

Investigation into Potential Lightning Ignition Sources Blakefield South Mine



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Table of Contents

	Page
1. EXECUTIVE SUMMARY	3
2. INTRODUCTION	10
3. SCOPE	10
4. INVESTIGATION	10
5. POTENTIAL IGNITION SOURCES	11
6. LIGHTNING IGNITION MECHANISM	11
7. LIGHTNING EVIDENCE	13
8. BORE HOLES	15
9. GAS DRAINAGE PLANT	17
10. PIEZOMETERS	17
11. POWER SYSTEM	18
12. UNDERGROUND ELECTRICAL WIRING/EQUIPMENT	21
13. CABLES USED UNDERGROUND	21
14. CABLES LEFT IN THE GOAF	22
15. CITECT ALARMS	22
16. LONGWALL CIRCUITS	24
17. MISCELLANEOUS SERVICES	25
18. CONCLUSIONS	26
19. RECOMMENDATIONS	30
20. REFERENCES	32
APPENDIX 1 – GPATS REPLY	34
APPENDIX 2 – KATTRON REPLY	36
APPENDIX 3 – KATTRON DATA 10KM RADIUS	38
APPENDIX 4 – LONGWALL CIRCUITS ENERGISED AT TIME OF INCIDENT	39
APPENDIX 5 – DAMAGE OR DEFECTS ON LONGWALL NO. 1 FACE CABLES AND/OR ELECTRICAL APPARATUS IN MONTH PRIOR TO THE INCIDENT	40
APPENDIX 6 – CABLES RECOVERED OR LEFT IN GOAF	41
APPENDIX 7 – UNDERGROUND CABLES	42
APPENDIX 8 – WEATHER DATA	43

1. Executive Summary

On 5th January, 2011, at approximately 7:36pm Eastern Daylight Saving Time (i.e. 6:30pm Australian Eastern Standard Time) there was a report of an explosion large enough to knock over a maintenance worker on longwall number 1 at Blakefield South Mine operated by Bulga Underground Operations Pty Ltd (formerly Beltana Highwall Mining Pty Ltd at the time of the incident). Subsequently, a flame was observed in the goaf at the tailgate end of the longwall. The mine personnel were then evacuated and the mine was sealed.

The scope of this investigation is to consider lightning and electrical installations that may have been the cause of the ignition. Furthermore, the investigation is to identify any substandard lightning protection or electrical practices associated with lightning protection.

The mechanism for lightning ignition is that the electric and magnetic field caused by nearby lightning is coupled into the hazardous zone of the mine and causes a spark which ignites combustible gases. Coupling may be either direct (i.e. conduction) or indirect (i.e. electromagnetic induction). Direct conduction requires either an insulated path, or a low loss path, from the surface down into the hazardous zone of the mine. For the case of direct conduction where the conduction path is in contact with strata (i.e. not insulated), it is possible that there is sufficient energy at the underground end to ignite explosive gases, even though there is significant dissipation into the surrounding strata before reaching the underground mine. Indirect coupling requires an insulated conductor in the hazardous zone of the mine.

Electrical wiring/equipment on the longwall or in the goaf area may cause gas ignition by:-

- Damaged electrical wiring or equipment initiating a spark.
- Short circuit or overload causing heating that ignites combustible gas.
- Electrical wiring not retrieved from goaf area as the longwall advances may develop induced voltages from lightning and cause a spark when insulation breaks down.

The investigation and this report are based on the two site visits and information supplied by DTI NSW (i.e. Department of Trade & Industry NSW) available at the time of writing this report. (Note that most information was supplied from Bulga Underground Operations.)

The following conclusions were reached by the investigation.

Lightning Activity

- 1.1. There was a thunder storm in the area of the mine on 5th January, 2011, on the day when the fire and ignition of gases occurred around 7:36pm Eastern Daylight Saving Time.
- 1.2. Based on the lightning data provided, it is not possible to confirm, nor deny, that a lightning strike occurred in close proximity to the mine. However, based on eye witness accounts, it is concluded that there were lightning strikes to the mine area around the time of the explosion underground.

Lightning Pathways Underground

- 1.3. A number of possible conductive paths for lightning entry from the surface down into the underground mine and goaf have been identified. These paths include piezometer cables, bore holes SIS 05 and SIS 08.

Bore Holes

- 1.4. Any bore holes with conductive structures extending down into the mine or goaf must be considered as a risk for lightning ignition. Therefore, lightning protection should be considered in the form of direct strike protection and surge protection for wiring.
- 1.5. Bore holes SIS 05 and SIS 08 with conductive casings provide a possible conductive path for lightning from the surface down into the goaf. Even though there are large distances from these bore holes to the tailgate end of longwall number 1, where the explosion was recorded, it is possible that lightning was conducted by collapsed roof mesh in the goaf, to the tail gate end of the longwall and caused the ignition.
- 1.6. As gas sampling tubes are non conductive, they are not considered a significant risk for lightning ignition.
- 1.7. No drilling was occurring in the vicinity of the goaf at the time of the incident. Consequently, the drill rig did not have conductive drill rods going from the surface into the goaf.

Gas Drainage Plant

- 1.8. No direct strike lightning protection was evident (e.g. lightning masts) on the gas drainage plant inspected (e.g. to intercept lightning so that it could not directly strike the flare stack and ignite gases.)
- 1.9. No direct strike lightning protection was evident (e.g. lightning masts) on the flare stacks inspected near the gas drainage plant.

- 1.10.** It is concluded that the lack of direct strike protection on the gas drainage plant and flare stacks inspected is a non-conformance to AS1768: 2007, Lightning Protection.

Piezometers

- 1.11.** Piezometers have been identified as conductive objects going from the surface into the goaf. Insulated conductors of the piezometers are expected to conduct any lightning energy down into the goaf with minimal attenuation. More lightning energy is expected to be conducted down into the mine from these insulated conductors than from bore casings in contact with the soil/strata. Even though there are large distances from the piezometer cable entry points in the goaf to the tailgate end of longwall number 1, where the explosion was recorded, it is possible that lightning was conducted to the tailgate end of the longwall by collapsed roof mesh in the goaf and caused the ignition.

Power Supply

- 1.12.** The following practices associated with the 11kV supply to the longwall are considered substandard when compared to electricity supply industry practice:-
- The 300mm² 11kV cable armour was not earthed at the point where it entered the ground to go down to the longwall.
 - 11kV longwall supply cable was laid unrestrained on the ground.
 - A joint in the 11kV longwall supply cable was deformed and does not look like it was made correctly.
 - No surge arrester was installed on the 11kV cable to overhead termination on the last pole closest to the longwall. (This is a non-conformance to AS/NZS 1768:2007, clause 6.6.3.4.)
 - The number 2 fan shaft, 11kV cable screens are earthed to the down lead connected to the overhead earthwire above 66kV on the overhead section.
 - There is a break in the duct that the 11kV cable for the longwall is laid on near mobile substation TX045. This creates a touch potential hazard.
 - The 15m separation between the lightning earth and underground mine earth was not adhered to.
 - The surge arresters were not removed from the mobile substation and mounted on the 66kV pole.
- 1.13.** A comprehensive study and earthing design for lightning was completed for the mobile substation and longwall supply by consultants PowerEarth Technologies. However, their design was not installed

correctly. This would indicate poor supervision or lack of understanding of details during construction.

- 1.14. Earthing and current injection tests performed by PowerEarth indicated some unbonded equipment and high resistance bonds to earth. It is unknown if these bonds were repaired. The mobile substation has been relocated so these bonds are no longer important.
- 1.15. Based on information from Ausgrid, there were no interruptions of the 66kV supply to Blakefield South Mine due to lightning at the time of the incident.
- 1.16. In lieu of a detailed check, the information provided indicates that protection relay co-ordination for underground power circuits has been considered by Ampcontrol.

Cables Used Underground

- 1.17. The investigation determined the following cables are used underground:-
 1. The conveyor signal line is for operational stop/start of the conveyor.
 2. The conveyor DAC line is used for point to point voice communications on the conveyor belt.
 3. The 10pair telephone line is used for voice communications in the underground mine.
 4. The 1pair telephone line is for voice communications on the longwall.
 5. The fibre optic cable is used for Citect monitoring data.
 6. The 2pair Decron cable is used for piezometers.
 7. The high tension cable to supply the longwall is 11kV, 120 mm², 3 core, paper insulated, lead screened with steel wire armour and red PVC jacket.
 8. Twinax cable by Belden is used for the data highway cable to allow access to the site computer network from underground.
 9. The 10 pair Decron cables are used for carrying signals for gas monitoring in the mine.
 10. The 35mm² type 275 cable is 1.1kV insulated overall semiconductor screened cable for shuttle cars and pump cable.
- 1.18. In the above list of cables, it is only the cabling for the piezometers that connect from the surface down into the goaf. Consequently, piezometer cables are considered a risk for conducting lightning into the goaf.
- 1.19. Based on no damage or interruptions to service recorded, it is unlikely that lightning entered the underground mine through the intrinsically safe cables (i.e. items 1,2,3,4,8 and 9) or power cables (i.e. items 7 and 10) in the list above.

Cables Left in Goaf

1.20. The following insulated cables left in the goaf when the longwall advances have been identified as possible circuits subject to induction from lightning with the associated risk of spark ignition:-

- 10 pair telephone cables of 110m lengths
- Figure 8, 1 pair, telephone cables of 30m lengths
- Conveyor signal lines of unspecified length

Citect Alarms

1.21. Based on the lack of recorded Citect alarms and no power outages at the time of the incident, it is concluded that if there was a lightning strike to the mine, it is likely to be of lower amplitude, or further away, causing only induced voltages into electrical circuits at the mine. However, a lightning strike may have occurred to the mine site at a location where there is no electrical power or data monitoring equipment.

Longwall Circuits

1.22. The 11kV cable for the AFC (i.e. armour faced conveyor) longwall No. 1 is not considered a risk that would cause ignition.

1.23. Based on the fact that there was no protection operation or damage to the substation supplying the longwall, it is considered unlikely that longwall 11kV power circuits provided a path for lightning to ignite gases at the longwall.

Summary

1.24. Based on the evidence available, it is not possible to confirm, or deny, that lightning was the cause of the ignition of gases on 5 January, 2011.

Based on the investigation, the following recommendations are put forward.

Lightning

1.25. It is recommended that more lightning locators be installed in the area to improve accuracy of lightning data.

Lightning Pathways Underground

1.26. It is recommended that lightning protection, in the form of direct strike protection and surge protection for any wiring, be considered for all conductive pathways from the surface down into the hazardous area of the mine.

- 1.27. It is recommended that the Blakefield South Mine site be checked to ensure conformance with AS1768: 2007, Lightning Protection and AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements. (See reference 18).

Bore Holes

- 1.28. It is recommended that lightning protection should be considered for bore holes (including SIS 05 and SIS 08) to ensure conformance to AS1768: 2007, Lightning Protection and AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements. (See reference 18).
- 1.29. It is recommended that direct strike lightning protection should be considered for drill rigs when drilling in the vicinity of the goaf or close to underground mine passage ways.

Gas Drainage Plant

- 1.30. It is recommended that installation of direct strike protection on the gas drainage plant and flare stacks be considered to ensure conformance to AS1768: 2007, Lightning Protection and AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements. (See reference 18).
- 1.31. It is recommended that the gas drainage plant be checked to ensure all separate equipment at the site has bonding conductors as per AS/NZS 1768: 2007, Lightning Protection, clause 6.6.3.5, to ensure all equipment is at a similar potential for a lightning strike.

Piezometers

- 1.32. It is recommended that fibre optic water pressure sensors be investigated for future installations to eliminate conductive piezometer paths underground into the hazardous area.

Power Supply

- 1.33. It is recommended that in future, independent experts oversee installation of earthing to ensure it is installed as per the design requirements for lightning protection and electrical step and touch safety.

Cables Left in Goaf

- 1.34. It is recommended that the policy be improved to ensure all conductive cables including telephone and conveyor signal cables are removed as the longwall advances.

Citect Monitoring

- 1.35. It is recommended that continuous monitoring of a spare wire, in Citect underground cabling, for induced voltages is investigated.

2. Introduction

On 5th January, 2011, at approximately 7:36pm Eastern Daylight Saving Time (i.e. 6:30pm Australian Eastern Standard Time) there was a report of an explosion large enough to knock over a maintenance worker on longwall number 1 at Blakefield South Mine operated by Bulga Underground Operations Pty Ltd (formerly Beltana Highwall Mining Pty Ltd at the time of the incident). Subsequently, a flame was observed in the goaf at the tailgate end of the longwall. The mine personnel were then evacuated and the mine was sealed.

An investigation was instigated to determine the cause of the ignition.

3. Scope

The scope of this investigation is to consider lightning and electrical installations that may have been the cause of the ignition. Furthermore, the investigation is to identify any substandard lightning protection or electrical practices associated with lightning protection.

4. Investigation

The following installations were inspected at the site visit to Blakefield South Mine with mine inspectors on Thursday 7th April 2011 :-

- 66kV power line from Bulga providing power for Bulga Underground Operations mines.
- First 66kV/11kV Bulga South substation SR001 for Bulga Underground Operations mine. This is a permanent substation.
- Mobile 66kV/11kV substation TX045 for Blakefield South longwall. (There is only one longwall, number 1.)
- 11kV power circuits for the longwall and vent No. 2.
- Bore hole for gas drainage from goaf.
- Gas drainage plant.

The following were also sighted but not inspected:-

- Emulsion plant near site where 11kV longwall cable goes underground.
- Cables going down the high wall to the mine entrance. (These cables do not supply the longwall.)
- Gas venting site.

Subsequently, a preliminary report was delivered on 13 April 2011.

A second site visit was made on Tuesday 14 June 2011 to inspect the underground electrical installations up to the 27th cut through. (Refer Blakefield South, Singleton NSW, Underground Power Distribution 2011-05-26 drawing.) Substations in this accessible underground area were inspected with a view to restoring underground power to the mine. There was no visible damage to cables

and substation equipment. There was some tar like deposits on horizontal surfaces. These deposits are typical residue from underground fires. Power was subsequently restored to allow water to be pumped from the mine.

A large volume of documents on the mine was supplied by DTI NSW (i.e. Department of Trade & Investment, NSW) for analysis. (Most information was from Bulga Underground Operations Pty Ltd.) See references 1, 2, 10 and 11 for details of material supplied.)

The investigation and this report are based on the two site visits and information supplied by DTI NSW, available at the time of writing this report.

5. Potential Ignition Sources

The following are some of the potential sources of the underground gas ignition:-

- a) Lightning
- b) Electrical wiring or equipment
- c) Cutting and welding
- d) Smoking
- e) Spontaneous combustion
- f) Mining operations
- g) Roof falls

Note that items (f) and (g) may cause a spark due to frictional heating or piezoelectric spark.

This investigation focuses on items (a) and (b) only. Note that for all of the ignition mechanisms identified, flammable gas must be present in the explosive range with oxygen which is 5% to 15% methane (Refer to reference 7).

6. Lightning Ignition Mechanism

The mechanism for lightning ignition is that the electric and magnetic field caused by nearby lightning is coupled into the hazardous area of the mine and causes a spark which ignites combustible gases. In the USA, at least 11 underground coal mine explosions have occurred between 1990 and 2007 in which lightning was suspected of being the cause. (See reference 19.)

Lightning may be cloud to cloud, cloud to ground or upwards from the cloud. Due to proximity, it is only the cloud to ground strikes that are of interest as possibly causing ignition.

Coupling may be either direct (i.e. conduction) or indirect (i.e. electromagnetic induction).

Direct conduction requires either an insulated path, or low loss path, from the surface down into the hazardous area of the mine. Soil resistivities are generally

low (ranging from 6.1 to 264 ohm.m from Drawing Number 2011070, rev 0, Soil Resistivity Data Collection Points, Beltana Highwall Mining Pty Ltd, Blakefield South, dated 18 January 2011) in the area of the mine. Soil resistivity was measured by the Wenner four electrode method and the accuracy of measurements was provided. The accuracy was better than 10% except for one measurement with 39.7%, two with 14.99% and one with 39.7%. Furthermore, at least the soil surface layers were wet on 5th January 2011 at the time of the incident due to rain from a storm in the area. Refer to Appendix 8, Weather Data, for details of rainfall. The presence of water will also aid in dissipation of lightning energy. Consequently, the electrical dissipation from a conductive object in contact with the strata is going to be significant. A conductive path that is in direct contact with strata (i.e. not insulated) will dissipate lightning energy along the way but may still have sufficient energy to cause ignition at a far underground end. References 7 and 8 give examples of modelling to show that conductive bore hole casings can conduct sufficient energy underground to ignite explosive gases. The shallower the mine (i.e. shorter length of bore casing) and the higher the soil resistivity, the more energy is conducted underground.

Some time ago there was an event where lightning struck a conductive bore casing at Springvale, west of Lithgow. The bore casing was used as a conduit for an 11kV cable to go down to an underground mine. A spark was observed in the underground mine from this bore casing to other metal at the time of a lightning strike. Strata surrounding this bore casing is high resistivity sandstone. Note that higher resistivity material will not dissipate lightning energy as well as low resistivity material.

Indirect coupling requires an insulated conductor in the hazardous area of the mine. Electromagnetic induction from lightning into this conductor must cause a large voltage with respect to surrounding strata. Voltage is induced along the length of the conductor. A single conductor may be earthed at one end with a small gap to earth at the far end. A loop formed by two conductors with one end shorted together and the other ends with a small gap between them is also possible. Breakdown of the insulation (either paper, polymeric or air gap) by this high induced voltage will cause a spark. A minimum energy of 0.3mJoules is required to ignite methane at 8.5% methane/air mixture (Reference 7). This is a very small amount of energy.

Indirect coupling from cloud to cloud lightning was the method attributed to the Sago mine explosion on 2nd January 2006 and subsequent death of 12 underground workers. A combination of testing and modelling was performed to verify this mechanism. (Refer to references 3, 4 and 19 for more details of the Sago incident.)

Indirect coupling into a conductive path that is in direct contact with strata (i.e. not insulated) is also possible. However, this is considered unlikely to cause ignition due to dissipation of the lightning energy into surrounding strata.

Possible lightning attachment points on the ground and pathways to conduct lightning underground into the hazardous area need to be identified. Furthermore, conductive objects in the hazardous area that are not connected to the surface must also be identified as possible sources for lightning induced ignition.

It is expected that if lightning strikes the site near an electrical installation, a number of alarms would be initiated in various electrical circuits. The Citect data would be expected to give a list of alarms at the time of any lightning strike.

This report will also consider whether or not the lightning protection at Blakefield South Mine conforms to AS/NZS 1768: 2007. In particular, AS/NZS 1768: 2007, Lightning Protection, section 6.1, recognizes that lightning is an additional hazard that may ignite flammable gases at mines. It also states that generally, lightning protection should be provided or precautionary work procedures adopted.

7. Lightning Evidence

The gas explosion incident occurred around 7:36pm Eastern Daylight Saving Time (i.e. 6:30pm Australian Eastern Standard Time) on 5th January 2011. There was a thunderstorm in the vicinity on this day. This was verified by eye witness reports and also lightning location systems.

Lightning data was available from two suppliers, Kattron and GPATS. Both systems are based on a network of lightning location stations that report into a central facility. Lightning location stations consist of a ground based antenna, radio receiver and processing unit. The antenna is used to detect an electric field disturbance caused by a lightning strike. Some local processing is required to verify that the disturbance signature waveform is due to lightning. Ideally, signatures that are typical for a lightning strike from cloud to ground are detected. These strikes are on average about 30,000 amps and are almost always of much higher amplitude than cloud to cloud strikes. However cloud to cloud strikes that are close to a sensor may also be recorded. Generally, it is the cloud to ground strikes that are of interest as these are potentially the most damaging to ground based equipment.

Three lightning locators must be able to detect the disturbance of a particular lightning strike to give a location. The system uses time of arrival to locate a particular lightning strike. The lightning locators time stamp the signal and send it to the central station for processing. The time stamp differences are then used in highly complex hyperbolic mathematical calculations to locate the source of the lightning signature waveform. In general, this method defines hyperbolic curves by their arrival time differences at the known receivers. The point of intersection of two hyperbolic curves defines the location of the source of the radio

transmission (the location of the lightning strike). In effect the technology is similar to a GPS locating device but in reverse.

The amplitude of the detected signal and the distance to the strike are used to estimate the amplitude of the lightning strike.

To achieve useful accuracy of both location and current amplitude, a number of ground stations are required in the area of interest. For improved accuracy, more ground stations are required.

Lightning data service provider, Kattron, supplied a diagram giving all detected lightning strikes between 10pm on 4th January 2011 and 10pm Eastern Standard Time 5th January 2011 within a 10km radius of the longwall. A position over the longwall was identified as Latitude: S -32.7031, Longitude: E 151.0797. This diagram is provided in Appendix 3. There are two lightning strikes within a few kilometres of the mine. They are recorded as:-

- 7kA at 7:32pm Eastern Standard Time, 2.3km away.
- 119kA at 7:35pm Eastern Standard Time 2.4km away from the mine.

GPATS also provided information on lightning strikes close to the mine. They recorded three strikes between 7:26pm and 7:35pm Eastern Daylight Saving Time on 5th January 2011, as follows:-

- 128kA at 7:26pm Eastern Standard Time, 3.3km away.
- 19kA at 7:30pm Eastern Standard Time, 2.5km away.
- 114kA at 7:35pm Eastern Standard Time, 2.5km away from the mine (identified as Latitude: S -32.7031, Longitude: E 151.0797).

Kattron were asked a number of questions to determine the accuracy of their recorded lightning strikes. The questions and answers are provided in Appendix 2. Only a “general” accuracy figure of +/-500m for lightning location could be supplied by Kattron for their LPATS system. Furthermore, they cannot process the data to give improved accuracy but they suggest there may be other agencies that can further process the data. No accuracy figure could be provided for lightning current amplitude.

GPATS were also asked questions on the accuracy of their lightning data. The questions and responses are given in Appendix 1. The following rather vague response was received to the question of position accuracy, “The sensor distance from an average cloud to ground strike event would ideally be of the order of 200km in order to give a typical detection efficiency of 95% and an accuracy of 250m RMS.” They cannot process the data to give improved accuracy. An accuracy of 25% was provided for lightning current amplitude, provided detectors were within 500km of the strike. Reference 6 is a reference to a paper comparing GPATS to CGR3 lightning recorders in the Brisbane area. This paper suggests that there were some significant discrepancies with GPATS data before 2007.

Overall, lightning data available is of insufficient accuracy to verify a direct strike to the mine. It is recommended that more lightning locators be installed in the area to improve accuracy of lightning data.

Based on the lightning data provided it is not possible to confirm, nor deny, that a lightning strike occurred in close proximity to the mine. However, one eye witness report was, "There was a lot of lightning strikes, strikes before the incident and there was one very close to the incident time that shook our building, and we sort of talked to each other about it that we weren't, you know weren't sure why the power was still on because, because of the size and nature of the strike." Another eye witness report was, "As that went on and the afternoon went on the belt was due, nearly due to go and the storm got heavier and the lightning actually started again, and there was a very heavy lightning, probably heavier than I've seen before because it actually made the office shake which is, it was quite unusual, and not just once there was several large strikes around the surface area. Some rain, not a great deal compared to what we normally do get in those sort of storms." Note that the office building is approximately 2kilometres from the centre of the longwall. The eye witness observations then compare favourably with the lightning data indicating lightning strikes 2.3km to 2.5km from the centre of the longwall. Katron and GPATS both recorded a strike, 119kA and 114kA, respectively, at 7:35pm Eastern Standard Time, 2.4km and 2.5km, respectively, away from the centre of the longwall. These recorded strikes were at a similar time, 7:36pm, when an explosive event was recorded by the Citect system. Consequently, it is concluded that there were lightning strikes to the mine area around the time of the explosion underground.

Observation of trees near the mine that appear to have been struck by lightning are not conclusive as there is no indication that the strikes were on 5th January 2011, or some other time.

8. Bore Holes

AS/NZS 1768: 2007, Lightning Protection, Section 6.6.3.5, Surface Structures, suggests lightning protection should be provided on all structures above underground openings, such as winder head frames. With other buildings and structures, the need to protect or not should be determined from Section 2, which is the risk assessment. Any bore holes with conductive structures extending down into the mine or goaf must be considered as a risk for lightning ignition. Therefore, lightning protection should be considered in the form of direct strike protection and surge protection for wiring.

The bore holes are a possible entry pathway for lightning.

There are a number of bore holes at the mine site. Bore hole types are:-

- Environmental (e.g. water pressure, gas sampling)
- Exploration geological cores
- Water drainage before mining
- Gas drainage in goaf area
- Service delivery into main mine e.g. stone dust

It was explained that the gas drainage bore holes have a steel collar at ground level and then connects onto polyethylene pipe. The depth of the transition from steel to polyethylene was not determined. The inspected bore hole on the site visit was for gas drainage. It appeared to have electrical bonding of all the metal to the steel fence around the site. The steel collar and fence were bonded to an earth stake. As the steel collar has a large surface area in contact with soil/strata, it would provide effective earthing and the earth stake is somewhat superfluous. However, the earth stake was installed to provide a separate dedicated lightning protection earth as suggested by standards and guidelines for lightning protection. The steel fence was higher than all equipment inside the compound so would act like a lightning protection system to intercept and conduct lightning to ground. It was subsequently determined that electrical wires do not go down into the mine for gas monitoring. Gas is monitored using tube lines to sample the gas underground.

It was explained during the site visit that gas sampling lines (also known as tube bundles) are stainless steel at the surface but that polymeric tubes are used at depth. Presumably stainless steel is only used at the surface for extra mechanical protection. As gas sampling tubes are non conductive, they are not considered a significant risk for lightning ignition.

Drawings supplied (Beltana Drawing 2011196, rev 0, dated 18/5/2011, Plan and Cross Sectional View ERD 03 Path Trace, Mitchell Drilling Contractors Well Casing Tally Drawings for SIS 4, SIS 5 and SIS 8) showed that conductive casings of SIS 05 and SIS 08 go from the surface down into the goaf. (Note that SIS means surface to in-seam.) Both SIS 05 and SIS 08 enter the goaf seam approximately 500m from where the fire was initially observed near the tailgate end of the longwall. SIS 05 is on the tailgate side of the goaf and SIS 08 is on the main gate side of the goaf. Bore holes SIS 05 and SIS 08 have conductive casings in contact with surrounding strata. It is possible that there may be sufficient lightning energy to ignite explosive gases in the goaf, even though significant dissipation into surrounding low resistivity strata is expected. Furthermore, it is possible that lightning may be conducted by metallic structures (e.g. conveyors, cables, roof mesh) from the bore hole entry point in the goaf to the tail gate end of the longwall. In particular, collapsed roof mesh in the goaf may provide this conductive path.

There may be other conductive bores going from the surface down into the mine that have not been identified by this investigation.

Investigations indicated that there was no drilling occurring in the vicinity of the goaf at the time of the incident. Consequently, the drill rig did not have conductive drill rods going from the surface into the goaf.

9. Gas Drainage Plant

Gas drainage from the goaf is taken back to a central gas drainage plant with gas flare stacks. At this site there was no direct strike lightning protection evident (e.g. lightning masts) on the gas drainage plant (e.g. to intercept lightning so that it could not directly strike the flare stack and ignite gases.) There were a number of separate installations at the gas drainage plant that may have been connected by earth leads. From inspection, it is unlikely that an earth mat was installed at the site to prevent damage/interruption due to lightning. Note that for reliable operation, bonding conductors would be required to ensure all equipment at the installation is at a similar potential for a lightning strike. This is also a requirement of AS/NZS 1768: 2007, lightning Protection, clause 6.6.3.5. It is recommended that the gas drainage site be checked for suitable bonding conductors between separate installations.

It was also noted that there was no direct strike lightning protection (eg. Lightning masts) on the gas venting installation, in close proximity to the gas drainage plant.

In conclusion, the gas drainage plant and the gas venting plant inspected do not conform to AS1768: 2007 for direct strike protection.

10. Piezometers

The water pressure monitoring system has conductive wires going into the goaf area down bore holes. 2 pair Decron instrument cables (7/0.25mm TAW, polypropylene, insulated each Aluminium/mylar tape screened on a common axis with 7/0.20mm drain wire, PVC black sheathed diameter 6.3mm) run to the surface. Vibrating wire piezometers are lowered into the bore hole with 6mm fibre core galvanised wire. Drawing 2011334 rev 0 shows the location of these piezometers. Insulated conductors of the piezometers are expected to conduct any lightning energy down into the goaf with minimal attenuation. More lightning energy is expected to be conducted down into the mine from these insulated conductors than from bore casings in contact with the soil/strata. Piezometer SBR97 in the goaf closest to the tailgate where ignition was reported is 420m from the tailgate end of longwall number 1. It is closer to the main gate end of the longwall number 1, 300m away. There are three other piezometers, SBR 113, SBR117 and SBR 98, in the goaf area but much further away from longwall number 1. Even though there are large distances to the tailgate end of longwall number 1 where the explosion was recorded it is possible that lightning was conducted by collapsed roof mesh in the goaf and this caused the ignition.

It is recommended that fibre optic water pressure sensors be investigated for future installations to eliminate conductive piezometer paths underground into the hazardous area.

11. Power System

Blakefield South Mine is supplied at 66kV from Bulga Substation. The 66kV line has an overhead earth wire which appears to be earthed at every pole. Earth faults on the 66kV line from Bulga Substation are limited to 188amps with a 0.11second clearing time. There is a section of 11kV under built on the 66kV line which is used to supply number 2 fan shaft. The 66kV line connects to the permanent 66kV/11kV Bulga South substation SR001 for Bulga Underground Operations mine. There was also a mobile 66kV/11kV substation TX045 for Blakefield South longwall number 1. Longwall number 1 was supplied by an 11kV circuit which had some overhead and on-ground sections. The overhead section was used to cross a road. Earth faults on the 11kV circuits from the mobile 66kV/11kV substation TX045 are limited to 10amps.

Mobile 66kV/11kV substation TX045 has since been relocated. Cabling has also been disconnected as longwall number 1 is not operational.

The following observations, from photos taken by John Waudby on 20 January 2011, pertinent to the investigation, were made:-

- It is assumed that the permanent 66kV/11kV Bulga South substation SR001 for Bulga Underground Operations mine has a separate power earth and underground mine earth with 15m separation between the two earths.
- Mobile 66kV/11kV substation TX045 (photo on front of this report) for Blakefield South longwall has a common earth for power and underground mine.
- Based on the response from Bulga Underground Operations, the 300mm² 11kV cable armouring was not earthed at the point where it entered the ground to go down to the longwall.
- 11kV longwall supply cable was laid unrestrained on the ground.
- A joint in the 11kV longwall supply cable was deformed and does not look like it was made correctly.
- Based on photos, no surge arrester was installed on the 11kV cable to overhead termination on the last pole closest to the longwall, at the time of the incident. (This cable was disconnected from the overhead connection after the incident to isolate electrical power.)
- The number 2 fan shaft, 11kV cable screens are earthed to the down lead connected to the overhead earthwire, above 66kV, on the overhead section. 11kV cable screens are connected to the overhead earthwire at the overhead-underground terminations at both ends of the overhead section.

- There is a break in the duct that the 11kV cable for the longwall is laid on near mobile substation TX045.

Separate earthing of the permanent 66kV/11kV Bulga South substation is as per the 1984 Coal Mine Regulations. This requirement was later changed to a less prescriptive, more performance based requirement. The main issue is to prevent lightning from being transferred into underground workings. AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements (reference 18) suggests that separate earth electrode arrangements may be required for high voltage systems and lightning protection systems. More details on separate earthing can be found in Technical Reference, Electrical Engineering Safety, EES005 document on the NSW government website for mining electrical safety legislation. (See reference 17.)

Since the legislation was relaxed, newer substations have been built like mobile 66kV/11kV substation TX045 (photo on front of this report) for Blakefield South longwall with a common earth for power and underground mine. Although this is not as effective as separate earthing, if designed correctly it is acceptable. See further comments, later in this section.

The written response from Bulga Underground Operations indicates that the 11kV supply to longwall No. 1 does not have the 11kV cable screen earthed at the surface, where it enters the borehole. As this screen is not earthed at the surface, it is a possible path for conduction of lightning to the underground mine. This is considered poor practice and of a lesser standard than what the electricity supply industry would install. It is considered substandard that this 11kV cable screen was not earthed at the surface to reduce the amount of lightning current that may be conducted underground.

The deformed joint and the practice of laying the 11kV cable unrestrained on the ground are also considered substandard compared to electricity supply industry practice.

The overhead 11kV section supplying the longwall is subject to direct lightning strike and also induced overvoltages. It is electricity supply industry practice to install surge arresters at all overhead to cable terminations to protect the cable from overvoltage. This is also a requirement of AS/NZS 1768: 2007, Lightning Protection, clause 6.6.3.4. In this case, surge arresters would also limit the amount of energy conducted underground by the 11kV cable. The fact that no surge arrester was installed on the 11kV cable to overhead termination on the last pole, closest to where the cable goes down the bore hole to the longwall is also considered substandard compared to electricity supply industry practice.

Lack of surge arresters at longwall supply 11kV overhead to cable terminations is a non-conformance to AS1768: 2007, Lightning Protection, clause 6.6.3.4.

Connecting the number 2 fan shaft, 11kV cable screens to the down lead of the overhead earthwire is not considered good practice. A lightning strike to the overhead earthwire will raise the voltage of the 11kV cable screen and may puncture insulation on the jacket.

The break in the duct that the 11kV cable for the longwall is laid on near mobile substation TX045 is a touch potential hazard for personnel. A bonding lead should be applied across the gap to electrically bond the different sections of duct together.

PowerEarth drawing, Blakefield South Project, 15MVA Mobile Substation, Earthing System, Connection Diagram, A3-2789_002, rev B, dated 8/6/07, has a number of requirements which were not adhered to. In particular:-

- No bore hole earthing installed.
- Insulated 70mm² copper conductor from mobile sub to bore hole earthing system not installed.
- A connection was made to the earthwire above 66kV when a note required, "No connection shall be made between either 66kV earthing system and the overhead earthwire".
- The 15m separation between the lightning earth and underground mine earth was not adhered to.
- The surge arresters were not removed from the mobile substation and mounted on the 66kV pole. (Arresters are visible in the photo on the front of this report.)

The 66kV arresters at the mobile substation will conduct lightning energy into the 66kV mobile substation earth grid which is then connected directly to the underground workings. This drawing was part of an extensive report by PowerEarth Technologies Pty Ltd, Beltana Mine, Blakefield South Project, 15MVA LW Mobile Substation, Earthing System Design, October 2009. A comprehensive study and earthing design for lightning was completed for the mobile substation and longwall supply by consultants PowerEarth Technologies. However, their design was not installed correctly. This would indicate poor supervision or lack of understanding of details during construction.

Earthing and current injection tests were performed by PowerEarth. (Refer to references 13 and 14.) The reports on these tests indicated some unbonded equipment and high resistance bonds to earth. It is unknown if these bonds were repaired. The mobile substation has been relocated and the longwall disconnected, so these bonds are no longer important.

Ausgrid advised, "There were no circuit breaker operations from midnight on 4/1/2011 through to midnight 7/1/2011 on the Singleton 66kV system. There were no other significant events during this period on that system. there was no power outage to the Bulga Coal connection point which feeds Blakefield South."

12. Underground Electrical Wiring/Equipment

Electrical wiring/equipment on the longwall or in the goaf area may cause gas ignition by:-

- Damaged electrical wiring or equipment initiating a spark.
- Short circuit or overload causing heating that ignites combustible gas.
- Electrical wiring not retrieved from goaf area as the longwall advances may develop induced voltages from lightning and cause a spark when insulation breaks down.

The above possibilities are considered in the next sections of this report.

13. Cables Used Underground

The investigation made every effort to identify all electrical wiring and equipment in the underground mine and goaf.

A list of all underground cables was supplied (refer Appendix 7) along with specifications for each cable.

The investigation determined the following functions of the underground cables:-

1. The conveyor signal line is for operational stop/start of the conveyor. Note subsequent isolation is required for work on the conveyor.
2. The conveyor DAC line is used for point to point voice communications on the conveyor belt. It has a speaker and microphone but no handset.
3. The 10pair telephone line is used for voice communications in the underground mine.
4. The 1pair telephone line is for voice communications on the longwall.
5. The fibre optic cable is used for Citect monitoring data. (The investigation found evidence that both 6 and 8 fibre optic cables are used.)
6. The 2pair Decron cable is used for piezometers.
7. The high tension cable to supply the longwall is 11kV, 120 mm², 3 core, paper insulated, lead screened with steel wire armour and red PVC jacket. Continuous rating is 212 amp in air and fault rating is 14.2kA for 1second.
8. Twinax cable by Belden is used for the data highway cable to allow access to the site computer network from underground.
9. The 10 pair Decron cables are used for carrying signals for gas monitoring in the mine.
10. The 35mm² type 275 cable is 1.1kV insulated overall semiconductor screened cable for shuttle cars and pump cable. This cable has interstitial earth conductors designed to reduce instances of wire breaks during reeling while under tension. The cable also includes one central pilot for earth continuity monitoring.

It is assumed that items 1, 2, 3, 4, 8 and 9 are installed in intrinsically safe circuits. The earthed screens of intrinsically safe cables are a possible pathway for lightning entry into the mine. However, no fuses were found to be blown in the intrinsically safe circuits. Item 5, the fibre optic cable has no metal and therefore cannot cause ignition. The power cable screens/armouring, items 7 and 10, are a possible path way for lightning into the mine. If lightning had been conducted down any of the power or intrinsically safe cables then damage to the electrical circuits would be expected. However, no damage or interruption to service on these circuits was recorded.

It is only the cabling for the piezometers that connect from the surface down into the goaf. Consequently, piezometer cables are considered a risk for conducting lightning into the goaf.

14. Cables Left in the Goaf

The Bulga Underground Operations written response indicates that only telephone cables were not recovered, when longwall No. 1 was advanced. Refer to Appendix 6. 10 pair telephone cables of 110m lengths and figure 8, 1 pair, telephone cables of 30m lengths were not recovered and not connected to the surface. Induction into these cables from lightning may be a cause of ignition as per the mechanism indicated for the Sago Mine (references 3, 4 and 19). However, interviews revealed that cable retrieval practices may not be uniform. In particular, telephone cables, conveyor signal lines and an orange communications cable were sometimes left in the goaf when the longwall advances. From the cable specifications, the orange communications cable is probably the 6 core fibre optic cable. The 6 core fibre optic cable has no conducting parts so it is not subject to direct or induced induction from lightning. Consequently, from a lightning ignition point of view, fibre optic cables are okay to leave in the goaf.

The following insulated cables in the goaf have been identified as possible sources of lightning induced gas ignition:-

- 10 pair telephone cables of 110m lengths
- Figure 8, 1 pair, telephone cables of 30m lengths
- Conveyor signal lines of unspecified length

It is recommended that the policy be improved to ensure all conductive cables including telephone and conveyor signal cables are removed as the longwall advances.

15. Citect Alarms

Based on eye witness reports, storms are not unusual in the area and on previous occasions sometimes the power had gone off during a storm, sometimes not. On 5th January 2011, one of the witnesses in the services room

(where the Citect display is located) was monitoring progress of the storm on the Bureau of Meteorology site. Due to the severity of the storm, he expected the power to go off and that electrical equipment would have to be reset afterwards so he took a crib break. When power is lost, many mine systems are tripped off which generates alarms.

Citect monitoring of gas pressures and percentages detected a sudden pressure increase at 7:36:39pm Eastern Daylight Saving Time. This pressure increase and the changes in other gas levels indicated an explosion in the tail gate area of the longwall. (Details are given in reference 16.)

For large amplitude direct lightning strikes close to the mine, it is likely that the power would go off and that other control and communication circuits would malfunction or suffer permanent damage. For lower amplitude lightning strikes and large amplitude strikes further away, it is likely that induced voltages may cause interference into electrical systems at the mine.

The Citect system is designed to monitor all the systems at the mine and provide a display or printout of alarms at the services room. On 14th March 2011, a complete list of alarm logs from the Citect monitoring system for 5th January 2011 was provided by Bulga Underground Operations (reference 5). I am not an expert on mine alarms. However, it is expected that a lightning strike entering the mine near electrical circuits would cause some loss of power and disruption to control, monitoring and communications electrical circuits and this would generate alarms. There is also the possibility that response time of the Citect system may be too slow, or that over voltage protection clamped any lightning impulses. A review of the Citect alarms for 5th January, 2011, indicates a more, or less, steady stream of alarms. There does not appear to be a large number of alarms occurring at around 7:36pm Eastern Daylight Saving Time from a lightning strike. However, there appears to be an excessive number of gas drainage communications alarms occurring throughout the day.

Eye witness reports were that there was no power loss at the time of the incident.

Consequently, based on the lack of recorded Citect alarms and no power outages, it is concluded that if there was a lightning strike to the mine, it is likely to be of lower amplitude, or further away, causing only induced voltages into electrical circuits at the mine. Note that a lightning strike may have occurred to the mine site at a location where there is no electrical power or data monitoring equipment.

It was determined during the investigation that any power supplies for Citect data monitoring equipment in the underground mine are installed in intrinsically safe circuits. Note that there is screening on intrinsically safe circuits which provides some immunity to induction from lightning and other electrical interference sources. Any large induced voltages are likely to blow the fuses in the intrinsically

safe circuits. However, no fuses were found to be blown in the intrinsically safe circuits.

It is recommended that continuous monitoring of a spare wire, in Citect underground cabling, for induced voltages is investigated.

16. Longwall Circuits

Drawings of the underground power distribution (Blakefield South, Singleton NSW, Underground Power Distribution 2011-05-26) and the underground services (Fire Fighting and Rescue Plan sheet 1 of 2, drawing number 2011095 Rev 0 dated 11/2/2011) were supplied.

A list of circuits that were energised on longwall No. 1 at the time of the incident was supplied. Refer Appendix 4.

A list of damage or defects on the longwall No. 1 face cables and/or electrical apparatus in the month prior to the incident was also supplied. Refer Appendix 5. No date and time was provided for these defects.

The possibility of frequent protection operations was investigated. However, only two electrical protection trips were reported in the month prior to the incident. These trips were identified as follows:-

- (a) 1 x S/C trip on 11Kv DCB supply; and
- (b) Reset shearer outlet over current trip
A/S (Afternoon Shift).

No date and time was provided for these trips.

Nothing conclusive could be determined from the energised circuits at the time of the incident, the list of defects or the electrical protection trips of the longwall.

Information on protection relay co-ordination was supplied. In lieu of a detailed check, the information provided indicates that protection relay co-ordination for underground power circuits has been considered by Ampcontrol (reference 15).

Information provided indicates that the AFC (i.e. armour faced conveyor) longwall No. 1 was isolated but the 11kV conductors in the cable were not earthed at the time of the incident. This would be normal practice. The circuit breaker would only be racked out and earthed if someone was working on the 11kV. As the 11kV cable for the AFC longwall No. 1 has individual earthed screening around each conductor and overall earthed screen/armour, it is considered an unlikely source of lightning induced voltage.

If lightning conduction or induction had occurred on the unearthed 11kV power cable and ignited the gases, then it is expected that there would be some damage to the electrical equipment. Note that the longwall is a large extended metallic structure in contact with strata and therefore is likely to provide a low resistance path to earth. Consequently, if there are other conductive objects carrying lightning, they may spark to the longwall. There was no protection operation or damage to the substation supplying the longwall. Consequently, it is considered unlikely that longwall 11kV circuits provided a path for lightning to ignite gases at the longwall.

17. Miscellaneous Services

There are a number of conductive services entering the underground mine, including cables going down the high wall to the mine entrance, conveyors and steel pipes containing water and air. The roof of the mine is also covered with steel reinforcing mesh. These services and the roof mesh are expected to have good electrical contact with surrounding strata. Although they are a possible path for lightning entry into the mine it is expected that there is a low risk of ignition as any lightning energy would be dissipated into surrounding strata at the mine entry point.

There may be other below ground conductive equipment that has not been identified. E.g. drill strings. As drill strings are conductive and in contact with surrounding strata they are considered low risk for lightning induced spark ignition.

The following above ground installations have been identified as possible attachment points for lightning:-

- Emulsion plants
- Gantry
- Drill Rigs
- Boiler gas plant
- Communication's sites

There may be other above ground attachment points at the mine. However, insufficient information has been available to evaluate whether, or not, these installations have conductive connections into the underground mine, or goaf.

18. Conclusions

Lightning Activity

- 18.1. There was a thunder storm in the area of the mine on 5th January, 2011, on the day when the fire and ignition of gases occurred around 7:36pm Eastern Daylight Saving Time.
- 18.2. Based on the lightning data provided, it is not possible to confirm, nor deny, that a lightning strike occurred in close proximity to the mine. However, based on eye witness accounts, it is concluded that there were lightning strikes to the mine area around the time of the explosion underground.

Lightning Pathways Underground

- 18.3. A number of possible conductive paths for lightning entry from the surface down into the underground mine and goaf have been identified. These paths include piezometer cables, bore holes SIS 05 and SIS 08.

Bore Holes

- 18.4. Any bore holes with conductive structures extending down into the mine or goaf must be considered as a risk for lightning ignition. Therefore, lightning protection should be considered in the form of direct strike protection and surge protection for wiring.
- 18.5. Bore holes SIS 05 and SIS 08 with conductive casings provide a possible conductive path for lightning from the surface down into the goaf. Even though there are large distances from these bore holes to the tailgate end of longwall number 1, where the explosion was recorded, it is possible that lightning was conducted by collapsed roof mesh in the goaf, to the tail gate end of the longwall and caused the ignition.
- 18.6. As gas sampling tubes are non conductive, they are not considered a significant risk for lightning ignition.
- 18.7. No drilling was occurring in the vicinity of the goaf at the time of the incident. Consequently, the drill rig did not have conductive drill rods going from the surface into the goaf.

Gas Drainage Plant

- 18.8. No direct strike lightning protection was evident (e.g. lightning masts) on the gas drainage plant inspected (e.g. to intercept lightning so that it could not directly strike the flare stack and ignite gases.)
- 18.9. No direct strike lightning protection was evident (e.g. lightning masts) on the flare stacks inspected near the gas drainage plant.

18.10. It is concluded that the lack of direct strike protection on the gas drainage plant and flare stacks inspected is a non-conformance to AS1768: 2007, Lightning Protection.

Piezometers

18.11. Piezometers have been identified as conductive objects going from the surface into the goaf. Insulated conductors of the piezometers are expected to conduct any lightning energy down into the goaf with minimal attenuation. More lightning energy is expected to be conducted down into the mine from these insulated conductors than from bore casings in contact with the soil/strata. Even though there are large distances from the piezometer cable entry points in the goaf to the tailgate end of longwall number 1, where the explosion was recorded, it is possible that lightning was conducted to the tailgate end of the longwall by collapsed roof mesh in the goaf and caused the ignition.

Power Supply

18.12. The following practices associated with the 11kV supply to the longwall are considered substandard when compared to electricity supply industry practice:-

- The 300mm² 11kV cable armour was not earthed at the point where it entered the ground to go down to the longwall.
- 11kV longwall supply cable was laid unrestrained on the ground.
- A joint in the 11kV longwall supply cable was deformed and does not look like it was made correctly.
- No surge arrester was installed on the 11kV cable to overhead termination on the last pole closest to the longwall. (This is a non-conformance to AS/NZS 1768:2007, clause 6.6.3.4.)
- The number 2 fan shaft, 11kV cable screens are earthed to the down lead connected to the overhead earthwire above 66kV on the overhead section.
- There is a break in the duct that the 11kV cable for the longwall is laid on near mobile substation TX045. This creates a touch potential hazard.
- The 15m separation between the lightning earth and underground mine earth was not adhered to.
- The surge arresters were not removed from the mobile substation and mounted on the 66kV pole.

18.13. A comprehensive study and earthing design for lightning was completed for the mobile substation and longwall supply by consultants PowerEarth Technologies. However, their design was not installed

correctly. This would indicate poor supervision or lack of understanding of details during construction.

- 18.14.** Earthing and current injection tests performed by PowerEarth indicated some unbonded equipment and high resistance bonds to earth. It is unknown if these bonds were repaired. The mobile substation has been relocated so these bonds are no longer important.
- 18.15.** Based on information from Ausgrid, there were no interruptions of the 66kV supply to Blakefield South Mine due to lightning at the time of the incident.
- 18.16.** In lieu of a detailed check, the information provided indicates that protection relay co-ordination for underground power circuits has been considered by Ampcontrol.

Cables Used Underground

- 18.17.** The investigation determined the following cables are used underground:-

1. The conveyor signal line is for operational stop/start of the conveyor.
2. The conveyor DAC line is used for point to point voice communications on the conveyor belt.
3. The 10pair telephone line is used for voice communications in the underground mine.
4. The 1pair telephone line is for voice communications on the longwall.
5. The fibre optic cable is used for Citect monitoring data.
6. The 2pair Decron cable is used for piezometers.
7. The high tension cable to supply the longwall is 11kV, 120 mm², 3 core, paper insulated, lead screened with steel wire armour and red PVC jacket.
8. Twinax cable by Belden is used for the data highway cable to allow access to the site computer network from underground.
9. The 10 pair Decron cables are used for carrying signals for gas monitoring in the mine.
10. The 35mm² type 275 cable is 1.1kV insulated overall semiconductor screened cable for shuttle cars and pump cable.

- 18.18.** In the above list of cables, it is only the cabling for the piezometers that connect from the surface down into the goaf. Consequently, piezometer cables are considered a risk for conducting lightning into the goaf.

- 18.19.** Based on no damage or interruptions to service recorded, it is unlikely that lightning entered the underground mine through the intrinsically safe cables (i.e. items 1,2,3,4,8 and 9) or power cables (i.e. items 7 and 10) in the list above.

Cables Left in Goaf

18.20. The following insulated cables left in the goaf when the longwall advances have been identified as possible circuits subject to induction from lightning with the associated risk of spark ignition:-

- 10 pair telephone cables of 110m lengths
- Figure 8, 1 pair, telephone cables of 30m lengths
- Conveyor signal lines of unspecified length

Citect Alarms

18.21. Based on the lack of recorded Citect alarms and no power outages at the time of the incident, it is concluded that if there was a lightning strike to the mine, it is likely to be of lower amplitude, or further away, causing only induced voltages into electrical circuits at the mine. However, a lightning strike may have occurred to the mine site at a location where there is no electrical power or data monitoring equipment.

Longwall Circuits

18.22. The 11kV cable for the AFC (i.e. armour faced conveyor) longwall No. 1 is not considered a risk that would cause ignition.

18.23. Based on the fact that there was no protection operation or damage to the substation supplying the longwall, it is considered unlikely that longwall 11kV power circuits provided a path for lightning to ignite gases at the longwall.

Summary

18.24. Based on the evidence available, it is not possible to confirm, or deny, that lightning was the cause of the ignition of gases on 5 January, 2011.

19. Recommendations

Lightning

- 19.1. It is recommended that more lightning locators be installed in the area to improve accuracy of lightning data.

Lightning Pathways Underground

- 19.2. It is recommended that lightning protection, in the form of direct strike protection and surge protection for any wiring, be considered for all conductive pathways from the surface down into the hazardous area of the mine.
- 19.3. It is recommended that the Blakefield South Mine site be checked to ensure conformance with AS1768: 2007, Lightning Protection and AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements. (See reference 18).

Bore Holes

- 19.4. It is recommended that lightning protection should be considered for bore holes (including SIS 05 and SIS 08) to ensure conformance to AS1768: 2007, Lightning Protection and AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements. (See reference 18).
- 19.5. It is recommended that direct strike lightning protection should be considered for drill rigs when drilling in the vicinity of the goaf or close to underground mine passage ways.

Gas Drainage Plant

- 19.6. It is recommended that installation of direct strike protection on the gas drainage plant and flare stacks be considered to ensure conformance to AS1768: 2007, Lightning Protection and AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements. (See reference 18).
- 19.7. It is recommended that the gas drainage plant be checked to ensure all separate equipment at the site has bonding conductors as per AS/NZS 1768: 2007, Lightning Protection, clause 6.6.3.5, to ensure all equipment is at a similar potential for a lightning strike.

Piezometers

- 19.8. It is recommended that fibre optic water pressure sensors be investigated for future installations to eliminate conductive piezometer paths underground into the hazardous area.

Power Supply

- 19.9. It is recommended that in future, independent experts oversee installation of earthing to ensure it is installed as per the design requirements for lightning protection and electrical step and touch safety.

Cables Left in Goaf

- 19.10. It is recommended that the policy be improved to ensure all conductive cables including telephone and conveyor signal cables are removed as the longwall advances.

Citect Monitoring

- 19.11. It is recommended that continuous monitoring of a spare wire, in Citect underground cabling, for induced voltages is investigated.

20. References

1. Letter dated 13 May 2011 from Mr Tim Flowers, Investigator, Investigations Unit of Industry and Investment NSW to Mr Mark Munro, Operations Manager, Beltana Highwall Mining Pty Ltd requesting information under section 62 of Occupational Health and Safety Act 2000, regarding the fire and ignition of gas on 5 January 2011 at Blakefield South Mine.
2. Letter dated 10 June 2011 from Mr Mark Munro, Operations Manager, Beltana Highwall Mining Pty Ltd to Mr Laycock, Investigator, Investigations Unit of Industry and Investment NSW providing response to section 62 notice dated 13 May 2011.
3. Internal Review of MSHA's Actions at the Sago Mine, Wolf Run Mining Company, Sago, Upshur County, West Virginia by U.S. Department of Labour, Mine Safety and Health Administration, Program Evaluation and Information Resources dated June 28, 2007.
4. Power point presentation Summary of Investigation, Fatal Underground Coal Mine Explosion on January 2, 2006 at Sago Mine, Wolf Run Mining Company.
5. Email from Jennie Stewart, Investigator, Investigation Unit, Mine Safety Performance, NSW Department of Trade and Investment, Regional Infrastructure and Services, on Wednesday 19 October 2011 to Tony Gillespie, Gillespie Power Consultancy.
6. Occurrence of positive and negative polarity cloud-to-ground lightning flashes: Case study of CGR4 and GPATS data for Brisbane, Australia, by Y. Kuleshov, P. Hettrick, D. Mackerras, M. Darveniza and E. R. Jayaratne, published in Australian Meteorological and Oceanographic Journal 61 (2011) 107-112.
7. Lightning propagation through the earth and its potential for methane ignitions in abandoned areas of underground coal mines by Thomas Novak and Thomas J. Fisher, published in IEEE Transactions on Industry Applications, volume 37, number 6, November/December 2001.
8. A method for estimating the probability of lightning causing a methane ignition in an underground mine by H. K. Sacks and Thomas Novak, published in IEEE Transactions on Industry Applications, volume 44, number 2, March/April 2008.
9. AS/NZS 1768: 2007, Lightning Protection.
10. Letter dated 22 December 2011 from Ms Jennie Stewart, Investigator, Investigations Unit of Trade and Investment NSW to Mr Mark Munro, Operations Manager, Bulga Underground Operations Pty Ltd requesting information under section 62 of Occupational Health and Safety Act 2000, regarding the fire and ignition of gas on 5 January 2011 at Blakefield South Mine.
11. Letter dated 5 January 2012 from Mr Mark Munro, Operations Manager, Bulga Underground Operations Pty Ltd to Ms Jennie Stewart, Investigator,

- Investigations Unit of Trade and Investment NSW providing response to section 62 notice dated 22 December 2011.
12. PowerEarth Technologies Pty Ltd, Beltana Mine, Blakefield South Project, 15MVA LW Mobile Substation, Earthing System Design, October 2009.
 13. PowerEarth Technologies Pty Ltd, Xstrata Coal, Blakefield South Project, Site Wide Earth Grid Testing, September 2010.
 14. PowerEarth Technologies Pty Ltd, Xstrata Coal, Beltana Blakefield South, Substation SR001 & TX045 Mobile Substation, Earth Grid Injection Testing, September 2010.
 15. Ampcontrol, Blakefield South Longwall Procurement Project, Subcontract No C5641, Power System Modelling #2, Document BKS2600-151 dated 9/12/2008.
 16. Blakefield South Explosion and Mine Fire Investigation, Analysis of Citect SCADA by Inspector B. Gittins, Report dated Monday 16 January 2012.
 17. Technical Reference, Electrical Engineering Safety, EES005, NSW Department of Primary Industries, Technical Reference, **Electrical Protection and Earthing**, *Coal Mine Health and Safety Act 2002, Coal Mine Health and Safety Regulation 2006*, December 2006 (version 1). Available from website <http://www.dpi.nsw.gov.au/minerals/safety/legislation/coal-mines/support-documents>
 18. AS 3007.2 - 2004, Electrical installations – Surface mines and associated processing plant, Part 2: General protection requirements.
 19. Sandia Report SAND2006-7976, Unlimited Release, Printed April 2007, Appendix DD – Measurements & Modelling of Transfer Functions for Lightning Coupling into the Sago Mine.

Appendix 1 – GPATS Reply

From: "michael" <michael@gpats.com.au>
To: <jennie.stewart@industry.nsw.gov.au>
Date: 07/10/2011 09:09 AM
Subject: RE: Lightning Info supplied on 18 January 2011 - request for additional information on accuracy of monitoring data.

Hi Jennie,

Sorry for the delaying in getting back to you. I just got the answers to your questions from our scientists today.

1. What is the accuracy of the lightning location?

The accuracy is a function of sensor location and distance from the strokes with an ideal situation of three sensors surrounding the event and each forming the apex of an equilateral triangle. The sensor distance from an average cloud to ground stroke event would ideally be of the order of 200km in order to give a typical detection efficiency of 95% and an accuracy of 250m RMS.

2. Can the lightning data be processed to improve the location accuracy?

This is only possible if sensor data was recorded from more than three sensors. Typically that information is available but is not normally archived, hence the answer is no. Going forward it may be advantageous to add more sensors in the vicinity (200 km or so) of the operations.

3. Where are the closest lightning location devices that were used to determine lightning location for the above coordinates? Can you provide coordinates for these?

The sensors are located at Bureau of Meteorology sites.

4. What measurement principle is used to determine lightning location?

GPATS system uses a Time Difference of Arrival (TDOA) technique applied to the transmission from a radio signal source, in this case a stroke of lightning. This TDOA technique is based on the time differences between the receptions of a radio signal at three remote receivers at known points from a single source. Each signal, travelling at the speed of light, or approximately 186,000 miles per second, is time-stamped by the receivers at the three known points. The time-stamp differences are then used in highly complex hyperbolic mathematical calculations to locate the source of the unknown radio signal. In general, this method defines hyperbolic curves by their arrival time differences at the known receivers. The point of intersection of two hyperbolic curves defines the location of the source of the radio transmission (the location of the lightning stroke). In effect the technology is similar to a GPS locating device but in reverse.

5. What is the system sensitivity to the different types of lightning strike (i.e. cloud-cloud, cloud-ground, upwards from cloud)?

The system ideally looks for signatures that are typical for a lightning stroke from cloud to ground. These strokes are on average about 28,000 amps and are almost always of much higher amplitude than cloud to cloud strokes. However cloud strokes that are close to a sensor may also be recorded.

6. What is the accuracy of lightning current amplitude data?

This is a more difficult calculation but is expected to be of the order of 25% in cases where ALL the reporting sensors were within about 500 km of the stroke. Should any one sensor be 500 or more km distant then the calculations may be more in error.

7. What measurement principle is used to determine lightning current amplitude?

The system data is normalized to be compatible with known current measurements based on the nationally accepted Anderson and Eriksson recorded data. The system relies on the voltages received at the sensor antennas.

8. Can the lightning data be processed to improve the current magnitude accuracy?

This is possible but complicated and dependent on sensor geometry and distance.

Investigation into Potential Lightning Ignition Blakefield South Mine

Hope the information helps. You can also refer to our website: www.gpats.com.au to find out more technical issue.

Kind regards
Michael

Appendix 2 – Kattron Reply

From: Kattron <katall@lightning.net.au>
To: jennie.stewart@industry.nsw.gov.au
Date: 04/10/2011 03:53 PM
Subject: Re: Attention Shane - re: Additional information on accuracy of monitoring data.

Hi Jennie

In reply to you email containing questions regarding the lightning data :

The data we provided was from our original LPATS lightning Network.

We are rolling out a new improved KWTLN (Earth Networks) latest technology network which we were implementing and reviewing at the time of your report request.

If we can encourage some mines in the Hunter to purchase some additional sensors to connect to the network it will further improve the coverage.

Below are responses (from my understanding) to you specific questions

1. What is the accuracy of the lightning location? It is noted that your reports quote an average position accuracy of 500m - Is this a general figure or can a more accurate figure be supplied?
This figure is a general figure. A more accurate value is not available for our LPATS network.
2. Can the lightning data be processed to improve the location accuracy?
Raw data is available from sensors and could be used (by third parties) to refine/recalculate the solutions
We do not directly reprocess the data from our LPATS network.
3. Where are the closest lightning location devices that were used to determine lightning location for the above coordinates? Can you provide coordinates for these?
We can extract data on the sensors used to produce solution If you provide us the details of specific strikes of interest.
4. What measurement principle is used to determine lightning location?
Time Of Arrival
5. What is the system sensitivity to the different types of lightning strike (i.e. cloud-cloud, cloud-ground, upwards from cloud)?
General figures for our LPATS network are 80-90% of CG (Cloud to ground) and 10% CC (Intracloud / Cloud to Cloud) We do not have any details about "upwards from cloud".
6. What is the accuracy of lightning current amplitude data?
As far as I am aware we do not have accuracy values for amplitude calculations
7. What measurement principle is used to determine lightning current amplitude?
The Amplitude of the detected signal and distance of strike are used to calculate amplitude
8. Can the lightning data be processed to improve the current magnitude accuracy?
We are not able to reprocess the data to improve the current magnitude accuracy for our LPATS network,

Investigation into Potential Lightning Ignition Blakefield South Mine

however there may be third parties that are able look at and reprocess the raw data.
Please contact us if you have any further questions.

Regards
Shane Prendergast

Kattron - The ALL AUSTRALIAN Lightning Data Service
P.O. Box 5220 CHITTAWAY BAY, NSW, 2261, Australia
Phone 02 4389 8486
<http://www.lightning.net.au>

Appendix 3 – Kattron Data 10km Radius



LIGHTNING DATA SEARCH

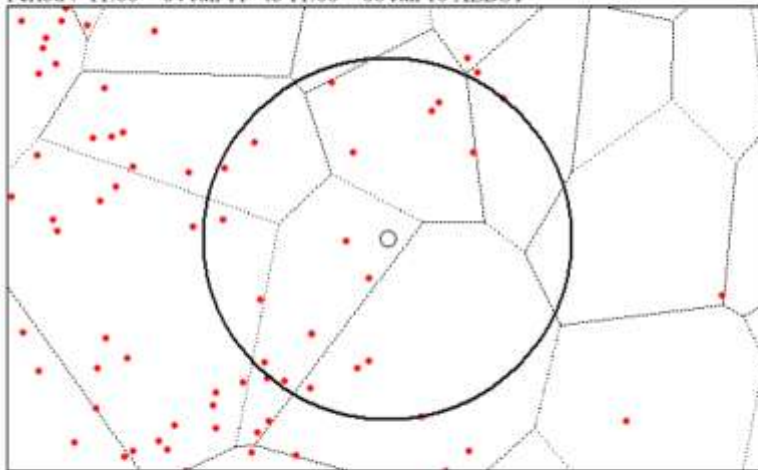
Kat Ref: \Lightning Searches\2010-2011\Xstrata-Beltana\

File : KWTLN\20101104-05

Period : 11:00 - 04 Jan 11 to 11:00 - 06 Jan 10 AEDST

Area: Supplied Coordinates for Hunter Valley site, NSW

Lat: S -32.6917 Lon: E 151.1042



Zoom View

This view shows an area, centred on the location. The list of strokes gives the detected location, time, date, polarity and amplitude for close strokes detected. Distance relates to location given above. The circle shown has a 10 km radius.

The two closest strikes detected to the location were

strokes
detected at:
AEDST

DATE	TIME	LAT	LON	Kamp	Dist (km)
5-Jan-11	19:32:25.844	32.694	151.08	7	2.260
5-Jan-11	19:35:40.966	32.712	151.094	119	2.444

IMPORTANT

Data and graphics are copyright and remain the property of Kattron and may not be reproduced in any form without the express permission of Kattron. Payment of the search fee entitles customer to use this information in support of a claim related to a lightning event.

Appendix 4 – Longwall Circuits Energised at Time of Incident

- (a) Burnbrite (face lighting) Junction Box supply;
- (b) RS20S (Roof Support) Intrinsically Safe supply;
- (c) 12 volt Intrinsically Safe lighting supply;
- (d) IMAC (Face Communications System) supply;
- (e) Gas Guard environment monitoring;
- (f) NLT (Northern Lights) wireless access points;
- (g) M/G (Maingate) and T/G (Tailgate) Intrinsically Safe telephones;
- (h) M/G and T/G CME's (Control and Monitoring Enclosure);
- (i) M/G CME;
- (j) T/G CME;
- (k) Face DCB (Distribution Control Box); and
- (l) AFC (Armoured Face Conveyor) DCB.

Appendix 5 – Damage or Defects on Longwall No. 1 Face Cables and/or Electrical Apparatus in Month Prior to the Incident

- (a) Shearer wireless not connected, no communications past 105 support;
- (b) Light on tank U/S (out of service) pump station;
- (c) No Mouse M/G CME;
- (d) Gear box oil temp sensor needs replacing: faulty;
- (e) Damage to marshalling and HII but safe pump cart;
- (f) Belt wander switch not good;
- (g) Cable damaged wireless aerial;
- (h) OWS (Off Walk Side) wander switch U/S;
- (i) 56/29 SC (Short Circuit) leg Txd's (Transducers);
- (j) Light missing from platform 3.3kv platform;
- (k) Up key U/S on PV (Panel View) button TG CME;
- (l) Replaced PSU (Power Supply Unit) at HS (Hydraulic Support) 36 and mimic at 42 supports;
- (m) Replaced IMAC/VAA unit at 145 support and replaced EOL (End of Line) unit at 157 support;
- (n) 30 support LED screen U/S mimic;
- (o) 133 and 144 (3 LED's out in each);
- (p) 4 monorail lights missing; and
- (q) Mimic on 86 support damaged also mounting bracket.

Appendix 6 – Cables Recovered or Left in Goaf

- (a) 10 pair telephone cable – 110m lengths, sections between recovered J boxes. Not connected to surface;
- (b) Figure 8 telephone cable – Up to 110m lengths – typically 30m lengths; Sections recovered between J boxes and telephones. Not connected to surface;
- (c) Fibre Optic Cable – 8 core multimode – recovered;
- (d) 2 pair Decron instrument cable – recovered;
- (e) High Tension cable – recovered;
- (f) Conveyor Signal line – recovered;
- (g) Conveyor DAC line – recovered;
- (h) Data Highway cable – believed to be recovered, not in goaf; and
- (i) 35mm² - Type 275 – believed to be recovered, not in goaf.

Appendix 7 – Underground Cables

- (a) Conveyor signal line;
- (b) Conveyor DAC line;
- (c) 10pr telephone line;
- (d) 1pr telephone line;
- (e) Fibre optic cable;
- (f) 2 pair Decron instrument cable;
- (g) High Tension cable;
- (h) Data Highway cable;
- (i) 10 pair Decron; and
- (j) 35mm² - Type 275.

Investigation into Potential Lightning Ignition Blakefield South Mine

Appendix 8 – Weather Data

Weather Records Summary

Date Time Sampled	Site	Air Temperature at 2m (°C)	Relative Humidity (%)	Air Temperature at 10m (°C)	Ave. Solar Radiation @10m (W/m ²)	Ave. Wind Speed @10m (m/s)	Ave. Wind Direction @10m (°)	Sigma theta @10m (°)	Max Wind Speed @10m (m/s)	Rainfall Total (mm)
5/01/2011 11:00 PM	Flares Weather Station	18.20	95.80	18.09	0.00	1.49	51.75	22.64	6.20	0.50
5/01/2011 10:00 PM	Flares Weather Station	18.27	94.80	18.17	0.00	0.85	307.90	18.09	2.45	2.00
5/01/2011 9:00 PM	Flares Weather Station	18.47	94.20	18.40	0.03	1.12	266.30	21.54	3.20	6.00
5/01/2011 8:00 PM	Flares Weather Station	19.64	93.70	19.49	1.27	1.19	210.20	28.80	4.70	6.00
5/01/2011 7:00 PM	Flares Weather Station	21.67	78.19	21.43	25.36	2.49	96.30	19.59	6.20	0.00
5/01/2011 6:00 PM	Flares Weather Station	23.26	70.25	22.65	108.20	3.51	75.92	21.70	7.70	0.00
5/01/2011 5:00 PM	Flares Weather Station	25.06	63.46	24.24	181.71	3.63	65.26	19.64	7.70	0.00
5/01/2011 4:00 PM	Flares Weather Station	26.42	57.16	25.13	383.30	2.86	49.70	23.76	6.20	0.00
5/01/2011 3:00 PM	Flares Weather Station	25.71	53.05	24.63	385.68	2.37	35.55	22.50	5.45	0.00
5/01/2011 2:00 PM	Flares Weather Station	25.52	56.47	24.61	411.73	1.36	58.05	47.84	4.70	0.00
5/01/2011 1:00 PM	Flares Weather Station	24.88	53.46	23.78	731.66	1.54	64.69	86.50	5.45	0.00
5/01/2011 12:00 PM	Flares Weather Station	24.02	58.65	23.09	614.44	1.61	8.96	38.35	5.45	0.00
5/01/2011 11:00 AM	Flares Weather Station	22.85	60.14	22.11	637.48	0.95	326.60	36.37	3.20	0.00
5/01/2011 10:00 AM	Flares Weather Station	21.82	61.79	21.30	568.51	0.83	76.73	38.78	3.20	0.00
5/01/2011 9:00 AM	Flares Weather Station	20.13	66.51	19.80	349.41	0.85	140.40	46.70	3.20	0.00
5/01/2011 8:00 AM	Flares Weather Station	18.85	74.30	18.70	179.96	1.05	176.00	20.19	3.20	0.00
5/01/2011 7:00 AM	Flares Weather Station	17.94	80.10	17.87	61.12	0.85	186.60	16.01	2.45	0.00
5/01/2011 6:00 AM	Flares Weather Station	17.80	82.50	17.76	1.63	0.88	189.20	18.28	2.45	0.00
5/01/2011 5:00 AM	Flares Weather Station	17.97	83.20	17.89	0.00	0.13	226.50	24.31	1.70	0.00
5/01/2011 4:00 AM	Flares Weather Station	17.82	81.70	17.90	0.00	0.83	185.30	14.47	2.45	0.00
5/01/2011 3:00 AM	Flares Weather Station	18.18	82.40	18.20	0.00	1.00	180.50	13.43	2.45	0.00

31/01/2011

1

Weather Records Summary

Date Time Sampled	Site	Air Temperature at 2m (°C)	Relative Humidity (%)	Air Temperature at 10m (°C)	Ave. Solar Radiation @10m (W/m ²)	Ave. Wind Speed @10m (m/s)	Ave. Wind Direction @10m (°)	Sigma theta @10m (°)	Max Wind Speed @10m (m/s)	Rainfall Total (mm)
5/01/2011 2:00 AM	Flares Weather Station	18.70	80.30	18.61	0.00	0.47	180.20	13.26	2.45	0.00
5/01/2011 1:00 AM	Flares Weather Station	18.95	79.43	18.84	0.00	0.38	178.00	11.00	2.45	0.00
5/01/2011 12:00 AM	Flares Weather Station	19.24	76.98	19.12	0.00	0.55	183.60	13.96	2.45	0.00