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CENTENNIAL COAL
CLARENCE COLLIERY

Trials of the Thin Sprayed Liner "Silcrete" for Rib Control Purposes

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REPORT TO :

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EXECUTIVE SUMMARY

This report summarises the initial outcomes of trials of a Thin Sprayed Liner (TSL), "Silcrete", for rib control on the Katoomba Seam at Clarence Colliery. The key questions addressed are:

- The functionality of the polymer lining; what it does.
- The performance of the lining, in the context of local ground behaviour.
- Implications for future applications at the mine and also elsewhere.

Silcrete is a current generation, urea-silicate ("PUS") resin; the applicator is DSI Underground and the manufacturer is Polymer Group Ltd. It has been used and trialled in several civil and mining applications, but the ongoing Clarence Colliery trials are the first rib control application in an underground coal mine in Australia.

The report presents some of the background to the development to the main polymer types of relevance to the Australian coal mining industry. However, it was not the purpose of this study to compare commercial products or list all the available, potentially useful, TSL options. The relevant technologies are continually evolving and there will remain a need to keep up-to-date by liaising with local applicators and manufacturers on product developments.

From a geotechnical perspective, the critical issue is the ability of the TSL to achieve (at least) a comparable rib support outcome to existing or alternative systems. In the Katoomba Seam environment, this study has found that the main function of the Silcrete is to penetrate dilated discontinuities (fractures, joints, cleats, bedding planes, etc.) within the immediate coal rib, thereby gluing blocks together to form bigger, more stable blocks and increasing mechanical interlock by filling the gaps between blocks, restricting relative movement and unravelling.

The highly favourable trial outcomes to-date are considered to reflect:

- the properties of the Silcrete,
- the properties of the rib and
- the timing and nature of rib deformation.

The key properties of Silcrete as a TSL are considered to be:

1) Crack penetration.
2) The absence of foaming (i.e. not forcing blocks of coal outwards and/or apart).
3) A very rapid build-up in adhesive strength (this also reduces wastage / drips).
4) A rapid build-up in tensile strength, creating a composite rib mass.
5) Compressive strength and stiffness (partly due to the lack of foaming), lending cohesion and rigidity to the final mass.

TSL performance is influenced by the coal seam properties and, in particular, the following:

a) Cleat spacing and properties, including the propensity for early dilation along cleat planes: the wider / bigger the discrete coal blocks and the more the resin can penetrate between those blocks, the more stable the final mass.

b) Coal strength: stronger coals will enhance the strength of the final aggregate mass.

c) In-seam dirt bands: the thickness and hardness of persistent partings / dirt bands would influence TSL adhesion and bridging across blocks.

Rib deformation in the Katoomba Seam is characterised by:

- immediate buckling due to dilation on discontinuities in the first metre of rib (mainly cleat planes) on drivage,
- minimal post-drivage deformation and
- the progression of fracturing deeper into the rib during secondary (partial) extraction.

Underground monitoring indicated that a Silcrete liner with an average thickness of 5-8mm maintained adequate stability of the rib through to the completion of extraction in the first Clarence Colliery trial in 908 Panel; the second trial site in 818A Panel will be extracted later this year. Furthermore, the available data suggests that the TSL may exceed the performance of the existing conventional rib support system (i.e. bolts and mesh). However, a larger local data set will be required to facilitate a full comparison.

The future potential of the Silcrete TSL at Clarence will be heavily influenced by productivity considerations and, in particular, the ability to incorporate the liner application into the mining process in a manner that facilitates large-scale use. A key aspect of this will be future controls / restrictions on the Silcrete application process. The Clarence process appeared to be well controlled and the environment appeared benign during application.

Regarding the potential success of Silcrete elsewhere in the underground coal mining industry, it is again noted that the outcome is a combined function of the properties of the Silcrete and the rib, as well as the timing and nature of rib deformation. Most mines would be able to quickly estimate the likelihood of success of a TSL trial, based on consideration of these parameters.

1.0 INTRODUCTION

This report outlines the initial trials of a Thin Sprayed Liner material, “Silcrete”, at Clarence Colliery and aims to summarise the practical and geotechnical outcomes to-date. The key questions addressed are:

- The functionality of the polymer lining; what it does.
- The performance of the lining in the context of local ground behaviour.
- Implications for future applications at the mine and elsewhere.

Silcrete is a urea-silicate (“PUS”) resin from DSI that is manufactured by Polymer Group Ltd. It has been used and trialled in several civil and mining applications, but the Clarence Colliery trials are the first use of the material for rib control in an underground coal mine in Australia.

The concept of Thin Sprayed Liners (“TSLs”) for ground control purposes has been around for at least 40 years. However, interest has grown markedly over the last two decades, as the understanding of both liner material properties and the interaction with the strata has grown.

From the mining perspective, the two critical issues are:

i) The ability of the TSL to achieve (at least) a comparable support outcome to existing / alternative systems.

ii) The potential for TSL application to productively and economically integrate into the mining process. This issue is not addressed in this report.

The report presents some of the background to the development to the main polymer types of relevance to the mining industry. However, it was not the purpose of this study to compare commercial products and it has been practically impossible to list all the available, potentially very useful, TSL material options. Therefore, the strategy adopted has been simply to “point the reader in the right direction”, such that “doing the homework” on a site-specific application becomes easier / more structured and the quality of the questions asked / dialogue improves.

Finally, it is important to note that the relevant technologies continue to evolve and some of the key information is not readily available; it represents the intellectual property of the polymer manufacturers and the applicators. Therefore, there will remain a need to keep up-to-date by liaising with the local applicators on product developments.

2.0 THIN SPRAYED (OR “SPRAY-ON”) LINERS

Sprayed liners for the purpose of improving tunnel stability date from the invention of shotcrete (i.e. sprayed concrete, originally patented as “Gunite”) in the USA in 1907. Subsequently, shotcrete technology has focussed on improving:

a) material properties, including specifically tensile strength and early strength,

b) process productivity, including the replacement of mesh with fibre-reinforced shotcrete and equipment developments / mechanisation and

c) rock mass characterisation, including the development of classification schemes, such as the Norwegian Geotechnical Institute’s Q System, for the purpose of support optimisation.

These technological improvements have generally sought to “achieve more with less”, given that the logistics of bulk material handling often dictate the efficacy of the overall operation.

Since the earliest applications of shotcrete as remedial support, it has become apparent that liners can serve several purposes, including control of the following (as well as combinations thereof):

- Strata
- Water
- Gas
- Spontaneous combustion

As applications proliferated, the functionality of liners evolved, becoming increasingly task-specific. In civil construction, for example, this now often includes colour matching of the liner to the host rock.

In mining, site-specific considerations include the following:

i) The service life of the excavation.

ii) The nature of the strata control issue, from simple weathering protection (sealing) to the control of active, large-scale fracturing.

iii) Liner permeability, in the case of water, gas and spontaneous combustion control.

iv) Liner mechanical properties, including adhesion, early strength, tensile strength, long-term strength, durability, viscosity, deformation characteristics, crack penetration capabilities and sensitivity to the mine environment (heat and water / humidity).

v) Application constraints, including liner material toxicity and flammability, as well as mine site familiarity and operator experience / training.

vi) The logistical issues associated with bulk handling favour the application of the minimum appropriate volume of material, making “Thin Sprayed Liners” or “TSLs” a relevant option of interest. In this regard, “thin” has come to mean <15mm and typically <10mm.

Overall, the desirability of achieving:

- improved logistics, via reduced material volumes,
- higher early strength and
- improved tensile strength, in particular,

has very largely driven the trend towards the increased use of polymers in underground mining applications since the 1960s. An overview of the main, relevant polymer types is provided in the following sub-section.

2.1 Relevant Polymer Types

In coal mine ground control, the three main polymer types that have been used for both strata injection and cavity filling are summarised as follows.

2.1.1 Phenolic / Phenolic-Formaldehyde (“PF”) Resins

These were developed from 1872 onwards and initially patented in 1907 as “Bakelite”; they became the first commercial plastics. Formed by combining phenol (an alcohol sourced from coal tar) and formaldehyde (a gas derived from methane), phenolics were noted for their adhesive and fire-resistant properties; they will char, but not burn. PF resins found widespread early application in electrical devices and are still highly utilised in situations that prioritise fire-resistance, including as adhesives in the manufacture of composite timber / building products and, in mining, for fibreglass ventilation tubes. However, PF resins tend to be more brittle and lower in strength than alternative polymers.

2.1.2 Polyurethane (“PUR” or “PU”) Resins

These were also developed from the late 19th Century onwards and commercialisation began in 1937, when **Professor Otto Bayer** and his German colleagues patented "***A Process for the Production of Polyurethanes and Polyureas***”. Formed by combining a diol or polyol (an alcohol with two or more reactive hydroxyl groups per molecule) with a di- or poly-isocyanate, polyurethanes were initially noted for their adhesive and elastic properties; their earliest application was in the production of synthetic rubber. The propensity for PUR to foam in the presence of water due to the generation of CO_2 bubbles was discovered in 1941 and led to the widespread use of PUR foam in the furniture industry and for insulation.

2.1.3 Urea-Silcate (“PUS”) Resins

As with PUR, the chemistry dates from the late 19th Century and relates to the work of **Prof. Bayer** in particular, but commercial applications only appear to date from the early 1970s. Formed by combining an alkali, sodium silicate (“water glass”) with a di- or poly-isocyanate, urea-silicates were noted for their adhesive and fire-retardant properties (>50% incombustible material). PUS resins have found increasing application as strong, durable protective coatings / liners in the building industry. Early silicate isocynate resin (“SIR”) formulations were very brittle; these resins have improved over time through the use of additives and terms such as “elastified silicate-isocyanate resin” (ESR) have been used to differentiate these improved materials, which developed since the late 1970s. Silcrete falls into this category of resin and the Technical Data Sheet for the product is attached as **Appendix A**.

2.2 Polymers as Ground Control Materials

Firstly, in assessing the application of polymers in underground coal mining, it is important to understand the chronology and, in particular:

i) The potential applications of PUR in the areas of strata consolidation, cavity filling and water sealing were identified first and pioneered by Ruhrkohle (RAG) at their Bergbau-Forschung GmbH research centre in Essen, West Germany during the late 1960s.

ii) The significance of the fire-resistant nature of PF resins has increased since the 1980s due to a number of incidents, including fires, associated with the exothermic PUR reaction. In this regard, it is worth noting that the 20th Century German coal industry was largely characterised by seam thicknesses of 1m to 3m, averaging 2.0-2.1m, such that heating issues associated with thicker seams would not have been prevalent.

iii) Major advances in PUS resin technology occurred later, notably from the 1990s onwards.

iv) Significant advances in the understanding of the relevance of a broader range of polymer properties were made between 1990 and 2010; for example, published research on liner permeability for gas, water and spontaneous combustion control only dates from 1993, even though the practical application of liners for these purposes dates (at least) from the 1980s. Many of the more recent advances have been driven by non-mining research, for example, in the fields of dam construction and post-earthquake building repair.

v) Much of the published literature relates to theoretical considerations, including laboratory test outcomes; there is very little of a practical, case-study nature to inform mine operators (**Butcher, 1987; Schaller and Russell, 1986; Strata Engineering, 2003**).

vi) The gradual decline of mining industry research bodies in the West has tended to "freeze" the general level of knowledge of the technology. Today, much of the understanding of current practice resides with polymer manufacturers, applicators / contractors and those individual collieries with site-specific circumstances and applications. Understandably, the intellectual property (e.g. with respect to additives in Component A) tends to be tightly held.

Therefore, in reviewing case studies, industry trends / preferences and the published literature on material properties, it is important to remember that polymer technology and the associated practices continue to evolve.

2.2.1 German Research

German coal industry research on the use of polymers for strata control is neatly summarised by **Junker (2009)**. The German research methodology was characterised by the development and application of laboratory tests that aim to mimic ground deformation processes, coupled to underground trials / investigations. The main points are as follows.

2.2.1.1 Deformation Work

The most important mechanical parameter was considered to be "Deformation Work". This parameter, which is little known outside of Germany, is the product of the load applied and the deformation withstood in a three-point bending test, see **Figure 1**. The test mimics the buckling of a roof beam or rib column. Deformation Work is a combined function of adhesive strength, tensile strength and the elasticity of the polymer. In simple terms, it measures the ability of the polymer to "keep on working" in an aggressive, actively deforming environment. Typical results are reproduced in **Figure 2**; the results for PUR are dramatically higher than any alternative product (either polymer or mineral / cementitious).

This led **Junker** to state the following:

> *"Only polyurethane resins are suited for the consolidation injection in front of the face. The bonding parameters, adhesive strength and deformation of other injection materials are too low to achieve an effective stabilisation in this dynamic, highly strained rock area above the coal face. However, pre-injections at larger distances from the face for the purpose of infilling larger cavities and to reduce costs can be carried out with mineral products".*

These findings underpinned the German focus on PUR for remedial work on longwall faces, which is consistent with Australian practical experience; PUR is, without known exception, the preferred tool for this application. The relevance of this finding to potential TSL applications warrants careful consideration and the following general comments are made:

i) Firstly, it is important to note that the relationship between “Deformation Work” and other polymer properties to any practical outcome, on the longwall face or elsewhere, is very largely empirical. Simply ranking polymers on the basis of their material properties is a useful step in developing an understanding of the ground support action and process, but ultimately a lower-ranked or “second choice” material may prove effective in a particular situation / environment.

ii) From the specific, roadway rib control perspective, it focuses attention on the timing and extent of rib movement versus the application of the polymer, both on drivage and through to the completion of the extraction process.

2.2.1.2 Adhesive Strength

The German measure of adhesive strength is also based on the three-point bending test and results against time are depicted in **Figure 3**. The following comments are made regarding these results:

i) PUS resins have the highest early (<1 hour) strength, which is very important for support processes that are on the “critical path” of the operation. This has very positive implications for the proposed Silcrete application as a TSL at Clarence (i.e. for immediate rib control).

ii) Although the graph suggests that the longer-term (>1 day) strengths of PUS and PUR are comparable, trade literature (data sheets) suggests that the current-generation PUS resins have consistently higher adhesive strengths than PUR.

iii) The “Slow” versus “Quick” PUR results illustrate the effect of additives to Component A, noting that the increased reaction time of “Slow” PUR increases fracture penetration, whereas “Quick” PUR is most useful in time-critical applications, such as water-sealing situations (i.e. to avoid wash-out of the polymer).

iv) The build-up of adhesive strength for cementitious products after 24 hours has to be seen in the context of the test method; cement should adhere to a grout block. However, it does confirm that these materials have some longer-term adhesion, which can be overlooked in ground consolidation applications (i.e. cements tend to be characterised as bulk fillers).

2.2.1.3 Crack Penetration

Crack penetration is a complex function of material parameters and environmental factors. One of several German laboratory tests involved measuring and comparing the build-up of the injection pressure over time at a standard (3mm) crack width, see **Figure 4**.

The following comments are made regarding these results:

i) The rapid build-up in pressure in the PUS resin is attributable to the slightly higher viscosity of the urea-silicate and the high speed of reaction (relative to PUR). The reaction speed is defined by the “Limit” or “Border Time”, the time taken to reach an adhesive strength of 1

MPa (this is referred to as the "Border Strength"). Limit or Border Times are typically < 5 minutes for PUS and ≥ 25 minutes for PUR.

ii) The build-up in pressure in the Quick PU resin is also attributable to the onset of foaming.

iii) The very slow build-up in pressure in the mineral grout reflects the slow reaction time of the cementitious material.

Viscosity is an important material parameter and the following is worth noting:

a) As PUS resins have evolved over the last 40 years, manufacturers have sought to lower the viscosity to achieve better crack penetration where required, such that some of the current generation products have comparable viscosities to PUR (i.e. 200-250 mPas). Conversely, it is possible to increase viscosity where appropriate (e.g. for cable grouting).

b) Viscosity has a strong inverse relationship to temperature. This has implications for crack penetration and, in the context of TSLs, it impacts on the ability to spray the material.

The German crack-width test involved injecting polymer into a crack between two rectangular grout blocks. Over a series of tests, the crack width was progressively reduced, until the crack could not be completely filled prior to hardening. The outcomes were then benchmarked against alternative materials, as illustrated in **Figure 5**. The following comments are made regarding these results:

i) Comparable performance is attainable between microfine cements, Quick PUR and PUS resins.

ii) Slow PUR has the smallest crack limit, which again is consistent with the use of such materials in water sealing applications.

The motivation for the assessment of crack penetration is obviously the theoretical desirability of filling all cracks during the ground remediation process. However, field investigations tend to indicate that some cracks go unfilled **(Strata Engineering, 2003)**. The significance of this depends on:

- the application (for example, in water sealing operations, it is usual to aim for 100%) and
- the practical, empirical result (i.e. is the desired outcome achieved, in terms of roof / rib stability).

Crack (including mining-induced fractures and pre-existing discontinuities) penetration is an important parameter for TSLs, as it influences the resistance to buckling of the sprayed rib, as will be discussed later.

2.2.1.4 Compressive Strength

Compressive strength is a function of the material properties, including the propensity of the polymer to foam. PUR foams in the presence of moisture, whereas PUS resin is hydrophobic and require additives, if foaming is desirable. Accordingly, compressive strength values vary widely, see **Figure 6**. The German approach to compressive (and tensile) strength testing involved the preparation of prisms (rectangles of polymer) that were vertically loaded.

For ground consolidation purposes, the Germans did not prioritise compressive strength; they were more interested in Deformation Work and regarded the foaming action of PUR as very positive, as it was considered to promote crack penetration (due to PUR “chasing” moisture) and adhesion.

However, for other applications, including cable grouting and TSLs, compressive strength is more relevant and foaming is undesirable. It is therefore worth noting that, depending on the foam factor of the PUR, the compressive strength of current PUS resins is typically much higher in practice.

It should also be noted that Australian experiences with, and attitudes towards, foaming differ, with many operators wary of causing highly fractured ribs to simply bulge or even “blow out” due to polymer injection and expansion. On longwall faces, for example, this has resulted in a trend towards deeper packer locations over the years.

2.2.1.5 Summary of German Research

German coal industry research into the use of polymers and other materials for strata control purposes illustrates a pragmatic approach to product development and problem solving in a geotechnical environment characterised by seam thicknesses of <3m. The preceding over-view assists in understanding their historical thinking and “how we got here”, especially with regard to the favouring of PUR for immediate, remedial ground consolidation on a longwall face, which persists to this day.

It also highlights the points of difference with other coal industries that have emerged over the last 50 years, including specifically:

- an increasing focus on fire-retardant / fire-resistant materials at seam thicknesses of >3m (also promoted by research in other countries, including France and Russia) and

- the proliferation of applications, including cable grouting and TSLs.

German research ended with the demise of their underground coal mining industry, a decade ago. A consequence has been an erosion of the commonality of laboratory testing approaches and associated understanding of practical implications. Accordingly, the technical literature, published papers and data sheets, now features a “smorgasbord” of test results and parameters, some of which have emerged from other industries. This can be unhelpful, when assessing products for a specific underground application. For example, it is now common to find flexural and tensile strength quoted in data sheets, both parameters being of interest to TSL applications. However, for the purpose of product comparison, it is vital that the testing methodology be understood, uniform and relevant to the proposed application.

2.2.2 Other Important Features of Polymers

The use of polymers and notably isocyanates in Australia (specifically NSW) is addressed by **MDG 3608: Non-Metallic Materials for Use in Underground Coal Mines (NSW DTI Mine Safety, 2012)** and in particular **Appendix D** thereof (**Polymeric Materials Test Manual –**

TRM003). Key stipulations in the guideline relate to underground polymer mixing by licensed operators, flammability and toxicity. By way of background to the NSW regulatory framework:

i) Following an incident at Westcliff Colliery in New South Wales in which PUR was found to have been responsible for a fire, the use of PUR was banned for four years (1986-1990). Subsequently, it was reintroduced on a risk-based approval basis, with restrictions on its use underground in coal mines. These restrictions include an injection limit of 200kg of PUR per hole, for any hole in which the PUR may come into contact with coal. Also, PUR may not be injected into strata that has been cement grouted within the previous 24 hours. Furthermore, PUR may not be used for cavity filling. These mass provisions do not apply to other polymers, such as PUS and PF resins.

ii) MDI, the Component B in Silcrete, is an irritant to skin, eyes and mucous membranes. An allergic respiratory reaction can cause asthma-like symptoms, if susceptible persons are over-exposed to isocyanate vapours.

iii) However, MDI has a low vapour pressure (i.e. a low propensity to vaporise), such that over-exposure should not occur, unless it is overheated or sprayed directly into the atmosphere. With regard to the latter, the pumps are designed to prevent the flow of any unmixed MDI.

iv) MDI is non-flammable, but it is combustible and if heated to >200^{o}C, it will decompose and emit toxic fumes.

v) As previously noted, the sodium silicate (Component A) of urea silicates such as Silcrete is non-flammable and non-combustible, although it is an alkali and should be handled accordingly.

The Silcrete product complies with the standards in MDG 3608 and was applied by competent DSI operators. In particular, the cured final resin is non-flammable and non-combustible (i.e. fire resistant). Further comments on these aspects are made later, in the context of the trial outcomes.

2.3 Summary - Polymers as TSLs

The key point from the preceding overview of polymer development and properties is that the technical suitability of a material is a function of the application. In this regard, the application of a polymer as a TSL for immediate rib control is very different from a more traditional strata injection / ground consolidation application. The application, in a given mining environment, determines the relative importance of the polymer properties. For example, it is relevant that the Silcrete PUS resin passes the anti-static test of MDG 3608, whereas some polymers (i.e. PUR) do not. The mechanics of rib behaviour and the key features of the Katoomba Seam are outlined in the following sections.

3.0 GENERIC RIB BEHAVIOUR MECHANICS

Essentially, there are three modes of rib behaviour, which can be summarised as follows:

i) Static behaviour, whereby the level of vertical stress is insufficient to cause failure of intact rib material and/or failure along pre-existing planes of geological structure or bedding, such as cleats, joints and clay bands. Static behaviour is the most stable condition, indicating that the rib retains appreciable beam action (self-supporting capability). It is characterised by ≤ 3mm of displacement, at a depth of 0.5m (i.e. excluding skin effects).

ii) Vertical stress-driven buckling, whereby the rib shears and separates predominantly along pre-existing geological structure (e.g. cleat and joints), displacing towards the roadway as an end-loaded column, see **Figure 7**. The potential for this mode of behaviour is typically associated with increased vertical stress, higher roadways / thicker seams, bright coal, weak / clay bands and/or structure sub-parallel (i.e. at <20°) to the roadway. If uncontrolled, the rib will shear and spall. Buckling is characterised by >3mm of displacement at a depth of 0.5m into the rib. This is the common mode of rib behaviour in the Katoomba Seam at Clarence Colliery.

iii) Geologically-driven block / wedge failure, whereby a section of rib shears along an existing plane (i.e. major structure, such as an inclined fault), see **Figure 8**. The probability of slip increases if the discontinuity is:

    a) dipping into the roadway at an angle of 50° to 70° to the horizontal,
    b) aligned sub-parallel to the roadway (i.e. within 20° thereof),
    c) clay-coated or slickensided,
    d) bounded along its upper surface by a weak band or plane and
    e) subject to a stress along the plane that exceeds its shear strength.

In terms of engineering adequate stability, support design should therefore recognise that:

i) Although a static rib can be said to be in an overall stable condition, the first 100 to 300mm or so could still break down and as a result, some form of rib support may be required as a means of surface protection or skin control. One of the main points to consider in this regard is the roadway's angle of intersection with geological structure and / or the presence of weak bands in the coal (e.g. bright coal and clay bands).

ii) In a buckling environment, the aim of the support system should be to limit displacement by maximising the thickness and hence, load-bearing capacity of any columns in the rib and also control material that may detach due to buckling. Considering the dynamics and geometry of rib deformation in a buckling environment, the support system should utilise the mechanical advantage inherent in a buckling column by ensuring that rib bolts are installed close to the face and concentrated around the buckling axis. Also, the bolts should anchor beyond potential failure zones and the system should incorporate some form of mesh, if the rib is susceptible to appreciable spall.

iii) Where geological structure-related block failure is considered likely, the rib support system should consider the need to anchor across significant discontinuities, such that they are reinforced and "keyed" into the main body of the rib. Also, there is a need to minimise the rib's propensity to buckling. As a minimum, the support system should aim to prevent sudden block detachment, which is a mechanism often associated with minimal warning and therefore a safety concern. The bolts should aim to anchor effectively beyond potential slip planes. "Mid-angle" structures, involving dip angles of 50° to 70° from the horizontal, are very rare in the Katoomba Seam at Clarence Colliery.

Rib height is a key parameter. The potential for rib deformation can be related to the height by considering the rib to be an end-loaded column subject to Euler buckling; this suggests that the propensity for buckling and instability is a function of the square of height. Therefore, if a 3m height is adopted as the standard (i.e. 100%), stability improves by 15% as the height reduces by ~7% from 3m to 2.8m (the latter being the current average height at Clarence).

The stability benefits of reduced drivage heights are compounded by three additional factors, namely:

i) Firstly, the hazard presented by rib instability increases with height, in that material falling from a height of say, 3.5m, has more capability for harm than the same material falling from 3m, as the potential energy associated with the falling mass increases linearly with height.

ii) Secondly, the hazard increases with height in that the likelihood of toppling rib material covering the full roadway width increases rapidly. Therefore, the likelihood of a person standing in the roadway being impacted reduces appreciably as height reduces.

iii) Thirdly, the rib instability hazard increases with mining height in that the potential location (i.e. height) of impact and the associated consequences to the individual also increase.

It is concluded that rib behaviour and the associated hazards to personnel are very strongly a function of rib height. It can be implied that the likelihood of rib deterioration being a hazard is almost certainly a function of the height to the third (if not a higher) power.

In other words, everything else being equal:

$$\text{Rib Hazard} = f\,(\text{Rib Height})^{\geq 3}$$

4.0 GEOTECHNICAL CHARACTERISATION OF THE KATOOMBA SEAM

4.1 Katoomba Seam Strength and Composition

The key strength and composition features are summarised as follows:

i) The Katoomba Seam is a particularly strong coal, both in Australian and world terms. This relative strength is evident in small scale sample tests (laboratory UCS results average 44 MPa) and also at the mass scale. There is very little overall difference in seam strength across the mine.

ii) Seam strength does not appear to correlate to seam height; this is important as the mine progresses towards generally thinner seam areas.

iii) The typical seam strength profile correlates to observed rib behaviour, creating a tendency for overhang formation at the corner of the roof and a bench or step near the floor, as seen in **Figures 9a-c**.

4.2 Roof and Floor Contacts

The roof is mainly sandstone and siltstone, although a thin (typically <0.5m) mudstone unit at the seam contact is common. This mudstone is of medium to high strength (i.e. 30 to 40MPa UCS) and not susceptible to weathering, although minor delamination can lead to localised spalling of the roof skin over time, to a height of typically 0.1m.

The floor is mainly sandstone and siltstone with a UCS of 20 to 40MPa. Immersion test data and practical experience indicate that the floor is not susceptible to weathering.

4.3 Geological Structure

Rib structural features are summarised as follows:

i) The four main cleat sets are orientated NW, NNW, NE and ENE. They form conjugate pairs, NW/NE and NNW/ENE.

ii) A fifth, NNE, cleat set is also occasionally encountered.

iii) The NW and NNW sets usually predominate and often they merge.

iv) In terms of initial stability, the main cleat orientations favour roadways driven between N/S and NNE/SSW. Over time, however, rib deterioration can occur at all roadway orientations.

v) Apart from the cleat, most of the major structures (e.g. faults and dykes) have a NNW-SSE orientation and locally impact on rib behaviour along roadways at similar (i.e. sub-parallel or within 20°) orientations.

vi) The configuration of discrete "pinnacles" (see **Figure 9b**) and columns partly depends on roadway direction, but large pinnacles can form at any orientation.

vii) The cleat typically results in the formation of rib columns and pinnacles with widths of 0.1m to 0.3m. Dull, strong coal has a wider cleat spacing and a propensity to form larger columns and pinnacles.

4.4 Stages and Nature of Rib Deformation Experienced at the Mine

Rib deformation on drivage is characterised by a number of distinct features, which are well illustrated in the borescope log from 908 Panel, G52 intersection, see **Figure 10**. Three distinct modes of fracturing are evident:

- Mining-induced fracturing related to rib buckling is evident in the first 0.7m of the rib.
- Between 1m and 9m into the rib, fracturing is almost entirely related to dilation along pre-existing cleat planes. Note that this "fracturing" does not materially decay with depth into the rib; this dilation largely pre-dates development.
- Between 9m and 10m into the rib, this particular hole encounters a localised geological structure zone (a minor fault).

Post-drivage and prior to secondary extraction, extensometry results demonstrate a state of equilibrium following drivage, with very little progressive, time-dependent rib movement, see **Figure 11**. This is at a minimum rib bolt density of one 1.15m long, mechanically anchored bolt per 2m, plus mesh over the top half of the rib (i.e. to within 1.5m of the floor).

Further rib movement during secondary (partial) extraction becomes evident when the lifting face is ~100m inbye, see **Figures 12a-c**. The support system maintains adequate control of buckling, with very little additional dilation within the first metre of rib during lifting. As the lifting face passes, active deformation of the spine pillars occurs between 1m and 4m in from the rib; this deeper deformation tends to cause the immediate rib to bulge outwards. Significant dilation at a depth of >4m into the spine pillars occurs once the lifting face is >150m outbye and is partly associated with extraction of the next adjacent panel. The post-lifting deceleration indicates that the system trends towards a new equilibrium upon completion of extraction.

5.0 SILCRETE TRIALS

Two silcrete trials have been undertaken at Clarence Colliery to-date; these are located as shown in **Figures 13** to **15** and the following initial comments are made regarding these trial sites:

i) The two sites are at practically opposite ends of the mine.

ii) The sealed roadways at the two sites are almost at right angles to each other.

iii) The first trial, in 908 Panel, involved a section of rib that had stood unsupported for around two years prior to sealing. The mining height at the site is 2.5-2.6m and the depth is 240m, noting that depth varies from around 100m to 320m at the mine and averages 230-240m.

iv) The second trial, in 818A Panel, involved two sections of cut-through driven within the previous 24 hours. The mining height at the site is 2.9-3m and the depth is 200-205m.

5.1 908 Panel

5.1.1 Application

The 908 Panel trial involved the application of silcrete to the top 1.7m of rib along:

- both ribs of 0.5C/T, A to B Heading (a distance of approximately 28m),
- the outbye rib of 1C/T, A to B Heading and
- an approximately 8m length of the A Heading barrier rib at 0.5C/T.

The purpose of the 908 Panel trial was to assess the performance of Silcrete in a secondary extraction / abutment loading environment.

The intent behind applying the TSL to the upper 1.7m of rib was simply to match the area that would normally be meshed and bolted. The total rib area sealed was approximately 160m^2.

Given that these ribs had stood for ~2 years, the area to be sealed was hosed down 24 hours before the application. Sections of the rib remained damp at the time of sealing.

The 908 Panel trial application occurred over two days. On the 23rd of December 2020, Silcrete was sprayed along the outbye side of 1C/T, A to B Heading, see **Figure 14**. The coal rib and ambient air temperature were both about 19°C, the Silcrete components were about 18°C and humidity was 94%. On the 21st of January, Silcrete was sprayed on both sides of 0.5C/T, A to B Heading; on this day temperatures were ~1°C cooler.

Initially, some clogging of old, previously used hoses occurred. These were replaced and no further operational difficulties were encountered.

Spraying was done in multiple passes, to build up the thickness to the target of 5mm. Good adhesion to the coal rib was evident, see **Figures 16a-c**. Initial resin cure occurred with one hour of application. Spraying the rib at moderate angles in two opposing directions (rather than perpendicularly) assisted with cleat / discontinuity penetration and in achieving a uniform coating.

The typical sprayed rib surface temperature trend, due to the exothermic reaction generated by the Silcrete, is shown in **Figure 17**. Maximum temperature was reached approximately one hour after application, followed by cooling to within 5°C of ambient temperature within two hours of application. Higher temperatures correspond to localised increases in liner thickness; a maximum of 68°C was recorded at one spot, due to pooling of dripped resin.

A minimum TSL thickness of 5mm was targeted. In practice, observed thicknesses on samples broken away from the rib varied between 3mm and 10mm, with the majority in the 5 to 8mm range. 1,160 litres of material were applied, which equates to a theoretical average thickness of ~7mm (i.e. reasonably consistent with the sample observations). Material losses / wastage due to rebound / drips were minimal.

5.1.2 Geotechnical Outcomes

Three main mechanisms can be envisaged, whereby a TSL enhances rib stability, as follows:

i) Firstly, the TSL prevents or at least minimises weathering of the rock mass. There are many examples of a variety of liner materials being successfully used for this primary purpose, including sealing mudstones exposed in high drivages at strategically important, long-term excavations. However, there are very few coal seams for which this would be an important, ongoing consideration.

ii) Secondly, the TSL adds tensile strength to the immediate skin of the rib, thereby enhancing the resistance to buckling. This theory features prominently in the literature and proponents accordingly advocate that the TSL be applied at a very early stage, prior to significant rib deformation. It is accepted that there is data to suggest that a polymer layer can appreciably enhance the tensile strength of a composite tunnel liner (e.g. fibre-reinforced concrete coated with a PUS resin).

   However, the coal rock mass, at the mine roadway scale, is essentially considered to have no tensile strength and a 5mm layer of polymer will not materially change the overall mass properties. Furthermore, in the context of the Australian mining industry, a coal rib that stands perfectly unsupported for the required time interval prior to spraying is unlikely to warrant the application of a TSL.

iii) Thirdly, the TSL penetrates dilated discontinuities (fractures, joints, cleats, bedding planes, etc.) within the immediate coal rib, thereby:

   - gluing blocks together to form bigger, more stable blocks and
   - increasing mechanical interlock by filling the gaps between blocks, restricting relative movement and unravelling.

It is this third mechanism that is evident at the trial site. The photographs in **Figures 18a-c** depict the rib conditions along 0.5C/T, A to B Heading, five weeks after the completion of lifting. The following comments are made regarding the observed outcomes:

i) The lined sections of rib are intact, with no spall.

ii) The Silcrete binds the discrete columns, pinnacles and blocks into one mass. In particular, the polymer penetrates and flows along cleat planes, causing individual columns to coalesce into one thicker and therefore more stable column, see **Figure 18a/b**.

iii) Apart from very localised dilation along cleat and bedding planes (signs of rib bulging, see **Figure 18c**), there is no evidence of relative movement between different sections of the rib.

iv) No sections of the liner would be described as loose or unstable; appreciable effort was required to knock down / tear off small samples for inspection.

These favourable outcomes are considered to reflect:

- the properties of the Silcrete,
- the properties of the rib and
- the timing and nature of rib deformation.

The key properties of Silcrete as a TSL are considered to be:

1) Crack penetration.
2) The absence of foaming (i.e. not forcing blocks of coal outwards and/or apart).
3) The very rapid build-up of significant adhesion (this also reduces wastage / drips).
4) The rapid build-up of significant tensile strength creates a composite rib mass.
5) Compressive strength and stiffness (partly due to the absence of foaming), lending cohesion and rigidity to the final mass.

TSL performance is influenced by the coal seam properties and, in particular, the following:

a) Cleat spacing and properties, including the propensity for early dilation along cleat planes: the wider / bigger the discrete coal blocks and the more the resin can penetrate between those blocks, the more stable the final mass.

b) Coal strength: stronger coals will enhance the strength of the final aggregate mass.

c) In-seam dirt bands: the thickness and hardness of persistent partings / dirt bands would influence TSL adhesion and bridging across blocks.

It should be noted that the same coal properties also generically influence rib strength and the performance of “conventional” support systems (i.e. bolts).

Although operator competency is usually considered a “given”, understanding the geological / geotechnical environment and, for example, quickly assessing the significance of structure orientation, is very important to this process. In this regard, the DSI operators were excellent.

Rib monitoring (Rock-it) results for the area of interest are illustrated in **Figures 19 to 21**. The following comments are made regarding these outcomes, referring also to **Figure 14** for the instrument locations and configuration of the secondary extraction process:

i) **Figures 19a-c** illustrate the results up to the extraction of Sequence 251 (1C/T, A to B Heading) and the instruments being cut out. Although the results for the outbye (lined) rib, **Figure 19b**, were superior to those from the meshed and bolted inbye rib, **Figure 19a**, it is important to note that the behaviour of the inbye rib reflects the final stages of extraction of the 1 to 2C/T pillar and therefore a higher level of vertical stress, see **Figure 19c**. Both outcomes were satisfactory.

ii) **Figures 20a-c** illustrate the results immediately outbye at 0.5C/T, A to B Heading, which remains accessible following the completion of extraction in the panel. Both ribs were supported with Silcrete only. Both ribs remained intact and displayed a favourable deceleration following the completion of lifting immediately inbye. The slightly increased displacement of the inbye rib, **Figure 20a**, reflects the higher final vertical stress on the remaining, partially lifted (~15m wide) 0.5-1C/T pillar, see **Figure 20c**. Both outcomes were satisfactory.

iii) **Figures 21a/b** illustrate the adjacent results from 0.5C/T, B to C Heading, which also remains accessible following the completion of extraction in the panel. Both ribs were meshed and bolted. Both ribs remained intact and displayed a favourable deceleration following the completion of lifting, noting that the B to C Heading, 0.5-1C/T pillar was not lifted at all. The slightly increased movement of the inbye rib, **Figure 21a**, reflects the higher final stress on the inbye side of the cut-through, see **Figure 20c**. Both outcomes were satisfactory.

These Tell-Tale results are generally consistent with previous results from elsewhere and the data set is too small to draw conclusions with regard to the relative performance of the Silcrete versus the rib bolts and mesh. However, if the results from 0.5C/T are compared, **Figures 20a-c** and **21a/b**, it is apparent that the results from the Silcrete trial area in A to B Heading, at a higher level of vertical stress, are similar to those from B to C Heading (meshed and rib bolted).

A further comparison is provided by survey results from along 0.5C/T in the form of 3D scans prior to and following lifting, see **Figures 22a/b**. Negligible rib deformation was measured in the Silcrete lined A to B Heading section, whereas the ribs in the meshed and bolted B to C Heading section loosened following lifting, with some rill evident.

Finally, and most importantly, it was observed that the Silcrete remained effective through to the moment of being cut out during lifting along 1C/T, A to B Heading (outbye rib). Specifically, the section of rib immediately adjacent to the active lift did not spall at all.

It is concluded that the Silcrete provided an adequate level of rib support throughout the lifting process in 908 Panel and remained effective at the magnitudes of deformation experienced.

5.2 818A Panel

5.2.1 Application

The 818A Panel trial area involved the following sections of roadway, see also **Figure 15**:

- 24C/T, B to A Heading: sprayed on the 26th and 27th of March 2021, and
- 25C/T, B to A Heading: sprayed on the 31st of March and 1st of April 2021.

Sealing was incorporated into the drivage cycle from B to A Heading in both cut-throughs, with rib spraying immediately following the installation of roof support. Accordingly, the ribs were "fresh", with typically <0.1m of spall, see **Figures 23a-c**. The following observations were made during the application:

i) Spraying of 24C/T was slower than during the first trial, due to:

   - lower polymer component temperatures of 9-13°C (and therefore higher viscosity),
   - lower face temperatures of 11-13°C and
   - low compressed air pressure at the site (35-40psi during spraying).

ii) Presumably because of the issues with spraying, the Silcrete application was slightly less consistent in 24C/T than at the 908 Panel site, with more drips evident, particularly on the first day, the 26th of March.

iii) The results at 25C/T were more consistent, due to slightly higher temperatures and air pressure.

iv) Maximum rib temperatures during curing of the Silcrete were similar to the 908 Panel trial site, at typically 40-50°C, with 84°C measured at one spot. Consistent with observations in 908 Panel, higher temperatures were associated with areas of locally thicker lining.

v) Approximately 720 litres of Silcrete were applied over ~220m^2 of rib in 24 and 25C/T, which equates to a Silcrete thickness of ~3mm (less than the 908 Panel site).

5.2.2 Geotechnical Outcomes

The trial area will only be extracted in late 2021 and is currently being instrumented for the purpose of monitoring that stage of the process. The following interim comments can be made:

i) The final appearance of the sprayed rib is similar to the 908 Panel outcome and rib stability is adequate for the purpose of development at the increased height (i.e. 2.9-3.0m in 818A Panel, versus 2.5-2.6m in 908 Panel), see **Figures 24a-b**.

ii) In contrast to the 908 Panel trial site, the sprayed rib had stood for <24 hours and had experienced limited deformation, with 0.1m of spall and initial loosening of pinnacles only. The outcome was still effective, with adequate rib mass cohesion.

iii) The sequence was sprayed on development in two sections; 0-14m on the 26th and 14-33m on the 27th of March. It was noted that the Silcrete near the face following the spraying of the first section (i.e. at the 12-14m mark) subsequently developed hairline cracks due to rib buckling as drivage continued to A Heading, approximately 12 hours after the first section was sprayed. This margin area was resprayed. This issue points to the importance of understanding the interaction between rib deformation (magnitude and timing) and the performance of *any* support system (i.e. not just a TSL).

iv) The operators subsequently working in the Silcrete trial area reported a safe working environment, with confidence in the lined ribs during the completion of cutting to A Heading and during B Heading breakaway formation.

6.0 DISCUSSION

The Clarence Colliery trials of Silcrete as a TSL are ongoing. Nonetheless, there is enough information and experience to state that the material, as applied, is capable of replacing the existing rib support system, in normal (i.e. TARP Level 1) conditions at the mine. Further trials would be required to determine the efficacy of a TSL in abnormal conditions for the mine (e.g. in drivages >3m in height, or zones of major geological structure). However, it is considered almost certain that, as a minimum, rib behaviour would be enhanced by incorporating the TSL into the support system, across the full range of rib conditions and circumstances locally experienced.

The future potential of the Silcrete TSL at Clarence will be heavily influenced by productivity considerations and, in particular, the ability to incorporate the liner application into the mining process in a manner that facilitates large-scale use. A key aspect of this will be future controls / restrictions on the Silcrete application process. The author cannot comment on the likelihood of potentially harmful vapours being generated, but would note that the process appeared to be well controlled and the environment appears benign during the application.

Finally, with regard to the potential use of Silcrete elsewhere in the underground coal mining industry, the point made in **Section 5.1.2** is restated; the success of the TSL is a function of:

- the properties of the Silcrete,
- the properties of the rib and
- the timing and nature of rib deformation.

It is suggested that most mines would very quickly be able to estimate the likelihood of success of a TSL trial, based on consideration of these associated parameters. For example, the author would have serious reservations regarding the potential use of Silcrete (in isolation) on a friable coal with closely spaced cleat; little benefit is likely to result.

7.0 ACKNOWLEDGEMENTS

The author wishes to specifically thank:

i) The Clarence Colliery staff (technical and operational) and in particular, Mine Geologist Lyle McLaren for diligent generation and compilation of the trial data.

ii) Scott Turton, Matt Pyniw and Aaron Martin of DSI for their practical insights, skill and patience during the trials.

iii) Hayden Nicholson, Andy Taylor and Ian Yates of Polymer Group Ltd., a New Zealand company, for their insights regarding polymer development, testing and properties.

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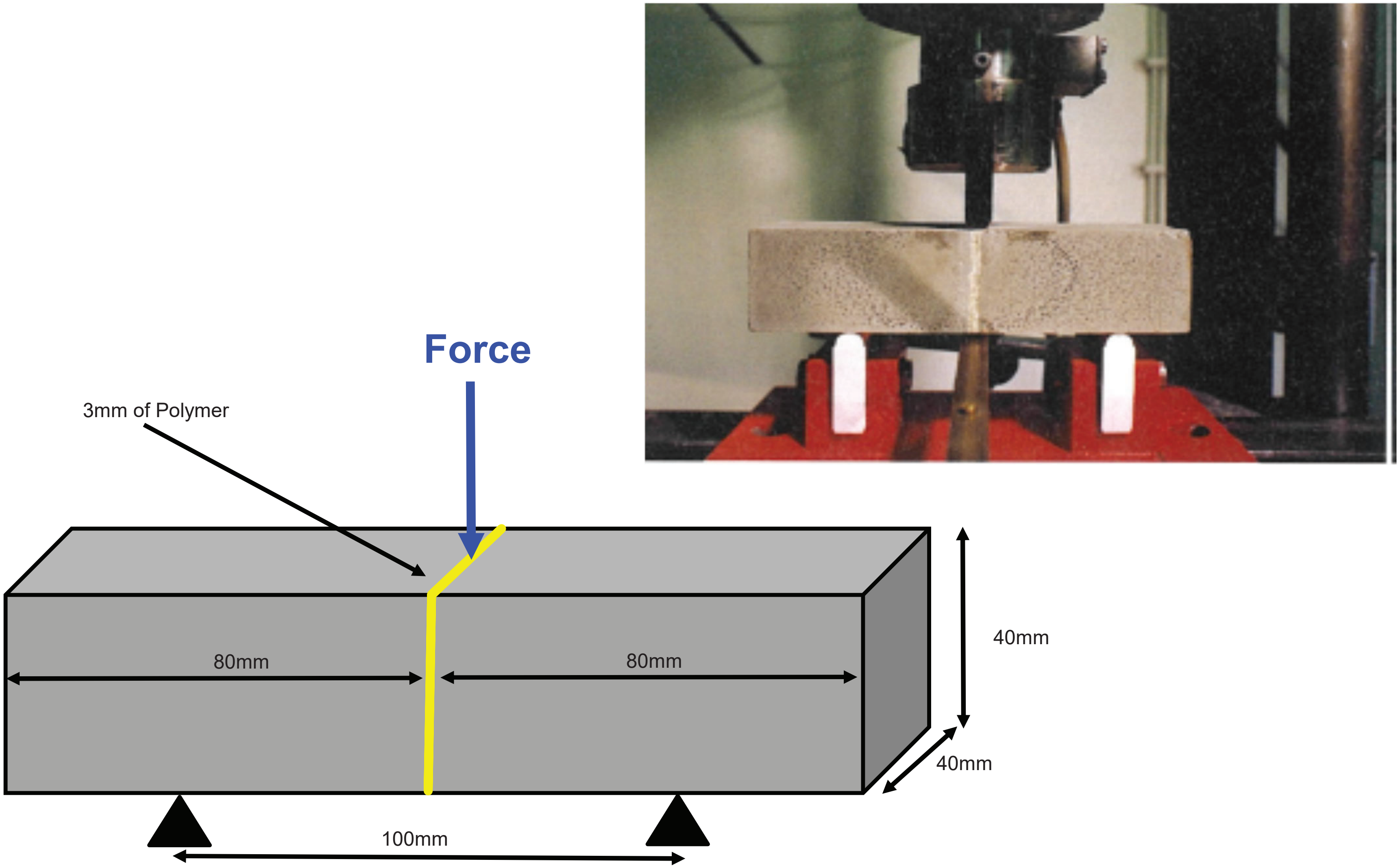

Engineer:	D. Hill	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	German Three-Point Bending Test (after **Junker, 2009**)		
Date:	26.04.21				
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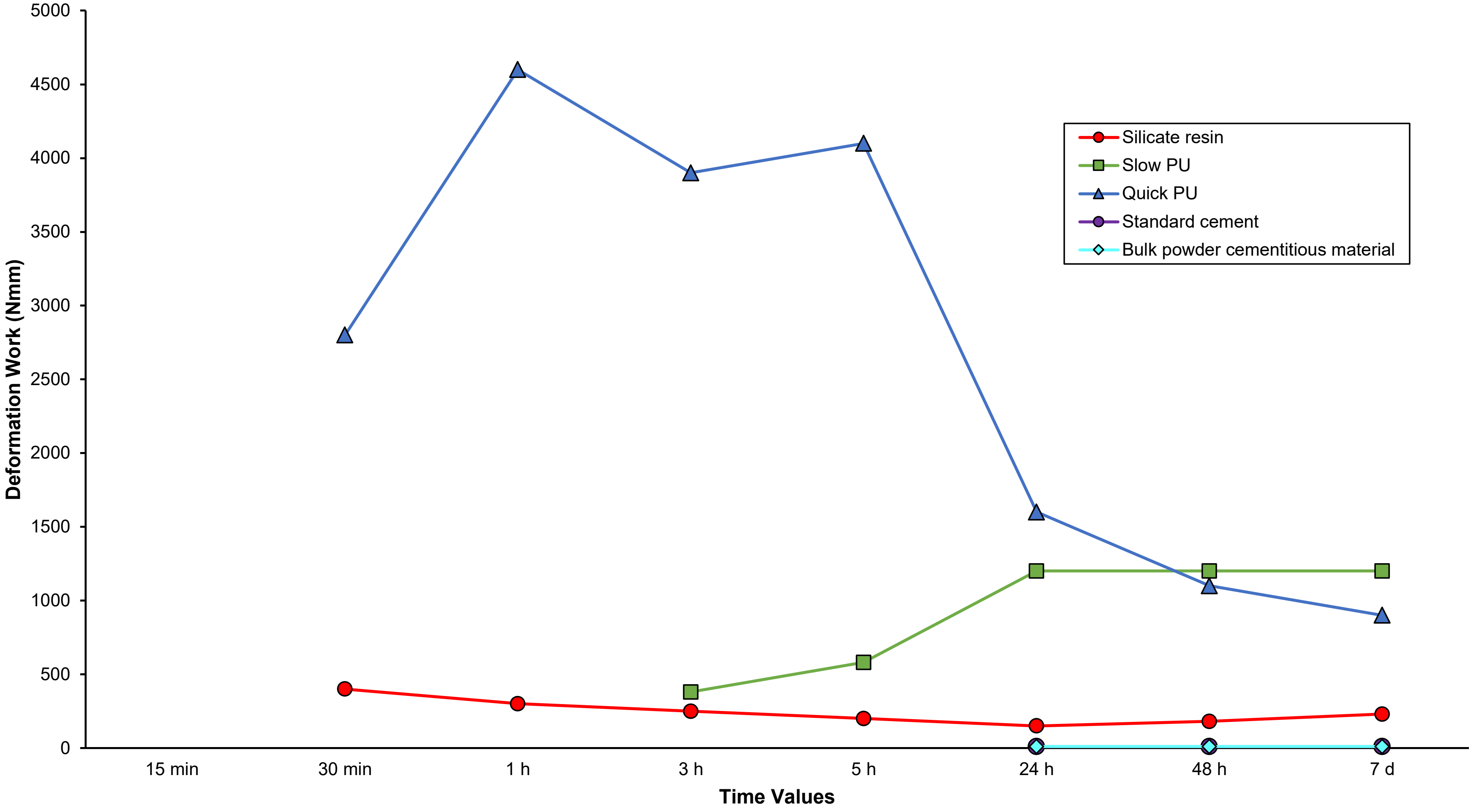

Engineer:	D. Hill	**Client:**	Clarence Colliery
Drawn:	I. Saliamon	**Title:**	Deformation Work of Injection Products (after **Junker, 2009**)
Date:	26.04.21		

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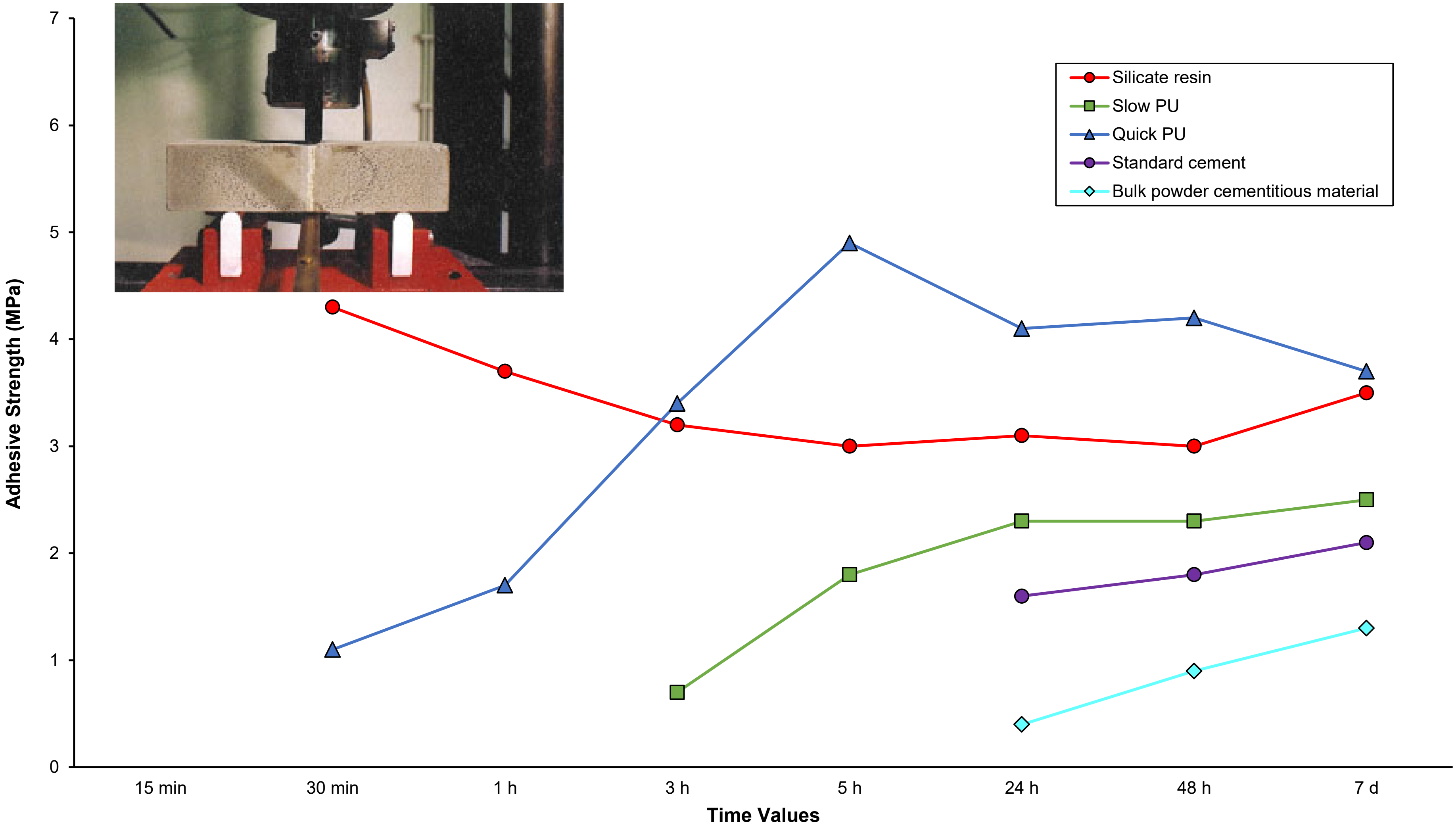

Engineer:	D. Hill	**Client:**	Clarence Colliery
Drawn:	I. Saliamon	**Title:**	Adhesive Strengths of Injection Products (after **Junker, 2009**)
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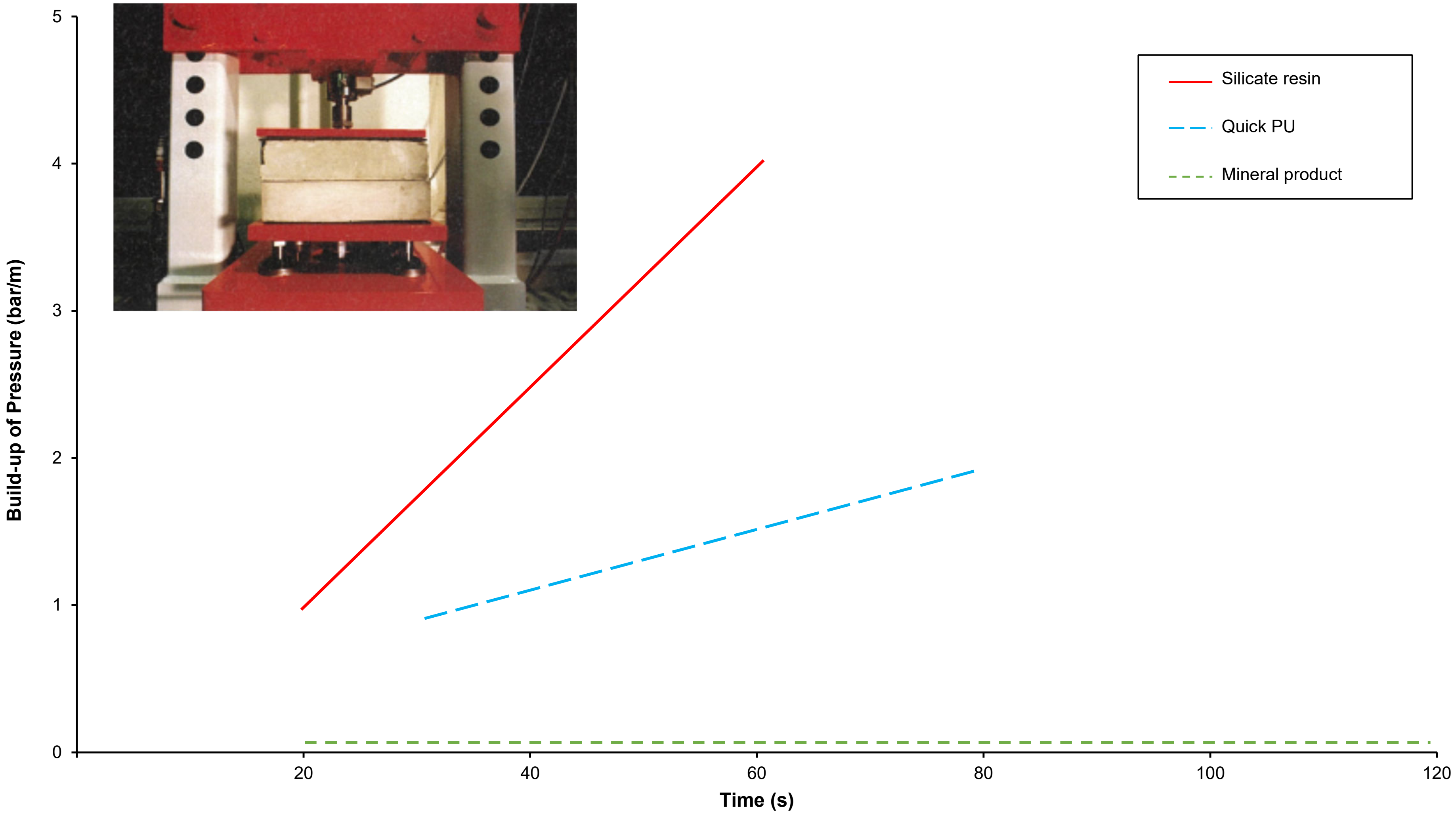

Engineer:	D. Hill	**Client:**	Clarence Colliery
Drawn:	I. Saliamon	**Title:**	Flow Resistance of Injection Products (after **Junker, 2009**)
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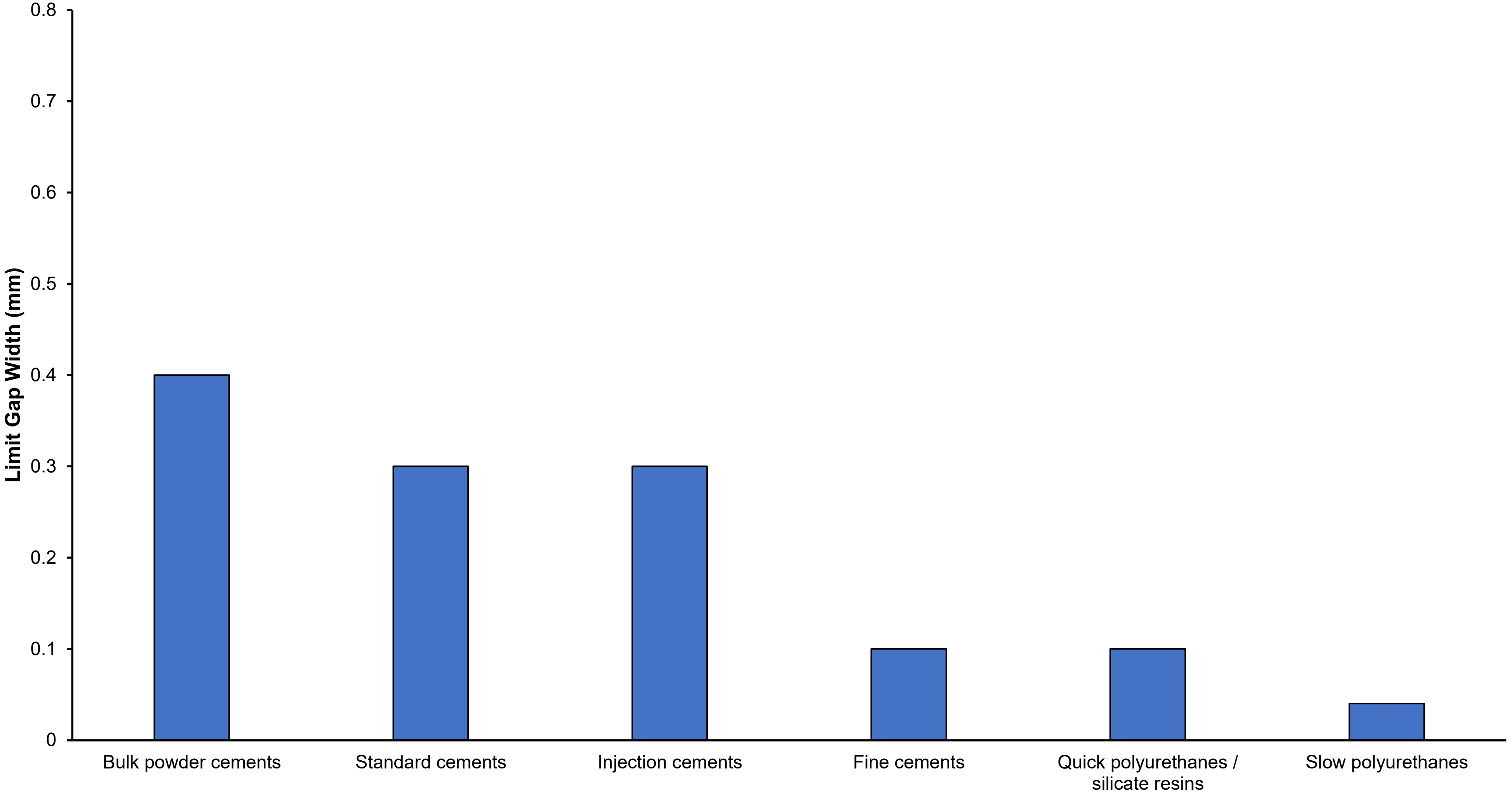

Engineer:	D. Hill	**Client:**	Clarence Colliery		
Drawn:	I. Saliamon	**Title:**	Limit Gap Width of Injection Products (adapted from **Junker, 2009**)		
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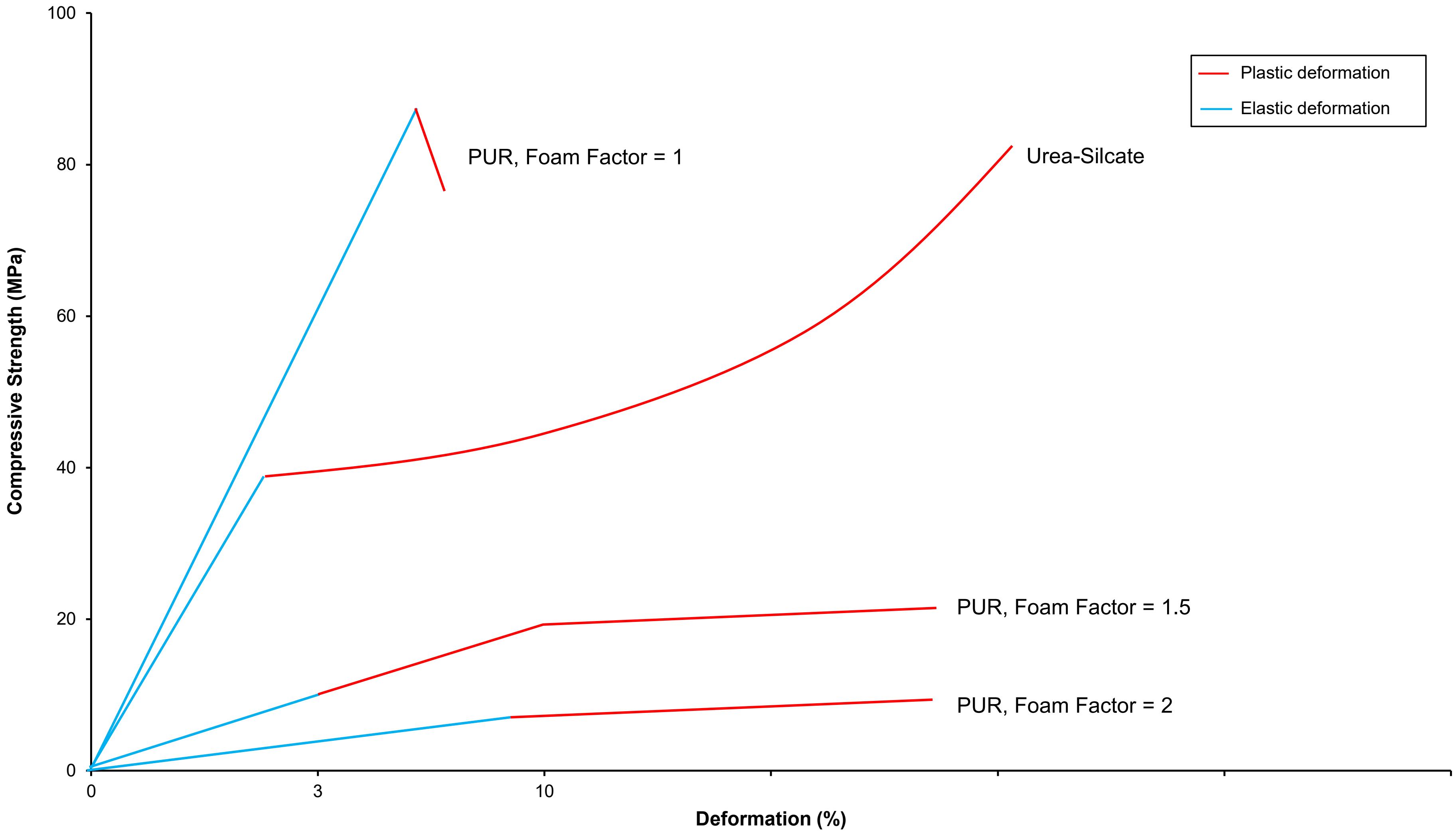

Engineer: D. Hill
Drawn: I. Saliamon
Date: 26.04.21

STRATA²

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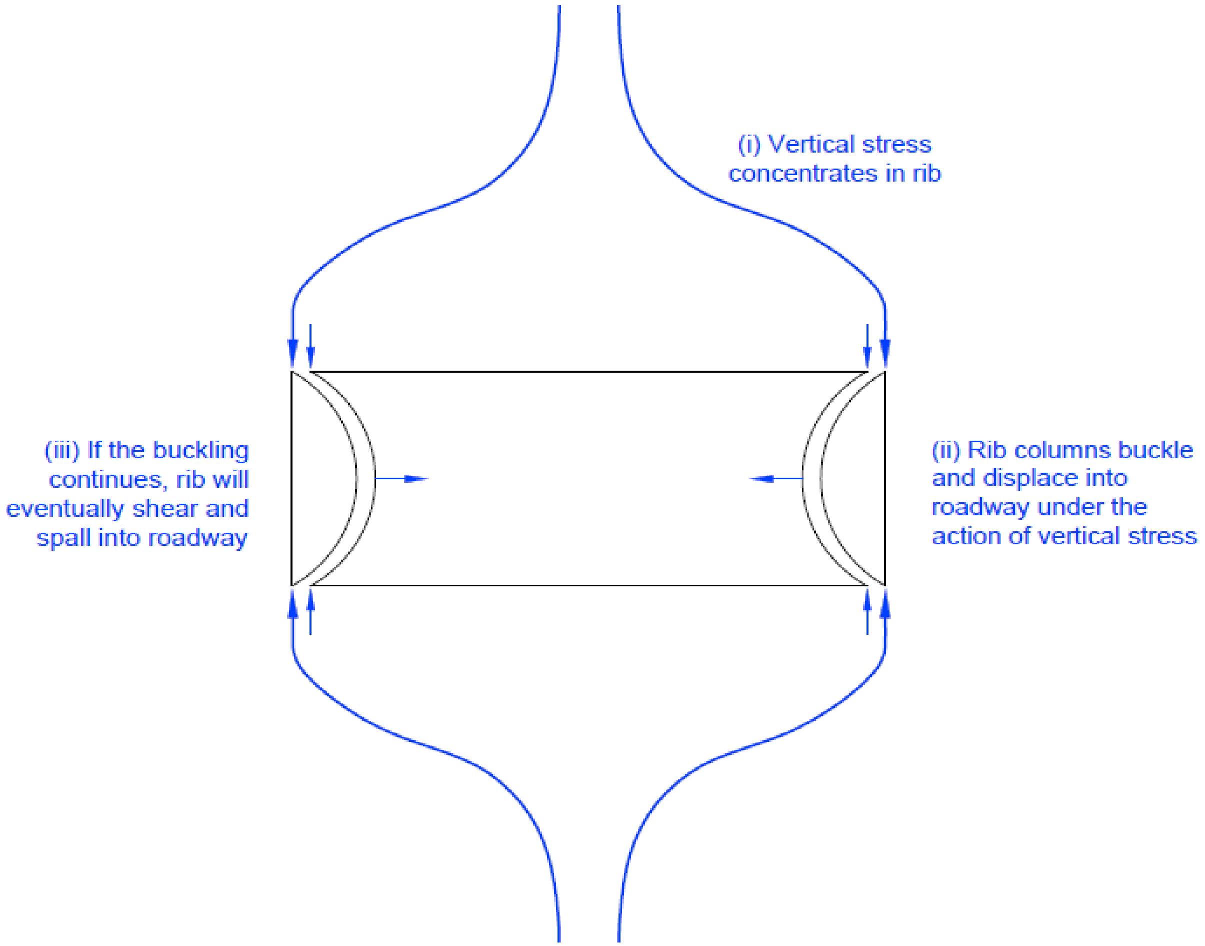
Title: Compressive Strength of Different Injection Products (adapted from **Junker, 2013**)
Ref: CLA-046
Revision No: 0
Scale: N/A
Figure No: 6



Engineer: D. Hill
Drawn: D. Hill
Date: 29.04.2021

Client: Clarence Colliery
Title: Rib Buckling Schematic plus Queensland Mine Example
Ref: CLA-046
Revision No: 0
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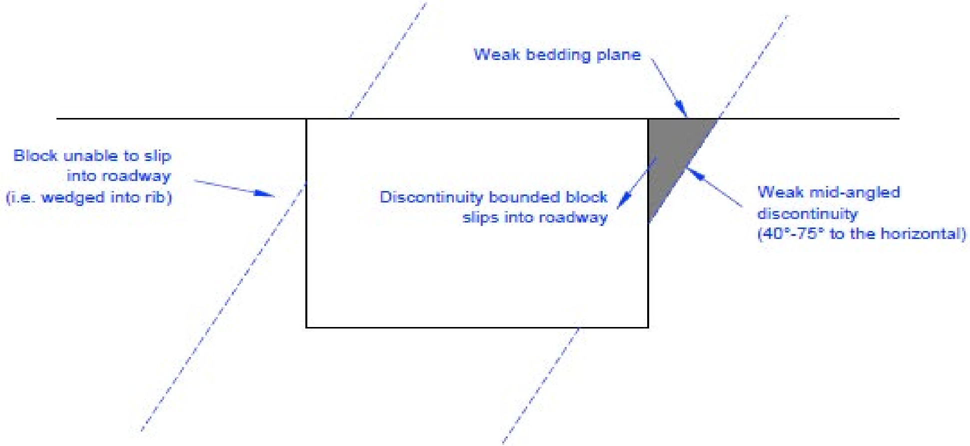
Figure No: 7



Engineer:	D. Hill	**Client:**	Clarence Colliery
Drawn:	D. Hill	**Title:**	Wedge Failure Schematic plus Examples from Other Mines
Date:	29.04.2021		

STRATA²

Ref:	CLA-046	**Revision No:**	0
Scale:	N/A	**Figure No:**	8

Figure 9a: Rib Strength and Ash Profiles

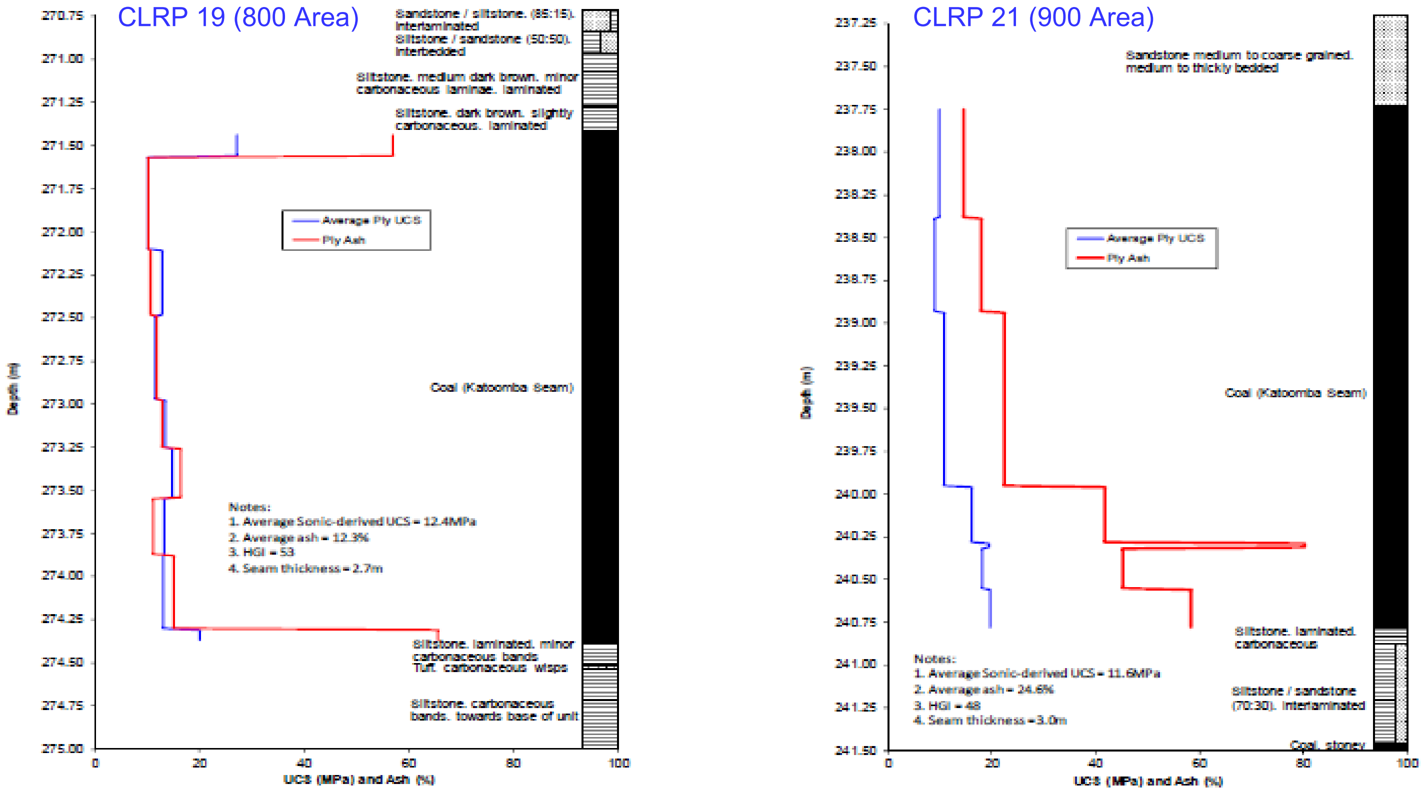


Figure 9b: Behaviour of Unbolted Ribs in the Older 400 and Outbye 900 Areas of Clarence

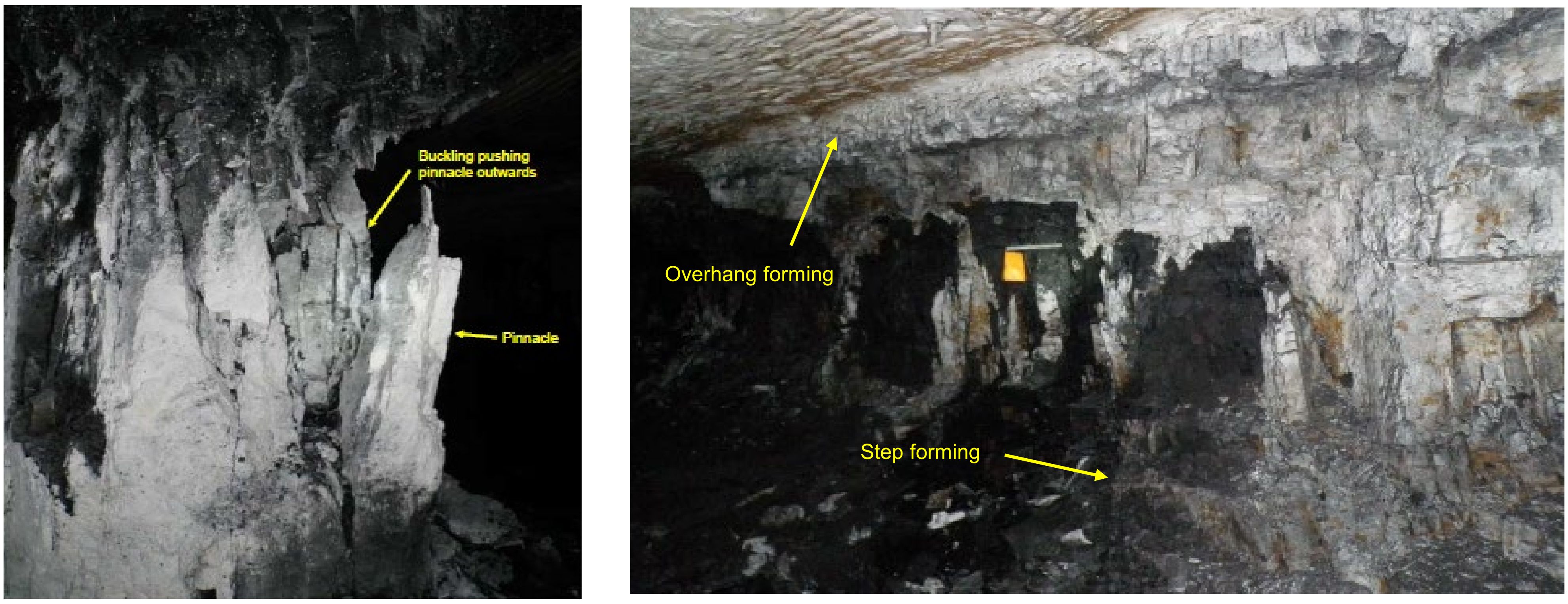
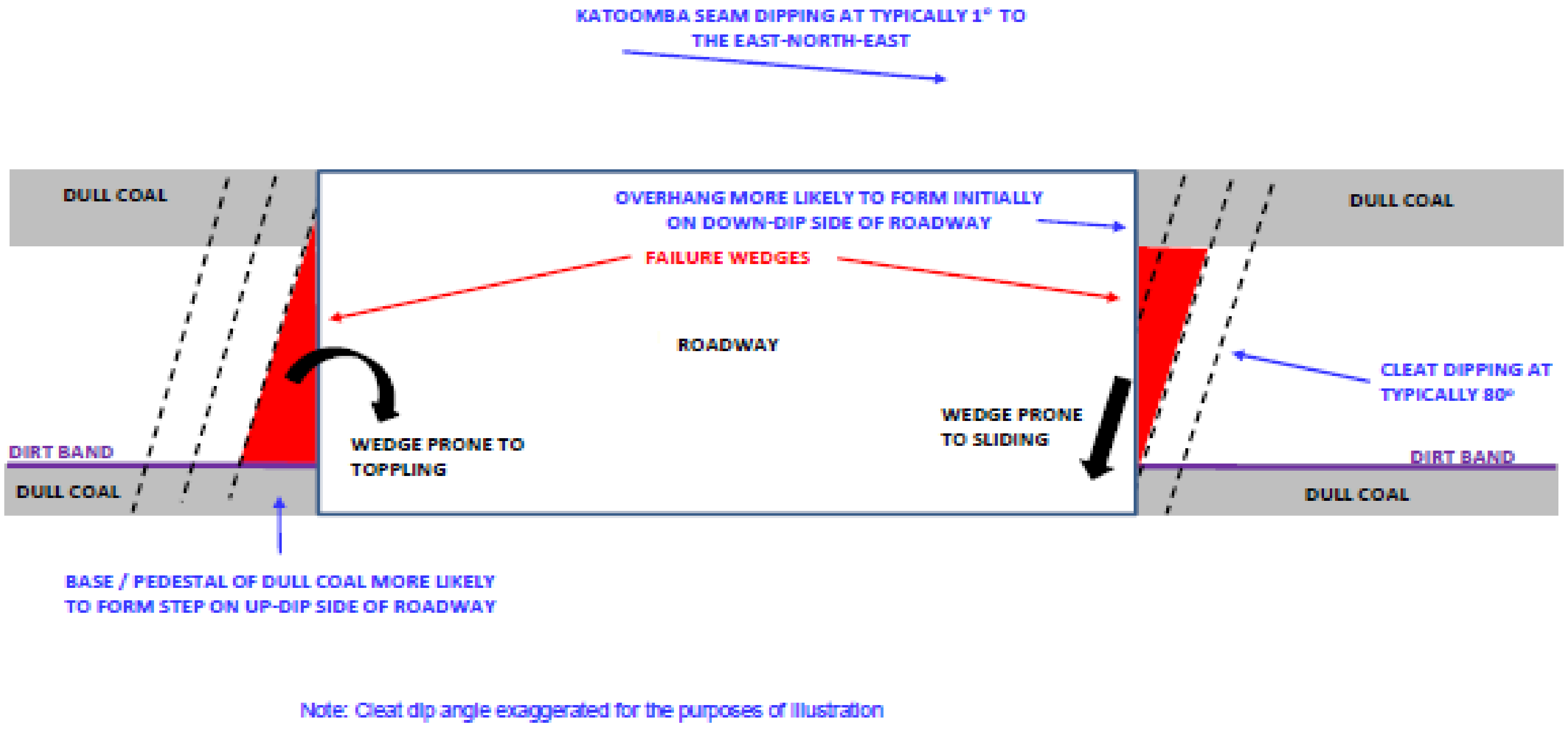


Figure 9c: Rib Wedge / Pinnacle Behaviour



Engineer:	D. Hill	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Clarence Rib Composition and Behaviour		
Date:	03.05.2021				
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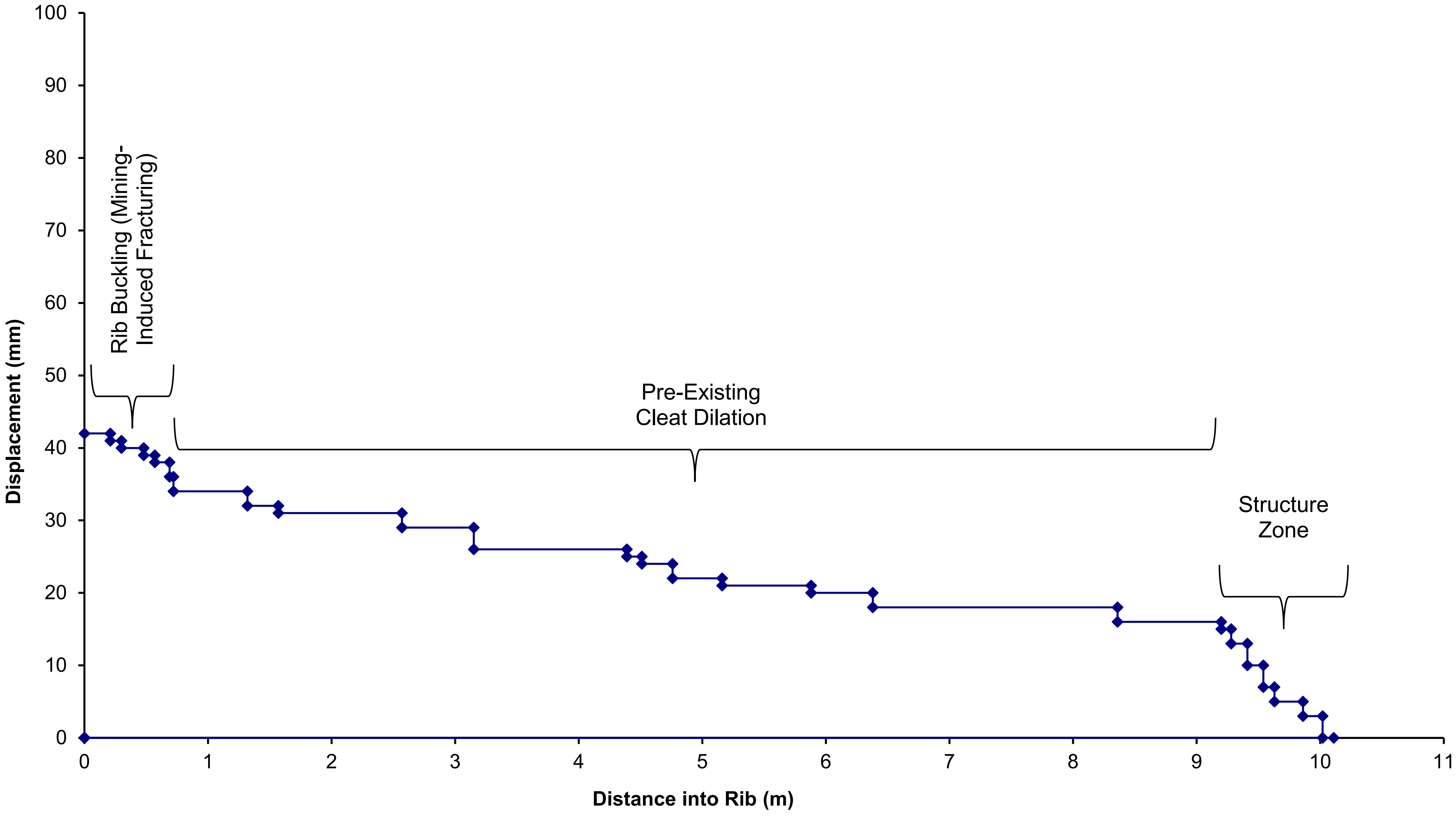

Engineer:	D. Hill	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Rib Borescope from 908 Panel (Mining Height 3m, Depth 320m)		
Date:	28.04.2021				
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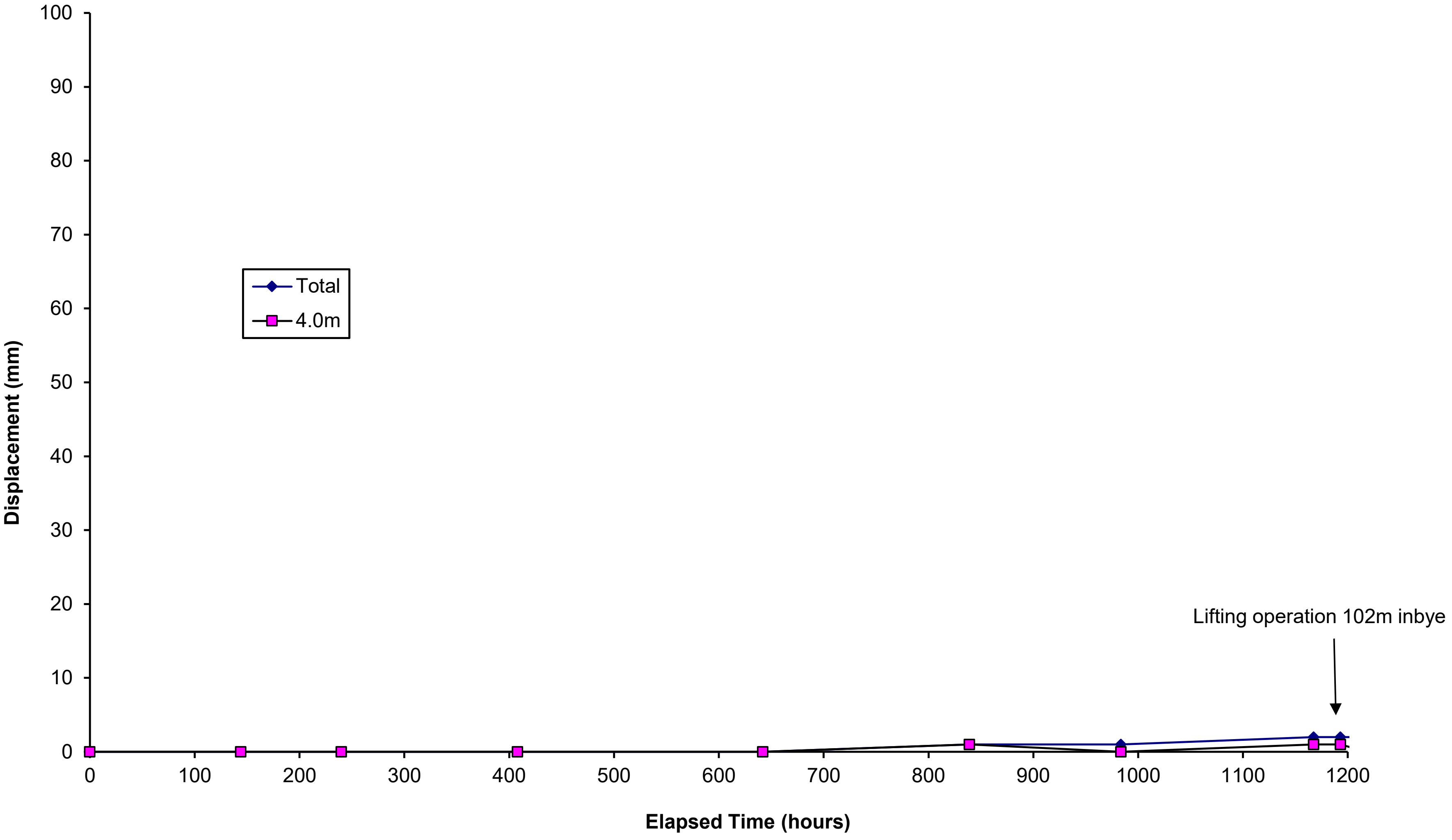

Engineer:	D. Hill	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Rock-it Results - Rib Behaviour Prior to Lifting, 910 Panel, 47C/T, C to D Heading		
Date:	29.04.2021				
STRATA 2		**Ref:**	CLA-046	**Revision No:**	0
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Figure 12a: 908 and 910 Panels, showing Monitoring Scheme

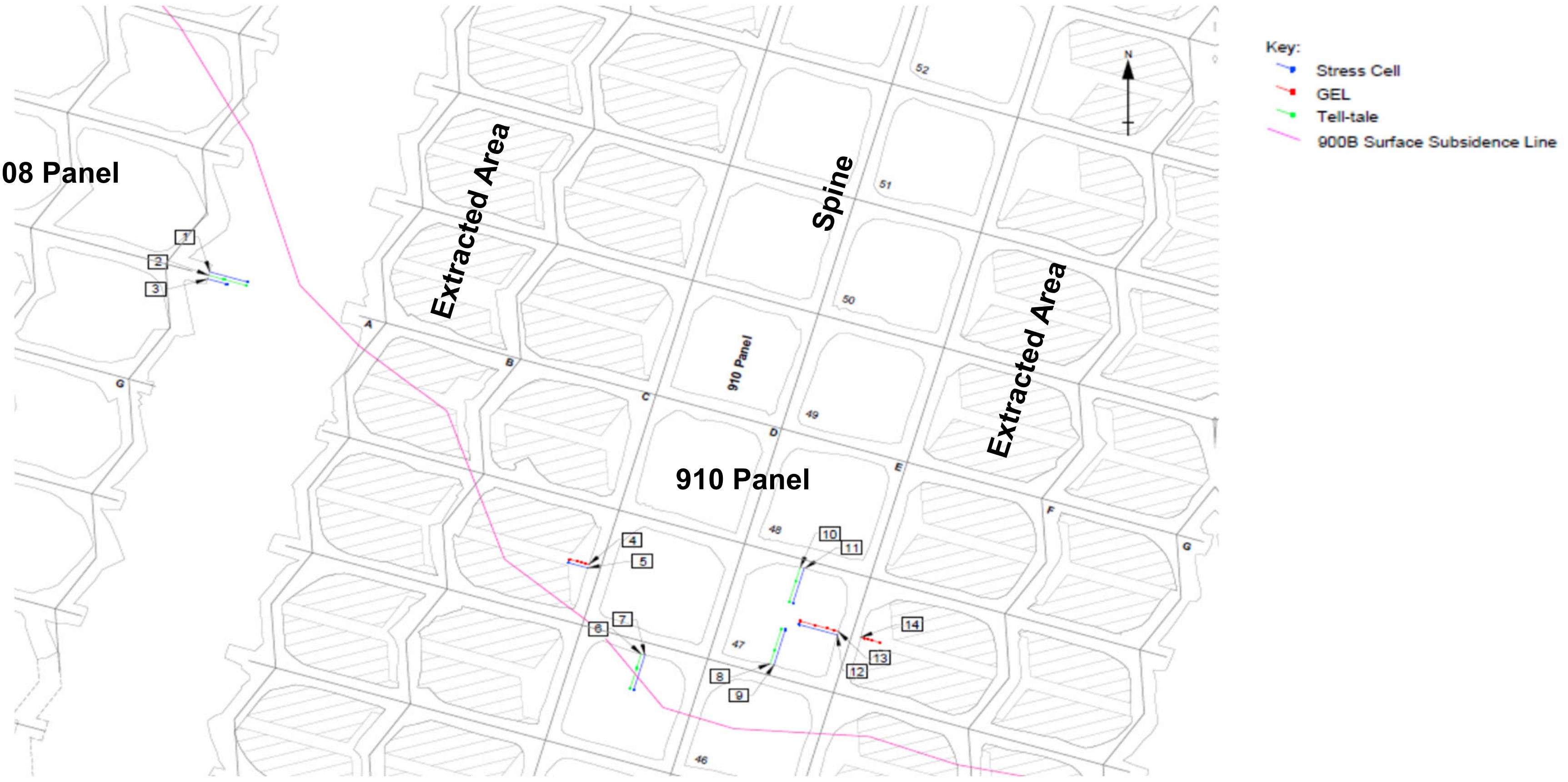


Figure 12b: 910 Panel, D to E Heading, 47C/T, - Rib Rock-it Displacement Results

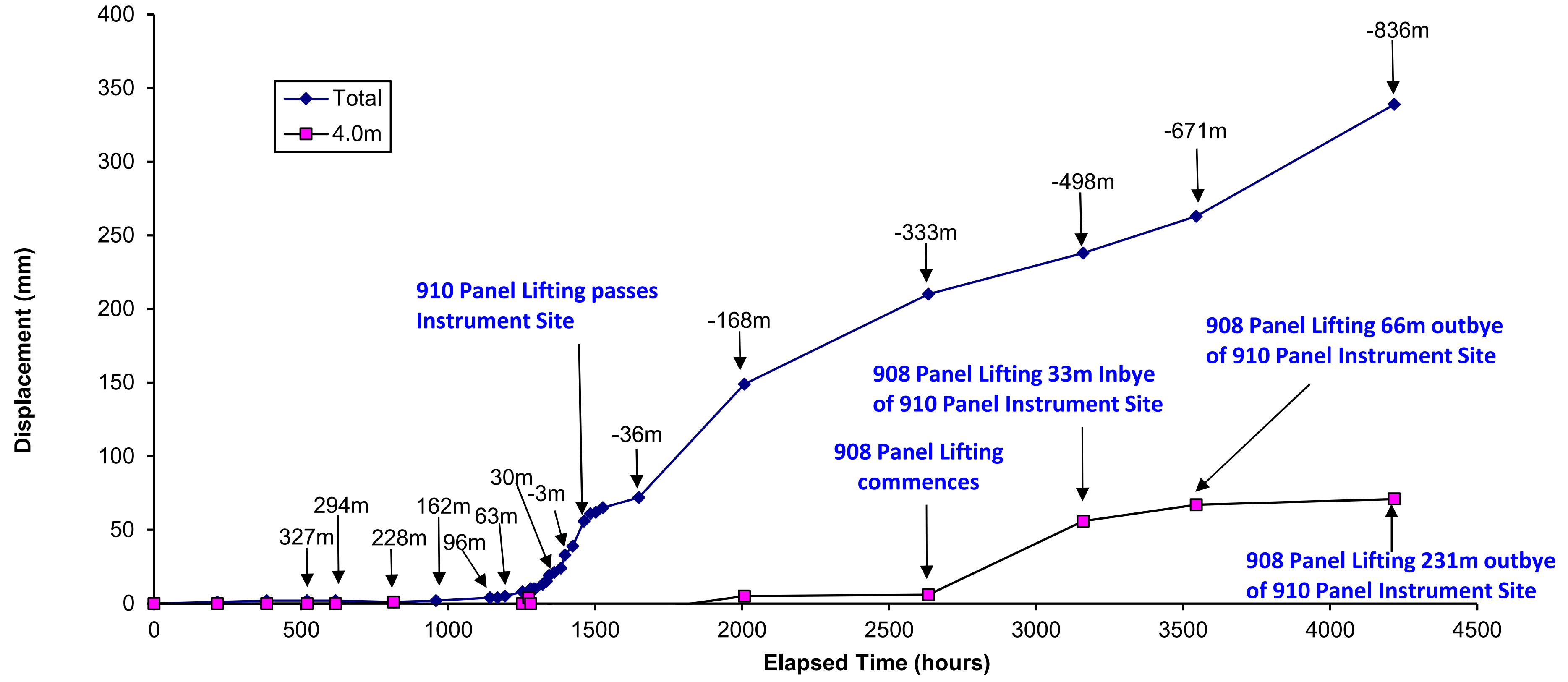
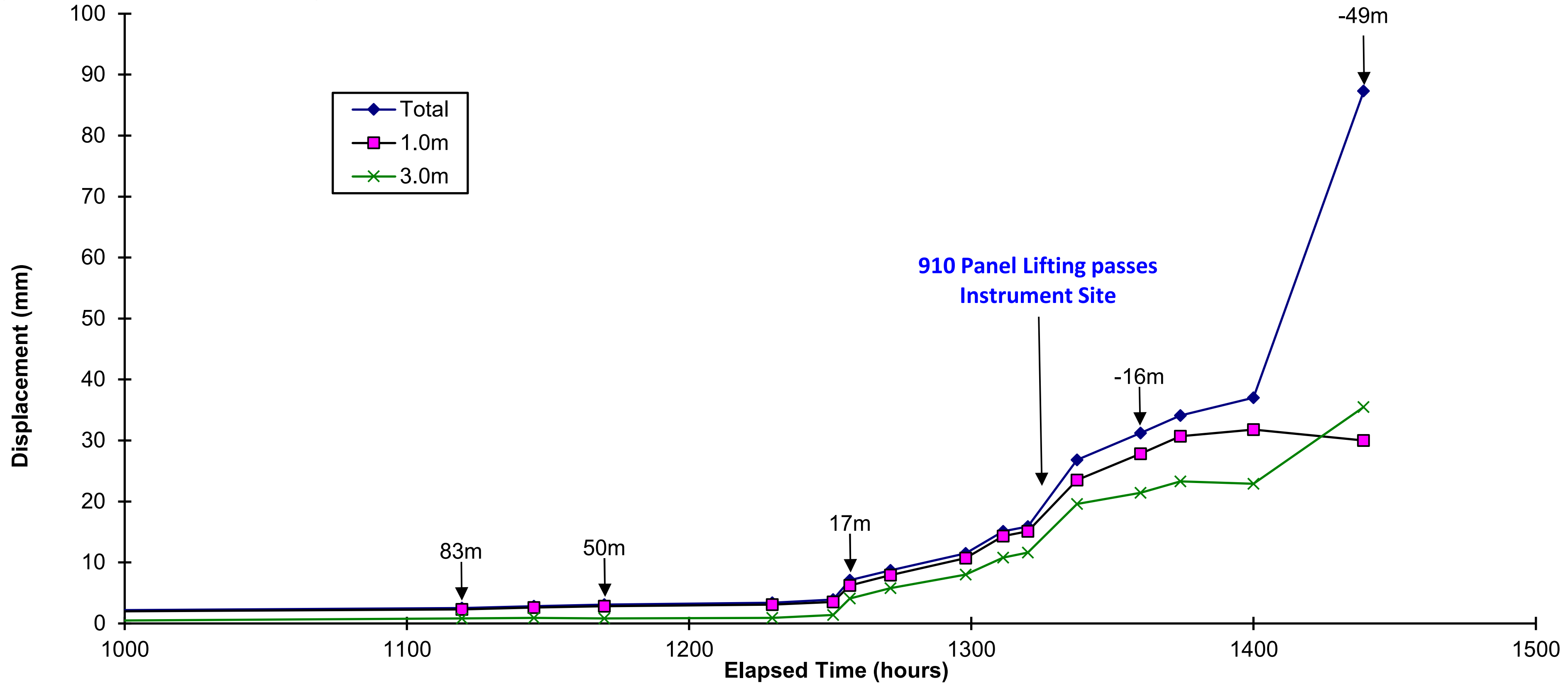


Figure 12c: 910 Panel, E Heading, 47-48C/T - Rib GEL Extensometer Displacement Results



Engineer:	D. Hill	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Monitoring Results from Secondary Extraction, 47-48C/T, 910 Panel		
Date:	29.04.2021				
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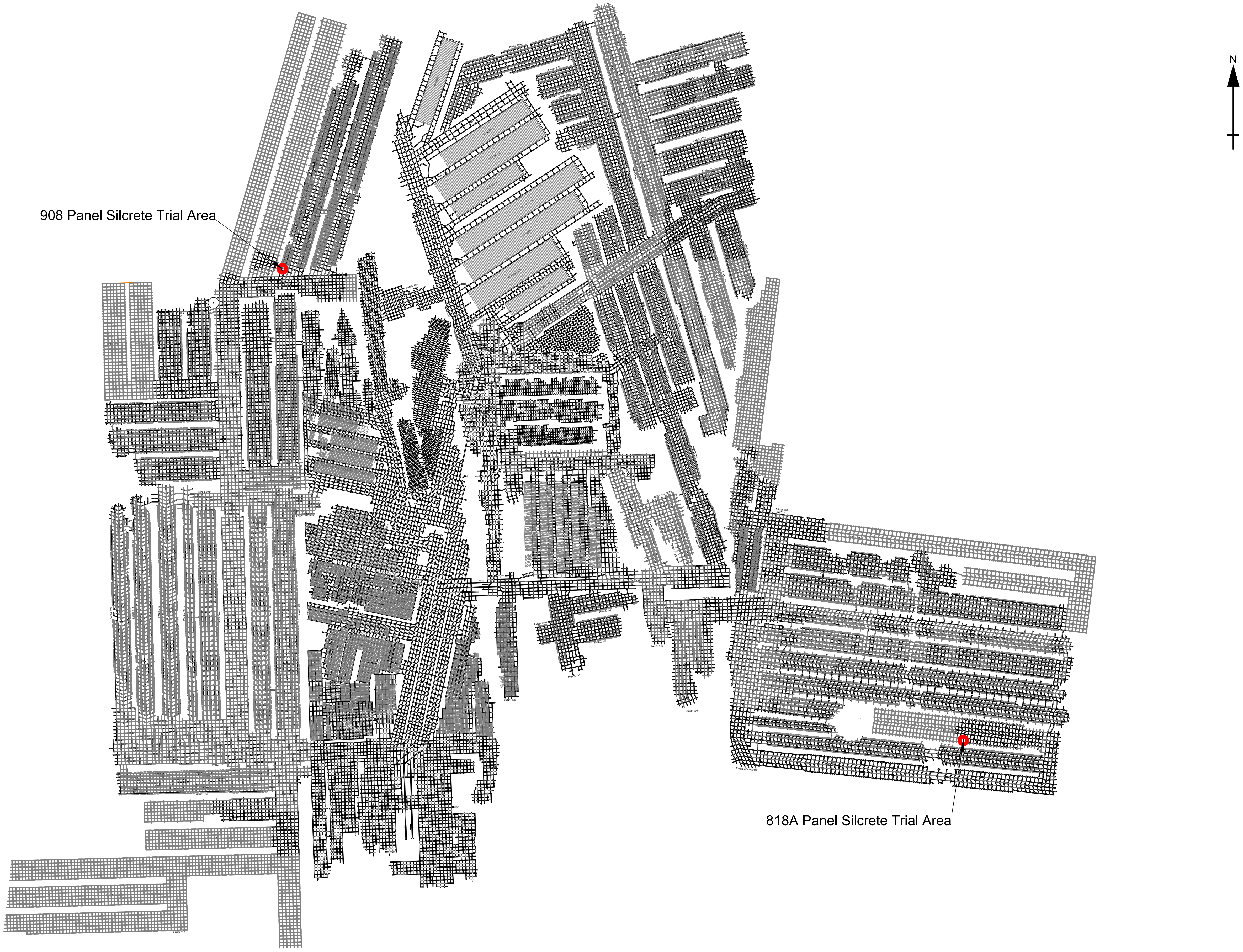


Key:

◉ Silcrete Trial Area

Engineer:	D. Hill	**Client:**	Clarence Colliery
Drawn:	R. de Laubadere	**Title:**	Silcrete Trial Areas
Date:	29.04.21		

STRATA^2

Ref:	CLA-046	**Revision No:**	0
Scale:	NTS	**Figure No:**	13

Figure 14a: pre-lifting

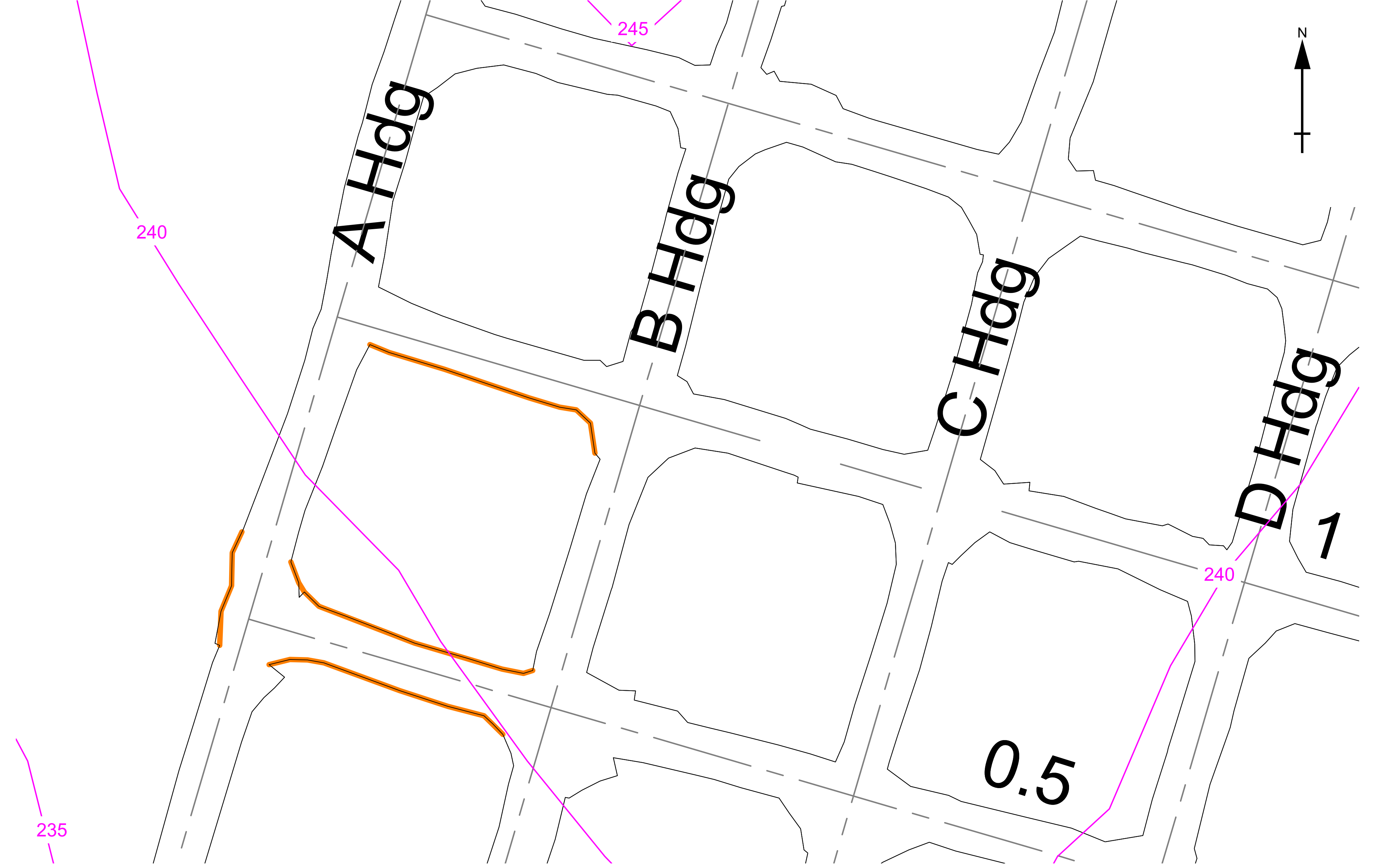
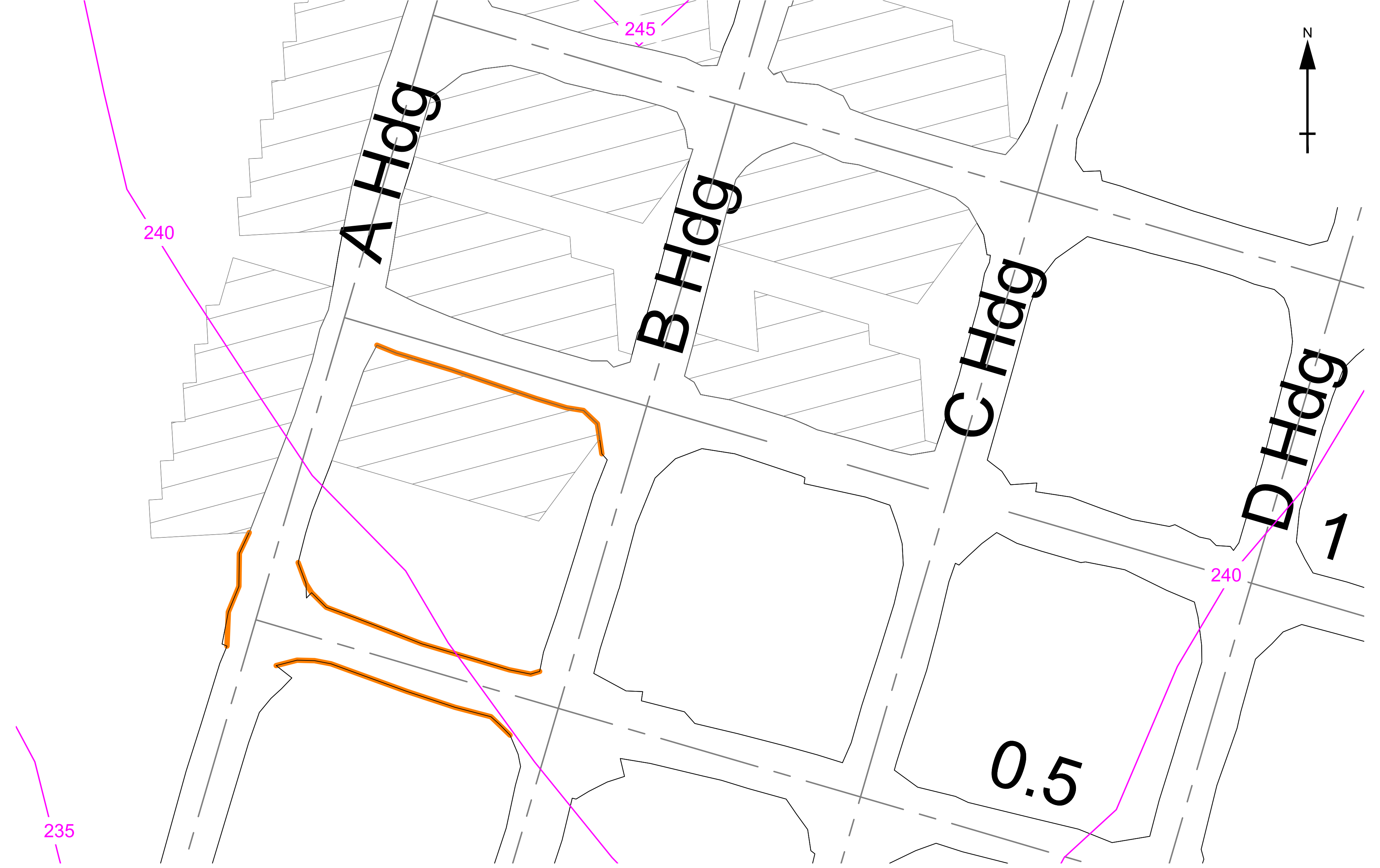


Figure 14b: post-lifting



Key:

🟧 Silcrete Resin

⟋ Depth of Cover (m)

Engineer:	D. Hill	**Client:**	Clarence Colliery
Drawn:	R. de Laubadere	**Title:**	908 Panel Silcrete Trial Area
Date:	27.04.21		

STRATA^2

Ref:	CLA-046	**Revision No:**	0
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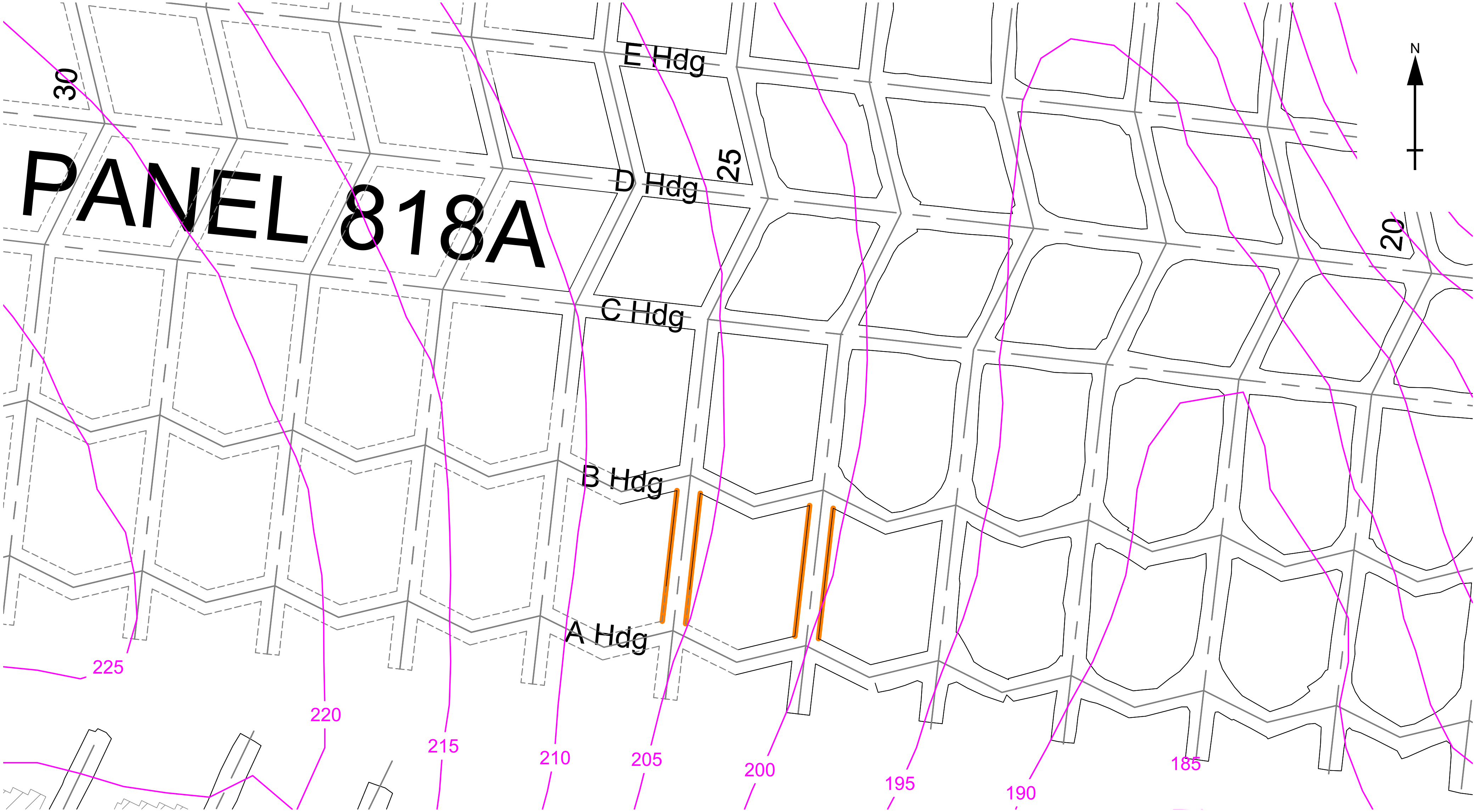


Key:

🟧 Silcrete Resin

Depth of Cover (m)

Engineer:	D. Hill	**Client:**	Clarence Colliery
Drawn:	R. de L.	**Title:**	818A Panel Silcrete Trial Area
Date:	05.05.21		

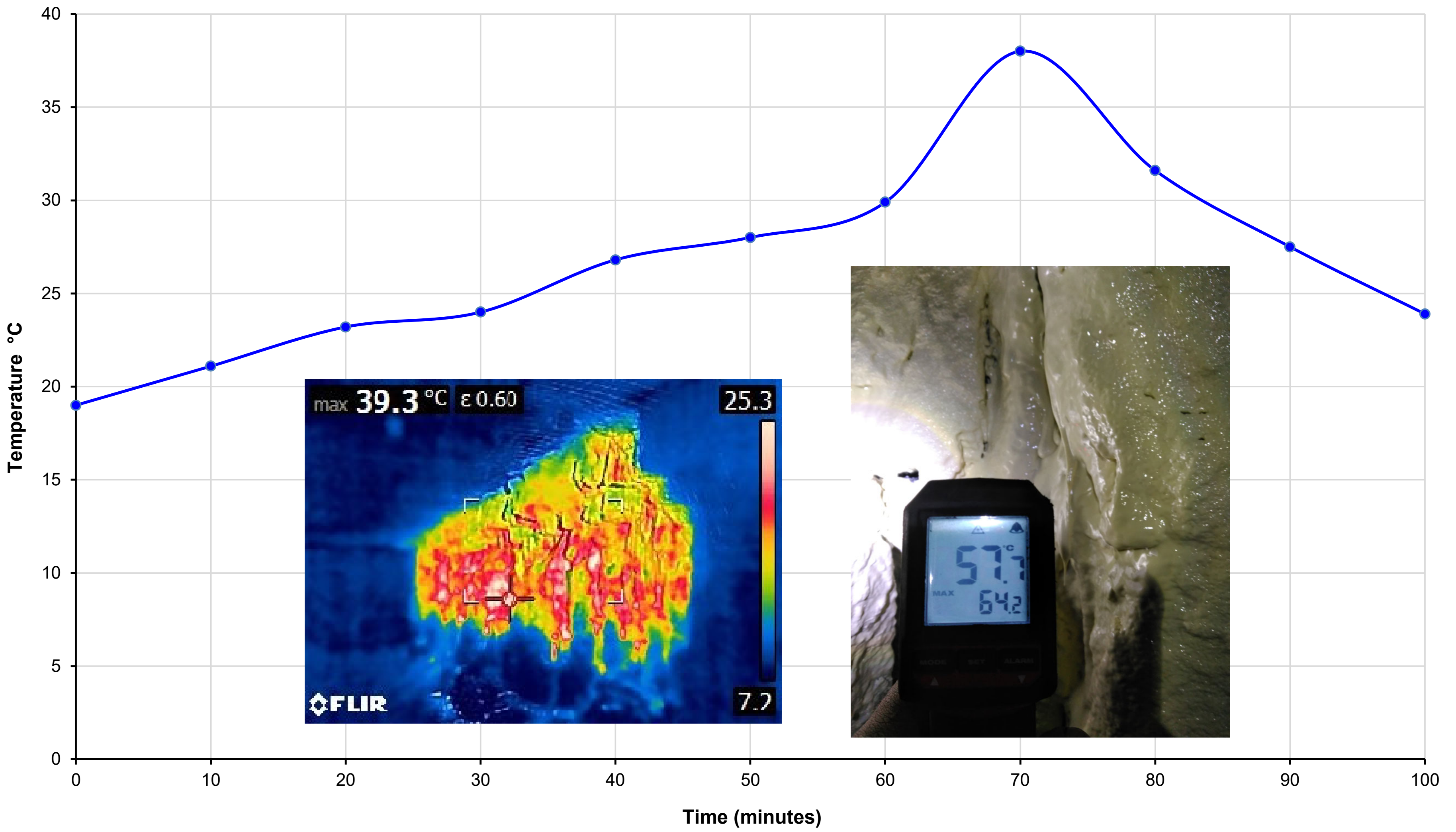
Ref:	CLA-046	**Revision No:**	0
Scale:	NTS	**Figure No:**	15

Figure 16a: Washed Down Rib prior to Sealing

Figure 16b: First Coat being Applied

Figure 16c: Subsequent Coats being Applied

Engineer:	D. Hill / W.L. McLaren	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Silcrete Application at the 908 Panel Trial Site		
Date:	30.04.2021				
STRATA^2		**Ref:**	CLA-046	**Revision No:**	0
		Scale:	N/A	**Figure No:**	16a-c



Engineer:	D. Hill / W. L. McLaren	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Typical Silcrete Liner Temperature Trend and Heat Gun Images		
Date:	30.04.2021				
STRATA²		**Ref:**	CLA-046	**Revision No:**	0
		Scale:	N/A	**Figure No:**	17

Figure 18a: Silcrete bridging Pinnacle

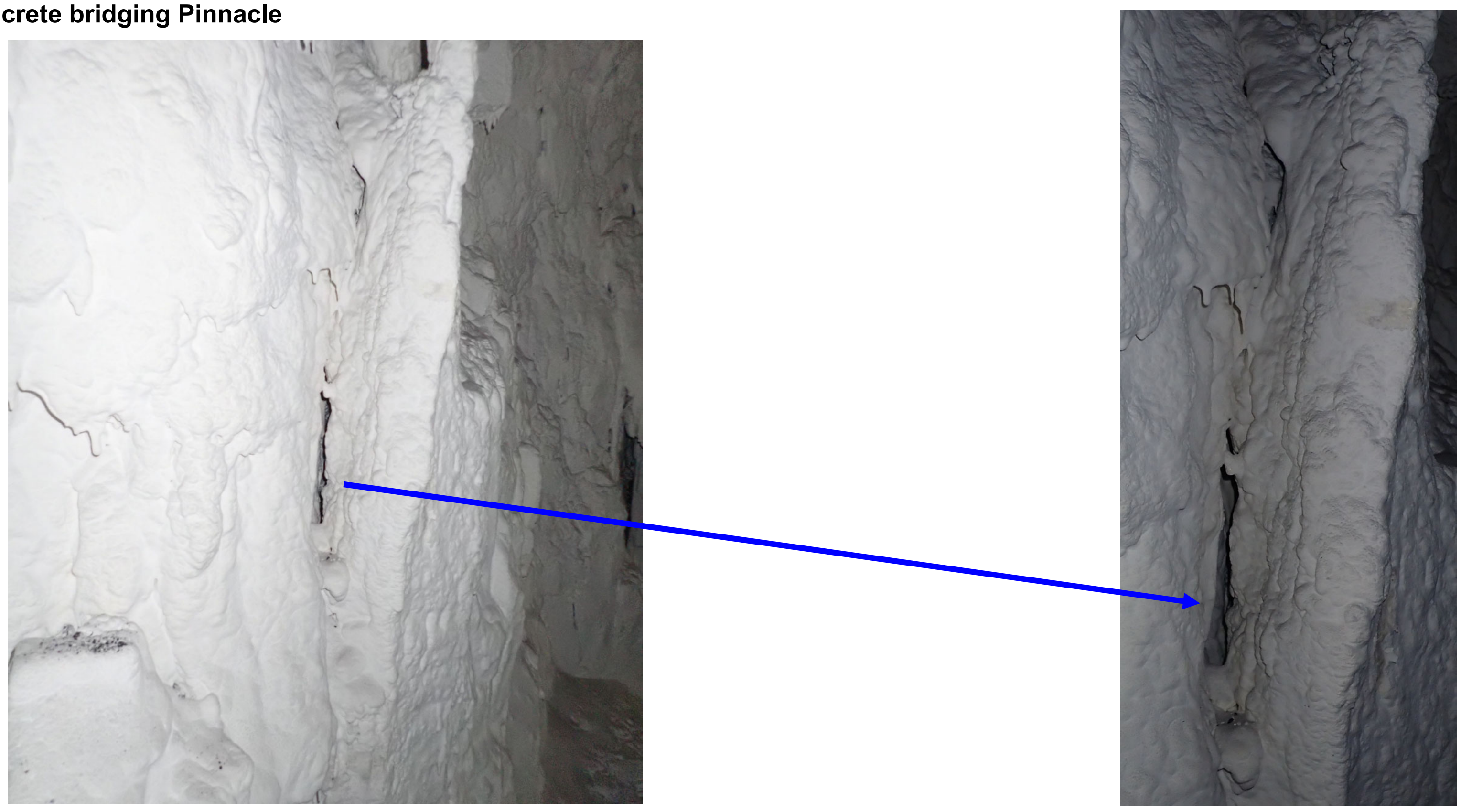


Figure 18b: Bridging Isolated Blocks

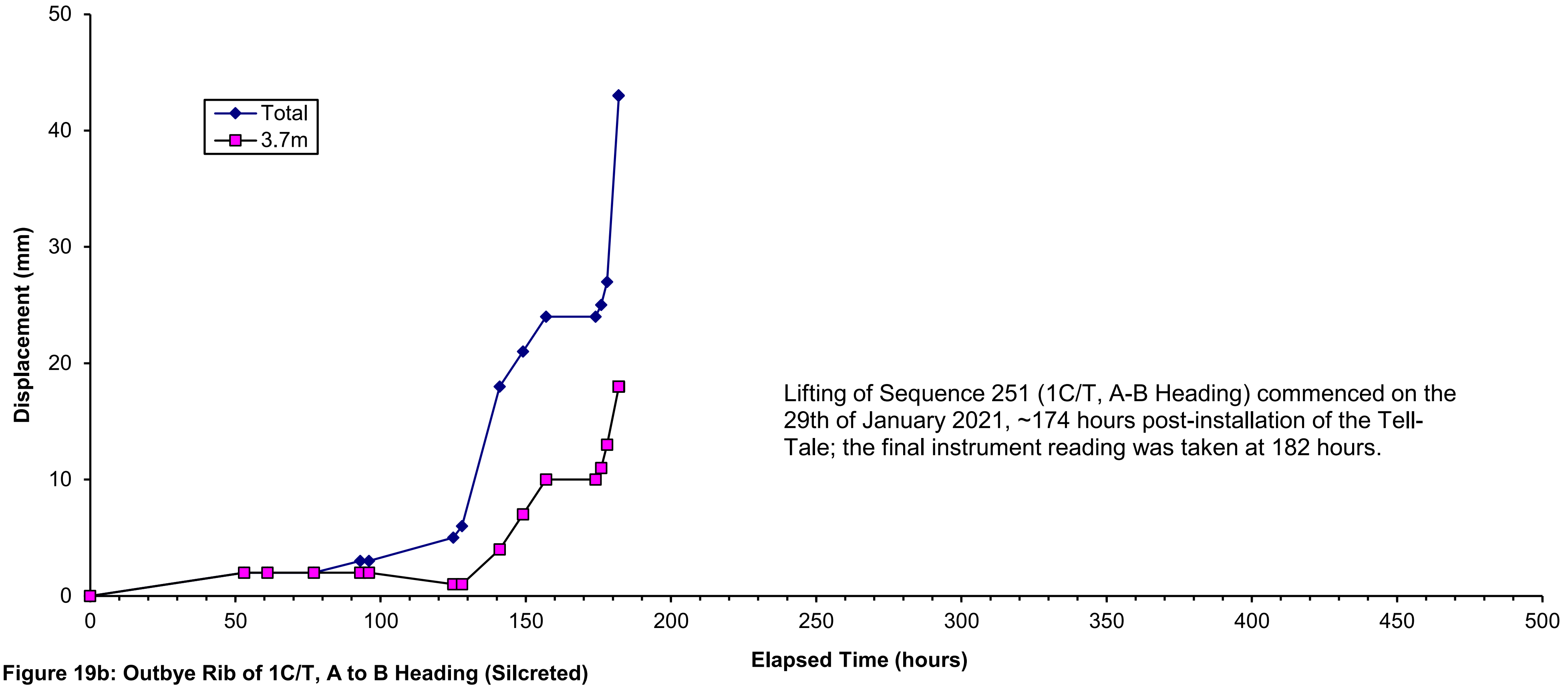
Figure 18c: Localised Dilation on Pre-Existing Discontiuities (Cleat and Bedding) - Inbye Rib of 0.5C/T, A to B Heading

Engineer:	D. Hill / W. L. McLaren	**Client:**	Clarence Colliery
Drawn:	D. Hill	**Title:**	908 Panel Trial Site Post-Extraction - Key Features of the Silcrete Liner
Date:	30.04.2021		

STRATA^2

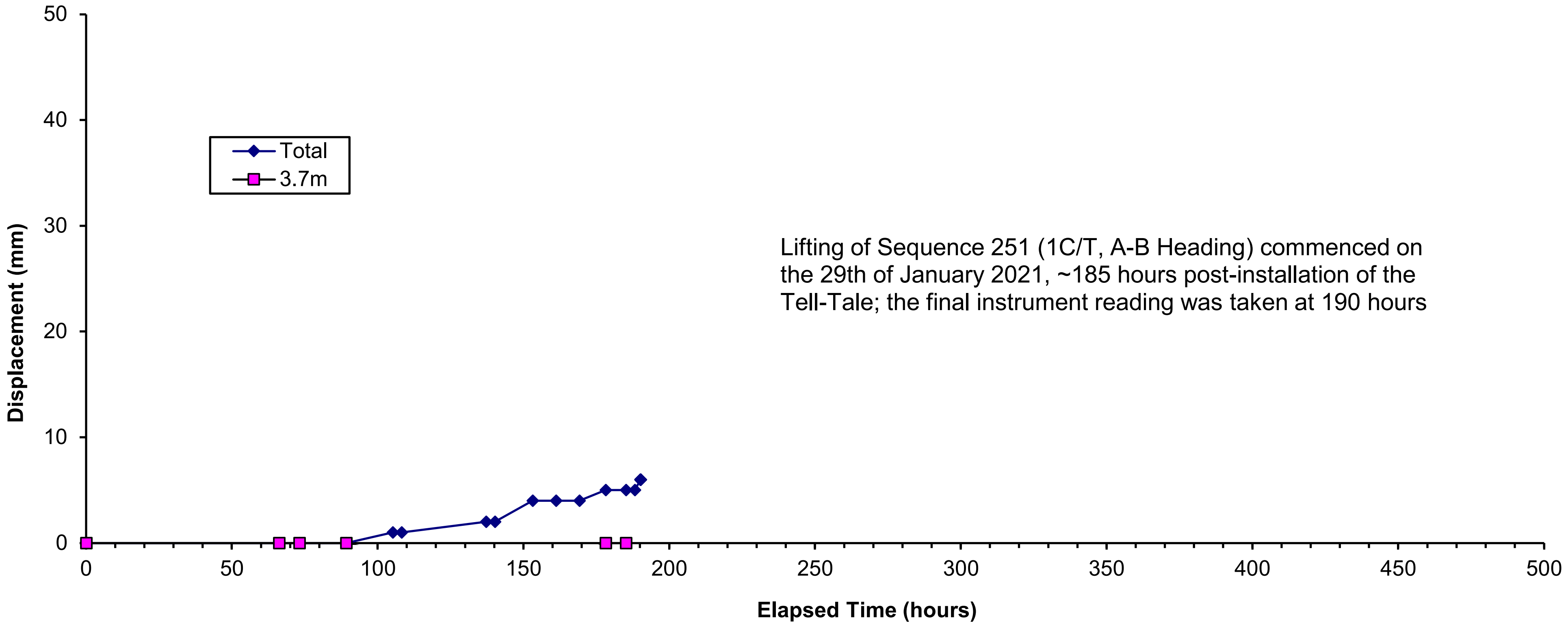
Ref:	CLA-046	**Revision No:**	0
Scale:	N/A	**Figure No:**	18a-c

Figure 19a: Inbye Rib of 1C/T, A to B Heading (Meshed and Bolted)



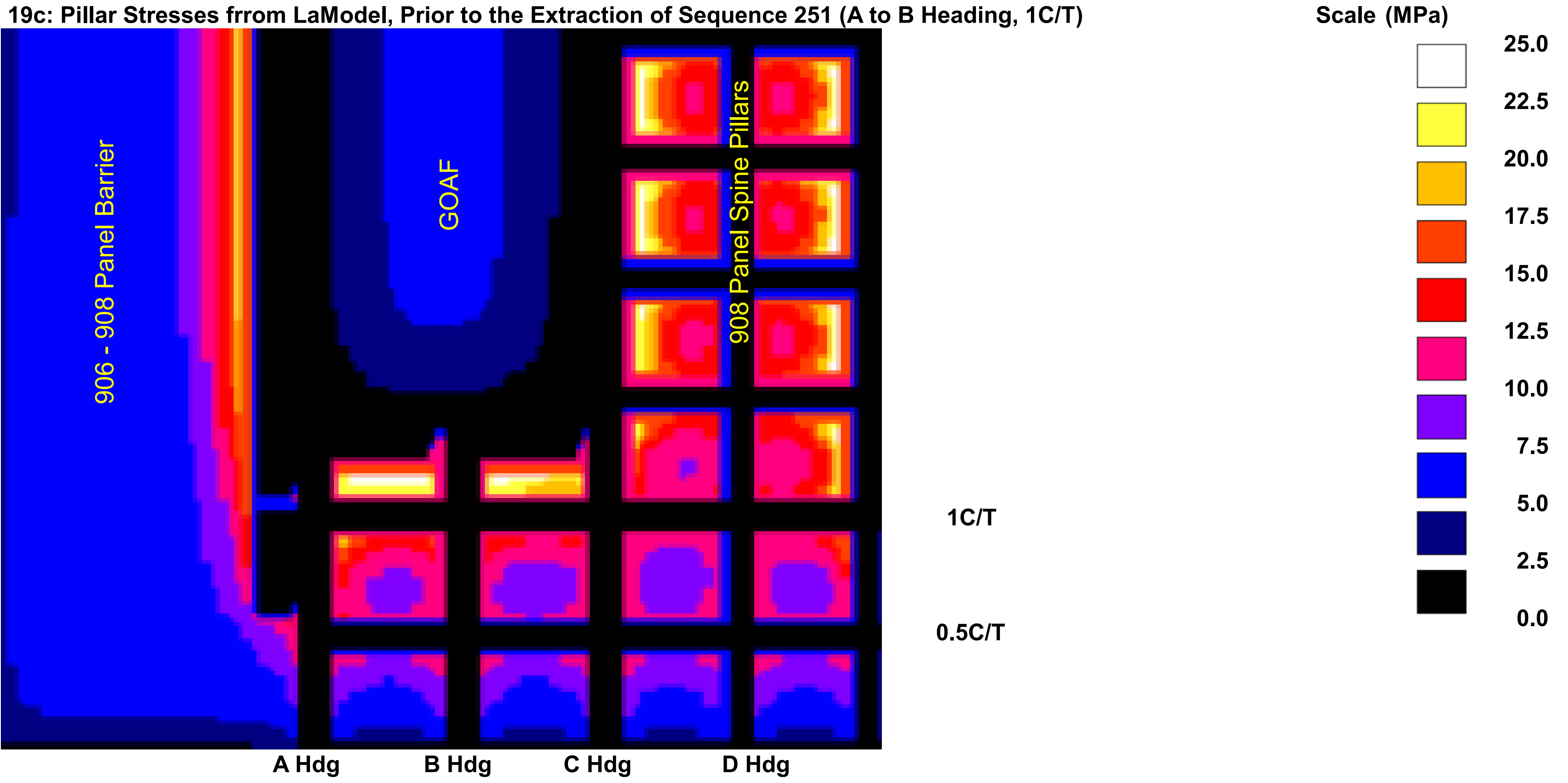
Lifting of Sequence 251 (1C/T, A-B Heading) commenced on the 29th of January 2021, ~174 hours post-installation of the Tell-Tale; the final instrument reading was taken at 182 hours.

Figure 19b: Outbye Rib of 1C/T, A to B Heading (Silcreted)



Lifting of Sequence 251 (1C/T, A-B Heading) commenced on the 29th of January 2021, ~185 hours post-installation of the Tell-Tale; the final instrument reading was taken at 190 hours

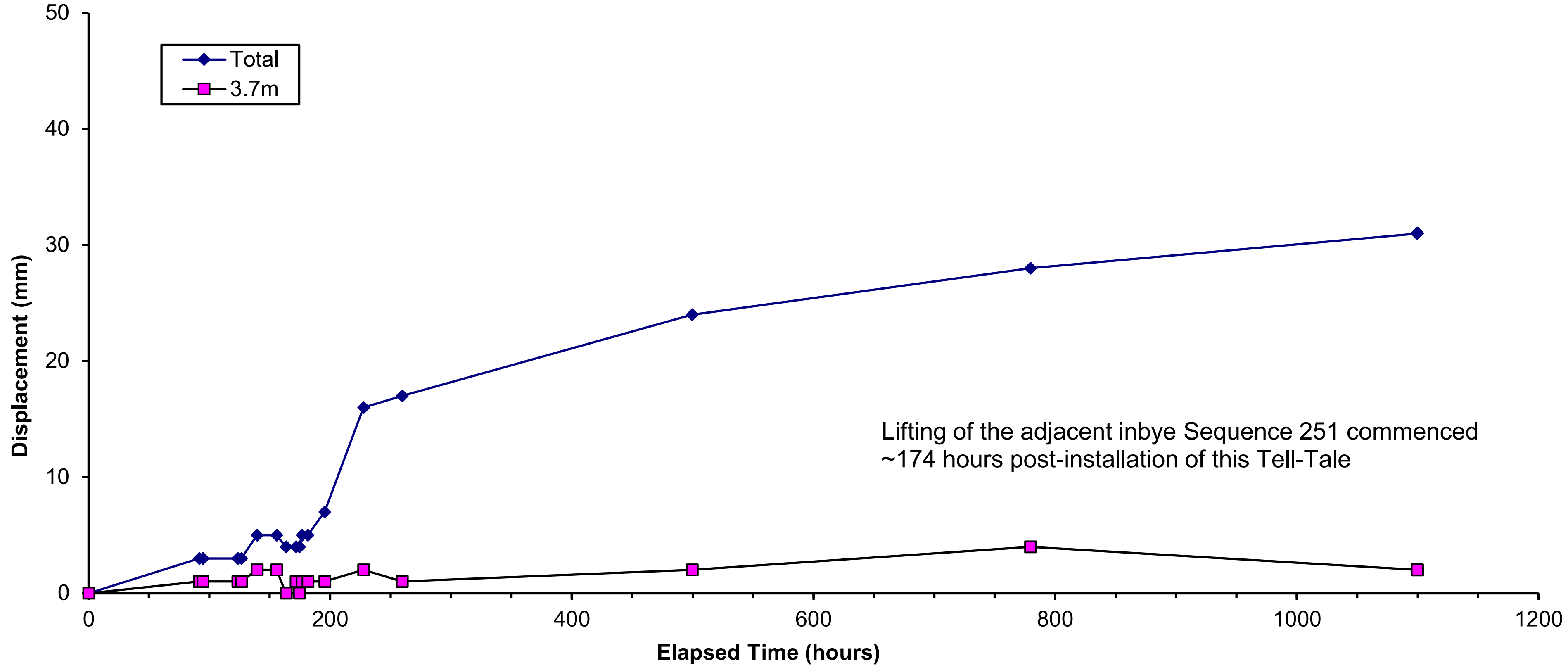
Figure 19c: Pillar Stresses frrom LaModel, Prior to the Extraction of Sequence 251 (A to B Heading, 1C/T)



Engineer:	D. Hill / W. L. McLaren	**Client:**	Clarence Colliery
Drawn:	D. Hill	**Title:**	Tell-Tale and Stress Modelling Results from 1C/T, A to B Heading, through to Extraction of Sequence 251
Date:	01.05.2021		

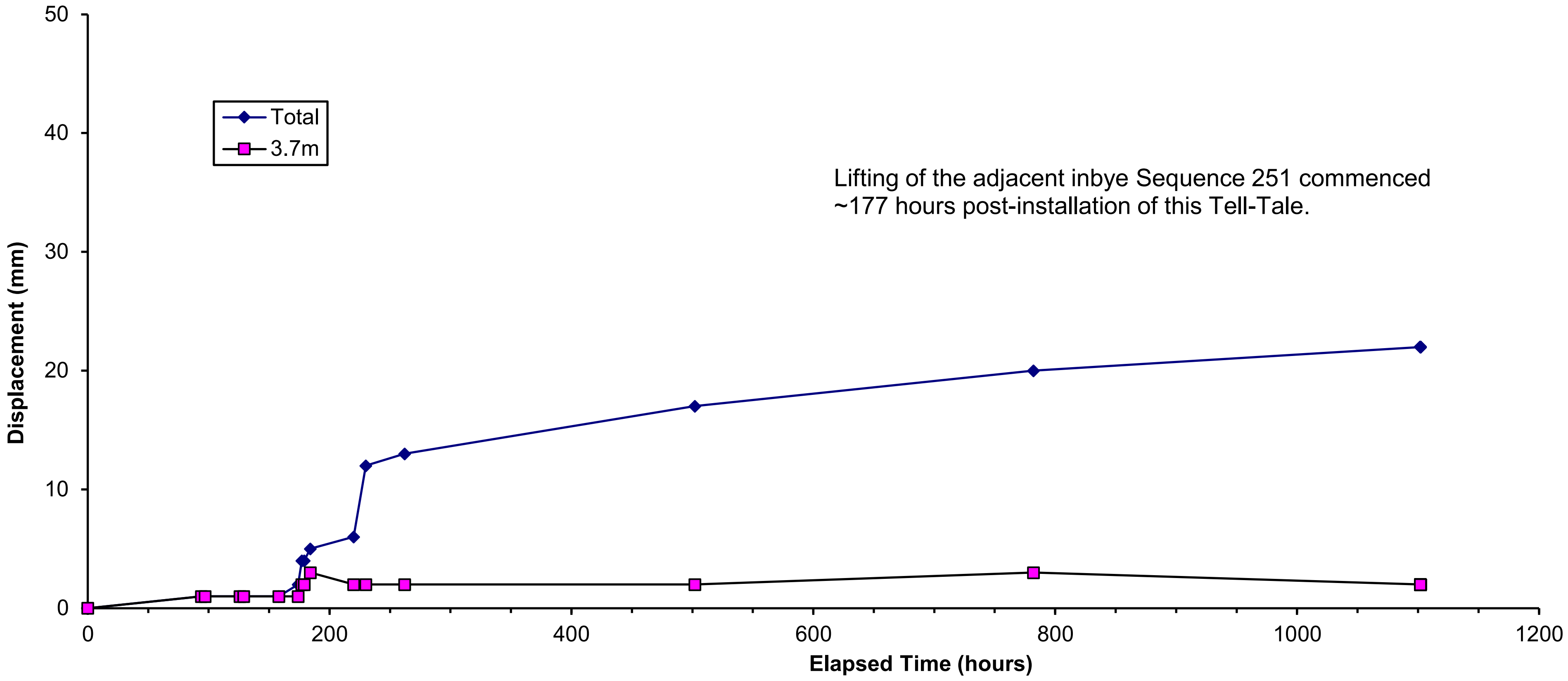
Ref:	CLA-046	**Revision No:**	0
Scale:	N/A	**Figure No:**	19a-c

Figure 20a: Inbye Rib of 0.5C/T, A to B Heading (Silcreted)



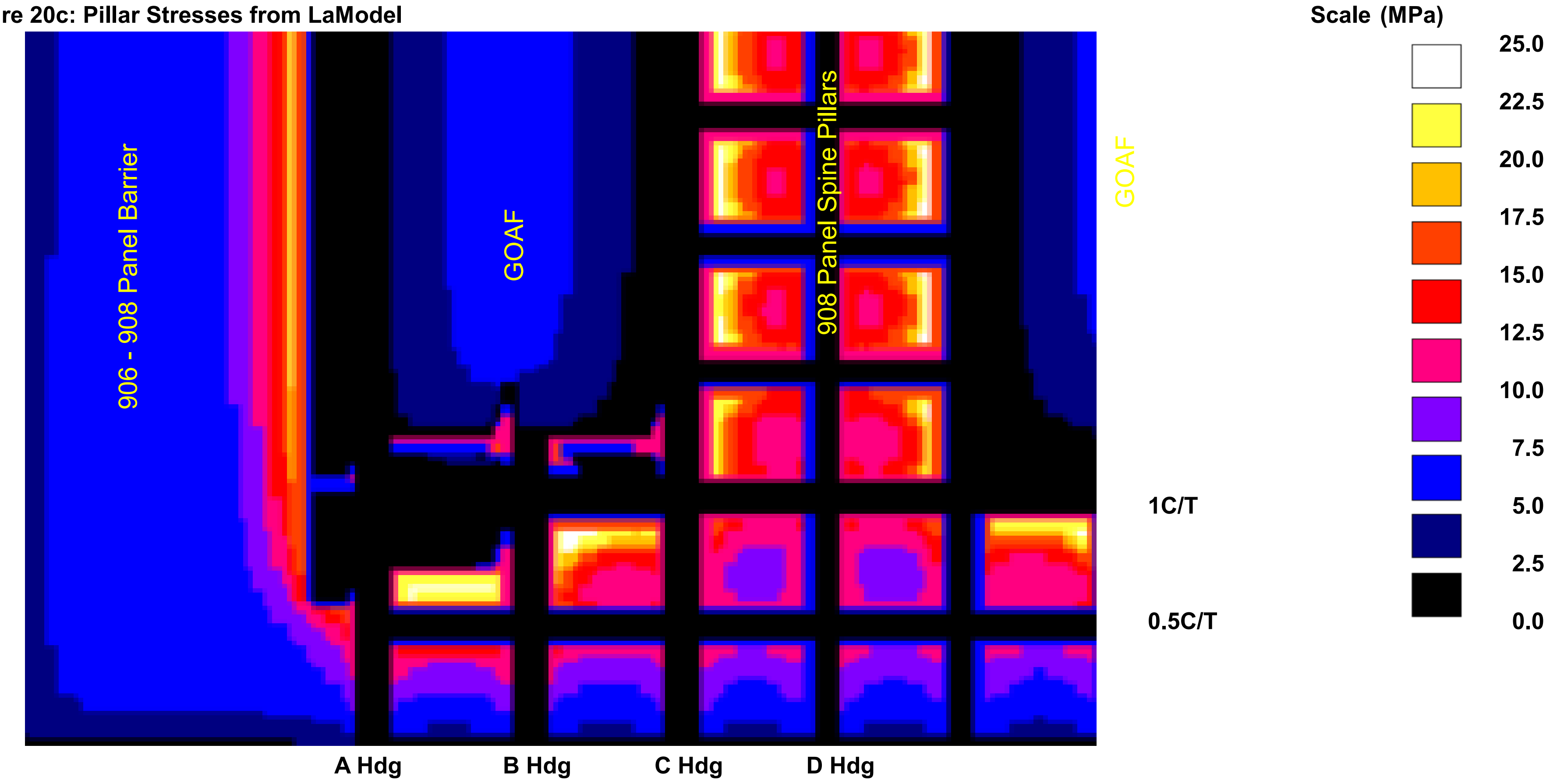
Lifting of the adjacent inbye Sequence 251 commenced ~174 hours post-installation of this Tell-Tale

Figure 20b: Outbye Rib of 0.5C/T, A to B Heading (Silcreted)



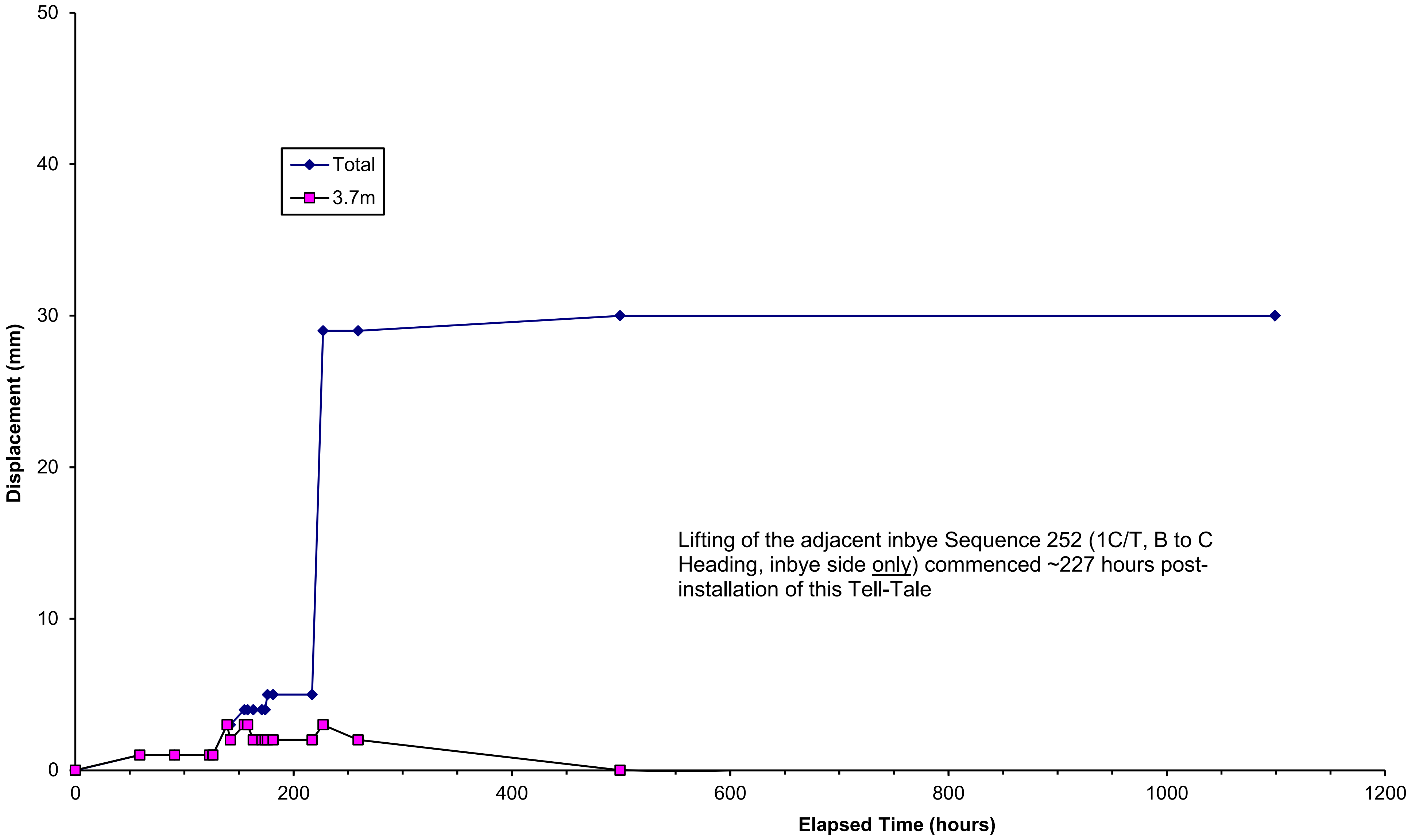
Lifting of the adjacent inbye Sequence 251 commenced ~177 hours post-installation of this Tell-Tale.

Figure 20c: Pillar Stresses from LaModel



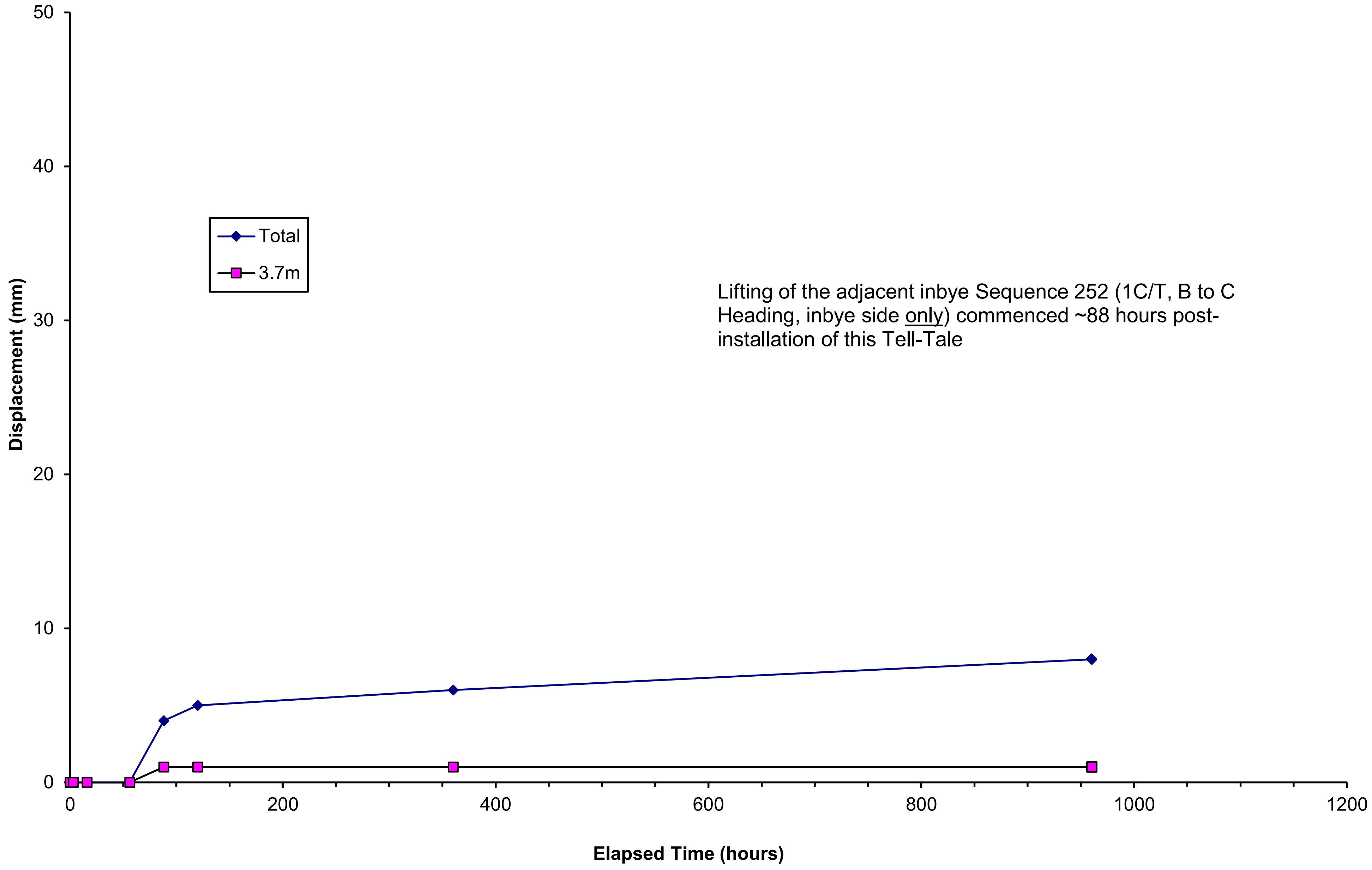
Engineer:	D. Hill / W. McLaren	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Tell-Tale and Stress Modelling Results from 0.5C/T, A to B Heading, including Post-Extraction		
Date:	01.05.2021				
		Ref:	CLA-046	**Revision No:**	0
		Scale:	N/A	**Figure No:**	20a-c

Figure 21a: Inbye Rib of 0.5C/T, B to C Heading (Meshed and Bolted)



Lifting of the adjacent inbye Sequence 252 (1C/T, B to C Heading, inbye side only) commenced ~227 hours post-installation of this Tell-Tale

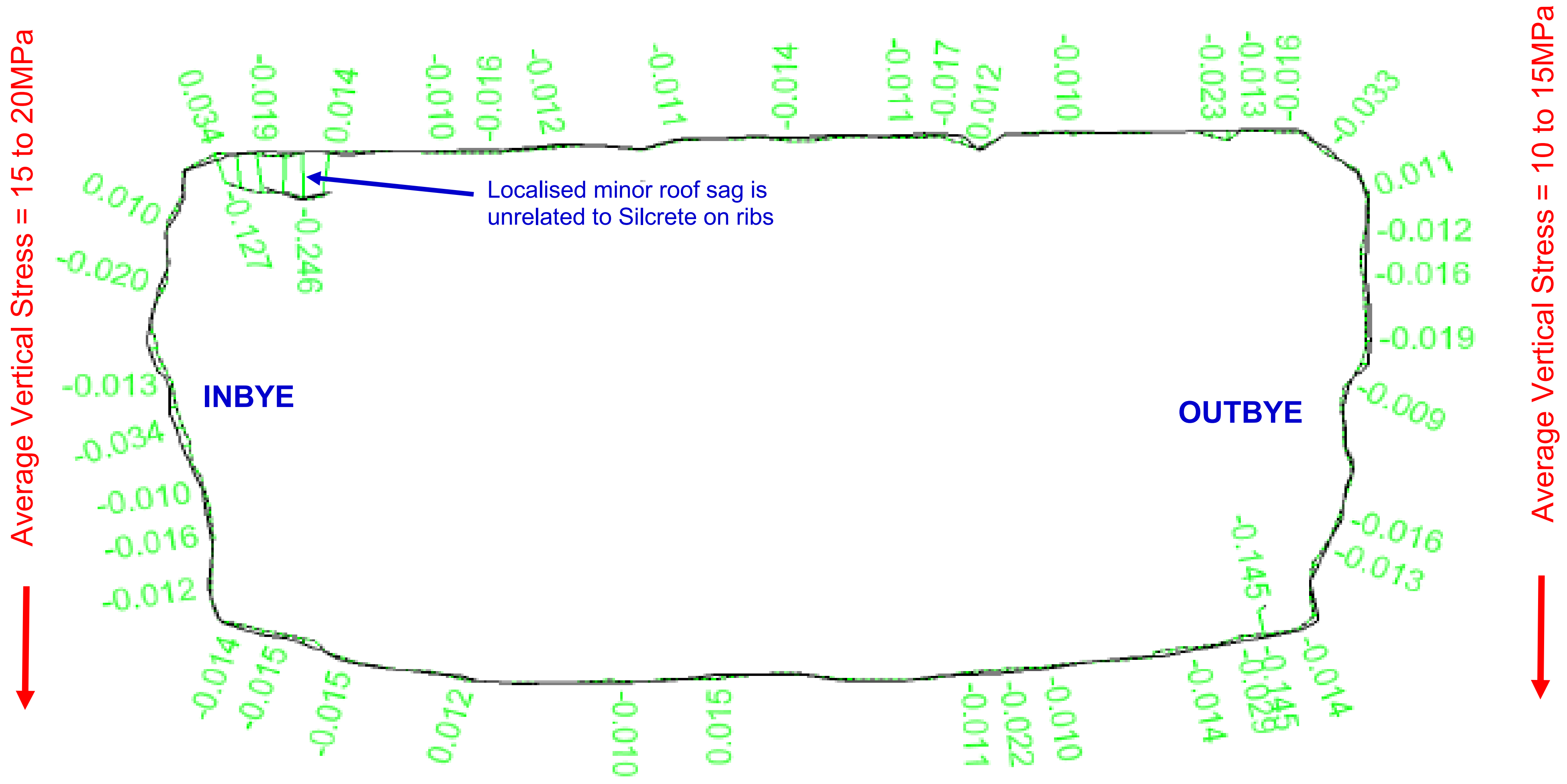
Figure 21b: Outbye Rib of 0.5C/T, B to C Heading (Meshed and Bolted)



Lifting of the adjacent inbye Sequence 252 (1C/T, B to C Heading, inbye side only) commenced ~88 hours post-installation of this Tell-Tale

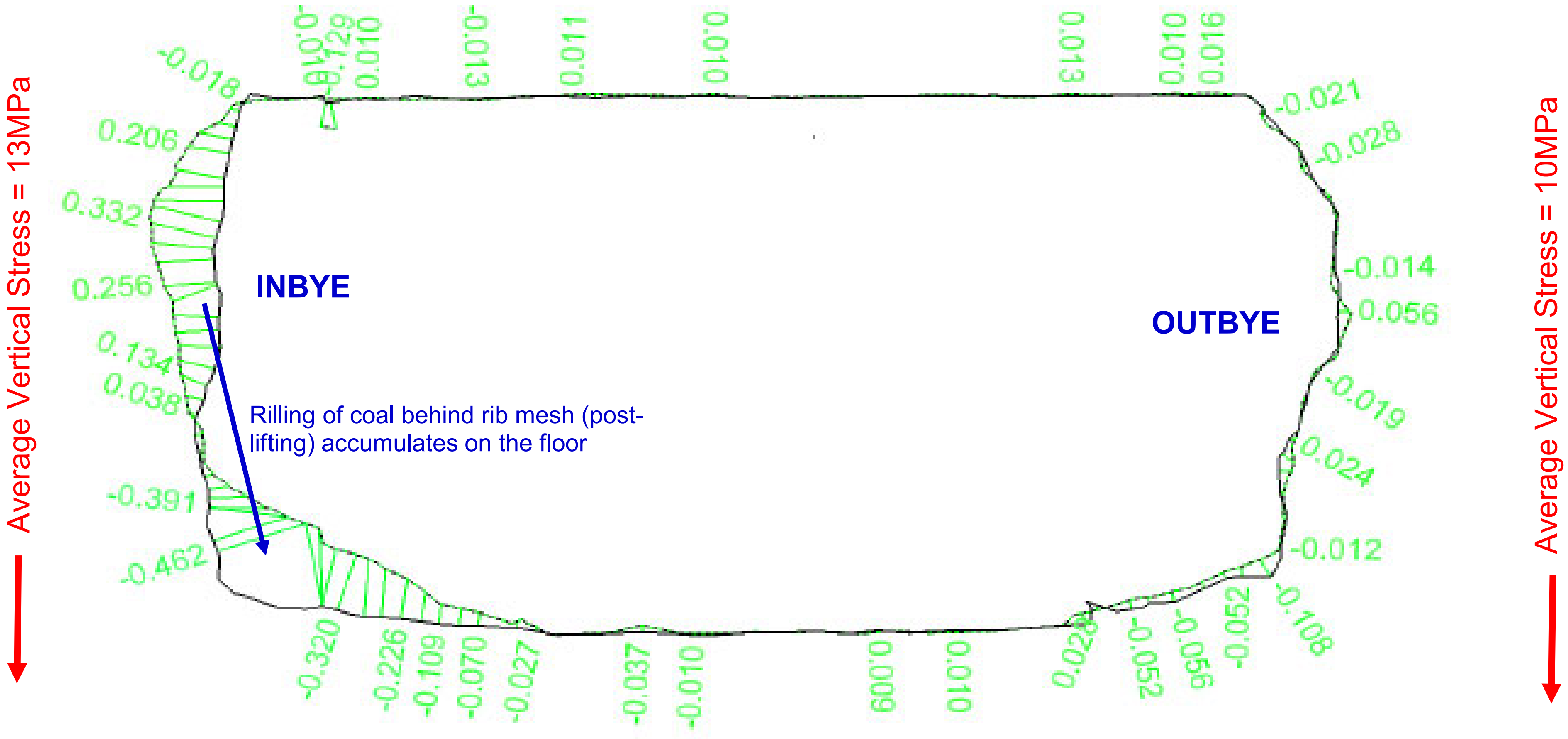
Engineer:	D. Hill / W. L. McLaren	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Tell-Tale Results from 0.5C/T, B to C Heading, including Post-Extraction		
Date:	01.05.2021				
STRATA^2		**Ref:**	CLA-046	**Revision No:**	0
		Scale:	N/A	**Figure No:**	21a/b

Figure 22a: 3D Scan Results from "Section 18", Mid-Way between A and B Heading (Silcrete Lined) - Negligible Rib Deterioration Post-Lifting



Localised minor roof sag is unrelated to Silcrete on ribs

Figure 22b: 3D Scan Results from "Section 48m", Mid-Way between B and C Heading (Meshed and Bolted) - Some Rilling Following Lifting



Rilling of coal behind rib mesh (post-lifting) accumulates on the floor

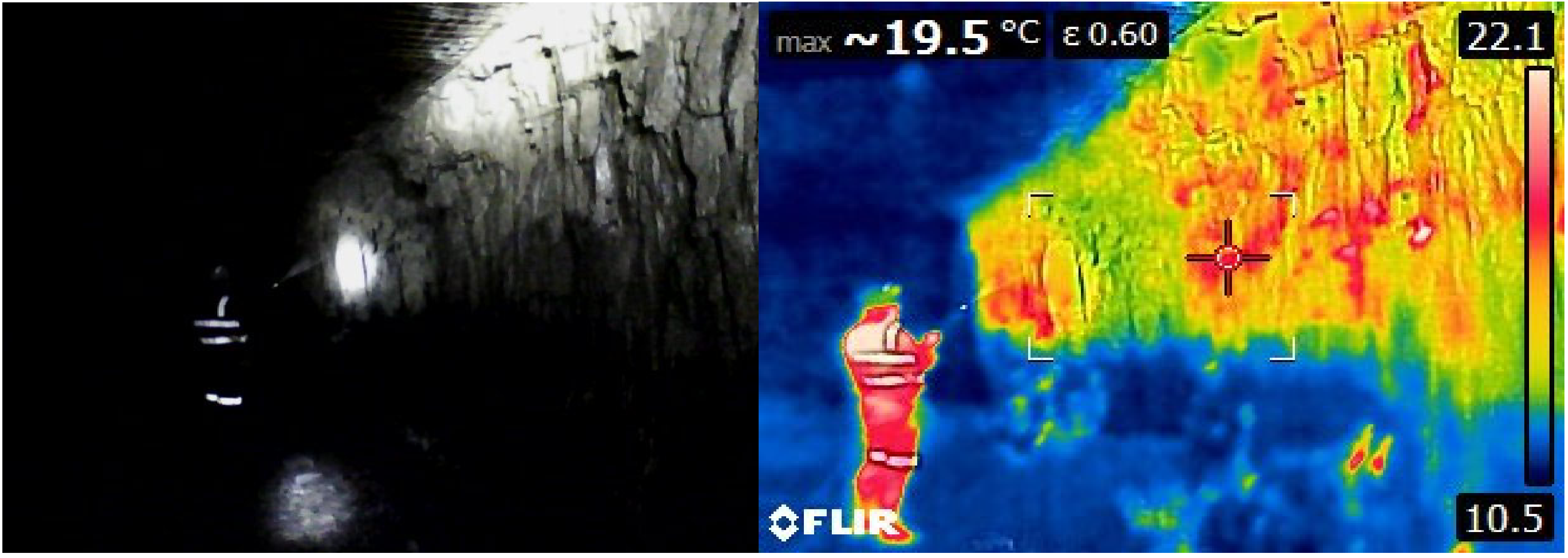
Engineer:	D. Hill / W. McLaren	**Client:**	Clarence Colliery
Drawn:	D. Hill	**Title:**	Samples of 3D Scan Results from 0.5C/T, Prior to and Following Lifting (i.e. Scan 1 on 21.01.2021 versus Scan 2 on 03.02.2021), plus Modelled Vertical Stresses
Date:	05.05.2021		
STRATA²		**Ref:**	CLA-046
		Scale:	N/A

Revision No: 0
Figure No: 22a/b

Figure 23a: Rib Condition prior to Spraying

Figure 23b: Spraying of the First Coat

Figure 23c: Thermal Imaging



Engineer:	D. Hill / W. McLaren	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Application of Silcrete TSL at the Second Trial Site, 818A Panel, 25C/T, A to B Heading		
Date:	02.05.2021				
STRATA²		**Ref:**	CLA-046	**Revision No:**	0
		Scale:	N/A	**Figure No:**	23a-c

Figure 24a: Western / Inbye Side of the Cut-Through

Figure 24b: Eastern / Outbye Side of the Cut-Through

Engineer:	D. Hill / W. L. McLaren	**Client:**	Clarence Colliery		
Drawn:	D. Hill	**Title:**	Final Appearance of the Ribs following Application of Silcrete TSL at the Second Trial Site, 818A Panel, 24 and 25C/T, A to B Heading		
Date:	02.05.2021				
STRATA²		**Ref:**	CLA-046	**Revision No:**	0
		Scale:	N/A	**Figure No:**	24a/b

Appendix A: Silcrete Technical Data Sheet

SILCRETE TSL

Product Code Prefix

SC

Polyurea Silicate Spray Thin Spray Liner

Product Code Guide	Designator	Group	Category	Type	Component	Quantity (kg)	Packaging
	IR	SC	TSL		A	1500	IBC
	IR	SC	TSL		B	1160	IBC

PRODUCT DESCRIPTION

SilCrete TSL is a Thin Skin Lining (TSL) designed specifically for the consolidation of stressed rock structures associated with mining to prevent unravelling of strata and the associated risks presented from falling ground. It also has potential for use as a fire retardant coating for various other substrates.

SilCrete TSL is a two component hard, tough, elastomeric material that is applied through low pressure plural component machinery with a static mixer. No heat is required. The product is flexible with good elongation and high early compressive and tensile strengths. Adhesion is outstanding, even to moist surfaces. 60 to 70% of the physical properties are achieved in 1-2 hours (depending on ambient temperature), set up time is only 10-15 minutes.

FEATURES AND ADVANTAGES

- High tensile strength—capable of holding together under extreme loading conditions
- High impact strength
- Compressive strength approximately 10 MPa after 30 minutes
- Good elongation—does not fail catastrophically but yields under load
- Outstanding adhesion—bonds to all (rock, coal, concrete) surfaces
- Fire Retardant
- Cream colour—for good light reflectance
- Water based
- Clean up with water
- Solvent free—therefore no flammable volatiles
- Simple technology—no expensive equipment requiring expertise.
- No raw material handling—no requirement to be handled other than connecting hoses to the material containers, drums or 1000 litre IBC's.
- No batch mixing—no cement or aggregates required.
- Applied at 5-8 mm thickness.
- Can be applied by hand gun or robotic spray apparatus.

TYPICAL APPLICATIONS

- Rock support in tunnels and mines
- Suitable for lateral work and in shafts
- Slope stabilisation
- Grouting applications
- Soil stabilisation in poor ground conditions

COMPONENTS DESCRIPTION

	Part A	Part B
Appearance	Clear, hazy liquid	Brown translucent liquid
Viscosity at 23°C ops	600 – 900 cps	500 – 600 cps
Density at 23°C	1.50	1.16
Mix Ratio	1 part by volume	1 part by volume

UPDATED NOVEMBER 2017

SILCRETE TSL

Product Code Prefix

SC

Polyurea Silicate Spray Thin Spray Liner

PERFORMANCE & CURED PROPERTIES DATA

Curing time to put into service	**1 – 2 Hours**
Compressive Strength	10 MPa after 30 mins 35 MPa after 5 days
Tensile Strength	10 - 12 MPa
Elongation	5 – 10 %

PACKAGING

- 20 litre pails, 60 and 200 litre drums, 1000 litre IBC's

STORAGE AND STABILITY

SilCrete TSL Part A has a storage life of 12 months from date of manufacture when stored at indoor ambient conditions (20—25°C) in unopened containers.

SilCrete TSL Part B is a diphenylmethane diisocyanate and will react with moisture generating carbon dioxide. The containers should be stored with the seals intact and opened containers used first. The reaction with moisture/water can lead to dangerous build-up of pressure in the drums. Therefore, partially used containers must be tightly re-sealed after use to prevent ingress of moisture. Do not reseal containers once the contents have been used up. Storage life of 12 months from date of manufacture when stored at in-door ambient conditions (20—25°C) in unopened containers. It is strongly advised to purge with dry nitrogen during use.

SAFETY AND HANDLING

SilCrete TSL Part A—is considered practically non-toxic, the usual precaution for handling chemicals should be exercised. Protective clothing should be worn and contact with the body avoided.

SilCrete TSL Part B—should be treated as a diisocyanate and the usual precautions should be exercised when handling this family of chemicals. Protective clothing should be worn and contact with the body avoided. Inhalation of spray aerosol must be strictly avoided and a protective mask, preferably with a clean air supply should be worn in the immediate spraying area.

PROCESSING AND INSTRUCTIONS FOR USE

These materials must be handled and applied only by trained operators.

SilCrete TSL is applied through a PGL plural component spray unit to spray direct to the application area either by hand gun or robotic arm application.
It is essential to force the spray material into all cracks and fissures to "lock up" lose strata.

The material is thixotropic as it leaves the spray head which eliminates drainage sagging and ensures the material stays where sprayed into cracks etc. The material is set up and tack free in 10-20 minutes depending on ambient temperature. The liner can be drilled through and if required rock bolts installed after 60 minutes.