CHAPTER 1

Exhausting the Sierra Madre

Mining Ecologies in Mexico over the Longue Durée

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The Cerro de San Pedro is the name of what used to be a small Mexican mountain. It is also the eponym of a small mining town perched in a highland valley overlooking the city of San Luis Potosí, Mexico. Today it is the object of a large-scale open-pit gold and silver mining project, one profoundly reconfiguring local topographies, hydrological systems, and the district's geochemical composition. Every day over the past six years the New Gold mining corporation has detonated massive charges of ANFO, Geldyne, Powerfrac, and Pentex. The mountain of San Pedro is no longer. It has now been reduced to neat set of benches that contour around an ever deepening and enlarging pit. The excavated material is trucked out to leaching piles, where it is sprayed with a cyanide-water solution to filch out microscopic particles of gold, or it is dumped in piles of waste that fill the valleys and arroyos of the surrounding watershed. The impacts on local waters are tremendous. Aside from the acidification and heavy-metal release that are contaminating the water, the pit is creating a massive well effect that is drawing in the region's subterranean water flows. By plugging up drainages, the mine is obstructing the movement of surface water. The liners underlying the leaching pads are sealing off one of the regional aquifer's most important recharge zones, and yet simultaneously the project draws in enough water from it to provision an estimated 50,000 people in the neighboring city of San Luis Potosí.

This has long been the way with mining. Since the arrival of Spanish miners in 1592, the extraction of metals from the subsurface has destroyed and re-created landscapes. Indeed, the layered traces of these past transformations remain visible today, even in the midst of the massive upturning of the land. The hillsides that surround the current operations are covered with a mix of exposed sheets of host-rock, patches of soil, and hardscrabble clusters of mesquite, scrub oak, long and spiky ocotillo plants, and a variety of cactuses. This kind of vegetative cover was historically produced during the Spanish period (1592–1821) as the demands for fuel drove deforestation across the region. Nineteenth- and early-twentieth-century mining left other kinds of traces. Much of the surviving built environment dates from that period as does an important network of dams, reservoirs, and millraces for washing ores or for high-pressure hydraulics. Mining also left large piles of tailings, mine waste, and *scoria* (pebble-sized twists of furnace discards), all heavily mineralized, open to the elements, and blooming into yellows, ochres, and a near blue-green.

The story of Cerro de San Pedro is but a thread in a much larger story that has come to define the landscapes of the Mexican mining belt, a territory composed of hundreds of mines scattered along the Sierra Madre Occidental and Oriental, the Central Mesa, and the highlands to the west and east of the Valley of Mexico. Mining's hold on this territory has proven remarkably persistent. The mining and processing of metals—copper and gold especially—began in the pre-Columbian period, but with Spanish conquest and colonization mining rapidly expanded to become one of the principal pillars of the economy. The core areas of colonial mining—Parral, southern Sonora, central Jalisco, Zacatecas, San Luis Potosí, Guanajuato, Taxco, Pachuca, the highlands of Guerrero and Oaxaca—were all brought into activity within a matter of decades between the 1520s and the 1590s. Its limits—the north of Sonora and the southeast of Chiapas—were set by the mid-seventeenth century and then stayed put. During the Bourbon revival of the eighteenth century, a royal commission inventoried some 453 active mining districts in the viceroyalty. Almost all of these had been established in the sixteenth and early seventeenth centuries.[1] At the turn of the twentieth century, at the height of the U.S. period in Mexican mining, a survey cosponsored by the American Institute of Mining Engineers and the Mexican Republic's Ministerio de Fomento counted 401 mines in exactly the same areas.[2] In 2011, Mexico's geological survey (SGM) listed 718 mines, the majority run by Canadian-based transnational corporations.[3] They are all situated in the same districts mined for the past five hundred years.

In short, Mexico hasn't seen green-field or first-strike mining since the colonial period. Instead it has been marked by a succession of mining regimes—colonial, industrial, and the *mega-minería* of today—that have occupied the same territories. This pattern is not peculiar to Mexico. Many of the core mining territories of the Americas passed through this same succession, over roughly similar time frames. We are familiar with the notion of mines booming and busting, but what the *longue durée* history of Mexico shows—and this is what deserves closer attention—is that this cycle repeated itself, and then repeated again. It is not what we might expect. Like other extractive industries, mining is based on the removal of a nonrenewable resource. Mineral stocks diminish from the very first day they are exploited to the moment of their exhaustion. This fact is reflected in the decline of ore grades over time. But mineral production in Mexico did not follow this decline in any neat and linear way. Quite the contrary: it moved through a series of cycles, each defined by the expansion, maturity, and decline of a particular mining regime.

This historical pattern raises the two key issues. The first concerns the characteristics and drivers of mining's cyclical history. Although ore grades have indeed declined across the centuries, each successive mining regime has proven to be more productive than its predecessor, producing more metal in any given year and removing a greater amount from the deposit overall. Thus, instead of exhaustion we see periodic phases of reanimation, acceleration, and amplification. This was the outcome, I argue here, of historical capitalism's reworking of resource extraction in this part of the world. Instead of extending a commodity frontier into untapped regions, capitalist forms of mining in Mexico (and most of Latin America) avoided the pinch of increasing metal scarcity through intensification.[4] At different junctures—during the Bourbon reforms of the eighteenth century, the first liberal period of the nineteenth century, and again in the 1990s—we see capitalist mining pushing past the limits of exhaustion thanks to new and more powerful assemblages of laws, technology, and energy flows.

The second issue concerns the environmental consequences of this parade of mining regimes over half a millennium. As each regime established itself within the Mexican mining belt, it created a distinct and coherent set of relationships with local waters, soil, and life. These relationships formed a mining ecology: the matrix of interacting components—socioeconomic relations, physical and biotic systems, as well as energy and material flows—that constituted the landscape wrought by mining. Seen in this light, mining ecologies are comparable to agro-ecologies in that they are part of the larger set of "second natures" created by human activity, but distinct from these in that they are created around the extraction and use of nonrenewable materials. Myrna Santiago's social and environmental history of the Mexican oil patch shows another extractivist ecology, an "ecology of oil," an assemblage of property regimes, laws, race and labor relations, and political economy that together conditioned the environmental consequences of resource extraction.[5]

This chapter focuses on the play of time, and follows the historical progression of Mexico's different mining ecologies over nearly five centuries: the colonial regime (1522–1821); the ecology formed around industrial mining during the late nineteenth and twentieth centuries (1883–1960s); and the open-pit mining ecology of our neoliberal present (1990s to today). To provide detail and continuity, it centers its account on the story of the Cerro de San Pedro, folding this narrative within a broader discussion of regional trends and variations. These show a centuries-long pattern of stepwise increases in capital investments, energy inputs, and material flows coupled with a corresponding intensification of mining's environmental footprint. These are the results of mining's centuries-long struggle against exhaustion.

A COLONIAL MINING ECOLOGY, 1522 TO 1821

Spanish colonization of what would become the Viceroyalty of New Spain was famously motivated by the quest for precious metals. At first, gold and silver were obtained as part of the spoils of conquest, but plunder quickly gave way to a more systematic search for, and exploitation of, precious-metals deposits. Only months after the final battles for Tenochtitlán (in August 1521), Hernán Cortés was dispatching expeditions to the gold-bearing placers of the Río Balsas and the Río Papaloapán in Oaxaca, as well as parties of miners and foundry men, to investigate reports of metal deposits in Súltepec-Taxco in the mountains 80 kilometers to the southwest of Mexico.[6] These areas became New Spain's first colonial mining districts, with production beginning in 1522 and 1524, respectively. Colonial silver mining was a paradigmatic example of an early modern commodity frontier. It moved north to Pachuca–Real del Monte, Zacatecas, Guanajuato, and Sombrete in the 1540s and 1550s, then to San Luis Potosí, Durango, and Parral (1590s to 1630s), and finally to Sonora—the northern edge of New Spain—by 1633.[7] Within a hundred years, the northern (Sonora) and southern (Oaxaca) limits of

New Spain's mining belt had been set, creating a mining region some two thousand kilometers long.

Spanish miners and officials developed a regime of high and long-lasting productivity. For close to three hundred years, colonial Mexican mining increased its production of silver, gold, and other metals (especially copper, mercury, and lead). There was a long lull in the seventeenth century, but it was overcome by the efforts of the Bourbon state in the mid- to late eighteenth century. By Independence in 1821, Mexico had produced close to 49,000 metric tons of silver, with annual production peaking at 611 tons in 1804.[8]

Colonial mining was one of the important forms of proto-industrial production in the early modern Atlantic world. It combined the European arts of mine building and metallurgy, private capital investment of colonial and Atlantic merchants, the work of the state to ensure the supply and regulation of labor (peasant-miners, corvée workers, or African slaves), and the intensive use of energy from hydraulics and biofuel consumption. The product was distributed globally through networks that reached as far as China as early as the late sixteenth century.[9]

Each individual mining operation was relatively small. Exploitation of the mine's one to three tunnels depended on the work of between eight and a few dozen men supported by mules and oxen and, where conditions permitted, a water mill. Milling, amalgamation, and smelting took place in the *hacienda de beneficio* (metallurgical works). Although there were important exceptions, these facilities were usually modest in size: a mill, a patio, one to three small smelting furnaces, and a dozen or so workers. The average mill processed slightly less than half a ton of ore per day—a good indication of the local rhythms of extraction.[10] Colonial mining scaled up by joining such operations together. The larger mining districts tapping larger deposits (e.g., Guanajuato, Zacatecas, and Pachuca–Real del Monte), combined dozens of such mining operations mobilizing tens of thousands of *operarios*. Medium-sized districts such as Parral, Cerro de San Pedro, Zimapán, and Taxco counted between five and ten thousand workers.

Cerro de San Pedro, 1591–1821

Colonial mining set in motion a series of ecological changes whose trajectories were complex and contingent on local variables of topography, climate, soil composition, and vegetation cover. This process is best viewed locally. The mines of Cerro de San Pedro, a middling-size mining district in Mexico's near north, were established in a valley perched among the rounded peaks of a subrange of the Sierra Madre Oriental. When the Spanish miners arrived in 1592, the sierras were covered in a mix of mesquite-oak and pine-oak forests with scrub, cacti, and denser stands of mesquite and willow along the watercourses of the larger valley. Lying beneath the plants were rendzina soils: a relatively thin layer of dark-red, fertile, and humus-rich soil spread out over the calcareous bedrock.[11] Sources mention surface water flows of intermittent arroyos, perennial streams and rivers, and extensive marshes where the watershed flattened out into the plain of San Luis Potosí.[12] Until the twentieth century, surviving wetlands continued to be one of the main recharge areas for the region's aquifer.[13] In precolonial times the variety of biomes had made the area a favored ground for local Guachichil and Pamé hunters and gatherers.[14]

Mining began in 1592, and within a year more than twenty mines were working their way into the mountain of San Pedro. Mills and foundries were established to process the ore, either in the neighboring valley of San Luis or wherever there was enough water flow to wash the ores and power the crushing mills. In 1630 there were more than fifty such mills. An estimated five thousand people labored at Cerro de San Pedro itself: mine workers, *carboneros* (charcoal makers), mill workers, muleteers, and artisans.

Colonial mining affected the regional environment in two main ways. The first was fuelwood consumption. An average of 126 square kilometers of forest were cut every year in and around Cerro de San Pedro for fuelwood.[15] The surrounding highlands were cleared by *carboneros* in a matter of years. Observers described the local landscape as completely denuded of any tree or sizable shrub save "a few surviving yuccas upon the bald hills."[16] Rapid and thorough deforestation had important repercussions on the local landscape that have endured to this day. From a human ecology perspective, the elimination of forests destroyed the subsistence base of local Guachichil and Pamé peoples, facilitating their incorporation into the Spanish colonial sphere as slave laborers and their eventual demise as an autonomous, living culture. From a landscape ecology perspective, the most important effect of deforestation was the massive erosion of the thin cap of rendzina soils. Precipitation in this area mainly comes in the form of intense summer rainstorms that can drop between 40 and 90 millimeters of rain at a time.[17] Without the protective cover of the leaf canopy or the anchoring function of root mats, the soils washed out at prodigious rates, leaving behind slabs of local blue limestones. Soil-building processes in the region's semiarid climate are extremely slow and were further impeded by the subsequent introduction of sheep and goat herding. Today, the soils of the Cerro de San Pedro range are limited to small pockets of very sandy and mineralized lithosols in the crevices of the bedrock and around the root mats of some tenacious shrubs and cacti.

With the forest cover gone and the soil cover going, local watersheds were less capable of modulating the pulses of seasonal and episodic rainfall. Severe flooding episodes powerful enough to wash out buildings and structures in the valley city of San Luis were recorded throughout the colonial period and continue to the present day.[18] Between the floods, the overall trend was toward a general desiccation of the landscape. The lack of forest and soil cover resulted in local watersheds draining faster and drying up sooner than they had before. Marshlands described in the early seventeenth century no longer appeared on maps drawn in the eighteenth and nineteenth centuries. Steady, year-round water flow in local rivers diminished and eventually disappeared. In the early eighteenth century an official report on the state of agriculture in the area in and around San Luis Potosí identified as central problems the chronic flooding, the constant droughts, and the generally thin and "sterile" soils.[19]

A second, more chronic kind of environmental change came from the production of mining waste. This material came in various forms: discarded rocks piled up at or near mine entrances; finer tailings generated after processing; and the scoria raked out from the smelters, all of which were laced with lead, zinc, manganese, and mercury. Its environmental effects were a function of quantity and concentration. In this first cycle of mining at Cerro de San Pedro, both of these measures were low. At an average ore grade for the period just shy of 7 kilograms per ore-ton, the total waste produced over two hundred years of mining would have amounted to some 675,000 ore-tons.[20] This waste accumulation made available for dispersion about 1,000 tons of lead and close to 5,000 tons of zinc.[21] Over 9,000 tons of mercury were brought into the mines of San Pedro as well.[22] These wastes were released across the fifty or so *haciendas de beneficio* and the dozens of mine-mouths in the district. Some were 20 to 50 kilometers away from one another. This made for a notably dispersed set of pollution points. The effects of occupational exposure to mercury and lead were much more intense since mill workers operated in direct contact with high concentrations of these metals, either in solution, in the slurry of the patio process, or as lead- and mercury-bearing vapors during smelting and refining.[23]

The patterns of environmental change described for the mines of Cerro de San Pedro obtained across Mexico's mining belt. Mass fuelwood consumption cleared an estimated 315,642 square kilometers of forests during the colonial period, a territory equivalent to the state of New Mexico or Poland. For the period 1570 to 1820, 64,470 tons of mercury were imported into the mining districts of Mexico.[24] Julio Camargo estimates that Mexican mining added an additional 13 percent to the globe's mercury emissions during this period.[25] The areas cleared of forests and the amounts of contaminants released into local environments were tremendous and in their respective ways transformed local ecologies.

The question of exhaustion was already posed in the early sixteenth century when the first viceroy, Antonio de Mendoza, warned in the 1520s that wood stocks were in danger of disappearing and would shut down the mines of Taxco if they did.[26] The German polymath Alexander von Humboldt, visiting at the turn of the nineteenth century, wondered how mining survived in a country "which wants combustibles, and where the mines are on table lands destitute of forests."[27] The first part of the answer is that Mexican smelters tapped wood reserves up to a hundred kilometers away, a distance unimaginable to Europeans.[28] The second is to be found on the world market for silver. Silver prices never dropped during this period, despite the constant increase in production. Mexican charcoal makers were simply paid enough to make the four- or five-day trip by ox train for fuelwood worthwhile. Tens of thousands of tons of mercury were shipped thousands of kilometers from Spain and Peru to allow the continued exploitation of declining grades of ore. Below the surface, renewed investment in the eighteenth century (and the Crown's military disciplining of mine workers in the 1760s) increased the ranks of the miners working veins ever deeper in the earth.[29]

The crisis of colonial mining came during the Independence era (1810–1824), when uprisings severely disrupted the flows of capital and trade. By 1825 the break from Spain severed the transatlantic networks of Basque and other Peninsular (Spanish-born) merchants. British and other Europeans took their place but failed miserably and never recouped their investments.[30] Without capital, Mexican mine operators could not pay workers or repair equipment and infrastructure damaged during the insurrection.[31] From 1810 to the early 1880s, many mines were left to the *gambusinos,* small parties—often kin and neighbors—of hard-scrabble miners who picked through what had been left by the colonial-era operations.[32] Other mines were abandoned entirely, especially those of the Sierra Madre that faced a revived indigenous resistance from the Yaquis, Raramuri, Apache, and Comanche peoples.[33] Either way, silver production dropped steadily. The nadir was reached in 1870, when the entire country's silver production amounted to less than 28 tons.[34] At their height in the eighteenth-century boom, the mines of San Luis Potosí alone produced four times as much in a year.

QUICKENING: THE INDUSTRIAL MINING REGIME, 1880S TO 1970S

The reanimation of the Mexican mining sector came in the late nineteenth century through industrialization and foreign capital. These twinned forces transformed the organization of the extractive complex toward the mass-processing of lower-grade ores.[35] New sources of energy—principally coal, gas, and hydroelectricity—provided the mechanical power and heat. New techniques and infrastructure provided the instruments, and the formation of a new and expanded class of industrial mine workers provided the labor. Such stepwise increases in energy, material, and human scales were financed by mass investment from abroad, mainly the burgeoning American capital markets of the Gilded Age. The expansion also resulted in new engagements with ecologies and human populations, both adjacent to and far beyond the mines.

The catalyst for the transformation of Mexican mining came from the regime of Porfirio Díaz (1876–1911). Díaz normalized relations with international capital markets and ushered in a series of reforms aimed at opening the mining sector to foreign investment.[36] Carlos Pacheco, minister of industrial development and colonization, was convinced that mining would prime the pump of the Republic's economic development, settle its national debt, and modernize Mexico's agricultural and manufacturing sectors.[37] Pacheco played a key role in realizing the new political economy of Mexican mining. He commissioned a nationwide survey of Mexico's mining districts and fed the results into Antonio García Cubas's landmark geographical survey of the country.[38] He also organized and steered political debate over the legislative reform of mining law, which reached its intended conclusion in 1883.[39] The mining code was then reformed twice more, in 1886 and 1892. The guiding aim of the1892 code was "Facility to acquire, liberty to exploit, and security to retain." The new codes opened Mexican mining to foreign ownership for the first time in the country's history. Foreigners could stake as many claims as they wished. This allowed a single company to consolidate control over an entire deposit and establish an operation of corresponding size. The claims themselves measured hundreds of acres in surface area and included expropriation rights.[40]

American mining companies quickly capitalized on the opening provided by the Mexican state. Financed by U.S. investors, these companies began acquiring Mexican mines and then bringing them back into operation. The volume of U.S. investments in Mexican mining grew twentyfold (from $2 million to $55 million) in the six years following the first mining code reform of 1886. It then doubled every decade until the Revolution began in 1911.[41] At first, American mine operators concentrated on the waste produced by Spanish-era mining operations. It was a considerable amount, and it was basically free for the taking. The Pachuca River Concentrating Company, for instance, acquired rights to tailings piles generated by over three centuries of mining at Pachuca–Real del Monte.[42] Then the companies began buying up thousands of acres in claims, thus acquiring entire mining districts. At its height, the American Smelting and Refining Company (ASARCO), the company that made most of the Guggenheims' fortune, controlled a nationwide network of dozens of mining districts and smelters spread from Sonora to Oaxaca.[43]

The central effect of the American mining companies' entry was to scale up the extractive system. Extracting and processing far greater volumes of ore were the means to overcome the limits imposed by low ore grades. This was done through the industrialization of mining operations using new and more powerful forms of extraction and refining. Pneumatic drills, air ventilators, water pumps, power hoists, rail carting, and aerial tramways—all of these worked together to extract an average of 1,350 tonnes (metric tons) of ore per day (a colonial mine head did well if it took out at least half a ton). This ore was then submitted to new forms of refining such as cyanide flotation and mass smelting. Driving the increasing scale of operations was the arrival of coal and, especially, hydroelectric power.[44] By the late 1920s (that is, before the advent of oil-fueled electricity generation), hydroelectricity accounted for 83 percent of Mexico's industrial power. Mining companies consumed over a third of this total.[45]

The scale of these operations required unprecedented amounts of capital—measured in the millions to tens of millions of dollars—that had even American investors balking.[46] It was certainly unavailable to Mexican miners and entrepreneurs. A contemporary observer, V.M. Braschi, warned that the Mexican mining industry was becoming "a series of large mines controlled by the smelting interests and a few independent large companies."[47] He was quite right. By the 1910s, foreign companies controlled between 97 and 98 percent of a steadily growing industry.[48]

Cerro de San Pedro, 1870–1948

Just as industrialization changed Mexican mining, it also reconfigured its environmental impacts. Like many other mines in nineteenth-century Mexico, Cerro de San Pedro was largely abandoned after Independence. For decades it was mainly worked by *gambusinos*. The return of large-scale mining at Cerro de San Pedro began in earnest in 1890 with the arrival of Robert S. Towne's Compañía Metalúrgica Mexicana. Towne's operations in the San Luis Potosí area also included the coal-burning smelter built on the western edge of the city, as well as the Mexican Northern Railroad and the Monterrey Mineral and Terminal Railway, which allowed him to process ores from mines across the region. A sizable timber concession in the nearby Sierra de Alvarez supplied timber and fuelwood for the company's operations. Inside the smelter new, coal-fired crushers milled the ore that was then fed into eleven separate furnaces. Every day, the smelter-mill processed just shy of 1,200 tons of ore. At this volume of production it took Towne's operations only a year and a half to work as much ore as the colonial mines of Cerro de San Pedro did in more than two hundred years. Eighty percent of the ore came from the mines of Cerro de San Pedro. Towne built a branch rail line to allow an ore train to run daily between the mines and smelters. Shafts were widened to allow the operation of new power-hoists. Pumping stations and new adits resolved the flooding problem. Pneumatics, trolleys, and bogie carts increased the rate at which miners could break up and extract material from the mine-face. And, not least, all of this work, while supported by the tools and power sources of the industrial age, was driven by a large force of miners, hoistmen, carpenters, mechanics, furnace-men, and laborers. Reduced to a small village in 1890, a decade later Cerro de San Pedro was a bustling town of close to eight thousand people. Another thirteen hundred workers worked down at the smelter in the city of San Luis Potosí.

The return of mining, this time on an industrial scale, ushered in new transformations of the landscape and ecology of Cerro de San Pedro. Again, the key issues were energy and mining wastes. The industrialization of the extraction process was undergirded by a shift in energy sources from local fuelwoods to coal and *chapopote* (a mineralized tar)

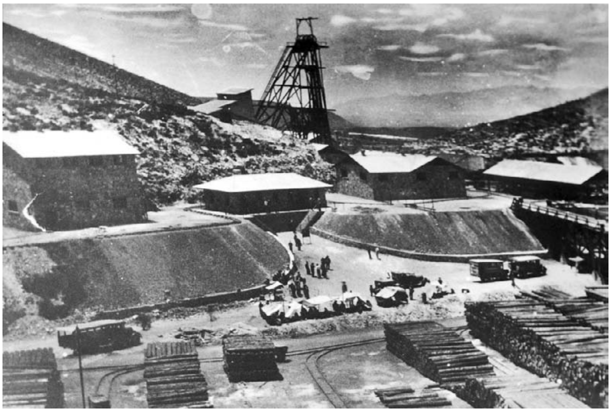

FIGURE 1.1. ASARCO operations at Cerro de San Pedro, 1920s. Courtesy of Armando Mendoza, Cerro de San Pedro.

hauled in by train from hundreds of kilometers away: the coal from the newly opened coalfields of Coahuila and the *chapopote* from Veracruz. Bringing energy from afar allowed local forests to continue a recovery that had begun with the early-nineteenth-century mining collapse. That Towne should have invested in timber concessions in the neighboring Sierra de Alvarez is revealing in this regard. Cleared by *carboneros* during the colonial period, the Sierra's forests had returned during the nineteenth century to the point that structural-grade timbers could be cut for use in the mines. This demand for lumber was important, and photographs of the period show large piles of timber stacked beside the railyards and warehouses of the mines (see figure 1.1), but it did not scour the forests to anywhere near the same extent as colonial charcoal making had.

The Mexican mining industry, however, was simply trading old sins for new. The move away from fuelwood consumption was made possible by the development of coal and hydroelectricity. These had their own impacts on the environment. The environmental costs of energy were externalized, displaced to the sites of hydroelectric projects, generators, and coalfields located elsewhere in the Republic and beyond.

The industrial scales of late-nineteenth-century mining greatly increased the generation of mining waste. Towne's smelter in San Luis Potosí produced close to a thousand tons of waste every day: tailings and slag left over from the refining process. Piles were also deposited around the various mine heads in Cerro de San Pedro proper. These consisted of extracted rock judged to be of too low a grade to be hauled down to the smelter. The quantities of slag and tailings sufficed to create embankments of between ten and thirty meters high at the southern outlet of the Cerro de San Pedro valley. Both tailings and waste rock piles stocked important quantities of lead, zinc, cadmium, copper, and arsenic that spread into the environment as waterborne sediments or wind-borne dust.

Another source of heavy-metal contamination came from emissions. The precise quantity and composition of heavy-metal emissions for the San Luis Potosí smelter remains to be determined but it is reasonable to think of quantities of over 1,000 kilograms of lead, zinc, and arsenic.[49] Contemporary environmental chemistry studies (2006 and 2008) show us the toxic legacies of the Towne-ASARCO smelter. They measure lead, cadmium, arsenic, and copper accumulated in local soils, rooftops, and air. These metals exist at high concentrations down to ten centimeters beneath the surface in local soils, which suggests long-term deposition.[50] The studies also demonstrate a clear spatial pattern of distribution, with the highest concentration values recorded in the city's poorer southeastern neighborhoods.[51] These neighborhoods are also at the outlet of the watershed that drains the Cerro de San Pedro valley and might therefore be receiving episodic pulses of waterborne contamination from the waste piles. Decades of heavy-metal contamination are recorded in the very bodies of those who live in these neighborhoods as well as in the immediate vicinity of the smelter complex. Their hair and blood contain levels of lead and arsenic well in excess of national and World Health Organization norms.[52]

Studies of other sites of industrial mining in Mexico paint a similar picture of heavy-metal contamination of waters and soils. The average mine produced roughly 400,000 tonnes of waste a year.[53] Tailings were rarely contained in impoundments, or if they were, were not reliable over the long term. At the mines of Zimapán, Hidalgo, for instance, arsenic from the tailings has been seeping into the water table since the 1930s. Enough accumulated to contaminate the aquifer of an entire valley.[54] Similar forms of water contamination by arsenic, lead, and other heavy metals from early-twentieth-century mining have been measured in other mining districts in Mexico, such as the Mineral de Pozos (Guanajuato), Matehuala (San Luis Potosí), and Santa Barbara (Chihuahua).[55] As for soils, heavy metals have been recorded at every site that has been studied: Baja California Sur, Torréon, Monterrey, Matehuala, La Paz (SLP), and Zimapán all register concentrations of heavy metals well above national or international norms.[56] Finally, since much of the tailings waste bears sulfides, industrial mining also set in motion processes of acidification and heavy-metal leaching through acid rock drainage (ARD). In places such as Zimapán or Taxco values of 2.6 pH and 2.8 pH were obtained in local soils.[57] This is a degree of acidity somewhere between that of vinegar and lemon juice, a level well past what most plants can tolerate.

Industrial mining in Mexico survived the shocks of Revolution, World War I, and the progressive reassertion of national control over the sector that followed the Great Depression. ASARCO, for instance, was able to negotiate the continuation of its operations with successive revolutionary leaders. The American period began to draw to a close only in the 1940s as the mines were "Mexicanized," taken over either by mine-worker cooperatives or by emergent conglomerates of Mexican capitalists.[58] Whether under Mexican corporate or cooperative ownership, the form of production—and thus the environmental impacts—remained the same: electric and coal-powered extraction, cyanide flotation systems, and high-energy smelting. However, the 1940s marked the beginning of a decades-long decline in Mexican mining. Deposits were worked out, ore grades dropped, and access to large volumes of investment capital was harder and harder to obtain. By the early 1970s, Mexican gold production was back down to less than ten tons a year.[59] As during the previous slack period in Mexican mining (1821–83), the shortage of capital meant that miners had gone about as far as they could go with the technology available. In the second slack period (1940–1993) profitable ores grew scarcer. Getting what metal remained would require new technology, more energy, and new injections of capital.

THE INVISIBLE GOLD RUSH, 1993 TO THE PRESENT

The latest Mexican mining boom began in the early 1990s when the sector was reopened to foreign corporations, but its deeper roots can be found at the Carlin Trend in Nevada. It was there in the 1960s that a small group of geologists and metallurgists working for the Newmount Mining Corporation had tested the theory that gold could be found in large disseminated porphyry deposits. It existed in tiny flecks of metal less than a micron in size (most bacteria measure one to ten microns across)—invisible gold. The means of obtaining it was simple and awesome. Open-pit mining techniques, borrowed from the copper industry, were combined with mass heap leaching with cyanide solution. The scales were massive, but the production costs were much lower than industrial tunnel mining and the total amount obtained from the deposit—in a shorter amount of time—was much higher than what could be drawn out under colonial or industrial regimes. Lower costs, higher amounts: it was an irresistible combination for a growing number of mining companies.

Mexican mining was opened to these new techniques and new corporations during the neoliberal reforms of the 1990s. A year before NAFTA, a new mining code was put in place, the Ley Minera of 1993. This was part of a broader trend at the time that saw the systematic liberalization of mining codes around the world.[60] The Ley Minera of 1993 was essentially a repeat of the Porfiriato's 1892 code, with its emphasis on freedom of access, liberty of operation, and stability of tenure. But it introduced a number of key innovations tailored to the new open-pit complex. For instance, claims on underground resources granted preeminent rights to the surface—a first in nearly five centuries of mining in Mexico. Mining claims were suddenly accorded precedence over forms of tenure such as the common-hold *ejidos* established after the Revolution, conservation and protected areas, and, in case of expropriation, private property. The new code also guaranteed that title and concession could not be legally revoked before term (companies found to be in breach of the law could only be fined), and it lengthened the duration of title. These were also critical measures for open-pit projects, given the massive amounts of financing they require and the need to amortize such investments over the long term.[61]

The principal players within this latest cycle in Mexican mining are corporations based in Canada. Within four years beginning in 1991, the number of properties owned by Canadian companies in Mexico almost quintupled (52 to 244).[62] In 2005, Canadian corporations controlled close to two-thirds of the Mexican mining industry, developing some 420 projects across the Republic. The latest figures (2010) show that 78.5 percent of the 718 mining projects then under development were under their control.[63] The predominance of transnational mining companies was in part attributable to the high capital costs associated with operating open-pit mines. These are significantly higher than for industrial tunnel mining—$500 million to $1.5 billion is the general range of what it costs to start an open-pit mine—and expenditures need to be paid out for a number of years before any gold is produced.[64] The technology involved is common to the industry as a whole, so what advantages Canadian corporations enjoyed were due to their access to the Toronto Stock Exchange (TSX). Thanks to a more favorable fiscal regime and an existing depth of technical and financial expertise in the sector, the TSX positioned itself as the world's principal hub for the capitalization of mining exploration and development.[65] In 2005 alone, the TSX provided close to $4 billion in financing to mining companies, by far the largest amount raised on the world's various exchanges.[66] The payoff so far has been excellent. The average cost of producing an ounce in an open-pit mine has always remained well below the metal's market price. In 2012, it varied between $225 and $275 an ounce when the price of gold was above the $1,600 mark.

The financial scale of open-pit mining is directly related to the physical and energy scales at which it operates, which are in turn made necessary by the physical characteristics of the porphyry deposits that it targets. Porphyries are large disseminated ore deposits that can stock enormous quantities of gold and silver. Take for example Goldcorp's Peñasquito project at Mazapil (Zacatecas), which began operations in 2010. It contains an estimated 17.8 million ounces of gold and 1,277 million ounces of silver, as well as important amounts of marketable zinc and lead.[67] The Peñasquito mine is located in the same zone that had previously been worked by ASARCO in the early twentieth century and by Basque miners back in the 1570s. This is the third pass over the same district, and the extremely low ore grades worked by Goldcorp reflect this.

There exists a rule in geological economics known as Lasky's Law, which holds that "the tonnage of ore increases geometrically as grade decreases arithmetically."[68] Given gold concentrations now as low as 1.8 parts per billion, Goldcorp will excavate and process truly astronomical quantities of the Sierra Madre in order to extract the $33 billion of gold and silver remaining in the deposit. Something on the order of 130,000 tonnes of ore will be processed on a *daily* basis. This does not include the large amounts of waste rock and overburden moved in the process. At the end of the project's remarkably short twenty-one-year life, Goldcorp will have moved close to a trillion tonnes of ore, created two large open pits (the larger measuring 4.5 kilometers in diameter and close to 1.5 kilometers in depth), and disturbed large swaths of the Mazapil valley for tailings impoundments, waste rock piles, a cyanide heap leaching pad, processing plants, and the other remaining infrastructure for the mine. For Mexico it is a form of mass terra-forming of unprecedented proportions.

The movement of so much physical mass requires enormous amounts of mechanical energy. In the case of Peñasquito, 25,769,628 megajoules per day will be used to run the mine's drills, haul trucks, crushers, mills, and grinders.[69] To put this energy requirement in historical perspective, a single Komatsu haul truck consumes as much energy during a single shift as an entire colonial mining operation consumed over fourteen years. Heat energy continues to be required for smelting, but in the open-pit complex this accounts for a small fraction of the total energy budget. Most is spent on moving matter.

All of this intensive mining activity carries important environmental costs, both locally and globally. Given that energy for open-pit mining principally comes in the form of diesel, and given the quantities involved, large gold-mining corporations have gone so far as to purchase their own oil companies to reduce and stabilize energy costs.[70] The extraction and processing of the fuel consumed by Mexican open-pit mines generate environmental impacts borne in oil fields and refineries across the world. Mining has now become one of the most important emitters of greenhouse gases (GHGs). In Canada, mining and oil extraction account for 21 percent of the country's GHG emissions.[71] Hydroelectricity continues to supply important energy inputs to open-pit mining, and here too environmental consequences are distanced from the mine itself. In Brazil, Chile, Panama, and Ecuador, hydroelectric development is being pushed by *mega-minería*'s high demands for energy.

In the immediate vicinity of the mine, the generation of waste rock and tailings creates the potential for acid rock drainage on a massive scale. Thousands of tons of heavy metals such as arsenic and lead are brought up to the surface, where they can move into local ecosystems and waterways. At the same time, the operation of open-pit mines requires large volumes of water—measured in the tens of millions of liters—on a daily basis to run solutions through the leach pads or for other extractive processes. The location of many open-pit mines in Mexico in semiarid highland areas creates important pressures on aquifers with low recharge rates. The excavation of deep pits also creates large well effects that further disturb local hydrological patterns. Finally, the compounds used to extract metal from the ore—especially cyanide used in heap leaching—are fatal if they accidentally come into contact with people or animals. Environmental toxicologists are only recently becoming aware of the negative effects to plant and water life exposed to more persistent forms of "weak" cyanide complexes.[72]

Cerro de San Pedro, 1996 to the Present

In the early 1990s, Cerro de San Pedro was inhabited by about 250 souls. They lived off the sparse resources that the land could still offer: goat herding, beekeeping, gathering, and family-scaled *gambusino* mining. Then Jorge Barnet arrived. He was a local "*corredor de minas,*" or mine-broker, who proceeded to buy out all the existing mining titles in the valley. Given the general opinion that the mines of San Pedro had given all they had, he obtained the titles for a pittance. He then sold his package to a consortium of Canadian companies that included Glamis, Cambior, and Metallica Resources and that in 2008 morphed into New Gold.

The project of reanimating gold mining at Cerro de San Pedro was stalled for almost ten years because of a series of lawsuits won by a determined local opposition. But in 2006, these decisions were overridden or ignored by state and federal officials, and the project began in earnest. The scale of the operation is awesome and so is the speed. It has taken New Gold six years to level the Cerro de San Pedro. It is now beginning the pit, which is projected to reach 600 meters in depth over the next six or seven years. When production ends, the company will have displaced a mountain and a half and recovered a cube of gold measuring less than 1.5 meters a side.

In the course of its operating life, the mine at Cerro de San Pedro will use 32 million liters of water per day. This is obtained from the regional aquifer, which has been dropping steadily over the past decades because of the demands of the city of San Luis Potosí (with a current population over 1 million). The leach pads cover close to seven square kilometers with impermeable sheeting that is then loaded with ore and cyanide solutions. They sit directly over an area of permeable rock that has traditionally been one of the aquifer's principal recharge areas. The pit itself will, when abandoned, put further stresses on local water because the water welling up from the pit floor will be both contaminated and available for high rates of evaporation.

The waste piles, an inescapable feature of each mining regime, have now become large enough to in-fill entire sections of the local drainage. When rain falls through this body of sulfide-bearing rock, it allows ARD generation on a massive scale. It is true that the rate of ARD and heavy-metal leaching are slowed by the modest overall precipitation levels of this area's semiarid climate. These effects might take decades or even centuries to be perceived. But since there is no adequate remediation or treatment plan for these wastes, these processes will take place sooner or later and will last for millennia.[73]

THE LONG-TERM VIEW

Looking at the history of Cerro de San Pedro over the long term allows one to follow the formation and reformation of mining ecologies over four hundred years. The account given here could be provided for mining districts across Latin America and other parts of the world where mining has been present for centuries. It shows how mining was able to continue the extraction of a nonrenewable metal deposit at an exponentially increasing rate. Whereas in the colonial period a mine expended a bit more than 1,000 MJ of mechanical energy per day processing half a ton of ore, a contemporary open-pit mine burns through 26,000 times that amount in moving 130,000 tons of material daily. Each regime succeeded in extracting metal at faster and faster rates. In the case of Cerro de San Pedro, average annual production figures rose from 23.4 tons of silver per year during the colonial period to 86 today.

This took place in a context of ever-decreasing ore grades, the standard measure of a deposit's exhaustion. Exhaustion and abandonment did indeed occur, once in the 1820s and again in the 1950s. The current mine at Cerro de San Pedro is slated to shut down in 2018. Each time, what brought mining back into operation was the application of more powerful energy sources and more efficient extractive systems. At each turn, these efforts were enabled by new political economies that geared themselves to extractivism, whether under the Spanish Habsburgs and Bourbons in the sixteenth and eighteenth centuries, the Porfiriato of the late nineteenth century, or the neoliberal government of today. Each was underwritten by ever-growing amounts of financial capital gathered on increasingly globalized networks.

What are the consequences of this history for landscape ecologies? The effects are layered. One can still see and feel the same rocky scrubland "created" after years of forest stripping in the colonial period. The same goes for the Towne-ASARCO mine's tailings, its waterworks, its buildings and mine heads, and the lead- and zinc-laced dust in the valley's neighborhoods and villages. Today's project will also leave its mark—now on a colossal scale. It is remaking the topography itself: erasing mountain drainages, flattening mountains, plugging up an entire region's aquifer. And then there's all that isn't seen. If in the colonial period, the mines introduced about 8 kilograms of heavy metals into the environment per day, today's mine brings to the surface 91 tonnes of heavy metals every twenty-four hours. This isn't good news for the 2 million citizens of the neighboring city of San Luis Potosí, whose aquifer is drying up fast and whose air, soils, and waters are already ranked among Mexico's most polluted.

Each mining regime cycled through the same phases of (re)activation, production, decline, and abandonment. But each boom was faster than the last. Over the long term one observes a kind of compression in time even as all the other scales (energy, material, capital, environmental effects) increased exponentially. Throughout this history, networks of capital and capitalist development were the main drivers of this process. This brings us to an important point made by Karl Marx in relation to how capital steals time from social and natural bodies. He was mainly thinking about human beings, showing how capital generates further profits by developing production systems ever more efficient at tapping into the vitality of labor, pushing it past the limits of health and social reproduction. Interestingly, he equated this process to the exhaustion of natural vitality: "It [capital] [. . .] attains this end by shortening the extent of the laborer's life, as a greedy farmer snatches increased produce from the soil by robbing it of its fertility."[74] If we apply Marx's insight to the natural bodies of mining districts, we see that extractive systems have become ever more powerful and intensive as greater and greater energy and matter are mobilized over shorter and shorter periods of time. The drafts on the natural capital of local and regional landscape ecologies have likewise grown and, in so doing, have sped up the exhaustion of the land. In the case of Cerro de San Pedro, mining has pushed the regional ecology past the thresholds of natural renewal and resilience. In certain mining districts of Mexico, it is true, the marks of past mining regimes are fading from the land. But in Cerro de San Pedro they are all still present and clear, and, given the rates of the geophysical and biochemical processes involved, they will likely last for millennia.

NOTES

1. See Alvaro Sánchez-Crispín, "The Territorial Organization of Metallic Mining in New Spain," in *In Quest of Mineral Wealth: Aboriginal and Colonial Mining and Metallurgy in Spanish America,* ed. Alan K. Craig and Robert C. West (Baton Rouge: Geosciences Publications, Dept. of Geography and Anthropology, Louisiana State University, 1994), 163.

2. "Special Map Supplement: The Mines and Railways of Mexico," *Transactions of the American Institute of Mining Engineers* 32 (1903).

3. Servicio Geológico Mexicano, *Anuario estadístico de la minería mexicana 2010* (México, DF: Secretaía de Economia—Coordinación General de Minería, 2010), 13–14.

4. The historical geographer Jason W. Moore lays out a clear definition of historical commodity frontiers and their place in the development of capitalism in "Sugar and the Expansion of the Early Modern World-Economy: Commodity Frontiers, Ecological Transformation, and Industrialization," *Review (Fernand Braudel Center)* 23 (2000): 409–33.

5. Myrna Santiago, *The Ecology of Oil: Environment, Labor, and the Mexican Revolution, 1900–1938* (New York: Cambridge University Press, 2006), 4. Other recent work on the environmental history of mineral extraction, not all of it framed in the same ecological terms, includes Kathryn Morse, *The Nature of Gold. An Environmental History of the Klondike Gold Rush* (Seattle: University of Washington Press, 2003); Timothy LeCain, *Mass Destruction: The Men and Giant Mines That Wired America and Scarred the Planet* (New Brunswick, NJ: Rutgers University Press, 2009); Peter Van Wyck, *The Highway of the Atom* (Montreal: McGill-Queens University Press, 2010); David Stiller, *Wounding the West: Montana, Mining, and the Environment* (Lincoln: University of Nebraska Press, 2000); Richard V. Francaviglia, *Hard Places: Reading the Landscape of America's Historic Mining Districts* (Iowa City: University of Iowa Press, 1991); Stephen Rippon, Peter Chlaughton, and Chris Smart, *Mining in a Medieval Landscape. The Royal Silver Mines of the Tamar Valley* (Exeter, UK: University of Exeter Press, 2009); Nicholas A. Robins, *Mercury, Mining, and Empire: The Human and Ecological Cost of Colonial Silver Mining in the Andes* (Bloomington: Indiana University Press, 2011).

6. Hernán Cortés, "De los muchos descubrimientos de minas y las expediciones que envio Hernan Cortes" in Javier Moctezuma Barragan y Sergio Pelaez Parell, eds., *Antologia minera de Mexico. Primera estación, siglo XVI* (México, DF: Sec. de Energia, Minas e Industria Paraestatal, 1994), 35–37.

7. Sánchez-Crispín, "Territorial Organization," 157–58; Peter Gerhard, *A Guide to the Historical Geography of New Spain* (New York: Cambridge University Press, 1972); Robert C. West, *Sonora: Its Geographical Personality.* (Austin: University of Texas Press, 1993), 45. On commodity frontiers, see Jason W. Moore, "Silver, Ecology, and the Origins of the Modern World, 1540–1640," in *Rethinking Environmental History: World System History and Global Environmental Change,* ed. Alf Hornborg, J.R. McNeill, and Joan Martinez-Alier (Lanham, MD: AltaMira Press, 2007), 123–42.

8. See the silver production series developed by Richard Garner, based on data compiled from the Royal Treasury Houses of New Spain, at http://www.insidemydesk.com/hdd.html.

9. On the early modern arts of mining, see Antonio Barrera-Osorio, *Experiencing Nature: The Spanish American Empire and the Early Scientific Revolution* (Austin: University of Texas Press, 2006), 65–70; Modesto Bargallo, *La amalgamación de los minerales de plata en Hispánoamerica colonial* (México, DF: Compania Fundidora de Fierro y Acero de Monterrey, 1961), and his *La minería y metalúrgia en la América Española durante la epoca colonial* (México, DF: Fondo de Cultura Económica, 1955), 107–60, 173–79, 196–203. For capital investments, see Juan Carlos Sola Carbacho "El papel de la organización familiar en la dinámica del sector mercantil madrileño a finales del siglo XVIII," *Historia Social* [Madrid] 32 (1998); Edith Boorstein Couturier, *The Silver King: The Remarkable Life of the Count of Regla in Colonial Mexico* (Albuquerque: University of New Mexico Press, 2003); Frédérique Langue, *Mines, terres et société à Zacatecas (Mexique) de la fin du XVIIe siècle à l'indépendance* (Paris: Publications de la Sorbonne, 1992); Peter Bakewell, *Silver Mining and Society in Zacatecas, 1546–1700* (New York: Cambridge University Press, 1970), esp.

ch. 2; David Brading, *Miners and Merchants in Bourbon Mexico, 1763–1810* (New York: Cambridge University Press, 1971); and John Tutino, *Making a New World: Founding Capitalism in the Bajío and Spanish North America* (Durham, NC: Duke University Press, 2011). On labor, see Silvio Zavala and Maria Costel, *Fuentes para la historia del trabajo en Nueva España* (México, DF: Centro de estudios históricos del movimiento obrero mexicano, 1980); Bakewell, *Silver Mining and Society*. On the provisioning of slaves to the mines, see Carlos Sempat Assadourian, *El tráfico de esclavos en Cordoba. De Angola a Potosi. Siglos XVI–XVII* (Cordoba: Universidad Nacional de Cordoba, 1966). On the Crown's authority over and regulation of the mines, see María del Refugio Gonzáles Domínguez, "Notas para el estudio de las Ordenanzas de Minería en México durante el siglo XVIII," *Revista de la Facultad de Derecho de México* 26 (January–June 1976): 157–67; and *Ordenanzas de la minería de la Nueva España formadas y propuestas por su Real Tribunal* (México, DF: UNAM, 1996). On hydraulics, see Diana Birrichaga Gardida, "El dominio de las 'aguas ocultas y descubiertas': Hidráulica colonial en el centro de México, siglos XVI–XVII," in *Mestizajes tecnológicos y cambios culturales en Mexico,* ed. Enrique Florescano and Virginia García Acosta (México, DF: CIESAS, 2004), 120; Robert C. West, *The Mining Community in Northern New Spain: The Parral Mining District* (Berkeley: University of California Press, 1949), 41–42; Sebastian de la Torre y León, "Informe sobre las minas de Bolaños, 1774," in *Las minas de Nueva España en 1774*, ed. Alvaro López Miramontes and Cristina Urrutia de Stebelski (México, DF: Instituto Nacional de Antropología e Historia, 1980), 44–45. On fuel wood, see West, *Parral Mining District*; Chantal Cramaussel, "Sociedad colonial y depredación ecológica: Parral en el siglo XVII," in *Estudios sobre historia y ambiente en América I: Argentina, Bolivia, Mexico, Paraguay,* ed. Bernardo García Martínez and Alba González Jácome (México, DF: Colegio de México, Instituto Panamericano de Geografia e Historia, 1999). On smelting, see Barba, *Arte de los metales: En que se enseña el verdadero beneficio de los de oro y plata por açogue, el modo de fundirlos todos, y como se han de refinar y apartar unos de otros* (Madrid: Imprenta del Rey, 1640), 100, 106–7, 131.

10. For San Luis Potosí, see Guadelupe Salazar González, *Las haciendas en el siglo XVII en la región de San Luis Potosí. Su espacio, forma, función, significado y la estructuración regional* (San Luis Potosí: Universidad Autónoma de San Luis Potosí, 2000). For Parral, Chihuahua, see West, *Parral Mining District.*

11. Author's field observations, Sierra de Alvarez, San Luis Potosí, February 2007 and July 2008; Instituto Nacional de Estadística y Geografía, *Carta de Suelos, San Luis Potosí, 250:000* (México, DF: Instituto Nacional de Estadística y Geografía, 1993).

12. Pedro de Arismendi Gogorron, *Denuncia de asientos de agua.* 27.04.1613, Archivo Historico del Estado de San Luis Potosí—Alcaldía Mayor (hereafter AMSLP), 1613 (2), exp. 40, CONAGUA, Servicio Meteorológico Nacional, 2011.

13. Instituto Nacional de Estadística y Geografía, *Carta estatal, hidrología subterránea, San Luis Potosí, 1:700,000* (México, DF: Instituto Nacional de Estadística y Geografía, 1993).

14. According to archaeological evidence and historical accounts, the most common animals were deer (both *Odocoileus hemionus* and *O. Virginianus*), hares, rabbits, squirrels, and porcupine. Leonardo Lopez Lujan, *Nomadas y sedentarios. El pasado prehispanico de Zacatecas* (México, DF: INAH, 1989), 21; Francois Rodriguez Loubet, *Les Chichimeques. Archéologie et ethnohistoire des chasseurs-collecteurs de San Luis Potosi, Méxique* (México, DF: Centre d'etudes mexicaines et centraméricains, 1985), 159, 162.

15. Daviken Studnicki-Gizbert and David Schecter, "The Environmental Dynamics of a Colonial Fuel-Rush: Silver Mining and Deforestation in New Spain, 1522 to 1810," *Environmental History* 15 (January 2010): 94–119.

16. Alejandro Montoya, "Población y sociedad en un Real de Minas de la Frontera Norte Novohispana. San Luis Potosí de finales del siglo XVI a 1810" (Ph.D. dissertation, Université de Montréal, 2003), 84; the quote is from *Ciudades, Villas y Lugares, Reales de Minas y Congregaciones de Españoles de el Obispado de Mechoacan,* 1649, MS 1106 A, f. 47r, Ayer Collection, Newberry Library.

17. Normales climatológicas, CONAGUA, Servicio Meteorológico Nacional, http://smn1.conagua.gob.mx/index.php?option=com_content&view=article&id=172&tmpl=component (accessed January 2, 2017).

18. *Informes y licencia de los pobladores de Tlaxcalilla sobre las lluvias,* AMSLP, 1626 (3), exp. 21, 21.08.1626; *Petición para reparar gran parte de la iglesia que se cayó a raíz de las lluvias,* AMSLP, 1626 (3), exp. 23, 21.08.1626; *Pleito sobre la edificación de una casa en un solar en la plazuela de Mascorro que sirve como desague de la lluvia,* AMSLP, 1673 (3), 29.08.1673; Montoya, *Población y sociedad,* 238.

19. *El alcalde mayor procede hacer informacion sumaria de oficio sobre la abundancia o escasez de mantenimientos que en esta ciudad hay* [. . .], AMSLP, 1739 (1), exp. 23, 20.10.1739.

20. Recorded silver production for the period 1628 to 1820 totaled 4,727,280 kilograms; see silver production data for Caja de San Luis Potosí, compiled by Garner, http://www.insidemydesk.com/cajas/S/slpotosi.txt (accessed May 13, 2011).

21. Richard J. Lambert et al., *Technical Report on the Cerro San Pedro Mine, San Luis Potosí, Mexico* (Toronto: Scott, Wilson, Roscoe, Postle Associates Inc., 2010), 17–5.

22. Estimates of colonial Hg:Ag production ratios of range from 2:1 (Bakewell) to 2.3:1 (Chaunu). Given the presence of galena and other lead-silver compounds in the Cerro de San Pedro deposit, mercury consumption was probably lower than the norm. See Peter Bakewell, "Registered Silver Production in the Potosí District, 1550–1735," *Jahrbuch für Geschichte Lateinamerikas* 12 (1975): 85; Pierre Chaunu, *Seville et l'Atlantique (1504–1650). La conjoncture. Tome VIII 2:2* (Paris: SEVPEN, 1959), 1976–77.

23. Kenneth Brown "Worker's Health and Colonial Mercury Mining at Huancavelica, Peru," *The Americas* 57:2 (April 2001): 467–96; Robins, *Mercury, Mining, and Empire.*

24. J.O. Nriagu, "Mercury Pollution from the Past Mining of Gold and Silver in the Americas," *Science of the Total Environment* 149 (1994): 167–81;

Julio A. Camargo, "Contribution of Spanish-American Silver Mines (1570–1820) to the Present High Mercury Concentrations in the Global Environment: A Review," *Chemosphere* 48 (2002): 53–54. See also N. Pirrone et al., "Historical Atmospheric Mercury Emissions and Depositions in North America Compared to Mercury Accumulations in Sedimentary Records," *Atmospheric Environment* 32 (1998): 929–40.

25. Camargo, "Contribution of Spanish-American Silver Mines," 53.

26. *Relación de Antonio de Mendoza a Luis de Velasco* (1550–1551), in *Los Virreyes Españoles en America durante el Gobierno de la Casa de Austria. Mexico 1*, ed. Lewis Hanke, Biblioteca de Autores Espanoles 273 (Madrid: Atlas, 1976), 40; Cramaussel, "Sociedad colonial y depredación ecológica," 99.

27. He was referring specifically to the districts of Zacatecas, Guanajuato, and Pachuca. Alexander von Humboldt, *Political Essay on the Kingdom of New Spain,* Vol. 3, trans. John Black (London: Longman, Hurst, Rees, Orme and Brown, 1814), 280.

28. Studnicki-Gizbert and Schecter, "Colonial Fuel-Rush," 103. For Chihuahua, see Cramaussel, "Sociedad colonial y depredación ecológica," 100. For comparison, see G. Hammersley's work on early modern English iron smelting, "The Charcoal Iron Industry and Its Fuel, 1540–1750," *Economic History Review* 26 (1973): 605.

29. Felipe Castro Gutiérrez, "El liderazgo en los movimientos poplares de 1766–1767," in *Organización y Liderazgo en los movimientos populares Novohispanos,* ed. Felipe Castro Gutiérrez et al. (México, DF: UNAM, 1991), 203–18; Noblet B. Danks, "The Labor Revolt of 1766 in the Mining Community of Real del Monte," *The Americas* 44:2 (October 1987): 143–65.

30. Horace Marucci, "American Smelting and Refining Company in Mexico, 1900–1925" (Ph.D. diss., Rutgers University, 1995), 41.

31. Stephen Haber, *The Politics of Property Rights: Political Instability, Credible Commitments, and Economic Growth in Mexico, 1876–1929* (New York: Cambridge University Pres, 2003), 36 ff.

32. J. M. G. del Campo, *Reseña del Mineral del Cerro de San Pedro Octubre 31, 1881, San Luis Potosi,* folder 1289, p. 17, Collection of Latin American Manuscripts, Yale University; Walter Harvey Weed, "Notes on Certain Mines in the States of Chihuahua, Sinaloa and Sonora, Mexico," *Transactions of the American Institute of Mining Engineers* 32 (1903): 406.

33. Marucci, "American Smelting and Refining Company in Mexico," 35.

34. This amount was produced by 255 operating mines. See ibid., 28.

35. At Cerro de San Pedro the grades, or metal-to-ore ratios, were as follows: average 2,300 grams of silver per metric ton (Ag/t) of ore; high 14,394 grams Ag/t; low: 120 grams Ag/t. For gold, the low-end cut-off grade was 1.5 grams Au/t.

36. William E. French provides a good overview in his "Mining and the State in Twentieth-Century Mexico," *Journal of the West* (1988).

37. Dennis Kortheuer, "Santa Rosalia and Compagnie du Boleo: The Making of a Town and Company in the Porfirian Frontier, 1885–1900" (Ph.D. diss., University of California, Irvine, 2001), 71, 81.

38. Antonio García Cubas, *Cuadro geográfico, estadístico, descriptivo é histórico de los Estados Unidos Mexicanos* (México, DF: Oficina Tipografica de la Secretaría de Fomento, 1884), 181–232.

39. Santiago Ramírez, *Apuntes para un proyecto de codigo de mineria: presentados al señor Ministro de Formento General D. Carlos Pacheco* (México, DF: Oficina Tipografica de la Secretaría de Fomento, 1884).

40. Richard Chism, "A Synopsis of the Mining Laws of Mexico," *Transactions of the American Institute of Mining engineers* 32 (1902): 5, 8, 40. Compilations of total areas of claims for the twentieth century are in Haber, *Politics of Property Rights,* 267, 277. The total area under concession was 446,000 hectares.

41. The breakdown of these investments is as follows: pre-1880, $1 million; 1886, $2 million; 1888, $3 million; 1892, $55 million; 1901, $101 million; 1911, $249 million. See Daniel Cosío Villegas et al., *Historia Moderna de Mexico. El Porfirato. Vol. 8, parte 2: La Vida Económica* (México, DF: Hermes, 1965), 1091, 1103, 1132–33.

42. Charles Bunker Dahlgren, *Historic Mines of Mexico: A Review of the Mines of That Republic for the Past Three Centuries* (New York: privately printed, 1883), 199.

43. R.F. Manahan, *Mining Operations of American Smelting and Refining Company in Mexico* (typeset report, 1948), pt. 2 (copy at University of Texas at El Paso library); Thomas O'Brien, "Copper Kings of the Americas: The Guggenheim Brothers," in *Mining Tycoons in the Age of Empire, 1870–1945: Entrepreneurship, High Finance, Politics and Territorial Expansion,* ed. Raymond E. Dumett (Farnham, UK: Ashgate, 2009), 195–98, 201–4.

44. Coal began to replace charcoal at Guanajuato in the 1880s. Margaret Rankine, "The Mexican Mining Industry in the Nineteenth Century with Special Reference to Guanajuato," *Bulletin of Latin American Research* 11 (January 1992): 43.

45. Marvin D. Bernstein, *The Mexican Mining Industry, 1850–1950: A Study of the Interaction of Politics, Economics, and Technology* (Albany: State University of New York, 1964), 42, 43, 159.

46. Christopher Schmitz, "The Rise of Big Business in the World Copper Industry, 1870–1930," *The Economic History Review* 39 (August 1986): 402.

47. Bernstein, *Mexican Mining Industry,* 41.

48. Helmut Waszkis, *Mining in the Americas: Stories and History* (Cambridge: Woodhead, 1993), 42–43.

49. This estimate is based on comparable figures from other smelters at the time, including, for example, the ASARCO smelters at El Paso (1,386 kg of lead [Pb] per day, 680 kg of zinc [Zn] per day, and 1.3 kg of arsenic [As] per day) and Tacoma, Washington (270 kg of Pb/day and 876 kg of As/day). See Senator Eliot Shapleigh, *ASARCO in El Paso: Moving to a Brighter Future—Away from a Polluted Past* (Austin: Senate of the State of Texas, 2007), 8, 10; Hilman C. Ratsch, *Heavy-Metal Accumulation in Soil and Vegetation from Smelter Emissions* (Corvallis, OR: National Ecological Research Laboratory, 1974), 1. The variations are mainly due to the chemical composition of the ores and not to any significant difference in emissions control techniques.

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