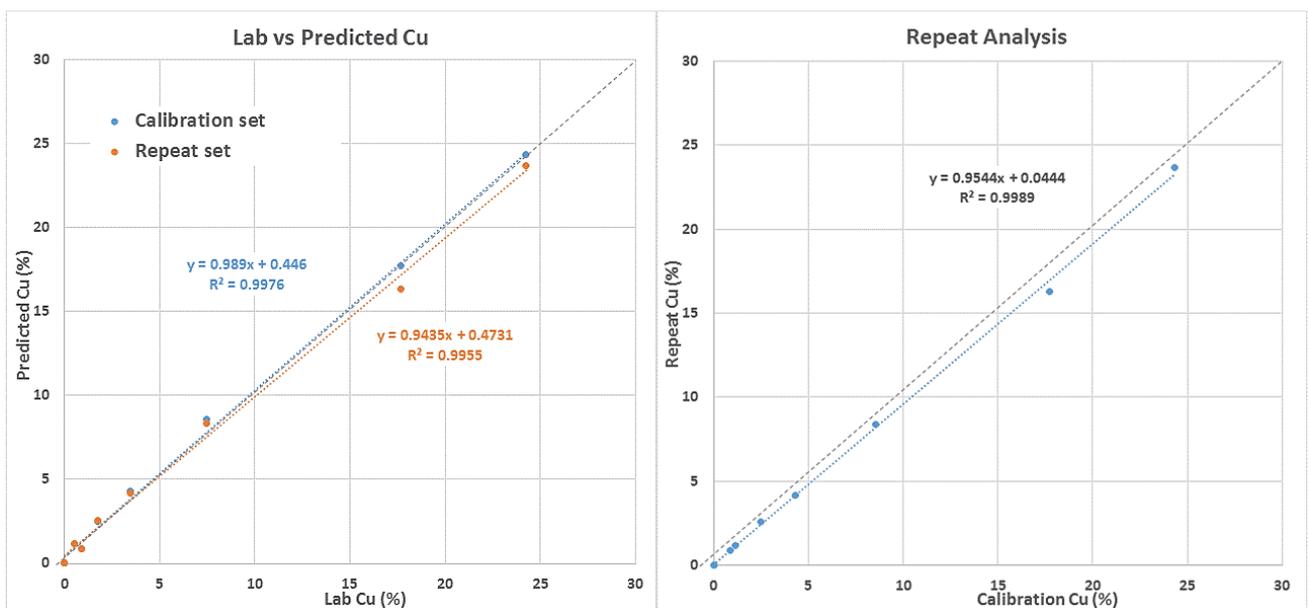
Figure 3: Comparison of iron grade predicted by the blast hole XRF against the laboratory assay grades of the CRM samples (left) as well the predictions of grade between the measurement made for calibration data set and repeat measurements taken several days later (right).

Excluding these problematic samples, largest absolute error between the predicted and laboratory iron grades for a sample outside of the calibration data set was 3.5% Fe (for a sample with an iron grade of approximately 60% Fe). The average difference between the predicted and laboratory grade for both the calibration and repeat set of measurements was 1.8% Fe, which is assumed to represent the nominal absolute accuracy of the tool.

The standard error between each of the 20 second readings that made up a single sample measurement was approximately 0.2% Fe. The average difference between iron grades estimated from the calibration and repeat measurements of the samples was 0.35% Fe (Figure 2, right), with almost no overall bias between the two sets of measurements. These values are assumed to be a good indication of the nominal measurement precision of the tool.

This experiment was repeated using a series of copper-bearing base metal samples, with the results shown in Figure 4. The results presented here do not contain any of the predictions from the iron ore suite of samples, all of which contained only trace (ppm) concentrations of base metals.
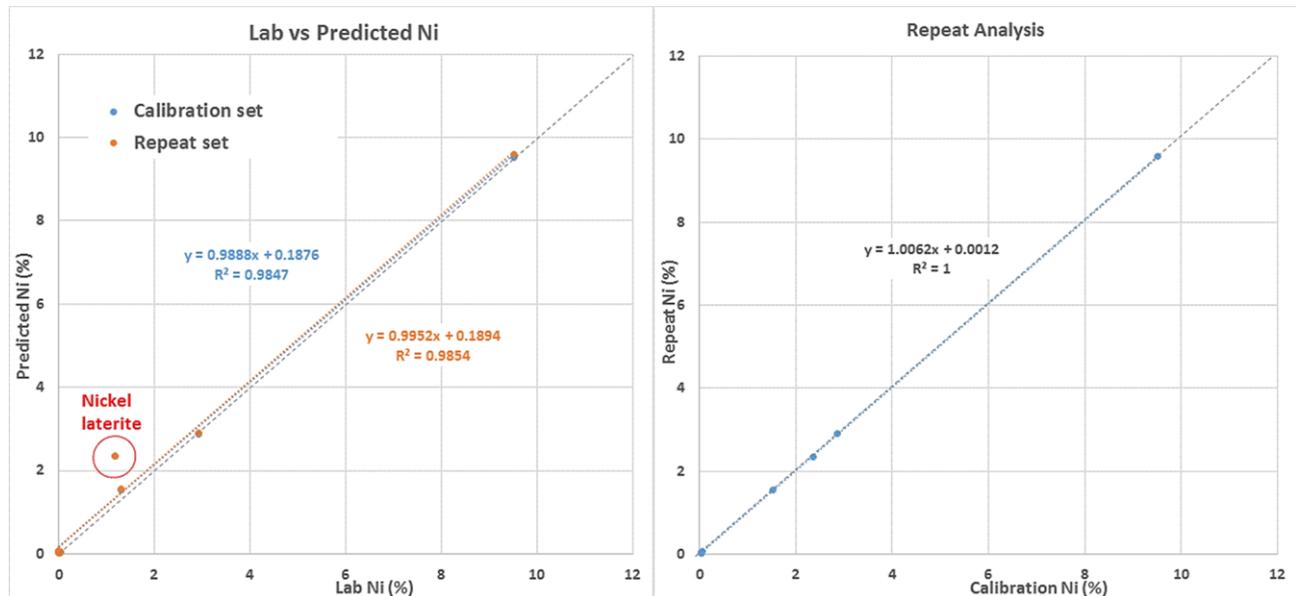

Figure 4: Comparison of copper grade predicted by the blast hole XRF against laboratory values and repeat measurements.

The largest error between the XRF predictions and laboratory assayed copper values was 1.4% Cu, which was for a high-grade sample containing 17% Cu. There was about a 4% relative bias between the XRF copper grade predictions between the first and

second round of measurements, which equates to an average absolute precision error of about 0.2% Cu for all samples included in the experiment. The standard error between the predictions derived from each of the 20 second readings was also about 0.2% Cu, which is assumed to represent the nominal measurement precision for this element.

A calibration for predicting the nickel grade using the XRF probe was also established using a smaller number of samples derived from sulphide nickel-bearing ores (Figure 5).

Figure 5: Comparison of nickel grade predicted by the blast hole XRF against laboratory values and repeat measurements.

This analysis showed an absolute measurement accuracy of approximately 0.25% Ni for the prediction of nickel grade in sulfidic ores, with an absolute measurement precision of better than 0.1% Ni. However, the system did consistently overestimate the nickel grade of one laterite sample using a calibration based off the sulphide ores.

CONCLUSIONS

We have constructed a prototype blast hole XRF probe which is proposed as a fit-for-purpose alternative to the large and expensive elemental analysis wireline tools that are based on nuclear (PNGAA) measurement techniques.

The use of essentially standard commercial components means that cost of construction of a single blasthole XRF probe is only a fraction of its nuclear counterpart. Its smaller size and weight also means it can be used by a single operator on a standard fit wireline logging truck. This makes it commercially viable to be able to include this elemental analysis tool as part of a standard suite of tools in a fleet of logging trucks rather than an exotic tool that requires a purpose-built vehicle.

The tool is intended to collect continuous elemental logs along the inside wall of the blast hole at a 30 cm sample interval, assuming 20 second readings and a logging speed of one metre per minute. The results of bench testing this tool against Certified Reference Material (CRM) standards demonstrate that this tool has sufficient measurement accuracy and precision to be of assistance in grade control for several types of metalliferous ores.

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