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MANDALAY RESOURCES

Costerfield – a narrow-vein case study

Over the last six years, Mandalay Resources has increased production rates and improved safety outcomes at its Costerfield mine in Victoria, Australia

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The Costerfield mine is an underground operation utilising narrow-mining techniques to extract vertical veins. It produces up to 80 000 equivalent ounces of gold per annum in both gold and antimony value. Costerfield sells a gold-antimony concentrate comprising 54 per cent antimony (Sb) and approximately 60 g/t gold. A gravity gold concentrate is also produced.

Costerfield has been operating for ten years, and has been owned by Mandalay Resources Corporation for the last six years. The asset is managed by a small team using narrow-vein underground mining methods, which has enabled it to maintain sufficient cash flow to be self-funding during the current commodities downturn.

Under the ownership of Mandalay, Costerfield has increased production rates to a record 42 000 oz of saleable gold and 3 700 t of the specialty metal antimony, or approximately 65 000 saleable ounces gold equivalent (Au eq. oz) in 2015.Operational improvement highlights from 2009 to 2015 include:

- improved mill throughput from approximately 170 t/d to approximately 420 t/d
- reduced mining cost per tonne from $260/t to $156/t
- changed mining method from cut-and-fill to blast-hole stoping with cemented rock fill
- contracted-out capital development
- increased sublevel spacing from five to ten metres
- growing mine life from zero reserves to roughly four years (please see Mandalay's Reserves and Resources Update Technical Report for 2015, filed on SEDAR March 2016 and found on the company's website) while mining continuously for six years.

Even with a decreasing antimony price since the boom (as shown in Figure 1), Costerfield has remained profitable, with all-in costs averaging US$760 ounces gold equivalent in the fourth quarter of 2015 (based on metal prices of Au US$1202/oz for gold and US$6820/t for antimony).

The operational challenges of narrow-vein mining include controlling overbreak as the veins being mined are only 300 mm wide. Costerfield has developed methods and modified equipment to suit extraction of these veins. Productivity improvements have involved developing a stoping method and equipment to suit 1.8 m wide development drives. Over the last five years and during a skills shortage, recruitment, training and retention of personnel has been key to keeping corporate knowledge and retaining skills to execute a careful, efficient mining technique to minimise overbreak.

Additionally, specific management strategies ensure efficient production and conversion to reserves of the high-grade antimony and gold resource. These include:

- a focus on culture and company values in leadership
- developing people and industrial relations
- ensuring quality standards are maintained to minimise dilution
- taking an innovative approach to modifying current technology and methods to suit narrow mining
- good stakeholder engagement
- a focus on 'keeping it simple'.

The mine has also invested substantially in executive coaching of its leadership team, which has paid dividends in the problem-solving potential of that team and ensuring that the operation delivers on its promises to all stakeholders. The operation has become safer, and employees are more aware of their individual contribution to safely and efficiently produce gold and antimony. This, in turn, benefits the whole operation, community and region.

Geology and mining method

The antimony-gold deposit at Costerfield is part of a geological province confined within the Siluro-Devonian Melbourne Zone. The mineralisation consists of faulted-hosted veins that are mostly less than 1.5 m in width and have been formed in multiple phases, including a bedding-parallel laminated barren quartz phase, followed by a quartz-pyrite-arsenopyrite phase with coarse gold, then a massive stibnite with distributed fine-grained gold phase. Reefs are 'en echelon'-style narrow-vein systems dipping from 25° to 70° west or 70° to 90° east. In-vein grades are generally around 30 per cent antimony and 50 g/t gold and, with planned dilution, average 3-5 per cent antimony and 8-12 g/t gold. Typical vein orientation is shown in Figure 2 (SRK Consulting, 2015).

The underground production areas are accessed by a decline to approximately 350 m below surface. The decline is constructed 4.5 m wide and 4.8 m high and is used for access and haulage. It has been developed using a twin boom jumbo. Waste access levels in the Cuffley deposit are 2.8 m high and 2 m wide, and are mined using handheld and single boom jumbo methods. Multiple veins are accessed from each decline cross cut.

The ore development mining method is based around a development width of 1.8 m, which is 0.3 m wider than a Sandvik LH203 bucket. As there are no personnel carriers used in this size drive, people walk to the working face, and the development drifts are up to 200 m long. The Sandvik fleet is used in development bogging, stope bogging and filling duties and for carrying baskets that hold pneumatic rock drills and legs, tools, explosives and charging equipment.

Once ore development is completed, longitudinal uphole stoping is used to extract towards the central access pillar. Access pillars in ore are staggered for stability, and crown pillars are left every 30 to 40 m vertically. These are eventually extracted using uphole retreat methods with teleremote loaders when the panel is completed. Typical stoping plans are shown in Figures 3 and 4.

Drill and blast operations use 51 mm diameter holes with two holes per ring, 650 mm hole spacing and 700 mm burden. Stable strike lengths are approximately 8 m. The aim is for a 1.2 m wide stope, but they generally average 1.5 m, depending on ground conditions. Level spacing is approximately 8 m, and after the initial 1.4 × 1.4 m slot is fired, the stope is bogged

and filled with cemented rock fill. Rather than drilling and firing a new slot, the operations have developed mesh tube rollers that take standard weld mesh sheets and roll them into tubes. These tubes are then lowered over the stope edge to form the void for the next firing.

The number of activities scheduled weekly is significant for Costerfield's small size. There are generally 65 development rounds at 1.8 m length and 25 stope firings each week. Each crew is multiskilled so that any leave is covered, and there is sufficient redundancy in both operations and service sections to cover roles. Developing employees to be proficient in other areas has also helped to maintain a workforce with low turnover.

Culture, values and developing people

Mandalay is a values-based organisation. These values are kept alive in conversations in quarterly business update meetings and in recognising actions that display the values of safety, responsibility, agility, performance, innovation and value creation. There have been numerous initiatives over the last five years, commencing with a 12-month executive leadership training program.

This program allowed the leadership team to understand themselves first, enhance their relationships and break down any views of the past that resulted in any 'silo' mentality. After completing the program, the leadership team has functioned cohesively, seeking out strategic opportunities to solve problems and create value. Trust between members of the leadership team and in other areas of the organisation was also elevated. The program was then rolled out to the next management level down, resulting in the entire workforce having an aligned vision and focused execution.

Department leaders within the mine are given the freedom to act as owners and are empowered to make resource and purchasing decisions in a way that adds value to the elements of the mine they provide services to. The operation has also recruited leaders with experience in running their own successful businesses, in some cases outside of the mining industry. Because these people have local relationships, they are able to deliver quicker, more cost-effective works to the operation.

The operation has also improved its safety performance, with lost time injuries reduced by 80 per cent. Safety processes are not overly prescriptive and are risk assessment-based. A site nurse oversees employee health and wellness programs and return-to-work processes, enhancing the preventative side of injury management. Minor aches and pains are directed to physiotherapists for assessment before any work time is lost, and fitness programs using exercise physiologists and personal trainers have been implemented, especially for sedentary staff such as truck and loader operators.

In 2016, the operation embarked on the 'Because we care' program, in partnership with the JMJ Group, to explore a number of adaptive challenges at Costerfield and mining in general. One of the visions for this program was assisting the workforce to be happy at and outside of work. This element of the culture at Costerfield – caring about the whole person and what is important to them – is one factor that attracts employees. The operation also partners with Risk Response and Rescue for incident response and emergency management training.

Quality standards to minimise dilution

The operation is currently plant-limited, and every additional waste tonne will displace metal and ounces through the plant. Quality standards are maintained in the development cycle by supervisor and foreman checks, survey calculations of monthly overbreak and giving the individual miner licence to alter drill and blast practices in poorer ground areas. Turn outs are often mined to design and then carefully stripped, depending on lode strike, to allow loaders to turn tightly to minimise intersection spans and dilution.

During the stoping cycle, a production drill leader oversees drill accuracy and training of staff, the majority of whom are internally trained to operate the production drills. A void laser scanner monitors performance and solves issues in narrow stopes (refer to Figures 5 and 6), and backup air-leg miners are trained to operate the production drills. Cemented rock fill quality has been improved by ensuring that only dedicated areas are used for mixing and that correct water and cement ratios are used, with mix data recorded and checked. This is critical to reducing overbreak as the 24-hour curing time allows for consolidation of the previous void and provides confinement for the adjacent stope to be fired.

Any stope bridge has a production loss report created, with an incident investigation performed to determine the cause. Initial slots for stoping panels are fired and then wire mesh tubes are used to create a stope void so that 100 per cent extraction can occur along strike. Loader operators are given licence to correctly install enough tubes to cover the length and width of the stope. Any deviation from the standard that results in a stope bridge is communicated back to the operator.

For mine planning, a pneumatic Kempe drill delineates ore structures and splays, ensuring a robust mine plan. The main orebody is drilled to indicated status on 40 m centres. Faces are sampled at least every 10 m along strike and fed into a block model that is updated at least quarterly. The Kempe drill regularly identifies additional ore outside of the mine plan, which is adjusted accordingly, and a quarterly mine forecast is presented monthly and adjusted to budget. A plan analysis is undertaken in the monthly reconciliation and communicated at meetings. Figure 7 shows a typical reconciliation waterfall chart, displaying the mine plan deviation and block model deviation. Annual budgets are completed to life-of-mine with exploration upside, and the annual plan is then used to produce quarterly, monthly and weekly forecasts.

Modifying equipment for narrow widths

The narrow mining widths at Costerfield present equipment selection challenges. As mentioned, the Sandvik LH203 loader, at 1.5 m wide, determined the initial drive width. Hand-held methods utilising pneumatic rockdrills for boring with 32-35 mm diameter face holes were initially used, and two trials were undertaken of boring with a H104 single boom jumbo. Both trials showed that overbreak was unacceptable, and the mine returned to hand-held boring on ore, using H104 in the waste access drives only. The H104 carrier was subsequently modified to drill 51 mm diameter upholes.

The equipment manufacturer Atlas Copco helped develop and refurbish the H104 single boom jumbo with a Cop1435 high-frequency rock drill suitable for drilling 10 m length production holes using 900 mm speed rods. No carousel can be fitted within the 1.8 m wide development drive, so rods must be added and removed manually, making it a two-person operation. The rigs often move during the shift for panel drilling, so the additional offsider can assist the

driller with site checks and checking hole accuracy by drilling holes to breakthrough. The cost of developing a production drill internally was approximately half that of purchasing a new machine and had a much shorter lead time. It also matched with the philosophy of keeping it simple and using what worked in the past.

Additionally, despite some suppliers initially indicating that it could not be done, teleremote guidance was successfully fitted to units in the existing LH203 loader fleet. Teleremote operations are now used every shift to extract ore from longer stopes and dangerous close-out areas, and the operation is moving to more teleremote loaders due to the reduced exposure to operators (the LH203 is an open-cabin loader).

Other equipment used for narrow dimensions includes agricultural tractors modified to transport explosives to development faces. Light vehicles are sourced locally from second-hand 79 series Land Cruisers to minimise costs. Maintenance is generally successful because of skilled personnel on site, including a boilermaker that is able to design and modify equipment.

Good stakeholder engagement

The Costerfield operations inject approximately A$50 million annually into the local economy. Heathcote, the nearest town, is 10 km south of the mine. Mandalay sponsors many local events, including food and wine shows and the Heathcote community games. The company also organises the annual Victorian Rock Drill Competition, showcasing the unique skills that make narrow-vein mining successful at Costerfield, and has commissioned a feasibility study for a childcare centre in Heathcote.

Understanding and listening to local stakeholders and the community has been critical to improving relationships over the time of Mandalay ownership. Even with a small team of four people in the sustainability department, the operation is able to liaise appropriately with the government and community, keeping it simple and making investments or other decisions that are reasonable and benefit local communities.

Conclusion

Management and staff of the Costerfield mine have developed a system and culture for profitably working a small, 420 t/d, narrow-vein mining and processing operation. The workplace culture and company values have resulted in effective industrial relations and high-quality standards to minimise mining dilution. An innovative approach is taken to modifying current technology and methods to suit the narrow mining conditions, and good stakeholder engagement is emphasised. Finally, an emphasis is placed on keeping things simple.

References

SRK Consulting, 2015. Costerfield Operation, Victoria, Australia, NI-43-101 report [online], prepared for Mandalay Resources Corporation. Available from: www.mandalayresources.com/wp-content/uploads/2015/03/Costerfield_NI_43-101_Final_Mar_2015.pdf

United States Antimony Corporation (USAC), 2015. Newsroom 2015 [online]. Available from: http://www.usantimony.com/2015_newsroom.htm

Figure 1. US dollar antimony price 2007-15 metal bulletin average. Source: USAC (2015).

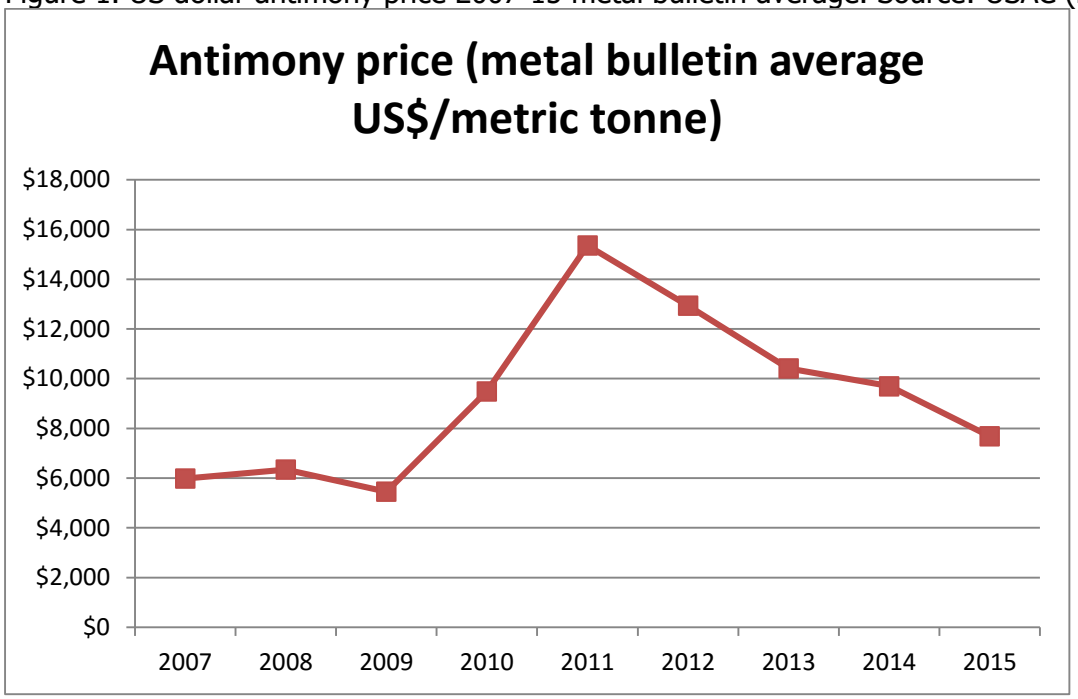

Figure 2. Typical vein widths in 1.8 m wide development.

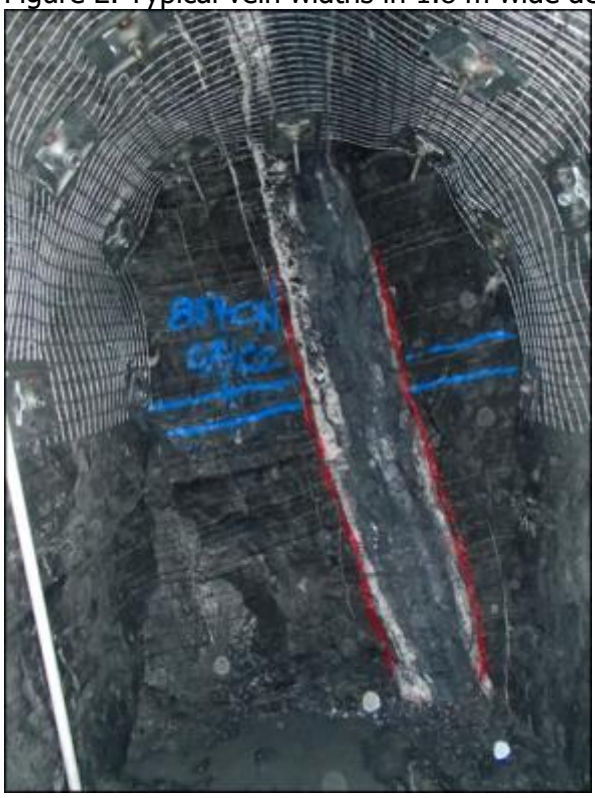

Figure 3. Typical longitudinal section of a stope.

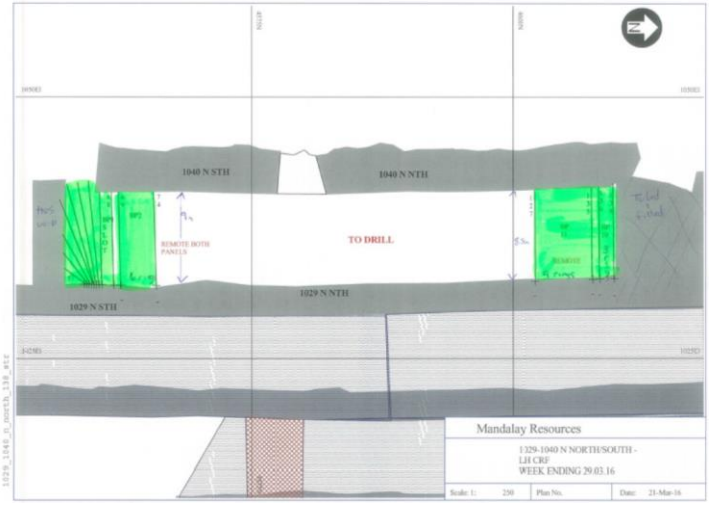

Figure 4. View of Cuffley inclined stopes.

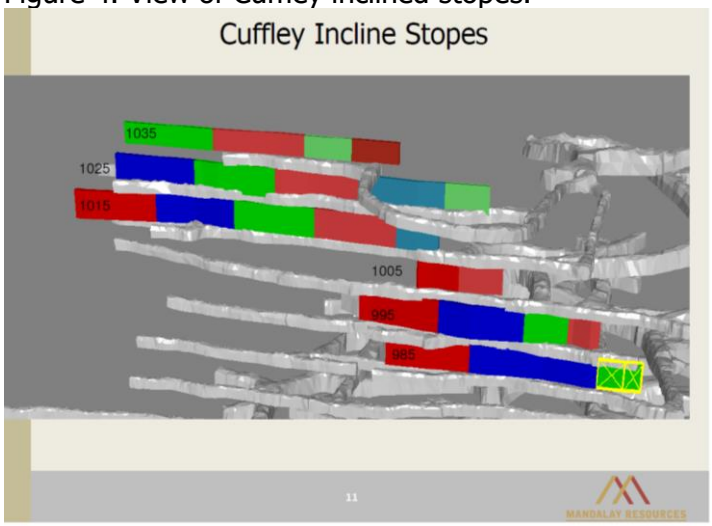

Figure 5. Void scanner image from 1.5 m wide stopes.

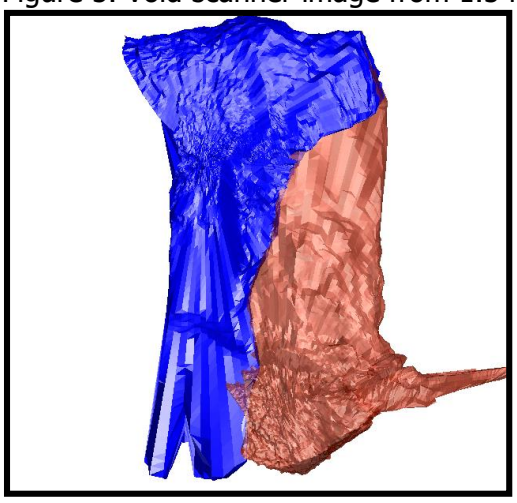

Figure 6. Photograph of void scanner equipment for 1.5 m wide stopes.

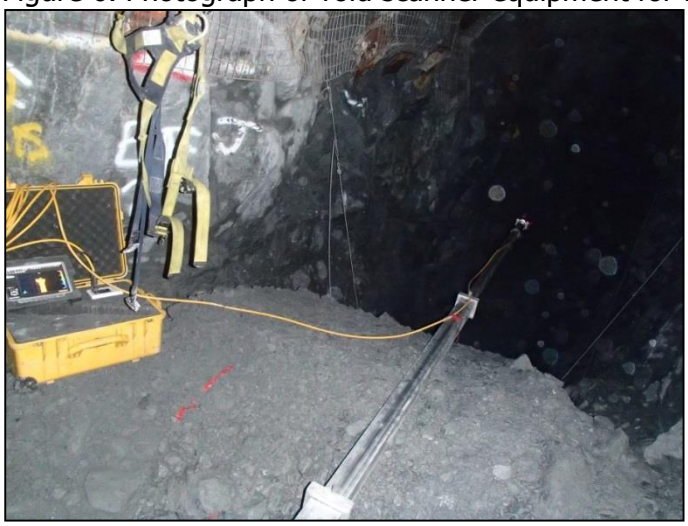

Figure 7. Reconciliation chart for October 2015.