WINNING GOLD

Roald Hoffmann

Brazil has been host to several contemporary gold rushes. Since 1982, the town of Poconé in the central western state of Mato Grosso has attracted thousands of gold miners seeking the precious metal, as it did once before, in 1777.

The gold-mining camps near Poconé are called in Portuguese *garimpos*, and the miners *garimpeiros*. The conditions are primitive. But if chemistry needs to be done, people will do it, anywhere. And if there is gold to be won, people are likely to ignore the risks in that chemistry. What chemistry? Amalgamation, combination with elemental mercury (Hg), and its reversal.

Why is chemistry required for mining for gold, when gold occurs in the native state, relatively pure? Because the age of panning for nuggets has passed. That was the first gold rush. Since then, the price of gold has risen; the rich veins have been exhausted. It has become profitable to work deposits of low gold content—too low to extract the gold by time-honored gravity methods. A miner describes the ore in Poconé as follows: "The gold here was loose, *ouro de quirera* (chicken feed), a gold I think they call alluvial. *Ouro solto* (loose gold) that the old timers didn't find because they couldn't trap it in their screens."

Gold forms a series of "amalgams," an ancient generic word for compounds or alloys of mercury with other metals. Most of us have a mercury-silver amalgam in our teeth (with some tin and copper as well). In mercury amalgams of gold, there can be two, three or four atoms of gold per mercury, giving the compounds Au_2Hg, Au_3Hg and Au_4Hg, respectively.

The Romans amalgamated gold with mercury and used this chemistry to recover gold from gilt objects and jewelry workshop remains. Here is what the Roman writer Pliny says:

> There is a mineral also found [in Spain] which yields a humour that is always liquid, and is known as quicksilver. It acts as a poison upon everything, and pierces vessels even, making its way through them by the agency of its malignant properties. All substances float upon the surface of quicksilver, with the exception of gold, this being the only substance that it attracts to itself. Hence it is, that it is such an excellent refiner of gold; for, on being briskly shaken in an earthen vessel with gold, it rejects all the impuritites that are mixed with it. When once it has thus expelled these superfluities, there is nothing to do but to separate it from the gold; to effect which, it is poured out upon skins that have been well tawed, and so, exuding through them, like a sort of perspiration, it leaves the gold in a state of purity behind.

That's not quite right, for what is left behind in the skin is the solid amalgam, not pure gold. But it's close enough, and makes the point that the technology is ancient. The Romans worked cinnabar (HgS, a mercury-sulfur compound) mines in Spain, importing in 77 C.E. about one ton of mercury for amalgamation.

Amalgamation has great staying power; it was used for extracting Mexican, Peruvian and Bolivian gold and silver, by American gold diggers employing pans, sluices and tables. Mercury poisoning was common among the gold panners and the cinnabar miners.

In the *garimpos*, the miners who dig out the quartz veins and alluvium bring the ore to *moinheiros*, operators of crushing, concentration and amalgamation plants. Amalgamation depends on intimate contact of the gold with mercury. So the rock is crushed, milled and centrifuged. The heavier ore portion ("gravity concentrate") is put with mercury into a rotating amalgamation drum. At least in the better *moinhos*. Gold pans are still used in more rudimentary settings.

The amalgam is a dense solid. A riffled sluice effects a first separation, followed by washing. The first loss of mercury to the environment is in the tailings here. Next the excess mercury is removed by wringing out the solids in cotton cloths (not that far from Pliny's skins).

The amalgam is about half gold, half mercury by weight. The mercury is then simply roasted

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off, great amounts of it volatilizing. Here occurs the major loss of elemental mercury to the atmosphere.

The spongy gold that remains contains some noble metals and silicates and, still, a little mercury (3 percent to 5 percent). It is taken to gold-buying shops in the nearby towns, where the gold is purified further at high temperatures, sending still more mercury into the air. The gold shops also process the crude amalgam.

There is a psychologically important point that has contributed to the historical persistence of amalgamation, even if the dangers of mercury exposure are known. This is that the chemistry must take place *before your eyes*. B. Traven's tale (or John Huston's classic screen adapation) of *The Treasure of the Sierra Madre* is a sufficient demonstration of the equation gold = greed = suspicion. Whatever chemistry is done in the gold fields, it had better take place in full sight of the (rightfully) suspicious *garimpeiro*. No backroom stuff here.

Mercury is not very healthy. Its toxicity depends on the particular chemical form it takes. The worst offenders are organomercurials—compounds such as salts of methyl mercury, CH_3Hg^+. These are stored in fat tissue, are easily transported across membranes and cause nerve damage. Ionic mercury, Hg^+ (in the form of Hg_2^{2+}) is not very toxic, for it forms the stable Hg_2Cl_2 (calomel) with stomach chloride. Mercuric ion, Hg^{2+}, is dangerous (it can be methylated, forming CH_3Hg^+, by bacteria), but not easily transported across biological membranes. Elemental mercury is very toxic when inhaled. Pascal, Faraday and especially the great German inorganic chemist, Alfred Stock, who suffered a painful irritation of the nose lining and bladder, as well as memory loss and impaired mental processes as a result of inhaling it.

Figure 1. After the gold rush, a Brazilian miner pans for gold. (Photograph courtesy of Julieta Sobral.)

The *garimpo* operations put vast amounts of mercury into the atmosphere and, through concentration-plant tailings, into the soil and waters. A lake near Poconé, adjoining the Pantanal ecological reserve, is silted up by more than 300,000 cubic meters of *garimpo* tailings. Fortunately, analyses show that not much ionic mercury is being released into the waters. Mercury in its metallic form is quite stable under ambient conditions, but there are concerns about its mobility, and what will happen when bacteria get their biochemistry working on the metal. There are excessively high local concentrations of mercury vapor, expecially where the amalgam is roasted to recover the gold. Within 100 meters and windward of the gold dealers' shops, mercury concentrations ranging up to 1.68 micrograms of mercury per cubic meter of air were measured, three orders of magnitude over the background. It was worse inside the shops.

The concentrations of mercury in and around Poconé are worrisome; in fact in 1987 the government tried to close down the *garimpos*. New ones have sprung up in other gold-mining regions. CETEM, a Brazilian research institute devoted to the investigation of the country's mineral resources, has done an exemplary cross-disciplinary study of the *garimpo* phenomenon. The study ranges from economic detective work to deduce the total mercury consumed, through the actual environmental analysis (which meant developing new field analyses), to the sociology of the *garimpeiros* and their interactions with the gold buyers, and remediation.

CETEM's economic analysis traces (no easy matter) the amount of mercury dispersed into the environment by the *garimpo* operations. The importation of mercury to Brazil took a leap in the 1980s with no discernible increase in industrial or dental demand. The estimate is that in 1989, of the 340 tons of mercury imported to Brazil, 235 tons is likely to have found its way to the gold fields. This substantiates reports from the field, indicating "metallic mercury is being openly traded in shops that sell gold prospecting equipment, and in chemists' shops, grocery stores, and other shops, in 100-gram flasks, packed as if meant for dentistry..."

Another part of the economic analysis makes it clear why mercury is used:

> Even at a price of around US$40 per kg, that is, 4.5 times higher than the international market price (US$8.7/kg FOB Europe), the mercury in the Poconé field represents an extremely cheap input. If 4 g of gold buys 1 kg of mercury and the mercury consumption is 3.0 g Hg/ton of ore, then even considering that no mercury is recovered in mining, its price would be equivalent to 0.012 g of gold per ton of processed ore.

Accepting that the process is here to stay, CETEM has focused on the steps that release

most mercury—roasting the crude amalgam and the gold sponge.

A simple retort technology can recover nearly all of the mercury distilled. Mercury-condensing hoods have been constructed and offered to the gold shops. There were also developed routes for reprocessing the tailings to extract mercury (and much remaining gold) from them, or fixing the mercury through polysulfides formed from a simple and soluble mixture of soda (sodium carbonate) and sulfur.

The sociological studies of the *garimpo* community by CETEM surprised me. A stereotype of the *garimpeiros* is that they are conservative and indifferent to the environment. One of their leaders drank mercury on TV to show how harmless it is. There is nothing pretty about the *garimpos*. But there is another side to this predatory extractive capitalism—namely entrepreneurship, which actually demands flexibility and openness to change, especially in methods and equipment. Indeed, it seems the *garimpos* are just that way, in constant technological flux.

One report on the reaction to placing mercury-recovery hoods in the gold-mining camps and towns says:

> Contrary to what prejudices would have us think, the hood, which is being monitored was accepted by the *garimpeiros* without any great resistance. Obviously they must have made their own tests as anyone would—regarding possible decreases in the final quantity of gold extracted. Since they did not find a reduction...

I think that's wonderful—not only did the *garimpeiro* buyer take on something new. He also did something that is so central to science—an experiment! Indeed, many miners and gold buyers have adopted the simple hoods and retorts. There is hope, but once a simple chemistry is in place, it's tough to displace it. Especially if one is winning gold.

Notes

With the exception of the passage from Pliny the Elder, all of the quotations in this article are from a series of papers by the Environmental Technology Program of CETEM (*Centro de Tecnologia Mineral*), Rio de Janeiro, Brazil. The project *Garimpo of Poconé—Mato Grosso* was coordinated by Francisco Rego Chaves Fernandes. The Pliny quote came from *Natural History*, Book XXXIII, Chapter 20.

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