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Miners walk between elevators en route to the depths of South Africa's TauTona mine, the world's deepest gold mine, 4 km below the surface.

MINING

Extreme prospects

High gold prices are making it worthwhile to look for gold in some unusual places.

BY BRIAN OWENS

The journey from the surface to the rock face at the bottom of TauTona, the world's deepest gold mine, takes almost an hour — even with the lifts that bring the workers down each of the mine's three shafts travelling at 58 km per hour. In the dark, hot, cramped tunnels nearly 4 km underground, workers excavate a thin dipping vein of gold ore. Rock is taken to the surface and the gold is extracted using a process that can be traced back to the 1880s: the ore is crushed and sprayed with cyanide to leach out the gold metal.

Gold has always been a valuable commodity, but over the past 10 years the price has risen dramatically — from less than US$400 per ounce in 2003 to almost $1,700 at the end of 2012. At the same time, gold production has seen only marginal increases, with few new mines opening. And it's getting a lot more expensive to extract the gold. In 2000, the average cost of extracting an ounce of gold was just over $200, says Jason Goulden, director of metals and mining at the SNL Metals Economics Group in Halifax, Canada. By 2010, he says, it had risen to more than $850.

Demand has never been higher, but nearly all the easy gold has already been mined. So, to maintain production, mining companies are turning to more difficult sources that would have been left in the ground if gold prices had been lower. From the depths of TauTona in the South African veldt, all the way up to Pierina in the Peruvian Andes, 4,100 metres above sea level, miners are digging deeper than ever before, going to more remote locations and politically volatile regions.

At the same time, significant amounts of gold can easily be obtained without digging into the earth at all — just by recycling the gold buried in the growing mountains of discarded electronics. The advent of more efficient ways to recycle gold from gadgets has turned scrap into a major source of the precious metal.

DIGGING DEEP

There are many factors that influence where and how deep a mining company will dig for gold, but in general "as you go deeper it gets

THINKSTOCK

more expensive and time-consuming", says Steve McKinnon, a mining engineer at Queen's University in Kingston, Ontario, Canada, who specializes in designing deep mines. It also gets more dangerous.

Mining at depths such as those of TauTona presents many unique challenges in protecting the miners, says McKinnon. First of all, it's hot. The temperature at TauTona's deepest levels is a stifling 58 °C. Air conditioning brings the temperature down to a toasty but more tolerable 28 °C.

Then there is the risk that digging can fracture the rock around the pit, triggering a seismic event. "Sometimes that fracture process can be very violent, because the rock behaves in a brittle manner," says McKinnon. "There have been events larger than magnitude 5" — equivalent to a moderate earthquake.

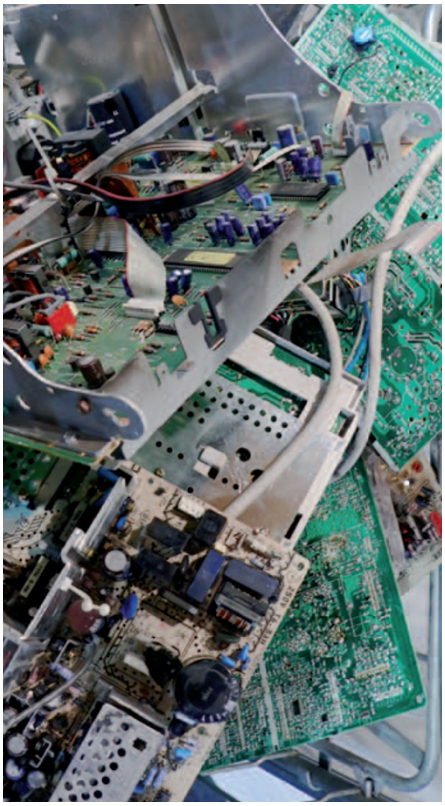
To minimize the risk, mines use 'yielding supports' that are able to deform as the tunnel walls move yet still retain their ability to support the structure. There are also networks of seismic sensors that constantly monitor the rock and develop a seismic 'fingerprint' for the region — any departure from an established baseline requires that workers be pulled out until seismic readings return to normal.

Engineers specializing in rock mechanics, such as McKinnon, also try to design mines in such a way as to minimize and control the forces exerted on the rock. Taking into account data on local stresses on the rock, and other factors such as the presence of nearby faults, they calculate the most favourable layout and method of ore extraction to minimize fracturing. This information helps engineers determine which bits of rock can be safely removed and which need to be left behind to support the rest — in much the same way as an architect decides where to put the pillars in a cathedral to hold up the enormous roof. This design modelling is "really at the limit of our technical ability now", says McKinnon.

But other new technologies are also making deep mining safer and easier. Self-driving trucks, for example, don't mind working in the baking heat. And while a robot buried in a rockfall would be an expensive loss, it's not a tragedy.

"We've got robotic vehicles that can drive, but there's still a lot of missing pieces when it comes to integrating them with the mining process," says Joshua Marshall, a robotics engineer at Queen's who is developing robotic vehicles. Marshall says these robots will eventually be efficient, safe and save money. The 'load–haul–dump' machines that transport ore and waste from the rock face to the surface are already pretty good at hauling and dumping autonomously, but they still need human help to load up. Marshall's group is developing a loading algorithm to fix that.

Marshall is also dealing with a major stumbling block to fully automated underground mining: knowing where all your robots are at any given time so they can be coordinated to move and work in the most efficient way. Open-pit mines already use global positioning system (GPS) to move their automated vehicles around in a way that maximizes productivity, but such satellite signals can't penetrate deep underground. Radio signals can't be used either because they bounce around too much inside the tunnels.



E-scrap has 250–350 grams of gold per tonne, far more than the 1–5 grams of a typical mine.

So Marshall's group is trying something different, using laser scanners to construct detailed three-dimensional maps of all the tunnels and mounting similar scanners on the vehicles. A robot can then find its location by comparing the map with the features its scanner can 'see' on the tunnel walls. "We don't rely on radio signals or trying to penetrate anything through rock, we just use the features of the environment themselves," he says. Several mining companies, keen to apply the efficiencies available through GPS above ground, have already shown an interest, Marshall says.

WASTE NOT

The high gold price and new technologies are also allowing companies to make use of easily accessible ores that were once considered to be too much trouble, such as those containing a mixture of copper and gold. These copper–gold ores are "a pain in the neck" to deal with, says John Monhemius, a mineral engineer at Imperial College London, because the cyanide used to leach gold from the ore tends to grab too much copper. In the worst cases the process doesn't pick up any gold at all — or so little that it's almost impossible to separate it in solution. Moreover, the activated carbon that is used to absorb the gold from the cyanide solution is also swamped by the less valuable metal.

New ion-exchange resins, developed by Johannesburg-based mineral research organization Mintek, are far more selective. These resins can extract the gold from solutions that contain 1,000 times more copper than gold, as found in the leach solution from the Gedabek gold–copper project in Azerbaijan. Although the resins are around five times more expensive than the conventional carbon used, Monhemius believes that high gold prices will result in this resin technology eventually displacing carbon in nearly all forms of gold extraction.

REUSE AND RECYCLE

Some companies have turned to a more reliable source: reclaiming and recycling gold that has already been mined. This 'urban mine' of electronic waste — old computers, mobile phones and the like — is far richer than natural deposits: a typical open-pit mine will yield between 1 and 5 grams of gold per tonne, but mobile-phone handsets can contain up to 350 grams per tonne of gold, and computer circuit boards up to 250 grams.

The explosion in the use of electronics over the past three decades has, in effect, created another kind of gold mine. Indeed, with legislation setting targets for the collection and treatment of electronics, recycling the precious metals from such waste has become a lucrative business, says Christian Hagelüken, a mining engineer who specializes in recycling materials from scrap electronics at Brussels-based Umicore, a leading precious-metals recycling company.

The process for extracting the gold and other precious metals from a pile of circuit-boards and mobile phones is straightforward. The material is shredded and sent to a huge smelting furnace, where it is melted down at 1,250 °C. Two phases form, a metallic layer of mainly copper on the bottom, and a slag layer on top. The precious metals, having a high affinity for copper, are dissolved in the bottom layer. Once cooled, the bottom layer is ground into a fine powder and mixed with sulphuric acid to dissolve the copper and leave behind the precious metals (the copper itself is also purified and sold). Then the various metals — gold, silver, platinum and others — are separated in a series of steps involving precipitation, distillation and ion exchange.

The innovation has come in the development of sophisticated recycling facilities such as Umicore's plant in Hoboken, Belgium. Such plants are entirely closed-loop systems, with companies finding a use for every bit of waste. Lead and other base metals can be refined from the slag, and even the sulphuric acid used to leach the precious metals

DIRTY GOLD

The seamier side of mining

Gold mining can be a dirty business, both environmentally and ethically. Extracting gold from the mined ore creates a huge amount of waste — roughly 20 tonnes of mining waste to make a single 18-carat ring containing less than 10 grams of gold, according to an estimate from Earthworks, an environmental watchdog based in Washington, DC. What's more, many small-scale operations in the developing world make use of child labour, and can support civil wars or local warlords.

The US Environmental Protection Agency rates the metal mining industry as the number one toxic polluter in the country in its Toxics Release Inventory 2011. A large part of this pollution is cyanide, the main chemical used to leach gold from crushed ore; it can contaminate surface and ground water if it leaks from waste sites. One of the worst such accidents occurred in Romania in 2000, when a burst dam sent cyanide-contaminated water into the Someş river, and eventually into the Danube. It killed large numbers of fish and poisoned the drinking water of more than 2.5 million people.

Mining companies often say that new technologies will make mining cleaner, says Alan Septoff, communications director at Earthworks, but that is rarely the case. Research commissioned by Earthworks found that, in the United States, "75% of mines wind up polluting water, no matter what they promise," he says.

This is at least partly because nothing is quite as effective as cyanide at getting gold out of rock. There have been attempts to find less dangerous chemicals, but they have been largely unsuccessful, says John Monhemius, a mineral engineer at Imperial College London. Thiosulphate, thiocyanate, perchlorate, chloride and bromine have all been tried, but none can match cyanide's specificity for gold.

"I did quite a lot of work on thiocyanate, but in the end I decided it wasn't any better than cyanide," Monhemius says. Although it is not as directly poisonous as cyanide, thiocyanate requires much higher concentrations so the results of an accidental spill would be just as bad — possibly even worse, he says. "Cyanide suffers from a lot of bad press," Monhemius adds. "If it is used properly, it doesn't cause a threat to the environment."

REUTERS/CORBIS

In 2000, a burst dam sent cyanide from a Romanian gold-processing plant into local rivers, killing large numbers of fish.

The gold mining industry's voluntary International Cyanide Management Code provides guidelines to ensure the chemical is manufactured, transported and used safely.

Unwanted neighbour

Gold mines can be a source of great wealth but they are not always welcomed by the local population. In Peru, for example, massive protests and nationwide strikes against the planned Conga gold mine eventually led to the suspension — although not the cancellation — of the project in 2012. People were concerned that the amount of water the mine would use would endanger agricultural and drinking water supplies in the region.

Earthworks is running a campaign called No Dirty Gold, which aims to encourage consumers to pressure the mining industry to be more environmentally and socially responsible. The industry is engaging with Earthworks and other civil society groups, says Septoff, although the two sides have not yet agreed on what "responsible mining" should look like.

In October 2012, the mining industry issued a Conflict-free Gold Standard that companies can use to certify that none of the proceeds of their gold — including any bought from local small-scale operations — is supporting "unlawful armed conflict". The first public announcements by companies that they are complying with it, which must be externally verified, are expected in early 2014 when they report on their 2013 activities.

Gold not green

But even avoiding mining by recycling gold from scrap electronics is not always the ethical or environmentally friendly option. Although advanced plants, such as precious-metal recycling firm Umicore's closed-loop facility in Hoboken, Belgium, release very little waste, this standard is not universally followed. In fact, much electronic waste is sent to the developing world, where piles of televisions and computers are burnt under the open sky, with cyanide poured over the slag to extract the precious metals. This not only releases dangerous fumes and chemicals, but also results in low yields.

"It is obvious that from an environmental and social point of view this unregulated recycling is a disaster," says Umicore recycling engineer Christian Hagelüken. The electronics recycling industry must be better managed and regulated, he says, to stop dangerous and wasteful operations. — ***B.O.***

from the copper is a by-product of one of the gases produced by the furnace. As well as being environmentally friendly, modern plants like these have yields "close to 100%", says Hagelüken.

The challenge lies in ensuring that the electronic devices reach such sophisticated plants at the end of their life — only a fraction of e-scrap currently does. The United Nations Environment Programme estimates that just 15% of the gold in waste electronics is recovered properly. Huge amounts are left sitting in drawers and attics, or worse, sent to landfill or incineration plants. "The one important point is how to boost collection," says Hagelüken, and ensure it is recycled properly.

But even with much higher recycling rates, e-scrap will never be able to supply our insatiable demand for gold. So the value of gold will continue to drive the miners of TauTona to ever greater depths. ■

Brian Owens *is a freelance science writer based in St Stephen, New Brunswick, Canada.*