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Outburst control in the Wongawilli seam

Dennis Black

OUTBURST CONTROL IN THE WONGAWILLI SEAM

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ABSTRACT: The Wongawilli coal seam varies from 8 m to 10 m thick and consists of interbedded bands of kaolinitic brown mudstone and coal plies. In the southern part of the coalfield, the lower section of the seam is higher quality and lower ash. Dendrobium mines the bottom 3.5 m to 4.0 m of the seam, producing hard coking coal for use in steelmaking.

Dendrobium has operated in an historically low gas environment and is now transitioning into a new mining domain that presents new challenges of increasing gas content, increasing CO2 seam gas composition, and low *in situ* permeability. Dendrobium has an established Outburst Principal Hazard Management Plan, consistent with Industry best practice, that defines standards and requirements for (a) Predicting areas where an outburst risk may exist, (b) Preventing an outburst event from occurring, and (c) Protecting personnel from exposure to an outburst.

Dendrobium's approach to outburst control in the Wongawilli seam is explained, along with a range of initiatives to improve drilling and gas extraction, and to improve the accuracy of identifying outburst risk zones and threshold limit values.

INTRODUCTION

Outburst has been defined as the sudden release of gas and material from the working place that can vary in magnitude and intensity (NSWDMR, 1995). The occurrence of an outburst is preceded by failure of the coal, and during an outburst, the failed material is ejected with energy and gas. Outbursts therefore represent a major safety hazard to mine personnel working near the coal face in areas of increased outburst risk.

Dendrobium mine is committed to reducing and minimising the risks associated with outburst in development mining panels and on longwall production faces, and this is achieved through:

- Implementing a system of measurement and assessment of outburst risk prior to authorising mining to take place,
- Draining gas from coal seams to reduce the gas content below the outburst threshold limit,
- Collecting core samples and confirming the gas content of the coal seam is below the outburst threshold limit,
- Subjecting the mining of areas, where seam gas content cannot be practically reduced below the threshold limit, to risk assessment to determine the specific controls required to minimise the risk of harm to people and equipment from outburst, and
- Providing all personnel with information and training on outburst warning signs and outburst management.

MINE OVERVIEW

Dendrobium is an underground longwall mine located in the Southern Coalfield, approximately 70km to the south of Sydney, and is a key asset of South32 Illawarra Metallurgical Coal (IMC) operations. Dendrobium commenced operation in 2002 producing predominantly high-quality metallurgical coal from the Wongawilli seam for steelmaking, which is shipped around Australia and around the world. Dendrobium is integrated with BlueScope's steelmaking infrastructure and IMC is the largest coal producer in the Southern Coalfield, supplying 60% of BlueScope's total Hard Coking Coal requirements.

Figure 1 shows the layout of current and future planned workings at Dendrobium mine, which are transitioning from a low gas environment experienced in Areas 1, 2, 3A and 3B, toward a higher gas environment in Area 3C.

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There has been no recorded outburst of coal and gas during mining operations in the Wongawilli seam, and Dendrobium has an established system to control and manage the potential outburst hazard.

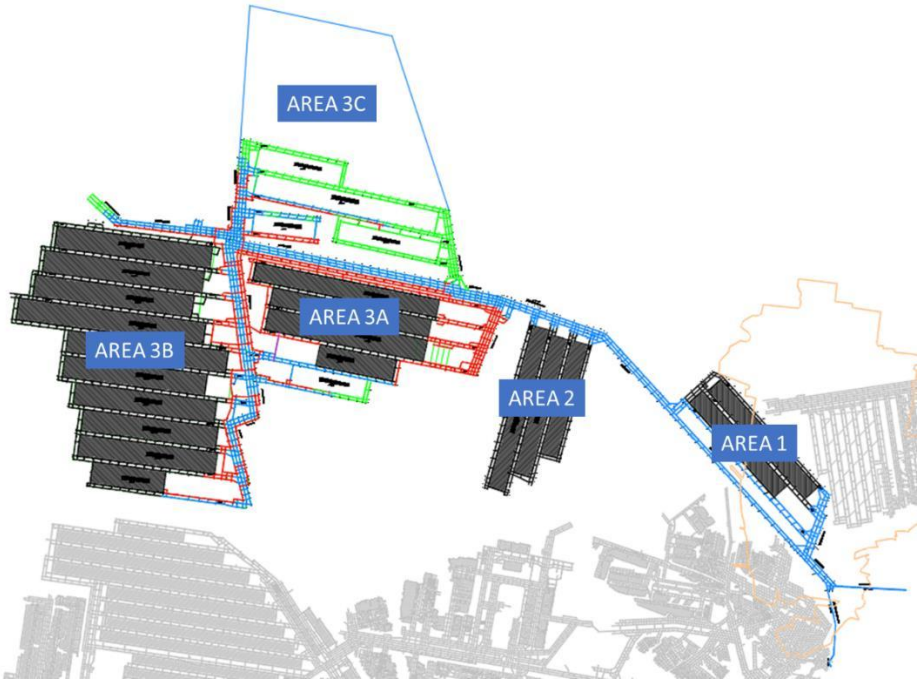

Figure 1: Extent of current and planned Dendrobium mine operations

Regional Stratigraphy

The Wongawilli seam is one of the three mining targets found within the Illawarra Coal Measures which consist of interbedded shales, mudstones, sandstones and up to 10 named coal seams. Overlying the Illawarra Coal Measures is the Narrabeen Group (**Figure 2**) which includes amongst others the Bald Hill Claystone (Chocolate Shales), the Bulgo Sandstone (medium to coarse grained sandstone) and the Wombarra Claystone. The Hawkesbury Sandstone is found immediately above the Narrabeen group.

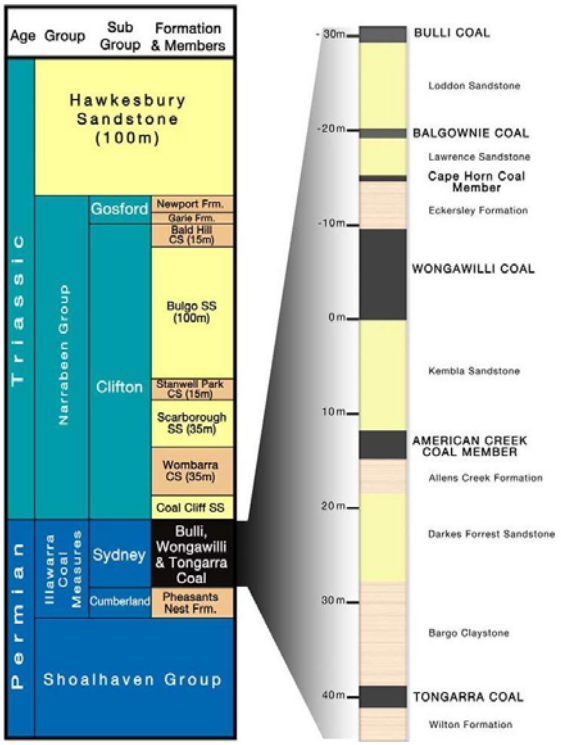

Figure 2: Generalised stratigraphic column – Illawarra Coal Measures

The uppermost coal seam is the Bulli seam, which has been worked extensively across the northern extents of the Southern Coalfield. The Bulli seam has been mined in adjacent and nearby mine leases of Mt Kembla, Wongawilli and Kemira. Across Area 3C the Bulli seam is generally about 2 m thick. The Bulli seam is generally located 20 m to 25 m above the Wongawilli seam.

The Balgownie seam, which sits from 5 m to 15 m below the Bulli seam and 10 m to 15 m above the Wongawilli seam, is typically about 1.0 m thick.

Stratigraphically below the Wongawilli seam in descending order are:

- The American Creek seam occurring about 10 m below the Wongawilli seam,
- The Tongarra Seam occurring 40 m to 50 m below the Wongawilli seam, and
- The Woonona, Figtree, and Unanderra seams.

The Illawarra Coal Measures outcrop towards the base of the coastal escarpment and depth of cover increases rapidly to the west and northwest away from the coast. Regional dip of the strata is generally to the north, with some regional anticlines and synclines locally complicating the regional trend.

Regional structure in the Southern Coalfield is predominantly orientated northwest-southeast but there can be significant local variation in this trend. Structures affecting mining generally are manifested as faults, dykes, joint zones, and sills.

Wongawilli Seam Description

The Wongawilli seam depth of cover increases from as low as 240 m in and around the Area 3C Mains entry increasing to 380 m along the western and northern extents of the Area 3C mine plan. The seam dips steadily to the northwest at a slope of about 1.5 degrees.

The Wongawilli seam varies in thickness from 8.5 m to 9.5 m across Area 3C. The basal 3.3 m to 3.5 m has been mined across Areas 1, 2, 3A and 3B at Dendrobium and is the mining target in Area 3C. The development working section is generally defined by the top of the 2nd Machine Band and the longwall section to include the WW2L ply (**Figure 3**).

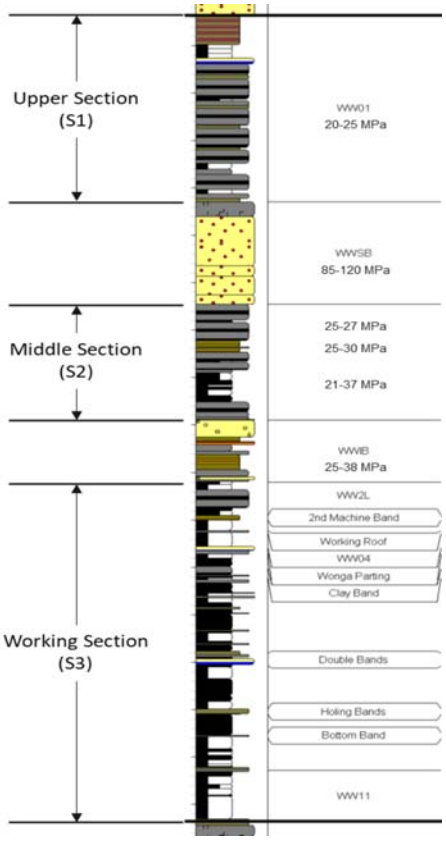

Figure 3: Generalised Wongawilli seam strata section – Area 3C Dendrobium mine

The Ironstone band (WWIB) which lies above the working section is typically about 0.8 m thick. The WWIB is described as stony coal and carbonaceous coal bands. Immediately above the WWIB is the Middle Section (MS), a coaly ply known as the WW02U, described as an interbedded stony coal and mudstones. The WW02U is on average about 1.2 m thick.

The Wongawilli Sandstone band (WWSB) separates the WW02U and the upper coaly section of the seam, the WW01. The WWSB which can vary from fine grained sandstone to a tuffaceous siltstone and is consistently 1.0m thick across Area 3C. The WW01, referred to as the Top Section (TS), is described as a stony coal with interbedded hard claystone, is typically about 1.8 m thick.

OUTBURST MANAGEMENT

Principal Hazard Management Plan

Outburst is a recognised Principal Hazard requiring mines to develop and maintain a risk-based management plan to effectively control and manage the risk of outburst to an acceptable level.

A principal hazard management plan must (a) provide for the management of all aspects of risk control in relation to the principal hazard, and (b) so far as is reasonably practicable, be set out and expressed in a way that is readily understandable by persons who use it.

Outburst Control Zone

Figure 4 shows the gas content threshold limit for seam gas compositions ranging from 100% CO2 (5.0 m^3/t) to 100% CH4 (9.0 m^3/t), above which is defined as an outburst control zone, in accordance with the NSW Work Health and Safety (Mines and Petroleum Sites) Regulation 2014.

Carrying out mining operations in an outburst control zone is identified as a high risk activity and the Operator of the mine must ensure that mining is not carried out in the outburst control zone unless (a) the Operator has submitted the required notice of the activity and additional information and documents to the NSW Resources Regulator, (b) the defined three (3) month waiting period has lapsed, and (c) the mining activity is carried out in the manner specified in the notice.

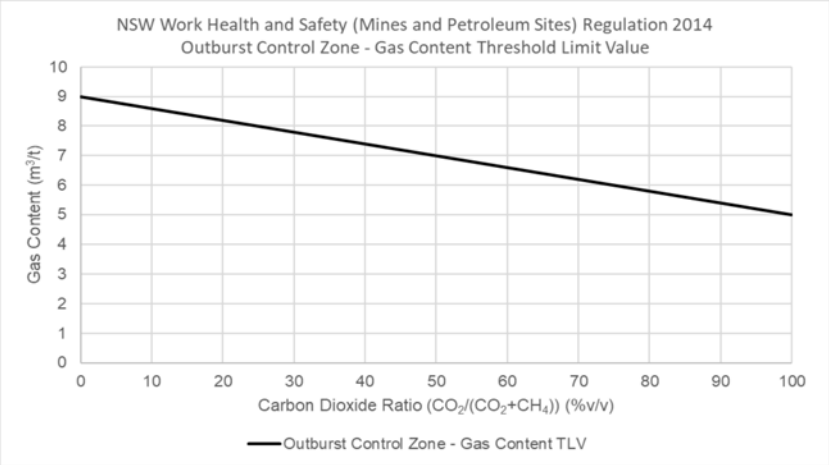

Figure 4: Outburst Control Zone (after NSW WHS Regulation, 2014)

Dendrobium Outburst Principal Hazard Management Plan

Dendrobium maintains an Outburst Principal Hazard Management Plan (PHMP) that details the methods, procedures, and technical standards to manage the risk of an uncontrolled outburst of coal and gas. These generally fall into one of the following three areas:

- Prediction – deals with collection and assessment of information required to complete a thorough assessment of outburst risk in each mining area, to allow for control measures to be properly planned,
- Prevention – deals with measures implemented to reduce outburst risk in each mining area to prevent an outburst from occurring, and

- Protection – deals with measures to protect personnel from the effects of an outburst should there be a failure in either the prediction or prevention stages of outburst management.

PREDICTION

Predictive information is collected, analysed, and used to assess the potential for increased outburst risk to be present in areas, prior to mining being authorised to proceed in those areas. This information includes:

- geological data to indicate the location, type, orientation, and projection of geological structures,
- coal seam characteristics, including gas content and composition, and
- historical information for both the area to be mined as well as previous and adjacent workings.

Predictive information can be obtained from a variety of sources, the most important of which are drilling logs, core sample collection and gas content analysis, routine roadway mapping, and inspection of anomalies uncovered during the mining process.

Geological and Gas Reservoir Information

Data relevant to developing an understanding of the geology and gas reservoir is obtained through:

- Underground mapping of mined roadways,
- Surface exploration methods, such as 2D and 3D seismic and aeromagnetic surveys,
- Surface exploration drilling data, and
- Underground inseam drilling data.

Qualified and competent personnel are responsible for the collection, analysis, and maintenance of geological and gas reservoir data. The drilling logs from each inseam borehole are examined to identify and assess the relevance of any reported anomaly that may indicate a potential outburst hazard.

A Geological Database is maintained that includes (a) details of all geological structures and other geological anomalies identified through analysis of exploration and gas drainage drilling, seismic surveys, routine roadway mapping, and inspection of anomalies identified during the mining process, and (b) details of each coal seam and gas bearing strata unit, including information such as, seam thickness, seam dip and depth of cover, coal strength, permeability, stress and cleat orientation, and seam gas pressure.

A Gas Database is maintained that includes detailed records of relevant gas reservoir data from each coal seam and gas bearing strata unit obtained through surface and inseam core samples, including gas content, gas composition, and ash content.

The main gas reservoir factors affecting the response of coal seam gas to mining and gas drainage include:

- Seam thickness and depth of cover,
- Gas content and composition,
- Gas reservoir size,
- Permeability, and
- Gas Saturation.

The gas reservoir characteristics at Dendrobium change in Area 3C, north of current mine workings, with gas content increasing in all coal seams, increasing CO2 seam gas composition, and low *in situ* permeability. Similar conditions have been encountered at Appin, and other NSW mines, which have been successfully drilled and drained to reduce seam gas content ahead of development.

Gas content of the major seams has been measured across the Area 3C mine plan from surface boreholes and both gas content and gas composition, as received, can be highly variable, with both varying significantly over relative short distances in some areas. The variation is found in all seams, as well as vertically within the Wongawilli, typically attributable to variations in seam ash content, with seam ash increasing upwards in the WWSM.

Gas Content and Gas Composition

The gas content of the working section of the WWSM changes rapidly from low levels, less than 4 m^3/t (on an as received ash basis) and higher in CH4 (55% to 67%) at the entry to Area 3C, increasing to an

average in the range of 12 m^3/t to 15 m^3/t and high CO2 (>95%). The maximum gas content recorded in Area 3C is 19.5 m^3/t at 96% CO2.

The gas content of the upper coaly plies of the WWSM are similarly high in CO2 (> 95%) across Area 3C at gas content levels that are generally less than the working section due to the higher ash characteristic, though still in the moderate to high range of 7 m^3/t to 12 m^3/t on an as received ash basis.

Figure 5 shows contours of gas content measured in the working section of the WWSM, reported on a standard 10% ash basis, and **Figure 6** shows contours of the gas composition measured in the working section of the WWSM, both presented relative to the current and future planned Dendrobium mine workings.

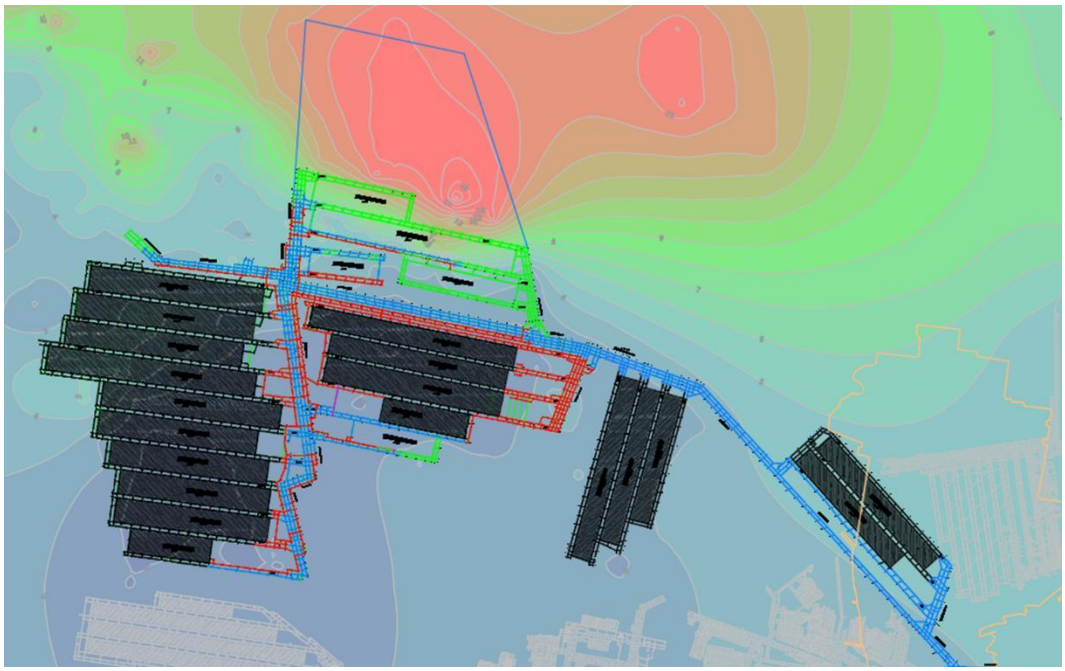

Figure 5: WWSM Gas Content reported at 10% Ash (Blue – low QM, Red – high QM)

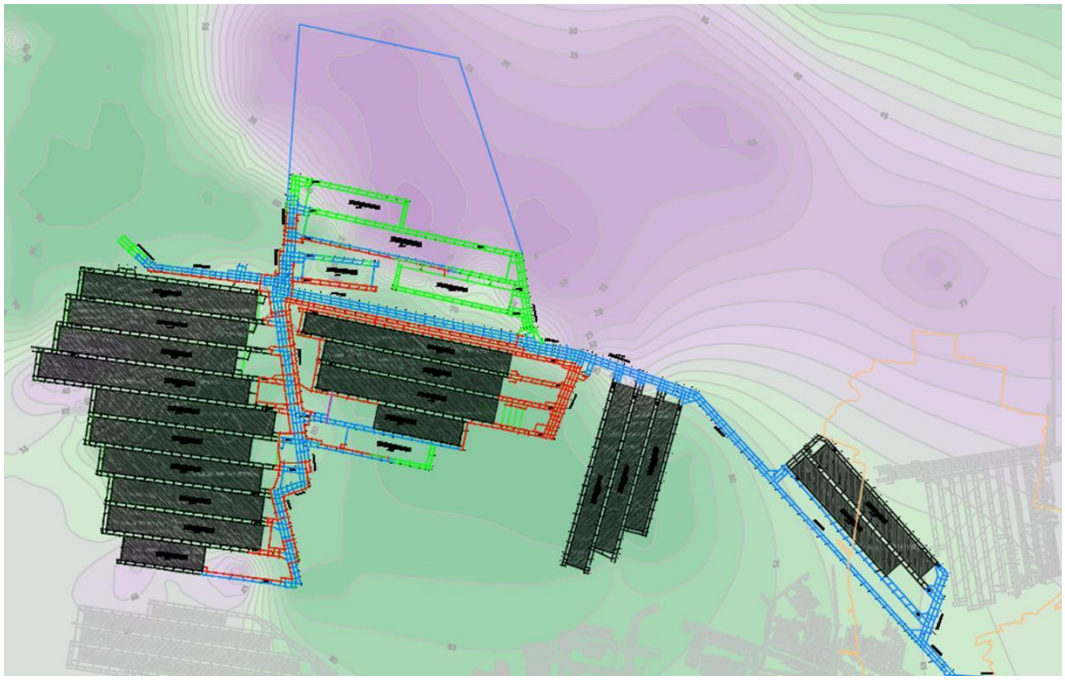

Figure 6: WWSM Gas Composition (Green – CH4 rich, Purple – CO2 rich)

Based on specialist review of available data, the Outburst Risk Review team is advised on the need for (a) additional exploration to delineate geological structures and indicated anomalies, (b) inseam or surface drilling to recover core samples for gas content and composition testing, and (c) other relevant testing to acquire data required to assess outburst risk.

Inseam Drilling and Seam Delineation

As shown in **Figure 3**, the Wongawilli seam (WWSM) includes three distinct coal sections and analysis indicates low vertical permeability across the Ironstone band (WWIB) that separates the lower Working Section (S3) and Middle Section (S2), and the Wongawilli Sandstone band (WWSB) that separates the Middle Section (S2) and Upper Section (S1).

While the working seam section is the primary focus of mining operations and therefore pre-drainage, the overlying seam sections are potential sources of elevated gas content and gas pressure, and their potential outburst risk must be assessed and managed.

The design of inseam drilling patterns considers the gas content and gas composition in each of the three distinct coal sections of the WWSM and drill sufficient holes to reduce the gas content of the three seam sections to below the defined outburst Threshold Limit Value (TLV).

Drill patterns are designed based on relevant data including, but not limited to, gas content, structure, seam dip, and available lead time, to effectively drain gas to reduce the gas content of the coal seam, in the area where mine workings are planned, to below outburst TLV. The drill patterns also consider the potential for geological structures to be present and the boreholes are drilled in a manner to intersect and locate potential structure.

The Drill Log of each inseam borehole drilled for the purpose of exploration, structure detection, core sampling, or draining gas, is reviewed by qualified and competent personnel and a Drilling Database is maintained for all underground inseam directional drilling at Dendrobium which contains the following details and data:

- Surveyed borehole locations,
- Copies of drill logs,
- Anomalies detected during drilling,
- Structures identified during drilling,
- Comments relating to drilling conditions,
- Core results, and
- Details of any lost drilling equipment.

Requirement for Flank Holes

The general design requirement for flank holes adjacent to development panels (gateroads, main headings, and bleeder headings) is to ‘close the grid’, thereby increasing the likelihood of intersecting and identifying any geological feature that may be present between the boreholes drilled in standard gas drainage and/or exploration drilling patterns. Flank holes are required when determined necessary by the OCI team, and for mining in level 2 TLV conditions, to confirm that there are no structures.

Flank holes are designed to run approximately parallel with the direction of the mining and offset into the adjacent coal block a distance not exceeding 50 m, measured from the centreline of the outer heading. The length of the flank holes shall extend a minimum of 15 m beyond the furthest point of the planned mine workings. All flank holes are logged and surveyed.

Surveying and Logging of Drilled Holes

Every UIS borehole drilled at Dendrobium that is greater than 25 m in length shall be surveyed and, as a minimum, the following details obtained during drilling shall be recorded on the Drill Log Sheet:

- Hole number and/or name,
- Date of drilling,
- Location, direction, and length,
- Serial number of survey tool and date of last calibration,
- Colour of cuttings,
- Drilling conditions encountered,

- Number of rods drilled,
- Motor torque and thrust readings while drilling (if available), and
- Details of anomalies and unexpected change in drilling conditions/performance while drilling (e.g., bogging, high gas emissions, water loss, emissions under pressure, large cuttings, lumps of coal ejected, mylonite, etc).

Details of the name/number and location of all inseam holes drilled at Dendrobium Mine are recorded by the Mine Surveyor, including the location and details of any anomaly, and location and details of any equipment lost in the coal seam/strata and unable to be recovered.

Identification of Geological Structures

All drilling and other exploration data is analysed for the purpose of determining the location and nature of geological structures and predicted structures that have not been intersected by the existing workings. This assessment is be based on consideration of underground and surface drilling data, geophysical exploration, and projection of known structures.

Identification and Treatment of Areas of Poor Drainage

Records of hole flow measurement are regularly reviewed to assess actual drainage performance relative to design, to identify holes requiring maintenance (dewatering and/or clearing blockages) and areas of poor drainage performance.

Estimates of the gas remaining in the reservoir can be made based on the results of the hole flow monitoring relative to virgin gas content. While these estimates are not intended to be used as the basis for authorising mining, they are used to identify poorly draining areas.

In addition to measuring gas flow from each hole, areas of poor drainage, or expected poor drainage, may also be identified by assessment of the gas reservoir properties, including seam permeability, degree of saturation, gas composition, and proximity to geological structure.

PREVENTION

Prevention of outburst is predominantly achieved through effective gas drainage to reduce seam gas content below the defined outburst TLV.

Gas Drainage

Gas drainage is fundamental to reducing outburst risk and reducing risk to personnel and production performance. With mine operations transitioning into a higher gas environment there has been significant investment in inseam drilling and data gathering to achieve increased drilling performance and gas drainage flow from the three highly banded sections of the WWSM.

Figure 7 shows the generalised objective of UIS pre-drainage drilling, used to drill into and drain gas from each section of the WWSM.

Figure 7: Generalised section indicating UIS pre-drainage drilling in the WWSM

Figure 8 shows the layout of planned UIS drilling to pre-drainage gas from the WWSM seam sections in advance of development in the first two longwall panels in Area 3C. While the techniques used to drill in the WWSM are evolving with operational experience, the gas drainage flows recorded to date have been favourable with increased flow from areas with higher gas saturation.

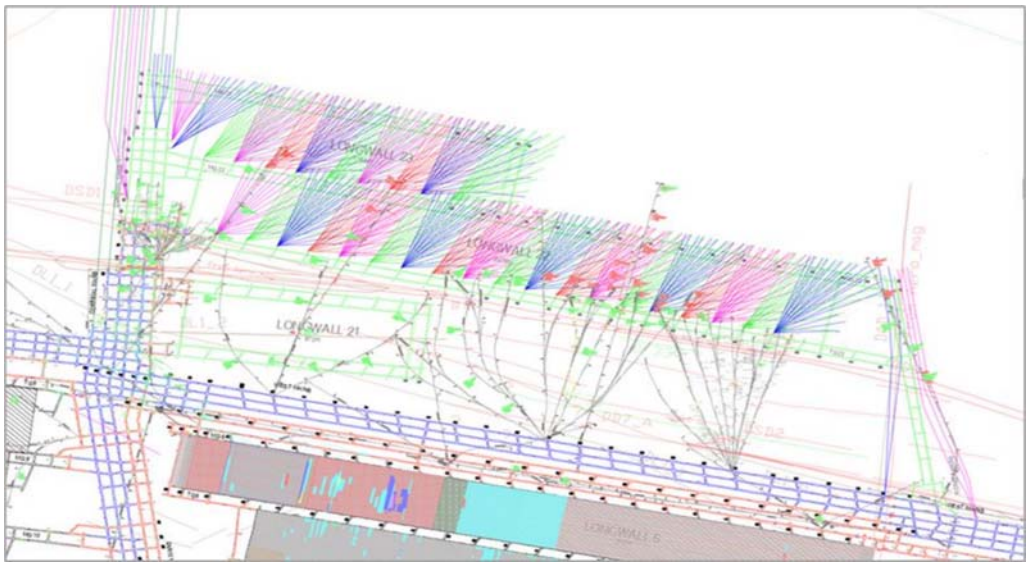

Figure 8: UIS pre-drainage drilling of WWSM in advance of planned development

The effectiveness of the gas drainage program in reducing the gas content of the coal seam is monitored through collection and assessment of gas drainage flow rates from individual boreholes. Regular review of gas drainage flow rate provides ongoing assessment of performance against expected drainage criteria. Where gas flow rates decrease below expected drainage criteria, the situation is investigated to determine the reason(s) for reduced flow performance and appropriate action is taken to increase gas flow rate, which may include dewatering and/or clearing blockages from boreholes.

Compliance core samples are collected from the “worst position” in a gas drainage drilling pattern, and near geological structures, to determine the effectiveness of the gas drainage program in reducing the gas content of the coal seam.

Core samples are sent to an accredited laboratory to determine gas content and gas composition in accordance with AS3980, or equivalent approved standard. The results are provided to the OCI team for consideration in the ATM process. While AS3980 recommends reporting gas content in either an as-received (AR) and/or dry-ash-free (DAF) basis, some laboratory service providers do apply in-house determined correction factors for variables, such as relative density (RD) of the coal sample and core sample recovery time, that increases the value of the reported gas content.

Where primary gas drainage is found to be ineffective by hole monitoring or core sample analysis, the area shall be identified as poorly draining and treated by one or more of the following:

- Additional drainage time,
- Additional inseam drilling, to increase hole density,
- Use of gas drainage enhancement and stimulation methods, and
- Use of remote mining techniques, if unable to reduce gas content to below outburst TLV.

In such cases, the area to be mined will be resampled to determine the gas content remaining after secondary drainage and/or additional drainage time.

Outburst Threshold Values

The outburst threshold limit values (TLV) applicable to all development and longwall mining, and igneous stone excavation operations in the WWSM at Dendrobium are shown in **Figure 9**. These TLV are applicable to the working seam section (S3) and the two overlying seam sections, S2 and S1.

The Outburst Thresholds can be calculated for any gas composition using the following equations:

- Level 1 TLV: QM = 8.2 – (0.02 x $CO2_R$) (m^3/t)
- Level 2 TLV: QM = 9.5 – (0.02 x $CO2_R$) (m^3/t)

where: QM is the TLV corresponding to the measured seam gas composition, and

$CO2_R$ is the carbon dioxide gas percentage of the seam gas, calculated using the equation $CO2_R = CO2 \div (CO2 + CH4) \times 100$.

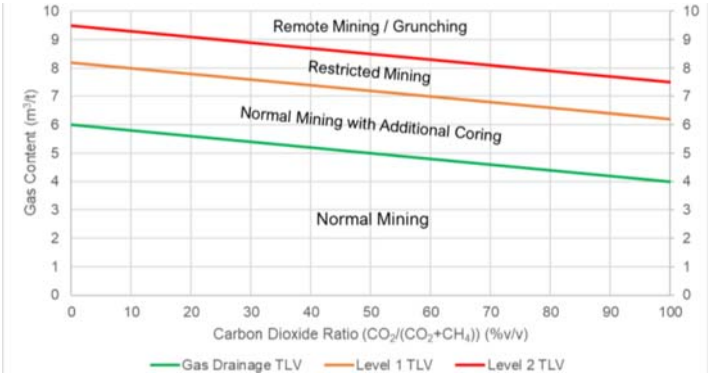

Figure 9: Dendrobium Outburst Thresholds

The Gas Drainage TLV defines high gas (above the gas drainage TLV) and low gas (below the Gas Drainage TLV) areas of the mine, based on gas testing of *in situ* core samples collected prior to gas drainage (i.e., virgin *in situ* gas content). Unless otherwise authorised by the OCI Team, all areas where the virgin seam gas content is known, or predicted, to be greater than the Gas Drainage TLV shall be pre-drained to reduce the seam gas content prior to being assessed and approved for mining.

The Gas Drainage Threshold can be calculated for any gas composition using the following equations:

- Gas Drainage TLV: QM = 6.0 – (0.02 x $CO2_R$) (m^3/t)

Given the banded nature of the WWSM and the potential for core samples to contain non-coal material, where the gas testing laboratory determines a core sample contains greater than 16% ash, in addition to reporting the 'as received' gas content and ash percentage, the laboratory also reports gas content equivalent to a sample with an ash content of 16%. For all coal core samples with ash content less than, or equal to, 16% the gas testing laboratory reports the 'as received' gas content.

The outburst TLV, presented in **Figure 9**, apply to 'as received' gas content values for samples with ash content less than or equal to 16%, and 'ash adjusted' gas content values, adjusted to 16% ash for those samples containing greater than 16% ash.

Details of the mining and coring controls required by the OCI team for authorising mining in areas of the WWSM where the gas content has been determined to be less than or equal to the Level 1 TLV, greater than the Level 1 TLV and less than or equal to the Level 2 TLV, or greater than the Level 2 TLV, are summarised in **Table 1**.

Table 1: Dendrobium Outburst TLV and Applicable Mining Controls

Outburst TLV	TLV Gas Content / Gas Composition	Mining Control Structures present	Mining Control No Structures present
Gas Drainage	≤ 4.0 m^3/t (100% CO_2) ≤ 6.0 m^3/t (100% CH_4)	Unrestricted Mining methods providing area has been reviewed by the OCI team.	
Level 1	≤ 6.2 m^3/t (100% CO_2) ≤ 8.2 m^3/t (100% CH_4)	Unrestricted Mining methods providing area has been reviewed by the OCI team. A High-Risk Activity Approval is required for areas containing cores above the Outburst Control Zone TLV.	
Level 2	≤ 7.5 m^3/t (100% CO_2) ≤ 9.5 m^3/t (100% CH_4)	Remote Mining or Grunching, subject to the OCI team and ATM process review. High-Risk Activity Approval required.	Restricted Mining, subject to the OCI and ATM process review. Restricted Mining Controls: • Restricted Mining using Conventional Mining methods restricted to 2.0m/hr and 24m/day, or • Remote Mining, or • Grunching High-Risk Activity Approval required.
Remote Mining	> 7.5 m^3/t (100% CO_2) > 9.5 m^3/t (100% CH_4)	Remote Mining or Grunching, provided the area has been assessed by the OCI team and High-Risk Activity Approval has been approved by the Resource Regulator.	

Core Sampling Requirements for Development Panels

The following minimum standards apply to sampling and gas drainage at Dendrobium:

- No mining will take place in any panel unless there is at least one (1) core sample result available ahead of the proposed panel driveages and the core should be recovered from the "worst position" in the drainage pattern.
- Core samples shall be maintained a minimum of 5.0 m ahead of the working face in the direction of panel advance.
- Any such sample must confirm the gas content is below the outburst TLV corresponding to the gas composition, as determined by analysis (AS3980, or equivalent), in order that the ATM may be issued.
- The approved laboratory conducting the analysis shall report details of the measured gas content and composition of each core. Full details of each core sample gas test shall be recorded in the gas database and summary details recorded on the mine plan.
- In the direction of panel advance, the maximum distance between core samples, required to be collected from the working seam section (S3) and the immediate roof seam section (S2), where the virgin gas content of the seam (S3) is greater than the Gas Drainage TLV, shown in **Figure 9**, shall be:
  - Never more than 150 m where compliance core gas content testing indicates the seam gas content is less than, or equal to, the Level 1 TLV, and
  - Never more than 50 m, where the compliance core gas content testing indicates the seam gas content remains greater than the Level 1 TLV.
- Where the virgin gas content is confirmed to be below the Gas Drainage TLV, the requirement for core sample collection from areas being considered for mining shall be specified by the OCI team.
- In the direction of panel advance, the maximum distance between core samples, required to be collected from the upper seam section (S1) where the virgin content is greater than the Level 1 TLV, shown in **Figure 9**, shall be never more than 150 m.
- In areas where the virgin gas content of the working seam section (S3) is greater than the Gas Drainage TLV, the following additional core samples are required based on panel width:
  - If the width of the panel is less than or equal to 60 m, then only a single line of cores is required across the panel.
  - If the width of the panel is greater than 60 m, but less than or equal to 120 m, then two cores are required across the width of the panel (in a direction approximately perpendicular to the direction of panel advance).
  - If the width of the panel is greater than 120 m, then three cores are required across the width of the panel (in a direction approximately perpendicular to the direction of panel advance).
  - For panels of greater than 60 m width, unless otherwise specified by the OCI team, one sample shall flank the panel on each side and the third sample, when required for panel width greater than 120 m, shall be in a central location at the widest point between drainage holes in the area to be represented by the samples.

Table 2 summarises of the development coring requirements corresponding to each outburst TLV.

Table 2: Dendrobium Outburst TLV and Applicable Coring Requirements

Outburst TLV	TLV Gas Content/ Gas Composition	Coring Requirements
Gas Drainage	≤ 4.0 m^3/t (100% CO_2) ≤ 6.0 m^3/t (100% CH_4)	Areas where virgin contents and composition have been assessed by the OCI team. Geological Structures to be cored as directed by the OCI team .
Level 1	≤ 6.2 m^3/t (100% CO_2) ≤ 8.2 m^3/t (100% CH_4)	≤150m core spacings in direction of Mining required in both S3 & S2. Additional cores for panel widths greater 60m required in S3 only. Additional coring required around Geological Structures.
Level 2	≤ 7.5 m^3/t (100% CO_2) ≤ 9.5 m^3/t (100% CH_4)	≤50m core spacings in direction of Mining required in both S3 & S2. ≤150m core spacings in direction of Mining required in S1. Additional cores for panel widths greater 60m required in S3 only. Additional coring required around Geological Structures.
Remote Mining	>7.5 m^3/t (100% CO_2) >9.5 m^3/t (100% CH_4)	No Minimum core spacing required in the direction of Mining

Sampling in the Vicinity of Structures and Drilling Anomalies

In addition to the requirements for routine sampling, additional sampling is required in the vicinity of structures and anomalies identified in the WWSM.

Structures – Extrapolated and Inferred

An extrapolated structure is a projection along strike of a known structure mapped in previous driveages and/or intersected by surface and inseam boreholes.

An inferred structure is a structure interpreted from known sources, such as surface mapping, surface seismic, RIM, aeromagnetic, and regional geology.

Extrapolated and inferred structures may not necessarily be associated with drilling anomalies. The outburst potential of structures decreases with effective gas drainage and should be sampled accordingly.

Types of extrapolated and inferred structures include:

- A structure with a history of outburst,
- Alignment of a series of drilling anomalies,
- Fault / joint / dyke / high stress zones – i.e., zones of disturbed coal varying in strength, permeability and gas content, over relatively short distances, that may be associated with elevated stress. The potential to outburst may increase with structural frequency and complexity due to increased risk of non-uniform and impeded gas drainage,
- Any type of fault (reverse, strike-slip, normal) and/or igneous material, such as dykes and sills, and
- Any structure containing mylonite, slickensides, or exhibiting the potential to cause anomalous drainage conditions.

Drilling Anomalies

Drilling anomalies are disturbances detected during drilling which may be indicative of the potential to outburst. The potential to outburst decreases over time with effective drainage.

These anomalies may or may not be associated with an extrapolated structure.

PROTECTION

Protection against the effects of an uncontrolled outburst is offered in the following ways:

- Routine training in Outburst Awareness,
- Provision of, and training in the use of, First Response and Escape Equipment, and
- Use of specific mining procedures in high gas environments, including remote operation of continuous miner units in development panel, and shearer and hydraulic supports in longwall panels, or the use of grunching.

Outburst, Coal burst and Inrush (OCI) Risk Review

The OCI team review areas planned for mining which includes assessing outburst risk, considering the nature of the structural geology in the area and the requirements for drilling (coring, hole spacing, flanking hole requirements).

Authority to Mine Process

The Authority to Mine is the one and only piece of documentation that may authorise mining in a particular area, by any means.

Prior to issuing an Authority to Mine (ATM), an Outburst Management Plan Check Sheet is completed, and the ATM is only issued following successful completion of the Outburst Management Plan Check Sheet.

Mining in High Gas Content Areas

If mining operations are authorised to proceed in areas where the gas content has been determined by sampling, in accordance with AS3980, to be greater than the Level 1 TLV, then operating procedures

specific to the authorised mining method, developed based on risk assessment, shall be used to control outburst risk and protect personnel from harm.

Table 1 provides a summary of the mining methods that may be considered by the OCI team for the authorisation of mining in areas based on measured gas content and composition, and the presence or absence of geological structure.

First Response and Escape Equipment

First Response and Escape Equipment is supplied and maintained in all Production Areas at Dendrobium Mine.

Training

All personnel who work underground complete annual refresher training in Outburst Awareness, which includes:

- An introduction and basic explanation of the mechanism of outburst;,
- The structure of the Dendrobium Outburst PHMP (including the ATM process),
- The function of the Outburst PHMP to predict and prevent outbursts,
- Escape and First Response Rescue principles and procedures, including the use of SCSR and CABA equipment, and
- Outburst Warning Signs and Outburst Indicators with a focus on what Operators should be looking for at the face, as indicators of increased outburst risk.

RESEARCH AND DEVELOPMENT

Dendrobium is supporting a variety of research and development projects to enhance the accuracy in identifying and classifying areas of increased outburst risk and improving the efficiency and effectiveness of measures to reduce outburst risk and prevent outburst. These projects range from improving the effectiveness of drilling to pre-drain the WWSM and methods to enhance gas production rate, to developing real-time monitoring of gas flow from UG pre-drainage and goaf gas extraction drilling, to developing a validated finite element model of the WWSM to model and assess outburst risk potential.

Improving UIS Drill Pattern Design

The complex, banded nature of the WWSM, particularly the S2 seam section, has contributed to difficulty in UIS drilling and completing drill patterns to design. In conjunction with our contract drilling partner, drill designs and corresponding gas flow performance is regularly reviewed, and through a focus on continual improvement, changes are identified and trialled with the aim of increasing drilling rate, maintaining hole stability, and increasing gas flow rate to reduce total drainage time.

Seam Ash Basis for Gas Content Reporting

It is common practice for laboratories to report coal mine gas content, for outburst risk review, normalised to a standard ash content. The purpose of this approach is to address variability in reported gas content due to changes in the ash content of the coal samples supplied to the laboratory for testing.

Dendrobium has for several years been reporting gas content normalised to 16% ash, for coal samples containing greater than 16%, which recognises the higher *in situ* ash of the WWSM, and is greater than the typical 10% ash basis used for reporting gas content at other mines, including Appin.

Recent studies have been undertaken at Dendrobium to investigate the variability of seam ash within the WWSM, particularly focussing on each seam section. These studies have highlighted that 16% ash is not representative and is not an appropriate basis to use for normalising the reported gas content of each seam section. The investigation is ongoing, with additional data being collected for analysis.

The outcome of this study will propose ash percentage values to be applied by gas testing laboratory for reporting ash-normalised gas content for each section of the WWSM.

Coal Toughness Testing

Dendrobium is working in collaboration with UoW to develop a standard method for testing coal and calculating the ***f*** index value, as a measure of coal toughness. The method is based on the principles of the Protodyakanov test, used in European and Chinese mines (Gray *et al.*, 2021) to measure the

toughness of coal and its potential to outburst. **Figure 10** illustrates the standard drop hammer equipment used in coal toughness testing.

Coal samples are being collected from normal, structured, and outburst areas and tested to determine the ***f*** index coal toughness value. Where possible, the coal from these areas is also tested to determine the UCS, and other relevant parameters, which will be analysed to determine potential correlation to the ***f*** index coal toughness value and outburst potential.

Figure 10: Drop hammer equipment used in coal toughness testing

Real-time Gas Flow Monitoring

Assessing the performance of underground gas drainage typically relies on periodic manual reading of gas flow rate from individual boreholes. In large gassy mines with extensive gas drainage drilling manual flow reading is labour intensive and the data collected from each hole is often sporadic and insufficient to support accurate assessment of gas drainage performance.

Dendrobium has been working to develop a monitoring system to support real-time measurement of gas flow from UG gas drainage drill sites. It is intended that this system will be operate similar to the UG real time gas monitoring system and similarly be connected to Citect to display current and trend gas flow performance data.

In addition to providing accurate data to determine the effectiveness of the boreholes in draining gas from the reservoir and producing characteristic drainage decline curves for use in future pre-drainage drilling designs, the data obtained from the real-time monitoring can also be configured to alert mine personnel to a developing problem at a particular drill site or in the gas reticulation pipeline network, such as a blockage, or accumulation of water or fines, requiring maintenance.

Outburst Propensity Investigation and Impact of Gas Composition

The outburst TLV defined for the WWSM at Dendrobium (**Figure 9**) have been based on the standard industry approach which requires lower TLV for rich CO2 conditions compared to rich CH4 conditions. The TLV have also been applied to each of the three seam sections of the WWSM, with the upper seam section, considered to present a similar risk of outburst to mining in the lower working sections, despite being separated by two strong and competent non-coal strata units, the 0.8 m thick WWIB that ranges in strength from 28 to 35 MPa, and the 1.0 m thick WWSB that ranges in strength from 85 to 120 MPa.

Dendrobium is supporting research to measure and assess the outburst risk potential to mining the lower working section of the WWSM, including assessing the outburst risk potential of the overlying middle and upper coal seam sections. A range of coal samples is being sourced from the WWSM in Area 3C for laboratory testing to provide the required input data to produce a representative finite element model to assess outburst risk potential.

The laboratory testing program will also extend the work of previous researchers (Black, 2018, Black, 2019a, Black, 2019b, Black, 2019c, Gray *et al.*, 2021, Ren *et al.*, 2022) to assess the impact of gas composition, and coal strength and coal toughness, on the propensity of coal to outburst.

Enhanced Gas Drainage

Methods to stimulate and enhance gas drainage from the WWSM are being investigated for use in areas where conventional UIS pre-drainage is determined to be incapable of reducing gas content at a sufficient rate to avoid production delays due to gas content remaining above TLV.

The method of enhanced gas drainage through injection of inert gas, or similar, as presented in Florentine et al 2010., Black *et al.*, 2011, Black, 2013, Ren *et al.*, 2017, Lin *et al.*, 2018, Lin *et al.*, 2019, is considered to offer the highest potential to enhance gas flow, with lowest impact on site operations and logistics. WWSM coal samples are being collected for laboratory testing to provide relevant data to inform the design of a site trial to assess the relative impact of enhanced gas drainage compared to conventional gas drainage.

CONCLUSIONS AND RECOMMENDATIONS

In the 20 years of mining in the Wongawilli seam at Dendrobium mine, low levels of gas have been present in the working seam section and adjacent coal seams and gas-bearing strata. Mining operations are now moving into a new mining domain and transitioning to a higher gas environment. Dendrobium has an established Outburst Principal Hazard Management Plan, consistent with Industry best practice, that defines standards and requirements for (a) Predicting areas where an outburst risk may exist, (b) Preventing an outburst event from occurring, and (c) Protecting personnel from exposure to an outburst.

As operations advance into this new mining domain, data and experience is being gathered and used to enhance capability to define outburst risk zones and treat those zones to reduce, or remove, the outburst risk ahead of mining.

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