

V. Woehling¹, J. Marks¹ & J. Lawell²

1 Lucas Drilling Pty Ltd., Brisbane, Australia 2 Peabody Energy, Brisbane, Australia

Introduction of an integrated coal seam drilling and boundary mapping service to the Australian coal mining industry

ABSTRACT

The application of bed boundary mapping resistivity (BMR) tools in coal seam drilling has become increasingly successful, offering significant advantages for structural interpretation. By integrating BMR data collected during drilling and logging operations, coal seam interpretation accuracy is greatly enhanced. By combining conventional drilling methods with advanced logging tools, technical expertise, and interpretation capabilities, a tailored service has been developed to meet the specific needs of coal mining. Integrating BMR into established, cost-effective drilling platforms provides a compelling technical and commercial solution. The service offers several advantages to mine operators, including optimised wellbore placement for gas drainage, improved hazard identification, enhanced risk assessments, and high-resolution mapping of seam structures such as dip and faulting.

This paper presents the successful introduction of the newly integrated coal seam drilling and boundary mapping service to the Australian mining industry, highlighting its impact and value in improving coal seam interpretation and resource management.

INTRODUCTION

Longwall mining has revolutionized Australia's coal industry (Bhattacharyya et al., 2023; Spearing et al., 2023). As part of ongoing efforts to improve efficiency, integrated drilling and logging services have been introduced to meet operational needs. This paper focuses on the application of coal seam Boundary Mapping Resistivity (BMR) services in Australian coal mining, enhancing precision in resource recovery planning. Traditional wellbore delivery methods pose challenges, even with the addition of near-bit gamma ray measurements (Thwaites et al., 2014), shortened seam exits and minimised overdrill. Surface-to-Inseam (SIS) multi-branch drilling with planned exit intervals leads to generating basic structural models (Figure 1). However, these models offer limited understanding, especially in low gamma ray areas where structural uncertainties arise. Conventional SIS drilling provides only a limited view of the seam, and the depth of gamma ray measurements is insufficient for accurate boundary mapping. This results in positional uncertainty, particularly when drilling for

gas production or degasification, requiring precise well placement.

The integrated BMR service overcomes these challenges by offering a depth of detection (DOD) up to six meters, providing real-time boundary mapping and structural data. This proactive approach improves wellbore placement and enhances gas extraction efficiency. Although boundary mapping has been used successfully (Abeida et al., 2023), it has been costly due to a complex technology application approach.

An Australian drilling operator now offers a cost-effective solution by incorporating the boundary mapping tool into a standard rig fleet and bottom hole assembly (BHA), reducing vendor complexity and cost. This new service improves structural clarity throughout the drilled wellbore, reducing the need for multi-branching and offering significant benefits for resource definition and risk mitigation.

The following sections discuss the implementation of this integrated service and how it addresses industry challenges.

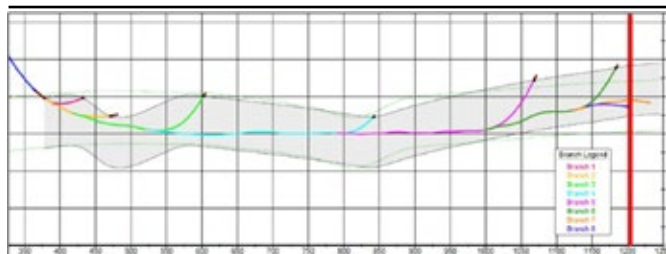


Figure 1. Conventional seam model created by drilling multiple roof branches. The pre-well mining model is shown by the green outline, with the red vertical well (VPW) at the toe.

INTEGRATION OF BMR AND ELECTRO-MAGNETIC MEASUREMENT-WHILE DRILLING (EMWD)

A successful boundary mapping service is commonly represented by four major service components. The service cycle (Figure 2) constitutes out of the downhole drilling and logging tooling assembly, the up-hole acquisition and communication module, the data interpretation and non-the less, skilled and trained personnel. This section describes the major service elements.

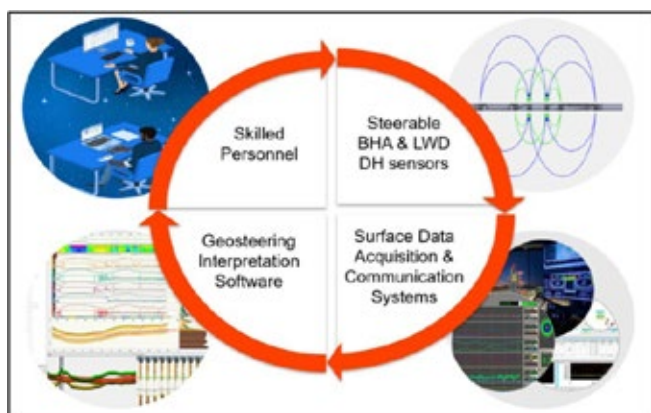


Figure 2. Integrated drilling and boundary mapping service cycle

Integration of triple frequency resistivity measurements

Azimuthal boundary mapping tools detect approaching boundaries using resistivity readings and are crucial for geosteering. Deep reading tools, described by major service providers (Burinda et al., 2009; Palmer et al., 2008), offer detection ranges of up to six meters (Li et al., 2017). These tools help determine coal seam boundaries, but accurate resistivity measurements can be challenging due to shoulder-bed effects, as shown

in Figure 3, where traditional responses (2 MHz, 400 kHz) fail to measure true coal resistivity.

The addition of a 4 MHz frequency offers three benefits: improved measurement accuracy in high-resistivity coal, reduced shoulder-bed effects, and better data assessment. As seen in Figure 4, the 4 MHz response accurately measures coal resistivity in the seam's centre, while the 2 MHz and 4 MHz responses provide good quality control through characteristic separations.

This higher frequency also enhances sensitivity to thin beds, improving coal seam characterization, especially during SIS drilling (Figure 5). Integrating the 4 MHz frequency into a triple-frequency resistivity array increases accuracy, supporting better geological modelling of coal seams.

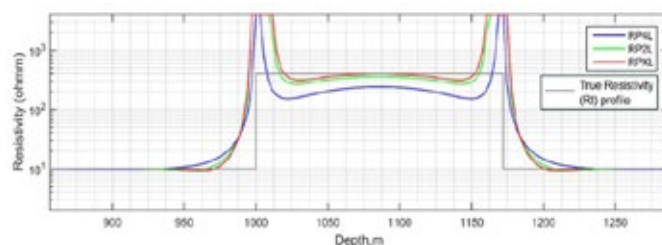


Figure 3. Non-directional bulk resistivity measurements along a trajectory crossing a 6 m thick coal seam in shallow angle of incidence. The model includes predicted resistivity responses of three different frequencies RP4L (400 kHz), RP2L (2 MHz), RPXL (4 MHz). Coal seam has a true resistivity of 400 ohm.m coal seam with embedding 10 ohm.m shoulder formations.

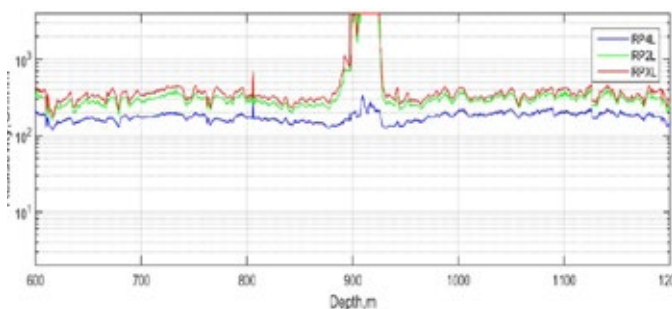


Figure 4. Field data from a logging run showing bulk resistivity and triple frequency curves. Curve separation follows the modelled curve behaviour. The BMR tool measures as expected, verifying that the expected resistivity contrast between coal seam and conductive shoulders is accurately represented. The significant increase halfway along the plotted interval is showing the expected polarisation horn effect near a major conductive boundary.

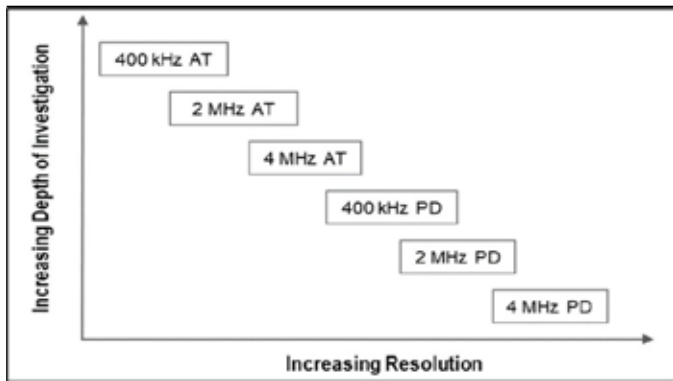


Figure 5. Relationship of vertical resolution and depth of investigation among the different measurements.

The integration aimed to develop a boundary mapping tool that operates while sliding as well as rotating during drilling. Traditional BMR tools only work in rotational mode, causing data gaps when sliding, which previously required costly re-surveying or relogging. Mapping bed boundaries while sliding is crucial for directional drilling with a motor. In sliding mode, the drill string above the mud motor does not rotate, limiting conventional boundary mapping tools that rely on rotation to detect boundary signals.

The new BMR tool overcomes this by using orthogonal transmitting and receiving antennas, enabling it to track boundary signals even without rotation. The data is processed downhole and sent to the surface. Figure 6 illustrates BMR measurements during frequent mode switches between rotating and sliding. The BMR signal remained stable between modes, eliminating data gaps in sliding intervals.

The patented technology ensures continuous azimuthal boundary mapping data without interruptions, even while sliding. Inversion earth models have been described by numerous publications (Sviridov et al., 2014, Sviridov et al., 2022). Inversion earth models, as shown in Figure 7, further enhance interpretation by providing a smooth profile across sliding and rotating sections, demonstrating stable transitions in measurements. This innovation eliminates azimuthal mapping gaps in SIS boreholes drilled with conventional directional motor BHAs.

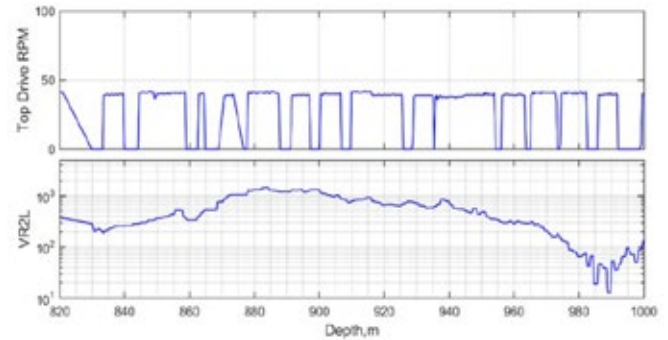


Figure 6. Continuous acquisition of directional boundary mapping information across intervals of sliding (Top Drive RPM '0'). Conventional boundary mapping data would show gaps across these sliding intervals or were linear interpolated. The new BMR tool provides permanent boundary mapping capability regardless of drilling mode.

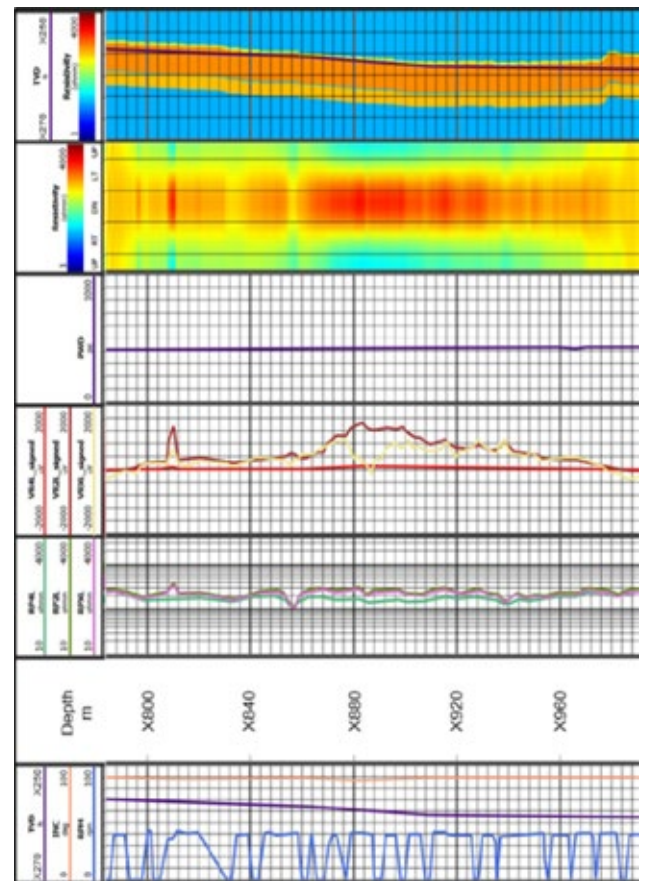


Figure 7. Example of BMR measurements in a horizontal inseam section and the inverted earth model in the top track. The plot includes multiple-sliding sections with zero RPM. Azimuthal resistivity measurements show stable transitions across the sliding sections.

Integration MWD and LWD technology

Downhole assembly

An established Measurement-While-Drilling (MWD) system provided the foundation for integrating the new formation boundary mapping tool (BMR), offering power and up-hole communication during live drilling. The BMR tool captures high-definition data, while effective communication with the MWD system is essential for seamless integration. The integrated tool string combines the BMR tool with MWD capabilities, featuring a 4 3/4" (120 mm) diameter and 13 m length. It can be assembled off-site to minimize rig time and is optimised for hole sizes between 5-7/8" and 6-3/4". The tool works effectively in both sliding mode (Figure 6) and at a rotary speed of 40 rpm.

Positioned behind the drilling motor, the BMR tool includes receivers 10 m from the bit and maintains consistent drilling rates. It offers real-time annulus pressure measurements, enabling monitoring of equivalent circulating density (ECD) and quick identification of well control issues. The integrated BHA also supports short-hop communication for azimuthal gamma ray and at-bit inclination measurements. Using electromagnetic (EM) telemetry, the MWD system transmits boundary mapping data in real-time, independent of drilling fluid. The BMR tool provides up to 256 azimuthal measurements across three frequencies (400 kHz, 2 MHz, 4 MHz). During the Australian field rollout, data was analysed and optimised for real-time transmission, with less critical data stored for post-drilling analysis. The MWD tool also supports magnetic ranging for vertical production well intersection, enabling smooth conventional SIS operations.

Power supply

The BMR tool is powered through hard-wired MWD tooling, eliminating the need for additional batteries. All measurements from the MWD and boundary mapping tool are time-stamped in real-time and stored in memory. The MWD clock is synchronized with the surface Electronic Depth Recorder (EDR), ensuring accurate depth referencing for all downhole data.

Data communication

Data transfer at the rig site uses the Wellsite Information Transfer Specification (WITS) for transmitting logging, drilling, and rig data in a universally recognized format. To support remote supervision of the boundary mapping service, WITSML (Wellsite Information Transfer Standard Markup Language) enables seamless data sharing from the rig to real-time monitoring experts. WITSML transmission is supported by satellite communication, ensuring coverage in remote Australian locations.

Software & Interpretation

Geosteering techniques (Meszaros et al., 2007) have evolved with software applications playing a key role. A critical need was to make real-time and memory boundary mapping data accessible in geosteering software. Vendor-independent solutions have gained popularity for their flexibility, supporting both live drilling and post-well analysis. The integrated boundary mapping service now offers real-time logging and interpretation, available to customers in Australia. The geosteering software converts triple-frequency BMR data with varying depths of investigation (DOI) into a geological coal seam model along the wellbore. The software was optimised in collaboration with the vendor to process the BMR data (see Figure 8).

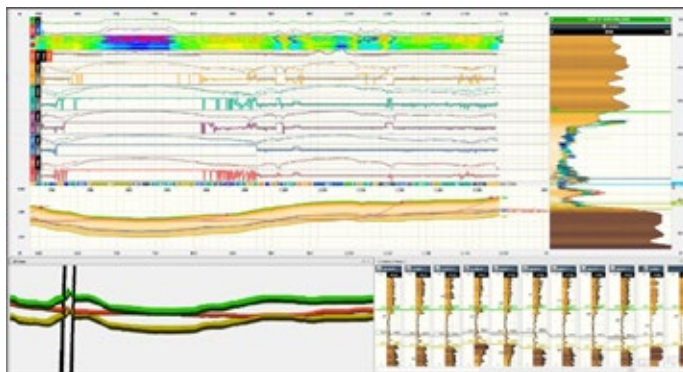


Figure 8. The plot demonstrates the setup of an interpretation project based on the new BMR tool multi-frequency logging data. The software was specifically updated to cope with the new BMR tool data.

Figures 9 and 10 show superior boundary detection, with the BMR tool effectively identifying major boundaries. The signal amplitude varies with distance to the boundary, allowing precise detection

of the coal seam roof and boundaries along the well. Compared to the conventional method, the new boundary mapping approach offers a more accurate coal seam model, reducing errors and improving interpretation.

Figure 10 compares the conventional method (solid grey outline, see Figure 1) with the new boundary mapping approach (see Figure 9). The light brown shaded structure shows the more accurate model from the deep reading BMR service, with a 3.5-meter difference, about half the seam thickness, between the two methods. The BMR interpretation aligns with roof exit points but reveals a more complex structure between them.

The BMR data provides a more detailed section along the wellbore (Figures 9; Figure 10). For operators, this enhanced interpretation improves the accuracy of mining models, eliminating uncertainties and significantly boosting longwall planning and coal mining operations.

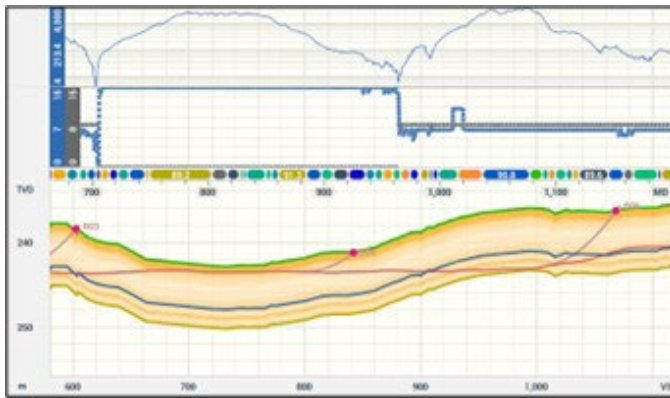


Figure 9. Geosteering interpretation based on the deep reading measurements of the directional boundary mapping tool. The resulting model in rack three resolves an interval of borehole approach to and departure from both roof and floor of the coal seam. The plot also indicates the conventional roof exit branches.

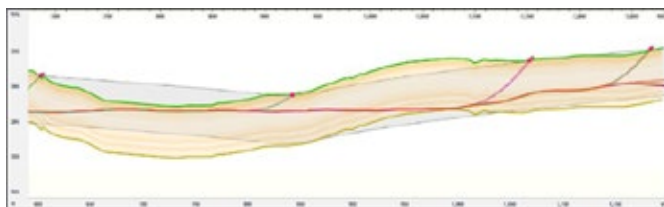


Figure 10. Geosteering interpretation based on deep reading boundary mapping measurements compared to as drilled interpretation based on conventional roof touches.

BMR DATA IN OPERATOR MINE MODELLING

This section highlights how integrating new drilling and logging technology improved seam alignment, aiding operators in creating a more accurate mining model. Using boundary mapping in SIS drillholes helped understand coal seam structure between known data points, such as vertical boreholes or conventional roof touches.

Historically, exploration drilling had borehole spacing of 250–350 m. The new BMR technology was applied to SIS boreholes along gate roads in proposed longwall operations, with wellbores geosteered along tailgate and maingate developments. Lateral well spacings were around 80–90 m, with individual well lengths up to 1850 meters (Figure 11). The ability to trace seam structures across boreholes and along planned gate roads was valuable for assessing seam consistency.

Limitations of Seismic Data and Advantages of BMR

Whilst While 2D and 3D seismic data was available, vertical resolution was limited due to thick tertiary and overlying coal seams, resulting in low-confidence interpretations of geological structures. BMR helped validate seismic interpretations, improving fault location and displacement estimates. For example, a fault interpreted from seismic with 0–3.5 m displacement was confirmed by BMR within 15 m MD, with a 5.5 m downthrow to the north. Follow-up drilling confirmed a 5 m thrust fault. In another case, seismic data suggested a fault with 0–11.5 m displacement, but BMR data from parallel SIS boreholes identified the structure striking 17° with 1–2 m displacement. Subsequent underground mapping of the gate road found there to be three faults within 10 m of each other, striking 13°–17°, with displacements ranging 0.4 – 2.7 m.

Integration into Geological Modelling and Mine Planning

Faulting data from BMR is integrated into the mine's short-term geological model using Maptek's Vulcan software. This includes roof and floor structure data, which informs targeted exploration drilling for geotechnical analysis, such as rock

strength and mass characterization around fault zones. The data contributes to geological hazard planning and mine development strategies.

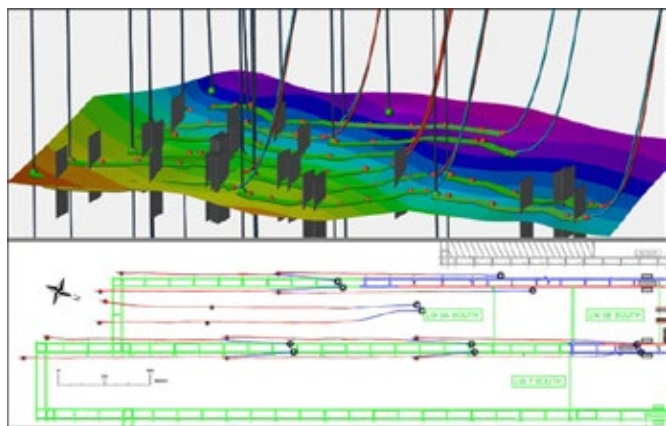


Figure 11. Geosteering model 3D-view in the upper graphic is presenting twelve Surface-to-Inseam wells drilled for the operator. Wellbores with red well paths were logged with BMR technology. The lower graphic presents the underground mining model. Wellbores were geosteered in successive sequence along the tailgate and maingate developments on either side (blue colour for the build section, red colour for inseam section). Vertical wellbores are vertical production wells, intercepted by the lateral SIS wells. Vertical rectangular shapes are representing fault locations derived from interpretations, applying data acquired from the new integrated drilling and logging tool applications. Lateral SIS well in the longwall block have been drilled to drain the area as pre-drainage to suit the subsequent UIS development.

Implications for Gas Conformance and Permitting

BMR data aids early identification of geological structures, supporting gas conformance drilling required for underground mining permits. It helps determine the locations for gas drainage and fault-targeted drilling, ensuring gas content is below outburst thresholds before issuing a permit. BMR data reduces the risk of redrills, lowers sampling costs, and minimizes surface drilling and development delays.

CONCLUSION

The new boundary mapping service successfully integrates downhole technologies into Australian drilling operations, enhancing coal mining models with improved structural accuracy. This service bridges gaps in conventional drilling, offering real-time decision-making that optimises wellbore placement and enhances structural interpretation, which improves the understanding of coal seam architecture. It supports geological modelling, exploration, and geotechnical data collection, while also aiding mine hazard planning and gas conformance drilling. By accurately targeting faults, the service reduces redrills, sampling costs, and downtime, ensuring safety compliance before mining. Since its market introduction in Q1 2024, the service has evolved into a full real-time offering by June 2024, with over 14,000 meters of open-hole logging completed across multiple wellbores. Real-time BMR operations continue, averaging two to three wells per month.

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