

Feature

The rich hill of Potosi

Silver mining in Bolivia exploited the richest hill on Earth to finance the imperial Spanish in the 16th century. The mines still operate at Potosi today, with primitive conditions underground, but silver production may be boosted by new geological understanding.

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Fig. 1. Scored by mine entrances, Cerro Rico rises beyond the houses of Potosi.

Potosi is the material of legends. High in the Bolivian Andes, a single conical mountain is the core of an eroded Miocene volcano, and is riddled with silver veins. It is known as Cerro Rico – Rich Hill; and justifiably so, as it is often claimed to be the richest hill in the world. The original Quechua Indian name for the mountain may be *Potojsi* (meaning thunder), which has been distorted to Potosi as the name of the city that has grown from a mining camp at the foot of the hill (Fig. 1).

There is some debate over how much the Incas knew about the Potosi silver, or whether they worked it on a small scale. But the Spanish conquistadores arrived in the region in the 1530s, developed other mines not far away, and soon heard stories of the Potojsi mountain. By 1545, their mine was registered and exploitation expanded rapidly. Within two years, the mine town housed 14 000 Indians and a few hundred Spanish. The first 20 years were the most fabulous, when the richest ores were worked most easily, and vast amounts of silver were hauled out on mule trains and then shipped to Spain – making a major contribution to that nation's wealth and its emergence as a world power in the 16th and 17th centuries. Meanwhile, the Indian miners lived and died in terrible working conditions; there were thousands of local free miners, together with many more thousands that had been forcibly conscripted from towns all over Spanish South America. The latter were kept in a state of virtual slavery, working 12 hours a day and often being kept underground for months at a time.

For a short time around 1611, Potosi may have been the largest city in the world, with a population exceeding those of contemporary London and Shanghai. And this was in the middle of a desert at a lung-straining altitude of 4090 m above sea-level. A mint was established in 1572, alongside some beautiful churches. But it was a typical mining town, where the wealth generated traders who sold every

conceivable luxury imported from the outside world, but in a crime-ridden, disease-ridden state of virtual anarchy. Potosi's wealth fluctuated with the mining yields, and was in serious decline by 1825, when the richest veins had been worked out, competition for the silver market came from new mines in distant countries, and Bolivia's independence saw the departure of the Spanish. But the mines have continued to produce wealth for the new nation, with phases when tin and zinc and then silver again have continued to pour from the veins of Cerro Rico.

A volcanic ore deposit

Potosi lies in the central cordillera of the Bolivian Andes, a great mountain chain composed primarily of fine-grained Ordovician and Silurian sediments. It is intruded by various Mesozoic granodiorites, and also by high-level Miocene intrusions that were underlying contemporary volcanoes. The modern volcanoes are in the western cordillera that defines the border with Chile. Along the western side of the central cordillera, a long and narrow tin-silver metallogenic province passes through Potosi, while parallel belts rich in gold-antimony and lead-zinc-silver lie consecutively to the east.

Cerro Rico originated where a Miocene volcano developed within the tin-silver belt. An early maar complex had explosively created the Pallaviri Breccia (Fig. 2), which was capped by a major cone (the Caracoles Tuff). About 13.8 million years ago, this volcanic edifice was intruded by a rising dome of porphyritic dacite; this is about 1500 m in diameter, tapering down to a neck that is only 100 m across at a depth of 800 m. The dome was only exposed during later eruptive events. Before these, cooling fractures within the dacite were permeated by hydrothermal solutions rich in metals, so that silver, zinc and antimony minerals were precipitated in the veins at higher levels, while tin (as cassiterite) and tungsten

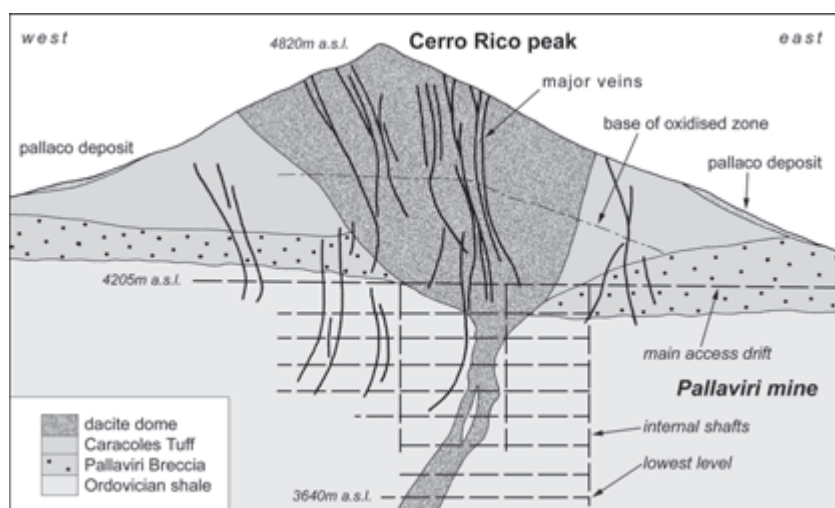


Fig. 2. Geological section through Cerro Rico.

(as wolframite) increased at greater depths, beside declining amounts of the other metals. The temperature-controlled mineral zoning reflects the well-known zones in Cornwall and elsewhere, which have lead, zinc, silver, copper and tin in a deepening sequence. There were hundreds of veins thick enough and rich enough to be mined within Cerro Rico; most were 100–600 mm wide, although some locally thickened to 4 m. There were 35 main vein systems, and only a few are shown on the cross-section (Fig. 2). The veins were banded with some open-space mineral fillings, and intersected each other on a close spacing with wallrock alteration and impregnation in between. Consequently, most of the mountain was mineralized, and the workings became extremely complex as they chased the best ore shoots.

Superimposed on the pattern of primary mineralization, there is a zone of oxidized, supergene enrichment about 300 m deep (Fig. 2). The primary ores average about 10 oz/ton (0.034 per cent) of silver, mainly from argentiferous tetrahedrite ($\text{Cu}_{12}\text{Sb}_4\text{S}_{13}$) and pyrargyrite (Ag_3SbS_2). But the secondarily enriched zone contained native silver and chlorargyrite (AgCl) that averaged more than ten times that value. Production from the richest ores, from 1545 to 1570, was hand-picked by the miners to reach the incredible grades of 7000 oz/ton – about 19 per cent silver – which were so easily smelted. Such grades could never be maintained, but Cerro Rico eventually yielded between 30 000 and 50 000 tonnes of pure silver. At greater depths, silver values declined, but the veins ran at 1–4 per cent tin in cassiterite (SnO_2). Sphalerite (ZnS) and galena (PbS) were significant by-products of the mining, and there was recoverable copper in chalcocite (Cu_2S) and covellite (CuS) in the supergene zone. Cerro Rico is capped by a thin silicified zone enriched in silver, which may have originated in a late stage of fumarolic activity.

Evolution of the mines

The steep hillsides of Cerro Rico, laced with innumerable veins that were so rich in oxidized ore, made the early mining unusually easy. Adits could be driven into the hill at any level and be guaranteed to reach workable veins. Silver production peaked in 1592, when there were 612 mines on the mountain, with shafts already reaching 250 m deep. There was an early claim that there were 3000 *minas bocas* (adit mouths) on the slopes above Potosi, though not all were worked at any one time (Fig. 3).

A modern mining operation would have taken the whole hill in one vast open pit, but the historical alternative was a host of small operations, each opening stopes in individual parts of the richer veins. This encouraged rapid growth in the mining, but eventually it had to wane, as extraction had to rely on the thinner, leaner and less accessible veins. The decline was steady and was almost uninterrupted from about 1700 to 1940. By then the silver was almost exhausted. It is estimated that the hill still contains 140 million tonnes of ore with 0.017 per cent silver in veinlets about 10 mm wide, but this could only be won by marginally economic open-pit working, though deemed unacceptable because it would destroy the 'sacred profile' of Cerro Rico.

From 1912 until the 1985 price collapse, tin ore was extracted from the deeper zone of high-temperature mineralization. The Pallaviri Mine worked from 1940 onwards, following the veins in and around the feeder neck beneath the dacite dome to a depth of 565 m (Fig. 2). And even when the large-scale extraction of tin finished, there were still two more phases of Potosi mining history to come.



Fig. 3. Miners roll a full tub of ore out of the gently inclined main level.

The mines today

Vein mining continues today in Cerro Rico, more than 450 years after it was started. The scale is now smaller, and the minerals are different, because today's main production is of zinc, with lesser values of silver, lead and tin (in that order of value). There are now about 6000 men working in and on Cerro Rico, including many that are in daylight processing



Fig. 4. The view down Cerro Rico to a modern mineral processing plant with Potosi town beyond.

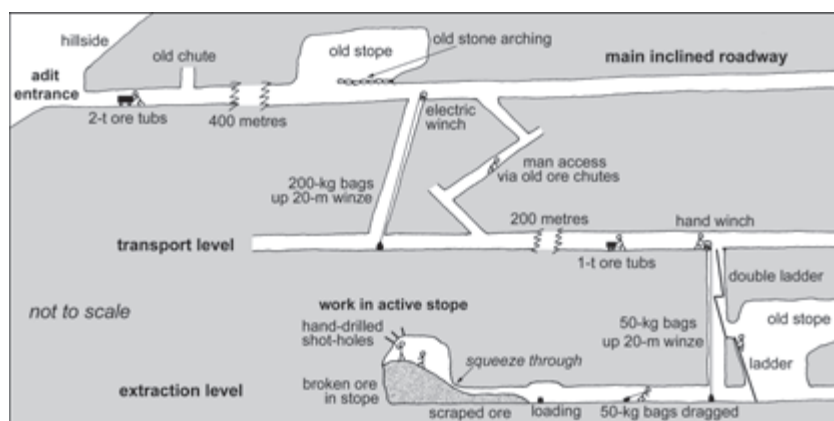


Fig. 5. Diagrammatic section through a part of the working mine.

plants, and some that are re-working old tip material. But there are still hundreds of miners working underground, mostly in small teams of 10–12 men. The available ore appears to be so marginal in value that hand-working by small teams probably offers the only scope for continuing extraction in Cerro Rico.

Each miners' co-operative has its own patch within the mountain, where they work one or more veins and gain access and ore transport out through the old levels (Fig. 3). The miners can work anywhere they want to, except where another group has already started. They then sell their raw ore to any of a dozen processing plants in Potosi (Fig. 4). These have required more capital investment, because they have had to install flotation plants to separate the sulphide minerals in the lower grades of ore.

The effort involved in extracting the ore is enormous, and is nearly all without machinery. Mineral from a single sample stope, visited by the writer inside Cerro Rico, takes a tortuous path to daylight (Fig. 5). Ore that is visibly rich in sphalerite is broken from a vein that is about 500 mm wide; explosive is used in shot-holes created by hand with hammer and star-drill (Fig. 6). It is scraped out by hand to where it is loaded into sacks and then dragged along a gallery. A hand-powered winch lifts it 20 m to the next level, where it is loaded into rail-tubs and pushed by hand along the transport level. The ore is tipped out (Fig. 7) and shovelled into leather sacks, to be hauled up the next shaft by electric winch. Re-loaded into larger tubs, the



Fig. 6. A miner rests from hammering a shot-hole into the vein in his stope roof.



Fig. 7. Tipping ore from a rail tub at the foot of the winze on the transport level.



Fig. 8. Squeezing over broken ore in the only way into the stope, where miners wait with cheeks full of coca leaves.



Fig. 9. Ladders down to the lower levels.

journey out to daylight is downhill (Fig. 3), though empty tubs are pushed back up by hand.

Working conditions are appalling – hot, dusty and low in oxygen (in thin air at an altitude of 4500 m). Many galleries require crawling to get through, and the only way into the small stope where two men were working was a squeeze over a slope of broken ore in the ore chute (Fig. 8). Ladders end on tiny platforms over deep shafts, timber supports vary considerably in their condition, and some galleries are protected only by old stone arches through tall and ancient stopes. The miners permanently chew wads of coca leaves so that they are too stoned to realize the awfulness of their environment.

The miners earn about 800 bolivianos (£80) per month, which is more than the potential earnings from desert farming or urban sweatshops. Some auxiliary income is now created from taking visitors on tours round the mines – though Potosi attracts relatively few visitors, and not many of these are crazy enough to take a mine tour. These are not for the faint-hearted. Hot, breathless, stooping walks, precarious ladder-climbing (Fig. 9) and flat-out crawling firmly place a mine visit in the 'interesting experience' category. Furthermore, they start with a visit to the miners' market to buy explosives, detonators and coca leaves to carry into the mine as a gift for the miners in the most distant stope (Fig. 10). Agents in Potosi run daily tours that are a convenient way of seeing the mines; for anyone who joins a tour, the experience is not forgotten.

A silver future

Not long ago, it seemed that the focus of mining was moving away from Potosi. A large open-pit mine has newly opened on a somewhat similar ore body exposed on the altiplano 250 km to the south west. This is at San Cristobal, where a new mine town has grown on the desert road popular with tourists from Uyuni to Laguna Colorada. About 200 million tonnes of workable ore should produce about 12 000 tonnes of silver – a grade of 0.006 per cent for the bulk ore of veins and wallrock, workable in a huge, modern open-pit, but a pale comparison to the 19 per cent in the richest of the Cerro Rico veins.

However, new geological explorations at Potosi have discovered more silver in a series of sedimentary deposits known as *pallacos*. There are two types of these. One group are crudely stratified gravelly clays with dacite clasts, thought to represent rain-triggered debris flows from scree on Cerro Rico. The others are totally unsorted, with dacite boulders up to 20 m across in a matrix of clay and tuff, and are interpreted as landslides or late-stage lahars off Cerro Rico. In both types, the dacite clasts are mineralized and silicified like their source material high on the mountain. Pallaco deposits up to 20 m thick are draped around the flanks of the mountain (Fig. 11), and contain at least 12 million tonnes of ore with a silver grade of 0.017 per cent; they could yield nearly 2000 tonnes of silver from shallow opencast operations.

These *pallaco* deposits have not yet been found elsewhere; they ought to exist on other mineralized and eroded volcanoes, but so far nobody has looked for them. Meanwhile, the San Bartolome Project has invested millions of dollars to start about now to extract silver and tin from 700 tonnes per day of the *pallaco* sediments. It would seem that Cerro Rico has not yet yielded all of its fabulous riches.

Suggestions for further reading

- Bartos, P.J. 2000. The pallacos of Cerro Rico de Potosi, Bolivia: a new deposit type. *Economic Geology*, v.95, pp.645–654.
- Timberlake, S. 2000. 'Treasure of the world, king of the mountains, envy of kings': the imperial Spanish silver mines of Potosi, Bolivia. *Mining History*, v.14(4), pp.31–39.



Fig. 10. 'Don't push the detonator into the dynamite' – visitors at the miners' store.

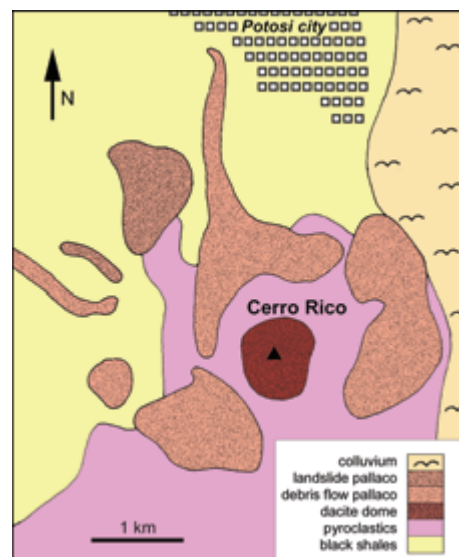


Fig. 11. Outline geological map of Cerro Rico and its pallacos.