*Exploration Geophysics (1997) **28**, 127-129*

New Applications of Borehole Geophysical Logging in Mining and Mineral Exploration

Gavin Selfe

Anglo American Corporation of South Africa Ltd.,
Geophysical Services Department,
PO Box 61587,
Johannesburg 2107, South Africa.

ABSTRACT

The application of borehole geophysical logging in three different geological environments is presented. The three case studies discussed are: the evaluation of the Sendelings Drift alluvial diamond deposit near Oranjemund in Namibia; the Sadiola gold orebody in western Mali; and a kimberlite pipe in central Botswana. It is shown that the usefulness of borehole geophysical logging is not confined to the oil industry, and that quantitative methods such as those used in the oil industry may be effectively applied to any ore deposit via lateral thinking and a sound understanding of the relevant geology. The methods described are considered especially useful in the case of marginal ore bodies where a rapid three-dimensional understanding of the deposit may become critical.

Keywords: borehole geophysical logging, Botswana, Mali, Namibia, alluvial diamonds, gold, kimberlite, orebody evaluation

INTRODUCTION

Borehole geophysical logging has long been a critically important part of the oil exploration industry, but has seldom been as successfully and as quantitatively applied in the diamond, base metal and gold geological environments. In these environments it has most often been used as a horizon delineation tool, with little or no attempt at quantification and further interpretation of the results. The Anglo American Corporation Geophysical Services Department (AAC GSD) has undertaken extensive research into these applications with some success. The methods discussed are useful primarily in the evaluation of new discoveries, and have proved especially important on marginal orebodies. These methods are not only capable of uniquely identifying the various lithological components of the wallrock, but also of accurately quantifying these components in a process of calibration and log unmixing. In combination with a variety of multi-disciplinary datasets, the geophysical log interpretation is also used to extensively aid the creation of a three-dimensional model of the orebody in a short space of time.

BOREHOLE PROBES USED

The borehole probes found to be most effective in the studies undertaken to date and described here are the density (g/cm^3), neutron (cps), and natural gamma (API) probes. These three probes prove useful under almost any circumstance. In addition, in certain conditions, the magnetic susceptibility (SI units), focused electric (ohm.m or mmho), P-wave sonic (m/s) and induction (ohm.m or mmho) probes have all been used effectively. A three-arm calliper probe is also used on every hole in order to ascertain the hole condition. All of the physical logging under discussion was undertaken by professional contractors.

CASE STUDIES

Sendelings Drift diamond alluvials

The Sendelings Driff alluvial diamond deposit is located approximately 70 km inland from Oranjemund on the north bank of the Orange River. For evaluation purposes the gravel terrace was drilled with a regular grid of holes down to bedrock (20 m to 30 m). The holes were geophysically logged with gamma, neutron, density, induction and calliper tools. The four objectives of geophysical logging were to aid in the quantification of: the clay and silt content of the gravel; the cementation (hardness) index; the boulder clast size; and the packing index. Estimation of the above parameters is subjective and at best only semi-quantifiable on examination of chips, and requires full-time input from the geologist involved. It was determined that both the neutron and induction logs were responding to the clay and silt components of the gravel, the clay horizons being more conductive and retaining more water than clay-poor zones. Figure 1 displays the linear relationship between these two logs with an increasing clay content.

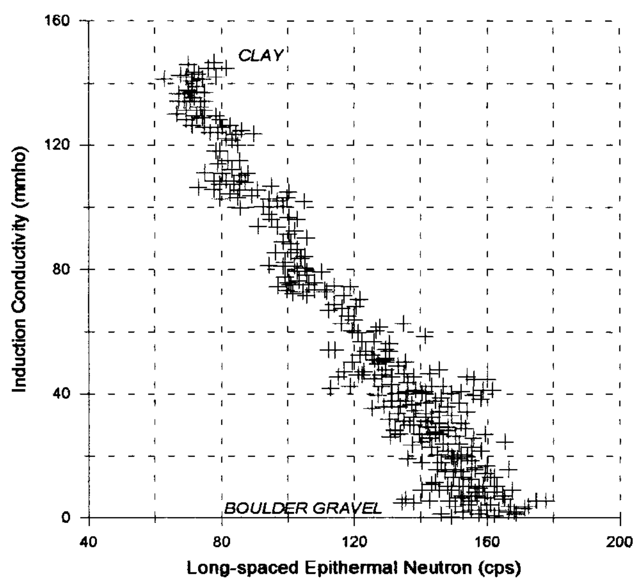

Figure 1. Cross-plot of conductivity versus neutron response for hole SE10\2, Sendelings Drift.

Both logs were calibrated using X-ray diffraction (XRD) data on a few trial holes to delineate problematic zones of high clay and silt content. On comparison with Portable Infrared Mineral Analyser (PIMA) data, it was found that the induction tool was more useful for clay quantification than the PIMA in this case, as it was responding to the bulk clay content of the entire sidewall. The PIMA responded to the amount of clay in the matrix only, owing to the nature of the sampling.

It was also established that the cementation or hardness index, important for mining in terms of blasting, could be semi-quantitatively derived by comparing the density, induction and calliper responses. The more highly cemented gravel horizons display higher density values, lower conductivities and smaller (less-caved) calliper values. Poorly cemented horizons are more conductive, less dense and cave more readily.

Two of the four objectives were therefore achieved. The clay and hardness models are presently incorporated into the mining plan for the deposit.

The Sadiola gold deposit

Geophysical logging of 162 holes drilled to a depth of 50 m in the Sadiola gold deposit was initially undertaken in order to create an in-situ density model of the orebody for reserve purposes. Conventional methods of density measurement (measuring mass and estimating volume) were found to be inaccurate in certain zones of the orebody due to material loss. The krieged geophysical density model of the deposit is incorporated into the mining database for the deposit as a result of this routine work.

However, by carefully analysing the geophysical density logs it was also established that these could be calibrated using XRD data in order to map the clay types present. Figure 2 is an example of the calibration for kaolinite. The calibration was produced at 2m intervals within the highly altered surface zone of the deposit for both kaolinite and smectite clays.

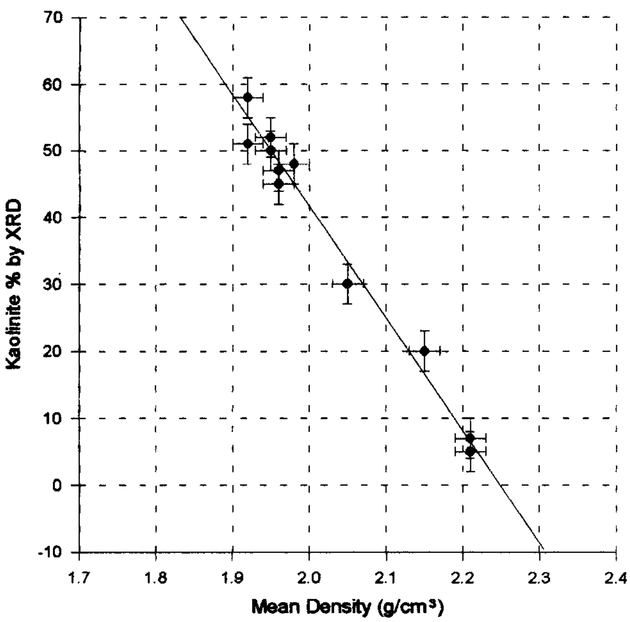

Figure 2. Calibration of mean density values for kaolinite mapping, Sadiola gold deposit.

This is of importance to the mine as both clays are potentially problematic in terms of ore treatment and plant processing. Good agreement with similarly calibrated PIMA logs was obtained and with hindsight the 3-D clay model for the mine, produced using a PIMA, could have been produced using the already established in-situ density database at a considerable cost saving.

A qualitative relationship between the lowest clay densities and highest viscosities, related to the degree of crystallinity of the kaolinite present, has also been tentatively established at Sadiola. The PIMA proved an invaluable calibration tool in this regard, as careful analysis of the spectra yielded an estimate of the degree of crystallinity of the kaolinite. This relationship requires further study, but a viscosity model for the mlne could conceivably be produced using again the already established in-situ density database.

It was determined that induced polarisation (IP) logs are effective in mapplng the sulphide-rich zones at depth in the Sadiola deposit. This may become very important if and when it is decided to extend the pit to deeper than 50 m in order to exploit this marginal ore zone. However, IP was not capable, nor were any of the other logs, of mapping high grade ore zones.

Kimberlite pipe

Quantitative interpretation of geophysical borehole logs by the MC GSD is most highly developed in kimberlite pipes as it is with such targets that the GSD has most of its experience. The kimberlite pipe in this case study is a 12 hectare body of marginal grade in central Botswana.

The pipe is very complicated, with multiple intrusions and a great deal of country rock assimilation. Previous logging trials in kimberlite have shown that the various subtly different kimberlite types and country rock lithologies present are uniquely identifiable by their in-hole geophysical signatures. It was also established that holes close together yield almost identical geophysically interpreted geological sections, evidence that data repeatability is good. Considering these factors, logging was undertaken in one hole in every cluster of three holes drilled into the kimberlite during evaluation. The tools used were the gamma, neutron, density, magnetic susceptibility and calliper probes. Logging of the P-wave sonic and focused electric probes was discontinued due to the low water table.

The project was successful because, with the use of detailed geophysical log interpretation, petrographic studies and chip logs for 40 holes, a three-dimensional model of the pipe to a depth of 300 m was created within the space of a few months. Five subtly different kimberlite types (not identifiable in chips, and two types not easily identifiable in thin section) were uniquely identified using a diagnostic neutron-gamma cross-plot. Four country rock lithologies were also identified. Figure 3 displays the typical plotting positions of these lithologies on the abovementioned cross-plot. Two very similar kimberlite types, the central hypabyssal facies and the TKB (tuffisitic kimberlite breccia), were later confirmed to be different (and given these names) by detailed petrographic study. The dyke in Figure 3 represents a calcium-rich kimberlite dyke which was not identified in the chip logs.

The percentage ore dilution by country rock was also calculated for each hole using the geophysical log responses, for reserve purposes. Bi-component log-linear, ternary (Figure 4), and in some cases five-component unmixing relationships, were solved using standard oil-industry and in-house software. Previous work, confirmed by detailed core studies, has indicated an accurate prediction of basalt content in kimberlite to within 10% using these methods. In this case study, country rock dilution percentages were digitally supplied at 10 m bench levels for incorporation into the mine reserve model.

Magnetic susceptibility was determined to be the most useful log for initially detecting sandstone and mudstone (wall-rock) lithologies, both having very low magnetic

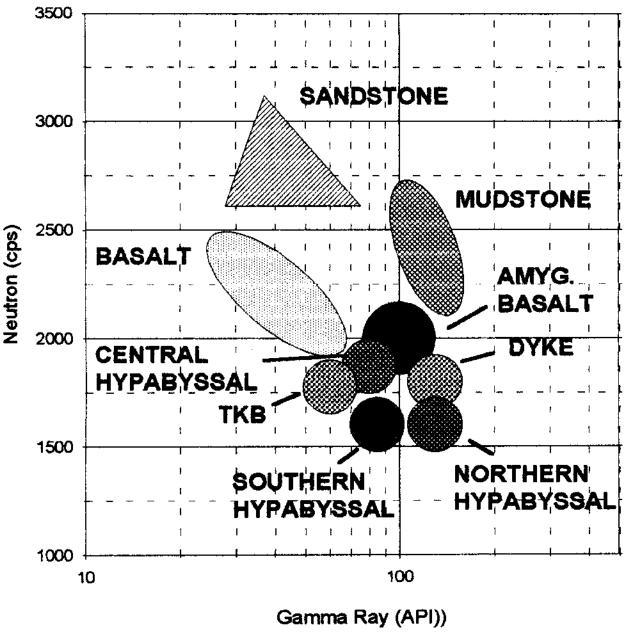

Figure 3. Neutron-gamma cross plot schematic of kimberlite pipe lithologies, central Botswana.

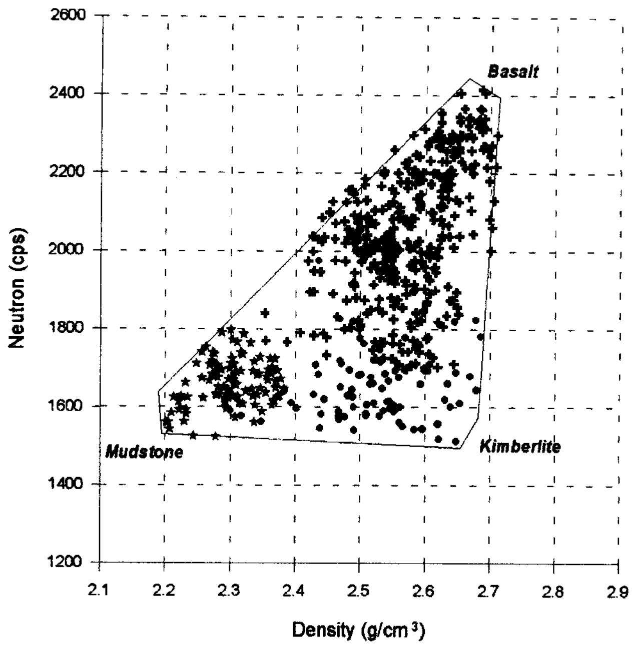

Figure 4. A typical neutron-density ternary unmixing relationship for basalt and mudstone in kimberlite, central Botswana.

susceptibilities. The gamma log proved most useful for separating between the two, with mudstone displaying higher gamma values. Density logs were utilised for identifying and quantifying mudstone within mudstone–kimberlite breccias, as it displays considerably lower density than kimberlite.

The information supplied by logging has proved critical in terms of the understanding of the pipe genesis and the creation of an accurate 3-D ore distribution model.

CONCLUSIONS

Borehole geophysical logging has proved to be an extremely useful tool in the evaluation of new ore deposits, in a diverse range of geological environments within which it has previously not been used to its full potential in South Africa. A new approach to the interpretation of such logs, with emphasis on quantification and calibration using XRD, PIMA and petrographic data, has yielded good results. The potential of this method in assisting the evaluation of almost any ore deposit awaits still further development.

ACKNOWLEDGMENTS

The author would like to thank Anglo American Corporation for supporting the development of this geophysical method, and for allowing this paper to be published. Thanks are also extended to the Oranjemund, Sadiola and Orapa mine geologists for their valuable input into these studies, and especially to Matthew Field of Orapa for sharing his extensive knowledge of kimberlites. Thanks, too, to Dave Underwood for making his PIMA data freely available.