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ABSTRACT

By designing comminution circuits for mineral liberation rather than the final recovery process and by using high mass pull gravity recovery, the concept of underground processing has become a reality. Gekko has found that many ores respond favourably to fine crushing with either high pressure grinding rolls or vertical shaft impactors which when combined with the inline pressure jig gravity separator and coarse flotation results in a narrow, low-head, compact processing plant that can be sensibly fitted in existing underground openings. The focus on fine crushing reduces the power requirements of the plant to approximately 5 kWh/t for a capacity of up to 20 t/h run of mine ore feed. The use of water recycle systems places no extra load on the mine’s normal water handling system. Gekko’s underground processing plant, the ‘Python’, has been designed to be towed down the decline or lowered down a shaft and is capable of being installed in sloping, non-linear drives for placement close to the working face. The overall benefit to mining companies of this concept has been estimated to be a significant operating cost-saving, lower cut-off grade and a significantly smaller environmental footprint.

INTRODUCTION

The concept of processing orebodies on the surface is a traditional paradigm. A process of treating ore underground, if achievable, would result in a major shift in mine operating costs. In particular mineral bearing ore, or a large proportion of it, will not need to be transported to the surface and considerable environmental and financial benefits will be the outcome. The key concept is to preconcentrate the ore underground as close as possible to the working areas, and only take the small proportion of the ore containing the valuable mineral to surface for further processing. This has the potential to increase the economic and financial benefits that will be the outcome.

The coupling of highly-controlled comminution and fine mineral separation by gravity and/or flotation represents the heart of the technology. The more efficient both the comminution and the gravity/flotation systems are, the smaller the units become, and the lower the cost of operation (eg power requirements).

Traditional surface processing for gold recovery is designed to achieve recovery through ‘whole ore leaching’. This involves grinding 100 per cent of the ore into sub 50 - 75 micron particles. The Python relies on coarse grinding (much cheaper) and liberation of the gold-bearing minerals rather than preconcentration of the gold itself. This will provide a substantially reduced feed to the final gold production process.

It should be noted that only preconcentration is being proposed underground. Classical gravity concentration processes features high grade, low mass pull units. Gekko are proposing a mass pull of ten to 35 per cent with recoveries greater than 90 per cent giving concentrate grades of three to ten times mined grade. The security concerns which normally accompany ‘gravity concentration’ are no greater than those associated with conventional high grade mining.

It is proposed that the Python rejects up to 65 per cent of the feed mass, as a 65 per cent bulk density factor is typically applied to backfilling (ie only 650 kg for every 1000 kg mined can be returned for backfill). Recovery can be easily optimised into this relatively high mass pull.

There are a number of advantages to preconcentrating the ore underground, which were the driving forces for Gekko to commence the research project and some of these are summarised as follows:

• improvement in mine call factor due to fewer handling points for the ore en-route to the plant,
• reduction in tramming and hoisting costs due to lower tonnage required to be moved,
• increased metal capacity of hoisting systems due to higher grade,
• no necessity for backfill to be produced on the surface and sent back underground,
• reduction in required surface plant capacity and costs due to higher grade,
• increased haulage rope life due to lower tonnes hoisted,
• much reduced power consumption over conventional processing (estimated underground consumed power of 5 kWh/t versus 14 to 16 kWh/t conventional milling power consumption), and
• no detoxification requirements on backfill produced by this stage of processing, as it has not been exposed to cyanide.

PREVIOUS WORK

There are some historic examples of underground processing being carried out by Morgan Gold Mining Company at Gwynfynd in Wales, with the milling and gravity concentration of a gold ore (see Figure 3). The plant was permanently installed in the drive and the ore was found to be amenable to this very simple circuit due to the gold’s unusually large grain size (Aur Cymru Ccc, n/d).

In 1996, Sedimentary Holdings Pty Ltd applied to patent the concept of continuous mining by roadheader, crushing and sizing, conversion to a slurry and concentration using inline pressure jigs (Devereux and Gray, 1996) (Figure 4). Roadheader technology at the time limited this invention’s applications but the use of the inline pressure jig for simple, low cost concentration formed the basis for the current unit.

Bamber et al (2006) describe previous work undertaken to evaluate the potential of underground preconcentration, predominantly in South African deep mines. They concluded that: the implementation of preconcentration 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.
Fig 1 - Schematic of the Python installed in a mine.

Gekko Systems: Underground Processing Schematic

Loader Feed → Closed Circuit Primary Crushing → Secondary Screening → Primary Gravity Concentration → Tertiary Screening → Scavenger Gravity/Flotation Concentration → Tailings Disposal

Concentrate Collection:
Concentrate to be pumped to station or central collecting point

Tailings either dewatered/thickened or gravitate straight to backfill

Fig 2 - Underground processing unit operations.

Fig 3 - Gwynfynydd phase one underground processing plant.

Fig 4 - Continuous mining, transport and treatment system.
Gekko’s drive to investigate the concept of an underground minerals processing plant is based on ongoing discussions with the company’s customers around the world, observation of current mining practices and the problems associated with these. The overall thrust of Gekko’s recent R&D program and product introduction program has been to extend the viability of physical, as opposed to chemical, minerals extraction. This work has effectively established the feasibility of the concept of minerals processing underground by demonstrating that the use of large amounts of toxic chemicals is not as necessary in minerals extraction as conventional wisdom might suggest. In particular, the combination of individual elements of a minerals processing plant, arising from recent Gekko R&D, together with the use of existing technologies in an unconventional way has provided a high level of confidence that underground minerals processing is viable.

Testing on over 100 ore samples from across the world has shown a high potential for recovery based on gravity and flotation methods. Approximately ten per cent of all ores Gekko has tested would have potential to utilise the existing recovery methods available. Further development of the combined comminution and recovery system will enable the expansion of this potential to a 25 to 40 per cent of all gold mines.

**METALLURGICAL DESIGN BASIS**

The plant design (Gekko Systems Pty Ltd) relies on the recovery of heavy minerals using inline pressure jigs and flash flotation cell(s) at a relatively fine crush/coarse grind.

**Specifications**

- The current Python PPP200 (patent pending) has a capacity of ten to 20 t/h run-of-mine ore feed.
- Target crush size – P80 - 500 µm to 800 µm. For soft ores use vertical shaft impactor. For hard ores or less than 500 µm grind, a high pressure grinding rolls could be used.
- Mass pull by gravity: five to 35 per cent.
- Mass pull by flotation: one to five per cent, up to four minutes residence time.
- Installed power is 160 kW with consumed power expected to be approximately five to 8 kWh/tonne excluding pumping of concentrates and tails to final destinations.

- Labour requirement is estimated as two dedicated operators, one to operate the load haul dump (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.
- Plant dimensions: 2 m wide × 4.8 m (max) high × 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.

**Process description**

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 (eg bucket teeth, rock bolts and plates) off the conveyor prior to ore delivery to the jaw crusher. A weightometer records the feed rate (see Figure 5).

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 transported via a conveyor with a weightometer and transferred to a second belt which discharges to the wet secondary screen (nominally 4 - 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 vertical shaft impactor (VSI) for further size reduction.

The secondary screen undersize slurry is pumped to a rougher inline pressure jig (IPJ). The IPJ concentrate (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 1 mm aperture static screen). The tertiary screen oversize drops into the coarse ore bin for reprocessing in the VSI. The tertiary screen undersize is pumped to water recovery (a hydrocyclone designed to recover most of the solids in the underflow and recycle water back to the IPJs and screens).

The cleaner IPJ tailings flow under pressure to the secondary screen for reprocessing through the jig circuit and to help ‘wet’

![Fig 5 - Process flow diagram for the python processing plant.](image)
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 (gravity tailings) is pumped to the flash flotation cell. Copper sulfate, PAX and frother are added to the slurry from header tanks to float the fine gold and sulfides. 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 (excluding the flotation module), is shown in Figure 6.

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.

Installation in a drive

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 × 5 m drive is shown in Figure 7. It can be seen that there is sufficient room to drive a small vehicle (Landcruiser utility or similar) past the unit once it is installed against one wall.

The Python modules are able to be installed on a sloping floor, up to a nominal 1:50. All modules must be level across their width (2 m) but only a small number have to be level across their length allowing for a very flexible installation (Figure 8).

Alignment of the five ‘dry’ Python modules can vary by up to seven degrees between modules with the remaining four modules joined only by pipes. This allows for non-linear drives or even installation on two different drives.

The skids have a male and female end to guide entry and use a pin and clevice to ensure final accurate location (Figure 9).

Transport down the decline

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 tonnes and have a rollover factor of safety of 0.76 (Figure 10) 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 (Figure 11). 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 tonne (capacity) underground truck used in the design of the Python (Figure 12) was thought to be a worse case scenario.

These factors restricted the length of any single module to 7.7 m and resulted in the need to use two LHDs to push/pull the modules down the mine to get them around tight corners.

PROCESS CONTROL

The Python uses a control system typical of Gekko’s other modular processing systems.

The plant control mechanism is built from Allen Bradley architecture 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
Fig 8 - Schematic showing which Python modules have to be levelled versus which modules can be placed directly on the drive floor.

Fig 9 - Aligning skids (left) and skids ‘aligned’ (right).

Fig 10 - Rollover factory of safety for the Python in transport mode.

Fig 11 - Bogies for transport (left) and a module in transit (right).
shared between controllers over an Ethernet network. The system is interfaced using RSView Supervisory Edition for the purpose of Supervisory Control and Data Access (SCADA) process monitoring and control.

The PLC program encompasses the following tasks as a minimum:

- automatic/manual functionality for all devices,
- sequence stop/start/crash of the modularised plant,
- full open and closed loop control of appropriate analog devices,
- scaling and associated manipulation of analog data,
- interlocking,
- fault detection and action (process faults and instrument faults),
- devicenet data mapping, and
- ethernet messaging.

The SCADA system is built in sectioned components to represent the modular plant. The SCADA mimics each area of the plant for the purpose of monitoring and controlling the operation of each piece of equipment (Figure 13).

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.

**MAINTENANCE**

The Python breaks a number of paradigms associated with conventional processing plant design with its direct coupled crushing and concentrating circuits and its ‘slim’ design taking 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 piece of equipment. There is a need to remove the items above the one you want to get to. Notwithstanding this, it is expected that plant availability will be in excess of 85 per cent if good scheduled maintenance is employed. For higher availabilities and/or to insure against catastrophic failure, it would be entirely feasible to have spare modules ‘off the shelf’ to enable easy changeover underground and more extensive maintenance in the underground workshop or on the surface.

It is also highly likely that multiple Python units could be installed because either one Python won’t meet the total 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 won’t have as significant an affect on production as when the surface plant is shut down.

**THE PYTHON PROCESSING PLANT – FIRST INSTALLATION**

Central Rand Gold South Africa (Pty) Ltd (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 1970s and produced some 247 million ounces at an average grade of 8.2 g/t gold. The mines were largely closed when they were considered uneconomic in the late 1960s and early 1970s due to the low gold price, inefficient mining practices and deep (>2500 m) producing faces.

The Central Rand Goldfield comprises a 7 km wide sequence of quartz pebble reefs and has indicated resources of 21.4 million ounces of gold at average grade of 8.9 g/t and 12.4 million ounces of inferred resources at average grade of 7.4 g/t as at July 2007, in accordance with the The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC) and South African Code for Reporting of Mineral Resources and Mineral reserves (SAMREC) Codes (Central Rand Gold).

The mine design process is being approached with the view to achieving optimal gold resource 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 the deeper ore resource with operations concentrated in underground workings. The use of proven modern mass mining techniques, such as underground processing, will hopefully reduce operating costs and minimise the environmental impact of any new workings, whilst enabling the rehabilitation of many old workings. At an anticipated production rate of 750 000 tonnes per month by 2013, the anticipated life of the mines are at least 15 years from the commencement of production.

CRG’s driving force to process ore underground includes:

- transport logistics due to proximity to an urban area:
  - the mine sites are scattered (see Figure 14);
  - the need for a slimes dam in an urban area:
  - additional environmental hazards and future rehabilitation costs, and
  - acid mine drainage concerns;
  - ability to backfill current and historically mined areas:
  - will be able to stabilise current unstable areas; and
  - reduced transport costs.

CRG ordered a Python 200 processing plant in May 2008 and the unit was shipped to site in August/September. Commissioning should be completed in October 2008:

- the aim is to produce a concentrate of approximately ten per cent of the mined volume using gravity and flotation concentration at a P80 of 500 µm;
- initially concentrators will be installed on the surface (see Figure 15):
  - to treat surface material and near surface material, and
  - concentrate to be transported by truck approximately ten per cent of mined volume;
- as the mining deepens concentrators can be relocated close to the mining operations:
  - initially concentrate transported by truck, and
  - once the sites are connected concentrate can be pumped to the central gold plant;
- tailings from the concentrator plants can be utilised as backfill:
  - current mining areas and historically mined areas, and
• tails will have low value of sulfides due to gravity and flotation concentration – this eliminates acid mine drainage;
• concentrate processed at the surface Central Gold Plant utilising fine milling and Conventional CIP; and
• tailings from the Central Gold Plant will be high in uranium and sulfides and may be able to be sold for uranium recovery and acid production.

CONCLUSIONS
This paper has described the new Python underground processing plant which has gone from concept to first installation in a period of only 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. Central Rand Gold has recognised the benefits of underground processing and is installing its first unit in October 2008.

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REFERENCES