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Geosensing for Exploration—New Technology for Underground Directional Drilling

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ABSTRACT

Geosensing is used in oilfield drilling in conjunction with geophysical tools to support characterization of rock properties, geology, and reservoir conditions. This technology is now available to the mining industry and has been successfully applied to underground in-seam directional drilling in Australian coal mines for geologic exploration and methane drainage. The system utilizes a range of drill rig and wellhead mounted sensors which, combined with analytical software, produce real-time data from which 3D spatial features can be accurately modelled significantly in advance of mining. This innovation greatly expands on the information obtained from current in-seam directional drilling practices and provides for improved characterization of coal seams, including soft and weak zones, locations of geologic discontinuities, and analysis of formation flow.

This paper provides a description of the geosensing system and the interpretation of actual data from long in-seam directionally drilled methane drainage boreholes at mines in Australia, and discusses how this system increases the value of directional drilling as an exploration tool for the coal mining sector, and the evaporite and hard-rock mining sectors where directional drilling is also applied.

INTRODUCTION

Background

Underground in-seam directional drilling is performed extensively in Australian coal mines as the primary tool for methane drainage in gassy mines. Although effective for methane drainage, in-seam directional drilling also creates an opportunity to record valuable geological data, which has not been effectively realized due to limitations in existing underground in-seam directional drilling technology.

Historically, underground in-seam directional drilling has been performed with methane drainage in mind, and not subsurface exploration. Geological uncertainty remains the bane of many high-capacity underground coal operations. There are many examples in which large geological structures (such as faults, intrusions, etc.) or smaller outburst-prone features have been missed by in-seam drilling programs, only to be subsequently intercepted by continuous miners or longwalls. This has serious safety and productivity implications and severely limits the development of mining automation technologies without greater certainty in geological interpretation in advance of the face.

Currently, these issues exist at many operations due to ambiguous interpretations of surface-based geophysical data; and the lack of certainty in data generated by surface exploration drilling and underground in-seam directional drilling programs, the latter of which are entirely reliant on the driller’s logs of “hard, soft, grey returns, coal/shale mix” or similar. Standards of reporting vary, and misinterpretation is common.

New developments in geosensing technology involve placing a series of real-time sensors onto existing underground directional drilling rigs, which integrate this data flow into the drilling process via interpretative software.

This technology has been applied at multiple high-productivity Australian longwall operations to effectively supply the information necessary to create geologic models, resulting in a complete reassessment of the overall exploration strategy in underground mining. This new approach also supports the management of outburst risk by providing key controls that reduce geological (including gas-related) uncertainty. An additional benefit of this new data is the provision of performance indicators for drilling operators using the system.

The results from this work provide a beneficial change in the management of geological risk by the utilization and subsequent visualization of reliable, interpreted in-seam directional drilling data.

The "Yabby"

CoalBed Innovations has been working in the underground in-seam directional drilling industry since the early 1990's and have long perceived the potential value of generating reliable geological data from in-seam drilling (for example, see Thomson, 1998; Brunner et al, 1999; Thomson, 2002; Thomson and MacDonald, 2003; Thomson et al, 2004: Thomson et al, 2006, and Thomson and Qzn, 2009). Many others have also contributed to the general discussion around getting more out of the inseam drilling process (for example, see Danell et al, 1995; Gray, et al, 2002; Hungerford, 1995: Lunarzewski, L. 1994, and Prochon, 2017). The lack of reliable, continuous, quantitative data, as is normal in exploration core drilling, was the main obstacle to further development of underground in-seam directional drilling for exploration.

Previously, the chief inhibitor to development in the underground in-seam directional drilling industry was the difficulty of placing permissible geophysical tools inside gas-producing in-seam boreholes. This has now been overcome by placing the measurement sensors on the rig and the wellhead, and by embracing some key principles common in oil and gas industry geosteering methodology and adapting them to suit the needs of the coal industry. This advance in data collection and interpretive power is now (Thomson et al, 2020a, 2020b, & 2020c) available to operators via the "Yabby" GeoSensing System.

HOW IT WORKS

Rig Installation Principles

Instead of investing in new downhole systems to create data, this approach involves implementing measurement and reporting systems onto existing machines. The measurement system (the "Yabby") is designed to receive a range of geosensing signals that currently remain operationally invisible.

The system consists of a series of sensors designed to measure and record the forces imparted on the drill pipe, pressures generated by the mud pump, speed and position of the drill bit, and flow rates of gas, water and cuttings, and gas compositions measured at the wellhead while drilling.

The sensors connect to a central enclosure mounted on the directional drill rig, and on the wellhead, where custom-developed software analyses the received signals to convert them into geosensing information. This data is then collected and downloaded or transmitted across a network for further processing and logging.

The system effectively converts underground in-seam drilling rigs into rock property testing instruments (Figure 1) that directly and continuously measure the mechanical properties of the formation along the borehole path through continuous destructive testing as drilling progresses. More than forty (40) individual drilling-related parameters are recorded and interpreted through software into a single property that resembles a wireline log trace. The key output is an objective measure of the observed rock strength relayed as an index of relative rock strength ("RSI"). The system is tailored to the individual drill rig, pump pressure and bit design to maximize the amount and quality of information obtained from the process. This new source of subsurface property measurement is combined with directional drilling data (positional and focused gamma) to generate detailed geological models and imaging that improves existing subsurface models. The system operates either in real-time or in a post-drilling processing mode.

Software and Processing

An immense amount of drill rig performance data is derived from the Yabby. Conceptually, drill rig monitoring systems are not new, although most are geared towards the enhancement of drilling performance and automation rather than geomodelling. The challenge for directional drill rig operators and mine geologists is to make sense of the data stream and deliver practical information. The software associated with the Yabby solves this issue and enhances the stream of data through ongoing calibration and quality checking throughout the process.

Visualization

As with most forms of geological data, visualization methods greatly enhance the practical value and impact of the presented results (Figure 2). Data from the Yabby GeoSensing system is processed using software and state of

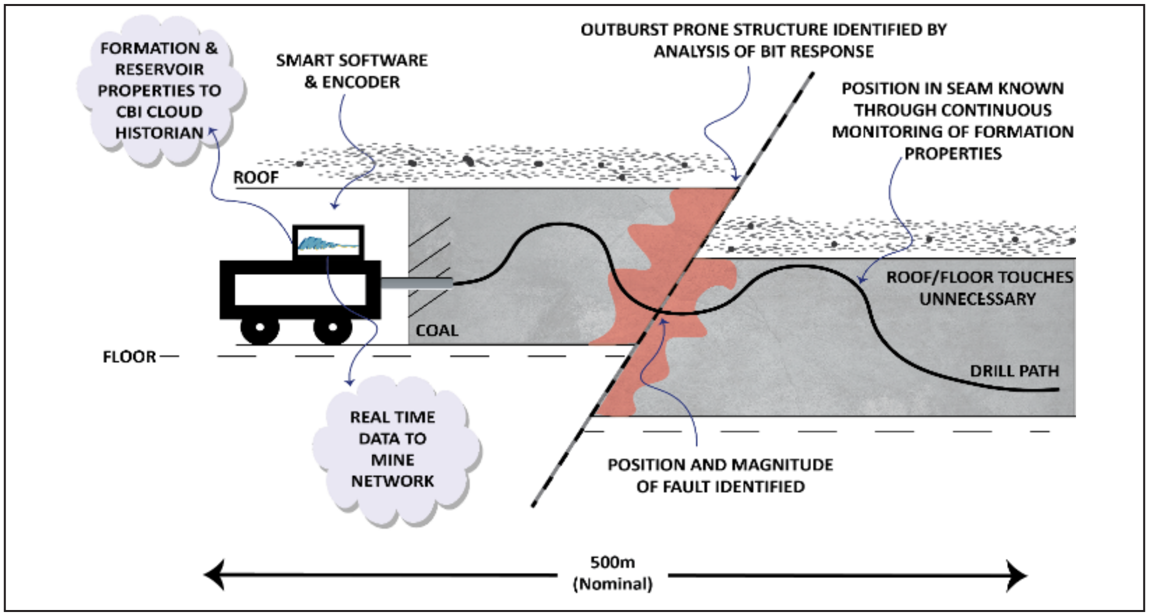

Figure 1. Schematic showing how the Yabby GeoSensing system provides information to improve geological models

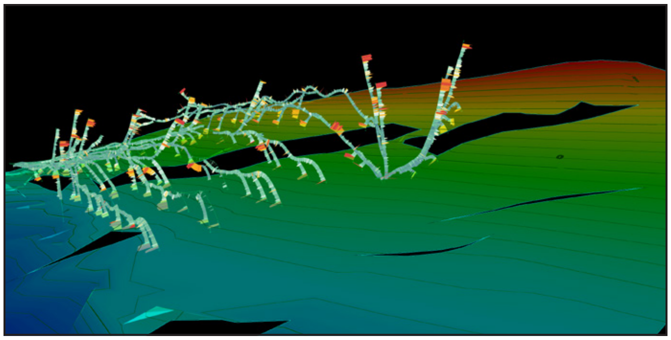

Figure 2. Visualization example using Yabby underground directional drilling data, superimposed on 3-D coal seam model showing interpreted structures. Relative hardness of the formation is represented by the hot/cold colors along the borehole path

the art oil and gas industry visualization tools, allowing for creation of images such as 3D wraparound perspectives as well as dynamic images.

USE OF RSI FOR GEOMODELLING

The properties of sedimentary rocks are anisotropic, varying greatly with changes in stratigraphic position while varying subtly with changes in lateral position. Significant differences exist when travelling up or down within the stratigraphy, and minimal changes when moving laterally within the same stratigraphic unit. This principle is obvious when you consider that within vertical millimeters, ground conditions may change through several coal lithotypes to sandstone – whereas a thin sandstone or tuff layer may persist laterally for kilometers. The Yabby system is also sensitive to variations in coal lithotypes.

This observation translates into what may be considered a stratigraphic strength profile: a characteristic signature that reflects the specific part of each seam the drill bit is cutting in. The shape of the profile may be used to correlate bit stratigraphic positions with high accuracy relative to the rock. The correlation between the bit stratigraphic position and strength profile is used as the key validator for modelling the actual borehole position relative to the stratigraphy, which is essential for geomodelling (Figure 3 and 4). The coal systems are clearly visible as low-density (low RSI) zones. The rig monitoring system reports data at a very high resolution, as the sampling density is effectively a continuous process as drilling advances. Sensitivity to strata changes depends on the unique properties of each formation but can be tailored to each seam through the software and even by modifying the drill bit to provide the necessary detail.

The unique properties of each rig and coal seam are modelled, and the possibility exists to tailor drill bit designs to magnify variance in stratigraphy, providing greater contrast and improving results accordingly.

APPLICATIONS FOR MANAGEMENT OF METHANE DRAINAGE

Globally, knowledge of a coal seam's gas reservoir properties is typically derived from sporadic, high resolution, low

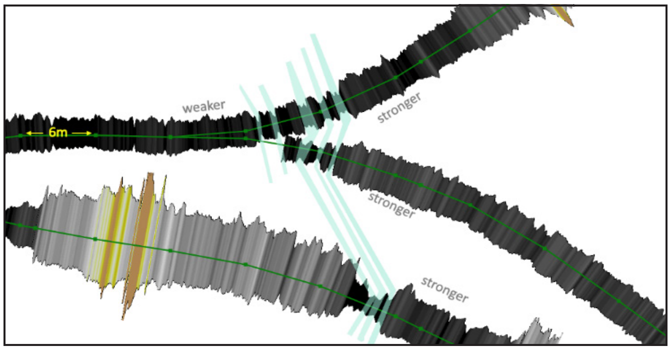

Figure 3. An example of an RSI log generated from the Yabby GeoSensing system shows relatively stronger and weaker parts of the formation. A crush zone (green) related to a structural disturbance is obvious. Non-coal zones show up as grey-brown

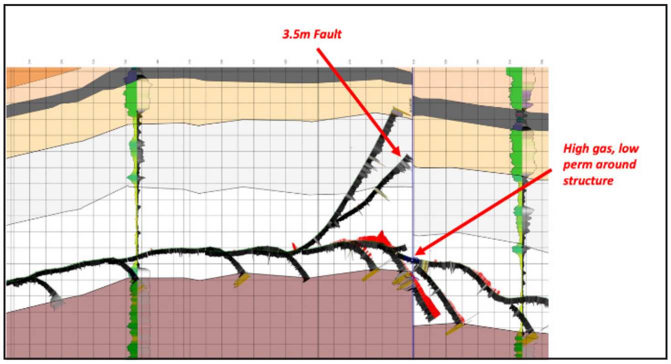

Figure 4. An example of an underground directionally drilled borehole and interpretation showing a substantial fault and higher gas emissions (red) around the structure. Integration of the model with vertical boreholes (if available) is part of the process - in this case, two vertical boreholes have been utilized as data inputs

lateral certainty spot sampling or through gas desorption and isotherm testing. Permeability data is typically sparse, and desorption rates and sorption capacity are derived from laboratory-based tests.

The authors support a change to this methodology by adopting a risk-based approach that measures a much greater volume of actual coal seam gas reservoir data and incorporates a strategy of risk management that proportionally considers the many elements that affect gas outburst risk.

The tools now exist to vastly improve our understanding of the gas reservoir properties of a coal seam, where underground in-seam drill-mounted gas analysis systems can provide vital geological and gas reservoir data, including gas content and make, desorption rate, permeability, RSI, and Gas Pressure continuously within a borehole. This provides a database of essential data for the entire length of an in-seam directionally drilled borehole. Instead of relying entirely on sporadic and potentially unrepresentative core-based data, a holistic view of the coal seam gas reservoir ahead of the face is now attainable with the Yabby GeoSensing System.

Yabby-derived RSI values identify zones of weak coal that may present an increased outburst risk (see Figure 3). Another development brought about by the Yabby GeoSensing System is real-time measurements to determine dynamic changes in gas flow properties within in-seam boreholes (see Figure 4 and Figure 5).

Filtering noise from gas surges is the main obstacle for gathering meaningful gas flow data from in-seam boreholes. It is well known that in-seam boreholes produce gas during drilling. It is less well known that the gas produced during drilling is a combination of gas that is progressively released from the formation surrounding the hole, and gas released by the drilled coal cuttings. By analysis of a continuous total gas rate signal, the component signals may be separated and utilised to directly measure gas-related properties during drilling.

A gas flow rate sensor is installed on the gas outlet of the Yabby Geosensing System's water/gas separator. The capacity of the gas sensor may be tailored as necessary to accurately observe gas rate and gas rate dynamics.

The signal interpreted by the Yabby Geosensing System contains multiple layers of information that must be separated, including a cumulative gas rate (in litres per second) which provides the baseline data (as gas from the entire borehole continues to contribute to the total) and a transient gas rate which reflects the effect of cutting through new parts of the strata. Separating the 'noise' from the balance of the signal results in a Formation Gas Production

Figure 5. Outburst event measured downhole. Note sudden peak gas influx (green) and steadily increasing density of returning drilling fluid (red) due to structure-related crushed coal flowing into the borehole

Index (GPI), which identifies the parts of a formation that produce the most gas.

DRILLING MANAGEMENT

The Yabby GeoSensing system has the potential to significantly increase the value of information from in-seam directional drilling, making the underground in-seam drill rig an important exploration tool in underground mining. Practical changes on an operational level will include a reduction of the need for tangential exploration boreholes, roof and floor touches, for example, and increase the use of the underground directional drill rig beyond just routine gas drainage. The Yabby GeoSensing system increases underground in-seam exploration capability and can decrease the cost of in-seam drilling for gas drainage.

Additional benefits to drill operators include the real-time rig performance parameters that enable rapid decision-making. The real-time supply of geological data to drill operators, drilling supervisors, mining clients and consultants simultaneously using underground networks allows for more timely decision-making. Driller supervisors and mine managers will understand more about individual driller performance, making the Yabby Geosensing System a valuable tool for training purposes.

CONCLUSIONS

Underground in-seam drilling has been used as an exploration tool and has supplied driller-interpreted data and driller-based positional and limited geophysical (focused gamma) information to coal mine operators over the past thirty years. The Yabby GeoSensing technology transforms the underground drilling rig to the most important geological interpretation tool in underground mining. Combined with advanced analytical software, the potential exists for Yabby-derived data to provide the necessary spatial information within a coal seam to significantly improve gas drainage and geologic modelling for mine planning and mine safety.

The Yabby Geosensing System can be applied to underground and surface directional drilling exploration projects performed for evaporite and hard rock mines, to improve identification and characterization of geologic features, including quantifying the relative magnitude of water production from different features, improving hydrogeologic models and benefiting mine planning and mine safety.

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Geoistical Evaluation of Polymetallic Veins

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ABSTRACT

This study is carried out in the Zenit mining concession, which is located in the city of San Pablo in the department of Cajamarca in Peru. The Project has 33 mineralized structures and according to laboratory analyzes we have the presence of gold and silver. The geostatistical evaluation provides an analysis on the distribution of precious metals in the vein. This information is used to improve the efficiency of metal extraction and to reduce costs. The general objective is to evaluate the polymetallic veins (Au and Ag), for which the classification of resources (measured, indicated, and inferred) has been carried out, taking into account the parameters of minimum distance from the composite, corresponding volume and tonnage calculation.

In addition, an inventory of estimated geological resources was carried out with the block grades obtained to generate the tonnage-grade curves.

INTRODUCTION

Investing in a greenfield project carries significant risks, so it is crucial to have a deeper understanding of the uncertainty associated with resources in mining concessions. In the mining industry, mineral resource modeling focuses especially on grade estimation. In this context, the variogram becomes relevant, an essential tool used to analyze the spatial variability of the data. It provides valuable information on the distribution of grade values or mineral concentrations as a function of distance and direction, thus contributing to more informed decision-making (Zaki, et al. 2022). For the planning and operation stage, the tonnage- grade curve influences the extraction sequence, mine design, and provides information on the profitability of the mining operation and long-term economic viability, this through visualization of the distribution of mineral tonnage and its average grade. The identification of the inflection point in this curve is known as the cut-off grade, which marks the threshold from which the mineral is considered economically exploitable. (De La Torre Palacios, 2019)

In the Zenit mining concession, located in the city of San Pablo in the department of Cajamarca, an exhaustive geostatistical evaluation of 33 mineralized structures was carried out. This analysis focused on detailed data review to define domains and perform parameter estimation, such as grade interpolation, cubing, and statistical analysis. The comprehensive process included a thorough variogram analysis. The strategic decisions were based on the information derived from the tonnage- grade curve for the polymetallic veins.

METHODS

The objective of this chapter is to describe the geostatistical methods and procedures that were used to collect, analyze and interpret data from the mineralized structures (33 polymetallic veins of Au and Ag).

Structures

A total of 30 of the 33 structures previously proposed for delimitation were modeled; three structures were not considered in the analysis due to the small amount of data obtained. The elaboration of the solids was carried out using an economic approach, considering the width of the structure. In this way, the drilling section that crossed the