

Ensuring Safety in a Deep Shaft Sinking Operation – Tubbing Lining at Woodsmith Mine

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Project Overview

The Anglo American owned Woodsmith project is situated in the North York Moors National Park. This project, currently under construction, will enable the extraction of Polyhalite between 1500 to 1550 meters below ground level (mBGL). Polyhalite contains four of the six critical elements that plants need to grow, hence will improve arable soils and crop yields, in a more sustainable way. The project consists of a 37km tunnel that will transport mineral from the Woodsmith Mine to Teesside, two auxiliary shafts intersecting this tunnel and the Woodsmith Mine, where the Production, Service and Mineral Transport System (MTS) shafts are situated.

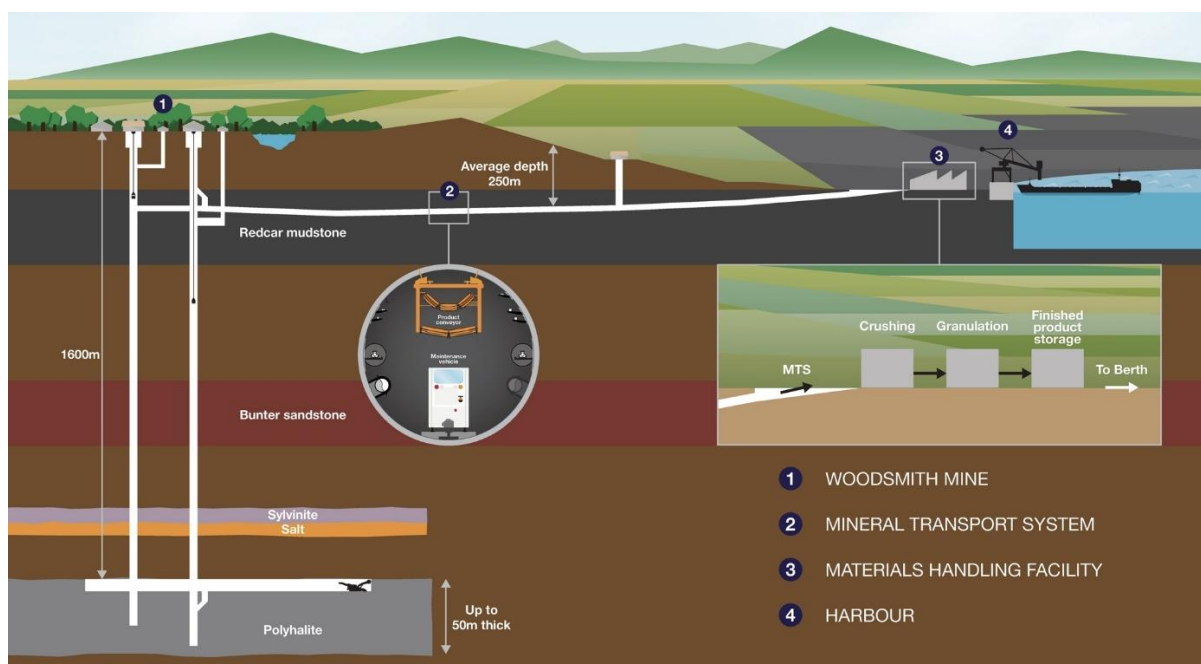


Figure 1. Overview of the Woodsmith Project (Anglo American, 2025)

The sinking of a deep shaft is a challenging and demanding engineering feat, particularly when considering the environmental and geological constraints at the Woodsmith Mine. Mechanisation of traditional shaft sinking methods have led to increased performance and improved safety standards, during construction. The Service and Production shafts at the Woodsmith Mine are currently being sunk with the latest fully mechanised shaft

sinking technology, the Shaft Boring Roadheader (SBR) manufactured by the company Herrenknecht (Schwanau, Germany). The SBR is capable of cutting, clearing waste rock, installing ground support, probe drilling and installing tubings, whilst maintaining elevated levels of safety for all personnel.

Currently, the planned target depth for the Service Shaft and Production Shaft are 1600.3 mBGL and 1620.7 mBGL respectively. Redpath Deilmann UK signed the contract in May 2022 to sink these two deep shafts, as well as the MTS Shaft and inset, that has been developed by drill and blast (refer to Figure 2).



Figure 2. Overview of the Woodsmith Mine (Anglo American, 2025)

Introduction

The cost of sinking deep shafts is a capital-intensive stage of any mining project and particular attention must be taken in the efficient planning, delivery, and execution of the operation. Redpath Deilmann UK are progressing with the Service shaft and have recently passed the halfway point, at 800 mBGL.

The water-bearing hard rock Sherwood Sandstone aquifer, lying at approximately 800 to 1000 mBGL necessitates the need for innovative engineering solutions to enable high-productivity shaft sinking at Woodsmith Mine, whilst maintaining long term stability and safe working conditions.

This paper will discuss the engineering philosophy and implementation of the newly developed engineering solutions, enabling the safe sinking and permanent installation of shaft lining through the Sherwood Sandstone.

Lining Types

Throughout shaft sinking, there will be nine distinct types of shaft liner utilised to effectively seal off the shaft walls and ensure long term stability of the excavation (refer to Figure 3). These include concrete, reinforced concrete, single and double tubbing, and a compressible lining.

The lining type selected between 800 to 1000 mBGL is type B2, comprising of rings of single tubbings and 300mm thick concrete, that will be installed in a top to bottom manner. This method of installation ensures that the exposed shaft walls are sealed off and permanently supported simultaneously with continual sinking.

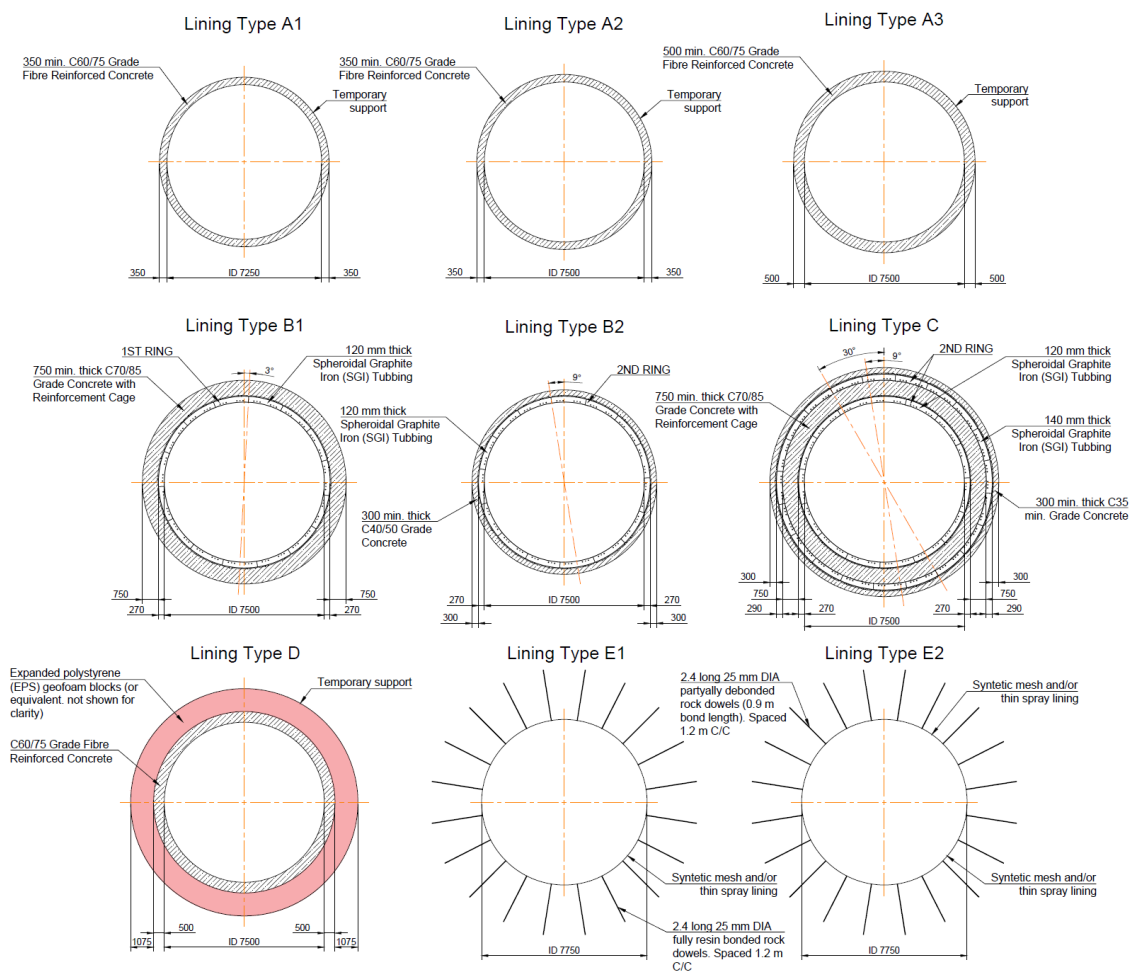


Figure 3. Shaft lining types used at the Woodsmith Mine

Geology

The elevations at which the different shaft lining types have been decided upon are based upon the geological, geotechnical, and hydrogeological conditions through which the excavation pathway of the shaft will encounter.

The installation of a single tubing ring (in either a *Bottom-Top* or a *Top-Bottom* construction methodology), with concrete backfill to be placed between the shaft wall and the tubing, is broadly planned between elevations 750 and 1000 mBGL:

1. **Rot Salt** (750 to 800 mBGL)

To offset naturally occurring *creep deformation* characteristic of rock salt strata, when excavated at depth and notably in the case of shaft sinking, is a well-documented phenomenon in Canadian potash mines. This mechanical property was explained by Swift & Reddish (2005) that it is time-dependent in nature and therefore informs shaft lining design. The viscous nature / elastic solid behaviour has also been detailed by Farmer (1968). Passaris and Horseman (1982) calculations (defining the rate of strain, from which varying shaft excavation radii over time can be deduced) has been the approach undertaken in Hollingworth, Colbeck & Auld's "The design of shaft linings to resist time dependent deformation in evaporite rocks".

2. **Sherwood Sandstone:**

- | | |
|----------------------------|--------------------|
| a. Upper Bunter Sandstone | (800 to 900 mBGL) |
| b. Middle Shale Unit | (900 to 940 mBGL) |
| c. Middle Bunter Sandstone | (940 to 1040 mBGL) |

The Sherwood Sandstone group is the principal aquifer of the region, approximately 240m in total: ~100m of massive fine sub-horizontally bedded argillaceous sandstone, interbedded with bands of mudstone, anhydrite and ~100m of argillaceous sandstone divided by ~40m of fine sandstone/siltstone. Groundwater is hypersaline and under high hydrostatic pressure. Previous exploratory boreholes and studies have been conducted, principally during the construction of Boulby mine, where such information was quantified and calculated – see Cleasby et al. (1974). The Sherwood Sandstone's hydraulic conductivity and transmissivity is considered much higher in areas of increased fracture of the rock mass (BGS/EA, 1997). Boulby mine experienced significant issues with water inflow into the shafts due to an absence of anhydrite and gypsum infilling the joints of the sandstone units (Woods, 1973).

Geological and Geotechnical testing is ongoing at Woodsmith, where bench core samples are taken during the sinking of the Service Shaft, and sent for laboratory analysis, not only for hydrogeological properties but also chemical analyses for the

interests of the progressing grout curtains which lead ahead of the sinking path and are the main strategy of 'water-proofing' the shaft excavation.

Scope of Works

During sinking through the Sherwood Sandstone, the installation of tubbings from top to bottom will be employed. This method has a variety of advantages, including efficiency and safety. The method of installing tubbings from bottom to top requires two passes of the SBR, the initial sinking stage and then raising the SBR whilst installing the permanent shaft lining (tubbings). However, the top to bottom method of installation requires a single pass of the SBR, as the sinking stage and installation of the tubbings occur in parallel.

The method of top to bottom installation enables continual sinking with parallel installation of the permanent ground support, single tubing lining. The first 54 rings of tubing lining will be installed from bottom to top; however, this leaves an approximate span of 70m of temporarily supported ground (mesh and bolting).

Due to the hydrogeological conditions present at approximately 810 mBGL, the shaft walls must be sealed off promptly to mitigate and control the amount of water flowing into the shaft. This means that the installation method of bottom to top is not feasible for below this elevation, due to the large span of temporarily supported ground. The process of top to bottom installation enables a span of just 10m temporarily supported ground, far lower than the 70m mentioned previously. This is the main reason this method of installation has been chosen, during sinking through the Sherwood Sandstone.

Equipment

Critical equipment required to carry out the process of installing tubbings from top to bottom include: a **hydraulic curb ring** that is mounted on hanging rods around the periphery of the shaft, a tubing **erector arm** that is mounted between work decks 2 and 3 and the **kinematic arms** that probe drill and grout ahead of sinking.

There are also key logistical challenges to the process of tubing lining installation, that is described in the tubing delivery section below. To ensure the entire process runs efficiently, these logistics have been thoroughly planned to reduce overall cycle times, whilst ensuring safety.

Tubbings

The cast iron tubing segments are supplied by Woosung Metal Co Ltd, based in South Korea. Typically, tubbings have been supplied by Eastern Europe for shaft sinking projects, however this was not possible due to supplier issues. These tubbings must be of sufficient strength to resist the hydrostatic and ground pressure at depth and require

precision machining to achieve this (refer to Table 1). A lead gasket installed between adjacent tubing segments deforms under contact pressure to provide a watertight seal.

Dimension of Segment	Fabrication Tolerance (mm)
Dimensions over a machined face	± 0.1
Casting thickness	± 3.0
Segment height	± 0.2
Internal diameter of completed test ring	± 12
Flange thickness	± 3.0
Bolt hole drilled diameter	0/+1
Bolt hole spacing	± 1.0
Distance of bolt hole circle from inside of flange	+5/-3
Measured bolt hole pitch circle radius deviation from theoretical dimension	± 1.0
Height difference between lowest and highest tubing segments in a ring	0.2

Table 1. Fabrication Tolerances of the Single Tubing Lining

Individual tubing segments have a height, radial length, and thickness of 1200mm, ~1600mm and 270mm respectively, with a mass of ~2.9t. These segments are bolted together to form a complete ring of 15 segments and the next ring is rotated through 12 degrees to ensure that the horizontal flanges do not align (refer to Figure 4 and 5).

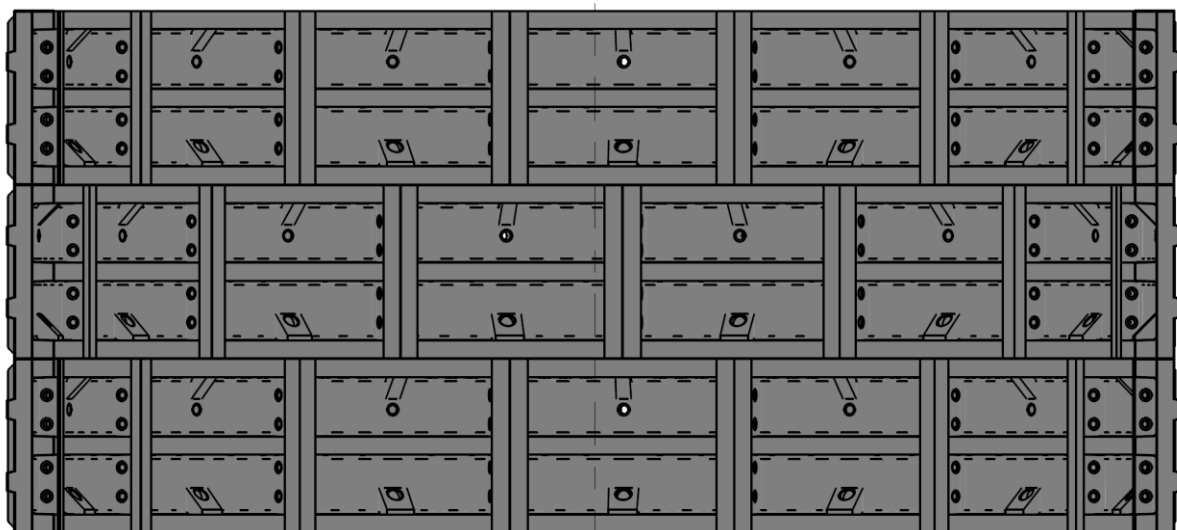


Figure 4. Three Rings of Tubing Lining

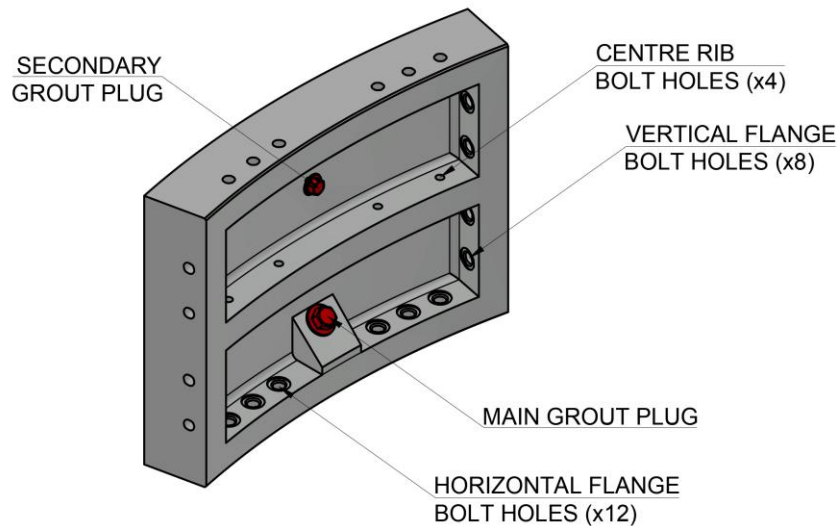


Figure 5. Segment of the Tubbing Lining

Tubbing Delivery

Due to the mine site being in a National Park, all permanent infrastructure for hoisting has been constructed to reduce visibility from the surrounding area. This poses a unique challenge to the Woodsmith Mine when compared to other mine sites that have a traditional shaft with large headframe arrangement. Both the deep shafts have a wider diameter foreshaft that has been sunk to 43 mBGL, where the shaft collar doors are situated. For this reason, materials require double handling, firstly from the surface to 43 mBGL and then from 43 mBGL through the shaft collar to their required elevation. This imposes a key logistical challenge and a well-executed plan is required to reduce cycle times throughout the installation of the single tubbing lining.

Tubbing segments are delivered from a designated laydown storage area to the shaft collar house (0 mBGL), by forklift. Four tubbing segments are transported at a time using a tubbing frame. This frame is lowered from the shaft collar to 43 mBGL using a Kone crane. The tubbing segments are then unloaded at 43 mBGL, using a mobile crane, onto the tubbing rail cart. This rail cart is then moved to the auxiliary bucket well of the shaft collar. A lifting tubbing traverse is attached to vertical flange of the tubbing segment, which is hoisted up and transported through the collar doors, down to the SBR.

Hydraulic Curb Ring

The hydraulic curb ring was designed by Redpath Deilmann GmbH, to be used as a temporary works support ring, serving to position the tubbing segments prior to final installation. This ring is fixed horizontally by six hydraulic cylinders, that are raised by a maximum of 400mm. An additional eighteen threaded hanging rods provide additional security. During top to bottom installation, the new (lower ring) is positioned under survey control on the curb ring, which is then raised, and the lower ring is bolted to the

already installed tubing ring above (upper ring). Once all bolts are torqued, the curb ring is lowered by ~1500mm using four chain hoists attached to the SBR and the cycle repeats. Three cycles of tubing rings are completed (3.6m) before concreting (refer to Figure 6).

Concreting is carried out through the main grout ports of the tubbings. The curb ring has twenty-four hydraulically operated drawers that seal the void between the lower most tubing ring installed and the shaft wall. Once this concrete has cured, the sinking cycle continues.

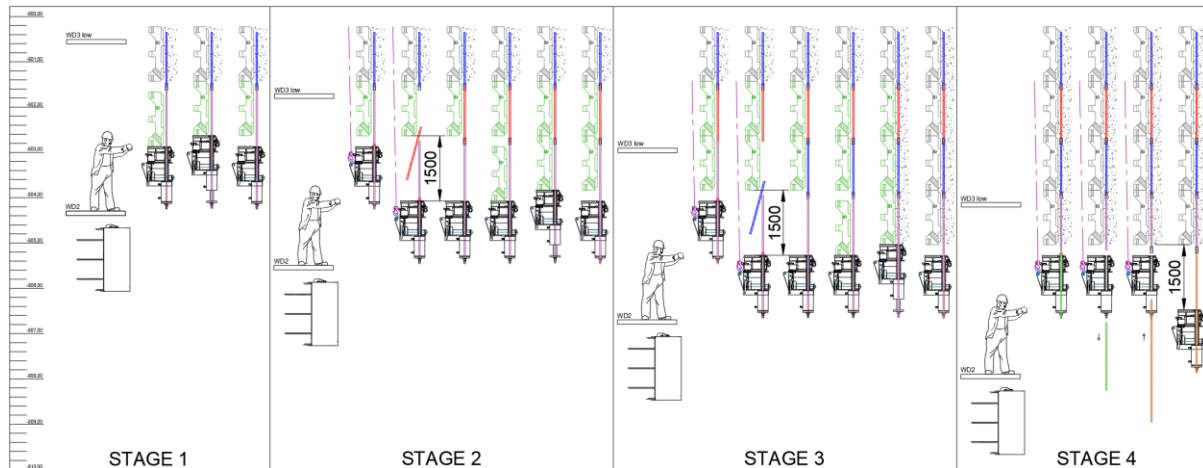


Figure 6. Typical Cycle of Installing Tubings Top to Bottom

Tubing Erector Arm

The tubing erector arm was designed by Herrenknecht (Schwanau, Germany) and is installed between work decks 2 and 3 of the SBR. They completed a full test in Germany, simulating the shaft conditions and successfully fulfilled the construction of 6 tubbings and a keystone segment (critical for the double tubing lining).

This mechanised piece of equipment is designed to handle tubing segments and is controlled remotely. The Erector arm removes operatives from the line of fire and reduces the risk of entrapment as the positioning of the tubing segments into design position can be controlled from a safe distance, ensuring that a safe exclusion zone can be maintained.

The arm can rotate 360 degrees around the central axis of the SBR, +/-55 degrees around the Z axis and 0/90 degrees around the Y axis, to position the segment into its design position.

Conclusion

The success of any mining project is not only influenced by performance, but safety is also paramount. Everyone on a mine site has a duty of care to ensure that all workers return home safely after their shift. The adoption of mechanised sinking technology has

allowed for safer working conditions due to the removal of workforce directly at the cutting face. This technology has enabled critical sinking tasks to be carried out by remote control, from the safety of the operator's room.

RDUK have deployed innovative technological solutions to successfully sink through the Rot Salt, Sherwood Sandstone and through the full depth of the shafts to their target elevation. The method of installation of the tubing lining from top to bottom, as highlighted in this paper, has been selected to effectively seal off the shaft walls and install permanent shaft lining in parallel with continual sinking.

This ensures long term stability to the excavation; during construction and for the life of mine, increasing safety performance to all operatives working on the SBR today and the mine for the future.

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