

Development of underground gravity gold processing plants

S. C. Dominy^{a,b,*}, T. R. Hughes^c, N. J. Grigg^c, A. H. Gray^c, G. Cormack^d

^a Snowden Mining Industry Consultants Limited, Abbey House, Wellington Way, Brooklands Business Park, Weybridge, Surrey KT13 0TT, England

* Corresponding author. E-mail address: sdominy@snowdengroup.com

^b School of Science and Engineering, University of Ballarat, Mount Helen, Ballarat, VIC 3353, Australia.

^c Gekko Systems Pty Limited, 321 Learmonth Road, Ballarat, VIC 3350, Australia

^d Central Rand Gold Limited, 6-10 Riviera Road, Houghton, Johannesburg 2198, South Africa

ABSTRACT

Underground processing plants have advantages related to a low environmental footprint, reduced mining costs, improved security and increased value of the product delivered to surface. This paper presents a case study of the world's first operational underground gravity gold plant at the former Gwynfynydd mine and innovation leading to a new 'Python' modular underground system. The Gwynfynydd mine is located in north Wales, United Kingdom. In response to the environmental constraints of being located within a National Park, the operator designed and built a mill underground based on physical separation. Many gold ores liberate favourably using fine-crushing techniques such as High Pressure Grinding Rolls or Vertical Shaft Impactor. Using comminution circuits for mineral liberation, rather than for final recovery process, and by utilising a relatively high-mass pull high-recovery process route, the Python pre-concentration plant was developed for underground operation with a capacity of 20 tonnes per hour. The Gekko Python is currently operating at the Central Rand gold project in South Africa.

Keywords: Gold ores; Crushing; Gravity concentration; Ore handling; Mining

1. Introduction

The concept of processing gold ores on the surface is a traditional paradigm. A process of pre-concentration or full concentration of ore underground, if achievable, would result in a major shift in operating costs. In particular, run of mine ore or a large proportion of it will not need to be transported to the surface. As a result, considerable environmental and financial benefits are likely to be the outcome.

Probably the first reported underground gravity gold processing plant was operated between 1991 and 1999 by Welsh Gold PLC at their Gwynfynydd gold mine in north Wales, United Kingdom. The plant was permanently installed in old workings and was a traditional gold concentration process. The ore was found to be amenable to a simple gravity circuit due to the generally large (>100 µm) gold particle size in the ore.

In 1996, Sedimentary Holdings Pty Limited applied to patent the concept of continuous mining by road header, crushing and sizing, conversion to a slurry and then concentration using InLine Pressure Jigs (Devereux & Gray, 1996). At that time the road header technology limited the invention's applications.

In a recent review Lane, Fountain & La Brooy (2009) note that underground pre-concentration is likely to result in significant savings in ore hoisting and trucking costs if 40% of the ore (or concentrate thereof) could be taken to surface. Bamber et al. (2005) suggest a number of advantages for underground processing, including; reduced haulage and transport costs, lower cut-off grades due to reduced costs, increased reserve base due to lower cut-off, reduced mining selectivity needs, bulk mining

approaches and improved ground conditions due to availability of coarse backfill from the plant.

Bamber et al. (2006) describe previous work undertaken to evaluate the potential of underground pre-concentration, predominantly in South African gold mines. They concluded that *“the implementation of pre-concentration underground will result in substantial operating cost savings, thus lowering the cut-off grade and increasing the potential reserve, as well as increasing the value of ore delivered to the surface”*.

In late 2004, Gekko Systems Pty Limited (“Gekko”) commenced a research and development project to design, construct and test a modular processing plant that was compact enough to operate underground and efficient to achieve economic recoveries. The concept was to pre-concentrate the ore underground as close as possible to the working areas, and only take a small proportion of the ore containing the valuable mineral to surface (Fig. 1).

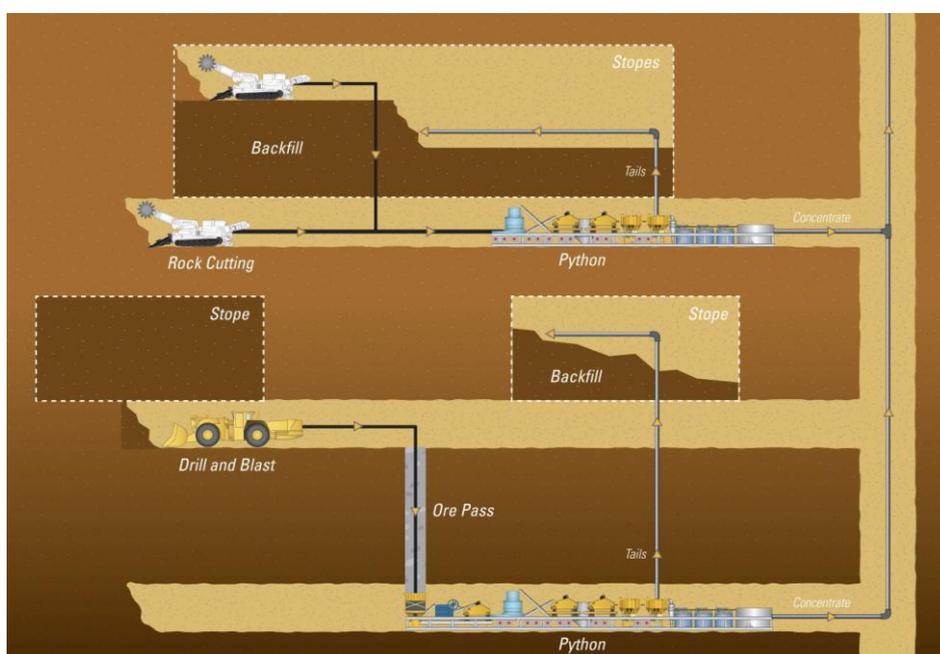


Fig. 1. Schematic of the Python underground system installed in a mine.

The programme yielded the Python system, which consists of five key connecting components: 1) coarse and fine crushing; 2) screening; 3) gravity and/or flotation separation; 4) concentrate handling; and 5) tailings disposal systems.

Traditional surface processing for gold recovery is normally designed to achieve recovery through whole ore leaching (e.g. CIL/CIP). This involves grinding 100% of the ore into sub-50 μm to 75 μm particles. The Python relies on coarser grinding (i.e. fine crushing) and pre-concentration of the gold-bearing minerals rather than liberation of the gold itself. This potentially provides a substantially reduced feed to the final gold production process. At present, only pre-concentration is being proposed for underground use. Classical gravity concentration processes features high-grade, low-mass pull units. The new system will provide a mass pull of 10% to 35% with recoveries potentially greater than 90%, providing concentrate grades of three to ten times the mined grade.

There are clearly a number of advantages to both pre-concentrating and concentrating the ore underground, principally related to reduction in ore transport costs, reduced

power costs, and reduced surface footprint and environmental impact of the mine site. Bamber et al. (2004) indicated that an underground pre-concentration plant could increase the capital cost of a project by up to 6%, with the milling component increasing from 35% to 47%. However, if the system could yield at 95% or better recovery into 40% of the mass, then overall operating costs could be reduced by 20% to 40%. Gray & Hughes (2007) suggest that operating costs could be reduced by about 25%.

This paper presents a case study of the underground Gwynfynydd mine concentrator plant and development of the Gekko Python plant leading to the commissioning of the prototype in South Africa.

2. Case study: Gwynfynydd gold mine

2.1 Introduction

The Gwynfynydd gold mine is 8 km to the north of Dolgellau in north Wales, United Kingdom. The mine and its mineral right area are sited within the Snowdonia National Park and Coed-y-Brenin Forest. Since production was first recorded in 1863, over 1.5 t of gold has been produced from the mine. Welsh Gold PLC was the most recent owner, commencing operations during 1991 and terminating in 1999. Annual ore production was between 10 000 t and 15 000 t from stoping and development, pillar and fill recovery in historical workings, and surface dumps. The mine is currently closed, but the entire Dolgellau gold-belt area is being re-evaluated by Victorian Gold Limited (Dominy, 2009a).

Gold distribution in the quartz reefs of Gwynfynydd and other deposits in the area are extremely erratic (Platten & Dominy, 2003; Dominy & Platten, 2008). Localised very rich pockets, yielding 1,000 oz/t Au or more, are sparsely distributed through the reef structures. Gold assay values between the pockets are low, commonly between 1 g/t Au and 5 g/t Au and in some areas below 0.1 g/t Au.

2.2 Mine geology

The mine contains a number of east-north-east-trending reefs hosted by Cambrian metasediments. The reefs occupy normal faults, whose strike, dip and width vary according to the host rock type. All twentieth century production came from the steep-dipping Chidlaw Reef, which varies in thickness from about 1 m to 8 m.

The principal mine lithologies are the Maentwrog and Clogau Formations, which are fine-grained variably carbonaceous shales; and the lower Gamlan Formation, which is composed of coarse-grained greywackes. All lithologies are cut by doleritic dykes and sills known as greenstone.

Gold-bearing mineralisation is present where the Chidlaw Reef is hosted in either the Maentwrog or Clogau Formations. All gold grades are located on the footwall of the reef. The gold occurs in rich pockets found within an easterly plunging oreshoot showing an elevated background level of gold (Platten & Dominy, 2003).

2.3 Mineralogy and gold particle sizing

During operation, a detailed study was undertaken to investigate the controls on gold mineralisation and the nature of the gold particle sizing and distribution at Gwynfynydd (Platten & Dominy, 2003; Dominy & Platten, 2007; Dominy, Xie & Platten, 2008).

The quartz-dominated reefs contain up to 20% sulphides comprising sphalerite, galena, pyrite, and chalcopyrite, with minor carbonates. High-gold grades are generally

associated with a light-brown coloured sphalerite, with a background association with galena. Gold is generally coarse-grained (up to 3,000 μm), though this is highly variable. In high-grade regions, over 65% of the gold reports to the +300 μm fraction and over 80% to the +150 μm fraction. Less than 5% generally reports to the -53 μm fraction.

In the low grade regions (1 g/t Au to 5 g/t Au), recovery was found to be lower due to the dominance of fine gold particles. This reduced gold recovery to between 70% and 80%. Lower efficiency was related to the relatively higher level of fine <50 μm gold particles in these areas and the inability of the plant to recover them. Local small clusters were observed within the background gold mineralisation. Visible gold particles to 1,500 μm were still seen in low grade zones.

2.4 Mining and infrastructure

The mine employed fourteen persons working a double eight-hour shift (10 man day crew and four man night crew), five days per week with some maintenance and milling undertaken at weekends. Main (150 kVA) and back-up (20 kVA) generators provided power for lighting, pumps and the mill, together with a compressor for mining equipment. A fully equipped workshop provided an on-site facility for routine maintenance and repair. The mine buildings housed offices, smelting/refining laboratory, sampling room, miners change room, canteen and visitor changing facilities.

Underground access was via the 6 Level portal located next to the site access road and mine buildings. The Link Zone production area was reached via a 55-m vertical 3-m diameter shaft. The shaft collar was reached along 360 m of tracked drive from the portal. Hoisting and ore dumping was undertaken by an electric winch and hopper system located on the 6 Level shaft plat. Ore was then trucked (rail bound) either to a surface stockpile or directly to the mill.

Production was undertaken using overhand shrinkage stoping, which was well suited to the complex nature of the reef as it allowed good control and selectivity (Dominy & Phelps, 1997; Dominy et al., 2009). Block development was undertaken by establishing a 2.5-m wide lode drive and 1.5 m to 2 m wide sub-level and raise(s) on the footwall of the reef.

2.5 Historical approaches to gold extraction in the Dolgellau gold-belt

The coarse nature of gold in Dolgellau was long known from historical accounts of visible gold in the reefs and localised areas containing between 20% to 40% gold (Hall, 1988). During the late 1800's to early 1900's, processing at various mines including Gwynfynydd and Clogau, was based on Californian stamps, amalgamation plates, Berden and Britten pans and shaking tables. In a 1980's revival of Gwynfynydd, flotation was used after gravity concentration to produce a lead-zinc-gold concentrate. During the 1990's extraction at the Clogau mine utilised a jaw crusher, ball mill and Micron-wave tables.

2.6 Gwynfynydd processing plant

The company located its entire milling facility in a chamber 150 m from the 6 Level entrance.

Crushing was undertaken using jaw and gyratory crushers, followed by grinding in a rod mill and then gravity circuit (Fig. 2 and 3). Because of the small-scale design of this circuit, it could easily be used in 'batch mode' to allow bulk sampling of certain development rounds (25 t to 50 t) or parcels of stope ore. This capability was extremely important during the evaluation of mining blocks.

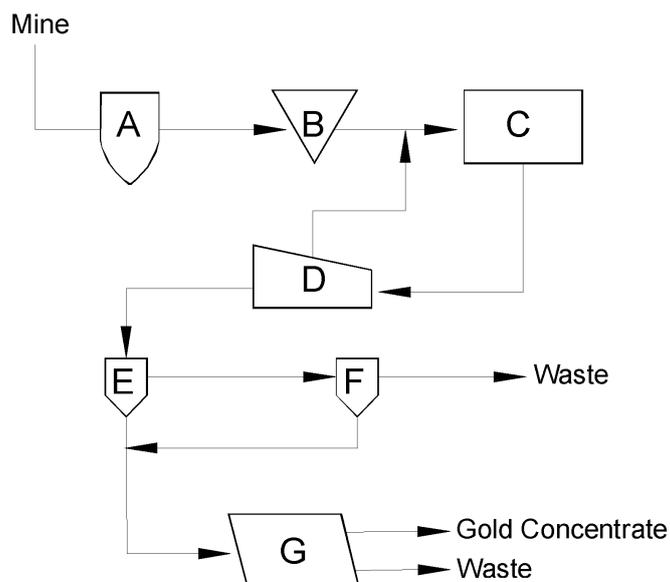


Fig. 2. Schematic diagram showing the mill circuit at Gwynfynydd mine. [A] jaw crusher; [B] gyrotory crusher; [C] rod mill; [D] screen; [E] 12" Knelson Concentrator; [F] 7.5" Knelson Concentrator and [G] half-size Wilfley Table. A hopper classifier was located between the two Knelson Concentrators. A gold trap was located at the outflow of the rod mill [C]. Gold concentrate from [G] was smelted and refined on site. See also Fig. 3.

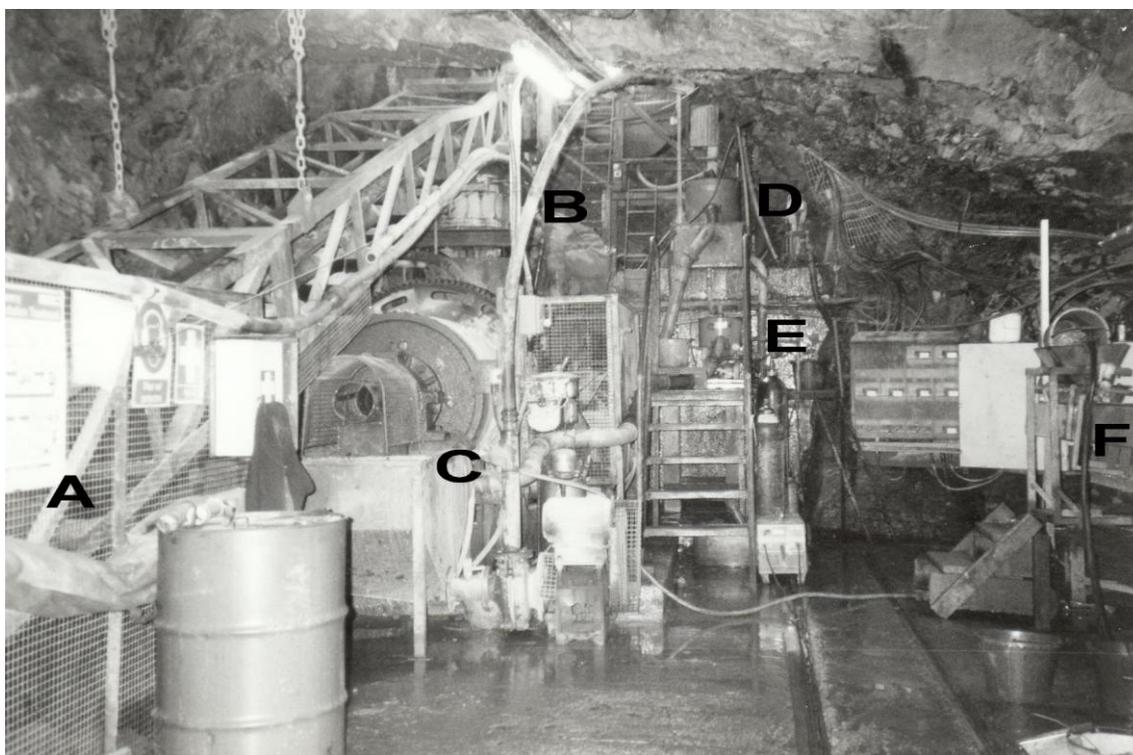


Fig. 3. General view of the underground mill at Gwynfynydd mine. [A] jaw mill (behind guard); [B] gyrotory crusher; [C] rod mill and outflow gold trap; [D] 12" Knelson concentrator; [E] 7.5" Knelson concentrator; and [F] half-size Wilfley table.

Mine staff constructed the underground plant in 1995, with components such as the conveyor systems, hoppers/screens and gold traps fabricated in-house. The overall capital expenditure associated with construction was about GB£200,000. Milling costs in 1995 were about GB£15 per tonne.

Prior to 1995, a small gravity circuit with a 0.5 t per hour capacity was in operation based on a single 7.5" Knelson Concentrator. This unit was a batch process, with broken rock fed by hand into the system.

2.7 Underground mill circuit

Ore was trucked to the mill in strings of 6 by 1 tonne side-tipping Hudson wagons and fed into a primary hopper. A conveyor from the hopper fed a Goodwin Barsby 405 mm by 255 mm primary jaw crusher with a Hardox jaw extension. The primary crushing capacity was 8 t per hour to yield a P_{80} product of -25 mm. Output from the jaw crusher was fed via a conveyor to a secondary Kue Ken 450 mm rotary cone crusher to yield a product of P_{80} -8 mm.

The cone crusher product was gravity fed, via a surge hopper, into a 1.8 m by 0.9 m Denver Rod Mill. Output from the rod mill (P_{80} -850 μ m) passed into a series of traps to recover coarse gold and was then pumped to a 1 mm screen. The screen used an irrigated stainless steel mesh motivated by rotating cam. The oversize was returned to the rod mill via gravity and the undersize fed to two Knelson concentrators.

A gold trap was located immediately after the rod mill, collecting up to 40% of the gold (generally above 1 mm in size).

The Knelson Concentrators extracted the gold-galena fraction from the mill feed. The primary 12" Knelson Concentrator had a capacity of 4 t per hour solids and required 140 litres of water per minute.

Tails from the primary Knelson were fed to a 400 mm by 600 mm 15° hopper-type classifier with water feed. Heavies from the classifier were fed to the secondary 7.5" Knelson that had a 0.6 t per hour capacity.

Concentrates from both Knelson units were sent to a half size Wilfley table for further cleaning up. Fine repeat tabling of the Knelson concentrate produced a clean concentrate with gold, galena and some pyrite. Laboratory cleaning of concentrate with concentrated nitric acid removed most of the pyrite and galena.

2.8 Plant operation

The head grade was highly variable ranging from near zero through to 30 g/t Au or higher. Because of the high-nugget effect, the mill operator had to rely on a semi-quantitative estimate of grade from the mine geologist (Dominy et al., 2009) and used the quantity of sulphides in the tails to give a reflection of recovery. When high sulphide content was present, the Knelson's required more frequent cleaning and consequently their feed rate was reduced. The plant mass yield ranged between 2% and 12%.

The 25 t per shift capacity mill proved to be highly effective, due to the coarse nature of the gold particles (>100 μ m). During mill operation, the tailings were regularly sampled and sent for analysis. This grade was recombined with the smelter return to enable a mill head grade to be determined. In general the mill recovered between 94 to 97%.

Small amounts of very high-grade material (>1,000 g/t Au) encountered underground was selectively mined by hand (e.g. small compressed air picks and/or small quantities

of low power explosive) and milled in small batches in a laboratory-scale plant at surface. This unit comprised a jaw crusher, ball mill, 3" Knelson Concentrator (45 kg/hour capacity) and spiral panning unit.

2.9 Tailings management

Tails from the plant were pumped to surface where they were placed in a settling tank with a screw classifier to recover the sands. These sands provided a useable by-product as they met the BS1200 standard as concreting sand.

Dirty water was returned to the mine and placed into an old stope for settling. The water eventually entered the mine outflow channel, which discharged to the surface settling and liming tanks.

2.10 Water supply

Water supply was sourced from a dammed level situated about 15 m above the plant. With normal rainfall the water supply was adequate for operation throughout the year. In a few summer months the supply could be limited, and backup water was pumped from old stopes below the plant. On a couple of occasions lasting a week or so, milling was suspended due to lack of water.

2.11 Plant maintenance

Maintenance was relatively straight forward and facilitated by two staff fitters who had been involved in the original plant design, construction and commissioning. Routine maintenance was undertaken on night and weekend shifts where possible. Basic spare parts and consumables were kept on site. Plant availability was generally above 85%.

An annual closure was undertaken over three days of 24 hour working, which included a full strip and cleaning of all parts. The rod mill was also cleaned and re-rodded where required.

2.12 Health, safety and security

During construction in 1995 and operation through to late 1999, only one lost time injury (LTI) was sustained in the plant. This related to an operator that was not wearing safety glasses and sustained a minor injury through a dirt particle in his eye. All moving parts were protected by guards and electrical systems by cut-outs. The plant chamber was gated to facilitate security, and contained a vault chamber for gold concentrate storage. Access was restricted to certain staff only.

2.13 Conclusion

Gwynfynydd mine was a small-scale underground operation extracting gold from a high-nugget high-grade reef, which made mining technically challenging (Dominy & Phelps, 1997; 2002). In addition, its location within the Snowdonia National Park also added to the challenge due to strict environmental constraints.

Gold from the mine was exclusively used to manufacture Welsh gold jewellery, which held a premium above the gold price of up to six times bullion value. Thus security during processing was also important to the company.

By virtue of the coarse free nature of the gold, the company was able to base its plant on a simple gravity circuit using modern technology. To yield additional benefit, the entire plant was sited underground at a location that was easily accessible for services and ore supply. The plant proved relatively simple to operate and maintain, and yielded good gold recoveries.

3. Development of the Gekko Python plant

3.1 Introduction

The driver to investigate the concept of an underground processing plant was based on discussions with operators around the world and general observation of current mining practices and problems. The overall thrust of the recent programme was to extend the viability of physical, as opposed to chemical minerals extraction. This work has effectively established feasibility of the concept of processing underground, by demonstrating that the use of toxic chemicals is not as necessary as conventional wisdom suggests. In particular, the combination of individual elements of a processing plant, together with the use of existing technologies in an unconventional way, has provided a high level of confidence that underground processing is viable.

3.2 Crushing to maximise gravity

One of the most significant cost and environmental issues in processing is comminution. As the target P_{80} grind becomes finer, the energy and associated costs rise exponentially. If a critical mineral can be liberated and recovered at a coarse particle size, it is a major environmental, throughput and cost advantage.

Testing on over one-hundred ore samples from across the world has shown a high potential for recovery based on gravity and flotation methods. Approximately 10% of all ores tested would have potential utilising the existing recovery methods available. Further development of the combined comminution and recovery system should enable the expansion of this potential to 25% to 40% of all gold mines.

In a typical flow-sheet, crushing is generally undertaken first to bring the particle size down to around 8 mm to 12 mm. Further comminution by grinding mills reduces the size down to the required level of P_{80} to between 75 μm to 106 μm for CIL circuits.

Fine crushing devices such as a Vertical Shaft Impactor (VSI), High Pressure Grinding Rolls (HPGR) and Hammer Mill (HM) can be used to liberate gold without the effect of flattening and smearing. In essence, low aspect ratio shaped particles are typical in a crushing circuit, whereas grinding mills tend to flatten free gold and over-grind sulphide minerals. The premise of gravity separation is the coarser the mineral liberation (particle size), the higher the probability of effective recovery.

The use of fine crushing to liberate coarse gold particles has been successfully applied to ores in the Central Victorian goldfields of Australia. In Ballarat, all the gold and sulphides are recovered by crushing with VSI and gravity only (Gray et al., 2006), and Bendigo's HPGR crush and gravity accounts for >85% of total gold recovery (McLean et al., 2007). In the case of Ballarat, test work indicated liberation for the optimum gravity recovery occurs at a crush of 600 μm compared to relatively poor gravity recoveries at 106 μm size. Recent optimisation of recovery resulted in a crush size in excess of 1 mm, achieving significant power savings and throughput benefits.

An additional approach to gravity recovery is to concentrate gold as both liberated gold and gold-bearing sulphides such as arsenopyrite. The gold in the mixed concentrate can be extracted using an InLine Leach Reactor (ILR) (Gray & Hughes, 2007).

Ore characterisation is critical in the assessment of amenability to this processing option. The liberation size is determined by testing the ore and interpreting typical gravity yield recovery curves for different type ores. Typical yield recovery curves for a Ballarat coarse gold ore and fine-gold Witwatersrand ore are given in Figs 4 and 5.

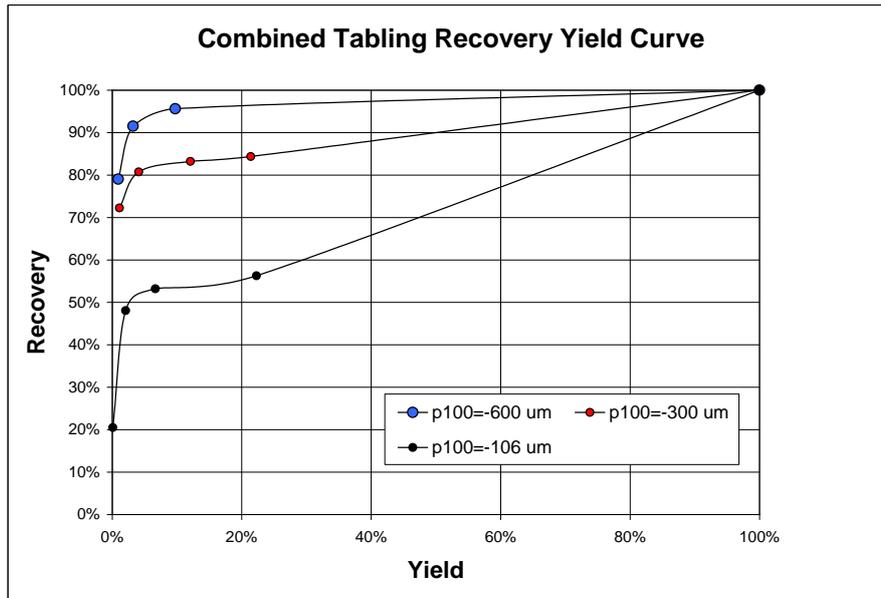


Fig. 4. Laboratory gravity yield/recovery curves for typical Ballarat gold ore.

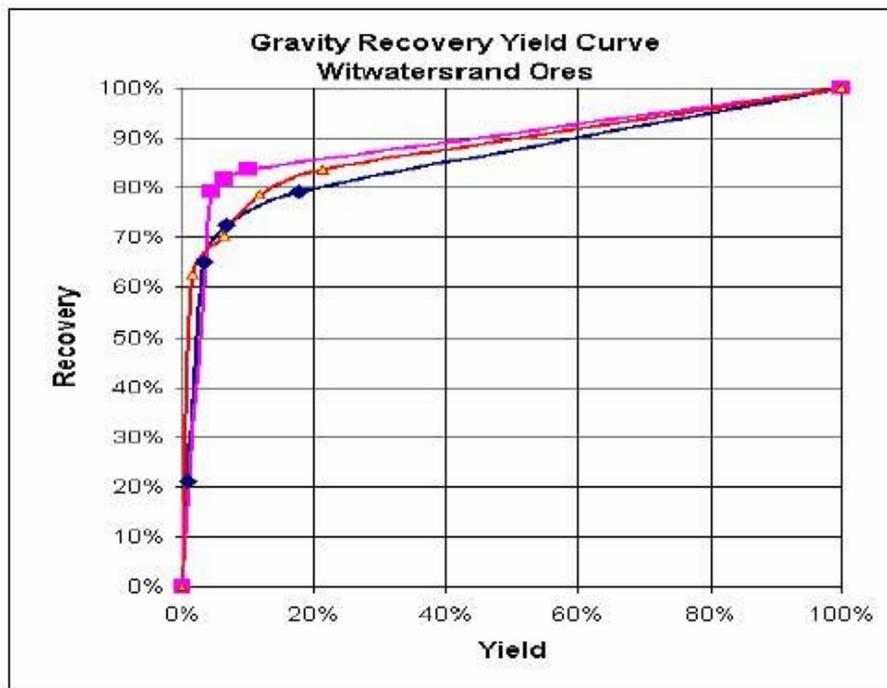


Fig. 5. Laboratory gravity yield/recovery curves for typical Witwatersrand gold ore.

These curves represent the un-optimised single pass gravity recovery. A rougher/scavenger type application has been recently commercialised, which increases the recovery achievable in practice. The addition of a flash flotation module further increases the recoveries achievable from the fine (-150 μm) fractions.

3.3 Metallurgical design basis

The Python plant design relies on the recovery of heavy minerals using InLine Pressure Jigs ("IPJ") and flash flotation cell(s) at a relatively fine crush/coarse grind (Fig. 6). The specifications of the current system are:

1. The current Python PPP200 (Patent Pending) has a capacity of 10 t to 20 t per hour run of mine ore feed.
2. Target crush size of P_{80} -500 μm to 800 μm . For soft ores use VSI. For hard ores or less than 500 μm grind, an HPGR could be used.
3. Mass pull by gravity 5% to 35%.
4. Mass pull by flotation 1% to 5%, up to 4 minutes residence time.
5. Installed power of 160 kW with consumed power expected to be approximately 5 to 8 kWh/tonne excluding pumping of concentrates and tails to final destinations.
6. Labour requirement is estimated at two dedicated operators, one to operate the LHD and plant front end and a gravity/flotation circuit operator. This is unlikely to change as the size of plant increases, unless the LHD operator becomes a full time job.
7. Plant dimensions of 2 m wide by 4.8 m (max) high by 68 m long. The plant can be split in two same width and height, but in two sections 35 m and 33 m long and installed on two mining levels with piping and power cables run between them.

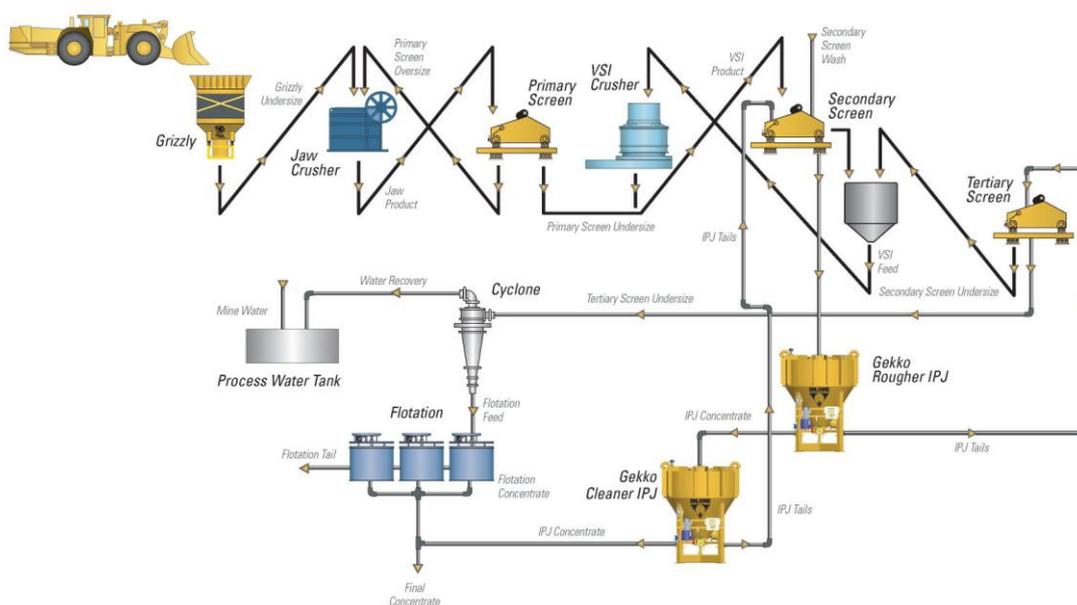


Fig. 6. Process flow diagram for the Python plant.

3.4 Process description

The plant is based on the flow diagram presented in Fig. 6.

Run-of-mine ore is tipped over a 300 mm aperture static grizzly to a feed hopper. Ore is withdrawn from the hopper by a vibrating feeder onto a rubber conveyor. A belt magnet removes tramp metal off the conveyor prior to ore delivery to the jaw crusher. A weightometer records the feed rate.

The jaw crusher, operating at a small closed side setting (40 mm), discharges ore through a vibrating feeder onto a belt conveyor where it is carried to the primary screen (nominally 35 mm aperture). The oversize ore reports to a rubber belt conveyor that returns the oversize material to the jaw crusher. The undersize ore is conveyed via a conveyor with a weightometer and transferred to a second belt which discharges to the

wet secondary screen (nominally 4 to 5 mm aperture). The oversize material from the secondary screen is discharged to the coarse ore bin.

The material in the coarse ore bin is discharged via a vibrating feeder onto a short belt and then transferred to a belt feeding the VSI for further size reduction.

The secondary screen undersize slurry is pumped to a rougher IPJ. The IPJ concentrate comprising gold and/or other heavy minerals is pumped to another IPJ for cleaning. The tailings from the rougher IPJ flow to the tertiary screen, nominally a 0.85 mm aperture vibrating screen. The tertiary screen oversize is combined with the secondary screen oversize for reprocessing in the VSI. The tertiary screen undersize is pumped to a water recovery unit, essentially a hydrocyclone designed to recover most of the solids in the underflow and recycle water back to the IPJ's and screens.

The cleaner IPJ tailings flow under pressure to the secondary screen for re-processing through the jig circuit and to help wet the new feed. The cleaner concentrate flows to the final concentrate pump to be either pumped to the surface or dewatered and placed in skips or trucks for cartage to the surface.

The dewatering cyclone underflow (e.g. gravity tailings) is pumped to the flash flotation cell. Copper sulphate, Xanthate and frother are added to the slurry from header tanks to float the fine gold and sulphides. The flotation concentrate flows to the final concentrate pump. The flotation tailings are either pumped to the surface or dewatered and placed in backfilling sites.

Air for valve actuation is supplied by the on-board compressor. Power to each processing module is supplied by a single multi-core, plug-in cable except for the jaw crusher and VSI which have individual power cables due to their motor size.

The plant, as constructed and installed in operating condition is shown in Fig. 7.



Fig. 7. Photograph of the Python plant operating at Central Rand Gold Limited in Johannesburg, South Africa. From left to right the modules are grizzly feed; primary crusher (jaw); primary screen and VSI; conveying; gravity separation (IPJ); flash flotation; water supply and MCC container.

3.5 Underground design basis

The Python consists of nine modules, is an overall 68 m long, 2 m wide and up to 4.8 m high. The drivers for these dimensions are given below.

Whilst the width of the Python was restricted as much as physically possible, it was only possible to reduce the width of the unit to 2 m due to the physical size of key components. The height of the unit is 4.8 m at its highest point. The size of the Python in relation to a 5 m by 5 m drive is shown in Fig. 8. It can be seen that there is sufficient room to drive a small vehicle past the unit once it is installed against one wall.

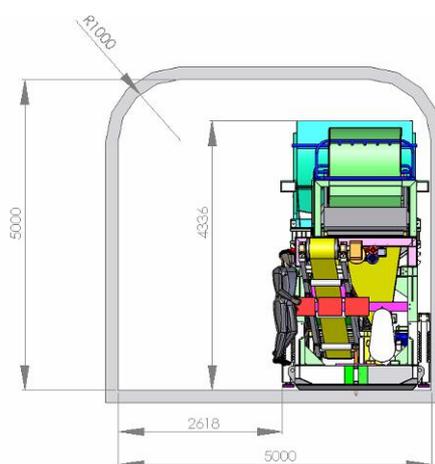


Fig. 8. Python operating position in an underground 5 m by 5 m drive.

The Python modules can be installed on a sloping floor, up to a nominal 1:50. All modules must be level across their width (2 m), but only three have to be level across their length - these include the VSI, gravity and water supply modules.

Alignment of the five dry modules can vary by up to 7° between modules with the remaining four modules joined only by pipes. This allows for non-linear drives or even installation on two different drives if required.

The skids have a male and female end to guide entry and us locating pins to ensure final accurate location.

The Python modules need to be transported to the working areas of the mine. A system of two bogies that fit under either end of the individual modules is used. The bogies are designed to carry a maximum 24 t and have a rollover factor of safety of 0.76 with a theoretical cornering speed of 26 km/h. However it is recommended the unit is towed at no greater than 10 km/h.

Transport height was restricted to 3.5 m so that the total height was no more than 4 m including bogies during transport . This restriction was to ensure that the modules didn't impact on mine services running down the decline. This was achieved with minimal equipment removal and the use of hinged boxes to make replacement of equipment easier. The turning circle of a 50 t (capacity) underground truck used in the design of the Python was thought to be a worse case scenario.

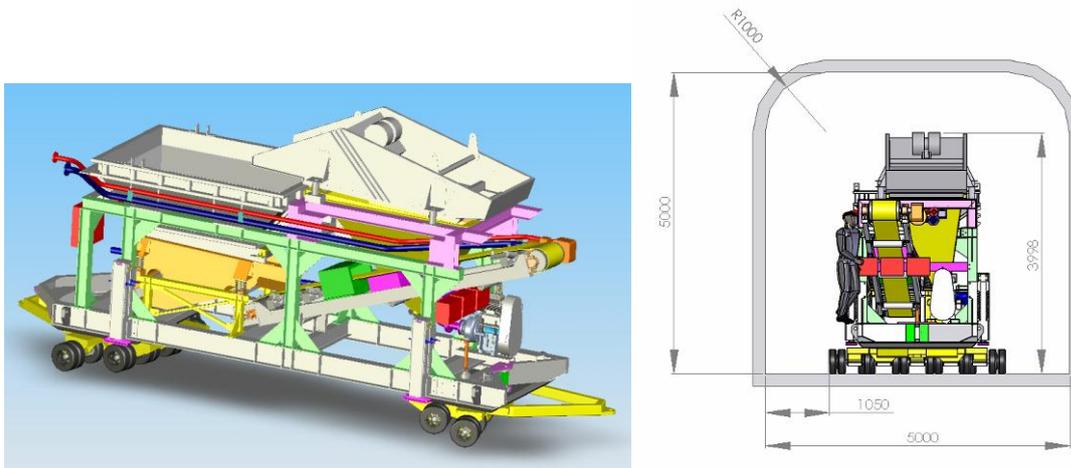


Fig. 9. Bogies for module transport (left) and module in transport position (right).

These factors restricted the length of any single module to 7.7 m and resulted in the need to use two Load-Haul-Dump (LHD) units to push/pull the modules into the mine and navigate tight corners.

3.6 Process control

The plant control mechanism is built to suit the hardware chosen for motor control and instrumentation. The motor currents are regulated using PowerFlex drives and SMC Flex soft starters, and instrumentation is picked up via remote IO field nodes. The information is gathered by the ControlLogix PLC via DeviceNet networks, and shared between controllers over an Ethernet network. The system is interfaced using RSVIEW Supervisory Edition for the purpose of SCADA (Supervisory Control and Data Access) process monitoring and control.

The PLC program encompasses the following tasks as a minimum:

1. Automatic/manual functionality for all devices
2. Sequence stop/start/crash of the modularised plant
3. Full open and closed loop control of appropriate analogue devices
4. Scaling and associated manipulation of analogue data
5. Interlocking
6. Fault detection and action (Process faults and instrument faults)
7. Devicenet data mapping
8. Ethernet messaging

The SCADA system is built in sectioned components to represent the modular plant; it mimics each area of the plant for the purpose of monitoring and controlling the operation of each piece of equipment.

The operator can control all facets of the plant from the control room. It is entirely possible for the plant to be at least monitored, if not controlled, remotely.

3.7 Maintenance

The Python breaks a number of paradigms associated with conventional processing plant design. These include its directly coupled crushing and concentrating circuits and its narrow design that takes away the opportunity to install standby equipment in the plant. The compact design has resulted in the plant taking on the look and maintenance requirements of any other underground equipment. It is expected that plant availability will be in excess of 85% if effective scheduled maintenance is

employed. For higher availabilities and to insure against catastrophic failure, it is feasible to have spare modules off the shelf to enable easy changeover underground and more extensive maintenance in the underground workshop or on surface.

It is likely that multiple Python units could be installed, because either one Python could not meet the processing requirements or the mine layout favours multiple units to keep tramming distance to a minimum. Use of multiple modules means that having one unit down for maintenance would not have as significant an affect on production as when a surface plant is shut down.

4. Python 200 processing plant: Central Rand gold project

4.1 Introduction

Central Rand Gold Limited (CRG) is a South African mining company established in 2006 to re-explore and re-mine the Central Rand Goldfield directly south of the city of Johannesburg. The Central Rand Goldfield was mined from 1886 until the early 1970's and produced some 247 Moz Au at an average grade of 8.2 g/t Au. The mines were largely closed when they were considered uneconomic in the late 1960's and early 1970's due to the low gold price, inefficient mining practices and deep (>2,500 m) producing faces.

The project has an Indicated Mineral Resource of 21.4 Moz Au at average grade of 8.9 g/t Au and 12.4 Moz Au of Inferred Mineral Resources at average grade of 7.4 g/t Au as at July 2007 (Snowden & Snowden, 2007). The resources are reported in accordance with the JORC and SAMREC Codes.

4.2 Geology, mineralisation and mineralogy

The Central Rand Goldfield comprises a 7 km wide sequence of clastic sedimentary rocks. The gold reefs are generally greyish in colour and comprise metamorphosed conglomerates of water-worn pebbles cemented by a fine-grained matrix. Most pebbles are less than 50 mm in size, being either quartz vein material or quartzite.

The matrix material, which locally contains gold, comprises quartz with sericite and chlorite. Elsewhere the matrix contains pyrite, pyrrhotite, chalcopyrite, etc. There is a broad correlation between pyrite content and gold grade.

Studies conclude that gold particles are generally within the range 5 µm to 500 µm in size, with often 50% <50 µm in size, with a maximum size of 500 µm and P₉₅ value in the range 210 µm to 250 µm (Dominy, 2009b). Local grade variability is explained by gold particle clustering at different scales.

4.3 Project basis

The mine design process is being approached with the view to achieving optimal extraction with minimal surface impact. It is envisaged that the major reefs will be exploited by means of slot, undercut and shallow mining as well as mining of deeper underground reserves. The use of proven modern mass mining techniques, such as long hole open stoping supported by underground processing, will hopefully reduce operating costs, minimise the environmental impact of any new workings, and enable rehabilitation of old workings. At an anticipated production rate of 750,000 t per month by 2013, the life of the mines are at least 15 years from the commencement of production.

Key drivers for an underground processing option at Central Rand are:

1. Transport logistics due to proximity to an urban area
2. The mine sites are scattered
3. The need for a slimes dam in an urban area

4. Additional environmental hazards and future rehabilitation costs
5. Acid mine drainage concerns
6. Ability to backfill current and historically mined areas
7. Will be able to stabilize current unstable areas
8. Reduced transport costs

CRG commissioned the Python 200 system in October 2008. The aim is to produce a concentrate of approximately 10% to 15% of the mined volume using gravity and flotation concentration at a P_{80} of 500 μm . Initially the system has been installed on surface (Fig. 7) to treat open cut material. The concentrate, approximately 15% of mined volume, will be transported by truck.

As mining deepens multiple concentrators will be located close to the mining operations, where initially concentrate will be transported by truck. Once the sites are connected, the concentrate will be pumped to the central gold plant.

Tailings from the plants will be utilised as backfill, which owing to their coarse nature will be stronger and a low sulphide content will reduce acid mine drainage potential.

4.4 Summary

The Python underground processing plant has passed from concept to first installation in four years. A significant amount of effort has been put into the design to minimise the impact of the Python on underground operations by minimising the unit's width and taking into account transport and installation needs.

CRG has recognised the benefits of underground processing and has installed the first unit in October 2008. This unit is currently operating on the surface, though will be re-located underground in due course. The company has since commissioned Gekko to develop two 50 t per hour units (Python 500) to be delivered by the end of 2009.

5. Conclusions

This paper suggests that underground concentration and pre-concentration plants have advantages based on a low environmental footprint, reduced mining costs and improved security. In addition, this will be of great benefit to deposits that are either low grade or deep seated, or both.

The Gwynfynydd mill was probably the world's first operational underground gold processing plant. It was a static concentration system, which was constructed principally in response to environmental constraints. Development was made easy due to the coarse nature of the gold mineralisation and amenability to gravity concentration. The key advantages of the system at Gwynfynydd were:

1. Physical chemical-free system
2. Avoided increase of the surface mine footprint in an area of severely limited space and environmental sensitivity
3. Proved relatively easy to operate and maintain and had an availability of greater than 85% over four years of operation
4. Flexible, since it could be used in either batch mode for bulk samples or continuous mode for development and stope ore
5. Enabled a proportion of the tailings to be placed into old workings
6. Effective security as the plant could be locked and isolated

Following from the Gwynfynydd and other underground concentration concepts, recent innovation has led to the development of an underground pre-concentration plant. This is based on the characteristic that many gold particles and gold particle-associations (e.g. gold-sulphides) liberate using fine crushing. Based on comminution circuits for mineral liberation and utilising a high-mass pull high-recovery process route, the Python plant was developed. The system has a number of advantages:

1. Improvement in Mine Call Factor due to fewer handling points (leading to gold loss) for the ore en-route to the plant
2. Reduction in tramming and hoisting costs due to lower tonnage required to be moved
3. Increased metal capacity of hoisting systems due to higher grade
4. No necessity for backfill to be produced on the surface and sent back underground
5. Reduction in required surface plant capacity and costs due to higher grade
6. Increased haulage rope life due to lower tonnes hoisted
7. Much reduced power consumption over conventional processing (estimated underground consumed power of 5 kWh/t versus 14 kWh/t to 16 kWh/t conventional milling power consumption)
8. No detoxification requirements on backfill produced by this stage of processing, as it has not been exposed to cyanide
9. Improved security

System development includes up-scaling the plant to a 50 t per hour capacity.

A number of barriers have been suggested to the development of underground processing options including maintaining an adequate water supply, and construction, operational and maintenance issues. A key operational issue is that of safety of operators and increased risk by being underground. Like all challenges, these can be engineered and managed to give optimum performance. The issue of manpower safety is clearly an important one, but really comes down to good design and effective training. Current development aims to increase the level of automation in the plant, thus reducing the manpower required underground.

Underground concentration and pre-concentration options should be considered for all mines during feasibility, given the potential benefits to the operator and environment. Metallurgical and mineralogical testing and economic evaluation is required to determine application.

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