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Report On

Quinsam Coal Mine Subsidence Assessment

Prepared for
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Introduction

As requested, Michael Cullen Geotechnical Ltd (MCG) has completed an assessment of the affects of mining related subsidence at the Quinsam Coal Mine (QCM). Specifically the work has investigated the following:

- Changes to the hydrologic properties of the rocks caused caving and subsidence.
- Potential interaction between the existing 5South Mine (5S) and proposed 7South Mine (7S).

The investigation was commissioned by Quinsam Coal Corporation (QCC) to assist with obtaining an amendment to Mine Permit C-172 for the purposes of operating the 7S Mine. Sections of the proposed 7S Mine overly mined out areas of the 5S Mine; the potential interaction between the two mines needs to be assessed for both stability and hydrogeological considerations. The Ministry of Energy Mines and Petroleum Resources[1] specifically requested that the following be provided:

> *Design information on the interaction between 7S and 5 South*
> *Records of subsidence monitoring undertaken to date on the 2-North and 5-South.*

It is understood that coarse coal rejects (CCR) and fines generated from mining 7S are potentially acid generating (PAG), and that some of these materials may be stowed in mined out areas under subaqueous conditions. The mining induced changes to the hydrologic properties of the rocks needs to be understood in order for detailed hydrogeological modeling to be completed. The results of this investigation will contribute to a hydrogeological study being completed by Lorax Environmental Services Ltd.

Site Description

The proposed 7S mining area is located on the south side of the Quinsam River. Figure 1 (from QCC 2011) is an overview plan showing the location of the proposed 7S mine in relation to the remainder of the mining operations. Figure 2 (from QCC 2011) shows the areas where underground CCR and fines stowing is being considered at the mine.

Figure 3 (from QCC 2009) shows a generalized stratigraphic profile or the rocks at the Quinsam Mine. The 7S Mine will extract coal from the #4 Coal Seam whereas the active 5S and 2N Mines are extracting the #1 Coal Seam. The #4 Seam is approximately 110m above the #1 Seam. The rock sequence includes the Cumberland and Dunsmuir Formations.

For the most part the Cumberland Formation consists of siltstone (with occasional interbedded sandstone and mudstone). The siltstone is considered a weak to medium strong rock with UCS of 10 to 20 MPa and Coal Mine Roof Rating (CMRR) of 30 to 40. The Dunsmuir Formation consists of sandstone (with occasional interbedded conglomerate and siltstone). The sandstone is considered a strong rock with UCS of 40 to 70 MPa and CMRR of 80.

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[1] "Quinsam – MEMPR Review of the Proposed 2-South CC Storage and 7 – South Mine Development" dated June 16, 2010.

The strata are cut by numerous discontinuities including bedding planes, local depositional faults and slickensides, and larger faults that transect both the Cumberland and Dunsmuir Formations. Depositional features occur in the siltstone and mudstone units only; they may affect local excavation stability but have little or no affect on subsidence or changes to rock hydrologic properties. Larger faults have the potential to cause anomalous subsidence behaviour and changes to the hydrologic properties of the rock. The term "significant faults" is used throughout this report to identify faults that may affect subsidence and hydrologic properties. Based on experience at the QCM significant faults typically have the following attributes:

- Faults that extend through both the Cumberland and Dunsmuir Formation.
- Faults with greater than 1m vertical offset
- Open faults or fractures.
- Faults with trace length greater than one hundred meters.
- Faults that have resulted in distinctive linear features on surface such as thick till cover and swamp systems. In some instances significant faults have been inferred in areas yet to be mined where these linear features have been identified on surface.

The significant faults shown on the figures within this report are those identified by QCM geologists, and previous work by the MCG, as meeting the above criteria.

Investigation Procedures

To date there have been no detailed assessments of the impact of mining induced subsidence on the hydrologic properties of the rock, or of multi seam mining interaction at the Quinsam Mine. As such, the approach taken in this investigation was to calibrate established industry models using data collected from QCM. The following work was completed.

- A literature review of multi seam mining stability, mine subsidence, and the effects of mining on the hydrologic properties of rock.
- A review of existing subsidence information from the Quinsam Mine, including recent subsidence surveys above the 5S Mine.
- Drilling holes to assess the extent of ground disturbance and hydrologic changes above both the 2N and 5S Mines.
- Assessment of stability and interaction between 5S and 7S with the National Institute of Occupational Safety and Health (NIOSH) programs Analysis of Multi Seam Stability (AMSS) and Analysis of Retreat Mining Pillar Stability (ARMPS).

Definitions

There are several terms that are unique to subsidence engineering. The terms and definitions used in this report are defined below; these definitions are typically used in the North American Mining Industry and are presently used at QCM. The definitions are illustrated on Figure 4.

Gob: term given to mined out areas once pillar extraction has occurred.

Extraction Ratio: the ratio between the total amount of coal within a mining area and the amount of coal actually mined. In the case of retreat pillar mining the unmined coal is usually left as remnant pillars within the gob.

Surface Subsidence: vertical movement of the ground surface that is the result of mining.

Angle of Draw: the angle between a vertical line at the edge of the gob and a line drawn between the edge of the gob and the maximum extent of detectable surface movement that is attributable to mining.

Angle of Fracture: the angle between a vertical line at the edge of the gob and a line drawn between the edge of the gob and the extent of the fracture zone. At shallow depth the angle may be negative.

Caved Zone: zone of rock immediately above the mine excavation that has fallen into the gob. The falling rock rotates and the original structure within the rock strata is generally lost. The caved zone extends up to where either the caving is choked off, or to where a competent rock unit bridges the cave. In shallow mines the caved zone may extend to surface where it results in a highly irregular surface profile with open fractures, stepped fractures, and sinkholes.

Fractured Zone: zone of rock that overlies the caved zone. The strata in this zone are fractured; however, blocks do not rotate, and the basic structure of the rock mass is preserved. In deeper mines, the fractured zone extends to where the stresses no longer exceed the strength of the rock mass. At shallow depth mines the fractured zone may extend to the ground surface where it results in open fractures with occasional steps.

Literature Review

Most of the research on hydrologic changes to strata, and the hydrogeological impacts from mining has been concerned with the following:

- Protecting overlying water supplies
- Protecting streams, rivers and other resources above mines
- Preventing water inundation to mines

It is well documented that underground mining can cause changes to the hydrologic properties of the overlying rock, most notable are increases in transmissivity and water storage. These changes may have an impact on the ground water table elevations, ground water movement, and water inflow to the mine. The extent of the impact is a function of many factors including rock properties (strength, modulus, weathering characteristics), mine depth, extraction ratio, excavation size, mining method, and topographic setting. No information was found in the literature review that addressed hydrogeologic issues specific to the underground stowing of CCR or fines.

In conventional room and pillar mining where there is no appreciable caving or subsidence hydrologic changes will be small. Provided that pillar and room spans are appropriately sized for long term stability the changes will be limited to strata immediately adjacent to the mine openings. Although Booth (2006) notes that if the mine workings intersect pre-existing faults or fractures with high permeability, drawdown of water tables may extend over greater distances despite relatively small changes in hydrologic properties of the rock around the mine.

High extraction coal mining (e.g. longwall or retreat pillar mining) that results in caving may have a significant effect on the hydrologic properties of the overlying strata. Most of the literature on coal mine subsidence and hydrologic changes has been completed for longwall mines. The results from longwall studies may not be directly applicable to retreat pillar mining. Moebs (1982) reports that attempts by the USBM to apply longwall subsidence prediction methods to retreat pillar mining sites met with only limited success owing to the erratic and unpredictable subsidence upon removal of pillars. Kohli et al (1982) reports that room and pillar mining with an 80 % extraction results in subsidence profiles similar to longwall. Peng (1992) suggests that longwall subsidence prediction techniques can be applied to room and pillar mines provided that total extraction occurs. In practice, total extraction seldom occurs in retreat pillar mining. At the Quinsam Coal Mine the average panel extraction ratio is between 75% to 95%. The overall the extraction ratio at the mine is about 73% when barrier pillars are included. It is believed that applying the results from longwall mining to room and pillar mining will produce either similar or more conservative results.

Figure 5 illustrates the generally accepted model of subsidence zones and hydrologic response for longwall mines (Kendorski 2006, Booth 2006, Peng 1992, Dawkins 1999, Tieman and Rauch 1987). The various zones are discussed in detail in Table 1. Zone heights are directly related to the height of the mining or extraction height ‘t’.

The height of the fractured zone is found to increases with increasing rock strength; the extent of hydrologic changes due to mining are generally reported to be less in weak rocks (e.g. Cumberland Formation siltstone) than in strong rocks (e.g. Dunsmuir Formation sandstone). Furthermore, fractures in weak rocks are more likely to close with time thus restoring pre-mining hydrogeologic conditions (Peng 1992). Peng 1992 and Kendorski 1995, report that the fractured zone may extend to greater than forty times the thickness of the worked seam (40t) if the overburden consists of strong rock such as sandstone. Bai 1996 determined that where the overburden consists of weak rocks the maximum fractured zone height is 24t, but if the overburden consists entirely of strong rock the fractured zone could extend to 60t. In situations where there is weak rock overlain by strong rock, such as at QCM, the overlying strong rock may reduce total subsidence by bridging.

The surface cracking zone extends from the upper rock surface down; it is the result of high tensile stresses created as the subsidence line advances. In Australia it is typically found to range between 15 and 20m (Dawkins 1999). In the US the typical value reported is 15m (Peng 1992).

Table 1: Description of Subsidence Zones above a High Extraction Panel

Zone	**Description**	**Hydrogeologic Changes**	**Height above mine in terms of height of extraction (t) or meters (m)**
Surface Cracking	High tensile strains result in bed separation and rock fractures. Greatest disturbance occurs at gob edge where highest strains prevail.	Increased permeability and storage. May experience drop in GWT that recovers with time	upper 10m to 20m of bedrock
Constrained Aquiclude	Compression zone	No significant change in permeability or storage	60t to bedrock surface less 15m
Dilated Aquiclude	Bed separation with horizontal fractures.	Increase in horizontal permeability and storage. May experience initial drop in GWT that recovers with time.	30t to 60t
Dilated Transition	Transition Zone Bed separation with horizontal fractures. Vertical fractures common at bottom, less common to nonexistent at top.	Increase in horizontal permeability and storage. Increase in vertical permeability that diminishes with height above the fractured zone, and also diminishes with time.	
Fractured	Bed separation and vertical fractures	Increased horizontal and vertical permeability. Drains to mine workings.	6t to 30t but may extend to 60 t
Caved	Zone of complete disruption		3t to 10t

Experience in Australia has found that there is typically no hydraulic connection between surface and underground where the mining depth exceeds 100m (Dawkins 1999). This is assumed to represent the maximum combined height of the fractured zone, transition zone, and surface cracking zone. US experience is that the distance will typically vary from 90 to 150m but can be as little as 60m (Booth 2006).

The extent to which hydrologic changes to the rock extend out laterally can be broadly defined by the angle of draw. Within the literature the angle of draw is reported to be between 0 and 40 degrees for full extraction coal mines at moderate to deep depths. Most subsidence data is from moderate to deep longwall mines which may not be applicable to relatively shallow room and pillar mines. Previous measurements at the Quinsam Mine show that the angle of draw has a range of between 0.6 and 5 degrees at depths less than 100m. Similar results for shallow coal mines have been reported by other researchers such as Peng et al 1995, McNally 2000, Holt 2001.

The angle of fracture defines the extent of the fractured zone. The strata located between the angle of fracture and angle of draw is bent and dilated only. Numerical modelling completed by Cullen et al (2000) for 100m depth of cover predicted an angle of critical deformation (which is analogous to the angle of fracture) of 1.2 degrees, based on a limiting strain of 2%.

The influence of geologic structure on subsidence and hydrogeology is well documented in the literature, e.g. Cullen 1996, Kendorski 2003, Peng 1992, Shadbolt 1987, Whitaker and Reddish 1989. Faults and other significant geologic structure may increase the fracture zone height, and increase the angle of fracture and angle of draw. Pre-existing high permeability fractures may cause enhanced hydraulic conductivity through the aquiclude zones. The accepted industry practice is to treat faults and other significant geologic structure on a case by case basis.

Quinsam Mine Subsidence Program

Active subsidence monitoring stations are located above Panel 103, 108, 109, 110 and 111 at the 5S Mine, and above the Quinsam River Barrier Pillar Panel (RBPP). The location of these stations is shown on Figure 6. These stations were installed prior to any pillar extraction with the exception of those above Panel 103 which were installed after completion of pillar extraction. Additional subsidence monitoring stations are planned over Panels 110, 111, 112 and the barrier pillars at the 5S Mine. The location of these proposed stations is also shown on Figure 6.

Pillar extraction has occurred in Panel 103 and 108 at the 5S Mine. To date the level surveys have not recorded measurable ground subsidence based on a +/-40mm survey accuracy. Ground traverses completed by Michael Cullen over the 5S area have not identified any indications of surface subsidence. The results of the subsidence surveys completed by the Mine are attached as Appendix 1.

Subsidence measurements were completed by the Mine in 2007 above 3N Mine Panel 19 and Panel 20, in the vicinity of the Mine access road and the Argonaut Main. However, the results from this work were determined to be unreliable as a result of excessive survey errors and inadequately installed subsidence stations (pers. Com. Cale Dubois 2010).

Surface cracks, troughs and sinkholes have developed above the Quinsam Mine. Figure 7 shows the location of features that developed above the 2N and 3N Mines. Figure 7A shows the location of subsidence cracks that developed above Panel 101 and 102 at the 2S Mine, this information is also summarized in Table 2. The surface cracks have been sub-divided into “major” and “minor” features. Major features are defined as follows:

- cracks with greater than 0.15m vertical offset and greater and 0.15m width
- cracks with width greater than 0.3m
- cracks with connectivity from surface to underground
- sinkholes.

Minor cracks are smaller features that are less easily identified and may be obscured by vegetation or soil cover. Recent surface traverses over old mining areas have shown that all minor and many major subsidence features disappear with time, most exceptions are sinkholes and major cracks associated with significant faults.

Insufficient data is available to complete a meaningful statistical analysis; however, the following general observations can be made.

- Considering the extent of the area that has been undermined, and the relatively shallow depth, the number of surface cracks and sinkholes is small.
- In most cases anomalous subsidence cracks can be attributed to the presence of known significant faults.
- Where significant faults are not present sinkholes have only been encountered where the depth of rock cover above the mine is less than 20m.
- In the vicinity of significant faults sinkholes have only occurred where the depth of rock cover is less than 40m.
- Where significant faults are not present major subsidence cracks have only been encountered where the ratio of rock cover to mined height (t) is less than 17 (e.g. 45 to 60m of rock cover).
- Where significant faults are present major cracks have been encountered where the ratio of rock cover to t is up to 28 (e.g. up to 80m of rock cover).
- Minor cracks have been encountered where the ratio of rock cover to t is up to 23 (e.g. up to 72m of rock cover). Beyond a depth of about 50m minor fractures have only occurred above the gob edge where high strains develop.
- The amount of surface cracking diminishes with increasing depth of cover.
- The amount of surface cracking diminishes with increasing thickness of the surficial till layer. Major cracks may propagate through the till; however, the data suggests that till layers thicker than about 4m will bridge over minor cracks. Minor cracks do not typically occur where the till cover exceeds 4m.
- The till layers may “heal” larger subsidence fractures and sinkholes. This is demonstrated at the sinkholes located above the 3N Mine where all sinkholes are presently holding water. Till thickness exceeds 14m in all cases.
- Ground surface subsidence, including cracks and sinkholes, typically fully develop within 2months of pillar extraction and caving. The exceptions are where the depth of rock cover is less than about 30m, or where thick till cover and significant faults are present.

QCM is presently preparing an updated hazard map for the use of forestry work above mined out areas.

Table 2: Summary of Surface Subsidence Features

Mine	Panel	Mined Height 't' (m)	Rec. %	Rock Cover (m)	Till Cover (m)	Surface Subsidence (m)	Sub. Crack[5]	Ratio rock:t	Presence of Significant Faults[4]	Connect to Mine	Crack(s) Present in 2011 Survey	Comments
2S	101	2.8	92	32	0	1.91	major	11	no	yes	no	Following mining in 1994 numerous surface cracks up to 1m wide 3m deep 0.1m step were noted. Area was subsequently logged. No definitive subsidence cracks were located during review in 2009.
2S	102	2.8	92	38	1	0.8	major	14	no	yes	no	Following mining in 1994 numerous surface cracks with steps >0.1m were noted. The area was logged prior to mining.
2S	204	2.8	na	30	0	na	major	10	yes	na	yes	Following mining in 1998 several subsidence troughs up to 0.5m deep with leaning trees developed on upper slopes above Long Lake. Area was excluded from logging.
2N	101	2.8	80	48	2	0.9	major	17	no	yes		Following mining in 1996 numerous surface cracks some with step >0.1m were noted.
2N	101A	3.5	85	38	2	na	sink hole	11	prob.	yes	no	Following mining in 1995 several surface cracks some with step >0.1m were noted. A 5m diameter sinkhole also developed. No definitive subsidence cracks were located during review in 2011.
2N	102	2.8	90	55.0	2	0.5	major	20	prob.	yes	yes	Following mining in 1995 2 surface cracks, 0.1m wide, 1.5m deep, 5m long, upcasting air were noted. The cracks reactivated when Panel 101 was mined in 1996.
2N	103	2.8	88	65	3.5	0.9	minor	23	no	no	no	Following mining in 1995 3 surface cracks up to 0.2m wide developed at the gob edge.
2N	2 Main	2.5	82	40	1.5	0.9	minor	16	yes	prob.	yes	Following mining in 1994 no surface cracks were noted. During review in 2011 several, <0.1m wide, <10m long, 0.3m step cracks were noted close to portals.
2N	201	2.5	88	39	1	0.9	major	16	no	na	na	Following mining in 1994 6 surface cracks up to 0.2m wide, 1.0m deep, 0.1 step, developed over the gob edge.
2N	202	2.5	88	43	1	0.9	minor	17	no	no	yes	Following mining in 1994 no surface cracks were noted. During review in 2011 one 1m deep, 0.1m wide, <10m long, <0.1m step crack was noted, see Photo 2.
2N	204	2.5	85	50	2.5	na	minor	20	no	no	yes	Following mining in 1995 no surface cracks were noted. During review in 2011 several healed cracks, <10m long, <0.1m step where noted.
2N	205	2.9	85	55	1	na	major	19	yes	prob.	yes	During review in 2011 a crack >5m deep, 0.8m wide, >10m long, with 0.8m step was located, see Photo 1.

Mine	**Panel**	**Mined Height 't' (m)**	**Rec. %**	**Rock Cover (m)**	**Till Cover (m)**	**Surface Subsidence (m)**	**Sub. Crack^5**	**Ratio rock:t**	**Presence of Significant Faults^4**	**Connect to Mine**	**Crack(s) Present in 2011 Survey**	**Comments**
2N	206	2.8	85	79	2.8	1.3	major	28	prob.	yes	no	Following mining in 1995 5 surface cracks up to 0.5m wide, 2m deep, 10m long, and upcasting air were found over the center of the Panel. A major fault is identified on south side of the panel. The area has now been logged, and the crack location is under a logging road. A field review completed in 2011 found no sign of the cracks. TimberWest reports encountering occasional cracks during logging but not having any significant concerns.
2N	208	2.5	92	52.0	8	0.7	major	21	prob.	no	no	Following mining in 1995 a 2m deep, 0.6m wide, 40m long crack was located along crest of slope. The area has been logged. A field review completed in 2011 found no sign of the crack. TimberWest reports encountering occasional cracks during logging but not having any significant concerns.
2N	301	2.8	80	74	1	0.5	no	24	na	no	na	
2N	303	2.5		60	1	0.3	no	26	na	no	na	
2N	302	2.5	80	60	1	0.3	no	26	na	no	na	
2N	401	2.8	75	59	1	0.3	minor	21	prob.	no	no	Following mining in 1998 hair line surface cracks where noted where depth of cover was less than 70m. Panel encountered numerous small scale depositional faults and many pillars were left.
3N	8	2.5		65	6	na	major	26	prob.	yes	yes	Field review in 2011 identified numerous small open cracks in swamp. Swamp now dry. A linear draw that extends from the swamp is also dry. The draw is parallel to orientation of major faults and is probably a fault trace.
3N	19	3		10	25	na	minor	3	yes	no	yes	Following mining stepped cracks occurred across Mine access road. Cracks could not be traced into surrounding area demonstrating the ductility of the thick till layer, see Photo 6.
3N	15	3		40	3	na	major	13	yes	no	yes	A field review in 2011 found several 2.5m deep, 2m wide, 30m long cracks in 30m x 30m area, see Photo 5. The area was originally within a logging block but was subsequently excluding suggesting that the fractures occurred post block layout.
3N	17 NW	3.5		15	15	na	sink hole	4	no	yes	yes	Following mining numerous sinkholes and troughs occurred at the north end of the Panel. Leaning trees are common where the depth of rock cover is less than 20m. Area has been excluded from logging.

Mine	Panel	Mined Height ‘t’ (m)	Rec. %	Rock Cover (m)	Till Cover (m)	Surface Subsidence (m)	Sub. Crack[5]	Ratio rock:t	Presence of Significant Faults[4]	Connect to Mine	Crack(s) Present in 2011 Survey	Comments
3N	17 SW	3		14	8	na	sink hole	5	no	yes initially	**yes**	Area logged prior to mining. A field review in 2011 identified a new sinkhole, 20m diameter, holding water, see Photo 3.
3N	17 SW	3		18	5	na	sink hole	6	no	yes	**yes**	Area logged prior to mining. A field review in 2011 identified new cracks around a sinkhole that developed following mining.
3N	17 mid	3		23	3	na	minor	8	prob.	yes	yes	A field review in 2011 found swamp area to be dry with small cracks around side. Swamp is a linear feature with same orientation as major faults, and is probably a fault trace.
3N	12	3		65	5	na	major	22	yes	yes	yes	Following mining numerous small open cracks occurred in swamp that resulted in water flow to Mine, see Photo 7.
3N	4 22 XC	3		25	36	~1m	trough	8	yes	no	yes	Subsided area approximately 40m by 40m has ponded water that has caused trees to die. See Photo 4.
3N	4 Main 22 XC	3		25	36	na	sink hole	8	yes	yes initially	yes	Following mining 2 sinkholes occurred, both about 20m diameter and presently holding water. No evidence of ongoing instability. Located in area of deep till cover and major fault zone. Area was logged with small buffer zones around SH.
3N	4 Main	3		16	45	na	sink hole	5	yes	yes	yes	Following mining 1 sinkhole occurred, originally ~15m. A field review in 2011 identified new cracks around the sinkhole. Located in area of deep till cover and major fault zone. Area was logged with small buffer zones around SH.
5S	104	2.8		150	0	-	no	54	no	-	-	Field review in 2010 did not encounter any surface cracks.
5S	105B	2.8		160	0	-	no	55	no	-	-	A field review in 2010 did not encounter any surface cracks.

1) “t” is the mined height or thickness of coal extracted.
2) Blank cells indicate that information is not known.
3) na indicates that data is not available
4) Significant faults are faults identified to potentially cause anomalous subsidence behavior. “yes” indicates that anomalous subsidence attributed to faults has occurred. “prob” (probable) indicates that significant faults and fault control is suspected based on best available information and experience
5) Major cracks are defined as: a) having a step and width greater than 0.15m, b) having width greater than 0.3, c) having connectivity from surface to ug. d) sinkholes

An extensive subsidence monitoring and research program was completed above the 2N and 2S Mines between 1994 and 1996 (Cullen 2002). The information from this work is considered current and applicable to both the assessment of changes to the hydrologic properties of the rock and multi seam interaction. The relevant conclusions from this work are as follows:

> Strata movement over shallow mines is significantly different to that over deep mines. Most existing methods for predicting strata movements were developed at moderate and deep mines and are therefore not applicable where the depth of cover is less than about 100m. The differences in strata response is attributed to the effects of mining induced stress. Numerical modeling shows that the magnitude and vertical extent of the tensile stresses increase with decreasing depth of cover and increasing excavation width; as the cave zone height increases, the magnitude of the tensile stresses will tend to increase over shallow mines, but they will decrease over deeper mines.
>
> Where the depth of cover is less than 100m and significant faults are not present
>
> - The angle of draw has a mean value of 0.6^0 and a range of 0^0 to 5^0.
> - At shallow depth mines ground subsidence is not a function of the panel width.
> - The subsidence factor (a) which is the ratio between vertical surface movement and mined thickness (t) can be estimated by the following formula which is considered applicable for depths between approximately 50 and 150m:
>
> $a = 4.721*D^{-0.6883}$ where D is depth of cover
>
> - Beyond a height of 20 times the mined thickness surface fractures are typically only found above the edges of the gob or in the vicinity of significant faults.
> - Full caves do not occur until pillar extraction creates open spans with hydraulic radius (ratio of area to perimeter) greater than $7.8m^2/m$ which is equivalent to a span of 31m by 31m.
> - Surface subsidence typically does not occur until the hydraulic radius exceeds $10.8m^2$ (span of about 43m x 43m).
> - The maximum extent of ground subsidence and surface cracks typically occur within 2 months of the full cave occurring.
> - Thick till layers will bridge over and/or blind off fractures.
>
> Where the depth of cover is less than 100m and significant faults are present
>
> - The caving zone may extend to a height of 11 times the mined thickness.
> - The fractured zone may extend to a height of up to 30 times the mined thickness. Where the fractured zone extends to surface discontinuous surface subsidence may occur.
> - Prediction of ground subsidence parameters is not possible within a discontinuous subsidence zone.
>
> The angle of fracture defines the lateral extent of the fracture zone (shear failure boundary) over shallow mines, see Figure 4. Ground movements that occur beyond the angle of fracture are expected to be small and continuous as compared to those occurring within the angle of fracture.
>
> Large ground movements may occur beyond the angle of fracture where significant faulting is present. Significant faults are defined as those that result in anomalous behavior, typically they are tectonic features that cut through both the Cumberland and Dunsmuir formations and have an offset component to them.

Drilling and Hydrogeologic Investigations

The assessment of changes to rock hydrologic properties included a drilling program over mined out and caved areas of the Quinsam Mine. Three holes (Qu10-12, Qu10-13, Qu10-14) were completed over the 2N Mine, and three holes (Qu10-15, Qu10-16, Qu10-17) were completed over the 5S Mine in the vicinity of the proposed 7S Mine. The location of these drill holes, along with other drill holes used in the investigation, are shown on Figure 8. Figures 9 to 12 show cross sections cut through the drill hole locations. The drill hole locations were selected to assess variable conditions above mined out workings with depth of cover greater than 120m. Previous subsidence investigations at the Mine (Cullen 2002, 2001) had adequately assessed response at depths less than 100m. Table 3 presents details on the drill whole locations.

Table 3: Drillhole Location Summary

DH #	Mining Area	Collar Elev	Depth of Soil Cover (m)	Depth of Rock Cover (m)	Mined height t[1] (m)	Recovery[2]	Presence of Significant Faulting	Notes
Qu10-10	2N	244.3	17	142	0	-	no	Located 200m beyond edge of mining
Qu10-11	2N	249.1	9	149	0	-	yes	Located 200m beyond edge of mining
Qu10-12	2N #5 Mains.	267.9	21.5	111	3.0	high	probable	
Qu10-13	2N #1 Mains	270.7	1.5	147	3.0	low	yes	
Qu10-14	2N Panel 216	280.1	2.5	150	3.0	high	no	
Qu10-15	5S Panel 104	291.8	19.5	148	2.5	high	no	
Qu10-16	5S Panel 104	289.6	17	152	2.5	average	no	
Qu10-17	5S Panel 105B	287.2	1.6	162	0 (2.5)	high	no	Located 6m beyond panel edge
Qu05-13	5S Panel 104	288.6	5.4	166	2.5	low	no	Open borehole to 5S. Hole went dry after mining 5S Panel 104
Qu08-08	5S Panel 105B	287.2	4.8	160	2.5	high	no	Located just inside panel edge.
Qu09-01	5S	287.2	0.6	-	0	-	na	Located 75m beyond edge of mining. Open borehole to #4 Seam

Notes:

1. Mined height based on historic records from Mine. The minimum mined height was typically 2.8m through 2N Mine and 2.5m through 5S Mine regardless of coal seam thickness.
2. Recovery was assessed based on historic Mine records: high = greater than 85%, average 75 to 85%, low is less than 75%.

The six holes over mined out areas were advanced by rotary drilling followed by video logging, packer testing, and water monitoring well installation. Consideration was given to rock coring rather than rotary drilling; however, coring into fractured and caved rocks is often problematic and there is a risk of jamming the drill string in the hole. Also, experience has shown that drill core fractures may not correlate well to hydrological changes in the rock (Holla and Buizen 1990).

Drilling was completed by DrillWell Enterprises. The drillers recorded rock type, water inflow, air/cuttings return, drill string drops, and other unusual events. Drill monitoring was completed by Michael Cullen or Lara Fletcher when the hole approached within 40m of the mined out horizon. Drill hole video logging was completed by DrillWell under the direction of Lara Fletcher or Michael Cullen, the images were recorded to DVD for subsequent review and analysis. Packer testing and subsequent water monitoring well installation were completed by DrillWell under the direction of Lara Fletcher or Michael Cullen. Drill logs are included in Appendix 2, these present lithology, notes from drill monitoring, notes from the video records, location and results from packer testing, and water monitoring well completion details.

Table 4 summarizes the results of the packer testing completed by MCG in holes Qu10-12 through Qu10-17. Our assessment of rock hydrologic properties was only concerned with order of magnitude changes to the permeability (as measured by hydraulic conductivity or transmissivity). As such a detailed interpretation of the testing results was not completed. Graphical results from the packer testing are presented in Appendix 3. Table 4 also presents our interpretation of the hydrologic subsidence zone indicated at each test location.

Figure 13 and 14 present results from the Quinsam Mine groundwater monitoring program being completed by MCG, Lorax and Golder Associates. Table 5 summarizes the results from the drilling, video logs, packer testing, and groundwater monitoring as well as presenting our interpretation of the results.

Table 4: Summary of Packer Test Results

DH #	Depth from (m)	Depth to (m)	Average Transmissivity (m^2/s)	Hydraulic[1] Conductivity (m/s)	Comments on Test	Interpreted Subsidence Zone
QU10-12	26.7	30.6	9.3E-06	2.4E-06	Increasing flow with decreasing pressure.	surface fracture zone
	38.9	42.8	8.5E-06	2.2E-06	High flow.	fractured zone
	38.9	42.8	1.2E-05	3.0E-06	High flow.	fractured zone
	45.3	49.2	< 1.0E-10	<1.0E-9	No measurable flow.	fractured zone
	51.4	55.3	4.0E-06	1.0E-06	High flows, permeability increases as test progresses.	fractured zone
	58.1	62.0	3.5E-07	9.1E-08		fractured zone
	64.2	68.1	2.3E-06	5.8E-07	High flow.	fractured zone
	70.9	74.8	1.2E-06	3.2E-07	Pressure dropping with increased flow.	fractured zone
	77.0	80.9	1.1E-05	2.8E-06	High flow.	fractured zone

DH #	Depth from (m)	Depth to (m)	Average Transmissivity (m^2/s)	Hydraulic[1] Conductivity (m/s)	Comments on Test	Interpreted Subsidence Zone
	89.8	93.7	na	na	High flow.	fractured zone
	102.6	106.5	5.7E-06	1.5E-06	High flows, permeability increases as test progresses.	fractured zone
	109.0	112.9	3.0E-06	7.5E-07	Pressure dropping with increased flow.	caved zone
	113.2	117.2	< 1.0E-10	<1.0E-9	No measurable flow.	caved zone
	119.6	123.6	3.9E-06	9.9E-07	Permeability increases as test progresses.	caved zone
	124.2	128.2	na	na	High flow.	caved zone
QU10-13	26.5	30.5	8.0E-9	2.0E-9		constrained aquiclude
	45.7	49.7	< 1.0E-10	<1.0E-9	No measurable flow.	constrained aquiclude
	52.1	56.1	2.0E-07	5.1E-08	Permeability increases as test progresses.	dilated aquiclude
	58.5	62.5	1.6E-06	3.9E-07	Permeability increases as test progresses.	transition
	64.9	68.9	< 1.0E-10	<1.0E-9	No measurable flow.	transition
	77.7	81.7	na	na	Very high flow rates.	fractured zone
	109.7	113.7	7.7E-06	2.0E-06		fractured zone
QU10-14	32.8	36.8	1.2E-05	3.0E-06		dilated aquiclude
	35.9	39.8	8.8E-06	2.2E-06		dilated aquiclude
	45.6	49.6	6.9E-06	1.7E-06	Increasing permeability as test progresses.	transition
	58.4	62.4	2.2E-07	5.6E-08		transition
	71.2	75.2	9.2E-06	2.3E-06	Permeability increases as test progresses.	fractured zone
QU-10-15	26.5	30.4	3.2E-07	8.0E-08		surface fracture zone
	32.9	36.8	< 1.0E-10	<1.0E-9	No measurable flow.	constrained aquiclude
	45.7	49.6	9.6E-06	2.4E-06	Laminar flow.	dilated aquiclude
	48.7	52.7	3.5E-07	8.9E-08		dilated aquiclude
	58.5	62.4	8.4E-06	2.1E-06	Permeability increases as test progresses.	dilated aquiclude
	80.7	84.7	1.1E-05	2.7E-06		transition
QU10-16	26.5	30.5	< 1.0E-10	<1.0E-9	No measurable flow.	constrained aquiclude
	32.9	36.9	< 1.0E-10	<1.0E-9	No measurable flow.	constrained aquiclude
	48.6	52.6	6.5E-07	1.6E-07	Small increase in permeability as test progresses.	dilated aquiclude
	52.0	55.9	8.7E-06	2.2E-06	High flows, permeability increases as test progresses.	dilated aquiclude
QU10-17	26.4	30.3	< 1.0E-10	<1.0E-9	No measurable flow.	constrained aquiclude
	42.2	46.2	1.9E-05	4.8E-06	Permeability decreases as test progresses.	dilated aquiclude

Table 5 Summary of Results from Drilling and Testing Investigation

DH #	Drilling and Video Records	Packer Testing	Water Well Data	Comments and Interpretation
Qu10-10	• DH making ~10gpm at el 196m • DH making ~12gpm at el 104m	• Low permeability over entire Cumberland Fm. (siltstone) • Moderate permeability over lower Dunsmuir Fm. (sandstone)	• Shallow well located above #4 Seam records steady GWT at ~ el 209m. • Deep well across #1 Seam records steady GWT at ~ el 209m.	
Qu10-11	• DH making ~40gpm from fracture at el 208m • Water flowing out adjacent DH during drilling • DH making 12 GPM at 158m • DH making 11GPM at completion • DH producing methane	• Low permeability over #4 Seam and sandstone immediately above and below #4 Seam.	• Shallow well located above #4 Seam records steady GWT at ~ el 248m. • Deep well across #1 Seam records steady GWT at ~ el 236m. • Artesian conditions occur in exploration drill hole located 5m away.	
Qu10-12	• DH terminates in #1 Rider Seam • DH making ~30 gpm at completion • Very occasional small fractures from rock surface to 75m depth. • Small open horizontal fractures common from 75m depth to 131 (EOH)	• Moderate to high permeability entire tested DH, exceptions are low permeability siltstone unit below #2 Seam and 5m sandstone unit at el 204m depth.	• Shallow well records steady GWT at ~ el 220m. • Deep well in caved zone. GWT at el 207m (this is the Mine water el set by pumping).	• The packer and video data indicates that the hydrologic properties of all strata above the mine have been altered. Although the perched water table in the shallow well could indicate the presence of a dilated aquiclude zone, we consider it more likely an isolated block, and consider that the fractured zone, transition zone and surface fracture zone combine thus creating increased hydraulic connectivity from the mine to the ground surface.
Qu10-13	• Possible open pre-existing fractures el 259m • Small open fractures at el 214m. • Small open fractures at el 151m • Start of large open fractures at el 146m	• Low permeability above el 219m. • Moderate permeability below el 213m. • High permeability below el 195m.	• Shallow well located above #3 Seam over small horizontal fractures, records steady GWT ~ el 214m. • Deep well in caved zone. GWT at el 155m (this is the Mine water el set by pumping, note that this is different section of Mine than Qu10-12 and Qu10-14).	• The shallow well is considered to be in dilated aquiclude zone.
Qu10-14	• Pre-existing open fractures el 256m and 250m. • Small new open fractures at el 245m. • Drill string drop, lost circulation, preexisting fractures and small voids at el 208m. • Start of open horizontal and vertical fractures at el 184m, see Photo 6.	• Moderate to high permeability over entire tested DH.	• Shallow well records steady GWT at ~ el 242m. • Deep well in caved zone. GWT at ~el 206m (this is the Mine water el set by pumping).	• The shallow well is considered to be in dilated aquiclude zone. • Data indicates that the pre-existing fractures increase permeability and may result in enhanced hydraulic connectivity through all strata.

DH #	Drilling and Video Records	Packer Testing	Water Well Data	Comments and Interpretation
Qu10 -15	• Open fractures present from rock surface to depth of 12m. See Photo 1. • No fractures el 260 to 252m, see Photo 2. • Open pre existing fracture with Fe stain at el 261m, see Photo 3. • DH stopped at el 178m, due to encountering methane. • Hole drawing air down • Hole not holding water • No fractures el 262 to el 252m. • Water inflow from horiz fracture at el 252m.	• Moderate permeability above el 262m. • Low permeability el 260 to 252m. • Moderate to high permeability below el 262m	• Shallow well located over #3 Seam in zone with no fractures (el 233 to 224). GWT is slowly lowering. • Middle well located at el 210m to 206m in zone of fractures and high K. GWT steady at ~207.8m el.	• The shallow well readings are slowly declining. • The middle well is considered to be in the transition aquiclude zone due to vertical fractures and high permeability (despite apparent perched GWT). • Deep well in fractured zone at el 192m; however, a block of unfractured rock creates apparent GWT at el 185.8m.
Qu10 -16	• Open fractures surface to el 268m • Tight fractures only el 268 to 253m • Small open fractures below el 253m • Larger open fractures below el 243m (#4 Seam)	• Low permeability el 263 to 253m • Moderate to high permiability over #4 Seam (el 242m)	• Well installed over #4 Seam (el 244 to 233) GWT at 251.3m.	• #4 Seam is considered to be in dilated aquiclude zone since similar GWT to non mined areas zone.
Qu10 -17	• DH making ~40gpm el 272, pre-existing open fracture, see Photo 1. • Open bedding plane fractures start at 241m, see Photo 5	• Low permeability el 260 to el 256m • Moderate permeability el 244 to 241m (above #4 Seam in zone with no fractures evident.	• Shallow well located above #4 Seam in zone with tight fractures (el 249 to 243). GWT at 276.7m. • Deep well located just below #4 Seam el 210 to 206m in zone of fractures. GWT at 257.2m.	• #4 Seam is considered to be in dilated aquiclude zone since similar GWT to non mined areas in deep well.
Qu05 -13	• Surface fractures extend to 14m. • Seepage into DH at 116m			• Surface fractured zone is 14m thick • Dilated zone extends to 53t, it is not possible to distinguish between dilated transitions zone and dilated aquiclude zone.
Qu08 -08		• T in #4 Seam estimated to be 1E-7 m*2/s. • T at 27m depth estimated at 1E-4 m*2/s (results from Golder Assoc.)	• Shallow well located above #4 Seam reports GST at ~el 270. • Deep well located across #4 Seam reports GWT at ~el 243m. • Both shallow and deep wells experienced drop in summer 2010 but recovered in fall.	• #4 Seam is considered to be in dilated aquiclude zone since similar GWT to non mined areas in deep well.
Qu09 -01		• T of #4 Seam estimated to be 1E-7 m*2/s (results from Golder Assoc.)	• Uncased well to #4 Seam reports a gradual increase in GWT from 265m to 275m el.	• Represents GWT away from 5S mining area
Qu11 -03	• Fractures >50mm start at el 230.			• Start of caved zone at 230m el. • caved zone extends 15m into sandstone

Table 6 presents our interpretation of the subsidence zone heights in terms of mined thickness t for each of the drill holes.

Table 6: Subsidence Zones in Terms of Multiples of Mined Height t

DH #	Mined Height t (m)	Caved Zone	Fractured Zone	Dilated Transition Zone		Dilated Aquiclude Zone		Constrained Aquiclude Zone		Surface Fracture Zone	Remarks
		height times t	height times t	from times t	to times t	from times t	to times t	from times t	to times t	(m)	
Qu10-12	3	2	na	na	34	np	np	np	np	10	Combined fractured zone, transition zone and surface fracture zone extends over entire hole (111m of rock).
Qu10-13	3	8	24	24	30	30	32	32	44	15	
Qu10-14	3	na	27	27	37	37	47	np	np	10	The dilated aquiclude zone extends through to surface. The higher starting point for the dilated aquiclude zone and missing constrained zone are attributed to the presence of pre-existing fractures.
Qu10-15	2.5	na	29	29	37	37	52	52	56	12	
Qu10-16	2.5	na	na	na	na	na	52	52	59	5	
Qu10-17	2.5	na	na	na	na	na	48	48	64	np	
Qu05-13	2.5	na	20					53	62	14	
Qu11-4	3	10			29						caved zone extends ~15m into Dunsmuir sandstone. Last open fracture noted at 21m depth.

Notes: shaded numbers are inferred values
np = not present

Room and Pillar Mining Areas

The investigation program did not include areas of conventional room and pillar mining. As previously discussed, provided that pillar stability and roof span stability are maintained, it is expected that there will be minimal changes to the rock hydrologic properties, any changes that do occur will only affect rock within a few meters of the excavation.

Previous work has demonstrated that the computer program Analysis of Retreat Mining Pillar Stability (ARMPS) NIOSH 2009, is applicable for design of pillars at QCM. It is generally considered that to prevent pillar failures the minimum ARMPS factor of safety (FOS) of should be 1.5. Mark et al 1995 found that 94% of all back analyzed designs were stable at this value. To assure longterm stability that accounts for pillar deterioration as well as increase the estimated reliability to greater than 94% a factor of safety of 1.7 is recommended. However, if a pillar will be completely surrounded by CCR or fines a minimum ARMPS FOS of 1.5 would be appropriate as the material surrounding the pillar will provide confinement that effectively increases the pillar strength, as well as minimizes the height to which any roof instability might extend.

Excavation spans need to be designed for long term stability not only to prevent significant roof failures but also to ensure long term pillar stability. The ARMPS FOS is very sensitive to pillar height. A 1m increase in pillar height will result in a 15 to 20% reduction in pillar FOS (Cullen et al 2000). Previous work by Cullen et al 1996 determined that in the siltstone above #1 Seam primary caves extending to a height of up to 4m may occur when excavation spans exceed 10m. Full caves do not occur until the excavations have a hydraulic radius greater than 7.8 m^2/m which is equivalent to a 31m by 31m excavation. Experience at the mine has also demonstrated that when not affected by geologic structures, 6m wide roads and 8.4m wide intersections in siltstone will only experience local failures (less than 2m) even when not supported. This experience was verified by recent inspections in the 2S workings that were mined out in 1995. Detailed assessments of stable working spans in the sandstone roof have not been completed at QCM; however, it is expected that spans greater than 10m can be sustained due to the greater strength and absence of local geologic features such as slickensidess. Drillhole Qu11-01 was recently drilled above the 4S mine where partial pillar extraction had occurred. The drill hole was advanced to the extracted coal seam elevation without encountering a caved zone. Based on mine maps the roof span at the location of drillhole penetration is about 24m.

Conclusions and Recommendations

Changes are expected to occur to the hydrologic properties of the strata above mined out areas at the Quinsam Mine. Where room and pillar mining is carried out without pillar extraction, and where the room spans and pillar dimensions are adequate to prevent major roof failure, there will be minimal changes to the rock hydrologic properties; any changes that do occur are expected to be restricted to the immediate roof rocks.

Where retreat pillar mining is carried out with subsequent caving and subsidence, the hydrologic properties of the rocks above the area may be changed. This investigation has determined that, at the Quinsam Mine, the affected strata can be divided into 5 subsidence zones as illustrated on Figure 15 and listed in Table 7. The results at the Quinsam Mine are consistent with the findings at other coal Mines.

The height to which the various subsidence zones extend above the mining excavation is a function of several variables the most important being the height mined, rock strength, and depth of cover. This assessment involves rocks that are all in a similar geologic setting (Cumberland Fm. overlain by Dunsmuir Fm.) and all at similar depth (110 to 180m), as such the effects of rock strength and depth of cover will be consistent over the assessed area. Table 7 and Figure 15 provide the expected <u>maximum</u> height of each of the subsidence zones above the #1 Coal Seam in terms of mined height.

Insufficient information was available to complete a statistical evaluation or other form of risk assessment. As such, the zone height values presented are the maximum, or most conservative based on the collected information. As more information is collected it may be possible to adjust the values. The values given to the dilated transition zone are considered to have the greatest uncertainty; it is conceivable that some of this zone is within the dilated aquiclude zone such that the aquiclude zone would start at less than 37t.

The findings indicate that the depth of rock cover may need to be as much as 37t plus 15m in order to ensure development of an aquiclude zone. Where the depth of rock cover is less than that needed to develop an aquiclude zone there is potential for enhanced hydraulic connectivity between the ground surface and underground.

Figure 16 shows the areas over the 2N and 5S Mines where there is potential for enhanced hydraulic connectivity (e.g. flow on a network of connecting horizontal and vertical fractures induced by subsidence) between the ground surface and underground. It is defined by areas where retreat pillar mining has taken place, or is planned, and where the depth of till cover is less than 10m, and where the rock cover is less than 37t plus 15m. Where the thickness of till cover is more than 10m the limit on rock cover is 29t. Experience at QCM has shown that where the till layer is greater than about 10m thick it will bridge over and heal subsidence cracks.

Table 7: Subsidence Zones Determined for The #1 Seam at Quinsam Mine

Zone	**Description**	**Hydrologic Changes & Expected K value**	**Height above mined out seam in terms of mined height (t) or meters (m)**
Surface Cracking	High tensile strains resulting in bed separation and fracturing.	Increased permeability. K ~5e-7 m/s	0 to 15m below bedrock surface
Constrained Aquiclude	No significant fractures or bed separation	No significant change in permeability K ~ 1e-9 m/s	52 t to bedrock surface less 15m e.g. if t = 3m zone will be between 156m above the mine to 15m below the ground surface
Dilated Aquiclude	Bed separation and creation of horizontal fractures.	Increase in horizontal permeability. K_h ~ 1e-6 m/s K_v ~ 1e-9 m/s	37 t to 52 t e.g. if t = 3m zone will be between 111m and 156m above the mine elevation
Dilated Transition	Bed separation with horizontal fractures. Vertical fractures common at bottom, less common to nonexistent at top.	Increase in horizontal permeability. Increase in vertical permeability that diminishes with height above the fractured zone. K_h ~ 1e-6 m/s K_v ~ 1e-9 m/s to 1e-6 m/s	29 t to 37 t e.g. if t = 3m zone will be between 87m and 111m above the mine elevation
Fractured	Bed separation and vertical fractures	Increased horizontal and vertical permeability. Potential for hydraulic connection to mine workings. K > 1e-4 m/s	up to 29t if t =3m height may be up to 87m
Caved	Zone of complete disruption		3 to 11 t

Notes
1. Results are considered applicable to depth of 200m.
2. No information is available on impact to surficial till layer
3. Significant faults may cause anomalous changes; where present potential impact should be assessed.
4. The hydraulic conductivity values given are average values of a very small data set. Interpretation and use should consider the size of the data set as well as specific results (see Table 3 and Appendix 3).

The lateral extent beyond the edge of the mine workings to which hydrologic changes to the rock may extend is defined by the angle of draw, see Figure 15. For depths less than 100m the angle of draw has been shown to range from 2 to 5 degrees at the Quinsam Mine. At the present time the Quinsam Mine is operating to depths up to 180m. Industry experience and previous research (Cullen 2002) indicate that the angle of draw will increase as the depth increases. Information to date confirms that the angle of draw exceeds 5 degrees at a depth of 180m; however, there is no information as to what the maximum angle might be. Statistical analysis of data from US Coal Mines (Peng et al 1995) indicate that the average angle for a depth of cover of 180m is 6^0 with an upper bound of 14^0. Based on site experience at the QCM we consider 10^0 to be appropriate for general design purposes. However, in critical situations a safety factor should be added.

Significant faults may increase the fracture and transition zone height, increase the angle of fracture, and potentially negate the aquiclude zones above the mine. A significant fault is defined as any feature that results in atypical strata response. Based on experience at the QCM significant faults typically have the following characteristics:

- Faults that extend through both the Cumberland and Dunsmuir Formation.
- Faults with greater than 1m vertical offset
- Open faults or fractures.
- Faults with trace length greater than one hundred meters.
- Faults that have resulted in distinctive linear features on surface such as thick till cover and swamp systems. In some instances significant faults have been inferred in areas yet to be mined where these linear features have been identified on surface.

The significant faults shown on the figures within this report are those identified as potential significant by QCM geologists and previous work completed by MCG.

Based on the results of the current and previous investigations, and discussions with Quinsam Mine geologists, it is understood that potentially significant faults occur throughout area and could occur in any new mining areas. Photos 3 and 4 show pre-existing open fractures encountered in the recent drillholes, these types of fractures could be significant if they extend to depth. The potential impact of significant faults on the subsidence zones, hydrologic properties of the rocks, and hydrogeologic model should be assessed on a case by case basis.

Changes to Rock Hydrologic Properties above Retreat Pillar Mining Areas

Retreat pillar mining with subsequent caving and subsidence was used throughout most of the existing 2N, 3N and 5S Mining areas. The hydrologic properties of the strata above the mined areas have been altered. Figure 15 and Table 7 provide the best guidance on the extent of the changes. These figures can also be used to predict future changes in areas where retreat pillar mining is planned.

5 South - 7 South Mine Interaction

There is potential for both ground instability and enhanced hydraulic connectivity between the proposed 7S Mine and existing 5S Mine.

The potential for interaction resulting in instability was assessed using the computer programs Analysis of Multiple Seam Stability (AMSS) and Analysis of Retreat Mining Pillar stability (ARMPS), NIOSH, 2009. The analysis indicates that a major interaction is unlikely and no remedial stability measures are required. The results from the analysis are presented in Appendix 4. The drilling investigation has shown that the section of the proposed 7S Mine that overlies the 5S Mine are within the dilated aquiclude zone; bed separation has occurred and new horizontal fractures will be present, see Photo 5. Any mining in the area directly over the 5S workings may experience an increase in local roof instability as a result of these horizontal fractures.

As indicated on Figure 17 the sections of the proposed 7S Mine that lie directly above the 5S Mine are within the dilated aquiclude zone. Based on the recent investigations it is conceivable that pre-existing geologic structure are present within this zone, and these may provide enhanced hydraulic connectivity between the 7S and 5S Mines. Any mining that extends into the dilated aquiclude zone has the potential to create a hydraulic connection to the 5S Mine: first by horizontal flow on the separated beds, followed by vertical flow on the pre-existing fractures as illustrated in Figure 17. Such a connection may not be identified unless it was encountered within a roadway. To prevent this possible connection it is recommended that a 30m horizontal setback from the edge of the 5S mining area be maintained as indicated on Figure 17 and 18. The recommended setback includes an additional 10m "safety" zone beyond the zone of influence as predicted by the 10 degree angle of draw.

Changes to Rock Hydrologic Properties above Room and Pillar Mining Areas

Room and pillar mining with no, or limited, pillar extraction has occurred, or is being planned for the 4S Mine, River Barrier Pillar, 7S Mine, and western end of the 5S Mine. Provided that the mining is completed using room spans and pillar dimensions that prevent major roof collapse, minimal changes to the rock hydrologic properties are expected; the changes that do occur will only affect rock within a few meters of the excavations.

To maintain excavation stability and prevent significant changes to rock hydrologic properties in the room and pillar mining areas the following is recommended:

- Design pillars with a minimum ARMPS factor of safety of 1.7. If the pillars will be surrounded by CCR or Fines to within 1m of the roof the minimum ARMPS FOS may be reduced to 1.5.
- #1 Seam ARMPS Coal Strength should be taken as 7 MPa.
- The minimum pillar dimension should be 5m where no mud or siltstone parting is present. If a parting is present the minimum dimension should be 7.5m.
- Maximum excavation spans where the roof is siltstone or mudstone should be 7m (resulting in 10m at intersections). Where the roof is sandstone or where the excavations will be filled with CCR or fines larger spans may be appropriate.
- If significant geologic structure is encountered its affect on pillar and room stability should be assessed on a case by case basis.

Limitations and Conditions

Michael Cullen Geotechnical Ltd (MCG) prepared this report for the use of Hillsborough Resources. MCG does not accept liability for any damages suffered where a third party uses this report, or where it is used for purposes other than intended.

This report has been prepared in accordance with standard geotechnical engineering practices using the degree of skill and care normally exercised for such work. No other warrantee is inferred or implied.

This written report is of a summary nature and is not intended to stand alone without reference to the instructions given to us by the Client, communications between us and the Client, and to any other documents relative to the subject site, which in aggregate form the whole report. In order to properly understand the recommendations and opinions expressed herein, reference must be made to the whole of the Report.

The conclusions and recommendations in this report are based primarily on surface observations coupled with subsurface observations and measurements from a limited number of drill holes. Geological and hydrological conditions can vary significantly over a very short distance, or depth, and may also change with time. The field investigation cannot practically cover the entire area and will only identify soil conditions at the point and time of sampling. Actual conditions encountered can vary significantly from test locations. Any variation in the conditions presented in this report that are discovered at a later time should be brought to the attention of MCG in order to evaluate the impact on the conclusions and recommendations presented in this report.

The conclusions and recommendations in this report are based on information made available at the time the report was prepared. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, errors, omissions, or misrepresentations, of others. Any changes to construction plans, or other information used by us for completion of this report, should be brought to the attention of MCG in order to evaluate the impact on the conclusions and recommendations presented in this report.

The information, interpretations and conclusions in the Report are based on our interpretation of conditions revealed through a limited assessment, conducted within a defined scope of services. MCG cannot accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others, which may be based on information contained in the Report.

Closure

We trust that this report satisfies your present requirements. Should you have any questions, please do not hesitate to contact me. The opportunity to be of service to you is appreciated.

Sincerely
Michael Cullen Geotechnical Ltd.
per

seal and signature on original file copy

Michael Cullen, P.Eng.

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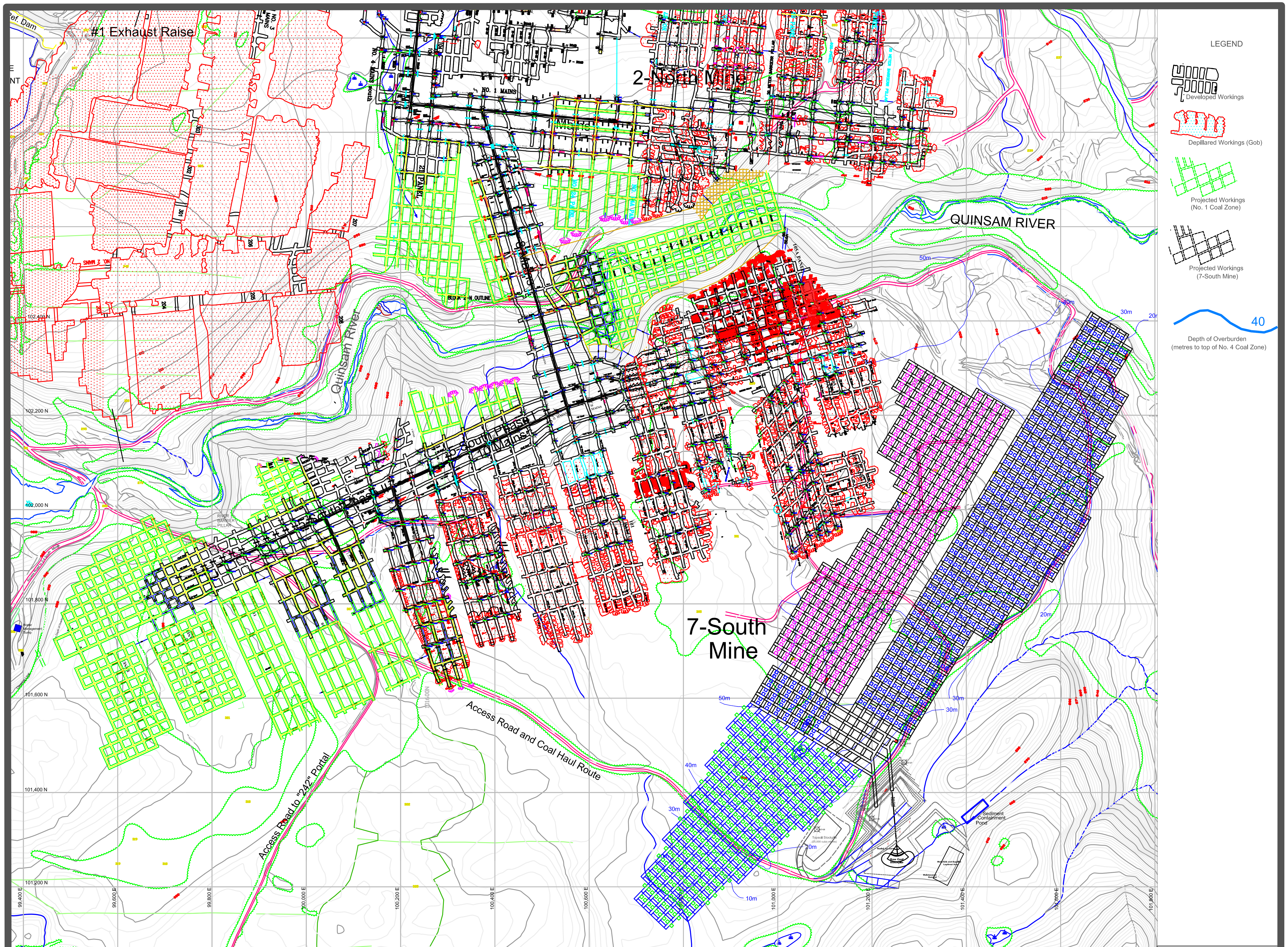

HILLSBOROUGH
Resources Limited

7-South Mine Layout & Features

Scale: 1:2 500

FIGURE:

C:\Documents and Settings\Michael\My Documents\Dr Cullen\2009 Proje

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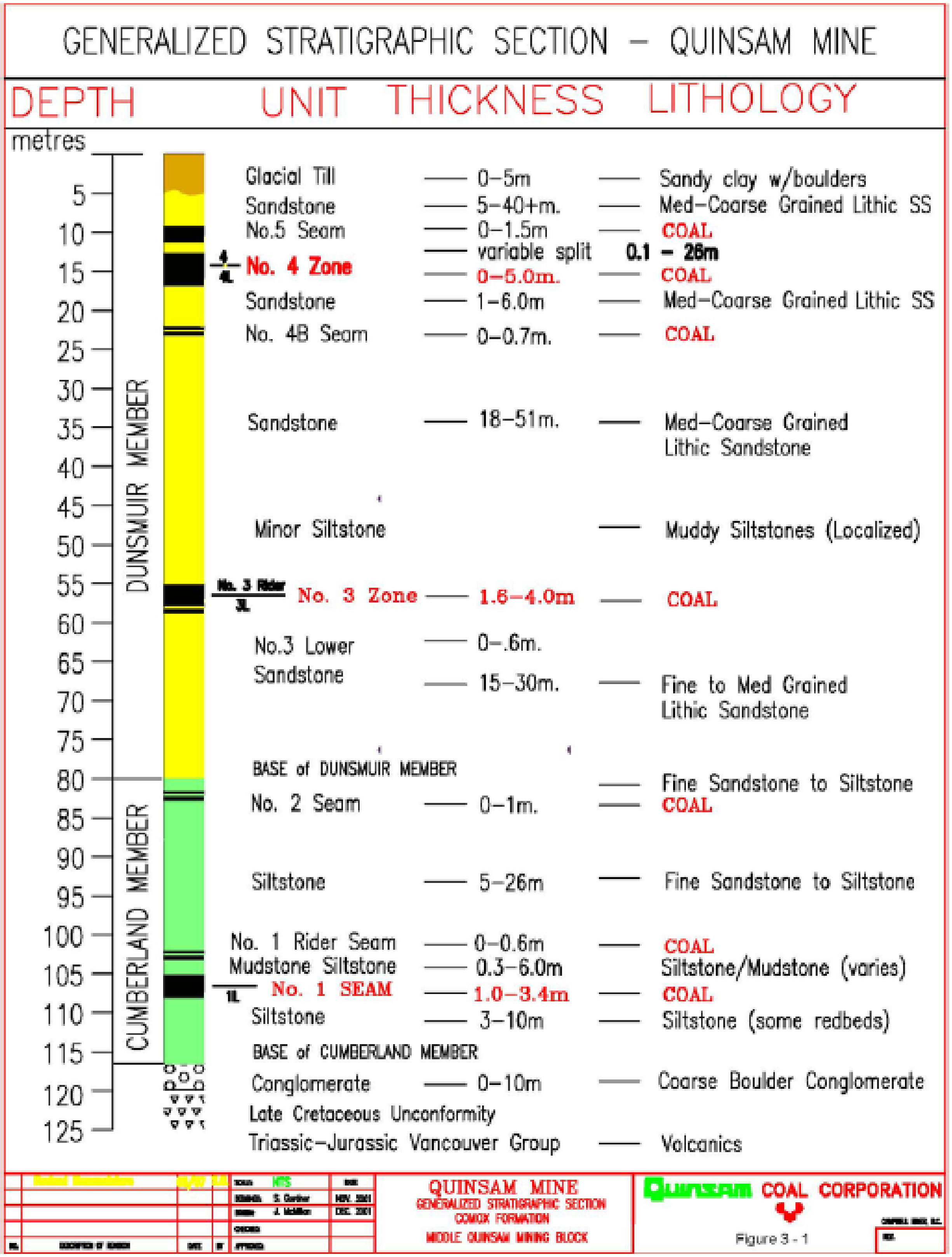
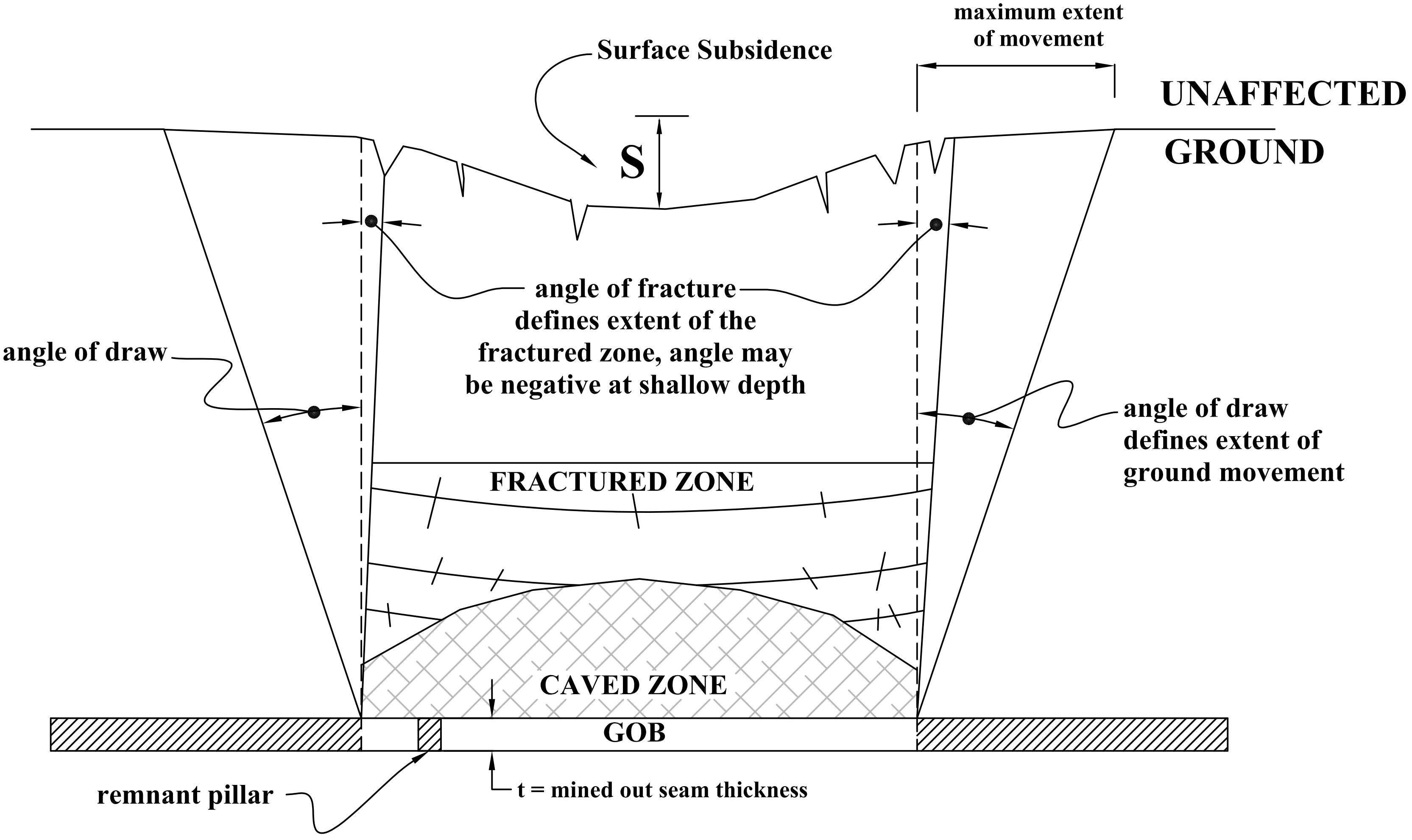
Figure 3: Generalized Stratigraphic Section (from QCC 2009)



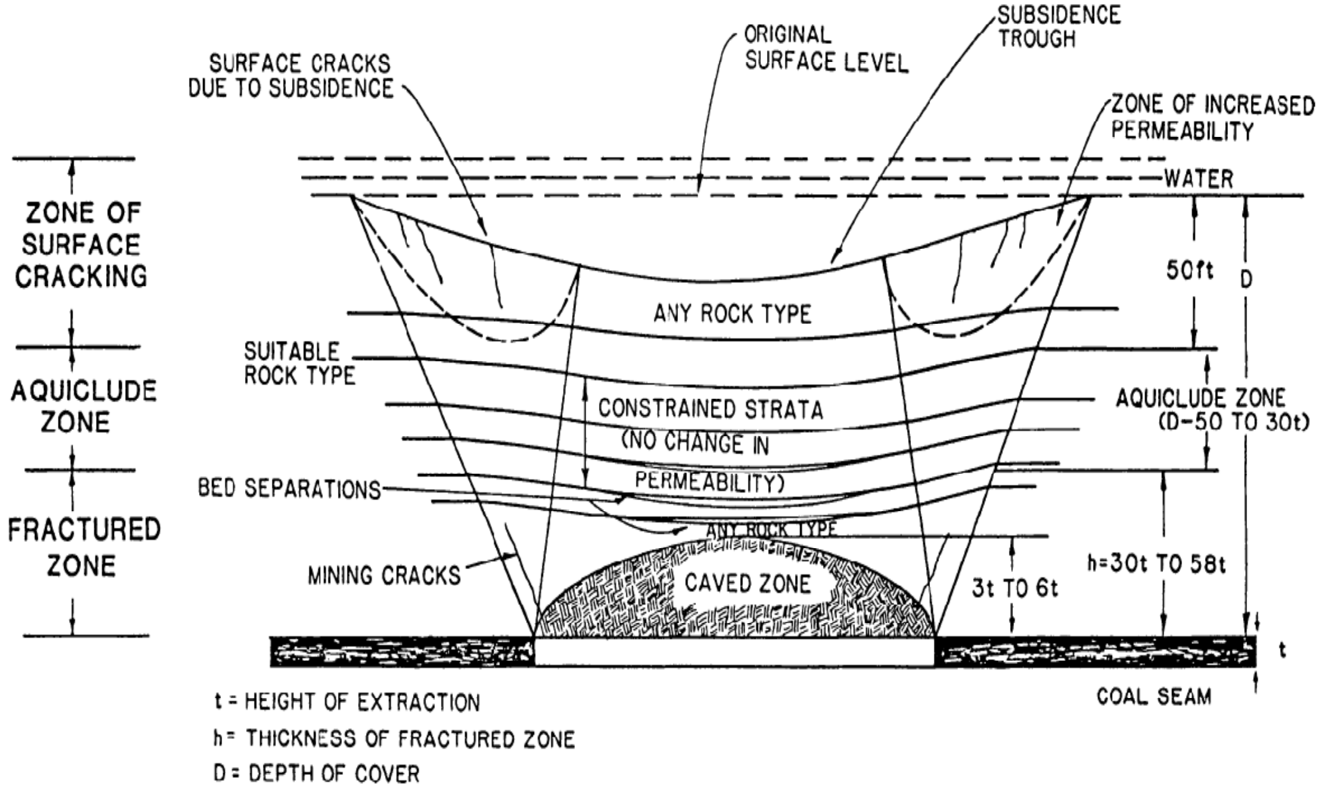


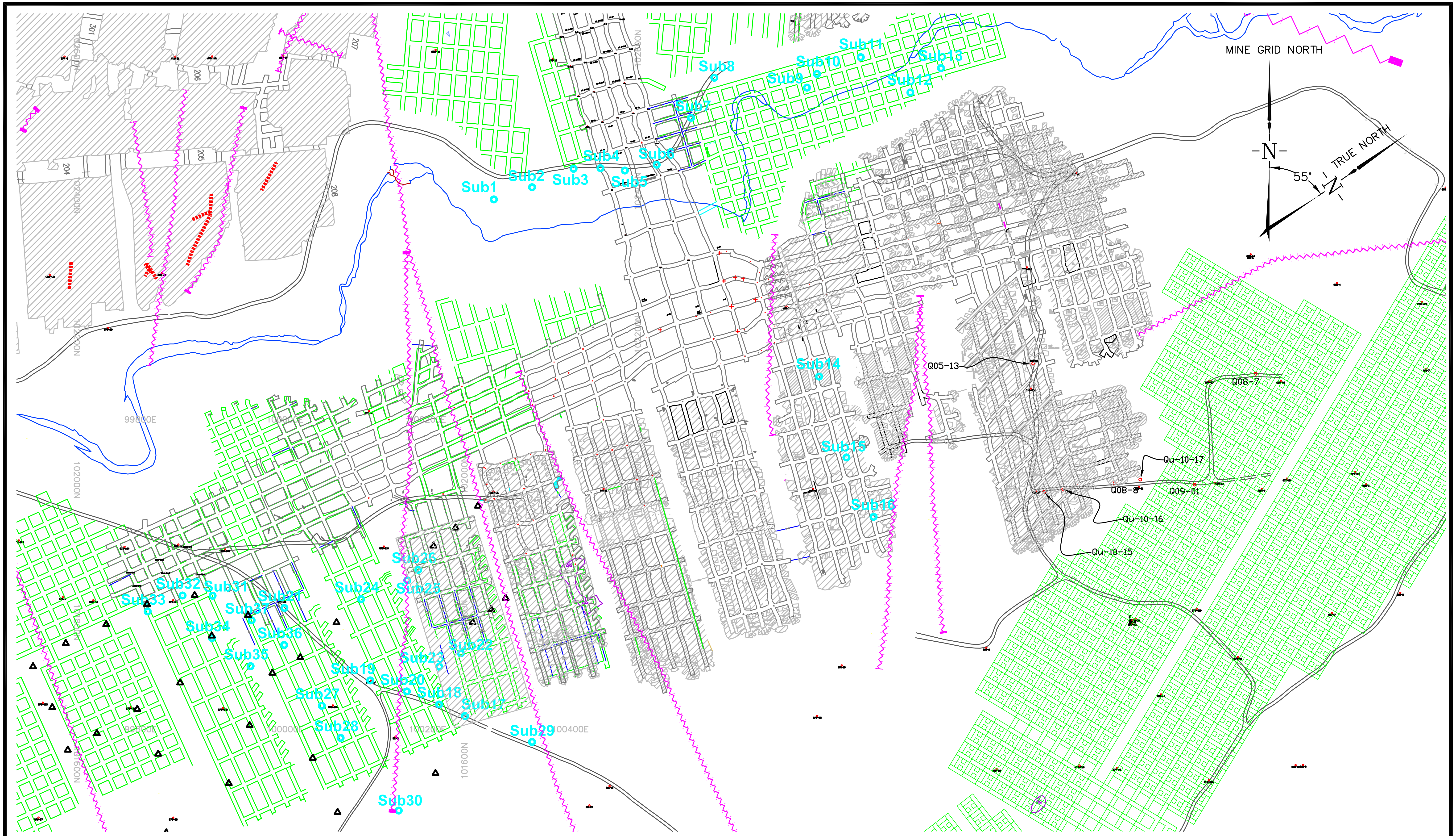
SCALE: N.T.S.

MICHAEL CULLEN GEOTECHNICAL LTD.	PROJECT QUINSAM COAL MINE SUBSIDENCE ASSESSMENT
CLIENT HILLSBOROUGH RESOURCES QUINSAM COAL MINE	TITLE DEFINITION OF SUBSIDENCE ANGLES

DATE 2011/02/01	DWN. JMG	CHKD. MC	FILE NO.	2009-16	FIGURE 4

Figure 5: Subsidence Zones above High Extraction Coal Mines
(from Singh and Kendorski 1981)





LEGEND:

▦ Proposed Mining

▨ GOB (mined out)

Surface subsidence cracks

Coal Pillar

Existing Mining

Significant faults

Sub30 ○ Active Subsidence Station

△ Proposed Subsidence Station

0 100m

SCALE 1:5000

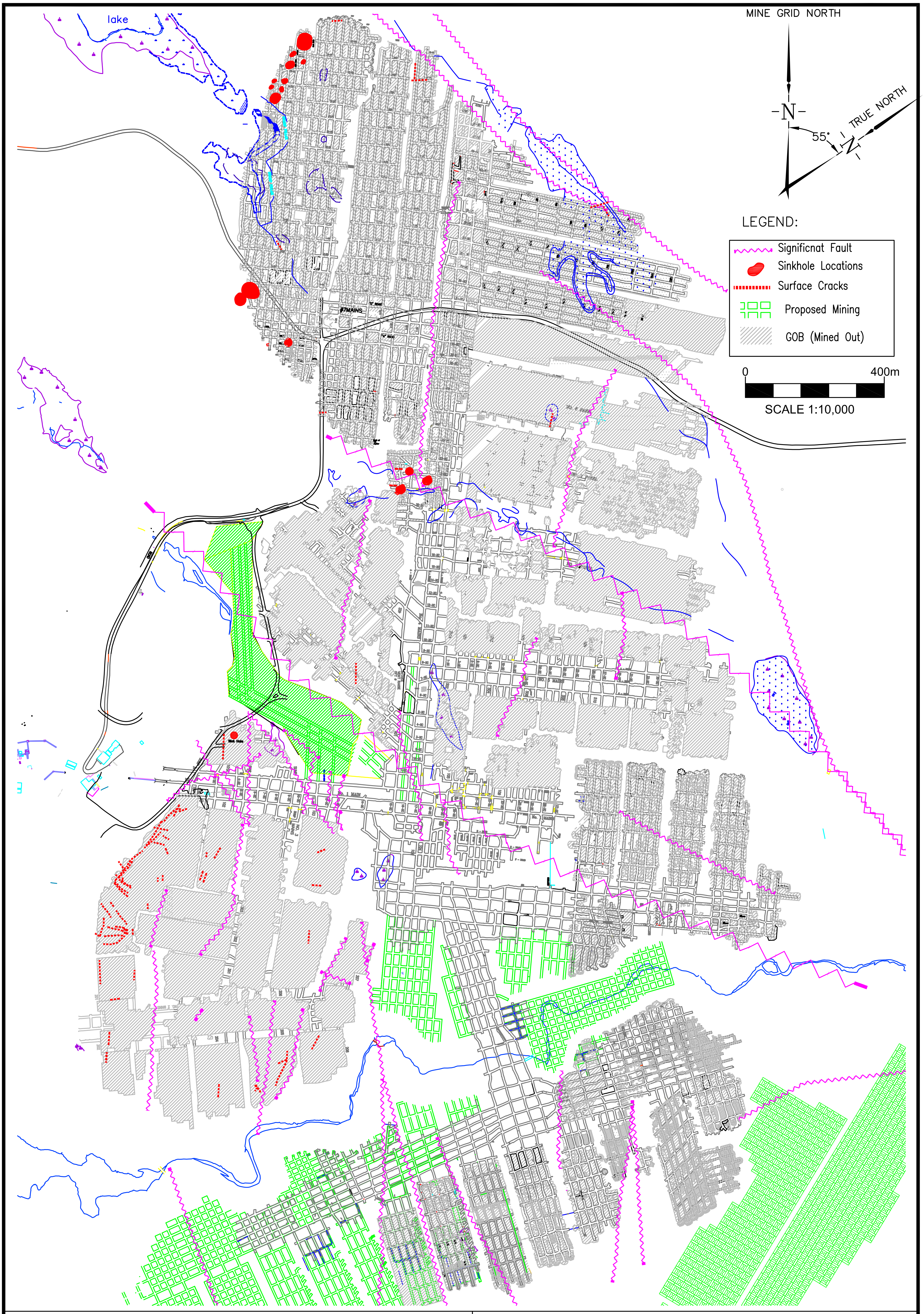
MICHAEL CULLEN GEOTECHNICAL LTD.

PROJECT QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

CLIENT HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE PLAN VIEW SHOWING ACTIVE & PROPOSED SUBSIDENCE STATIONS

DATE 2010/01/07
DWN. JMG
CHKD. MC
FILE NO. 2009–16
FIGURE 6



MICHAEL CULLEN GEOTECHNICAL LTD.

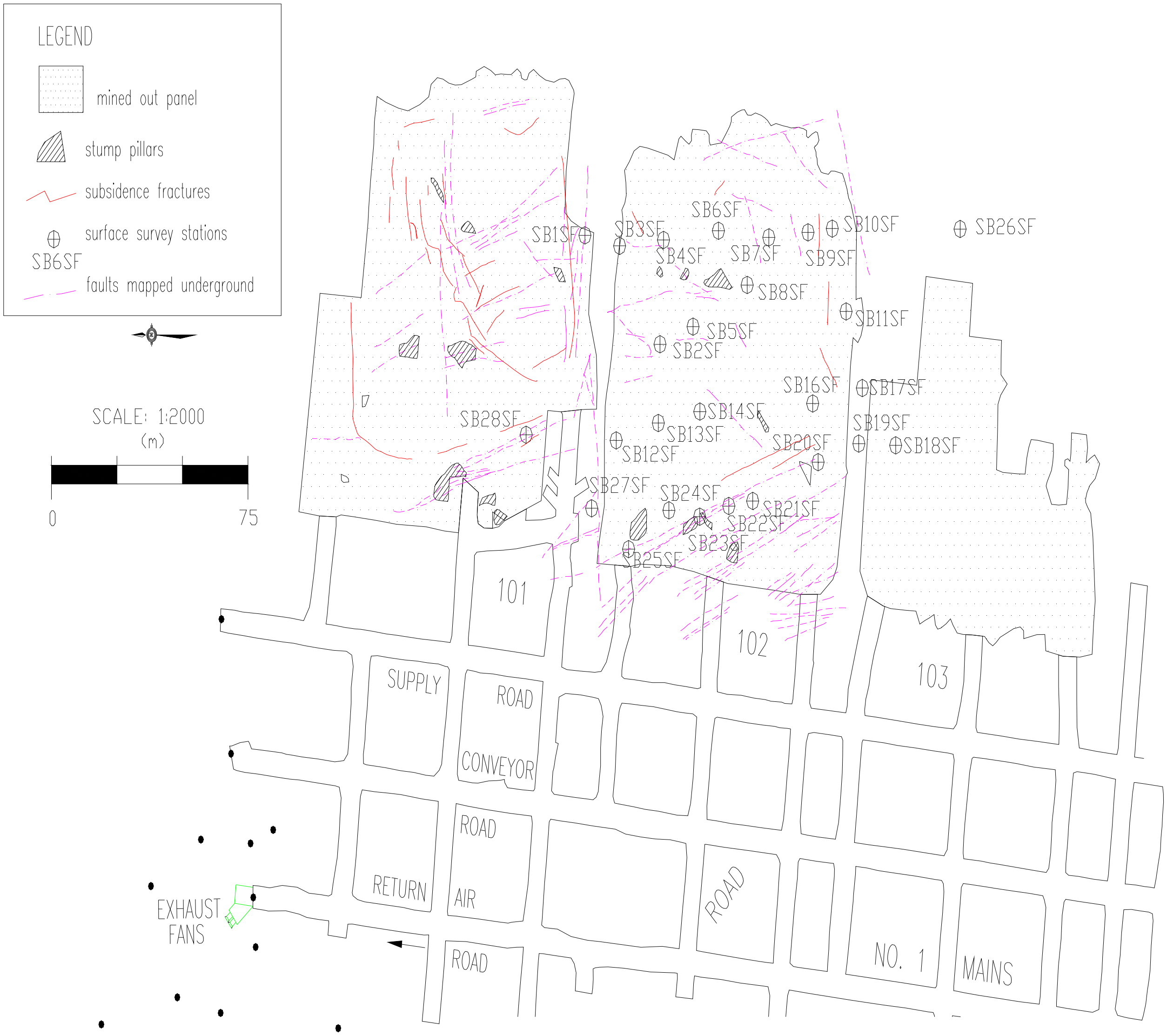
PROJECT
QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

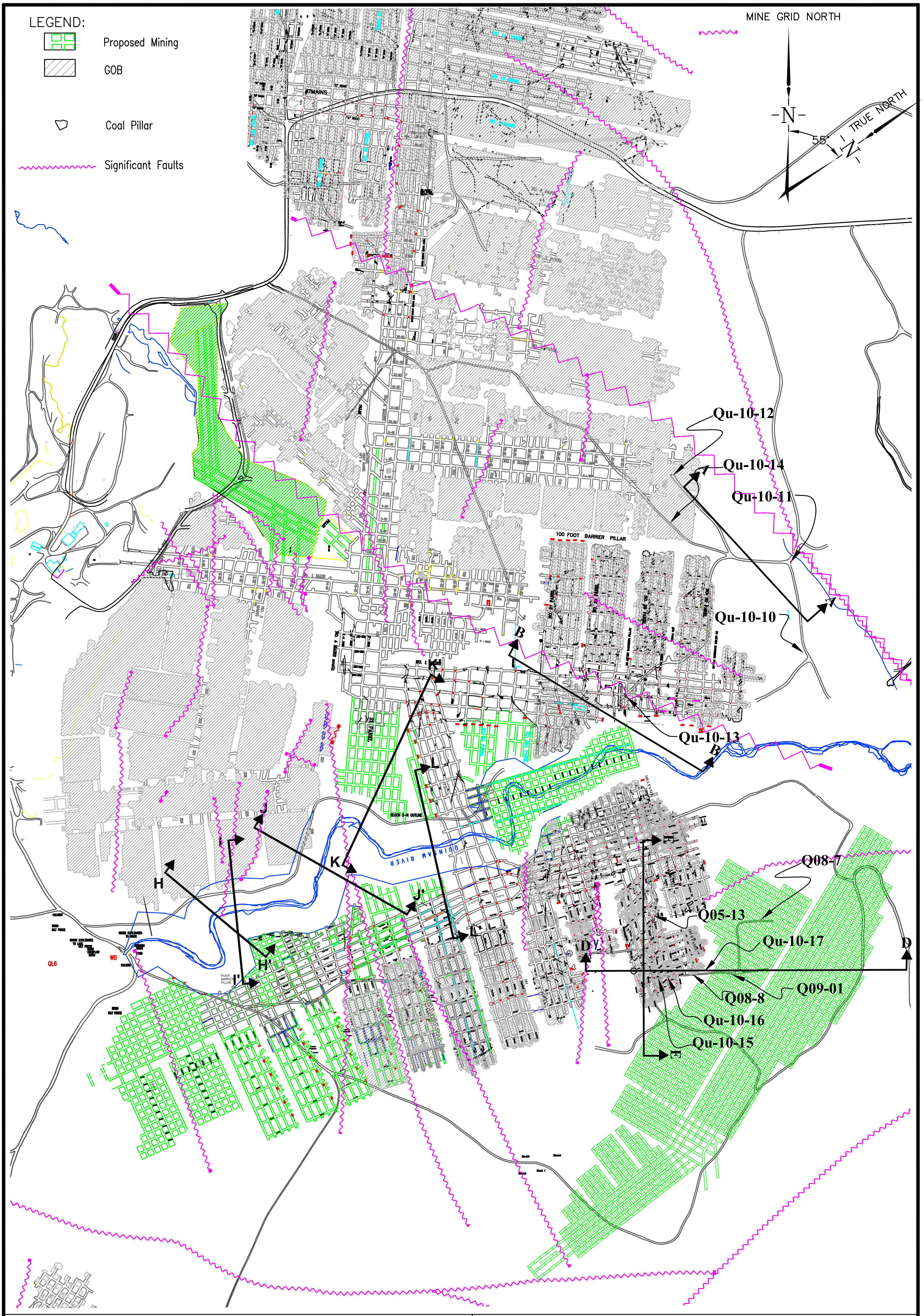
CLIENT
HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE
LOCATION OF MINING INDUCED SINKHOLES
AND OPEN SUBSIDENCE CRACKS

DATE	2011/02/01	SCALE 1:10,000	DWN.	JMG	CHKD.	MC	FILE NO.	2009–16	FIGURE 7

Figure 7A: Surface Subsidence Features above Panel 101 and 102, 2S Mine (from Cullen 2002)





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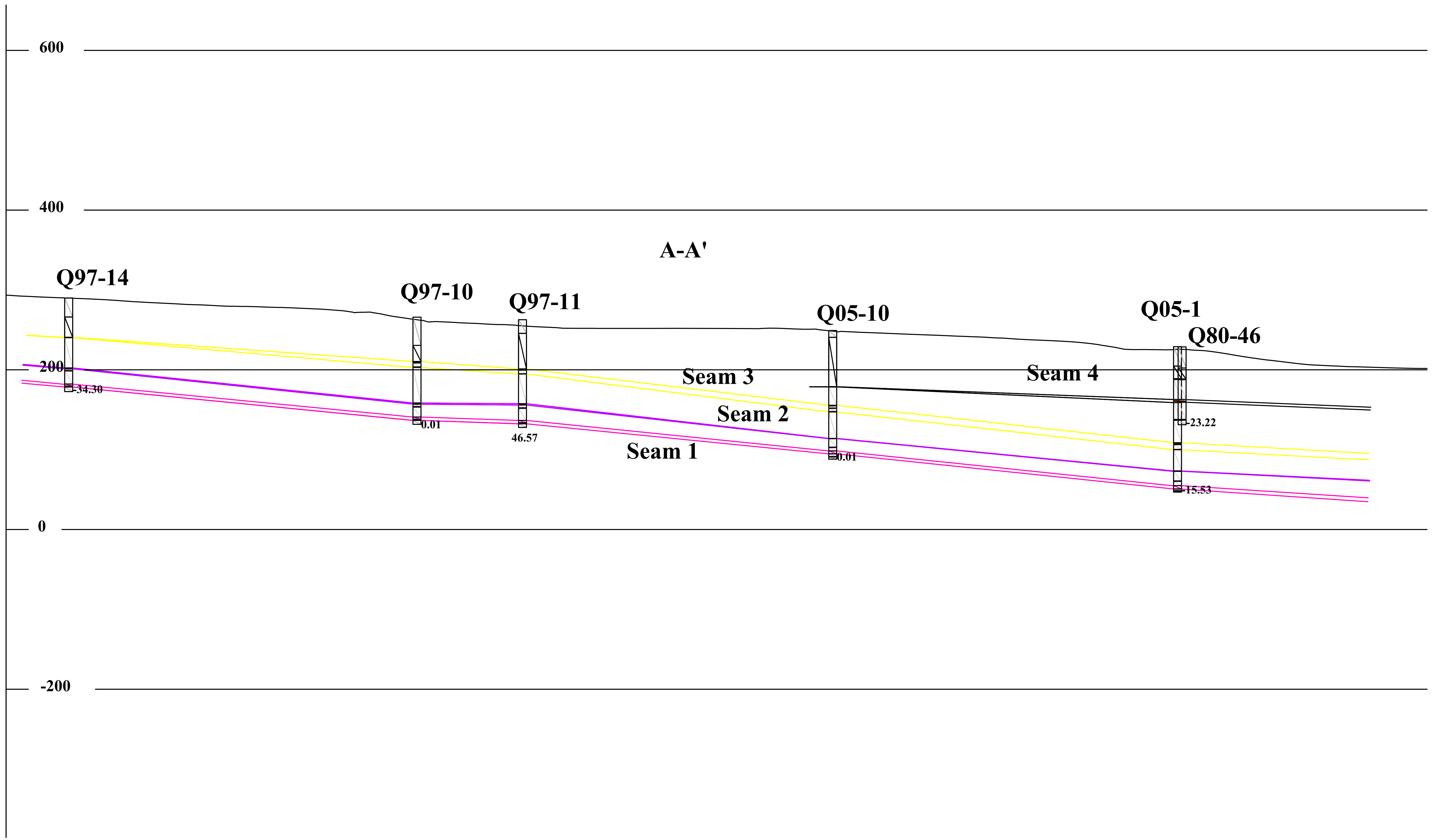
PROJECT
QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

CLIENT
HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE
LOCATION OF DRILL HOLES COMPLETED
FOR SUBSIDENCE ASSESSMENT

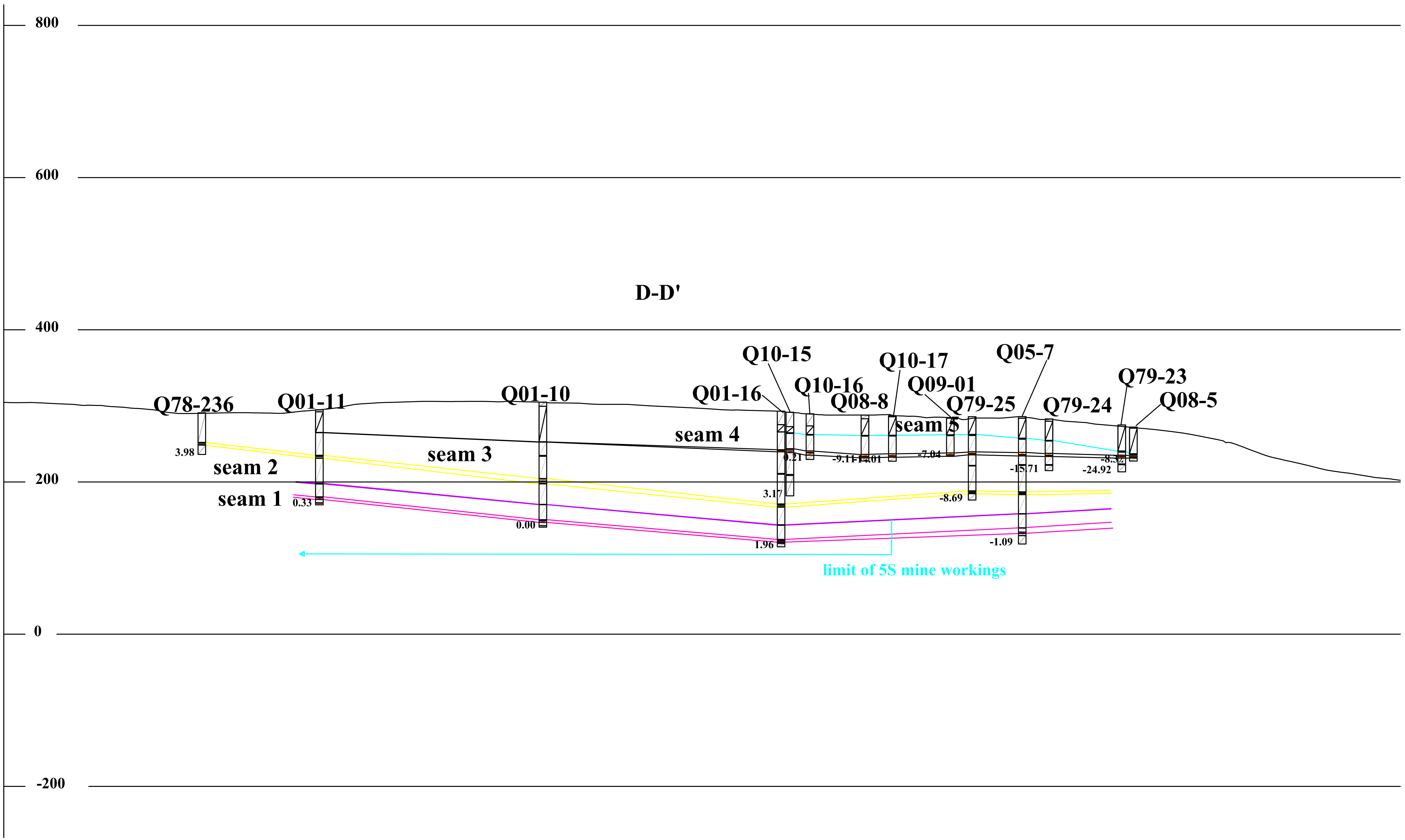
DATE 2011/02/01	SCALE 1:10,000	DWN. JMG	CHKD. MC	FILE NO.	2009-16	FIGURE 8



0 300m

SCALE 1:5000

MICHAEL CULLEN GEOTECHNICAL LTD.				PROJECT QUINSAM COAL MINE SUBSIDENCE ASSESSMENT	
CLIENT HILLSBOROUGH RESOURCES QUINSAM COAL MINE				TITLE CROSS SECTION A—A 2N MINE	
DATE 2011/02/01	DWN. JMG	CHKD. MC		FILE NO. 2009-16	FIGURE 9



0 300m

SCALE 1:5000

MICHAEL CULLEN GEOTECHNICAL LTD.

PROJECT QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

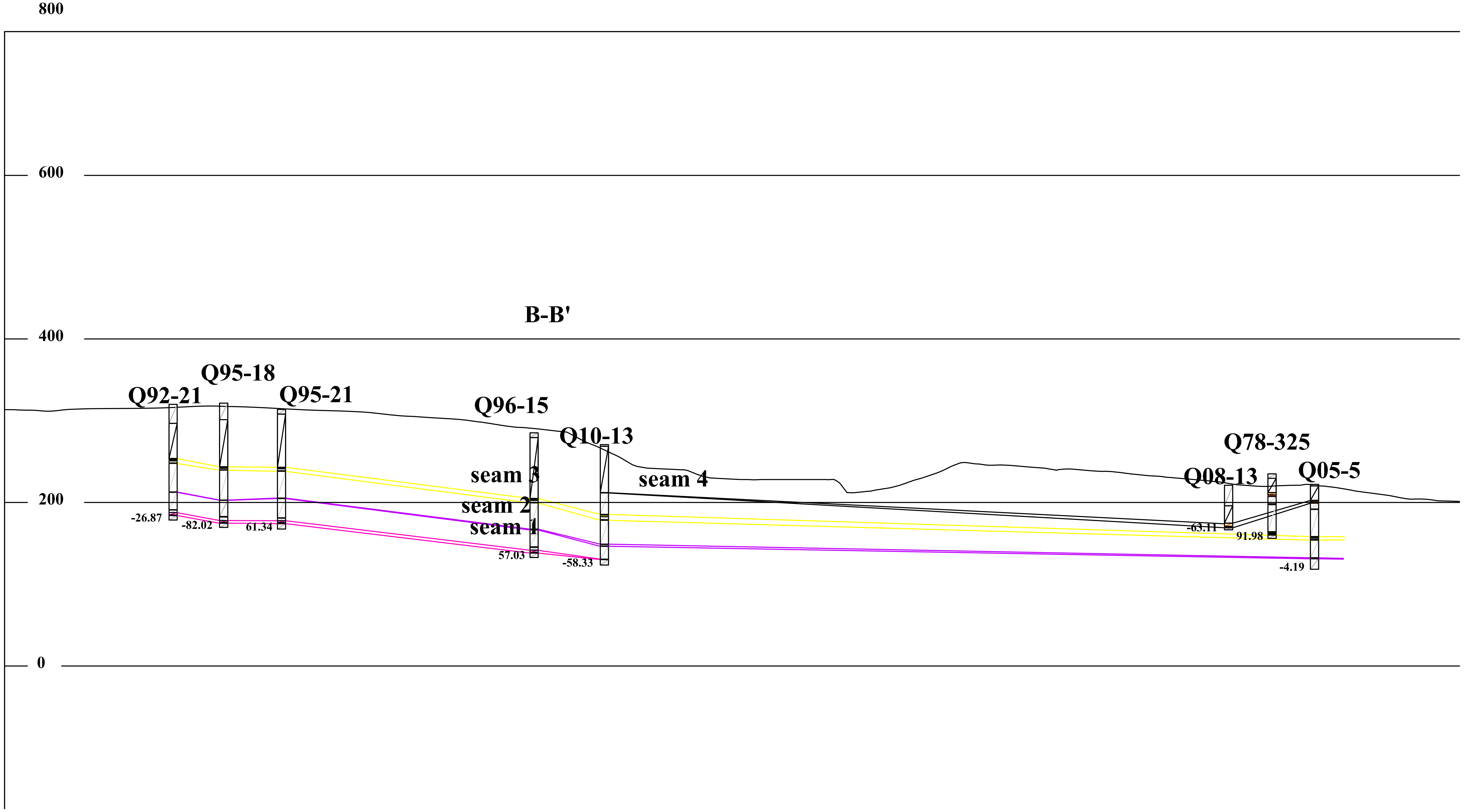
CLIENT HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE CROSS SECTION D–D 2N MINE

DATE 2011/02/01 DWN. JMG CHKD. MC

FILE NO. 2009-16

FIGURE 11

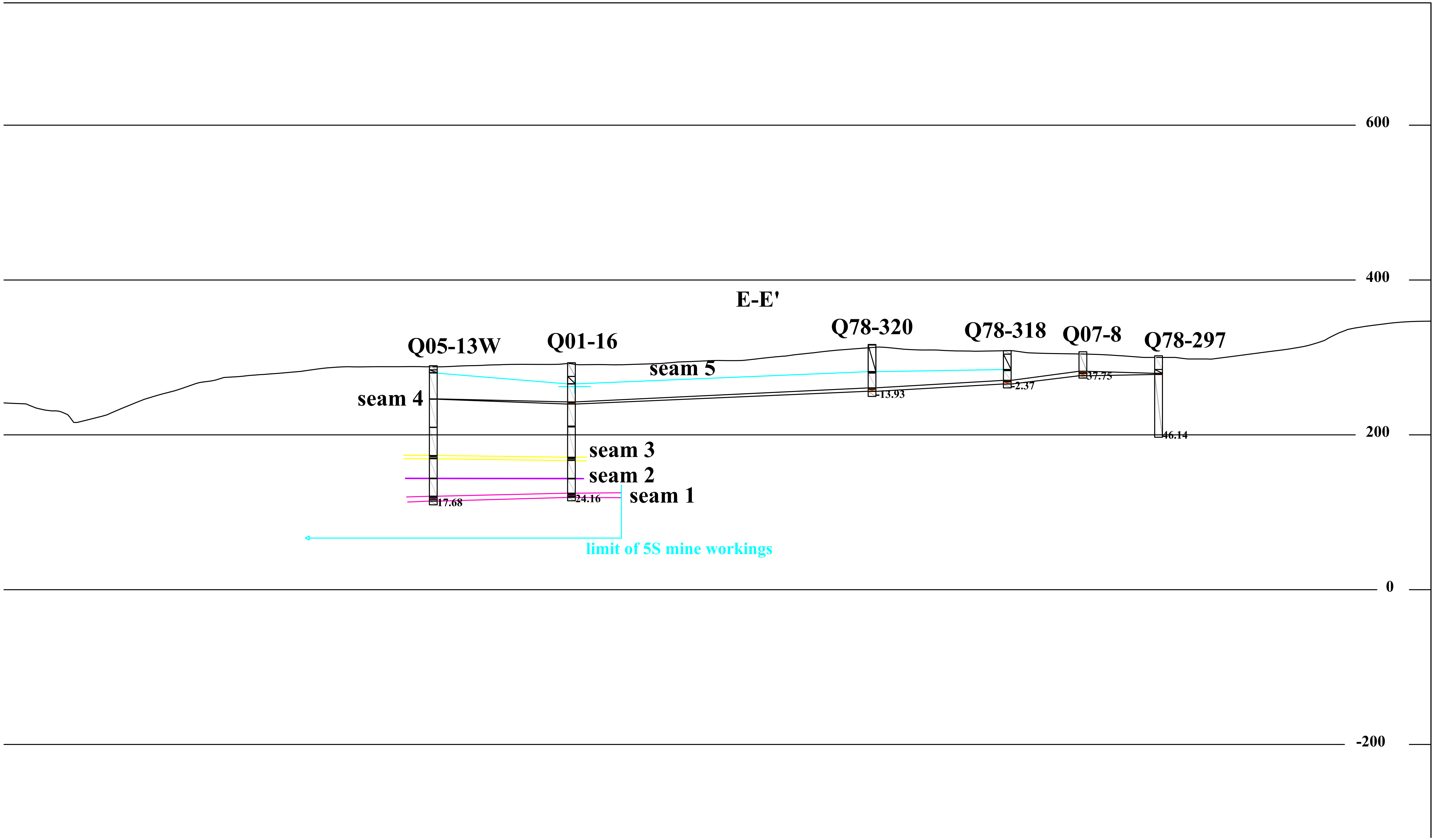


0 300m

SCALE 1:5000

MICHAEL CULLEN GEOTECHNICAL LTD.

PROJECT	QUINSAM COAL MINE SUBSIDENCE ASSESSMENT
CLIENT	HILLSBOROUGH RESOURCES QUINSAM COAL MINE
TITLE	CROSS SECTION B–B 2N MINE
DATE	2011/02/01
DWN.	JMG
CHKD.	MC
FILE NO.	2009-16
	FIGURE 10



0 300m

SCALE 1:5000

MICHAEL CULLEN GEOTECHNICAL LTD.

PROJECT
QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

CLIENT
HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE
CROSS SECTION E–E 2N MINE

DATE 2011/02/01
DWN. JMG
CHKD. MC
FILE NO. 2009-16
FIGURE 12

Figure 13: Groundwater Levels From Monitoring Wells in 2N

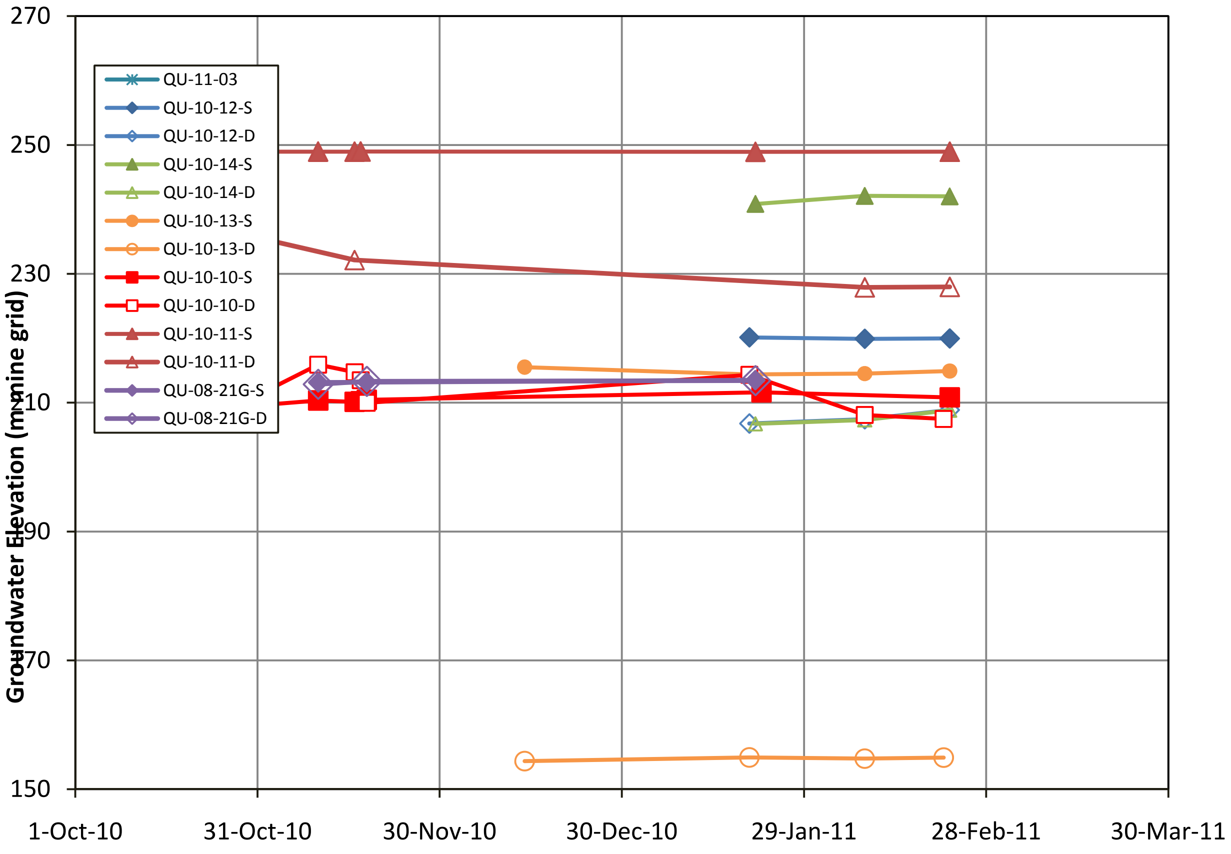
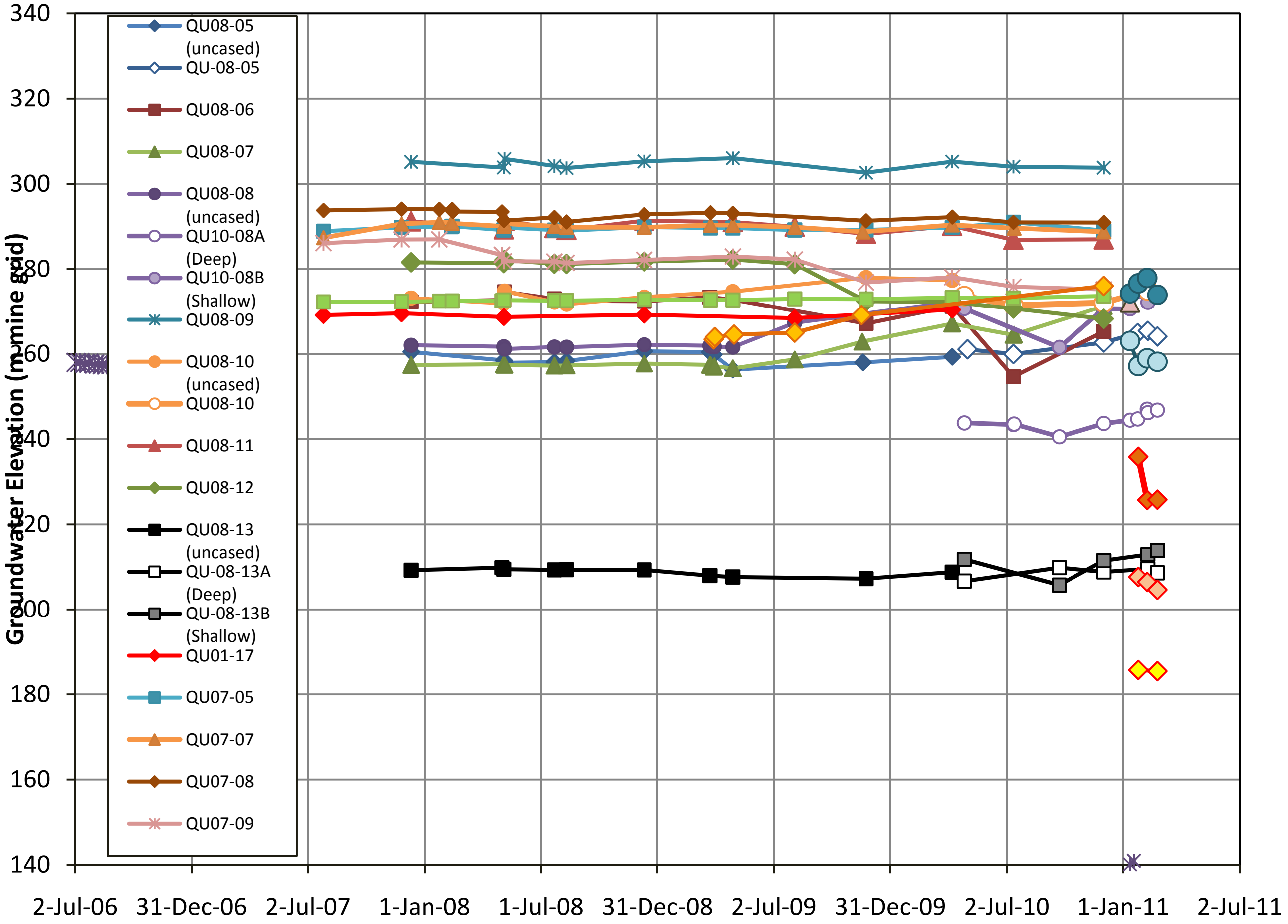
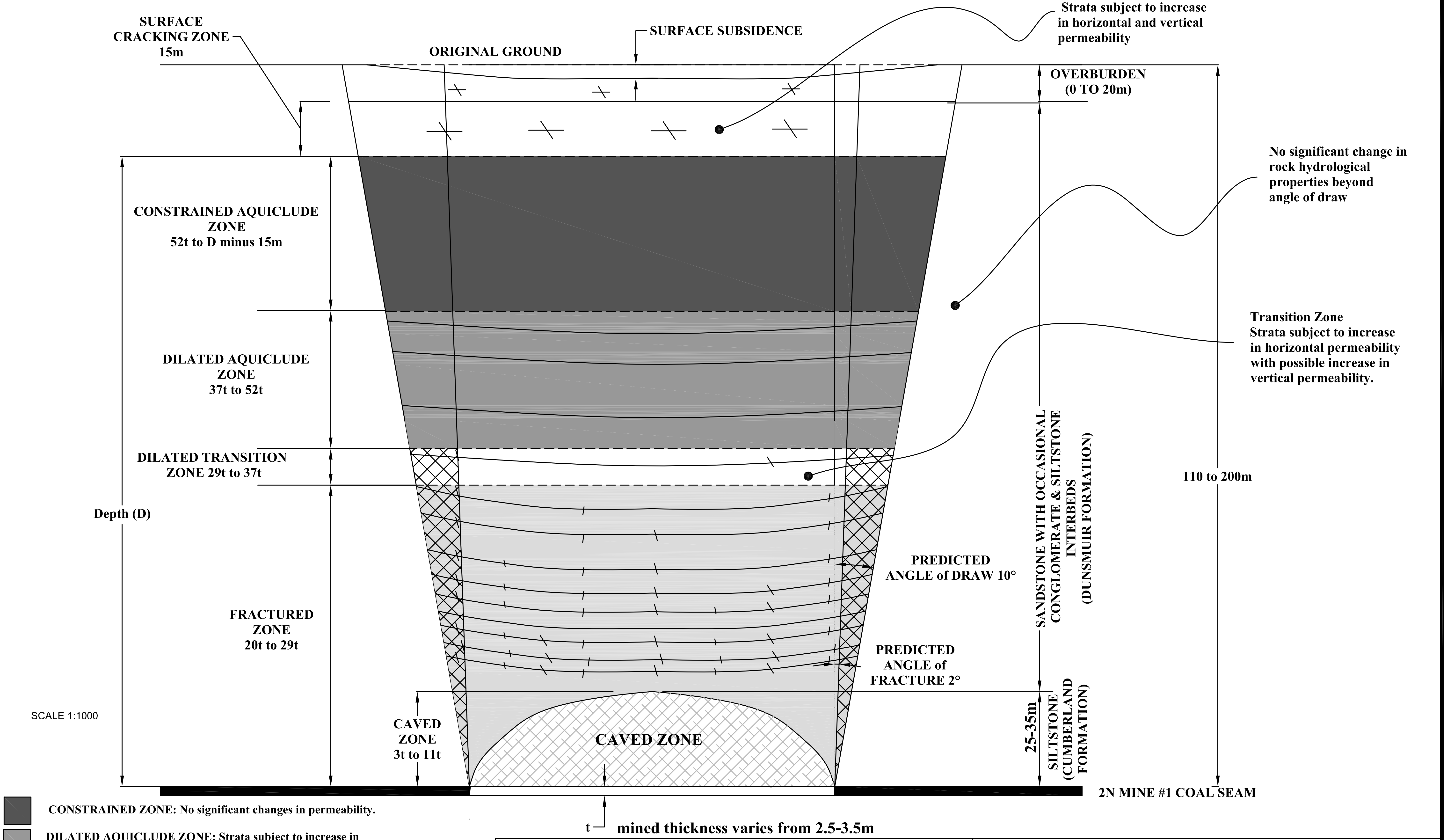


Figure 14: Groundwater Levels From Monitoring Wells in 5N





■ **CONSTRAINED ZONE:** No significant changes in permeability.

▩ **DILATED AQUICLUDE ZONE:** Strata subject to increase in horizontal permeability.

□ **FRACTURED ZONE:** Stata subject to increase in horizontal and vertical permeability; direct hydraulic connection to mine.

⊠ **Strata movement in area between angle of draw and angle of fracture is primarily bending and bed separation resulting in an increase in horizontal permeability only.**

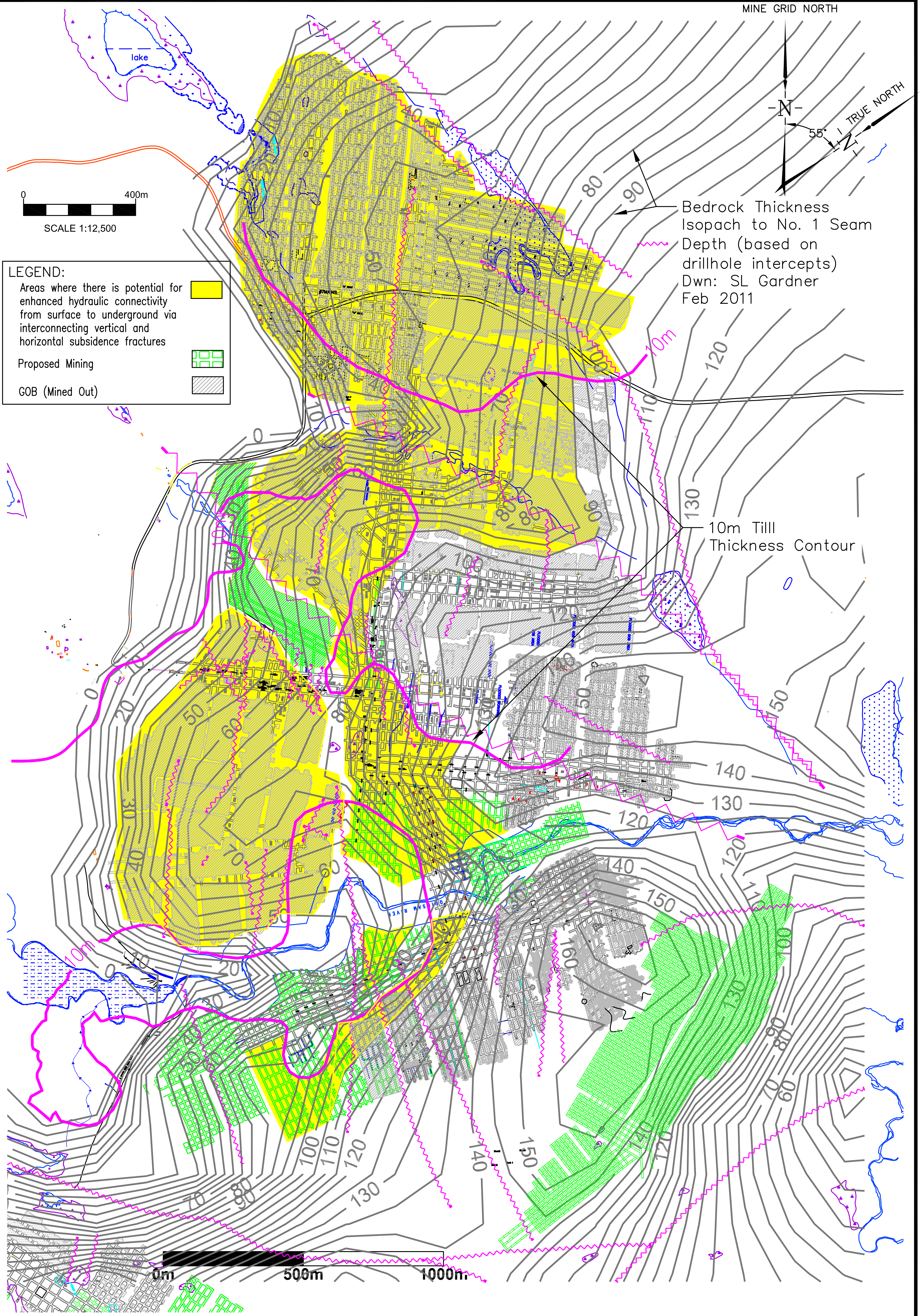
MICHAEL CULLEN GEOTECHNICAL LTD.

PROJECT QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

CLIENT HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE SUBSIDENCE ZONES ABOVE #1 SEAM

DATE 2011/02/01 DWN. JMG CHKD. MC FILE NO. 2009-16 FIGURE 15



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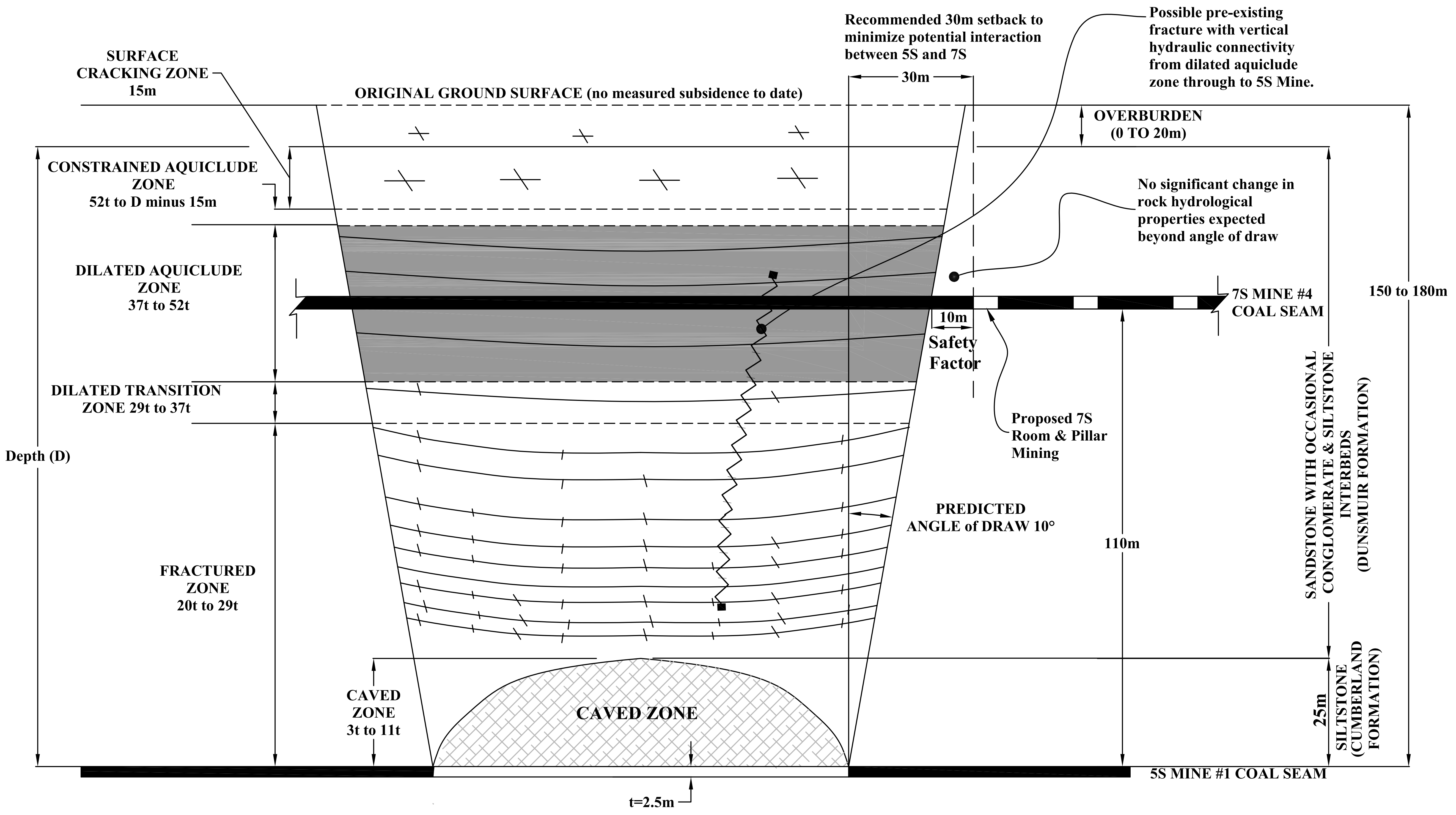
PROJECT
QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

CLIENT
HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE
AREAS WITH POTENTIAL ENHANCED HYDRAULIC CONNECTIVITY

DATE 2011/02/01	SCALE 1:12,500	DWN. JMG	CHKD. MC	FILE NO. 2009–16	FIGURE 16



LEGEND:

▨ **DILATED AQUICLUDE ZONE - Strata subject to increase in horizontal permeability.**

SCALE 1:1000

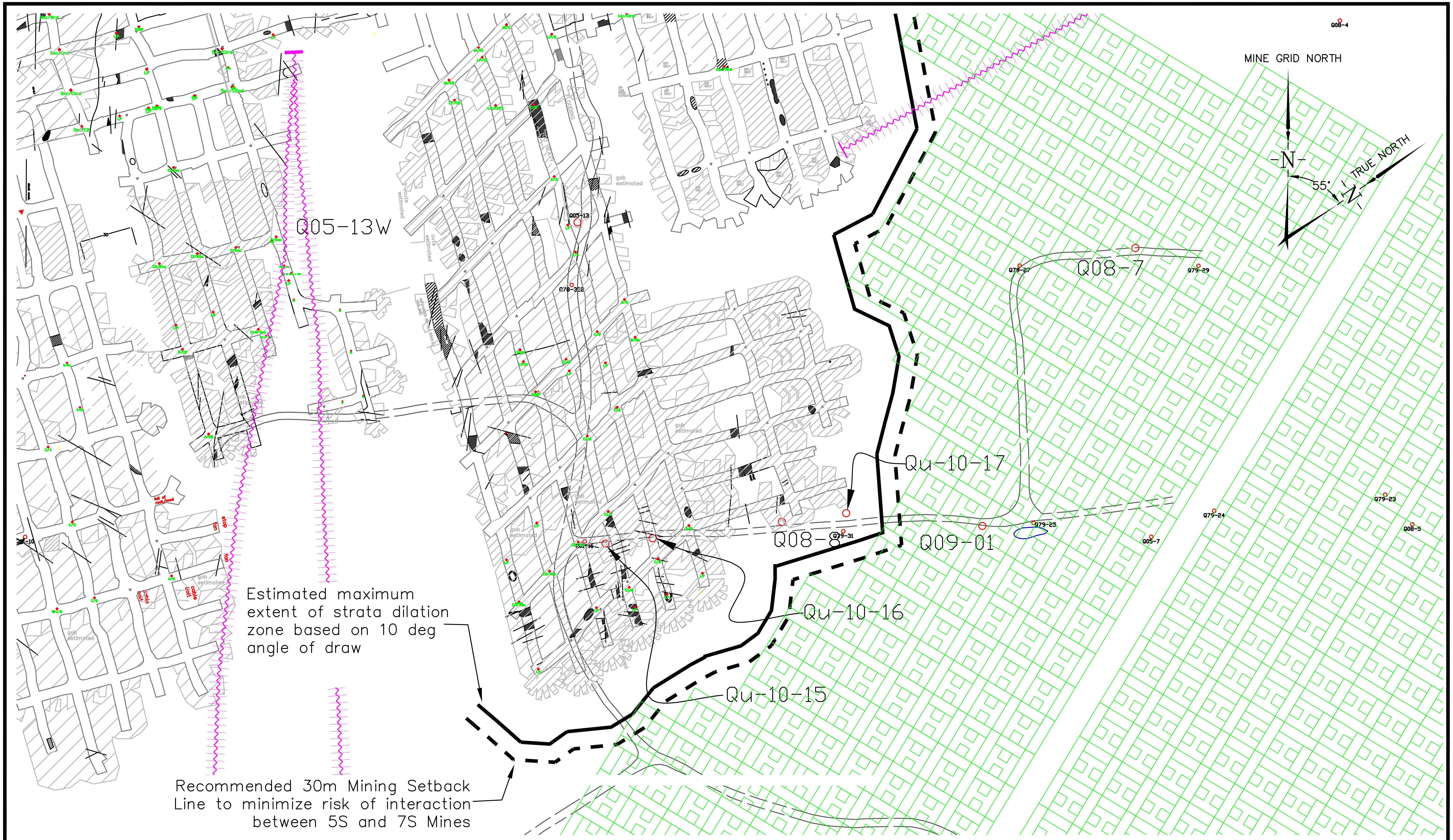
MICHAEL CULLEN GEOTECHNICAL LTD.

PROJECT QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

CLIENT HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE SUBSIDENCE ZONE
INTERACTION BETWEEN 5S & PROPOSED 7S MINES

DATE 2011/02/01
DWN. JMG
CHKD. MC
FILE NO. 2009-16
FIGURE 17



Estimated maximum extent of strata dilation zone based on 10 deg angle of draw

Recommended 30m Mining Setback Line to minimize risk of interaction between 5S and 7S Mines

LEGEND:

🟩 Proposed Mining

▨ GOB

☒ Full cave GOB (confirmed)

Coal Pillar

Significant Faults

0 50m

SCALE 1:2000

MICHAEL CULLEN GEOTECHNICAL LTD.

PROJECT QUINSAM COAL MINE SUBSIDENCE ASSESSMENT

CLIENT HILLSBOROUGH RESOURCES QUINSAM COAL MINE

TITLE RECOMMENDED SETBACK TO MINIMIZE INTERACTION POTENTIAL FROM 5S TO PROPOSED 7S MINE

DATE 2010/01/07 DWN. JMG CHKD. MC FILE NO. 2009–16 FIGURE 18

Photos

Photo 1: DH Qu10-15 26m depth.
Surface fracture zone. Fractures appear new but on pre-existing weakness plane.

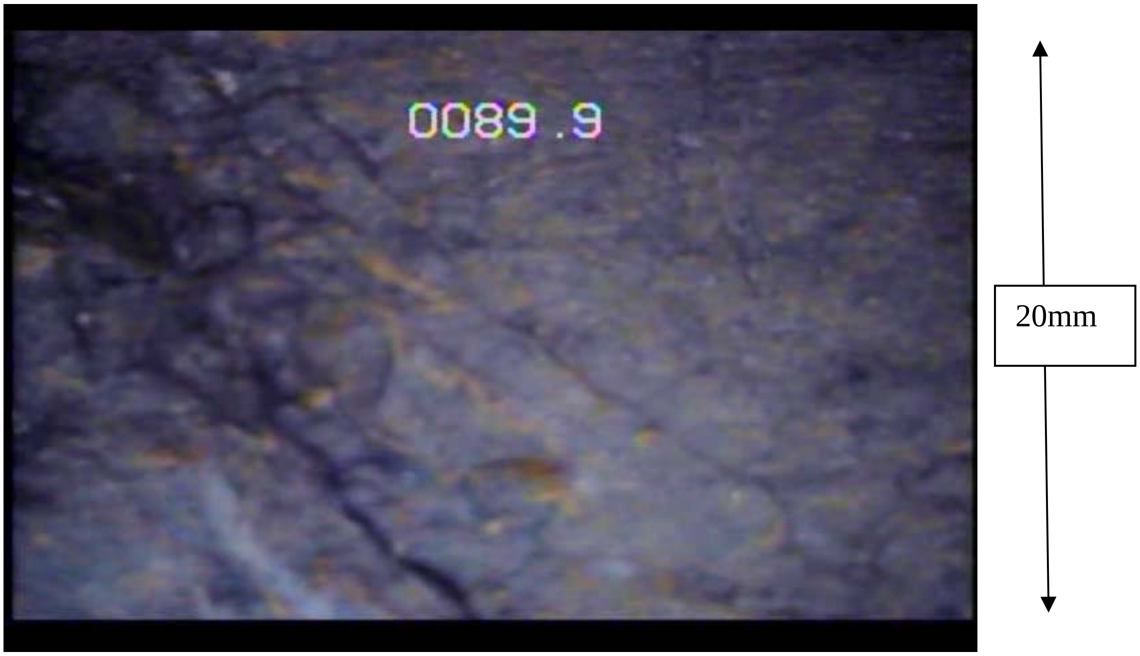


Photo 2: DH Qu10-15 40m depth.
Sandstone within constrained zone, K <1E-8 m/s

Photo 3: DH Qu10-15 41m depth.
Sandstone within constrained zone, pre-existing fracture, open and fe stained.

Photo 4: DH Qu10-17 14m depth.
Pre-existing fracture within constrained zone . Encountered large inflow of water during drilling.

Photo 5: DH Qu10-17 48m depth.

Open bedding plane fractures within dilated aquiclude zone.

Photo 6: DH Qu10-14 100m depth.
Rubble zone within caved or lower fractured zone.

Photo 7: DH QU10-15, 39.9m depth. Pre-existing fracture 20 degrees TCA with fe stain.

Photo 8: DH QU10-15. 40.7m depth, joint/fault 15 degrees TCA with trace gouge (non softening). 42.2 joints at 85 and 65 TCA with Fe stain

Photo 9: DH QU10-15. 42.7m (140 ft) depth . 30mm fault zone with gouge and rubble on bedding plane

Photo 10: DH QU10-15. 45.7m depth open micro-fracture 65 degrees TCA. 46.0m depth fault with trace gouge, fe stain, calcite coating

Photo 11: DH QU10-15 51.8m to 52.4m open micro-fractures in carbonaceous sandstone

Photo 12: DH Qu10-17 46.5m. Open micro-fractures on dark mineral bands

Appendix 1: Surface Subsidence Measurement Data 5S and RBPP Areas

Subsidence Station Locations and Measurements

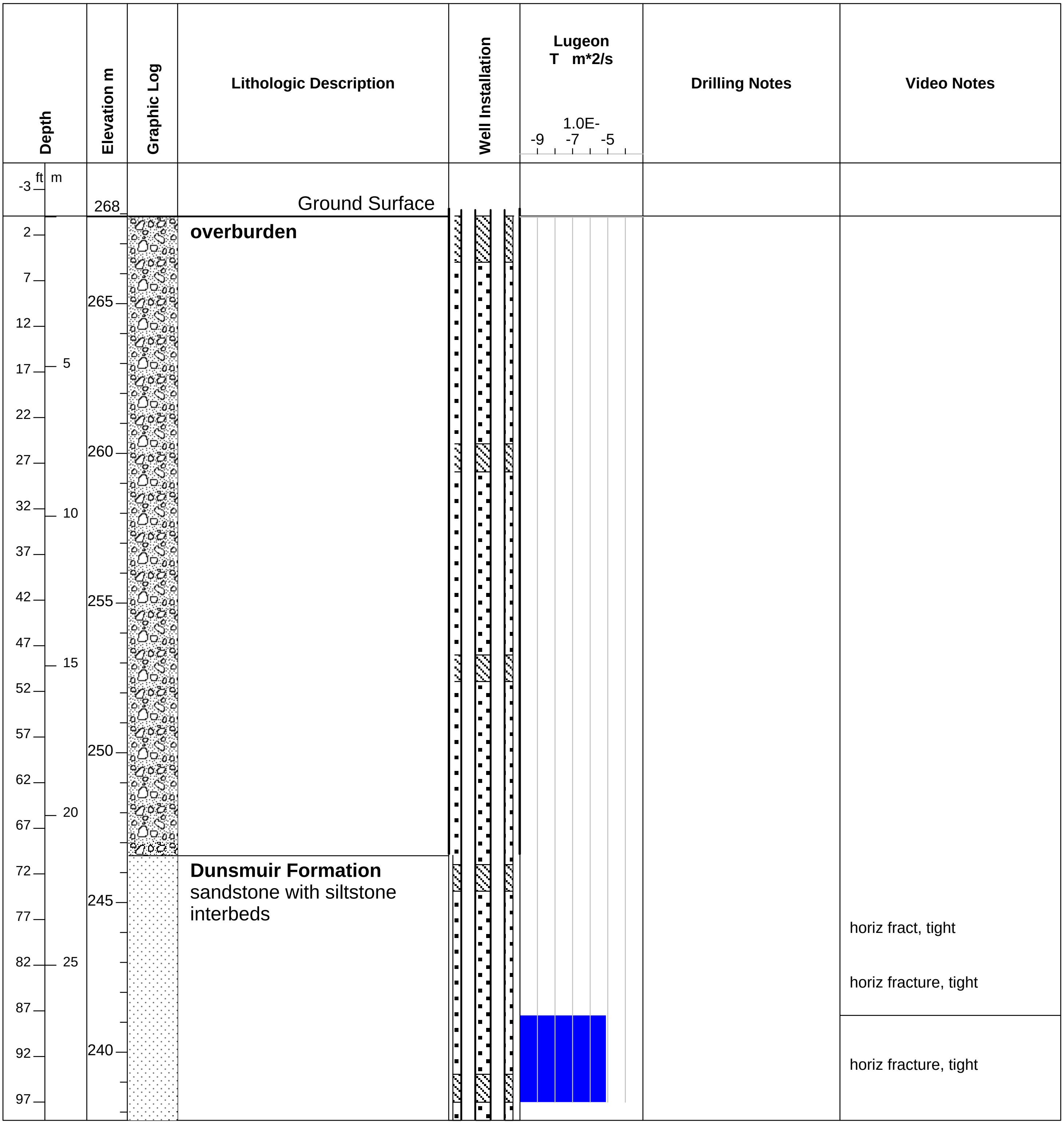
Station	Location	Easting	Northing	Install Date	Initial elev m	Measured Date	Measured elev m	Change in elev m
SUB1	8 Mains	100297	102391	March 2010	243.020	Nov 2010	243.072	0.052
SUB2	8 Mains	100351	102408	March 2010	242.726	Nov 2010	242.775	0.049
SUB3	8 Mains	100409	102434	March 2010	251.437	Nov 2010	251.437	0.000
SUB4	8 Mains	100447	102435	March 2010	255.070	Nov 2010	255.036	-0.034
SUB5	8 Mains	100481	102431	March 2010	254.633	Nov 2010	254.572	-0.061
SUB6	8 Mains	100526	102439	March 2010	253.993	Nov 2010	253.988	-0.005
SUB7	New RBP	100574	102505	Nov 2010	249.978			na
SUB8	8 Mains	100607	102561	March 2010	249.265	Nov 2010	249.268	0.003
SUB9	New RBP	100737	102547	Nov 2010	225.645			na
SUB10	New RBP	100751	102567	Sept 2010	226.309	Nov 2010	226.258	-0.051
SUB11	New RBP	100812	102590	Nov 2010	224.768			na
SUB12	New RBP	100882	102541	Nov 2010	229.908			na
SUB13	New RBP	100925	102575	Nov 2010	240.648			na
SUB14	102 Panel	100754	102142	March 2010	300.809	Nov 2010	300.809	0.000
SUB15	102 Panel	100792	102029	March 2010	303.365	Nov 2010	303.365	0.000
SUB16	102 Panel	100830	101946	March 2010	304.271	Nov 2010	304.271	0.000
SUB17	108 Panel	100257	101666	March 2010	304.170	Feb 2011	304.194	0.024
SUB18	108 Panel	100221	101683	March 2010	305.211	Feb 2011	305.234	0.023
SUB19	108 Panel	100124	101716	March 2010	309.301			0.013
SUB20	108 Panel	100175	101701	March 2010	308.447	Feb 2011	308.472	0.025
SUB21	110 Panel	100004	101818	Nov 2010	307.157			na
SUB22	108 Panel	100251	101754	Nov 2010	300.022	Feb 2011	300.009	-0.013
SUB23	Barrier Pillar	100221	101736	Nov 2010	302.262	Feb 2011	302.254	-0.008
SUB24	109 Panel	100111	101830	Nov 2010	306.430	Feb 2011	306.444	0.014
SUB25	Barrier Pillar	100176	101857	Nov 2010	303.599	Feb 2011	303.609	0.010
SUB26	108 Panel	100191	101871	Nov 2010	302.427	Feb 2011	302.435	0.009
SUB27	110 Panel	100056	101681	Nov 2010	313.572	Feb 2011	313.587	0.015
SUB28	110 Panel	100082	101636	Nov 2010	315.141	Feb 2011	315.156	0.015
SUB29	Outside Mining Plan	100351	101630	Dec 2010	306.480	Feb 2011	306.521	0.041
SUB30	Outside Mining Plan	100164	101534	Dec 2010	317.156	Feb 2011	317.190	0.033
SUB31	111 Panel	99903	101835	Dec 2010	313.781			
SUB32	111 Panel	99861	101835	Dec 2010	316.085			
SUB33	111 Panel	99812	101813	Dec 2010	320.812			
SUB34	111 Panel	99902	101776	Dec 2010	317.477			
SUB35	111 Panel	99956	101736	Dec 2010	315.874			
SUB36	110 Panel	100003	101766	Dec 2010	310.902			
SUB37	110 Panel	99958	101801	Dec 2010	311.915			

Appendix 2: Drill Hole Logs

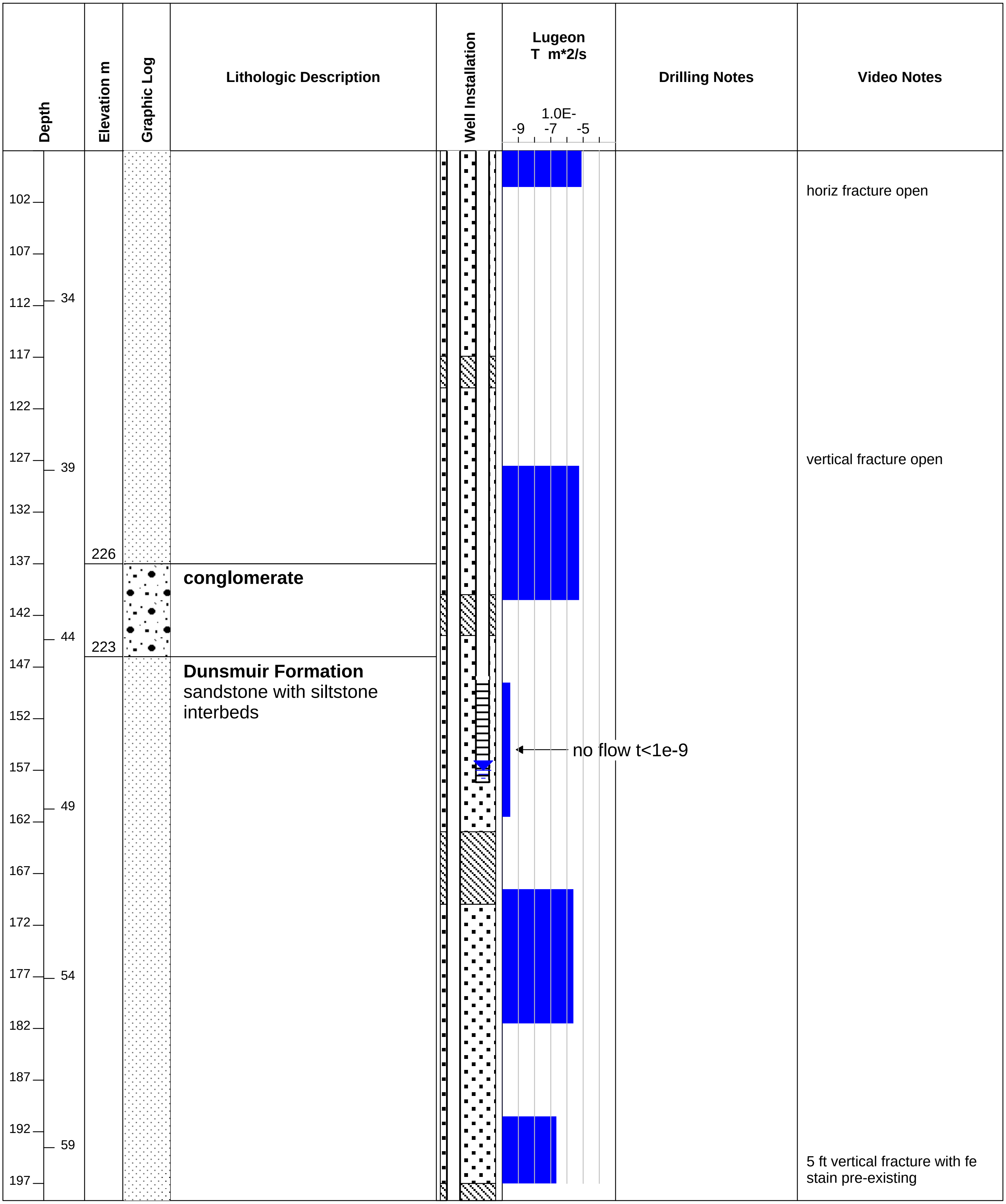
LOG FOR DRILLHOLE #: Qu10-12

Client: Hillsborough Res
Project: 7S Quinsam Mine Subsidence
Drilling Method: Rotary
Drilling Contractor: DrillWell
Engineer: M Cullen
Date Started: Nov 3, 2010

Co-ordinates:
Collar Elev.: 267.93 m
Dip/Dip direction: vert
Total Depth: 434 ft
Casing Depth: 70ft
Hole dia: 6 inch (155mm)



LOG FOR DRILLHOLE #: Qu10-12



conglomerate

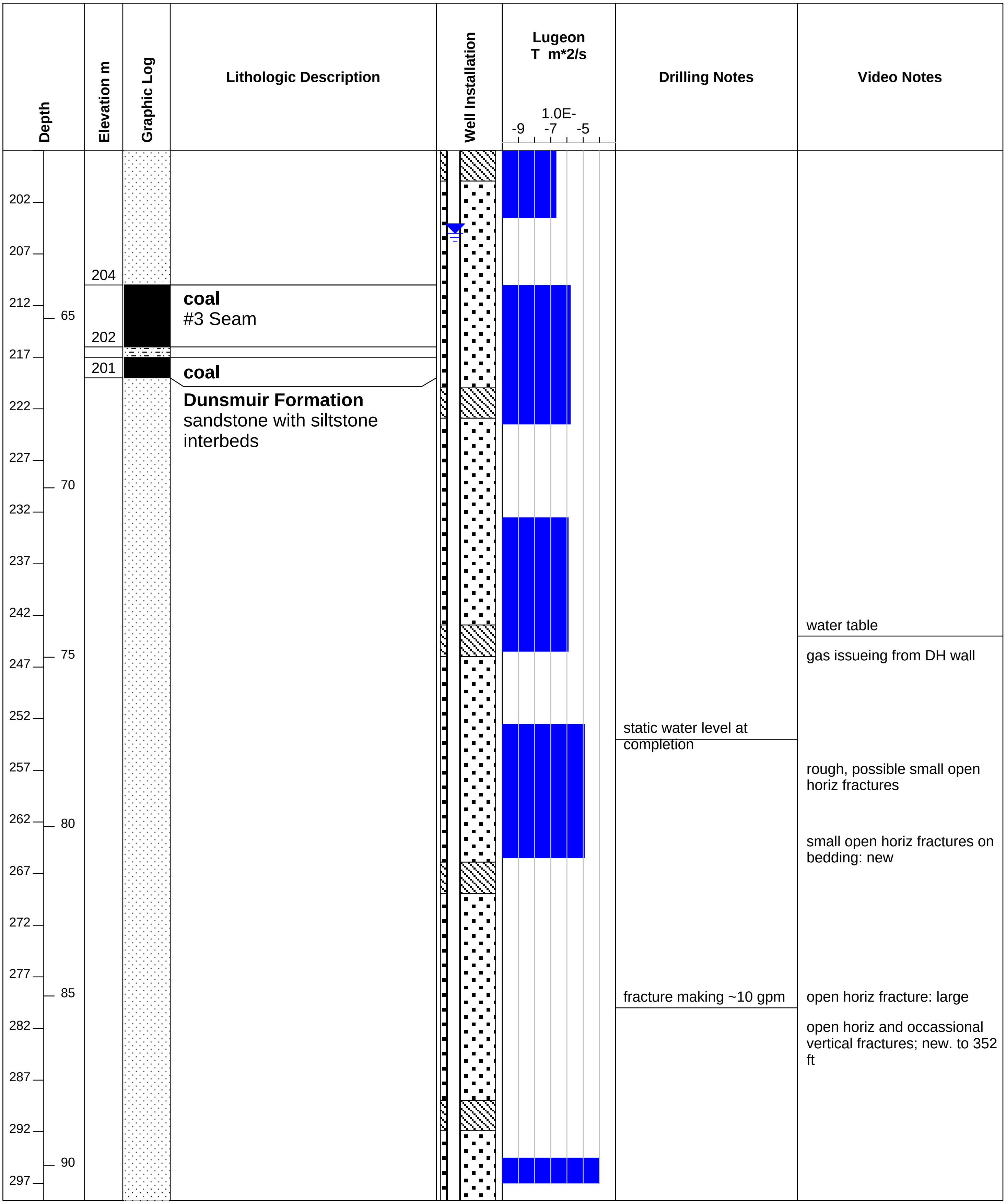
Dunsmuir Formation
sandstone with siltstone interbeds

horiz fracture open

vertical fracture open

5 ft vertical fracture with fe stain pre-existing

LOG FOR DRILLHOLE #: Qu10-12



coal
#3 Seam

coal

Dunsmuir Formation
sandstone with siltstone interbeds

Drilling Notes:

static water level at completion

fracture making ~10 gpm

Video Notes:

water table

gas issueing from DH wall

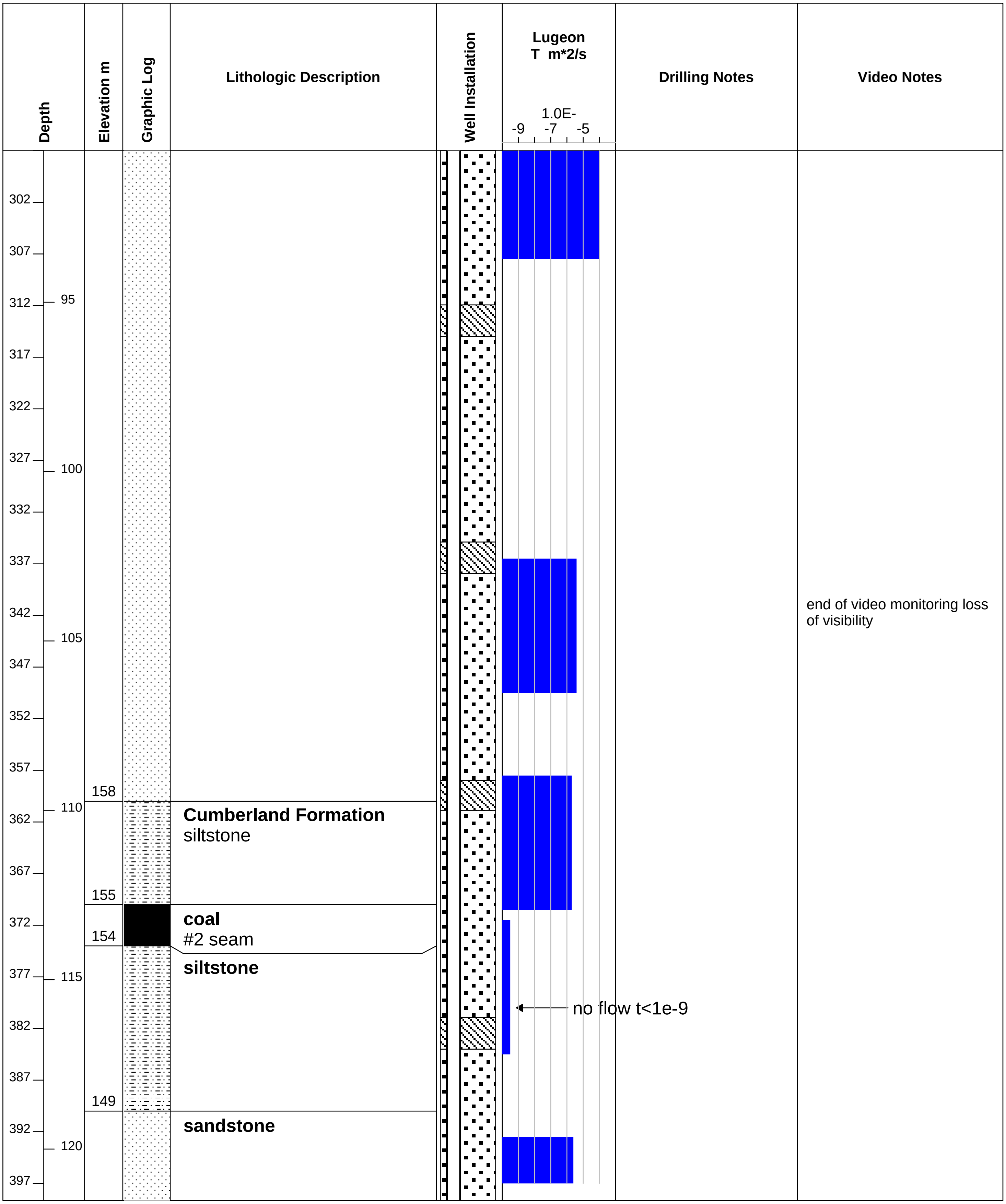
rough, possible small open horiz fractures

small open horiz fractures on bedding: new

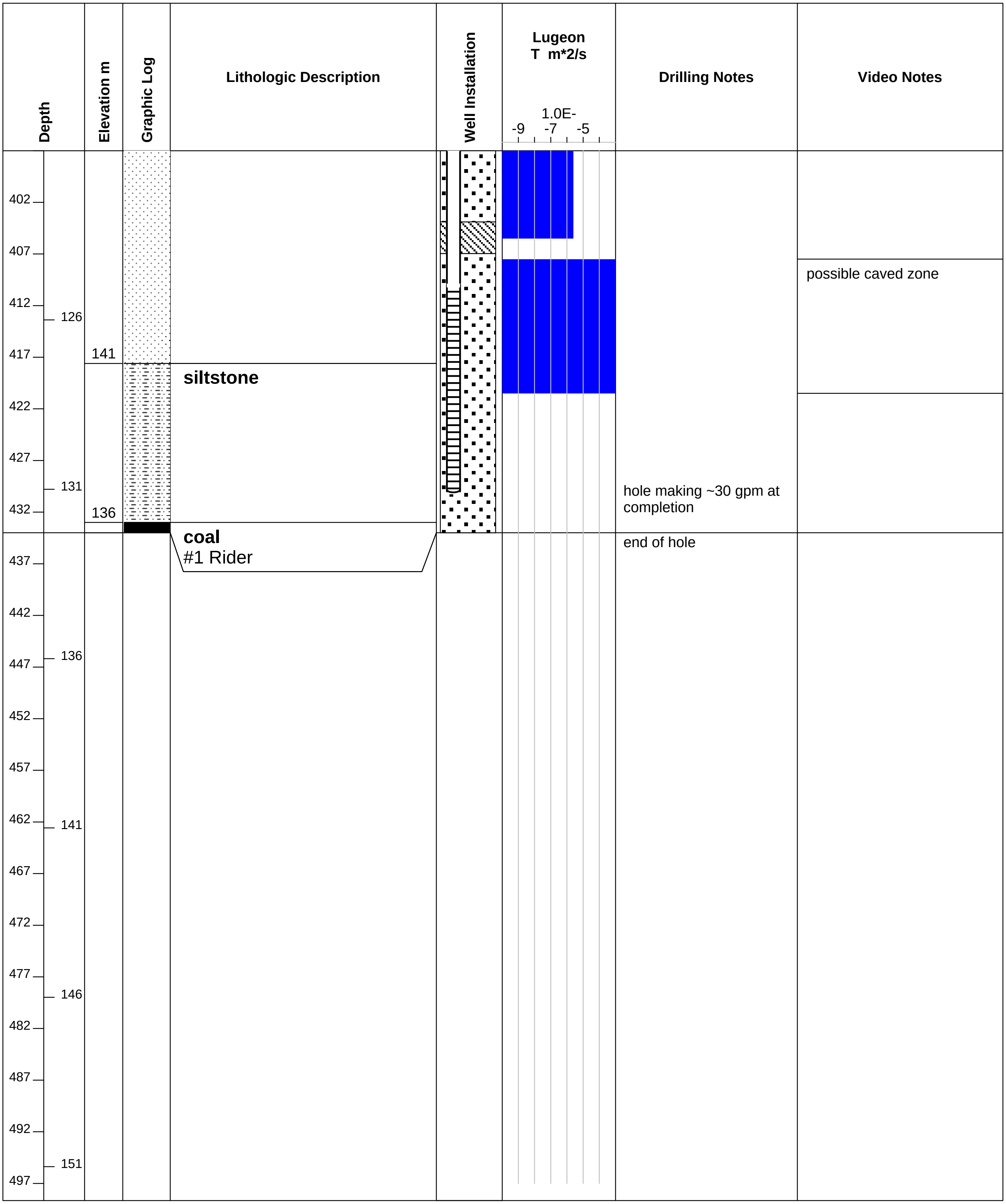
open horiz fracture: large

open horiz and occassional vertical fractures; new. to 352 ft

LOG FOR DRILLHOLE #: Qu10-12



LOG FOR DRILLHOLE #: Qu10-12



siltstone

coal
#1 Rider

Drilling Notes: hole making ~30 gpm at completion

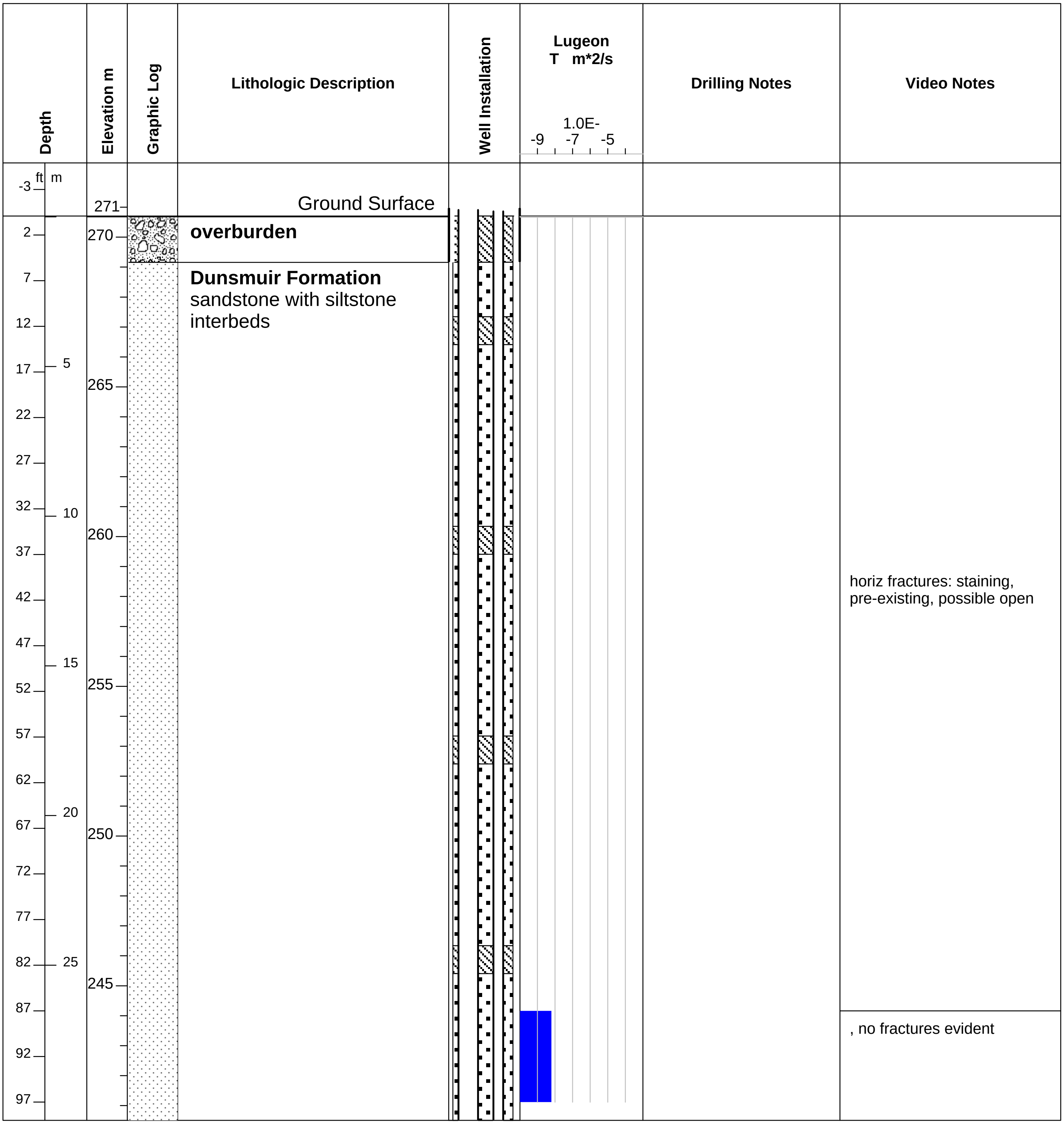
end of hole

Video Notes: possible caved zone

LOG FOR DRILLHOLE #: Qu10-13 **Page: 1 of 5**

Client: Hillsborough Resources
Project: Quinsam Mine Subsidence
Drilling Method: Rotary
Drilling Contractor: DrillWell
Engineer: M Cullen, L Fletcher
Date Started: Nov 5, 2011

Co-ordinates: 323413.8, 5535383.4 UTM
Collar Elev.: 270.7
Dip/Dip direction: vert
Total Depth: 483 ft
Casing Depth: 5 ft
Hole dia: 6 inch (155mm)

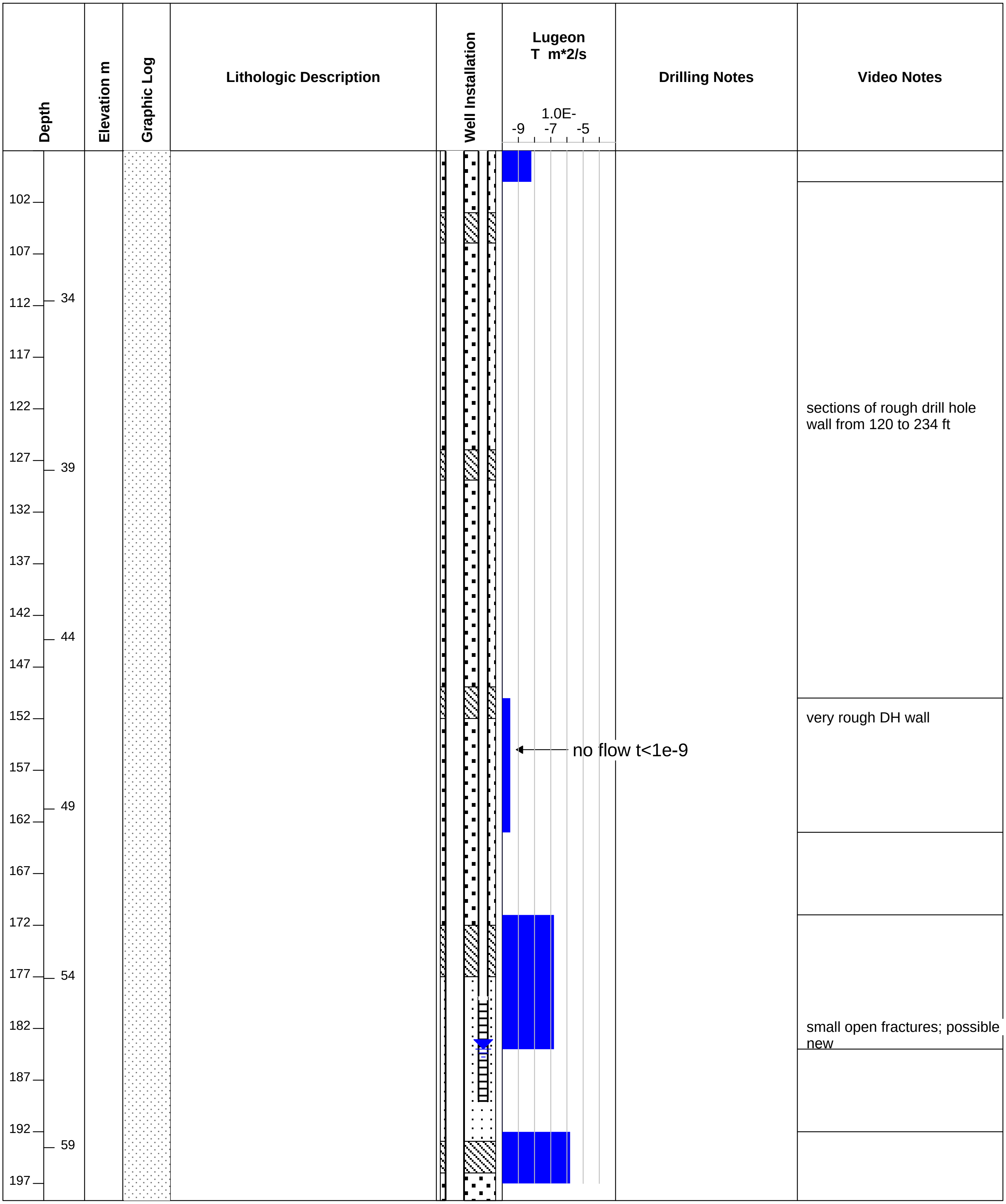


overburden

Dunsmuir Formation
sandstone with siltstone interbeds

horiz fractures: staining, pre-existing, possible open

, no fractures evident

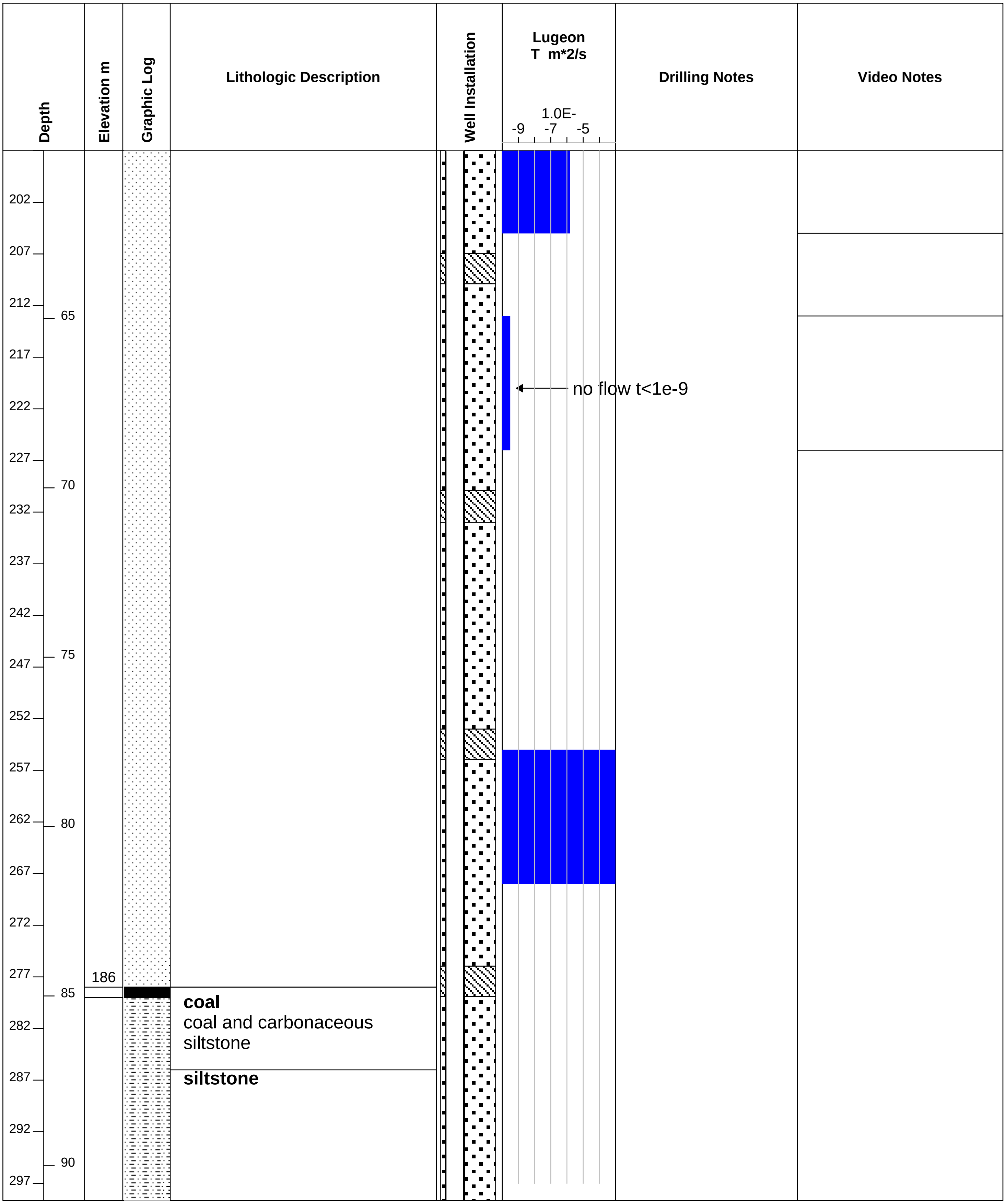


sections of rough drill hole wall from 120 to 234 ft

very rough DH wall

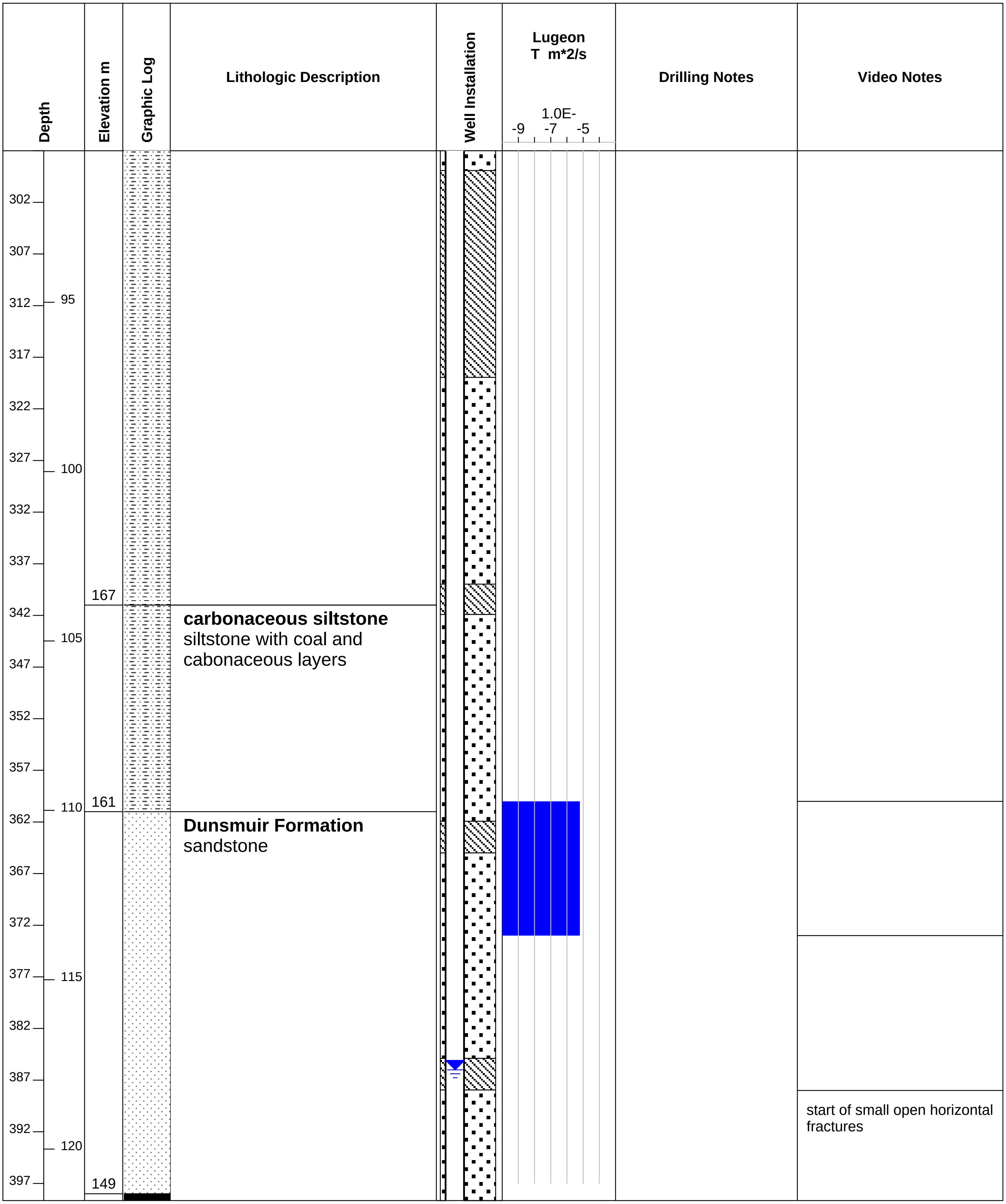
small open fractures; possible new

LOG FOR DRILLHOLE #: Qu10-13



coal
coal and carbonaceous siltstone

siltstone



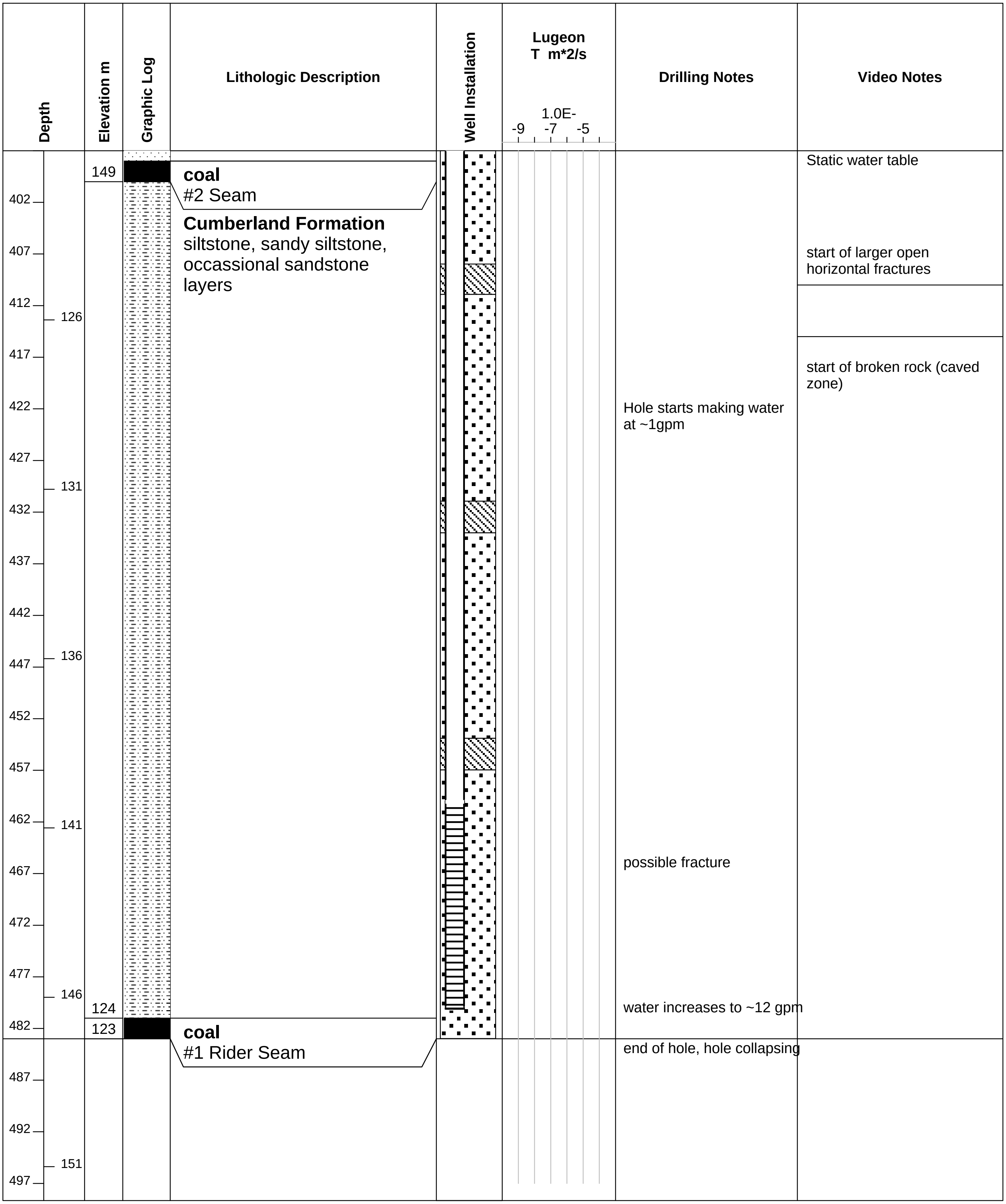
carbonaceous siltstone
siltstone with coal and cabonaceous layers

Dunsmuir Formation
sandstone

start of small open horizontal fractures

Michael Cullen Geotechncial Ltd.

LOG FOR DRILLHOLE #: Qu10-13 **Page: 5 of 5**



coal
#2 Seam

Cumberland Formation
siltstone, sandy siltstone, occassional sandstone layers

coal
#1 Rider Seam

Drilling Notes:

Hole starts making water at ~1gpm

possible fracture

water increases to ~12 gpm

end of hole, hole collapsing

Video Notes:

Static water table

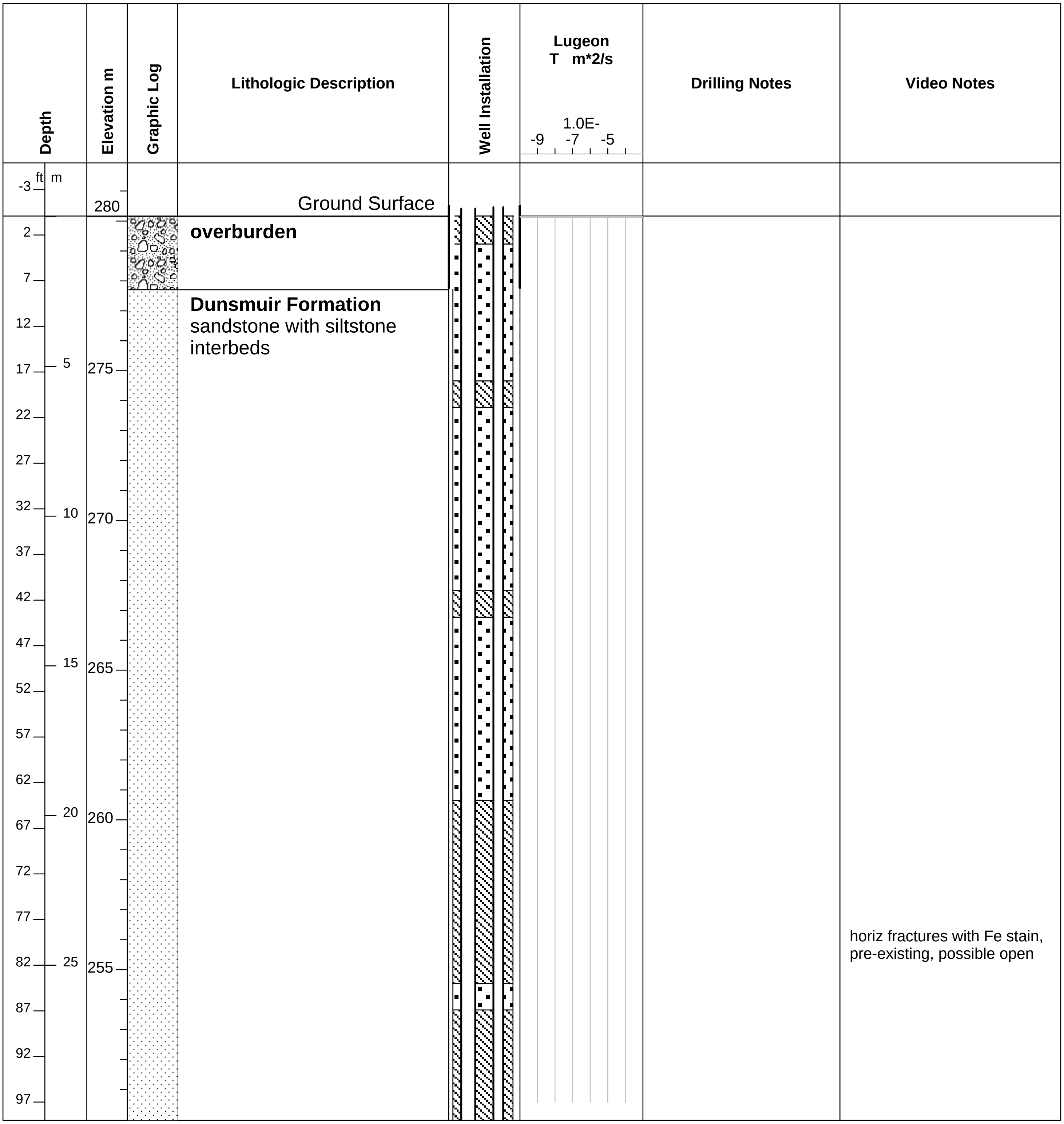
start of larger open horizontal fractures

start of broken rock (caved zone)

LOG FOR DRILLHOLE #: Qu10-14 **Page: 1 of 4**

Client: Hillborough Resources
Project: Quinsam Mine Subsidence
Drilling Method: Rotary
Drilling Contractor: DrillWell
Engineer: M Cullen, L Fletcher
Date Started: Nov 7

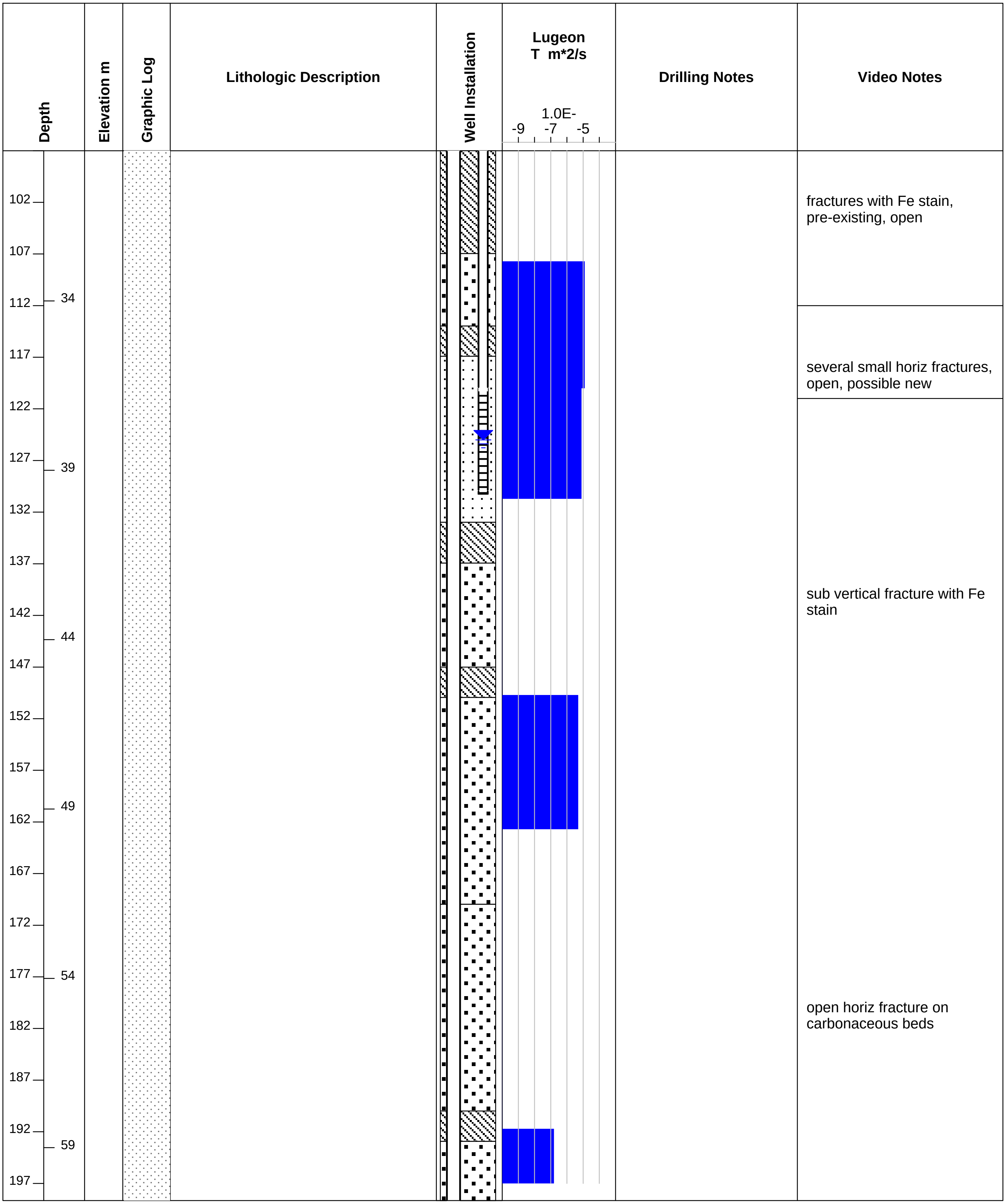
Co-ordinates: 322859.4 5535293.8 UTM
Collar Elev.: 280.14 m
Dip/Dip direction: vert
Total Depth: 341 ft
Casing Depth: 8 ft
Hole dia: 6 inch (155mm)



overburden

Dunsmuir Formation
sandstone with siltstone interbeds

horiz fractures with Fe stain, pre-existing, possible open



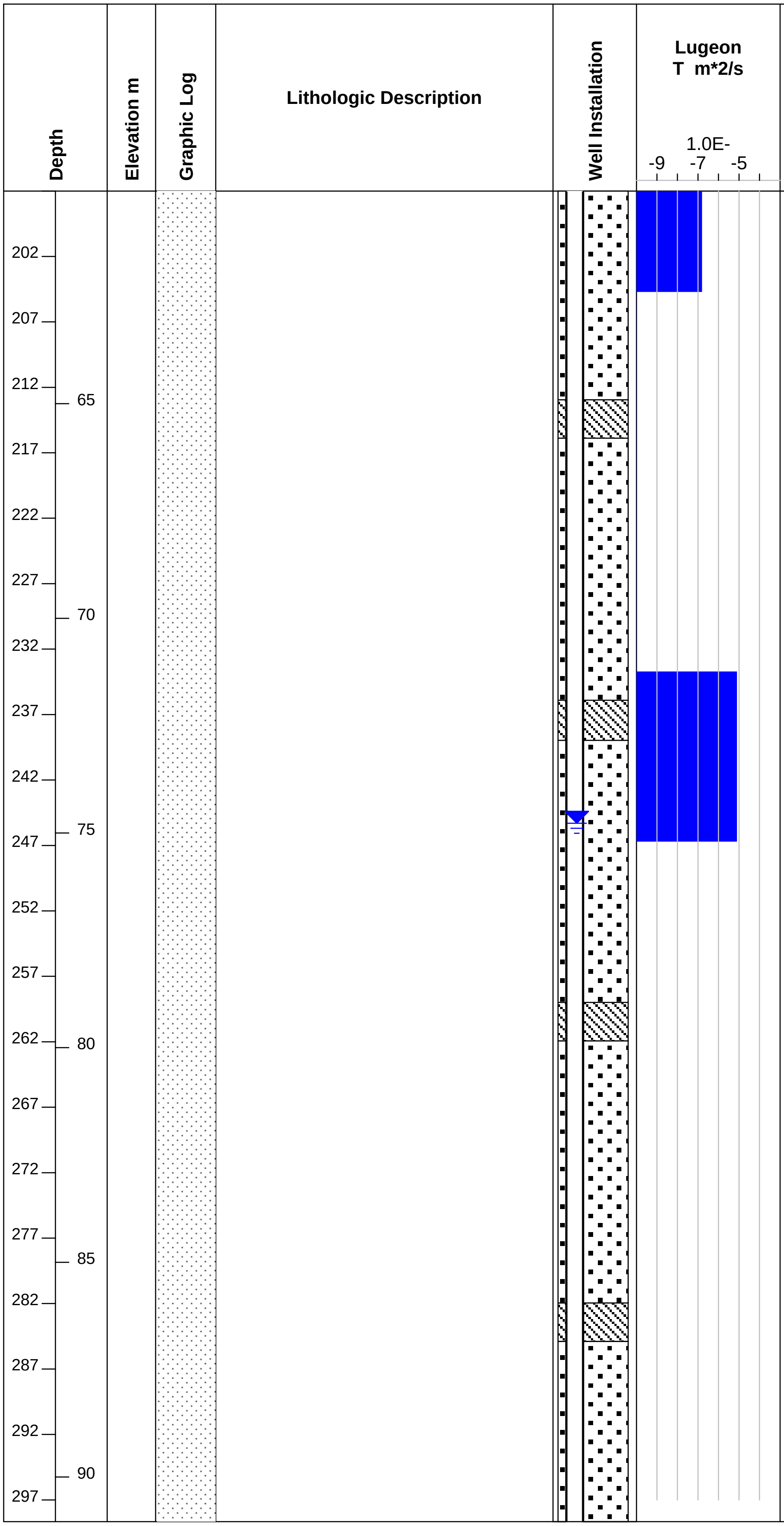
fractures with Fe stain, pre-existing, open

several small horiz fractures, open, possible new

sub vertical fracture with Fe stain

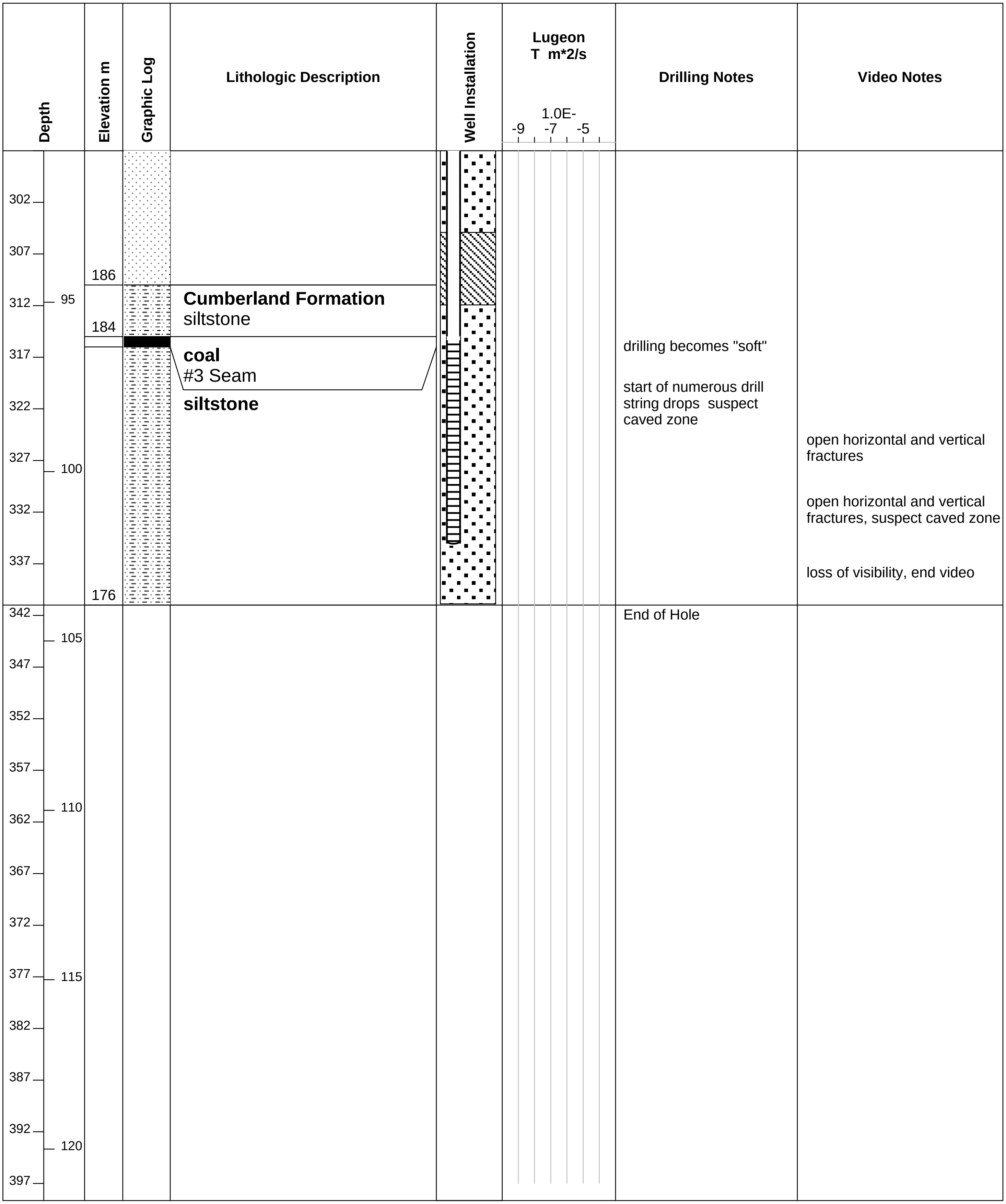
open horiz fracture on carbonaceous beds

LOG FOR DRILLHOLE #: Qu10-14



Depth	Drilling Notes	Video Notes
237	drill string drop, supect fracture, lost air circulation, no water partial air return,no cuttings	open horiz fractures and small voids, stained,
252	drill string drop suspect fracture	
282	limited cuttings returns	
287		water table

LOG FOR DRILLHOLE #: Qu10-14



Cumberland Formation
siltstone

coal
#3 Seam

siltstone

drilling becomes "soft"

start of numerous drill string drops suspect caved zone

End of Hole

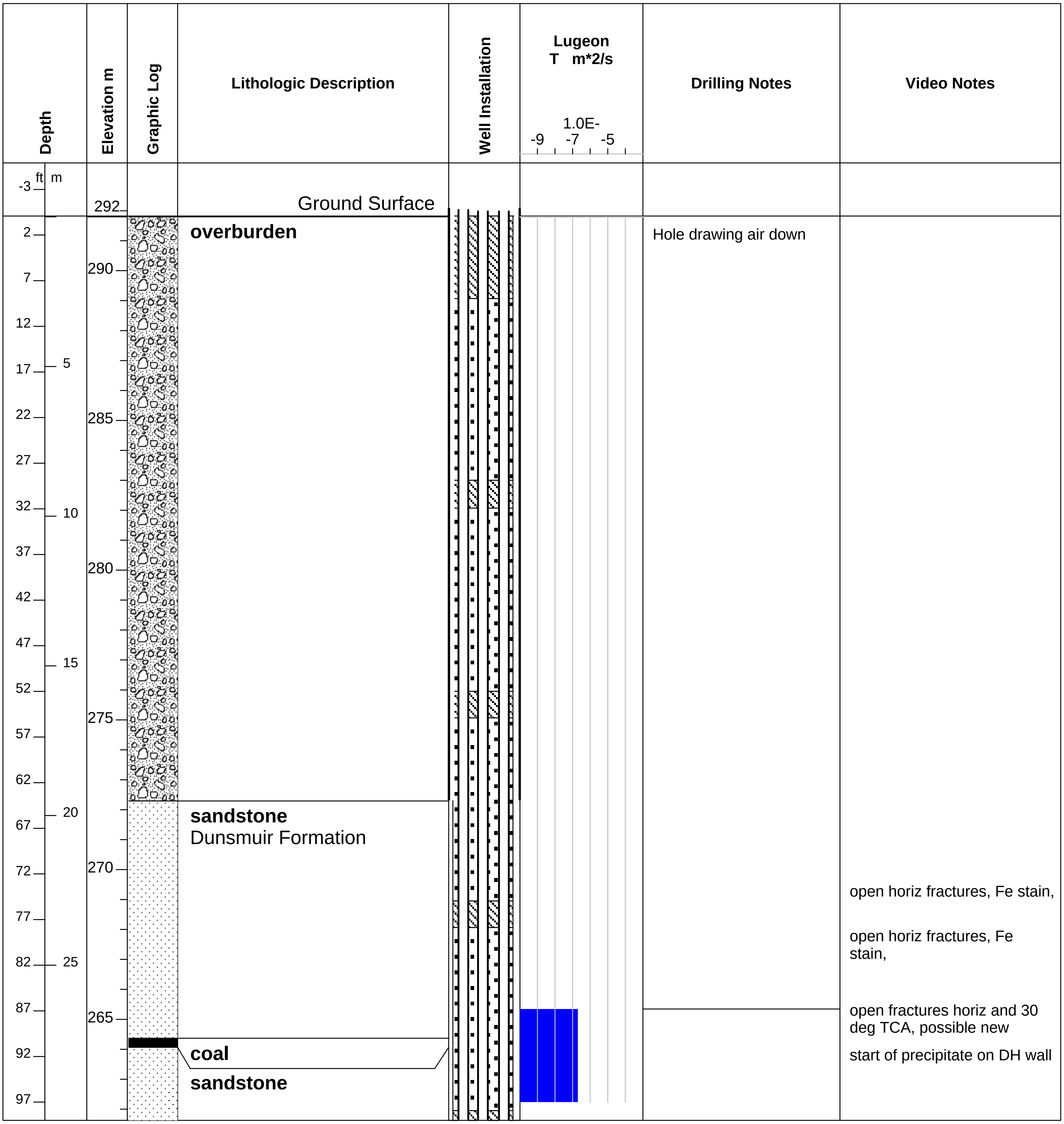
open horizontal and vertical fractures

open horizontal and vertical fractures, suspect caved zone

loss of visibility, end video

LOG FOR DRILLHOLE #: Qu10-15

Client: Hillsborough Resources	**Co-ordinates: 323890.8 5534481.4 UTM**
Project: Quinsam Mine Subsidence	**Collar Elev.: 291.80 m**
Drilling Method: Rotary / Core	**Dip/Dip direction: vert**
Drilling Contractor: DrillWell	**Total Depth: 373.5 ft**
Engineer: M Cullen, L Fletcher	**Casing Depth: 64 ft**
Date Started: Nov 23	**Hole dia: 6 inch (155mm)**



overburden

sandstone
Dunsmuir Formation

coal

sandstone

Hole drawing air down

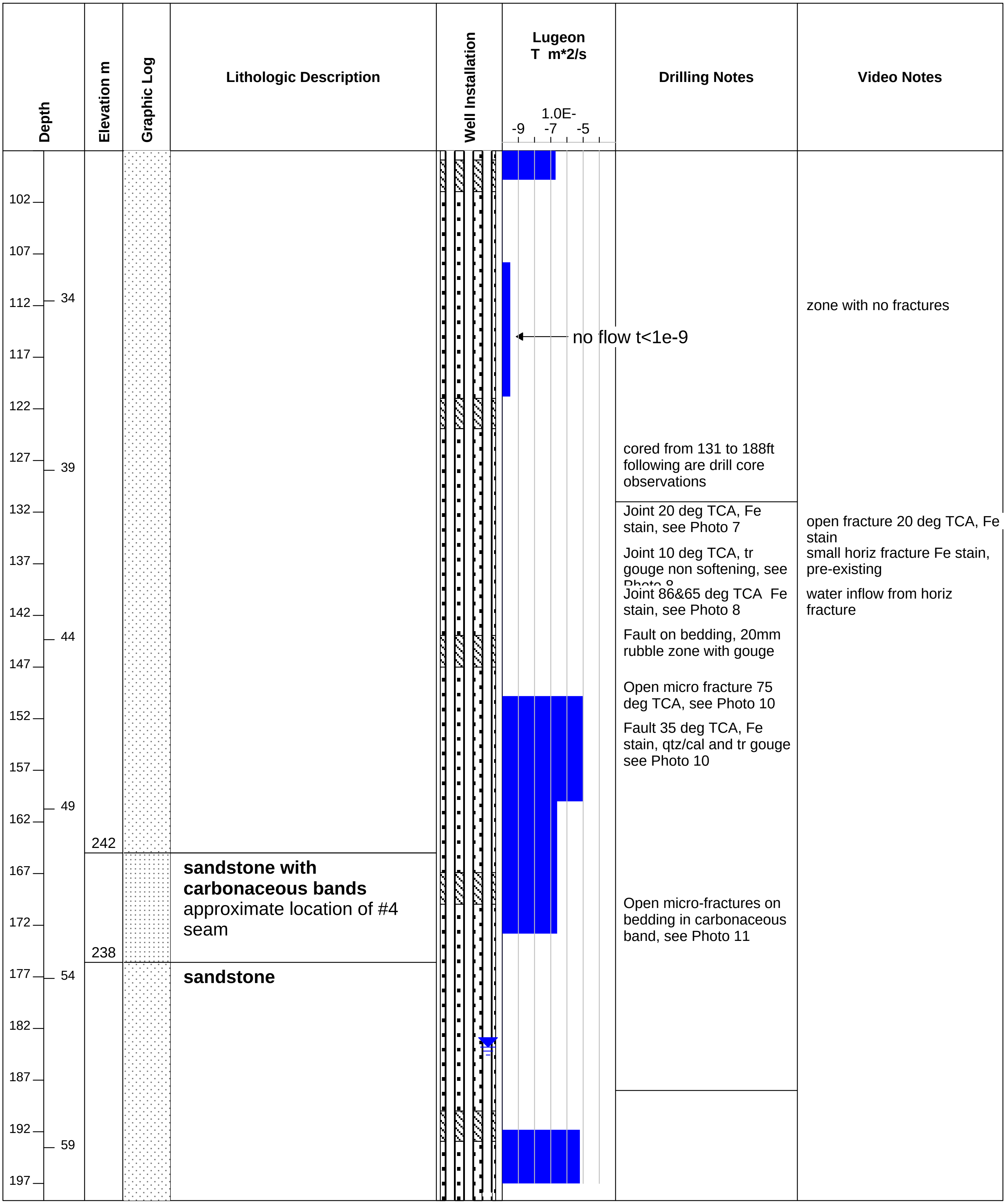
open horiz fractures, Fe stain,

open horiz fractures, Fe stain,

open fractures horiz and 30 deg TCA, possible new

start of precipitate on DH wall

LOG FOR DRILLHOLE #: Qu10-15



sandstone with carbonaceous bands
approximate location of #4 seam

sandstone

Drilling Notes:

cored from 131 to 188ft following are drill core observations

Joint 20 deg TCA, Fe stain, see Photo 7

Joint 10 deg TCA, tr gouge non softening, see Photo 8

Joint 86&65 deg TCA Fe stain, see Photo 8

Fault on bedding, 20mm rubble zone with gouge

Open micro fracture 75 deg TCA, see Photo 10

Fault 35 deg TCA, Fe stain, qtz/cal and tr gouge see Photo 10

Open micro-fractures on bedding in carbonaceous band, see Photo 11

Video Notes:

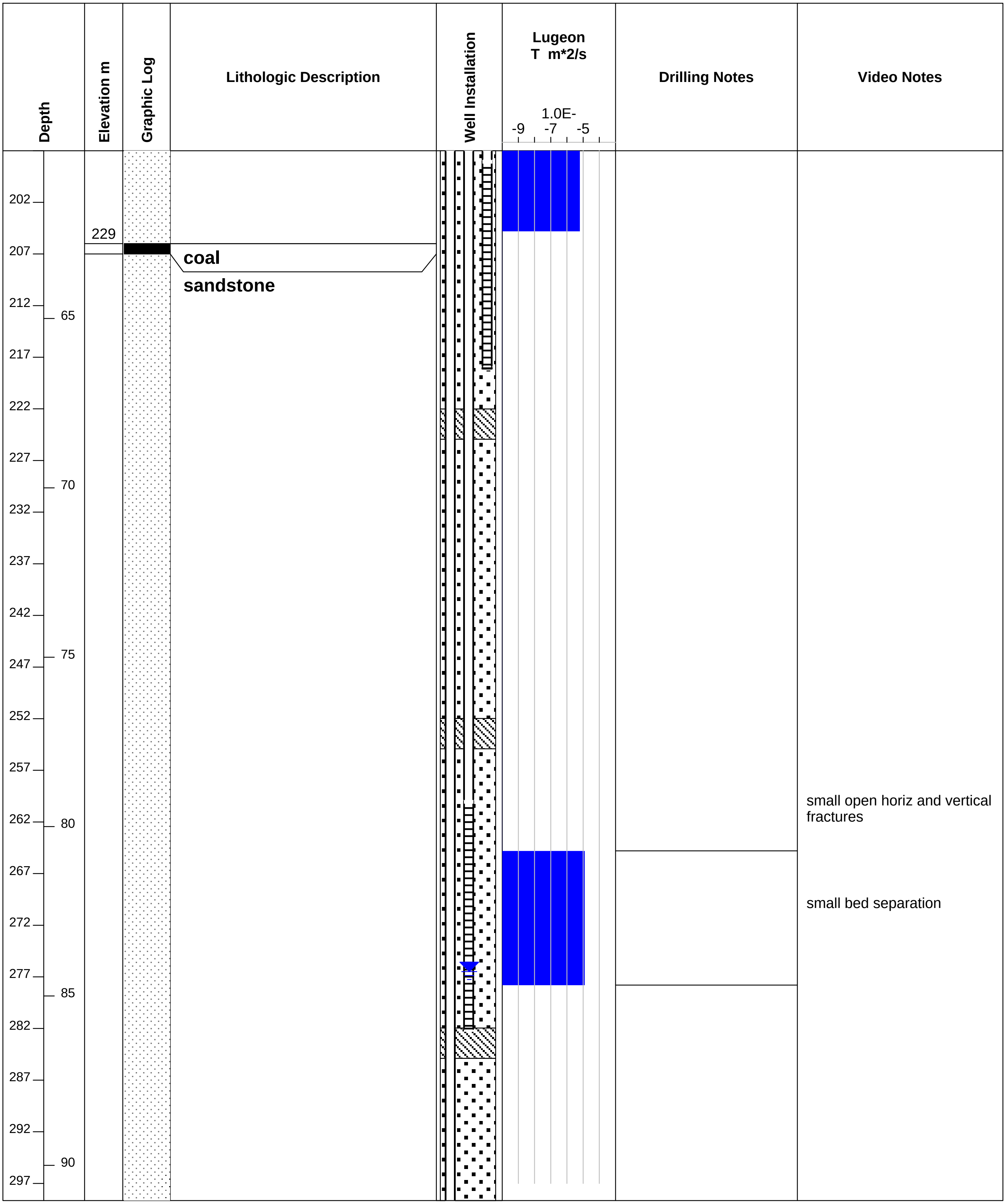
zone with no fractures

open fracture 20 deg TCA, Fe stain

small horiz fracture Fe stain, pre-existing

water inflow from horiz fracture

LOG FOR DRILLHOLE #: Qu10-15



coal

sandstone

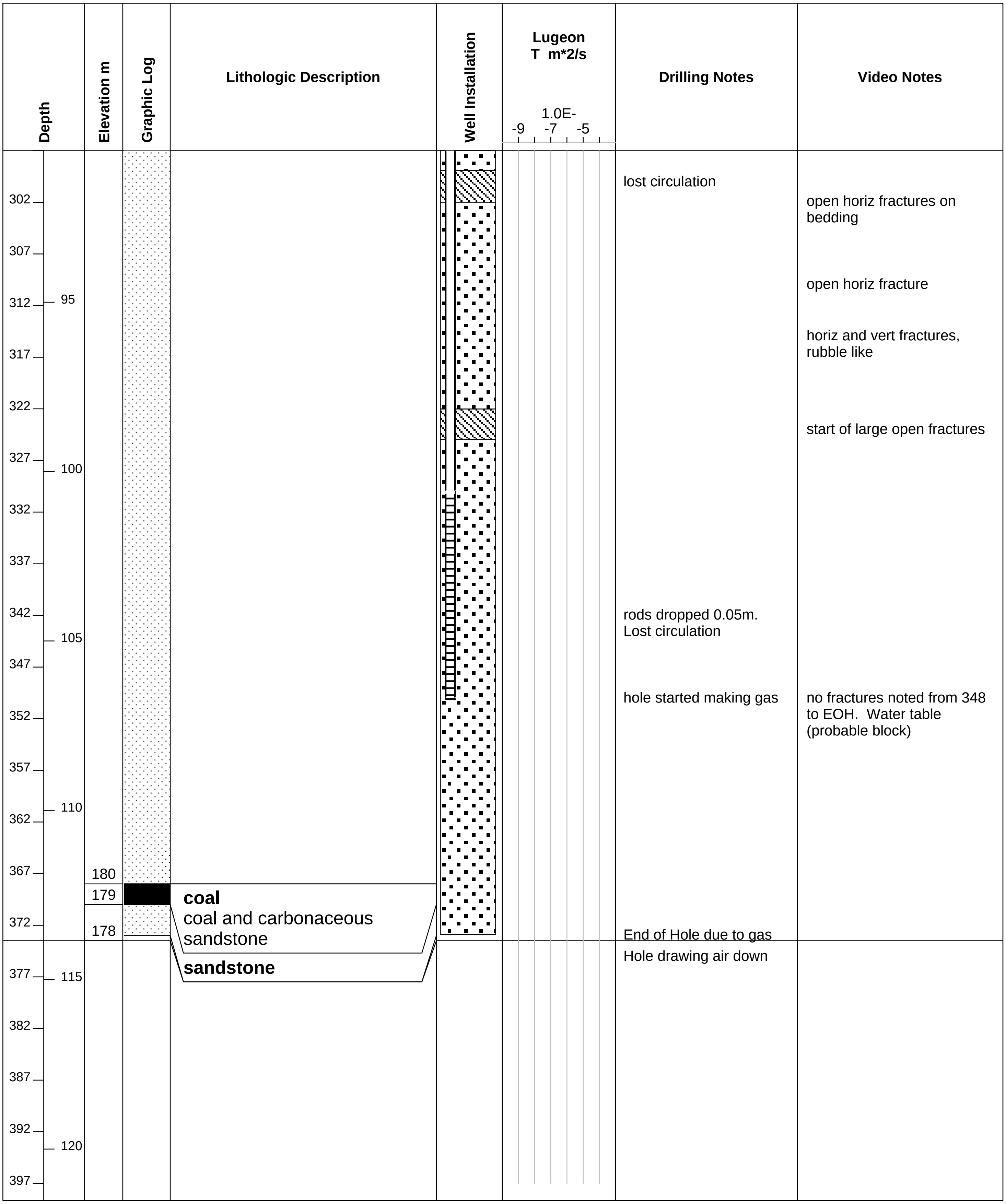
small open horiz and vertical fractures

small bed separation

Michael Cullen Geotechncial Ltd.

LOG FOR DRILLHOLE #: Qu10-15

Page: 4 of 4



Drilling Notes

lost circulation

rods dropped 0.05m. Lost circulation

hole started making gas

End of Hole due to gas

Hole drawing air down

Video Notes

open horiz fractures on bedding

open horiz fracture

horiz and vert fractures, rubble like

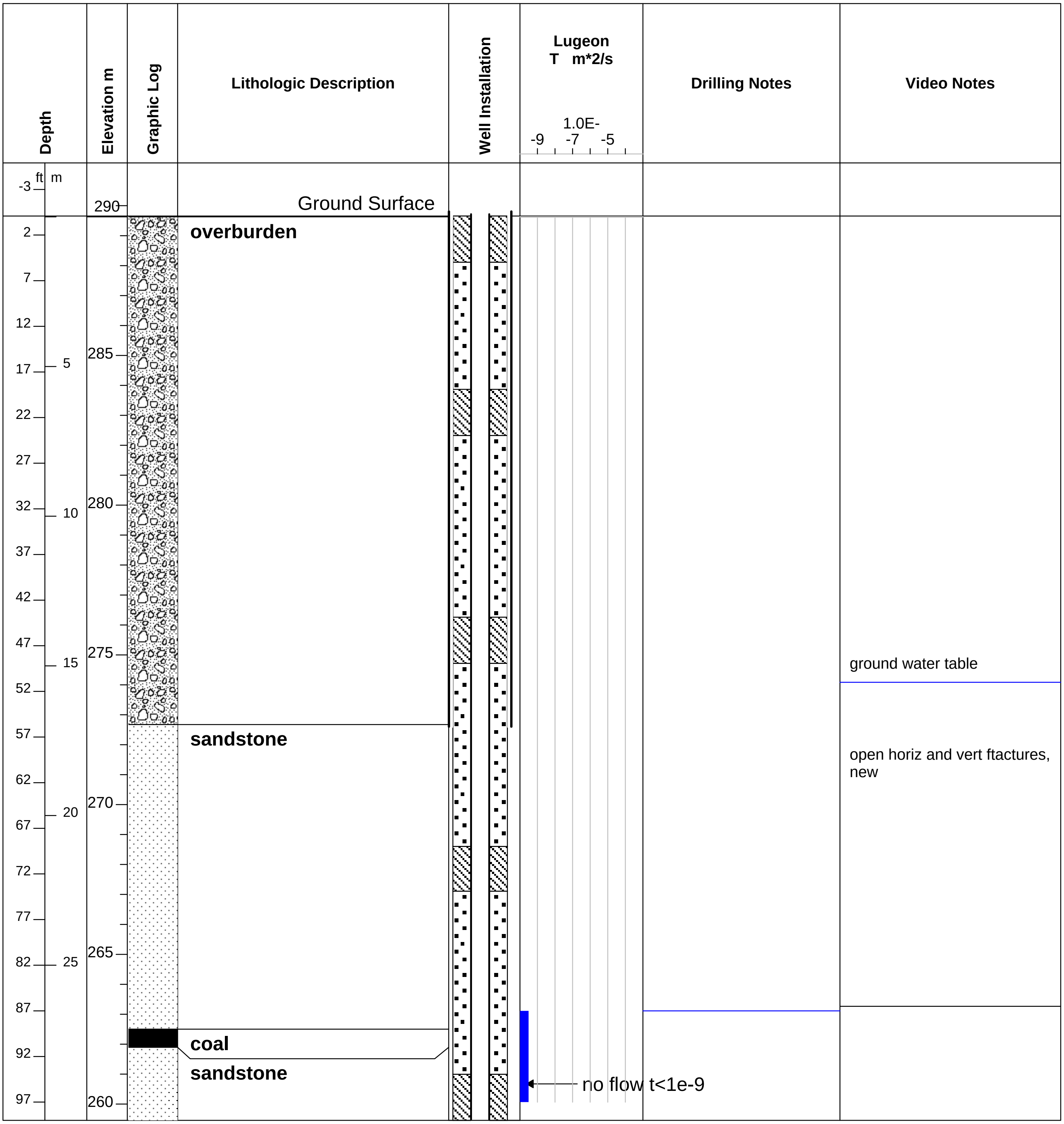
start of large open fractures

no fractures noted from 348 to EOH. Water table (probable block)

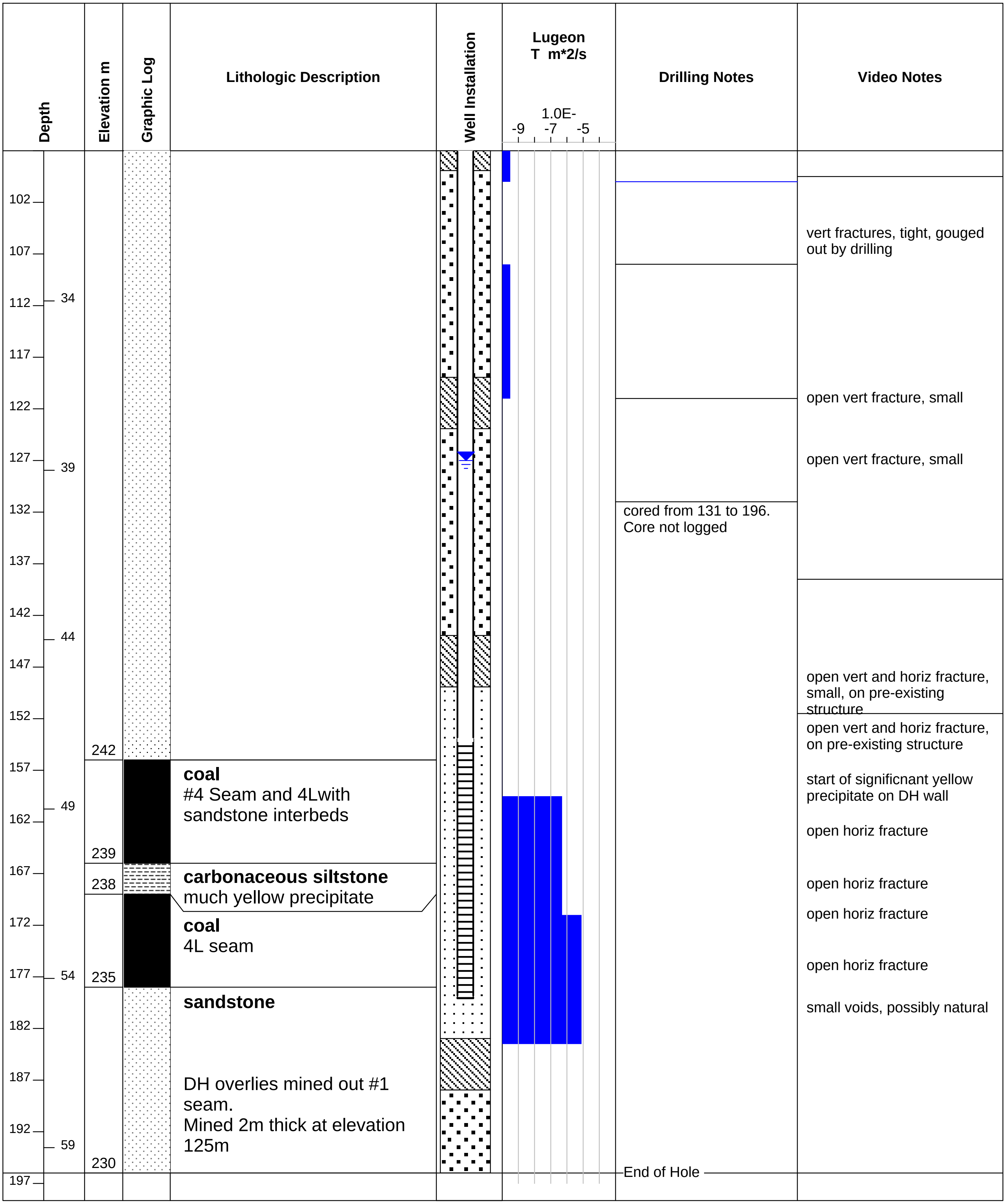
LOG FOR DRILLHOLE #: Qu10-16

Page: 1 of 2

Client: Hillsborough Resources	**Co-ordinates: 323904.3 5534504.2 UTM**
Project: Quinsam Mine Subsidence	**Collar Elev.: 289.63 m**
Drilling Method: Rotary / Core	**Dip/Dip direction: vert**
Drilling Contractor: DrillWell	**Total Depth: 196 ft**
Engineer: M Cullen, L Fletcher	**Casing Depth: 5 ft**
Date Started: Nov 27	**Hole dia: 6 inch (155mm)**



LOG FOR DRILLHOLE #: Qu10-16



coal
#4 Seam and 4Lwith sandstone interbeds

carbonaceous siltstone
much yellow precipitate

coal
4L seam

sandstone

DH overlies mined out #1 seam.
Mined 2m thick at elevation 125m

cored from 131 to 196. Core not logged

End of Hole

vert fractures, tight, gouged out by drilling

open vert fracture, small

open vert fracture, small

open vert and horiz fracture, small, on pre-existing structure

open vert and horiz fracture, on pre-existing structure

start of significnant yellow precipitate on DH wall

open horiz fracture

open horiz fracture

open horiz fracture

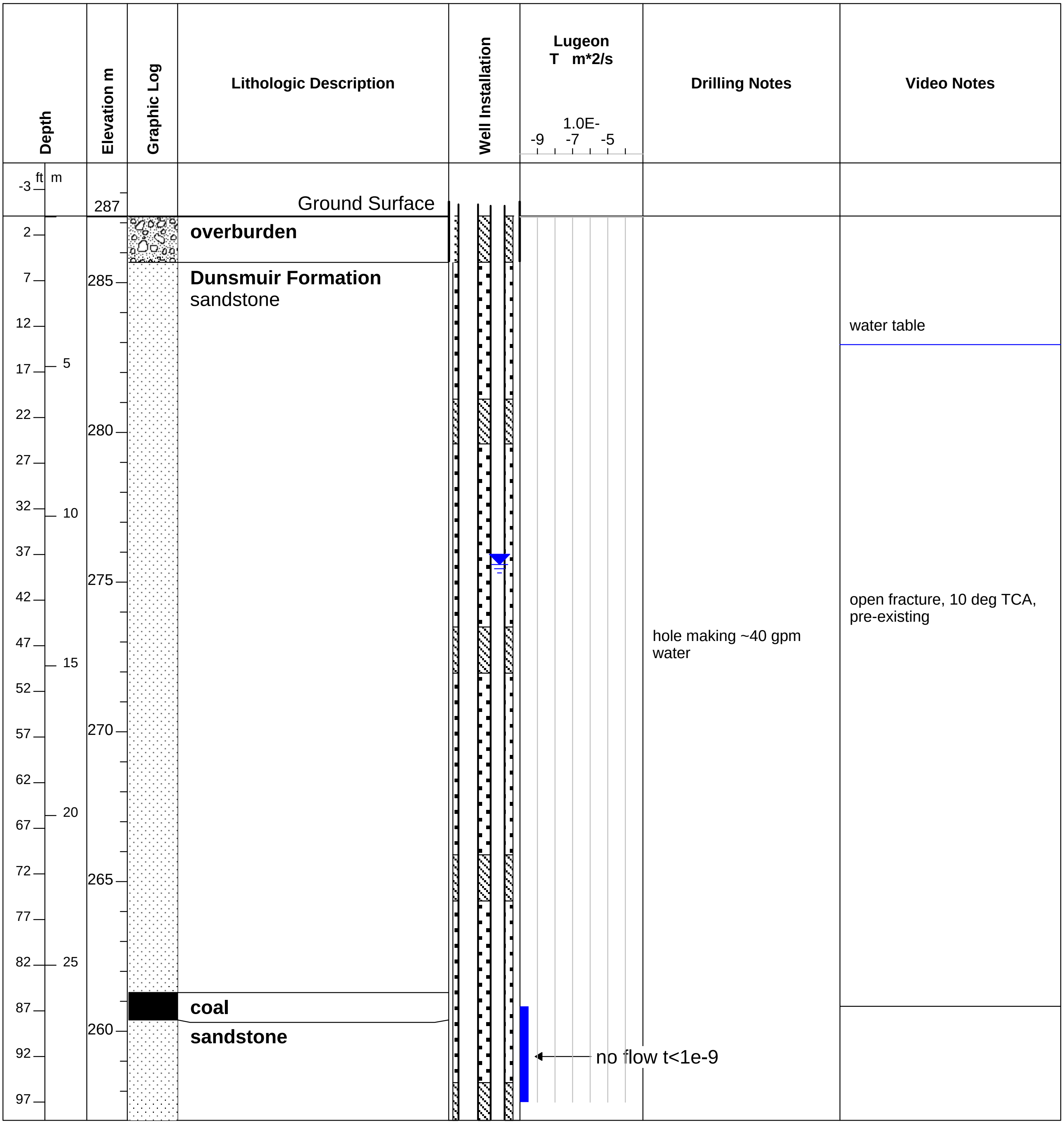
open horiz fracture

small voids, possibly natural

LOG FOR DRILLHOLE #: Qu10-17

Client: Hillsborough Resources
Project: Quinsam Mine Subsidence
Drilling Method: Rotary / Core
Drilling Contractor: DrillWell
Engineer: M Cullen, L Fletcher
Date Started: Nov 27

Co-ordinates: 323957.8   5534599.3 UTM
Collar Elev.: 287.21 m
Dip/Dip direction: vert
Total Depth: 196 ft
Casing Depth: 5 ft
Hole dia: 6 inch (155mm)



overburden

Dunsmuir Formation
sandstone

coal

sandstone

no flow t<1e-9

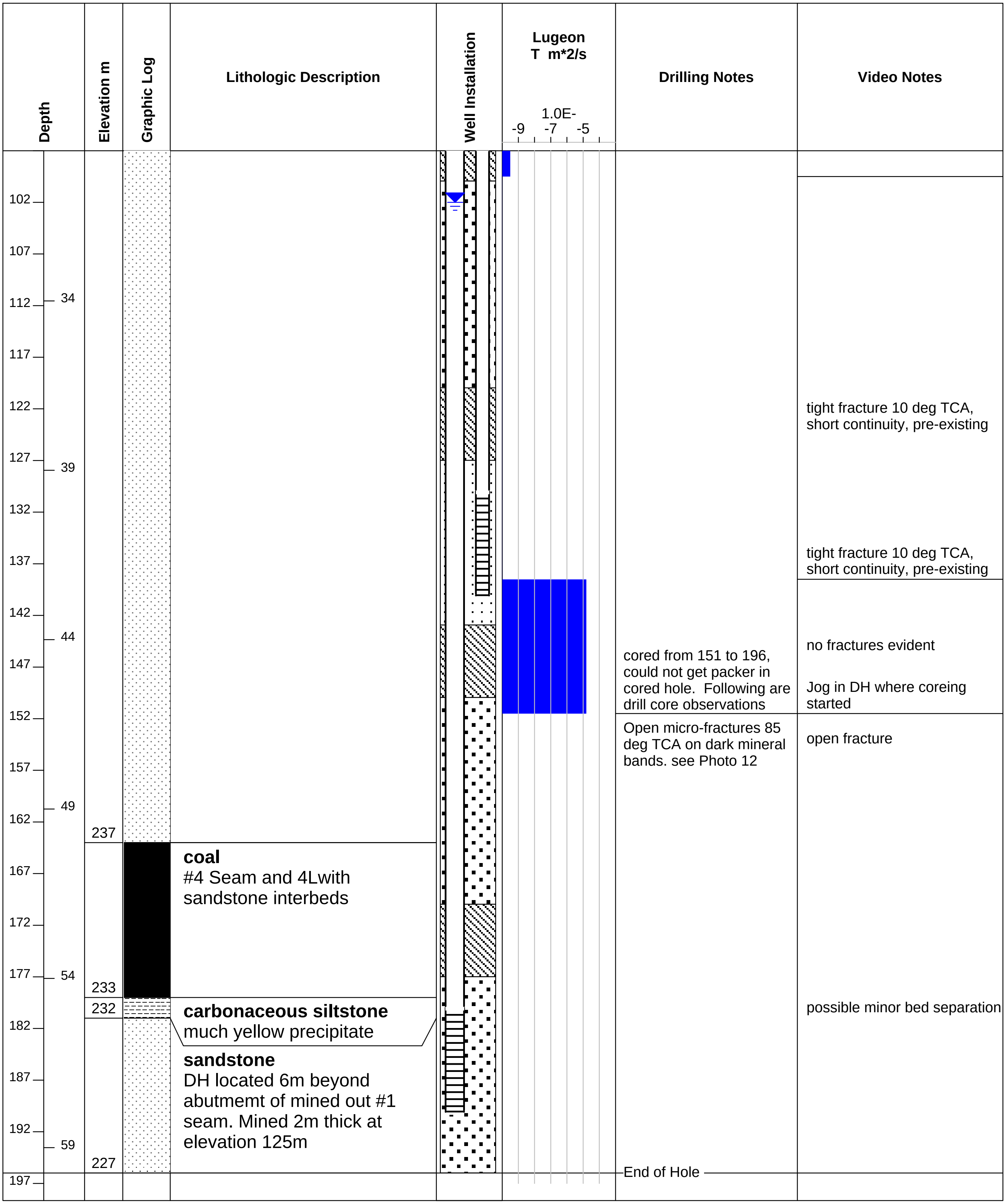
Drilling Notes: hole making ~40 gpm water

Video Notes:

water table

open fracture, 10 deg TCA, pre-existing

LOG FOR DRILLHOLE #: Qu10-17



coal
#4 Seam and 4Lwith sandstone interbeds

carbonaceous siltstone
much yellow precipitate

sandstone
DH located 6m beyond abutmemt of mined out #1 seam. Mined 2m thick at elevation 125m

Drilling Notes

cored from 151 to 196, could not get packer in cored hole. Following are drill core observations

Open micro-fractures 85 deg TCA on dark mineral bands. see Photo 12

End of Hole

Video Notes

tight fracture 10 deg TCA, short continuity, pre-existing

tight fracture 10 deg TCA, short continuity, pre-existing

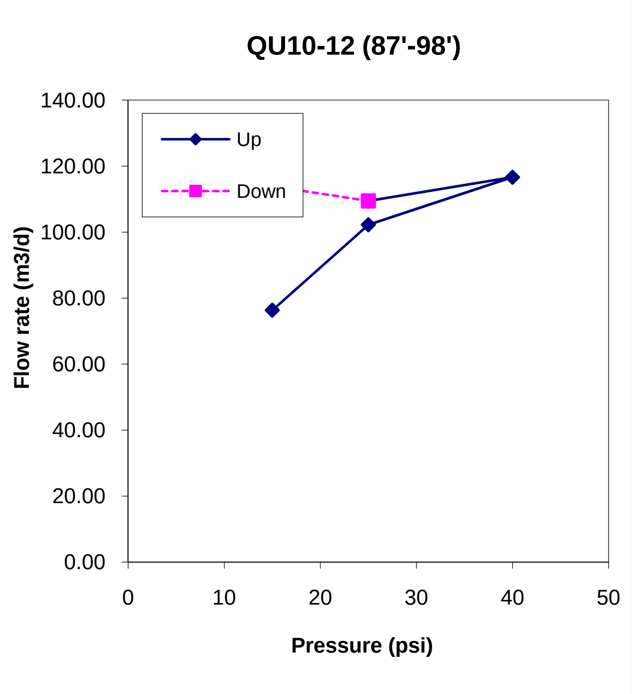
no fractures evident

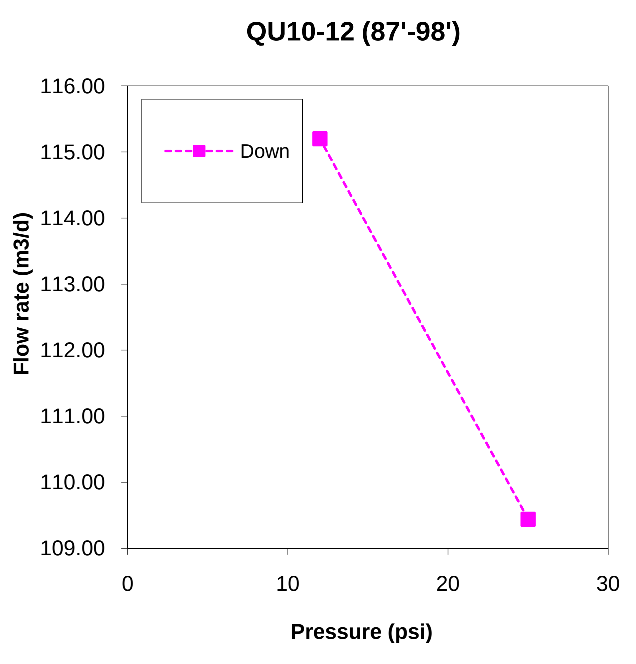
Jog in DH where coreing started

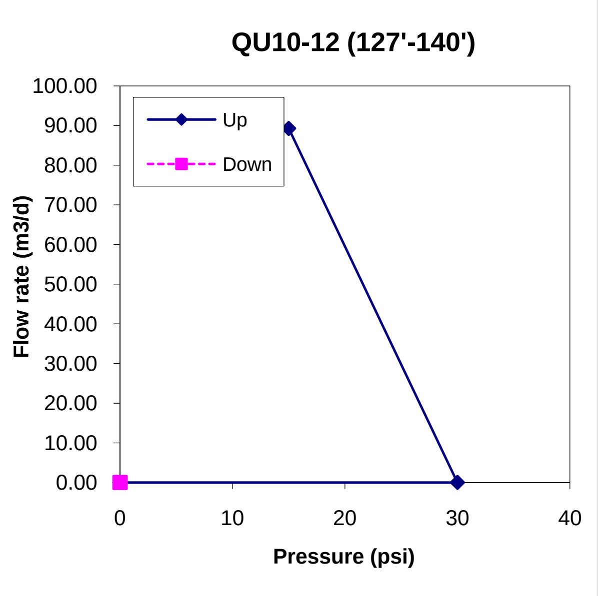
open fracture

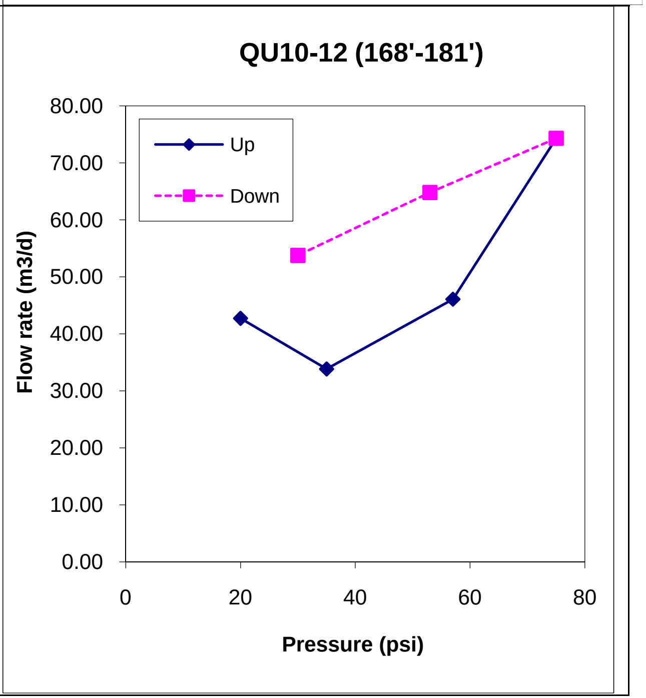
possible minor bed separation

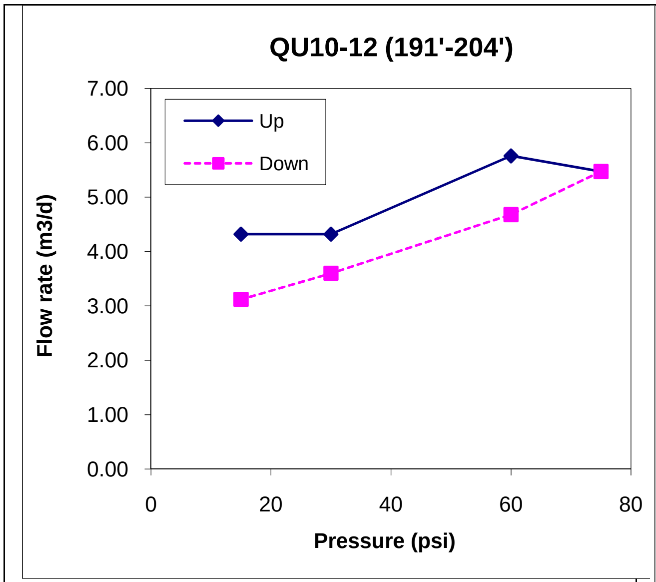
Appendix 3: Results from Packer Testing

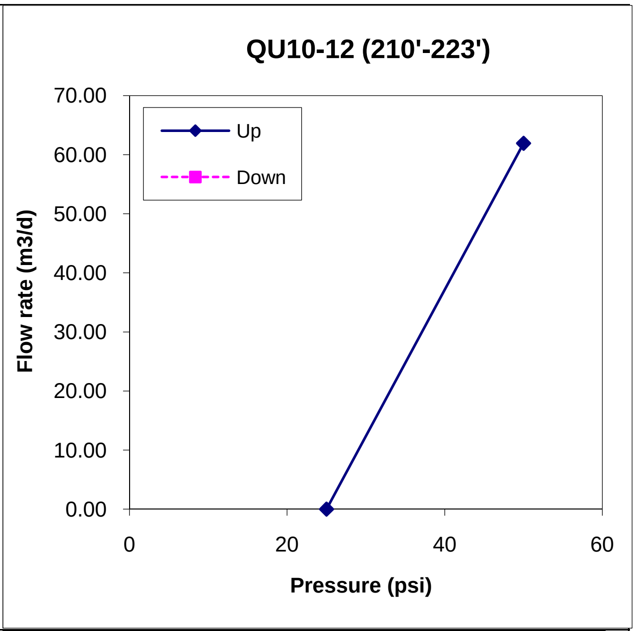


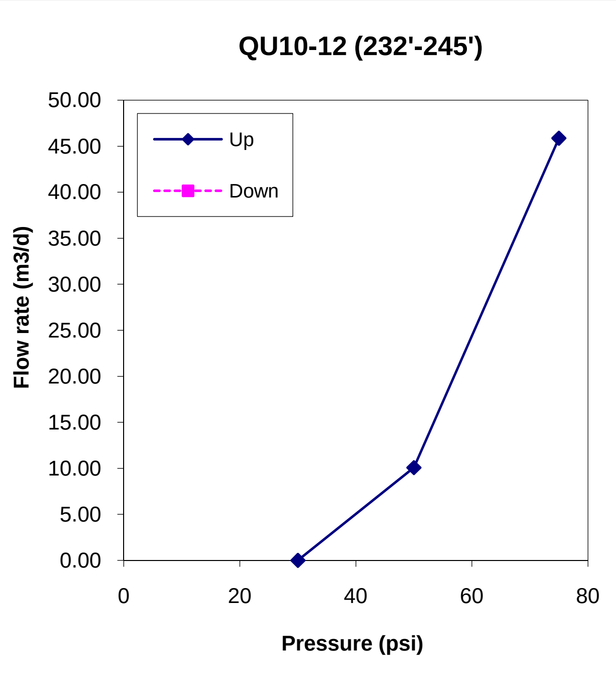


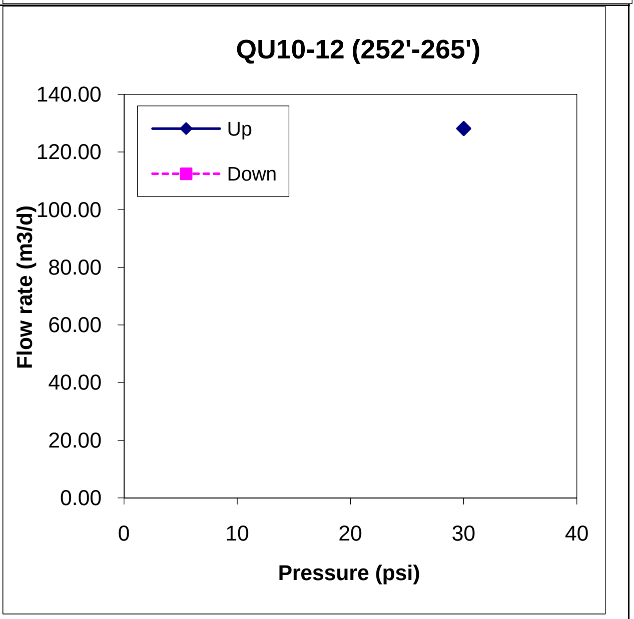


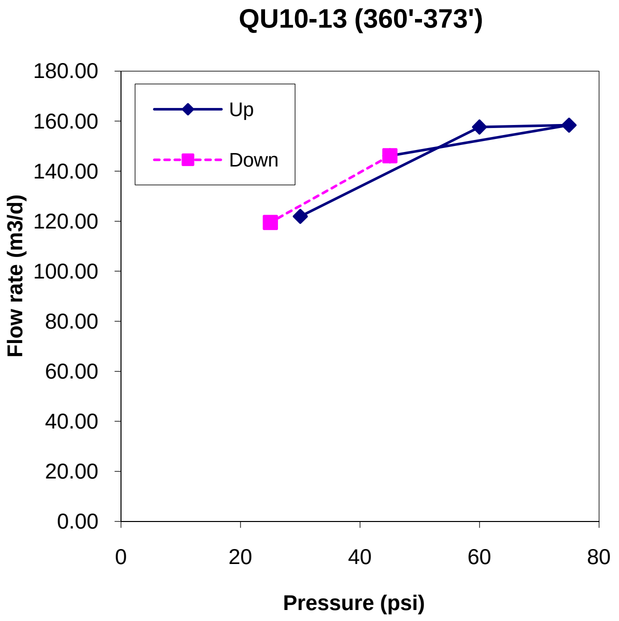


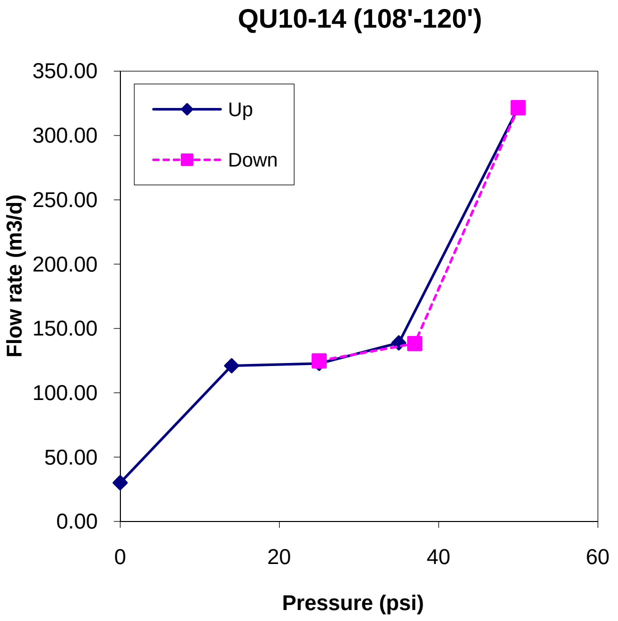

QU10-12 (191'-204')

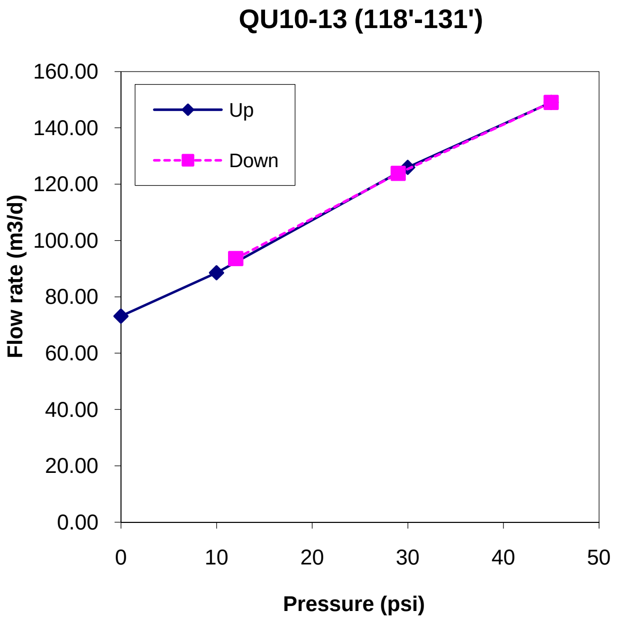

QU10-12 (210'-223')

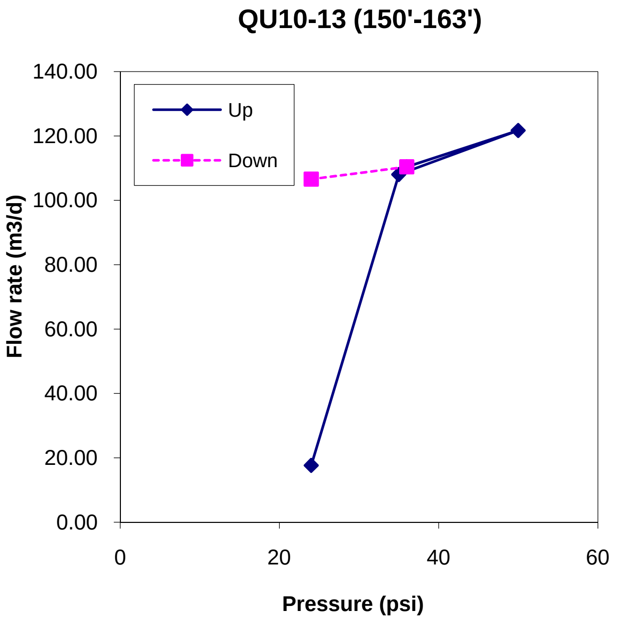

QU10-12 (232'-245')


QU10-12 (252'-265')

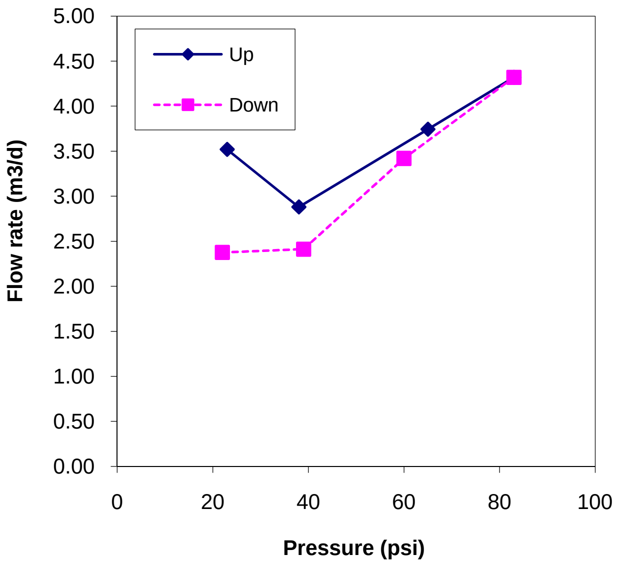

QU10-13 (360'-373')


QU10-14 (108'-120')

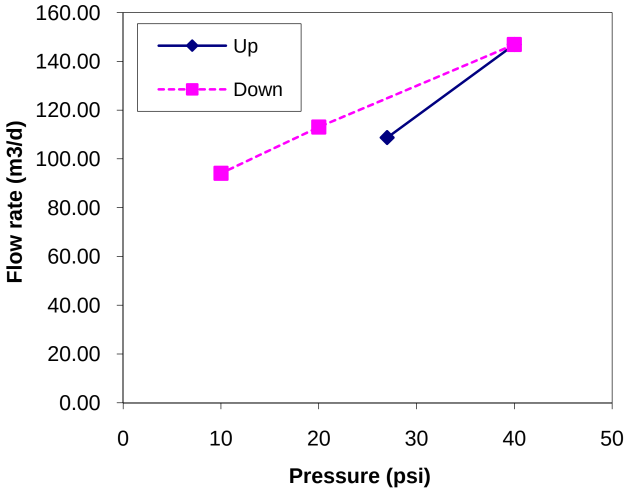

QU10-13 (118'-131')


QU10-13 (150'-163')

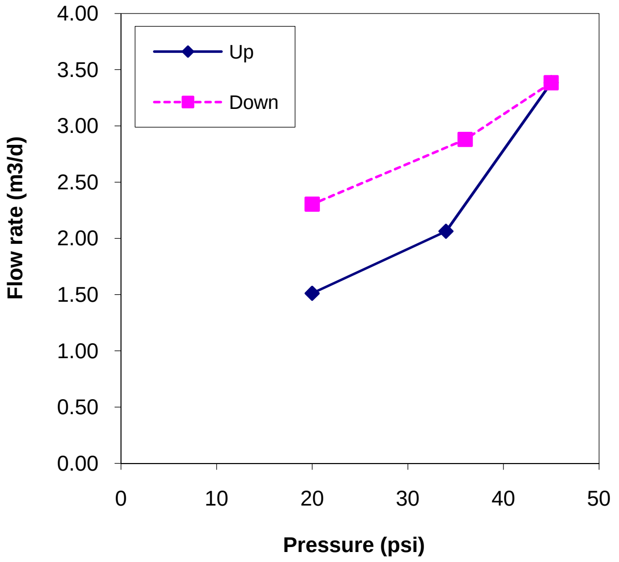
QU10-14 (192'-205')



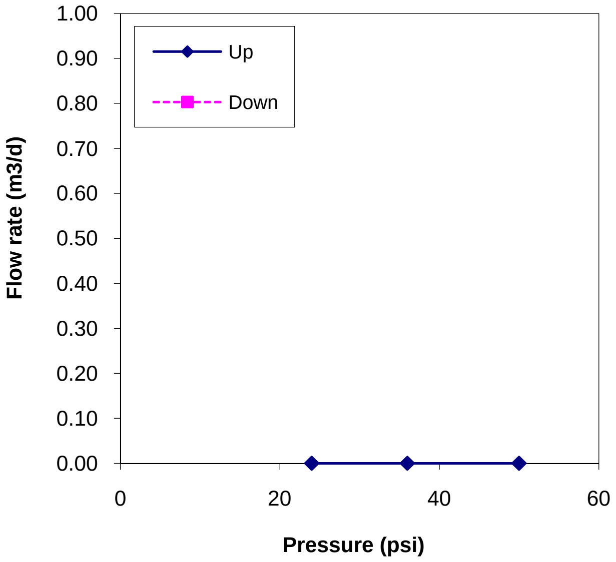
QU10-14 (234'-247')

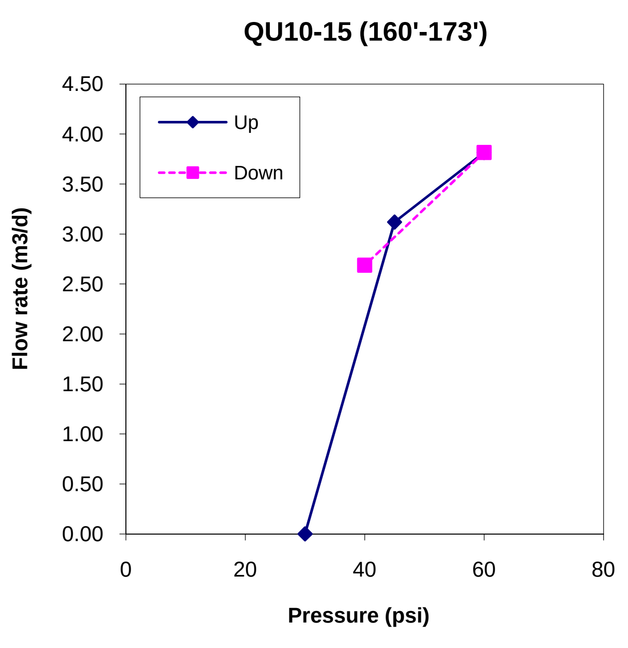


QU10-15 (87'-100')

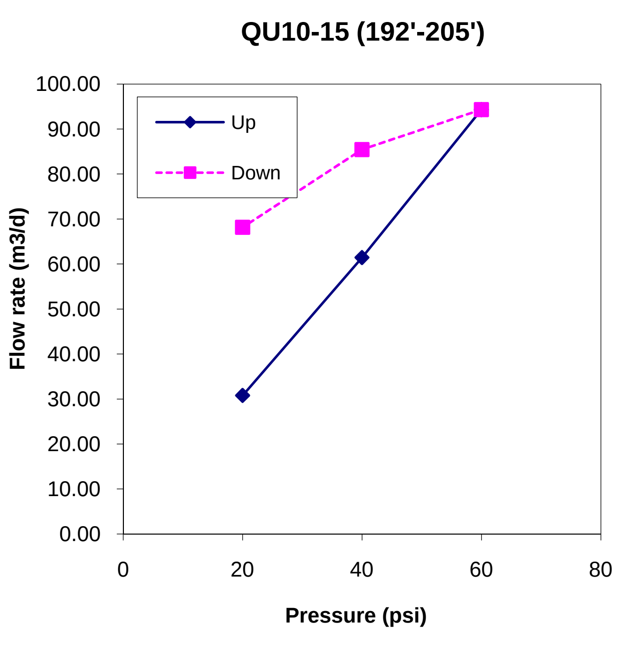


QU10-15 (108'-121')

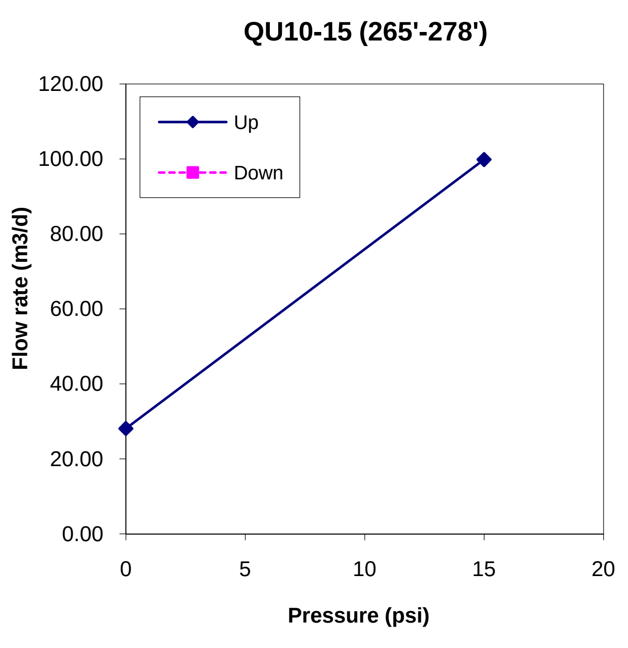




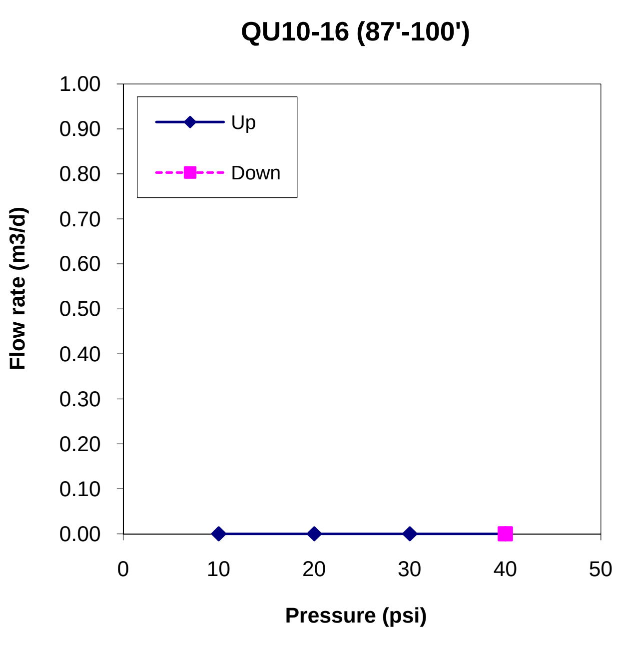
QU10-15 (160'-173')



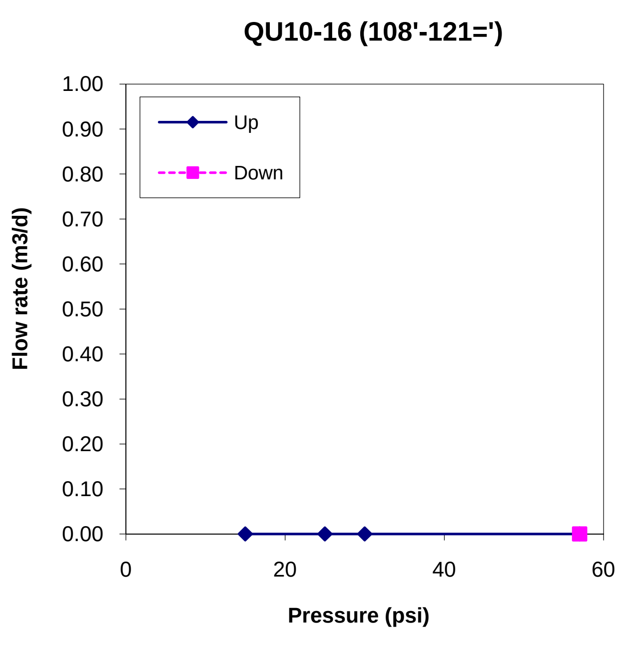
QU10-15 (192'-205')



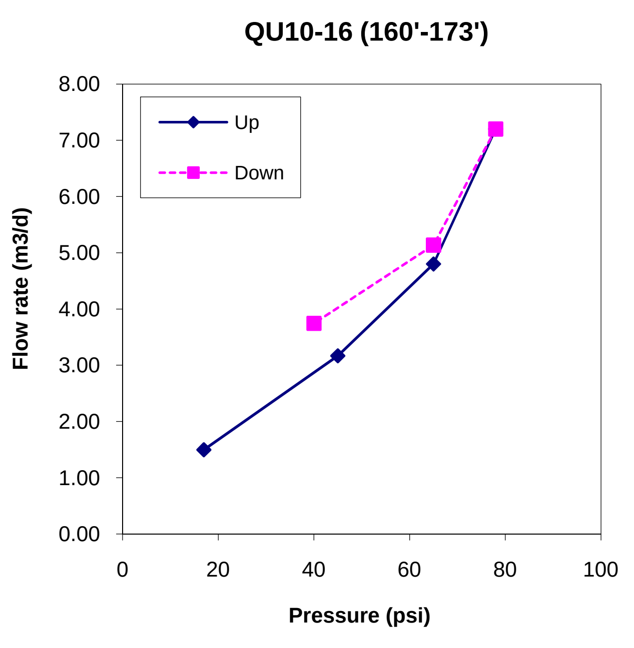
QU10-15 (265'-278')



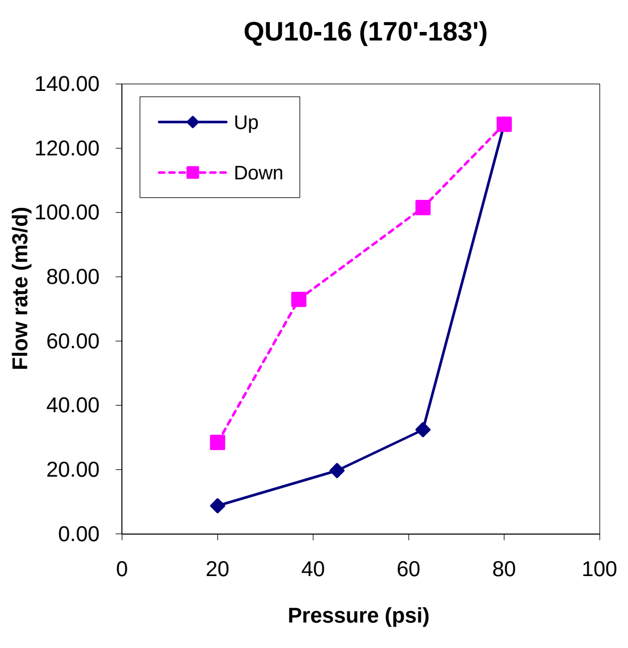
QU10-16 (87'-100')



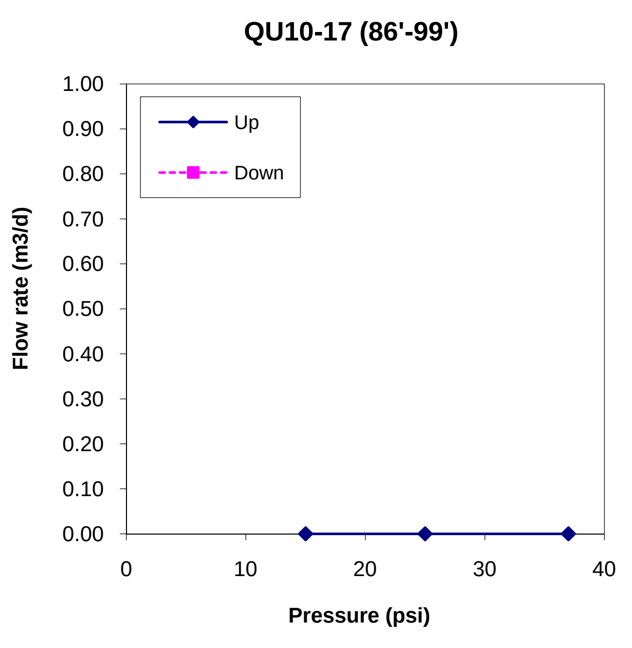
QU10-16 (108'-121=')



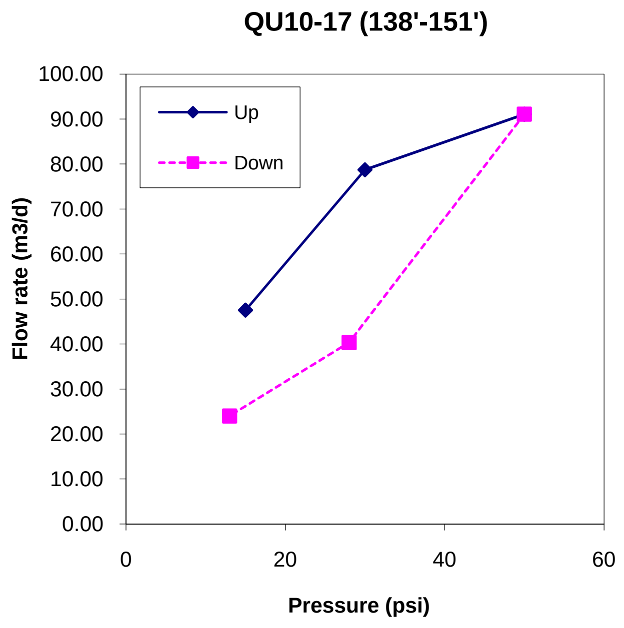
QU10-16 (160'-173')



QU10-16 (170'-183')



QU10-17 (86'-99')


QU10-17 (138'-151')
Up
Down
Flow rate (m3/d)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
20
40
60
Pressure (psi)

Appendix 4: Results From AMSS and ARMPS Analysis

```
AMSS module build: 1.0.56
Project File: 7S 5S Interaction Assessment
Input Units:  (ft) (psi)

 [MULTIPLE SEAM PARAMETERS]
Interburden Thickness.........360 (ft)
Previous Mining...............Gob Solid Layout
Vertical Position.............Active OVER Previous
Active Seam Mining Mode.......Analysis of Retreat Mining Pillar Stability

[PREVIOUS SEAM PARAMETERS]
Seam Thickness....................................8 (ft)
Width of Gob.....................................400 (ft)
Age of Workings..................................2 years

[ACTIVE SEAM PARAMETERS]
CMRR.............................................80

[ARMPS DATA]
Entry Height......................................10 (ft)
Depth of Cover....................................165 (ft)
Crosscut Angle....................................90 (deg)
Entry Width.......................................20 (ft)
Number of Entries.................................4
Crosscut Spacing..................................60 (ft)
Center to Center Distance #1......................60 (ft)
Center to Center Distance #2......................60 (ft)
Center to Center Distance #3......................60 (ft)

[ARMPS DEFAULT PARAMETERS]
In Situ Coal Strength.............................900 (psi)
Unit Weight of Overburden.........................162 (pcf)
Breadth of AMZ....................................64 (ft)
AMZ set automatically

[ARMPS RETREAT MINING PARAMETERS]
Loading Condition.................................DEVELOPMENT

[AMSS Output]

[MULTIPLE SEAM PILLAR STABILITY FACTORS]
Development Stability Factor......................2.79

Development pillar SF exceeds suggested value of 1.50

[PREDICTED CONDITIONS]
Development: GREEN:  A major interaction is unlikely.

Retreat: GREEN:  A major interaction is unlikely.
```

```
[CALCULATED STRESSES]
Single seam development stress....................418 (psi)
Multiple seam stress..............................252 (psi)
Total vertical stress (Development)..............670 (psi)

[SUGGESTED CRITICAL INTERBURDEN AND STRESS]
  Critical Interburden for Development............115 (ft)
  Allowable Total Vertical Stress.................7735 (psi)
If a pattern of supplemental roof support is installed, then:
  Critical Interburden for Development............35 (ft)
  Allowable Total Vertical Stress.................7362 (psi)

[ARMPS STABILITY FACTORS]
DEVELOPMENT........................4.48

[ARMPS STABILITY FACTORS - MULTI SEAM CONDITIONS]
DEVELOPMENT........................2.79

[ARMPS DATA ABOUT THE ACTIVE MINING ZONE (AMZ)]
AMZ Width...............................180.0 (ft)
AMZ Breadth.............................64.0 (ft)
AMZ Area................................11520.0 (ft)*(ft)
Extraction Ratio Within AMZ.............0.56
Development Load on AMZ.................3.08E+08 (lbs)

TOTAL LOADINGS ON AMZ, INCLUDING TRANSFER FROM BARRIERS
        LOAD       ABUTMENT     LTRANSBAR     LTRANSREM        TOTAL
     CONDITION    LOAD (lbs)      (lbs)         (lbs)          (lbs)
    DEVELOPMENT    0.00E+00      0.00E+00      0.00E+00      3.08E+08

R-Factor for front abutment is the percent of the total
front abutment load that is applied to the AMZ.

R-Factor for side abutment is the percent of the total
side abutment load that is applied to the barrier pillar
(the remainder is applied to the AMZ).

LTRANBAR is the load transferred to the AMZ from the
barrier pillar between the side and active gob if the
barrier's SF is less than 1.5.

LTRANSREM is the load transferred to the AMZ from the
remnant barrier between the side and active gob if the
remnant's SF is less than 1.5.

[ARMPS PILLAR PARAMETERS]
PILLAR       ENTRY      MINIMUM      MAXIMUM
           CENTER     DIMENSION    DIMENSION
             (ft)        (ft)         (ft)
    1       60.00       40.00        40.00
    2       60.00       40.00        40.00
    3       60.00       40.00        40.00
```

```
PILLAR      AREA     STRENGTH  LOAD-BEARING
                              CAPACITY
       (ft)*(ft)      (psi)       (lbs)
   1     1.60E+03     1.87E+03     4.31E+08
   2     1.60E+03     1.87E+03     4.31E+08
   3     1.60E+03     1.87E+03     4.31E+08

TOTAL LOAD-BEARING CAPACITY OF PILLARS WITHIN AMZ: 1.38E+09 (lbs)

[ARMPS STRESS ON INDIVIDUAL PILLARS WITHIN THE AMZ]
DEVELOPMENT STRESSES..............................418 (psi)
```