APPENDIX 8B

Blast Impact Assessment
Main Creek




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UMWELT (AUSTRALIA) PTY LIMITED
on behalf of
MOUNT OWEN PTY LIMITED

REVIEW OF THE IMPACT OF BLASTING ON ROCK STRATA FRACTURING ON MAIN CREEK

FINAL

Report No: UM-1705-240518

Thomas Lewandowski
24th May 2018

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1. INTRODUCTION

Enviro Strata Consulting Pty Ltd (ESC) was engaged by Umwelt Australia Pty Ltd (Umwelt) on behalf of Mount Owen Pty Limited (Mount Owen) to assess potential risks of strata fracturing from blasting in the vicinity of Main Creek and associated alluvium.

Proposed mining operations for the Mount Owen Continued Operations Modification 2 (Proposed Modification) will include blasting activities in the North Pit, in the vicinity of Main Creek, see **Figure 1**. The Main Creek Study Area was selected as the closest point between the eastern edge of the Proposed Modification Pit Shell and the top of high bank of Main Creek. In this location the Proposed Modification Pit Shell is approximately 160 m from the top of high bank of Main Creek. The Proposed Pit Shell is approximately 150 m from the edge of the mapped Main Creek alluvium, at its closest point. This proximity will result in risks such as vibration exposures for the creek banks as well as strata fracturing for the rock strata underlying the Main Creek and associated alluvium.

The main objectives of this assessment are:

- Review of local geological / geotechnical strata conditions for the Main Creek Study Area,
- Assessment of potential risks related to the adjacent open cut surface blasting, including vibration exposure and potential strata fracturing,
- Assessment of an allowable vibration limit for the high bank of Main Creek.

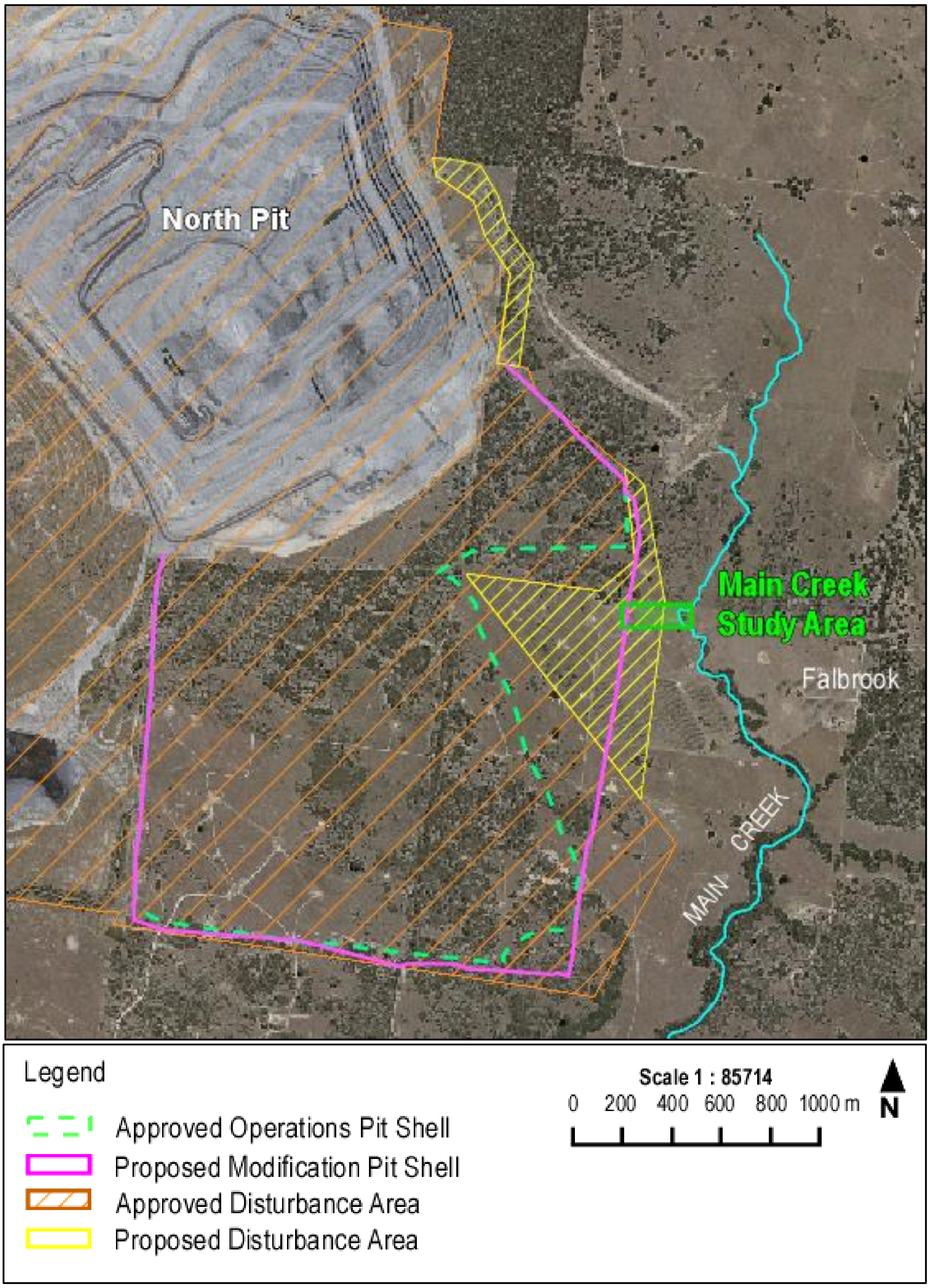

Figure 1 –Proposed Modification and Main Creek Study Area

2. GEOLOGY OF THE AREA – OVERVIEW

A layout of the open cut operations, Main Creek and the Main Creek Study Area are shown in **Figure 1.** In this area, the boundaries of the Proposed Modification Pit Shell approach the western side of Main Creek in a straight, approximately north-south, line. The extent of the alluvial material from the creek (AGE, 2017) is highlighted in **Figure 2**.

The assessment of the rock strata conditions is based on a review of geological conditions for the area. The information about the local geology was obtained from Mount Owen Complex and is presented in the form of borehole logs, see **Appendices 1A** to **1G**. The locations of the boreholes which are representative for the area of interest, are highlighted in **Figure 2**. Information available includes data from the closest six borehole logs, namely SMC031, SMC033, SMO042, SMO045, SMO047 and SMO048. All borehole logs revealed multiple layered rock strata.

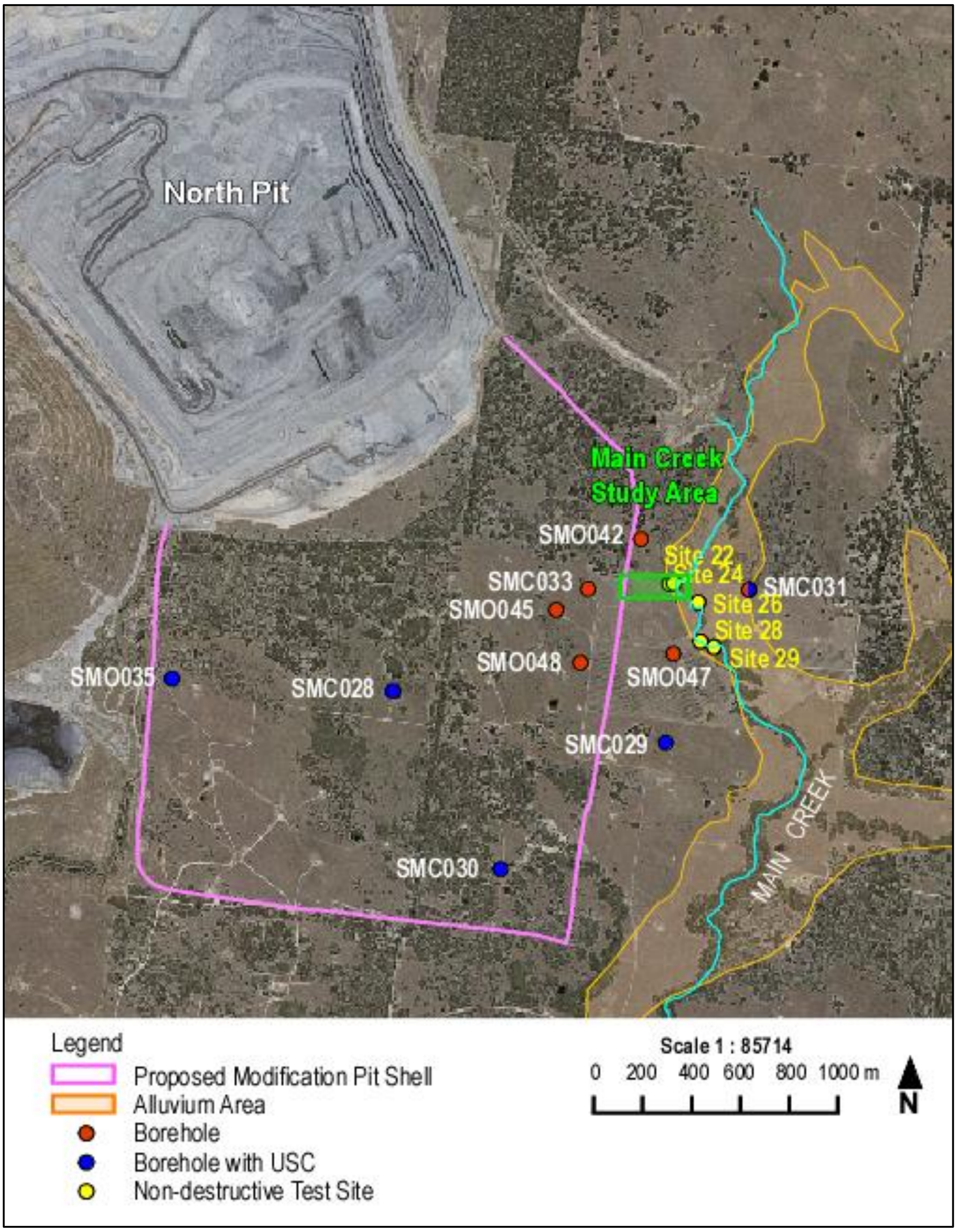

Figure 2 – Location of Boreholes (after Pells Sullivan Meynink (2017))

The Six boreholes selected are located within approximately 500 m of the Main Creek Study Area. Based on the provided logs, the dominant rock type in this region (within the first 30 m of depth) generally consists of a top layer of soil, conglomerate, interbedded sandstone and siltstone, coal (including other intrusions), with lesser amounts of claystone. A simplified stratification of the rock strata, based on adjacent borehole data, is summarised as follows:

SMC031 – (first 30 m) – 2 m of soil, 3 m claystone, 9 m of interbedded sandstone and siltstone, 4 m of coal (including tuff), 12 m of interbedded sandstone and siltstone.

SMC033 – (first 30 m) – 3 m of claystone, 1 m of coal, 2 m of claystone, 18.5 m of interbedded sandstone and siltstone, 1.5 m of coal, 4 m of conglomerate.

SMO042 – (first 30 m) 2 m of soil, 10 m of claystone (with 1.6 m of coal within), 5 m of sandstone, 8 m of sandstone, 2 m of conglomerate, 2.5 m of sandstone/siltstone, 0.5 m of coal.

SMO045 – (first 30 m) 1 m of soil, 14 m of conglomerate, 2.3 m of sandstone, 1.1 m of siltstone/coal, 6.3 m of coal/mudstone/tuff, 5.4 m of sandstone.

SMO047 – (first 31 m) 2 m of soil, 8 m of clay, 3.3 m of coal (including clay and tuff), 18 m of sandstone.

SMO048 – (first 32 m) 6 m of soil, 15.6 m of conglomerate, 4.4 m of coal (including mudstone and tuff), 6 m of sandstone.

It is concluded that the sequence is generally well bedded. Also, no sandy layers or weak strata materials were detected in the analysed borehole logs. Rock strata as described above are considered to form an adequate / strong base for the creek river bed and are not prone to surface cracking. The geology of the area is generally stable with the absence of any known significant features.

Structural data from acoustic scanner surveys available for the boreholes referenced in this report, as shown in **Figure 2,** identified two cases of joints and possible faults intersected by borehole SMC042. One case of joints and a possible fault occurs within LA seam interval at a depth of 74 to 80 m (RL of 35 m) and a second case occurs within LID 6/7/8/9 seam interval at a depth of 167 to 173 m (RL of -58). Considering the unfavorable scenario that the possible faults extend to the area underlying Main Creek (at 100 m RL), the vertical separation would be approximately 65 m. This represents a significant separation and it is highly unlikely for water to be siphoned through these possible faults. Based on the acoustic scanner surveys no joints or faults were identified for other neighboring boreholes.

Therefore, for the considered creek area while assuming the worst case scenario in which these faults extend horizontally to the creek area, the risks are considered to be insignificant.

A schematic cross-section of the Proposed Modification eastern pit wall and the Main Creek Study Area are presented in **Figure 3**.

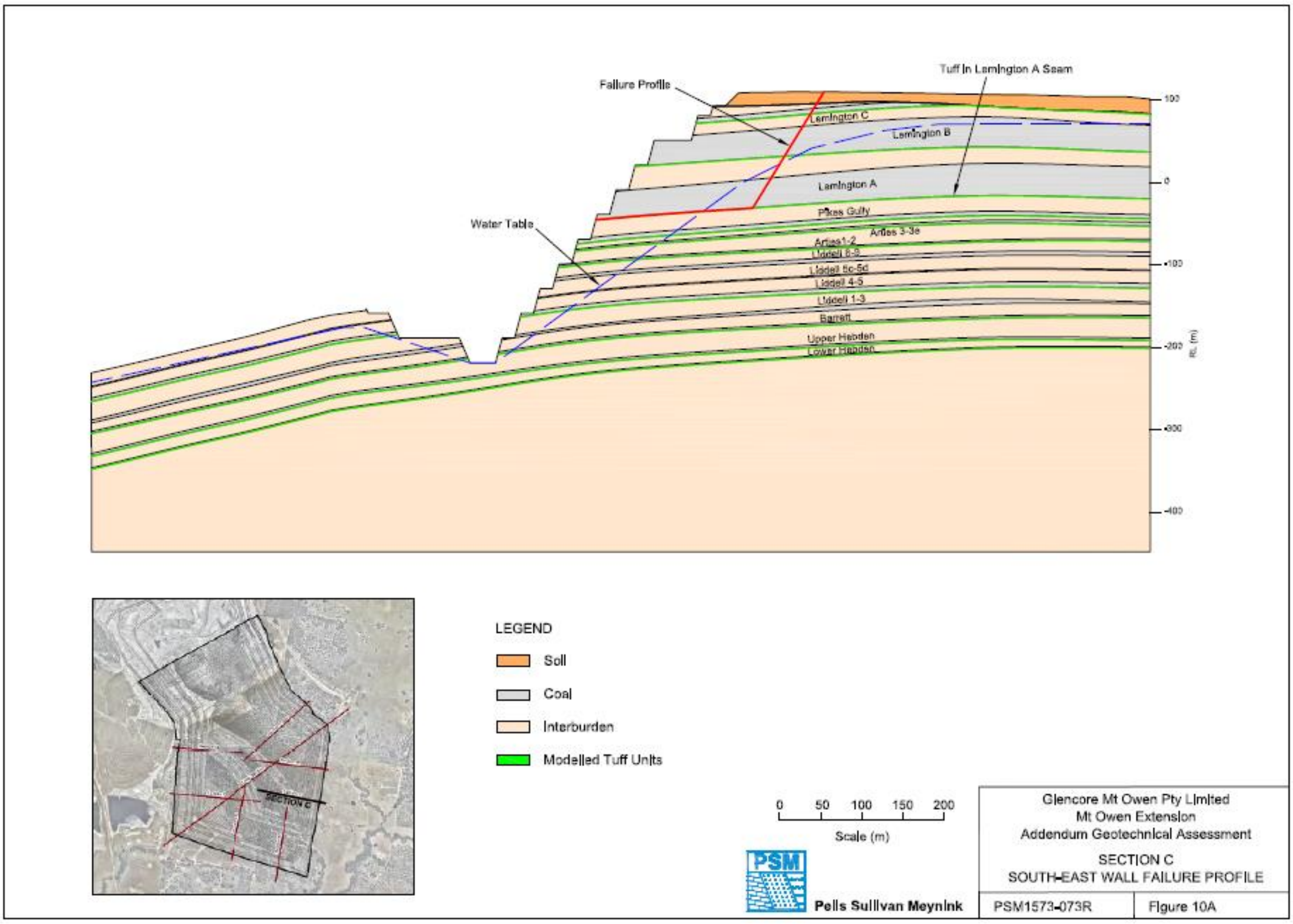

Figure 3 – Geological Model Cross-section through Eastern Pit Wall and Main Creek (after Pells Sullivan Meynink 2017)

Some of the boreholes available for the study also included indicative rock strength values. These are summarised in **Table 1** and were obtained from the following five boreholes SMC028, SMC029, SMC030, SMC031 and SMC035. The boreholes are located within or to the east of the Proposed Modification Pit Shell and are considered representative of the Main Creek Study Area, see **Figure 2**.

The data has been compiled and reviewed in the geotechnical assessment report (Pells Sullivan Meynink (2017)) and included a summary of 86 uniaxial compressive strength (UCS) test results (see **Table 1**), representative for the eastern section of the Proposed Modification Pit Shell.

Using average calculated values the following rock strength ranges were estimated:

Sandstone: 62 – 87.5 MPa

Mudstone and Siltstone: 36.9 – 55.3 MPa

Conglomerate: 36.5 – 80 MPa

Overburden (all): 50 – 76 MPa

From a blasting perspective these UCS values present relatively strong rock strata, which would not be easily fractured due to the adjacent open cut bench blasting.

Table 1: Summary of UCS Results for the Eastern Section of the Proposed Modification Pit Shell (after Pells Sullivan Meynink (2017))

Lithology	UCS Minimum (MPa)	UCS Maximum (MPa)	UCS Average (MPa)
SMC028			
Sandstone	22.5	100.7	62
Mudstone and siltstone	19.7	86.4	42
Conglomerate	53.6	104.3	80
Overburden (all)	19.7	104.3	57
SMC029			
Sandstone	54.8	106.8	77
Mudstone and siltstone			37 (one sample)
Conglomerate	62.6	88.2	72
Overburden (all)	37	106	73
SMC030			
Sandstone	40	145.6	87
Mudstone and siltstone	35.6	69.1	53
Conglomerate	36.1	76.2	56.8
Overburden (all)	35.6	145.6	63
SMC031			
Sandstone	52.5	86.5	69.5
Mudstone and siltstone	26.4	47.4	36.9
Conglomerate			36.5 (one sample)
Overburden (all)	26.4	86.5	50
SMC035			
Sandstone	55.3	116.1	87.5
Mudstone and siltstone			55.3 (one sample)
Conglomerate			N/A
Overburden (all)	55.3	116.1	76

A general site inspection of the area between Main Creek and the Proposed Modification Pit Shell was carried out by ESC's Principal Consultant in the presence of Mount Owen personnel on the 17.07.17.

The inspection included an overview of the eastern rock wall conditions of North Pit as well as surface soil conditions near the eastern wall area. This was to provide an indication of the potential rock strata behaviour when blasted and excavated near the Main Creek Study Area. The inspection of the eastern wall and adjacent surface area revealed the absence of any slope stability issue or the presence of any surface cracks, see **Appendices 2A** to **2D**. There is some ongoing minor water erosion at the top of the slope (limited to the soft strata layers), which is typical and non-consequential for development of adjacent surface strata cracking.

The inspection also included an inspection of the creek embankments, as well as the area located between Main Creek and the Proposed Modification Pit Shell corresponding to the study area, see **Appendices 3A** to **3H**.

To provide an indication about surface strata conditions a non-destructive type of testing was undertaken during the inspection using a Schmidt Hammer (operating range 10 – 60 MPA) and a penetrometer (operating range 0 - 5 MPa), see **Appendices 4A** and **4B**. The results of the non-destructive tests using the above specified instruments are summarised in **Table 2**. The sites where the testing was undertaken are marked in **Figure 2**.

The site inspection revealed that the majority of the strata around the Main Creek Study Area is of heavy compacted soil / clay material (in the top section) with approximate strength in the range of 5 to 10 MPa. Due to the operational ranges of the instruments it was not possible to determine the rock strength more accurately. The other observed material included alluvium and weathered conglomerate layers. There were also some weathered sandstone layers detected.

The inspection of surface strata between the Proposed Modification Pit Shell and the creek did not reveal any obvious signs of faulting, the presence of joints, unusual rock outcroppings or other obvious signs of potential weaknesses. The surface vegetation precluded a more detailed assessment.

Overall, the creek embankments present are stable and resistant to ground vibration. It should also be recognised that creek embankments will still be prone to water erosion (physical force of water action and moisture intake into the clay / soil material) and ongoing degradation. However, the water erosion will not have any effect on the underlying strata and its propensity to be impacted by adjacent blasting practices.

Table 2: Summary Results of Non-destructive Testing

Site	Penetrometer Rock Strength (MPa)	Schmidt Hammer (Rebound Number)	Schmidt Hammer Rock Strength (MPa)
Creek Area – Site 29 (324246; 6411516)			
29	5	Not engaged, <10	< 10
29	5	Not engaged, <10	< 10
Creek Area – Site 26 (324183; 6411696)			
26	5	Not engaged, <10	< 10
26	5	Not engaged, <10	< 10
26	5	Not engaged, <10	< 10
26	5	Not engaged, <10	< 10
26	5	Not engaged, <10	< 10
Creek Area – Site 24 (324084; 6411773)			
24	5	Not engaged, <10	< 10

Site	Penetrometer Rock Strength (MPa)	Schmidt Hammer (Rebound Number)	Schmidt Hammer Rock Strength (MPa)
24	5	Not engaged, <10	< 10
24	5	Not engaged, <10	< 10
24	5	Not engaged, <10	< 10
24	5	Not engaged, <10	< 10
24	5	Not engaged, <10	< 10
Creek Area – Site 22 (324067; 6411770)			
22	5	Not engaged, <10	< 10
22	5	Not engaged, <10	< 10
22	4.5	Not engaged, <10	< 10
22	3	Not engaged, <10	< 10
22	5	Not engaged, <10	< 10
22	5	Not engaged, <10	< 10
22	5	Not engaged, <10	< 10
22	5	Not engaged, <10	< 10
Creek Area – Site 28 (324192; 6411538)			
28	5	Not engaged, <10	< 10
28	5	Not engaged, <10	< 10

In summary, the geotechnical assessment of the rock strata did not identify any poor quality soils which are prone to vibration damage. The non-destructive testing in the Main Creek Study Area indicated strata strength generally in the order of 5 to 10 MPa, confirming an adequate strength to resist blast vibration damage.

Also, the obtained rock strength data from the boreholes showed relatively strong rock strata materials, which are highly resistant to rock strata fracturing due to the adjacent open cut bench blasting.

3. BLASTING AND ROCK STRATA DAMAGE - LITERATURE REVIEW

The assessment presented below aims to provide evidence related to:

- close range blasting in the vicinity of sensitive areas (i.e. adjacent benches, roads and underground tunnels), including the impacts on rock strata conditions and strata fracturing,
- vibration limits when blasting in the vicinity of creeks / rivers and the impacts on embankments and nearby infrastructure (including bridges and dams).

The presented review aims to provide an indication of potential blast impacts directly relatable to blasting impacts from the Proposed Modification on Main Creek and associated alluvium.

3.1 Assessment of Close Range Blast Impacts on Potential Bulk Displacement and Strata Fracturing for a 110 m Wide Strata Pillar (South Africa)

Rorke and Thabethe (2004) described large scale open cut blasting in South Africa immediately adjacent to the main national road. The road was positioned between two open cut voids (forming a road bearing pillar of 110 m in width) creating a risk of potential bulk displacement (i.e. rock strata displacement and related rock strata fracturing) due to a lack of confinement on both sides of the road. **Figure 4** presents a simplified section showing the risk of bulk displacement of the pillar (bearing the road) as a result of reaction forces from the blast. The large scale blast was undertaken immediately adjacent to the pillar. The risks were identified and included flyrock, vibration damage and bulk displacement. Each risk was dealt with appropriately.

To manage the risks the mine employed a smaller drill rig diameter (i.e. reduced from 250 to 200 mm) to reduce the charge mass of the explosives for the blast. The risk of flyrock was dealt with via the application of an adequate stemming column and air decks (including 3 m of stemming column applied above 1 m of air deck) to suppress potential flyrock occurrence. The mine also utilised quality stemming material including 19 mm screened hard rock aggregate.

For the road and subsurface (referred to as a well compacted material) a limit of 150 mm/s was considered safe and was used as a target vibration limit for the blast. The mine opted to utilise deck charges to minimise and control vibration levels. The maximum instantaneous charge mass (MIC) was reduced to 215 kg per deck. The mine also utilised a non-reinforcing (non-destructive wave interference) initiation sequence based on a single wave study. This was combined with the use of electronic detonators to ensure the accuracy of the initiation sequence and eliminate wave interactions.

To minimise any potential bulk displacement the number of rows was reduced to eight and deck charges employed with an appropriate initiation sequence. This was to minimise the amount of shock wave (minimise reaction forces to the block) delivered to the strata.

As a result of these blast design control measures the blast produced a low vibration impact, well below the specified limit of 150 mm/s. The back damage (behind the blast) was very limited and there was no evidence of bulk ground displacement. No damage to the road was detected.

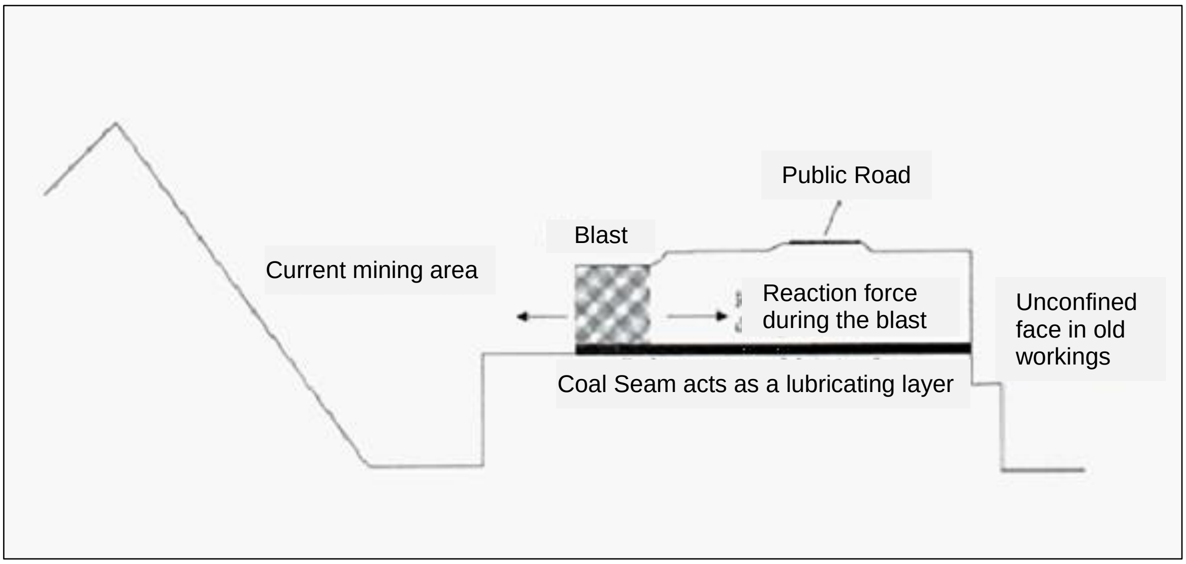

Figure 4 – A Simplified Cross-section Showing the Risk of Bulk Displacement of the Road Bearing Pillar as a Result of Reaction Forces from the Blast on the West Side (left) of the Road (after Rorke and Thabethe, 2004)

3.2 General Guidelines on Vibration Limits – ACARP Project C14057

ACARP Project C14057 is a research project sponsored by the coal mining industry. The publications from each project are recognised as reference materials. This type of study provides an independent opinion on various technical subjects.

Project C14057 produced general guidelines on allowable vibration limits for various infrastructure facilities. Unfortunately, there are no limits specified for river or creek banks. However, among the recommendations are limits for various infrastructure, including public roads and concrete bridges, see **Table 3**. The report recommends a limit of 100 mm/s. Since bridges are installed on or close to river embankments, it can be reasoned that this level of vibration exposure is safe for river / creek banks and hence the same limit of 100 mm/s could potentially be applicable.

In addition, the authors of the ACARP report postulated an indicative vibration limit for water dams of 100 mm/s with the commencement of observations at a 50 mm/s vibration level, see **Table 3**. This again is comparable to river / creek embankments.

Also, as indicated in the ACARP report, this is only an initial limit recommended without further study being undertaken by a specialist. The report indicates that higher vibration limits can be considered upon the completion of such a study. Therefore, one can infer a significant factor of safety in this recommendation.

Table 3: Recommended "Safe" Vibration Limits without more Detailed Analysis (after ACARP 2008)

Item		Previous Limit[5] (mm/s)	PPV Limit (mm/s)	Observation From (mm/s)	Possible Upper Limit (A) (mm/s)
Public roads		-	100		Block movement
Rail way lines		-	100*		Block movement
Concrete bridges		25	100≠[6]		200
Conveyor structures		25	100[6]		200
Power lines	Timber poles	-	100		200
	Concrete poles	25	100[6]		200
	Steel towers	25	100[6]		200
Electrical substations (Buckholz switches)			10-50	10	100[7]
Fixed mine plant and buildings		25	100		200
Underground workings		-	100[6]	10**/25	150[9]
Surface pipelines		-	100	25	150
Buried communication cables and pipelines		-	100	100	Block movement
Dams		-	100	50	200[10]
Heritage structures		-	BS7385 to 50mm[6]/s	20[x]	50
Mine offices, houses		10	BS7385 to 50mm[6]/s		200[8]

1* With track monitoring protocols and inspections
2** If men are present
3≠ Without traffic loads
4x In maintained condition
5(*) AS2187.2-1993
6(**) AS2187.2-2006
7 With reed switches
8 With minor repairs
9 Adequate ground support
10 Fell et al
(A) Only after a detailed investigation to determine frequency response and strain measurements

3.3 Close Range Blasting and Assessment of Rock Strata Fracturing – CSIRO Report

A CSIRO study presented by O'Regan et al (1983) produced a detailed assessment of rock strata behaviour immediately adjacent to a major open cut blasting area. The study was undertaken by the CSIRO with various monitoring equipment placed strategically behind the blasting area at Blackwater Open Cut Mine, see **Figures 5A** to **5C**. The study utilised accurate surface and sub-surface instrumentation (including extensometers and piezometers) as well as conventional ground survey techniques and cross hole seismic surveys.

The study aimed to identify blasting impacts, including the extent of fracturing, on the structural integrity of the newly formed highwall.

The study can be summarised as follows:

- The damage to the adjacent highwall is a function of both geology and blast design.

- The extent of damage, including back-break cracking, which developed on the surface (vertical cracks or semi vertical), was limited to 23 m from the highwall (based on extensometer results). Based on a seismic survey the extent of the damage is limited to approximately 30 m showing a reduction in the seismic velocity.
- The extent of the horizontal cracks (along the weak strata layer) was estimated to be 50 m horizontally from the blasting area (based on extensometer results). The mechanism of rock damage was described in detail and was driven by gas penetration of the blasting product through the rock strata.

The study also identified potential reasons behind the damage to the newly formed highwall, which included:

- A high concentration of explosives against the highwall face,
- Delayed movement of the lower section of the overburden sequence causing a release of gases through the interbedded rock strata layers,
- Lack of free row-by-row movement caused by short inter-row delays which resulted in blast chocking.

The presented study provides an extreme example of potential damage to the rock strata from the adjacent open cut surface blasting. By today's standard; it is apparent that the assessed blast was poorly executed, that is, ineffective timing and blast chocking (including inadequate face movement). Nevertheless, the study highlighted an extreme scenario of rock strata damage behind the open cut surface blast, as well as the potential maximum distance of rock strata damage behind the blasting area.

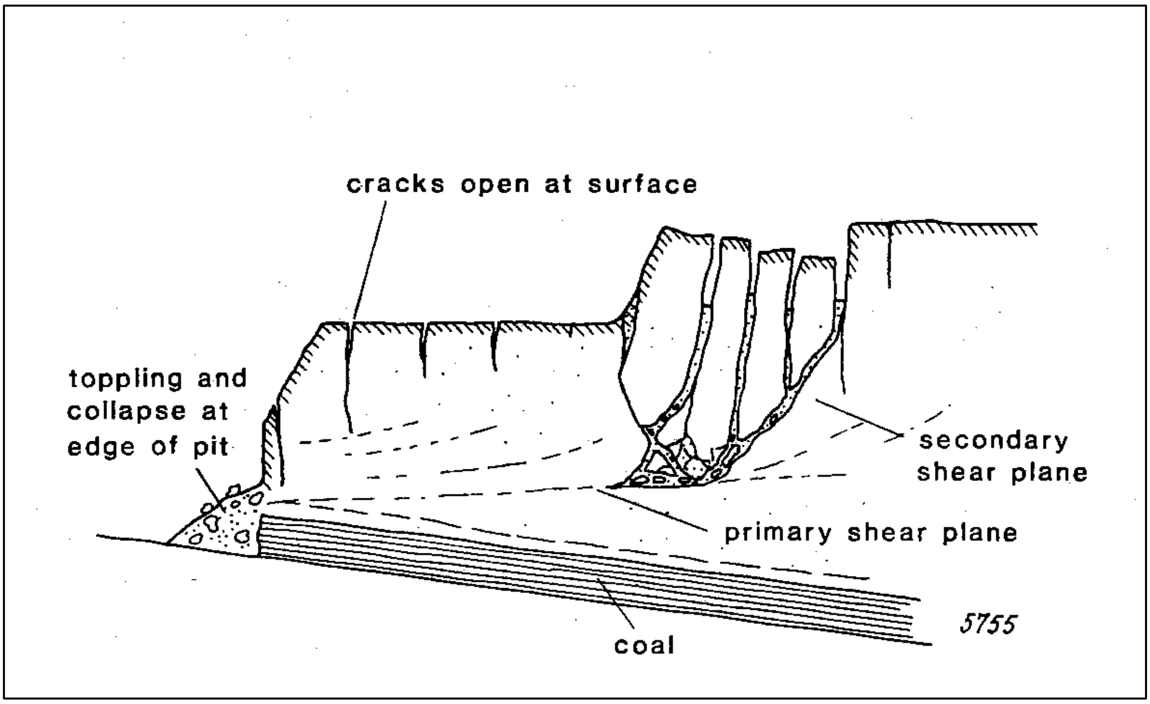

Figure 5A – Highwall Damage Due to Adjacent Blasting (after CSIRO 1983 Report)

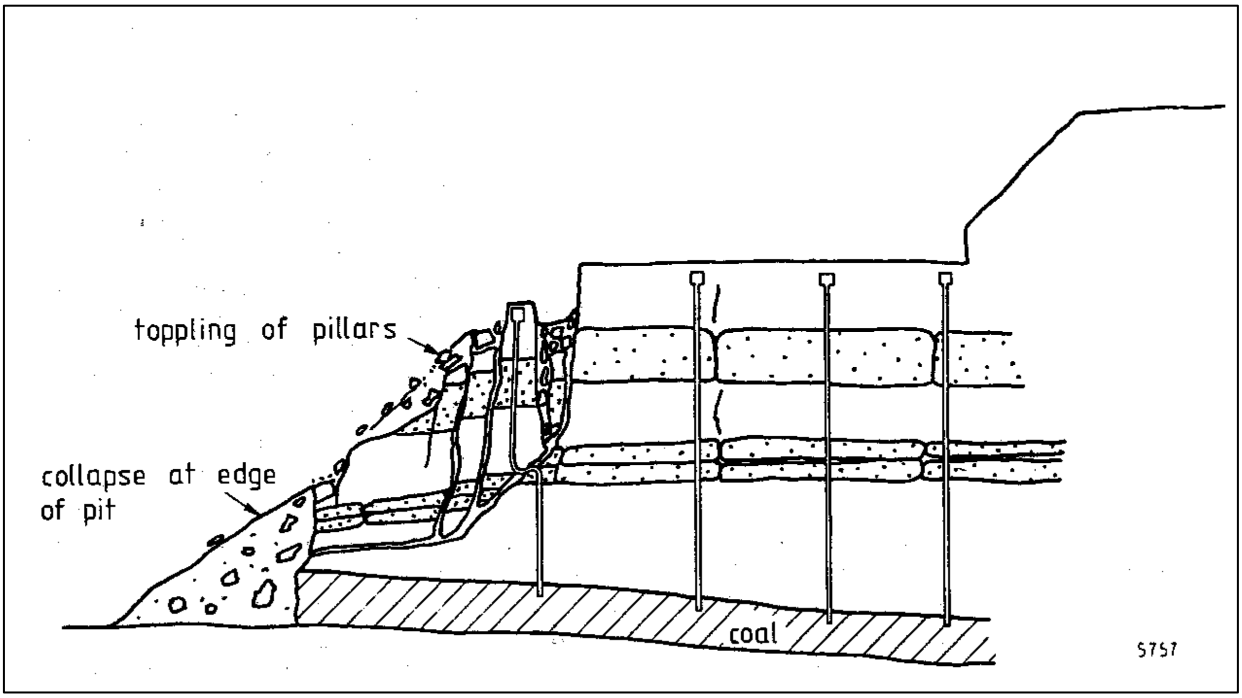

Figure 5B – Damage Showing Vertical and Horizontal Cracks (after CSIRO 1983 Report)

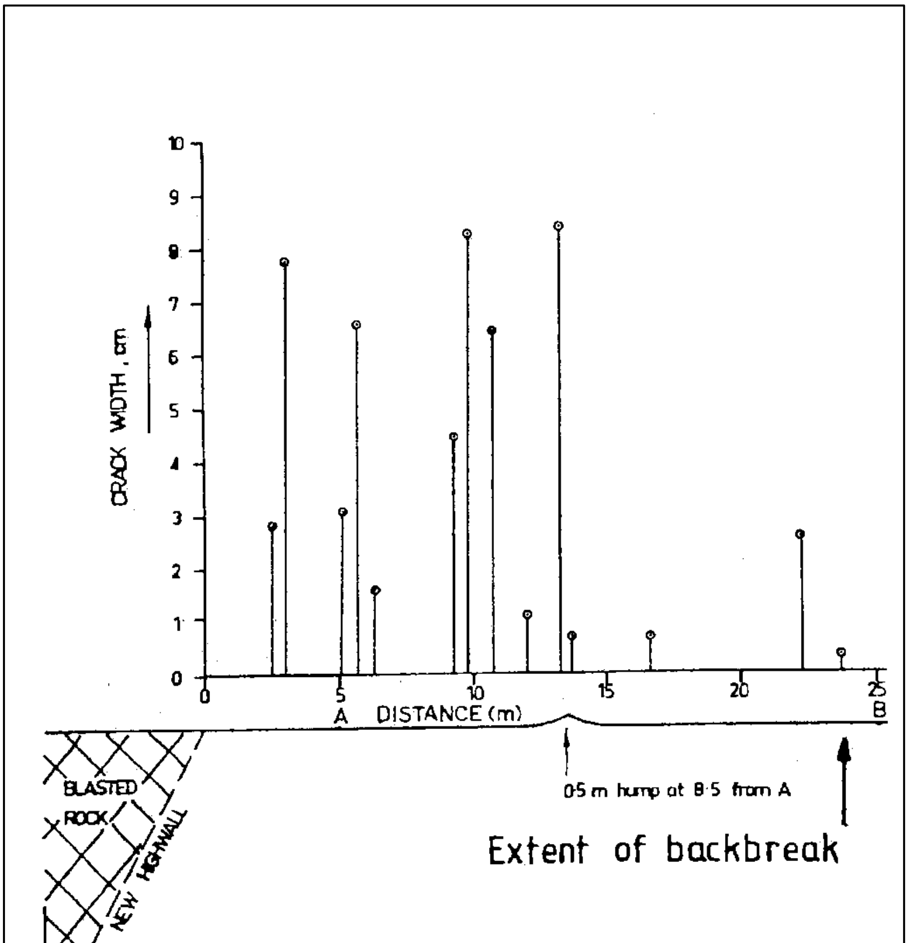

Figure 5C – Estimation of Back-break Cracking (after CSIRO 1983 report)

3.4 Close Range Blasting – Blast Impacts Study (Lewandowski and Cope 2009)

The study undertaken by Lewandowski and Cope (2009) dealt with the impacts of close range blasting on adjacent infrastructure at Bulga Open Cut Mine. The study also included a blast impact assessment on the local strata, specifically addressing damage from close range blasting. The surface strata included predominantly sandstone, mudstone, siltstone and coal bands, see **Figure 6A**.

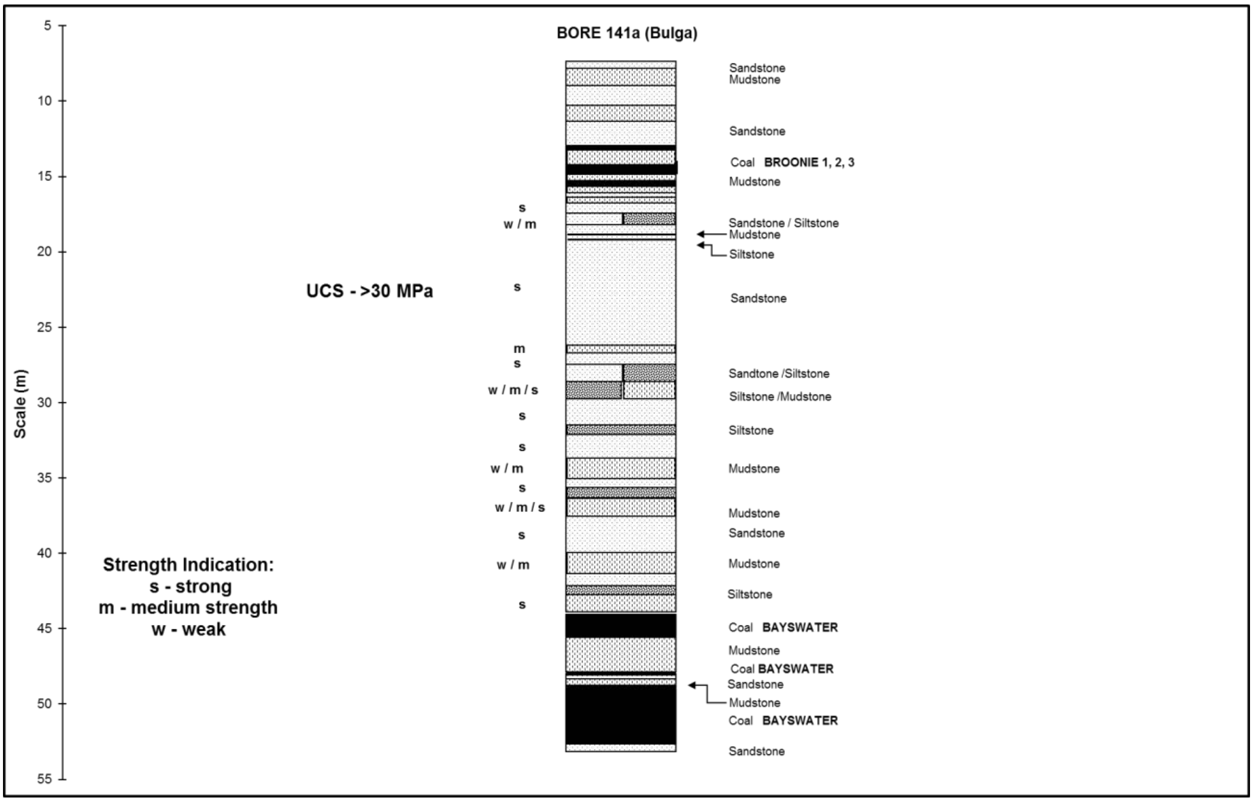

Figure 6A – **Geological Borehole Log – Borehole 141A (after Lewandowski and Cope 2009)**

The blasts of interest included pre-split blasts with an MIC of 530 kg. For these particular geological conditions the extent of damage was relatively limited and was in line with other open cut mine experiences in the Hunter Valley, i.e. up to approximately 20 m behind the blast. The detected damage (manifested as a number of surface cracks and some surface layer displacement) was estimated to be in the order of up to 17 m from the edge of the blast, see **Figures 6B** and **6C**.

Figure 6B – Impact of Blasting – Showing Surface Rock Strata Damage to Blasted Pre-Split Line; Extending up to 17 m from the Edge of the Blast (after Lewandowski and Cope 2009) ,

Figure 6C – Scanline behind the Pre-split Line and Surface Cracking (after Lewandowski and Cope 2009)

3.5 Close Range Blasting and Rock Strata Fracturing Assessment – ESC (2007)

To demonstrate in detail typical rock strata behaviour when exposed to surface blasting ESC undertook an in-depth close range rock strata assessment study in a Hunter Valley mine in 2007. The mine of interest blasted through interburden material composed of sandstone and shale rock strata layers. This is considered comparable to the Proposed Modification conditions. The explosive charges were in the order of 600 kg, which is also considered comparable to blast design details of the Proposed Modification.

The main aims of the study were specified as follows:

- to establish a ground vibration decay curve for the mine's conditions and
- to establish the extent of the damage zones behind the open cut blast.

The work included a detailed assessment of vibration levels and rock strata conditions (including logging of rock strata fractures) for the bench located behind the blasted bench.

For the purpose of the assessment a total of seven vibration monitors were placed behind the blasting area. The study was supplemented by detailed rock strata assessment including photography and a scanline survey of the rock strata. The main aim was to precisely delineate and describe the zones of actual rock strata damage caused by the adjacent open cut surface blasting. The vibration monitors were utilised to collect vibration monitoring data, which could assist in the development of an accurate vibration predictive model for these particular blasting conditions.

The findings of this study were summarised as follows:

- The extent of rock strata damage for the adjacent bench to the blasting area, including back break, was limited to approximately 11.5 m from the edge of the blasted bench.
- The damage zone, including back break, was exposed to vibration levels well in excess of 400 mm/s (i.e. beyond instrument capability, see **Figure 7**), confirming that extremely high vibration levels are required to induce rock strata damage.

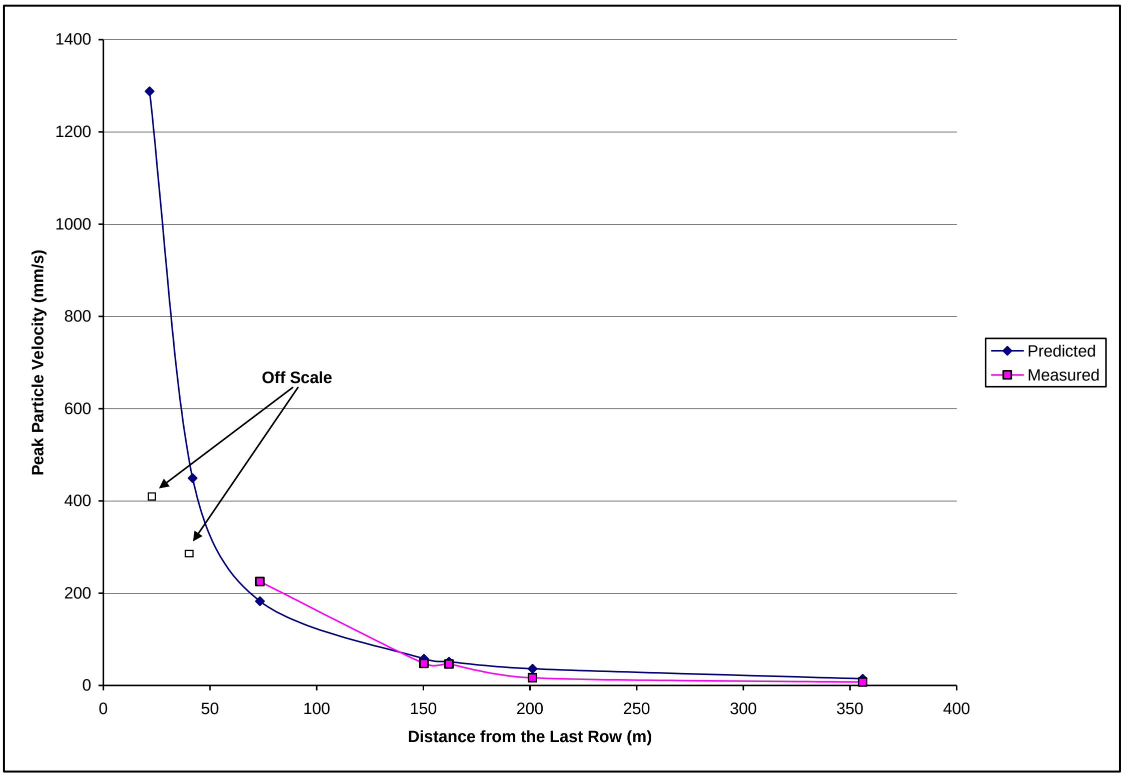

Figure 7 – Measured versus Predicted Vibration Behaviour

3.6 Underground Rock Tunnel off the Highwall – Assessment of the Rock Strata Damage from Blasting – ESC (2008)

The study undertaken by ESC in 2008 included an assessment of the impact of blasting on an underground mine tunnel located immediately off the highwall area. The highwall was originally formed by open cut blasting with an MIC in excess of 1,000 kg. Construction of the tunnel followed, which was located behind the previously fired blast and hence in the zone of highly fractured ground. It should also be noted that the highwall was not pre-split, therefore prone to more extensive strata damage. For a view of the highwall quality and underground mine entry refer to **Figure 8A**.

The study included an assessment of ground fracturing and rock wall damage within the underground tunnel, see **Figure 8B**. The assessment included a detailed inspection of the rock strata conditions for the underground tunnel, with the main aim to assess the level and extent of damage to the rock strata. A sample of the strata immediately above the roof of the underground roadways is shown in **Figure 8C.** The study was also supported by analysis of roof dilation data using roof extensometer measurements. This would provide evidence of horizontal crack formation caused by the adjacent strata blasting, see **Figure 8D**.

The rock strength data was also collated and included a review of the UCS values for the immediate roof strata. The moderately strong UCS values were measured for the immediate roof strata, ranging between 47 and 103 MPa. The UCS data was collated from a total of 16 borehole logs.

The study concluded that, in this particular case, the damage behind the highwall face (i.e. behind the blast) was limited to 12 m from the highwall entry. In this case both the horizontal and vertical cracks were limited to the quoted 12 m only. To combat the damage the underground mine had to substantially increase the bolting density (i.e. to mitigate the blasting damage effect of the rock strata), see **Figure 8B**. Note that beyond 12 m there was no apparent damage to the rock strata. Therefore the impact of blasting was relatively limited for these particular rock strata conditions which included predominantly mudstone, siltstone, sandstone and coal bands.

Figure 8A – Underground Mine Entry and Highwall Conditions after Blasting (ESC Study 2008)

Figure 8B – Underground Strata Conditions and Induced Damage due to Previous Surface Blasting (ESC Study 2008)

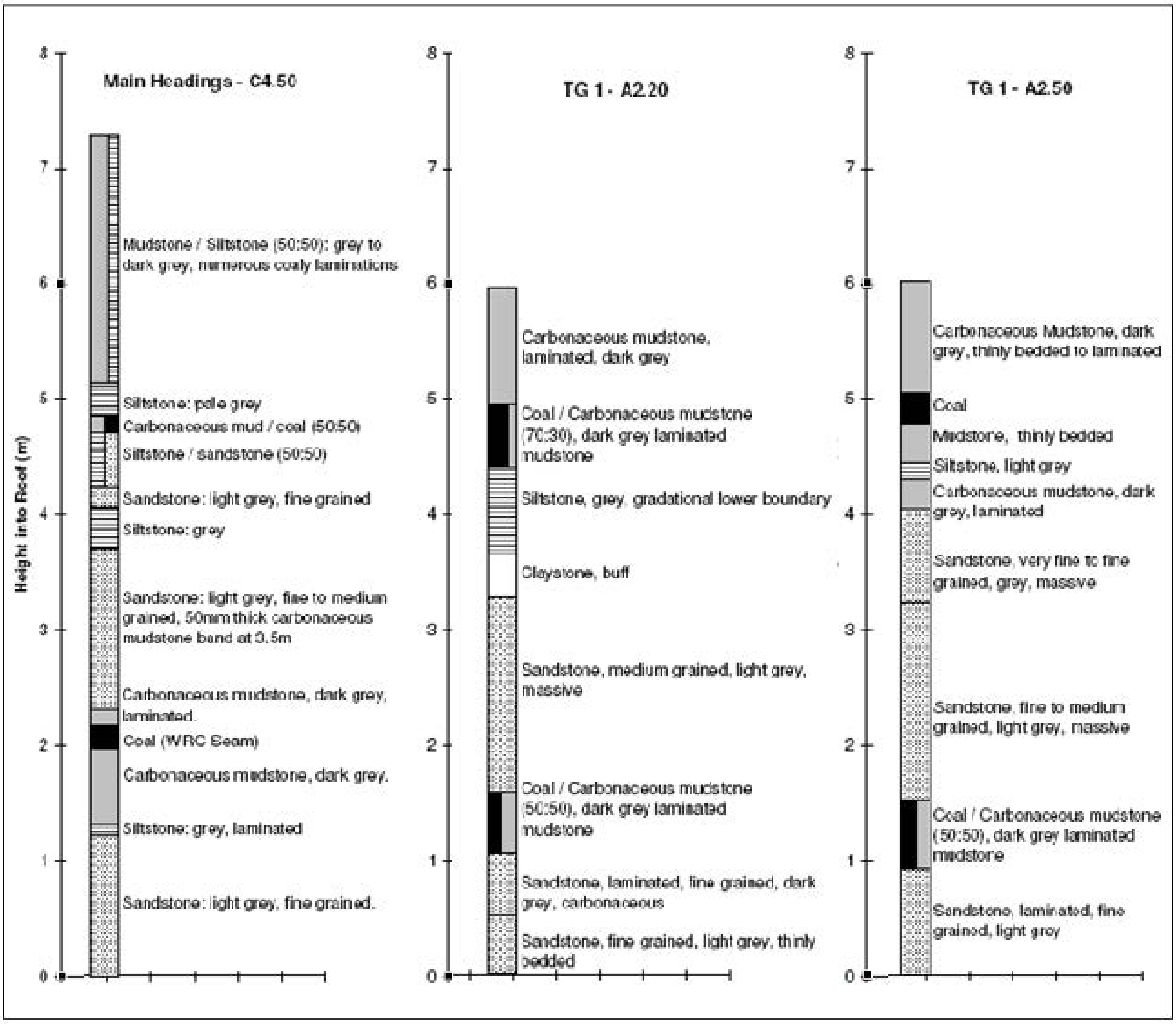

Figure 8C – Stratification of the Immediate Roof of the Underground Roadways in the Vicinity of the Underground Mine Entry (ESC Study 2008)

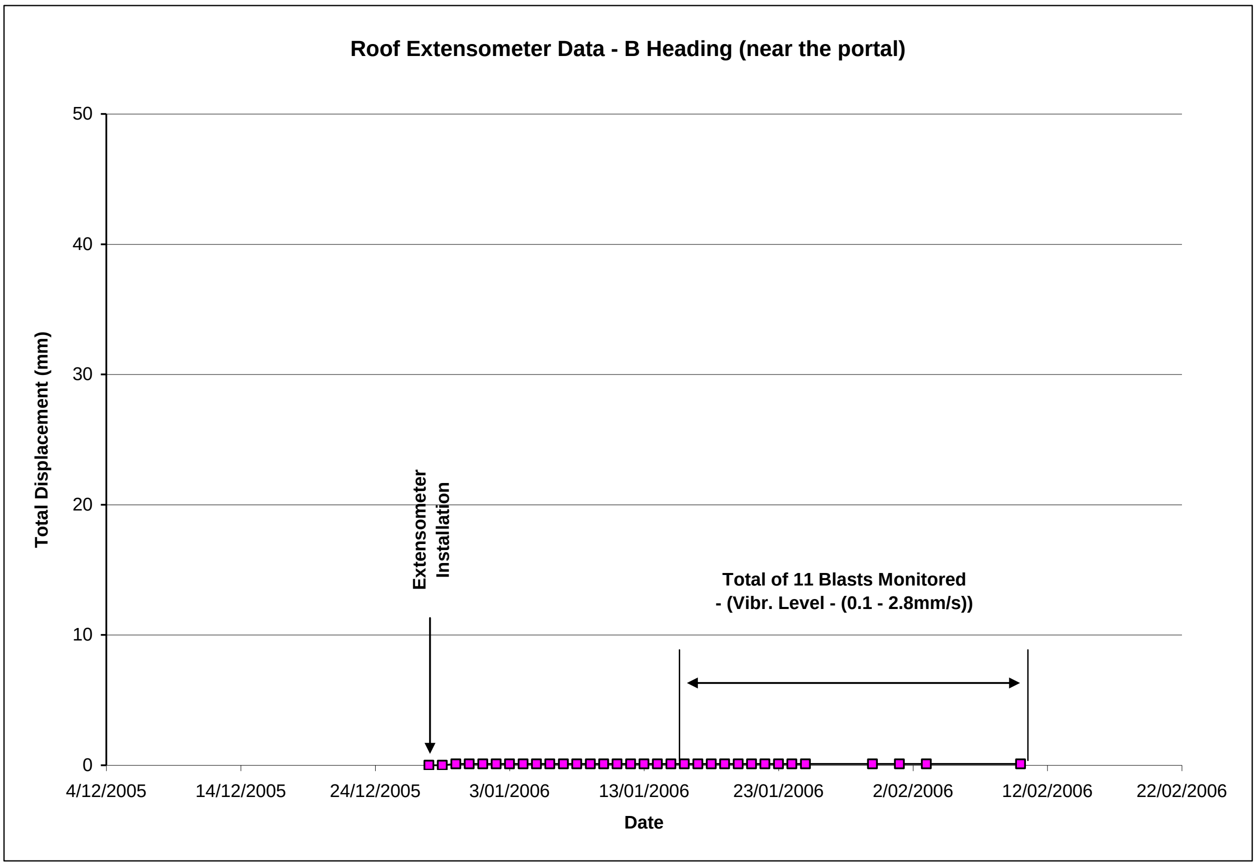

Figure 8D – Roof Extensometer Data near the Portal Entry

3.7 Blasting and Gas Monitoring through Fractured Rock Strata – McKenzie (1999)

Gas penetration, which occurs during the blasting process, assists in crack formation and subsequent crack progression within rock strata. The study undertaken by McKenzie (1999) provided a detailed summary of various research groups on gas flow into the adjacent rock strata. The gas monitoring in that case would provide strong evidence of the extent of rock strata fracturing behind the blasted bench. The elevated gas level is an indicator of the penetration of gases into the rock strata. From all these studies, McKenzie provided a concise summary of the relationship between gas pressure data and distance, see **Figure 9**.

The monitoring showed high gas levels measured within 5 m of the blast and a decrease in gas pressure with an increased distance from the blasting area. The study indicates that low pressure has been measured at 15 – 16 m from the blasting bench, which is equivalent to approximately two burden distances from the blasted hole. McKenzie concluded that the gas flow has been observed for distances up to 20 m behind the blasthole patterns.

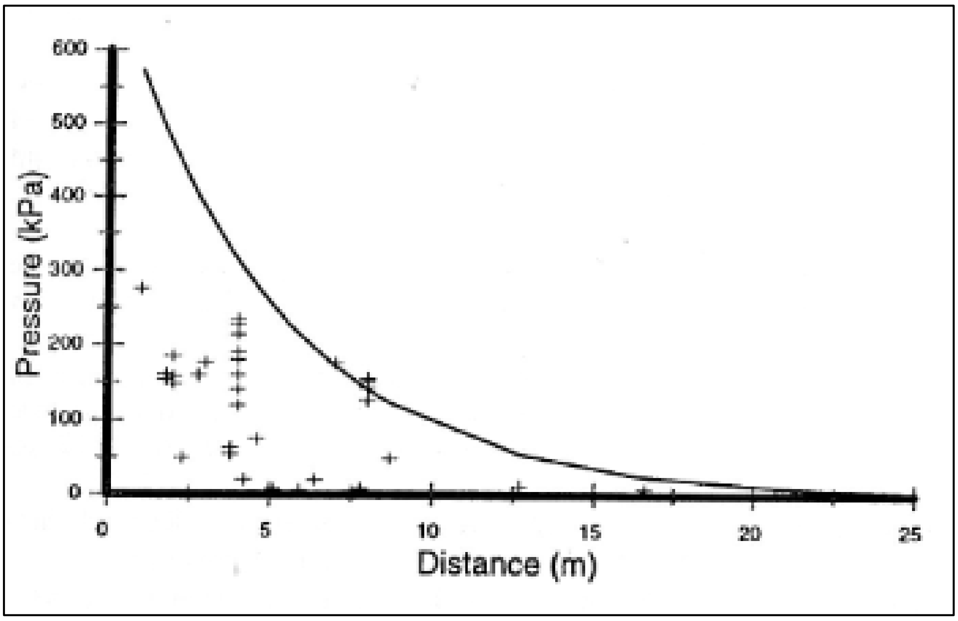

Figure 9 – **Gas Pressure Measured versus Distance – Obtained from Literature Review (after McKenzie 1999)**

3.8 Bench Dilation Measurements for Large Hole Blasting – LeJuge et al (1994)

The study was undertaken by LeJuge et al (1994) in the Rossing Mine in Namibia. The study concentrated on assessing the impact of blasting from large diameter hole blasts, including a 381 mm hole diameter. For the blast impact assessment the study utilised an extensometer measuring technique. This was to assess the impact of blasting on the adjacent area. The study concentrated on the measurement of ground heave and ground dilation. The study revealed that the dilation of the ground was limited to 20 m from the blasting area, indicating a relatively limited distance of rock strata fracturing. The study showed the highest ground heave adjacent to the blasted hole with a gradual decrease in the ground heave with increased distance. The effect faded away after 20 m.

3.9 Crack Dilation and Negative Pressure Measurements Behind Blasting Area – Brent and Smith (1996)

The study was undertaken in a Hunter Valley mine in NSW (Brent and Smith 1996). The impacts of blasting (including crack formation) have been measured behind the blasting area. The study covered confined and unconfined type blasts (as used in Hunter Valley mines) with a 200 mm hole diameter with burden and spacing of (7 x 8) m. The explosives used included ANFO and heavy ANFO product placed at the toe of the blast.

The study included the assessment of cracks in the test holes (located behind the blasting area) as well as the measurement of negative pressure (generated as a result of gas incursion into the strata). The results of the highest blasting impact (the worst case scenario) are summarised in **Figure 10**.

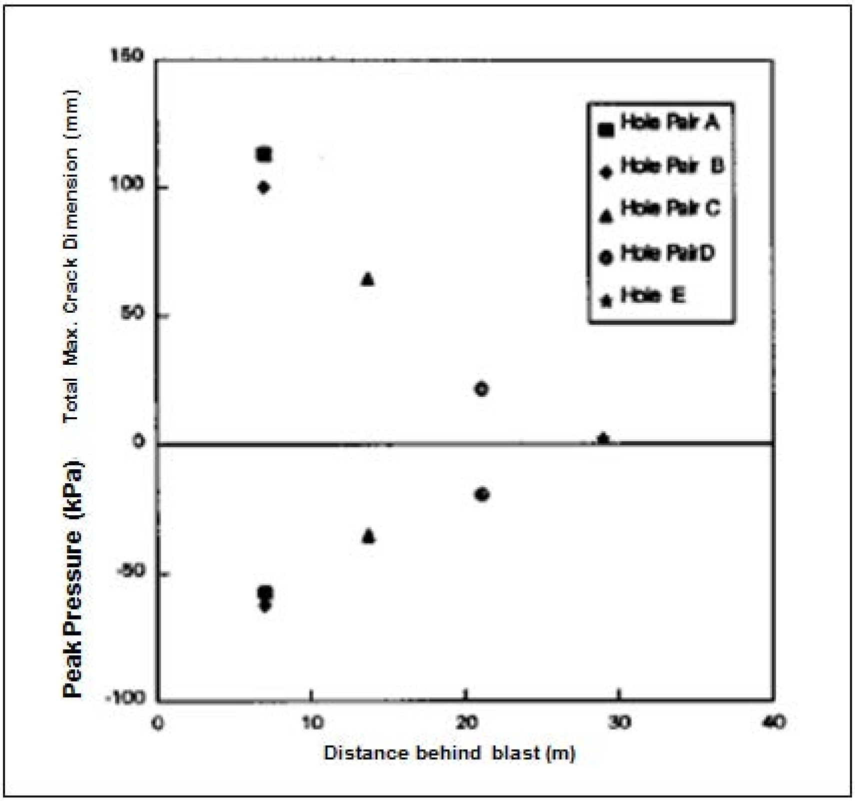

Figure 10 – Correlation of Negative Pressures and Visible Fractures (after Brent and Smith 1996)

The study revealed that there is a gradual decrease in crack dilation from approximately 60 mm at a distance of 15 m and approximately 20 mm at 20 m. The study concluded that at a distance of 30 m the impact of blasting dissipates, i.e. no measured negative gas pressure and marginal crack dilation. Therefore, the potential impact was limited to approximately 30 m.

4. ROCK FRACTURE MECHANISM FOR BLAST DAMAGE ZONES

The aim of the section below is to provide explanatory notes on the mechanism of rock strata damage which occurs during the blasting process. For ease of understanding the fracture mechanism for the blasted bench and adjacent bench are described separately.

BLASTED AREA

A detailed description of blast damage zones and each zones formation was provided by O'Regan et al (1983). This can provide an insight into the fracture mechanism within the blast area. The described processes apply to a distance of approximately 10 hole diameters from the blasted open cut surface hole. The rock fracture mechanism is described as follows:

Crushing
The damage within this zone is driven by high gas pressure. This causes an annulus of crushed rock around the blast hole. The zone is typically limited to twice the diameter of the borehole size.

Radial Cracking
The radial compressive wave propagates in all directions away from the borehole. This effect / impact develops tensile strain, which as a consequence induces tensile radial cracks. The cracks are distributed evenly around the borehole. Typically these cracks develop to half of the burden distance.

Internal Spalling
The compressive wave upon the intersection of a free face is reflected as a tensile wave. The rock is then damaged through a tension process, which causes rock slabbing (at the free face). Note that usually rocks are weaker in tension than in compression, i.e. rocks can potentially be up to 10 times weaker in tension than in compression. For sedimentary rocks the internal spalling generally can extend up to 10 hole diameters.

ADJACENT BENCH AREA

This behaviour as described below applies to the bench adjacent to the blasted bench. Therefore, the rock strata behaviour depicted in this section is very much applicable to the behaviour that can be expected for the area located between Main Creek and the boundary of the Proposed Modification Pit Shell.

Based on the presented studies above and other far distance studies, the following zone classifications were made:

Zone 1
Immediate blasting zone – there is a high probability of damage in this zone. The extent of this zone is relatively limited, typically 5 – 20 m for open cut mines, depending on the strata conditions, type of blast, the presence of pre-split and other factors. In extreme cases this zone can potentially extend up to 30 m. This behaviour has been demonstrated within the case studies in Sections 3.4 to 3.9 with the case described in Section 3.6 being most applicable to North Pit due to similar geological conditions.

Within this zone, one of the driving mechanisms of the induced damage is the invasion of high-pressure gases back into the highwall. The invasion usually occurs along both natural and blast-induced discontinuities. The following release of load rebound after the invasion of gases is the driving mechanism behind vertical fracture formation.

Generally, poor quality rock strata can be more susceptible to damage (or strata separation) within this zone compared to high strength rock strata with a limited number of bands.

Zone 2
Described as a high frequency zone. This zone extends from 30 m to approximately 350 m from the blasting area. The behaviour in this zone is highly influenced by the generated frequencies. Within this zone, there are high levels of vibration as well as high frequencies generated.

Damage is unlikely to occur within this zone, although it can potentially occur due to the liquefaction process, which is dependent upon the presence of specific soil conditions. There were no sandy soils present eliminating the possibility of liquefaction.

Zone 3
The third zone is between 350 m and approximately 2 - 3 km. In this zone some filtration of frequencies occur, that is, there is a substantial loss in high frequencies.

Zone 4
The fourth zone is described as the "far field" zone. This zone extends from approximately 3 km to 8 km. Basically, low levels of vibration are still transmitted and can be perceptible to humans.

5. DISCUSSION

Rock Strata Fracturing – Distance Estimation

The possibility of rock strata fracturing due to blasting was analysed in detail. A typical fracture damage zone (behind the blasted bench) is in the order of 5 to 20 m, with the most extreme cases extending possibly up to 30 m from the edge of the blasting area. There was only one study identified which indicated the potential for vertical cracking of 23 m and horizontal cracking up to 50 m. This, however, applied to a soft strata band and poorly executed blast (blast chocking conditions). Therefore it is reasonable to conclude that there is a potential blast impact limit of 30 m (i.e. worst case scenario) where strata can undergo fracturing and potentially induce some changes into the rock strata permeability.

Generally, the damage is dependent upon the rock strength characteristics and execution of the blast. The details were presented in sections 3 and 4 and are also summarised in **Table 4**.

The rock strength data from the eastern part of the Proposed Modification Disturbance Area, which is considered representative for the Main Creek Study Area, indicates moderately strong rock strata conditions (i.e. average UCS of 37.5 – 87.5 MPa). From a blasting perspective such moderately strong rock strata is not susceptible to fracturing from the adjacent open cut surface blasting.

A comparison of rock strata conditions revealed that the most likely potential damage zone for the Proposed Modification will be limited to a distance of approximately 12 m from the blasting area, as measured for North Wambo conditions of similar geology and comparable rock strength values (Section 3.6; study: Underground Rock Tunnel off the Highwall – Assessment of the Rock Strata Damage from Blasting – ESC (2008))

Table 4: Summary of Rock Strata Damage from Blasting Studies

Study	Rock Strata Strength (MPa)	Extent of Fracturing (m)	Vibration Exposure (mm/s)	Comments / Blast design
Rorke and Thabethe (2004) - South Africa	Inter-bedded shales and sandstone	No impact on stability of the 110 m pillar. Very little back damage – not quantified. No movement / damage for roadway.	150 mm/s – limit for roadway Measured vibrations below vibration limit	110 m bench/pillar not affected by adjacent blasting 200 mm – hole diameter 15 m benches Max MIC – 215 kg per deck
ACARP C14057	n/a	n/a	100 mm/s – bridges 100 mm/s – water dam	Recommended 100 mm/s vibration limits applicable to bridge / river embankments and dam embankments, comparable for creek conditions
O'Regan et al (1983) CSIRO study - QLD study	Well bedded strata consisting of claystone, sandstone, siltstone and coal bands	23 m – vertical cracks detected 50 m – horizontal cracks along weak strata	n/a	Detailed study of an adjacent bench to the blasted area using piezometers, seismic assessment and extensometer measurements Blast assessed as inadequate, i.e. chocking
Lewandowski and Cope (2009) Bulga – Hunter Valley Conditions	Sandstone (UCS: 30 MPa) / mudstone and siltstone (UCS: <10 MPa)	17 m - surface cracks identified	unknown	MIC – 530 kg Utilised detailed surface survey
ESC (2007) Wambo – Hunter Valley Conditions	n/a Sandstone / shale	11.5 m – from the edge of the blasted bench	>400 mm/s	MIC – 600 kg Investigation of rock strata damage due to close range surface blasting. Extremely high vibrations are required to induce damage to the assessed rock strata.
ESC (2008) North Wambo - Hunter Valley Conditions	UCS: 47 – 103 MPa Sandstone / mudstone / Siltstone /Conglomerate	12 m – assessed as underground (u/g) damage zone (including vertical and horizontal cracks)	inferred as >500 mm/s)	Assessed through u/g evaluation of u/g tunnel conditions – adjacent to previously blasted area. Underground surveys including extensometers.

Study	Rock Strata Strength (MPa)	Extent of Fracturing (m)	Vibration Exposure (mm/s)	Comments / Blast design
McKenzie (1999) Concise summary of various gas monitoring studies	Various rock strata from a number of different studies	20 m - concluded as gas penetration limit into adjacent strata	Unknown	Gas monitoring utilised to establish the extent of gas penetration into the rock strata and inferred potential strata cracking
LeJuge et al (1994) Namibia	Unknown	20 m – extent of damage Extensometer and ground heave measurements	n/a	Large hole diameter – 381 mm used
Brent and Smith (1996) Hunter Valley Conditions	Hunter Valley conditions	Crack dilation in tested holes potentially up to a distance of 30 m	n/a	200 mm - hole diameter, (7 x 8) m blasting pattern Accurate correlation of negative pressure and crack dilation in tested holes behind the blast

Vibration Limit

Upon review of the various studies presented above it is concluded that the 100 mm/s vibration limit for the Main Creek Study Area is considered to be an acceptable limit.

The limit is justified according to the geology of the area, with the soil conditions not conducive to liquefaction, permitting high vibration exposure.

A supporting argument for the postulated 100 mm/s vibration limit was provided by the various published studies and substantiated by the author's experience in the area of strata fracturing due to blasting. In addition, some recommendations have been provided and presented in ACARP Project No. 14057 (2008). The ACARP authors postulated an indicative vibration limit for water dams (i.e. comparable to river banks) of 100 mm/s with the commencement of observations at a 50 mm/s vibration level, see **Table 3**. A similar limit of 100 mm/s was recommended for bridges and therefore also applicable to river banks.

The method to establish a vibration limit as presented in this report is consistent with the approach postulated in the ACARP study, including an observational as well as measurement-based approach.

The alluvium material associated with Main Creek does not present any specific, distinct feature on the ground that could be affected by ground vibrations, therefore there is no need to establish a vibration limit for alluvium.

160 m Buffer Zone

The minimum distance from the Proposed Modification Pit Shell to the top of high bank of Main Creek is approximately 160 m and is at its closest point 150 m from the mapped extent of alluvium. Based on the results from the reviewed blasting studies this distance will be sufficient to provide an adequate buffer. In addition the Proposed Modification disturbance area extends approximately 50-100 m from the Proposed Modified Pit Shell, which would also adequately capture areas where cracking may occur from proposed blasting practices.

Mount Owen will continue to undertake site inspections including inspections along the eastern high wall of the Proposed Modification Pit Shell to identify and monitor blast induced surface impacts such as cracking. This would allow for an accurate assessment of rock strata response when blasting in the vicinity.

To conclude, based on the distances considered in the assessment for Main Creek (approximately 160 m, at the closest point), the risk of damage to rock strata and subsequent damage / crack formation between the blasting area and Main Creek, and damage to the creek banks, is low / negligible. In addition, any rock fracturing that results from blasting will not extend far enough to the east to intercept the Main Creek alluvium and result in leakage into the pit.

6. CONCLUSIONS AND RECOMMENDATIONS

At the request of Umwelt an investigation into the potential impacts of blasting from the Proposed Modification Pit Shell on Main Creek was undertaken. This included an assessment of the possibility of rock strata fracturing and an allowable vibration limit for the high bank of Main Creek.

The assessment was based on the following:

- A review of relevant Australian and international studies related to rock strata behaviour immediately adjacent to the open cut blasting areas,
- A review of rock damage studies undertaken by the author in the Hunter Valley area and considered representative for the Proposed Modification's rock strata conditions,
- A detailed assessment of the local rock strata conditions using available geological / geotechnical data,
- Site inspection and site testing including assessment for potential rock strata damage from the adjacent open cut blasting.

The results of the investigation are summarised as follows:

- The Main Creek Study Area is located to the eastern boundary of the Proposed Modification Pit Shell. Blasting will be undertaken at variable distances from Main Creek with the closest section of the creek (that is, top of high bank of the creek) located approximately 160 m from the blasting bench. The associated alluvium is 150 m at its closest from the blasting bench. The study revealed that the rock strata fracturing is dependent upon the rock strength characteristics and execution of the blast.

- The geological assessment of the area was based on a number of boreholes (located in the vicinity of the Main Creek Study Area). Indicative geological profiles of the area were presented in **Appendices 1A** to **1F**. The rock strata is comprised of a well bedded formation consisting predominantly of conglomerate, sandstone, siltstone, coal, claystone and a top layer of soil, without the presence of any significant weak strata layers. Based on the undertaken assessment the considered strata does not appear to be prone to surface cracking.
- The geotechnical assessment of the rock strata revealed moderately strong strata conditions (i.e. average UCS range 36.5 - 87.5 MPa), which can sustain substantial blast impacts. The site inspection confirmed adequate rock strata composition without any significant defects or cracks present.
- There were a total of nine studies quoted in this assessment across a variety of geological conditions. Based on these studies, the impact of blasting on the area behind the blast is relatively limited and can potentially range between 5, up to a maximum of 30 m and is highly dependent upon rock strength characteristics. This is for a vertical / horizontal crack formation (including ground heave) - classified as back break conditions. The quoted studies included various assessment techniques and are considered fully representative and appropriate for identification of potential blast impacts associated with the Proposed Modification.
- Based on the presented studies it is estimated that the risks of strata fracturing due to blasting in North Pit near the Main Creek Study Area are potentially limited to a distance of approximately 12 m from the blasting area.
- Based on the undertaken assessments, to establish an allowable vibration limit for the high bank of Main Creek it was concluded that the 100 mm/s vibration limit is considered to provide an adequate vibration limitation when blasting in its vicinity. The 100 mm/s limit, together with the continuation of high wall inspections, should provide an adequate measure to alert / prevent surface damage, including surface cracking taking place between the blasting area and Main Creek. Similar measures (including vibration limit and an inspection / observational regime) were postulated in ACARP project no. C14057. Therefore, the analysis undertaken and presented in this report is consistent with the approach postulated in the ACARP study.
- The associated alluvium does not present any specific features susceptible to vibration impacts, hence there is no need to establish a corresponding vibration limit.

In view of the above assessment of strata fracturing, from a blasting perspective, a distance of 160 and 150 m as a buffer between the Main Creek top of high bank and alluvium respectively and the boundary of the Proposed Modification Pit Shell is considered adequate for North Pit conditions. The risks of strata fracturing due to blast impacts were estimated to a distance of approximately 12 m from the blasting area. Therefore, the risks are considered low / negligible.

Thomas Lewandowski
ESC
24th May 2018

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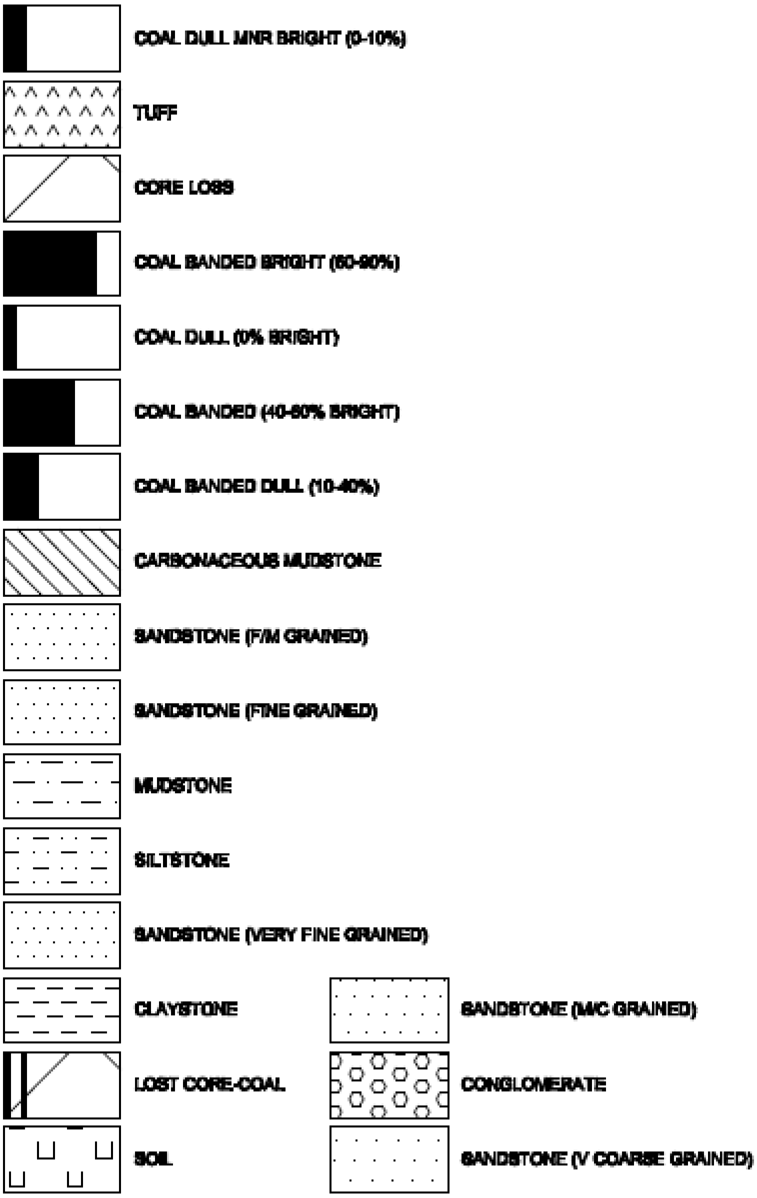
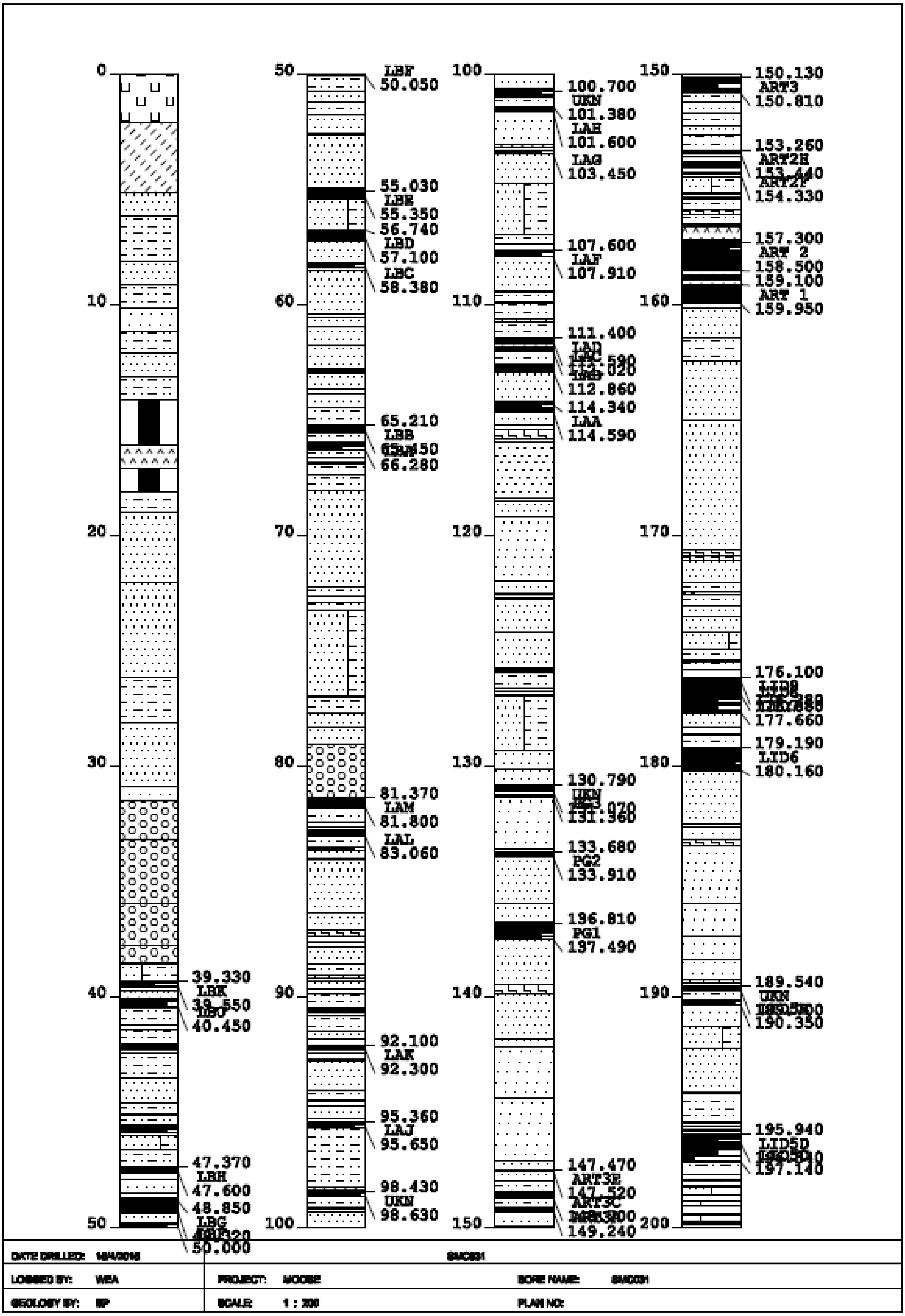
APPENDICES

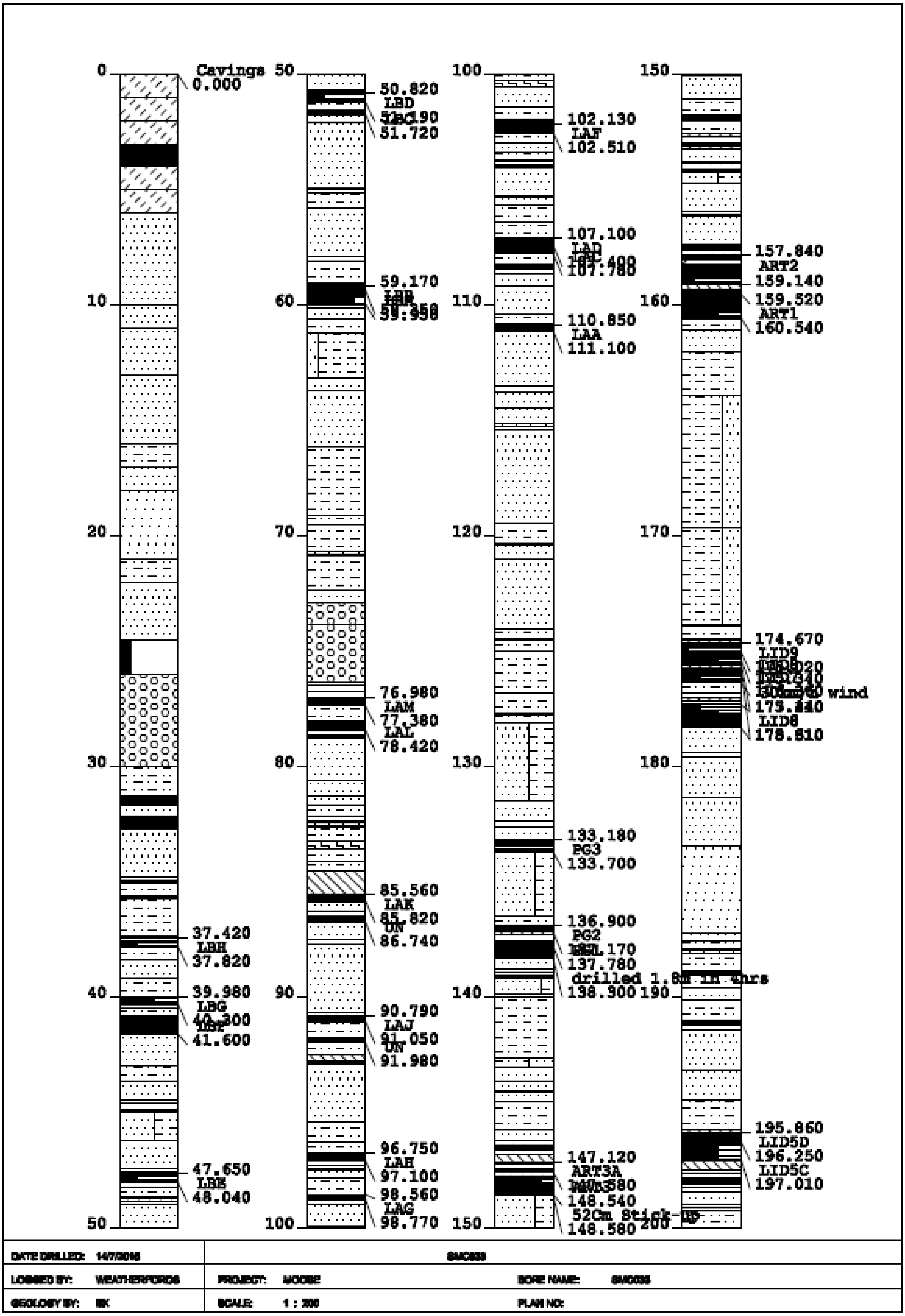
Appendix 1A – Borehole Log Legend



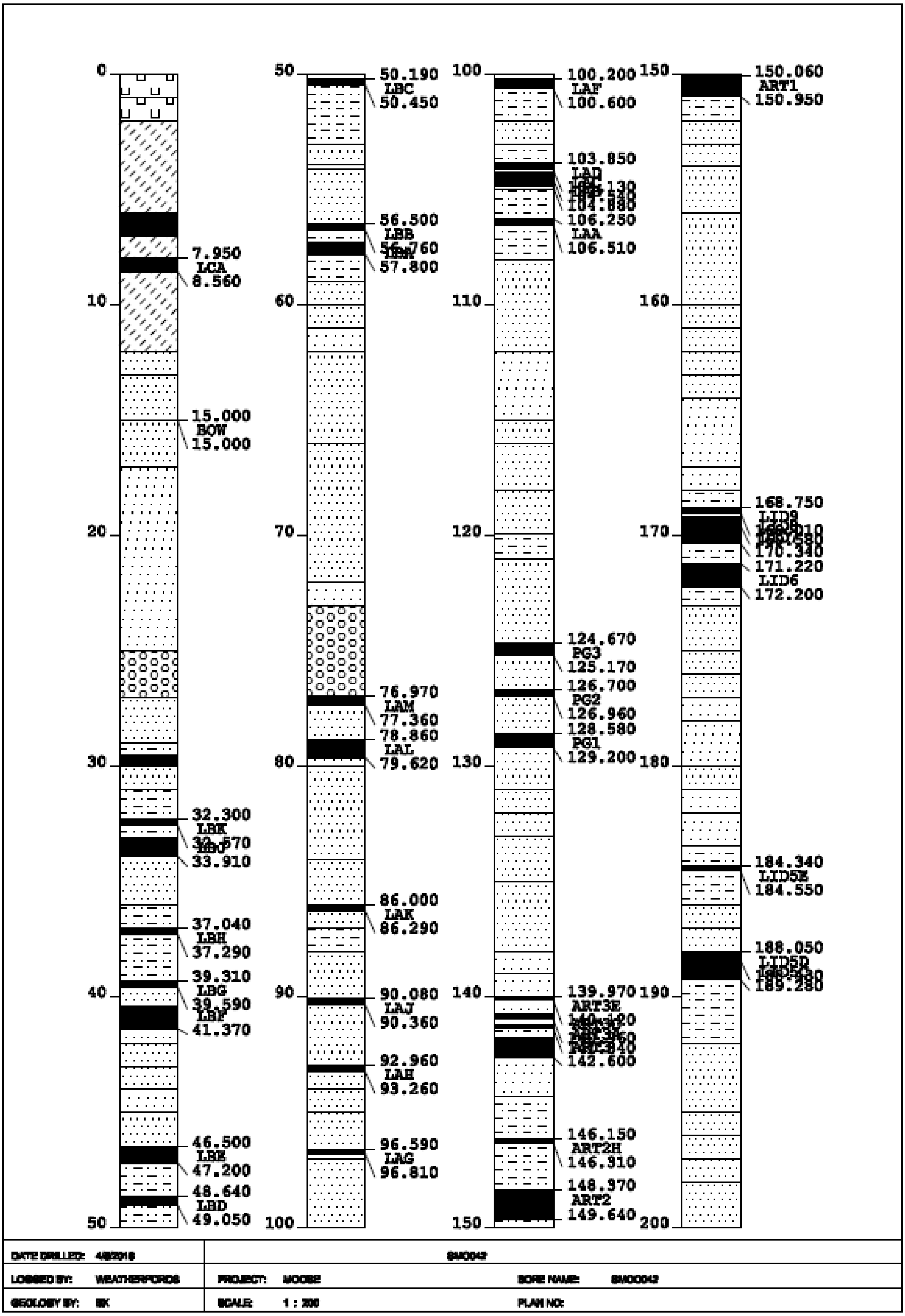
Appendix 1B – Borehole SMC031



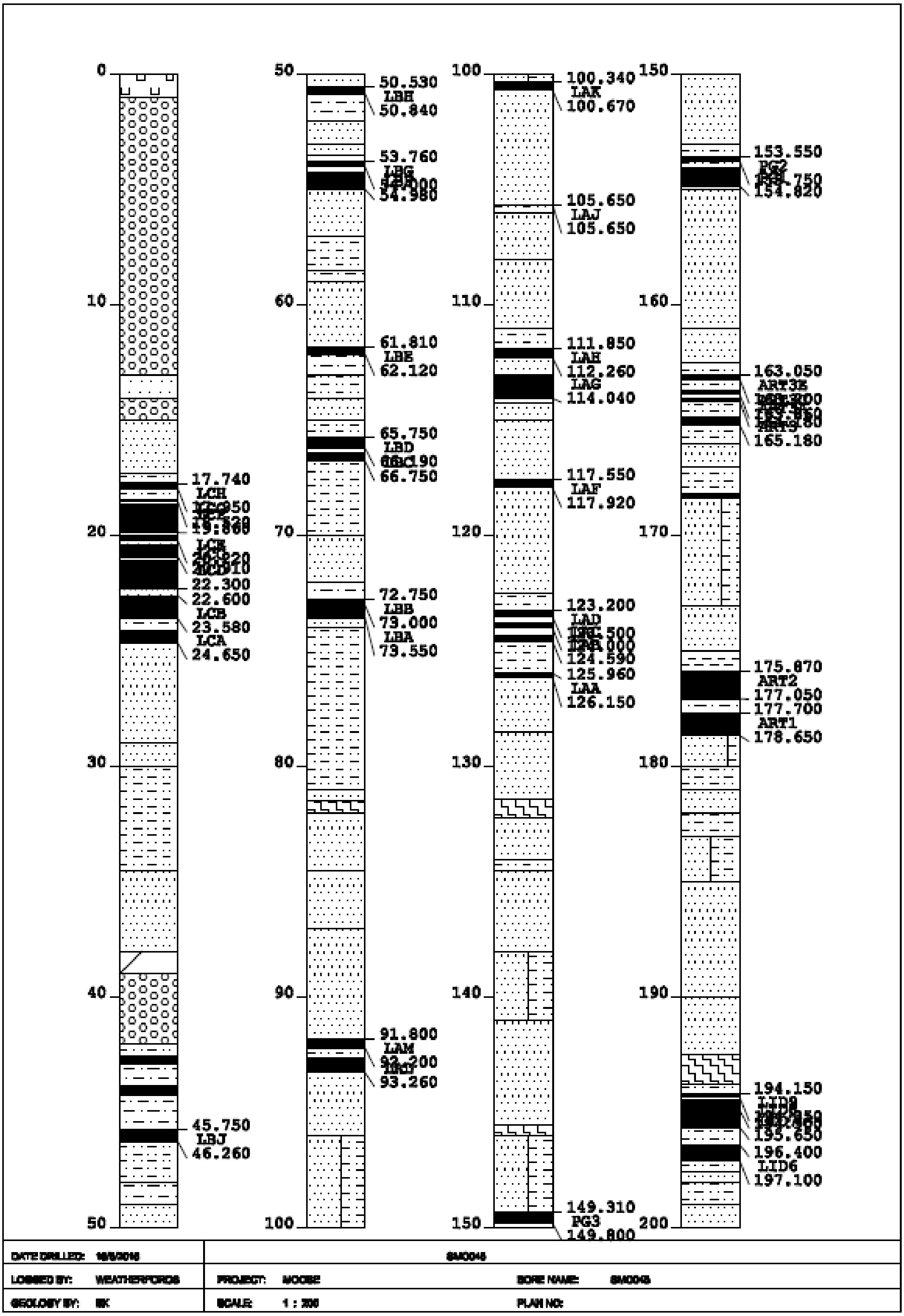
Appendix 1C – Borehole SMC033



Appendix 1D – Borehole SMO042



Appendix 1E – Borehole SMO045



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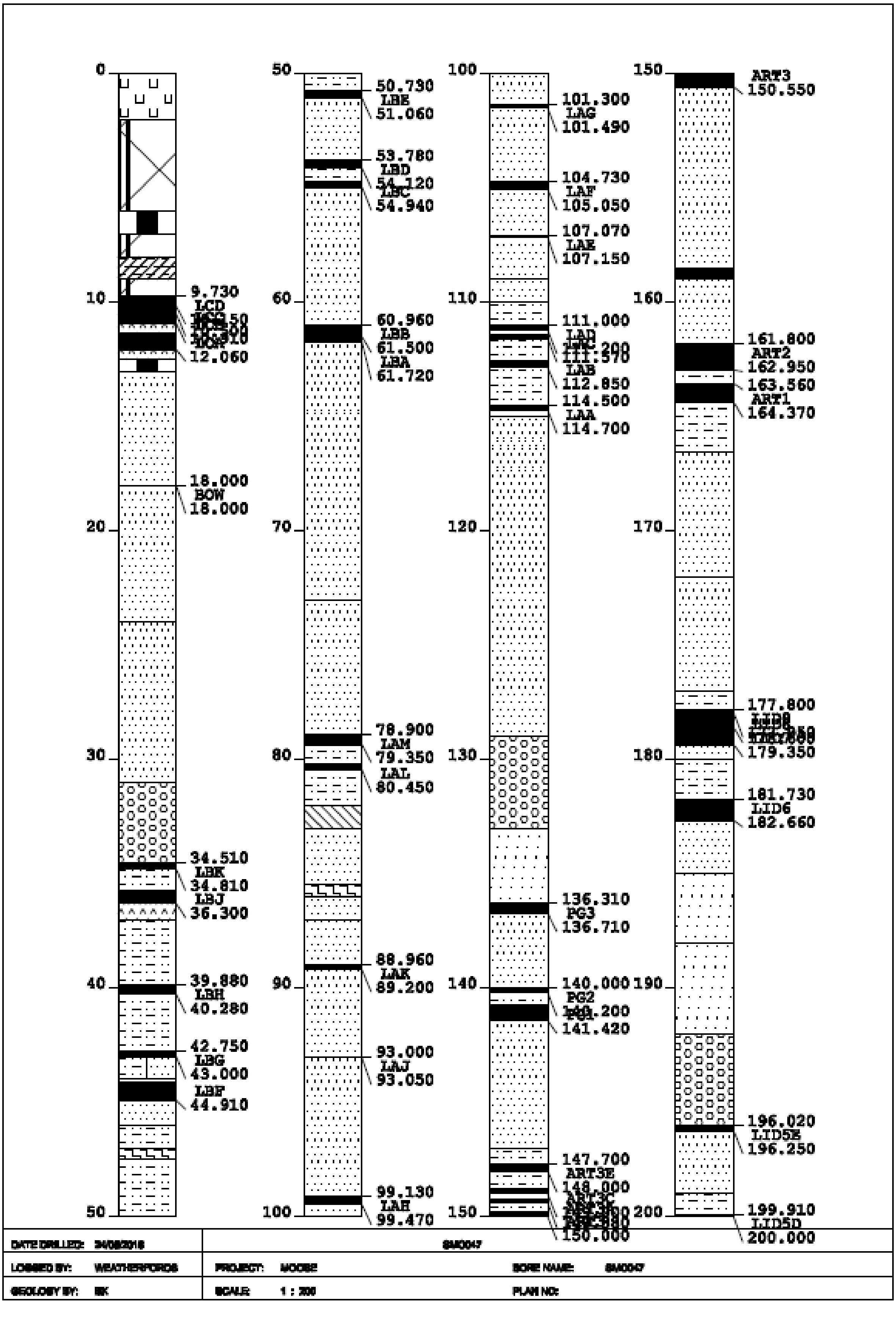
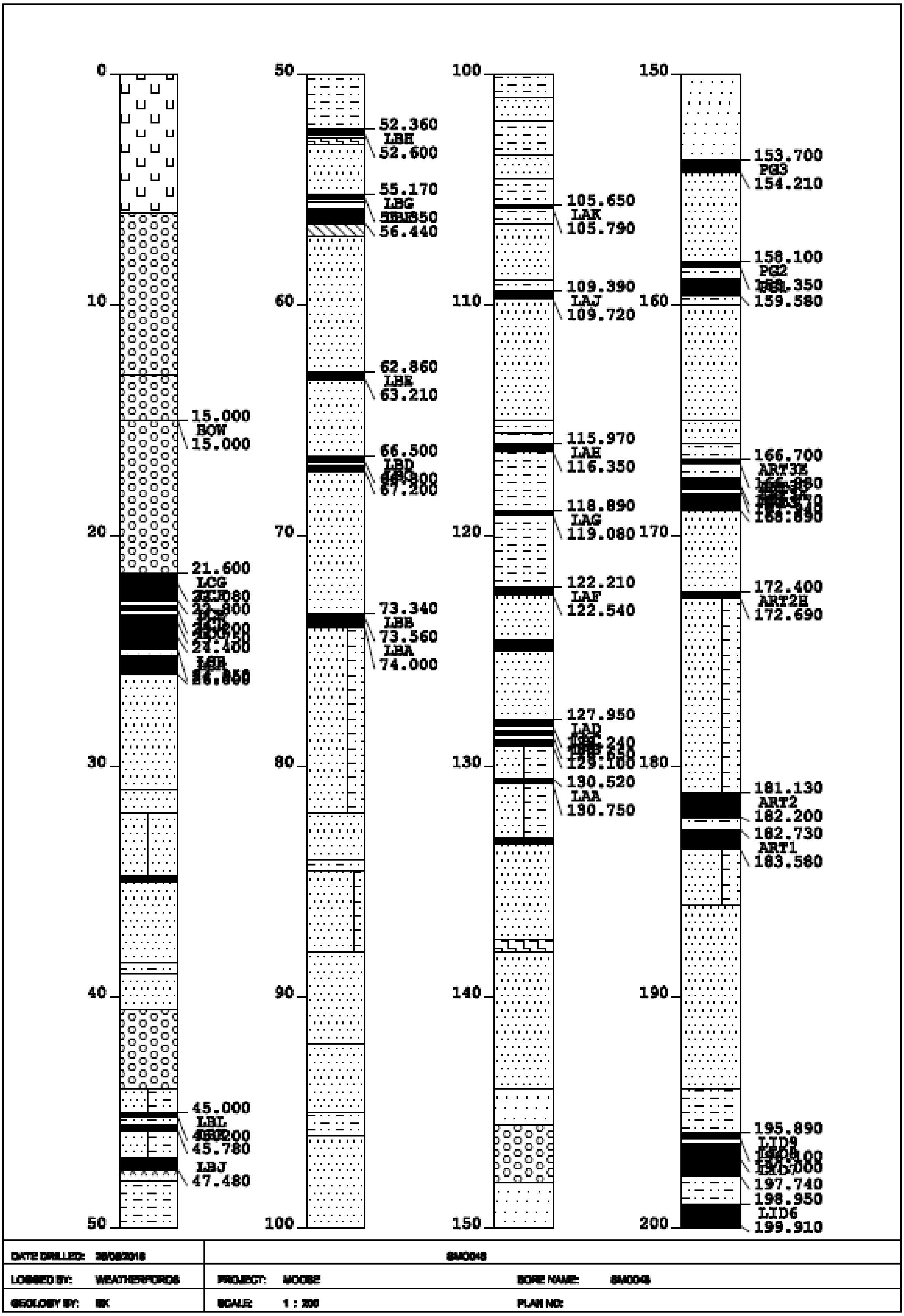
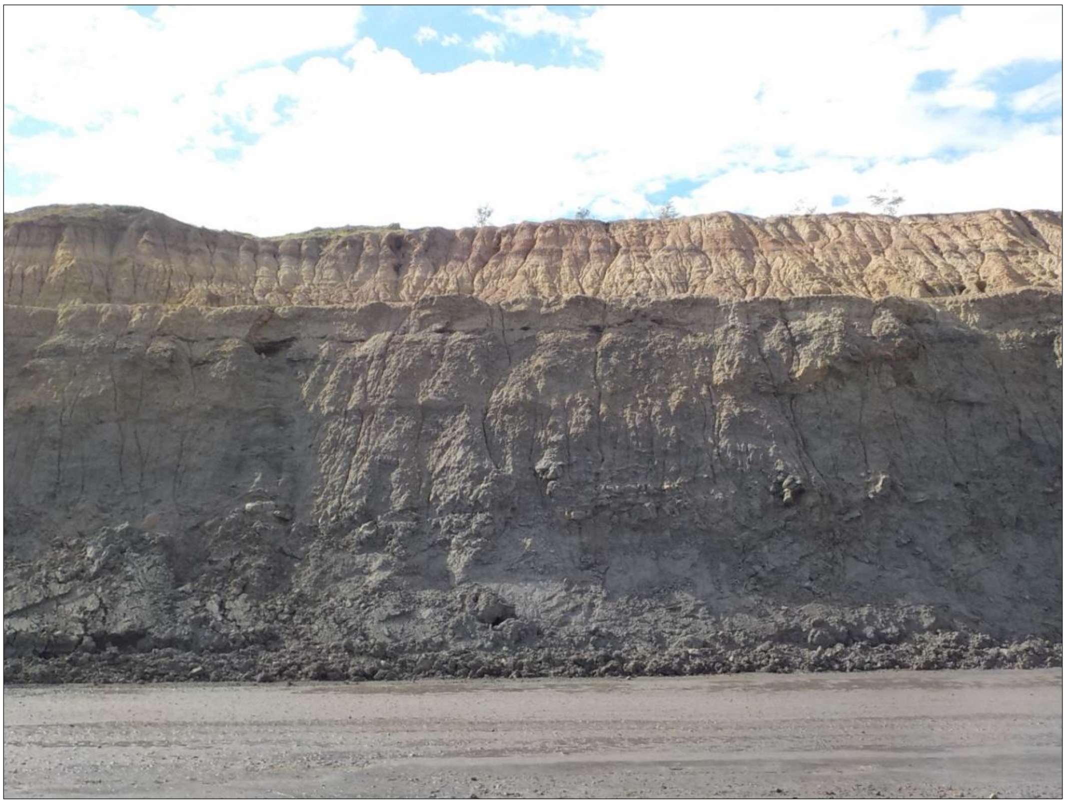


Appendix 1G – Borehole SMO048



Appendix 2A – View of Eastern Wall Conditions



Appendix 2B – View of Eastern Wall Conditions

Appendix 2C – View of Top Surface Strata Adjacent to Eastern Wall

Appendix 2D – View of Top Surface Strata Adjacent to the Eastern Wall

Appendix 3A – View of Main Creek Study Area and Embankment Conditions

Appendix 3B – View of Creek Embankment Area

Appendix 3C – View of Weathered Sandstone Strata Layer

Appendix 3D – View of Surface Strata between Main Creek Study Area and Proposed Modification Pit Shell

Appendix 3E – View of Embankment – Clay Conditions

Appendix 3F – View of Surface Strata – Conglomerate Conditions

Appendix 3G – View of Surface Strata – Conglomerate Conditions

Appendix 3H – View of Surface Strata – Conglomerate Conditions

Appendix 4A - View of Schmidt Hammer

Appendix 4B – View of Penetrometer