Exhausting the Sierra Madre:
Long-Term Trends in the Environmental Impacts of Mining in Mexico.[1]

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The question of the environment has been at the centre of polemics over metal mining from Antiquity to the present.[2] In the first modern printed mining manual, *De Re Metallica* (1556), Georgius Agricola dedicated a good part of the front matter to this polemic before launching into the book's more technical discussions on such topics as tunnel drainage, smelting procedures and ore composition. Critics, he recounted, argued that mining led to deforestation, the disappearance of wildlife, watershed contamination and the consequent impoverishment of neighbouring communities.[3] Interestingly, Agricola did not confront these charges head on, developing instead the arguments of necessity (metals provide the materials for civilization) and economic development (mining brings wastelands in fruition; mining creates more wealth than agriculture).[4]

Close to five hundred years later, the debate continues unabated. With the passage of time, history itself has come into the discussion. Arguments now turn, even if implicitly, around the comparative advantages and disadvantages of different mining systems associated with a particular period in the overall evolution of the industry. Last

[1] Draft for Rethinking Extractive Industry. Regulation, Dispossession, and Emerging Claims –York University. Please do not cite or circulate without permission.
[2] Glacken TRcaes, Erastosthenes re. Deforestation in 3rd c. Cyprus. Discussion in Peter Coates. *Nature. Western Attitudes since Ancient Times* (berekeley, 1998(, 28; J. Donald Hughes, *Pan's Travail: Enivronmnetal Problems of the Ancient Greeks and Romans* (JHUP, 1994), 149-168.
[3] Georgius Agricola, *De Re Metallica*. Translated from the 1st Latin ed. of 1556 by Herbert C. Hoover and Lou H. Hoover, (NY: Dover Publications, 1950), 11.
[4] Ibid., xxv.

fall, for instance, I overheard an exchange between a Peruvian congresswoman and the former Canadian ambassador to Peru. The congresswoman sought accountability from the Canadian state for the environmental damages Canadian gold mining corporations were causing with their new large-scale extractive processes. The ambassador countered by contouring the issue, accusing small-scale traditional Peruvian miners of being the real environmental vandals in the Andes. The exchange was quick but emblematic. It captured a series of dichotomies that structure contemporary debates over mining: social (local communities vs. corporations); technological (artisanal vs. mass industrial techniques); environmental (mercury contamination vs. water depletion, acid rock drainage and heavy metal pollution); and historical (traditional vs. modern).

The following paper does not propose to settle these debates. Instead, it asks how debates over the environmental impacts of different mining systems might be reconfigured when viewed over long term. The historical record, after all, provides ample data on these different forms. Furthermore, the *longue-durée* perspective seems particularly useful since anthropogenic environmental change is complex and unfolds over different rhythms and time horizons: decades and centuries of time. Considering the issue of mining's environmental impacts historically also helps clarify the trajectories that have brought us to our contemporary dilemma. Here are the classic tasks of history: identifying the characteristics of different historical mining systems; the timing and composition of the conjunctures that led to their transformation; as well as the nature and extent of systemic change.

The paper focuses on the case of Mexican mining from the Spanish conquest to the present. It describes the geological, technical, institutional and environmental aspects of three mining systems: the colonial-early national system (1522-1882); the industrial system of the late nineteenth and twentieth centuries (1883 – late 1980s); and the open-pit mining system of our neo-liberal present (1990s to today). Each was coherent and distinct in its configuration. Each impacted upon the Mexican environment in unique ways and did so over different rhythms and spans of time.

Over the course of more than three centuries the colonial – early national system (based on tunnel mining, mercury amalgamation, and wood-fuelled smelting) deforested large swaths of highland Mexico and released thousands of tonnes of mercury and lead into the environment. In the late nineteenth century, American companies took possession of these mines and significantly boosted their production through the application of new techniques such as cyanidation by flotation and new sources of coal power and hydroelectricity. These inputs had to be significant because Mexican metal deposits were close to exhaustion and only mass industrial techniques could recover profitable amounts of silver and gold. The greatly increased quantities of ore processed meant corresponding rises in the amounts of heavy metals and other contaminants into the environment. The American period in Mexican mining lasted some sixty years until the post-Revolutionary government reestablished sovereign control over the industry.

Since the 1990s a third mining system has been developing in Mexico. Lead by Canadian corporations this time, the arrival of open-pit mining is part of the "invisible gold rush" currently sweeping the globe.[5] It focuses on the recovery of metals situated in

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[5] See T. LeCain's work re. origins of open-pit mining in copper in the e. 20th c. American west, a complex that would subsequently be transferred, with certain technological adjustments such as heap-leaching, to gold and silver mining beginning in Nevada in the 1980s. Timothy LeCain *Moving Mountains: Technology and the Environment in Western Copper Mining.*2 vols. Ph.D. dissertation University of Delaware, 1998 forthcoming as, *Mass Destruction: The Men and Giant Mines That Wired America and Scarred the Planet.* (New Brunswick: Rutgers University Press, 2009). On the development of the first open-pit heap leach gold mines see Frank W. McQuiston and Robert S. Shoemaker, *Gold and Silver Cyanidation Practice.* 2

infinitesimally small concentrations in large porphyry deposits. It literally overturns the landscape, removing mountains and glaciers or excavating pits up to a kilometer and a half in depth.[6] The excavation and crushing of millions of rock requires enormous inputs of energy, water and reagents (especially cyanide) and releases ever-growing amounts of sulphides and heavy metals into the environment. We are less than twenty years into the development of this system.

I. The colonial & early national mining system in Mexico (1524- 1876)

Mining and high-temperature metallurgy were already well-established in Mesoamerica prior to the arrival of the Spaniards in 1519. The main zones of pre-colonial activity were the Tarascan zone of west central Mexico (gold, silver and copper), the escarpments of the central Sierra Madre Occidental (silver), the Balsas watershed (gold), and Oaxaca (gold). Spanish colonial mining began immediately after the fall of the Mexica state at Tenochtitlán. In the midst of the major social crisis triggered by the political upheaval of Native polities, the Spanish military conquest and the arrival of the first major epidemics, groups of Spanish miners staked out the first European claims to the mineral wealth of mainland Americas. These were at the gold placer deposits in the Papaloapan and Balsas watersheds in Oaxaca (1522) and silver ore deposits at Taxco (1524).[7]

From Taxco, colonial mining advanced quickly along a northwesterly axis, following the silver and gold deposits situated along the flanks of the Western and

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vols. (NY: American Institute of Mining, Metallurgical, and Petroleum Engineers, 1981) and Osvaldo A Bascur *Latin American Perspectives: Exploration, mining and processing*, (Society for mining, metallurgy and exploration inc., 1998), 341.

[6] One of the early celebrants of the form put as follows: “These men…not only shook the earth in passing, they shifted it, tossed it about literally, creating molehills out of mountain ranges.” Horace Dunbar, *Marcy’s Mill* (San Diego: Watson-Jones, 1944) cited in Timothy LeCain’s *Moving Mountains*, 734.

[7] “Relación de las Minas de Tasco”. ed. Rene Acuna, *Relaciones Geográficas del Siglo XVI: Tomo 7 México,* pt 2. (Mexico: UNAM, 1996). 109.

Eastern Sierra Madre with occasional forks along the traverse sierras of central Mexico and the Mexican volcanic belt.[8] The first major silver mining districts were established to the southwest of the Valley of Mexico in Taxco and the valley of Sultepec. Mining exploration and production then moved to the semiarid zones north of Mexico, first to Pachuca-Real del Monte, Zacatecas, Guanajuato and Sombrete in the 1540s-1550s, then San Luis Potosí, Durango, and Parral (1590s to 1630s), and finally to Sonora - the northern edge of New Spain – by 1633.[9] Within a hundred years, the northern (Sonora) and southern (Oaxaca) limits of New Spain's mining belt had been set, creating a mining belt some two thousand kilometers long. Established over the course of a century, the geography of Mexican mining would not substantially change to the present day, three hundred and seventy-five years later.

First strikes were known as "*bonanzas*" literally "boons" or "gifts", as if they were the metallic equivalent of manna – wealth freely obtained from the earth. The deposits worked by Spanish miners were unlike anything in European mining at the time (mainly silver, in Central and Eastern Europe). Extraordinarily high grades were obtained during the first years of mining: native silver and gold as well as high-grade ore veins at or near the surface. Miners simply panned, trenched and "gopher-holed" the deposits, basically by hand.[10] In their excitement, Spanish miners came to believe that the bounty of the Sierra Madre was both miraculous and inexhaustible. The seventeenth-century

[8] Sanchez-Crispín, "The Territorial Organization of Metallic Mining in New Spain", 157.
[9] Ibid., 157-58; Peter Gerhard, *A Guide to the Historical Geography of New Spain*, passim; Robert C. West, *Sonora: Its Geographical Personality*. (Austin TX: University of Texas Press, 1993), 45.
[10] Sanchez-Crispin, "Territorial Organization"

metallurgist Alonso de Barba recounted how miners held that the earth would regenerate the silver and gold veins of a mine much like a coppiced tree putting out new shoots.[11]

In reality of course, the ore grades in different Mexican mining districts dropped after the first years of the bonanza, but were still rich and plentiful. A sample of date from some eighty-six mines of the period renders an average ore grade just shy of seven kilos per ore-tonne[12] The colonial Mexican mining sector counted some 453 different mines and mining communities ranging from the great mining cities of Zacatecas, Guanajuato and San Luis Potosí to smaller towns and camps dispersed across the mountains and semiarid plains of central and northern Mexico.[13] From the early sixteenth century to the 1870s, Mexico produced over 75 000 metric tons of silver, close to 900 tons of gold, as well as other metals such as lead and copper and the various other metallic compounds used in mining processes.[14] In the early modern period the mines of Mexico accounted for half of the total precious metal production of the Americas and forty percent of the world's silver supply.[15]

The miners of New Spain hailed from the different corners of the Atlantic world. The masters and owners (*mineros*) came from Spain, Portugal, the Basque country, Flanders and Gemany. The workers (*operarios*) were central Mexicans (Nahua, Tarasco, Otomi), northern hunter-gatherering peoples (Pamé, Chichimecan, Raramuri, Tepehuanes and Yaquis), Kongolese, Angolan and the new communities of creoles and *castas*. They

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[11] Alonse Barba, *El arte de los metales*,
[12] Average silver ore grade: 6970 grams; low: 104 gr; high: 120 000 gr. The sample includes mines from Sonora, Chihuahua, Durango, Zacatecas, San Luis Potosi, and Hidalgo covering a period from 1621 to 1821.
[13] Crispin, "Territorial Organization"
[14] Schmitz, World Bullion Production and Prices; R. Garner, "Long-term mining trends in Mexico"
[15] Ward Barrett, "World Bullion Flows, 1450-1800," in *The Rise of Merchant Empires: Long-Distance Trade in the Early Modern World, 1350-1750*, ed. James D. Tracy (New York: Cambridge University Press, 1990), 225.

laboured for wages paid in ore and silver or under the yoke of slavery. As the bonanza period drew to an end, more elaborate systems of tunnel mining were developed to follow and excavate veins of high grade ore. The ore was processing by milling and then either smelted or amalgamated with mercury and refined. Each mining operation was relatively small. This was due in part to Royal Spanish mining law which limited the amount of claims an individual could stake to three. Claims followed a limited distance of a given vein and accorded no surface or water rights.[16] The exploitation of the one to three mine mouths depended upon the work of between eight and a few dozen men supported by mules and oxen and, when conditions permitted, a water mill.[17] Milling, amalgamation and smelting took place in the *Hacienda de beneficio* which was often attached to specific mining operations. These too were usually modest in size: a mill, a patio, one to three small smelters and a dozen or so workers.[18] The average mill processed slightly less than half a tonne of ore per day, a good indication of the local rhythms of extraction.

Although small, the mines and mills of colonial and early republican Mexico were numerous. Large deposits such those at Guanajuato, Zacatecas and Pachuca-Real del Monte were worked by tens of thousands of operarios. Medium sized districts such as Parral, Cerro de San Pedro, Zimapan and Taxco counted between five and ten thousand workers labouring in dozens of mines and haciendas de beneficio. Furthermore, the

[16] 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*, t.26, n°101-102 (Jan-Jun, 1976), 157-167; and her, *Ordenanzas de la minería de la Nueva España formadas y propuestas por su Real Tribunal* (México: UNAM, 1996).
Chism, Mexican mining laws, Galvao, Informes, books on 18th c. Bourbon codes.
[17] Spanish law limited the amount of mining claims an individual could stake to three
[18] Though see elaborate and large-scale works developed by the Condé de Regla in Pachuca-Real del Monte in the eighteenth century.citation, see Edith Boorstein Couturier, *The **Silver King**: The Remarkable Life of the Count of **Regla** in Colonial Mexico.* (Albuquerque: University of New Mexico Press, 2003) For San Luis Potosi, *Las haciendas de San Luis Potosí* (SLP: UASLP, 2002) for Parral, Chihuahua, see Robert C. West, The District of Parral.

eighteen mining districts were active for centuries, moving through production drops (1640s-1700s; 1830s-1860s) and rises (1550s-1630s; 1750s-1820s) that arched across decades.

The cumulative environment impact of this activity was remarkable. Silver mining in New Spain was an industry operating in a world without steel, concrete, fossil fuels or electrical energy. Consequently it was deeply reliant on wood for building and heat. Wood and fire were applied throughout the mining process, from the moment the ore was removed from the ground to its transformation into silver of mintable grades. Timbers of oak, mesquite and pines provided the shorings for kilometers of tunnels and adits; for the cut-rung 'chicken ladders' angled against the shaft walls; for the construction of buildings, mills and "*malacates*" (shaft winches) as well as other machinery.[19] *Tejamaniles* or wood shakes commonly dressed the roofs of the mining districts.[20]

But the most important use of wood, by far, was for heat. Arguably, the Ibero-American mining industry was by far the largest consumer of heat energy in the pre-Industrial Euro-Atlantic world. In addition to the important quantities of firewood consumed for heating, cooking and boiling by residents of the mining centers, wood or charcoal was used to produce heat at different points of the extractive process. Fires were set inside the mines against ore veins to crack and loosen them with their heat. Once extracted the ore was roasted to make its milling easier. Reagents such as *magistral*

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[19] Diana Birrichaga Gardida, "El dominio de las 'aguas ocultas y descubiertas': Hidráulica colonial en el centro de México, siglos XVI-XVII" in Enrique Florescano and Virginia García Acosta, *Mestizajes tecnologicos y cambios culturales en Mexico* (Mexico: CIESAS, 2004), 120; West, *Parral Mining District*, 42.

[20] Sebastian de la Torre y León, *Informe sobre las minas de Bolaños, 1774* in Alvaro López Miramontes and Cristina Urrutia de Stebelski, *Las minas de Nueva España en 1774* (México: Instituto Nacional de Antropología e Historia, 1980), 44-45; West, *Parral Mining District*, 41.

(copper-iron sulfite or chalcopyrite) also had to pre-roasted to become fully effective. Charcoal combustion was then use to produce the high temperatures needed for smelting or was used to accelerate the mercury amalgamation process. Other ovens burned off the mercury from the amalgam to recover the silver. Fire was applied a last time to refine the metal to mint grade.[21]

The demand for heat energy was such that anything that could be burned was burned: not only timber but also scrubwood and even certain species of cacti that are high in ligneous matter. The resulting landscape change was dramatic and not long in coming. Within decades of the striking of the first claims observers across New Spain described completely denuded landscapes extending for kilometers around the mines. The Haciendas de beneficio had to supply themselves with wood-fuel procured from forests sixty, eighty and even as far as 120 kilometers away, a sizeable distance in a world of mules and ox-carts.[22]

In a previous project David Schecter and I reconstituted the extent and effects of mining-driven deforestation in colonial Mexico.[23] We found that a considerable amount of the Viceroyalty's territory was cleared to smelt silver, some 315 642km² for the period 1558 to 1804 – just a bit more than the surface area of contemporary Poland. The major impact was felt in the eighteenth and early nineteenth centuries when seventy per cent of this total (223 765 km²) was felled. The most important regions of forest clearing were in the regions around Zacatecas (67 854 km²) and Guanajuato (56 483 km²). Together with

[21] Barba, *Arte de los Metales*, 100, 106-107, 131; Peter Bakewell, "Mining in Colonial Spanish America," in The Cambridge History of Latin America. Volume 2: Colonial Latin America, ed. Leslie Bethell, (New York: Cambridge University Press, 1984), 116-118.
[22] Refs. SLP, Charcas, Guanajuato, Parral
[23] "The Environmental Dynamics of a Colonial Fuel-Rush: Silver Mining and Deforestation in New Spain, 1540 to 1810." Currently (24.02.09) under revision for *Environmental History*.

San Luis Potosí these mining regions created an important cluster of intensive forest clearing activity in the central part of New Spain.

Although the total mass of ore milled was relatively small, cumulatively large amounts of mercury were applied to it to recover silver. For the period 1570 to 1820, 64 470 tonnes of mercury were imported into the mining districts of Mexico.[24] Close to the entirety of this amount was dissipated into the environment, both locally through soil and water contamination and globally through vapours that reached the troposphere. Julio Camargo estimates that Mexican mining added an additional 13% to the globe's mercury emissions during this period.[25] Local mercury depositions lasted for centuries and enough remains in the soils and former tailings that a handful of companies are currently extracting it for profit.[26]

No doubt a good deal of lead was likewise released by the mines of New Spain. The study of colonial lead remains to be done but we know that silver-lead ores were common in Mexico and that lead was often used as a flux to smelt other ore compositions. We also know that lead traveled far. Palynological studies of the lake sediments of the crate lake at Hoya Rincon de Parangueo (Gto.) detect lead released by colonial smelters located hundreds of kilometers away.[27] The environmental impacts of

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[24] Nriagu, J.O. "Mercury pollution from the past mining of gold and silver in the Americas," *Science of the Total Environment*,149 (1994), 167-181; Camargo, Julio A. "Contribution of Spanish–American Silver Mines (1570–1820) to the Present High Mercury Concentrations in the Global Environment: A Review." *Chemosphere* 48, no. 1 (2002): 53-54. See also: Pirrone, N; Allegrini, I; Keeler, GJ; Nriagu, JO; Rossmann, R; Robbins, JA. "Historical Atmospheric Mercury Emissions and Depositions in North America Compared to Mercury Accumulations in Sedimentary Records." *Atmospheric Environment* 32, no. 5 (1998): 929-40.; John F. Richards, *The Unending Frontier. An Environmental History of the Early Modern World.* (Berkeley: University of California Press, 2003), 369-370.

[25] Camargo, "Contribution of Spanish-American mines", 53.

[26] Tetsuya Ogura, Jorge Ramirez-Ortiz, Zenaida Maria Arroyo-Villasenor et al. "Zacatecas (Mexico) Companies Extract Hg from Surface Soil Contaminated by Ancient Mining Industries." *Water, Air and Soil Pollution* 148 (2003): 167-77.

[27] Jungjae Park, *Holocene Climate Change and Human Environmental Impacts in Guanajuato Mexico.* Ph.D. Diss. University of California at Berkeley, 2005, 81.

lead are basically similar to those of mercury. High exposures to lead and mercury cause severe neurological disorders, negatively impact on foetal and child development, and damage the cardiovascular system.[28]

The mining system described here survived the social and political shocks of Mexican Independence. The mines, it is true, were set back by the violence of the period and the disruptions of Mexico's ties with international markets vital for revenue and mercury supply. As work slowed or ceased entirely mine shafts flooded and caved in making their rehabilitation more complicated and costly. The work, however, did proceed. The mines of Mexico continued to produce silver and gold at levels comparable, and eventually superior to, the amounts produced under Spanish dominion.[29] It is worth noting that very little changed in the Mexican mining complex. The much studied exception are the innovations (esp. steam-driven pumping and hauling) brought by English capitalists and Welsh miners in such mining districts as Pachuca-Real del Monte, Guanajuato, and Real de Catorce (SLP). But in general the scales of the mining operations remained the same; human and animal power continued to supply the work of excavating, hauling and milling; mercury amalgamation and wood-fired smelting refined the ores; and the rhythms and nature of environmental impacts continued on as before.[30]

[28] To my knowledge no in-depth study of lead in colonial Mexico has been done. Much can be drawn from the excellent piece on the workers at Huancavelica, Peru by Kendall Brown, "Workers' Health and Colonial Mercury Mining at Huancavelica, Peru" *The Americas*, 57:4, (April 2001), 467-496.
[29] This is from Schmitz, corroborating evidence in E. Cardenas, "Algunas cuestiones sobre la depresión Mexicana del siglo XIX," *Revista latinoamericana de historia económica y social*, no.3 (1985).
[30] Wood fuel was used in mining until the advent of coal and hydroelectricity at the turn of the century, For late nineteenth-century accounts of mining-led deforestation. See, Conrad Joseph Bahre, *A Legacy of Change. Historic Human Impact on Vegetation in the Arizona Borderlands* (Tucson: The University of Arizona Press, 1991), 151; and Conrad J. Bahre and Charles F. Hutchinson, "The Impact of Historic Fuelwood Cutting on the Semidesert Woodlands of Southeastern Arizona," *Journal of Forest History* 29:4 (1985), 180.

II. The industrial system.

When in 1884 Antonio Garcia Cubas published his landmark survey of Porfirian Mexico he provided a detailed compilation of the republic's mines.[31] The count totals 1023: a considerable gain from the late colonial period. The number testifies to the steady growth and expansion of Mexican mining all along the nineteenth century. Garcia Cubas was capturing the end of a mining system established by the first Spanish miners. All this would change over the course of the next decade. Laws and regulation, methods, and energy sources were all reengineered to boost the scales of Mexican gold and silver production. This, despite ever-dropping ore-grades.[32]

The change began with the liberalizing reforms of the Mexican state. Under Porfirio Díaz the mining code was reformed twice over, once in 1886 and then again in 1892. The 1892 code stated that its aim was: "Facility to acquire, liberty to exploit, and security to retain." It met with stiff opposition from Mexicans, who denounced it as "anti-economic and anti-social". In London however, the view was quite to the contrary. W.H. Trewartha-Jones reported before the Institution of Mining and Metallurgy of London that the Porfirian mining code was, "the best of all extant laws" and "urge[d] its application across the world".[33] Specifically, the new codes opened Mexican mining to foreign ownership for the first time in its history. Foreigners, like Mexicans, could stake as many claims as they wished. The claims themselves were measured in hundreds of acres in surface area and were now attached to expropriation rights.[34]

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[31] Antonio Garcia Cubas, *Cuadro Geográfico, Estadístico, Descriptivo é Histórico de los Estados Unidos Mexicanos* (México D.F.: Tip. de la Secretaría de Fomento, 1884), 181-232.
[32] Average 2 300 gr Ag/ tonnes of ore; high: 14394 gr Ag/t; low: 120 gr Ag/t. For gold the low-end cut-off grade was 1.5 gr Au/t.
[33] Bernstein, *Mexican Mining Industry*, 27-28.
[34] Richard Chism, "A Synposis of the Mining Laws of Mexico" *Transactions of the American Institute of Mining engineers.* Vol. XXXII (1902), 5, 8, 40.

The guiding aim of these reforms was to use foreign capital and technology to draw out what remained of the gold and silver of the Sierra Madre. American miners and companies were the ones who capitalized most on this opening. Financed by US investors, these companies began acquiring and then reworking different Mexican mines. At first they concentrated on mines that were considered spent by local miners. The Pachuca River Concentrating Company for instance, acquired rights to tailings piles generated by over three centuries of mining at Pachuca-Real del Monte.[35] But American companies quickly grew in size, acquiring entire mining districts by buying up thousands of acres in claims. The American Smelting and Refining Company (ASARCO, the property of the Guggenheims, built up a network of dozens of mining districts and smelters spread from Sonora to Oaxaca.[36]

Technology and capital were the twin levers of the American takeover of the Mexican mining industry. Raising overall production in a context of diminishing ore grades could only be accomplished through the industrialization of mining operations. New and more powerful forms of extraction and refining were put in place. Pneumatic drills, air ventilators and water pumps, power winches, rail carting and aerial tramways worked together to extract an average of 1350 tonnes of ore per day (orders of magnitude more than the colonial system). This ore was then submitted to new forms of refining (cyanidation, flotation) and mass smelting. Driving the increasing scale of operations was the arrival of coal and, especially, hydroelectric power.

This is where Canada's connection to Mexican mining historically begins – indirectly, through the development of the hydroelectricity that powered the industry.

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[35] Dalhgren, *Historic Mines of Mex*., 199
[36] R.F. Manahan, *Mining Operations of American Smelting and Refining Company in Mexico*. (Type-set report, 1948), pt 2.

Companies such as the Mexican Power and Light Company and the Northern Mexican Power Co. built the first great dams of twentieth century Mexico. At La Boquilla, Chihuahua, the Northern Mexican Power Co. built the Boquilla dam that tapped off 26 MW from the artifical “Lago Toronto”. By the late 1920s (before the advent of oil), hydroelectricity accounted for 83% of Mexico’s industrial power. Mining companies consumed over a third of this total.[37]

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.[38] It was certainly unavailable to Mexican miners. A contemporary observer, V. M. Braschi noted that the Mexican mining industry was in danger of becoming, “…a series of large mines controlled by the smelting interests and a few independent large companies."[39] He was quite right. By the 1910s, foreign companies controlled between 97% and 98% of a steadily growing industry.[40]

As industrialization changed the nature of Mexican mining it also reconfigured its environmental impacts. Deforestation, for instance, almost entirely halted. In the majority of mining districts, afforestation began, only slowed by agricultural uses, existing soil fertility and climactic conditions (a few semi-arid districts, such Parral or Real de Catorce, would never recover).[41] Where mining-driven deforestation continued it was as the indirect consequence of opening up new railroads and thus access to the virgin timber

[37] Bernstein, 42, 43, 159.
[38] Christopher Schmitz, "The Rise of Big Business in the World Copper Industry 1870-1930" *The Economic History Review*, new series 39:3 (Aug., 1986), 402.
[39] Bernstein, 41.
[40] Waszkis, *Mining in the Americas.*, 42-43.
[41] R.C. West, “The Parral Mining District”, 39-44.

stands of the Sierra Madre.[42] Mercury amalgamation was abandoned in all except the smallest of operations, thereby dropping mercury pollution to practically nil.[43]

But really, the Mexican mining industry was simply trading off old sins for new. The move away from wood-fuel consumption was made possible by the development of coal and hydroelectricity but these, of course, had their own set of impacts on the environment. What is worth underlining here are the new spatial patterns of these impacts. The environmental costs of energy was externalized, displaced to hydroelectric plants, generators and coal fields located elsewhere in the Republic and beyond. Similarly, smelting took place in the United States or in a reduced number of Mexican smelting plants usually situated away from the mines themselves.

Local environmental impacts of the industrial system were mainly generated by the sharp increase in milled tonnes and creation of large tailings piles. The average mine produced roughly 400 000 tonnes of tailings a year, though the large smelters, tapping into the production of many mines, accumulated six times that amount.[44] Given the mineralogical composition of Mexican ore beds, the tailings piles concentrated large amounts of heavy metals: lead and arsenic in particular, but also zinc and manganese.

Although lead and zinc were increasingly captured in the course of gold and silver refining and subsequently sold on the market, the massive injection of heavy metals into the environment could have dire consequences. Tailings were rarely contained in impoundments or if they were they were not reliable over the long term. At the mines of

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[42] Norberto Dominguez, "The District of Hidalgo del Parral, Mexico in 1820," *Transactions of the American Institute of Mining Engineers* vol XXXII, 190? (1903), 473.
[43] Nicola Pirrone, Ivo Allegrini, Gerald J. Keeler et. al., "Historical Atmospheric Mercury Emissions and Depositions in North America Compared to Mercury Accumulations in Sedimentary Records," *Atmospheric Environment*, 32:5 (1998), 929-930.
[44] Walter Harvey Weed, "Notes on Certain Mines in the States of Chihuahua, Sinaloa and Sonora, Mexico," *Transactions of the American Institute of Mining Engineers* vol XXXII, 190? (1903), 434.

Zimapán, Hidalgo, for instance, arsenic from the tailings have been seeping into the water table since the 1930s. Over time enough arsenic has accumulated to contaminate the aquifer that supplies the water supply for an entire valley.[45] 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 (Gto.), Matehuala (SLP) and Santa Barbara (Chi.).[46] Heavy metals were also disseminated into the local environment through wind-borne dust particles from the tailings or particulate emissions from the smelters when they were in operation. The radius of impact is much more localized for solids-borne heavy metals. A recent study of the soils of Zimapán found detectable concentrations of arsenic only within a radius of three and a half kilometers, and high concentrations within 500 meters from the mines.[47] It bears mentioning here that although some have claimed that high levels of arsenic found in the water of mining districts are attributable to natural processes of leaching from local ores, a broad range of studies undertaken by Mexican and North American scientists demonstrate conclusively that these concentrations are primarily attributable to mining activity.[48]

The large concentrations of tailings generated by twentieth-century industrial mining also set it motion a new form of environmental pollution: acid mine drainage

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[45] Arsenic concentrations in Zimapán's water supply exceed the WHO drinking water standard by a factor of ten. MA Armienta; Rodriguez, CR; Ongley, LK; et. al., "Origin and fate of arsenic in a historic mining area of Mexico", *Trace Metals and Other Contaminants in the Environment* 9 (2007), 473-498.

[46] A. Carrillo-Chavez; Gonzalez-Partida, E; Morton-Bermea, O; et.al. "Heavy Metal Distribution in Rocks, Sediments, Mine Tailings, Leaching Experiments, and Groundwater from the Mineral de Pozos Historical Mining Site, North-Central Mexico", *International Geology Review* 48:5 (May, 2006), 466-478; and I. Razo,; Carrizales, L; et.al., "Arsenic and Heavy Metal Pollution of Soil, Water and Sediments in a Semi-Arid Climate Mining Area in Mexico", *Water, Air, & Soil Pollution* 152:1 (feb., 2004), 129-152.

[47] L.K. Ongley,; Sherman, L; Armienta, A; et.al. "Arsenic in the soils of Zimapan, Mexico", Environmental Pollution, 145:3 (Feb., 2007), 795-796.

[48] In addition to the studies cited above see, the overview provided in F. M. Romero,; Armienta, MA; Gutierrez, ME; Villasenor, G., "Geological and climatic factors determining hazard and environmental impact of mine tailings" *Revista Internacional de Contaminación Ambiental* 24:2 (2008), 43-54.

(AMD) or acid rock drainage (ARD). The presence of these processes depended upon the geochemistry of the local ore body. The key factor is the relative presence or absence of sulphides (pyrites especially). The extraction of sulphide ores from the earth and their subsequent exposure to water and air triggered acid-generating reactions. In places like Zimapán or Taxco (high sulphide areas), for instance, soil acidity values of 2.6 pH and 2.8 pH were obtained. Rising acidity has important impacts on local ecosystems and human communities but it also acts to increase the rate at which heavy metals such as lead and arsenic in the tailings are leached out and transported into the environment.[49]

The American period in Mexican mining lasted some sixty years until the post-Revolutionary government reestablished sovereign control over the industry. The industrial configuration of Mexican mining remained in place however. The mines now under Mexican ownership, and in many cases run by Mexican workers cooperatives, continued to use the same techniques of electric and coal-powered extraction, cyanide flotation systems and high-energy smelting.[50] The peak of this cycle occurred in the 1940s with silver and gold production declining steadily over the subsequent decades to reach, in the late 1980s, the levels set close to a century earlier.

3. The open-pit mining system of our neo-liberal present (1990s to today)

It was in the 1980s that Mexico's political economy began to shift once more and set the conditions for the development of the third system in Mexican mining. The decade saw the Mexican state pushed into fiscal crisis by the twin shocks of the 1982 debt crisis and

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[49] *Ibid.*, 52-53.
[50] A wonderful ethnography of post-Revolutionary mining cooperatives in Guanajuato is developed in Emma Ferry's *Not Ours Alone*: *Patrimony, Value and Collectivity in Contemporary Mexico*.(New York: Columbia University Press, 2005).

the subsequent 1986 drop in oil revenues. The conjuncture created an opening for major legal and institutional reforms aimed at reopening the Mexican economy to foreign direct investment and external technological modernization. Historians of Mexico focus on the lead up to, and signing of NAFTA in 1994 as the culminating moment in the renewed liberalization of the Mexican economy. While NAFTA was indeed a keystone to these shifts, it is worth noting that it was accompanied by a related set of sectorial reforms that drove towards the same overall ends. A year before NAFTA, a new mining code was put in place, the *Ley Minera* of 1993. This was also part of a broader trend in mining which saw the the systematic liberalization of mining codes around the world during this period.[51]

In Mexico, the new Ley Minera of 1993 was essentially a repeat of the 1892 code with its emphasis on freedom of access, liberty of operation and stability of tenure. But it introduced a number of key innovations that were tailored to the new open-pit complex. For instance, rights to sub-surface resources granted pre-eminent rights to the surface for the first time in close to five centuries of mining in Mexico. Mining claims were suddenly accorded precedence over other claims such as ejido tenure, agrarian use, and so on. Given the impacts open-pits have on the surface, this was a necessary amendment if the new model of mining privileged by mining companies was to take root. The new code came with the guarantee that title and concession could not be legally revoked before term (companies found to be in breach of the law can only be fined); and the lengthening

[51] Gavin Bridge, "Mapping the Bonanza: Geographies of Mining Investment in an Era of Neoloiberal Reform," *Professional Geographer,* 56:3 (2004), 407-08; Sánchez Albavera, Fernando, Georgina Ortiz, Nicole Moussa. (1999). *Panorama minero de América Latina a fines de los años noventa.* Santiago de Chile: CEPAL; David Szablowski provides an in-depth examination of the social and legal dimensions of these reforms in the case of community conflicts over mining in Peru, *Transnational Law and Local Struggles Mining Communities and the World Bank* (London: Hart Publishing, 2007).

of the duration of title. These are also critical measures for open-pit projects given the massive amounts of financing they require and the new to amortize such investments over the long term.[52]

As in the 1880s, these legal and regulatory changes were critical in drawing in foreign mining interests. The evidence suggests that at this juncture mining companies were not forcibly pushing for more access to the Latin American market. The recession of the 1980s greatly deflated commodity prices, eroded the capitalization of the mining industry in Canada, the United States and Australia, and reduced exploration budgets and projects. Larger, more established mining companies shied away from investing in such regions as Central America that were considered too destabilized by the endgames of the Cold War.[53] Rather, liberalization was an effort to entice foreign mining companies into the sector.[54] Entice it did. Further encouraged by the rising price of precious metals, foreign mining corporations returned their attentions to Mexico, exploring the possibilities of a second repass on the deposits of the Sierra Madre.

This time, however, the principal players have been corporations based in Canada. The 1990s saw the strengthening of environmental regulation of mining in Canada which lengthened the permitting process in certain cases to five years or more.[55] The stiffening of regulations in the domestic sector may have helped motivate Canadian companies to look overseas for development opportunities. Very quickly the number of projects under development by Canadian mining companies began to rise. Within four years beginning

[52] Estrada, Adriana and Helena Hofbauer. *Impactos de la inversión minera canadiense en México: Una primera aproximación.* Mexico D.F.: FUNDAR. (2001).
[53] Otto, James M. "Global Changes in Mining Laws, Agreements and Tax Systems." *Resources Policy* 24:2 (1998).
[54] Northern Miner. "Brazil attempts to attract more foreign capital to mining sector" *The Northern Miner* no. 82, (1996), D1.
[55] Otto, "Global Changes in Mining Laws".

in 1991 the number of properties owned by Canadian companies in Mexico almost quintupled (52 to 244).[56] In 2005 Canadian corporations controlled close to two-thirds of the Mexican mining industry, developing some 420 projects around the Republic. The latest figures (2008) show a drop in the number of projects but a consolidation of Canadian control (78.5%).[57]

The dominance of Canadian companies is in part attributable to the high capital costs associated with developing open-pit mines. These are significantly higher than industrial tunnel mining - $500 million - $1.5 billion appears as a rough range – and they need to be paid out for a number of years before any gold is actually produced.[58] The technology involved is common to the industry as a whole, so what seems to have distinguished Canadian corporations was their access to the TSX. Thanks to a more favourable fiscal regime and an existing depth of technical and financial expertise in the sector and integration of the TSX Venture, the Toronto Stock Exchange positioned itself as the world's principal hub for the capitalization of mining exploration and development.[59] 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.[60]

The spread of Canadian companies into Mexico was concurrent to their advance in precious metal mining sectors across the globe. As in the American case, their

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[56] André Lemieux, "Canada's Global Mining Presence" *Canadian Minerals Yearbook, 1995*. (Ottawa: Natural Resources of Canada, 1995).
[57] Other players include American corporations (13%), British (1.8%) and Swiss (1.3%). Servicio Geológico Mexicano, *Anuario Estadístico de la Mineria Mexicana* (2008), 19.
[58] Anthony Evans, An Introduction to Economic Geology and its environmental impact, Blackwell Science, Malden, Ma 1997, 22, 24.
[59] Darryl Swearngin, Richard Tremblay, and Jack Silverson "Home base for Chilean mining ventures: Canada versus United States - Some tax considerations" *Canadian Tax Journal* 46:1 (1998); Bonnie Campbell "Canadian Mining Interests and Human Rights in Africa in the Context of Globalization." (1999) Retrieved February 20th, 2008, from http://www.dd-rd.ca/site/, Rights and Democracy: http://www.dd-rd.ca/site/publications/index.php?id=1277&subsection=catalogue
[60] Compare w/ $1.6 B from London Stock Exchange or $41 million on NYSE for 2005.

successes have been tied to important transformations in the nature and configuration of mining itself. Some observers have called this the "invisible gold" rush because of the spread of new techniques that are capable of extracting gold in such low concentrations that it can not be detected by a microscope, let alone the human eye.[61]

The open-pit, cyanide heap-leach mine is the emblematic form of this kind of production. Just as industrial lode mining and smelters eclipsed colonial forms of extraction, the open-pit complex has quickly become predominant. Of the 402 existing gold mining projects currently in operation in Latin America, 323 are open-pit projects and many more are in development.[62] In Mexico these projects represent a second and sometime third pass over gold deposits originally worked in the colonial period.

The industry has adopted the open-pit complex for economic reasons. In the case of gold, it is actually cheaper – when measured on a per-unit cost – than tunnel and lode mining. Secondly, it is the only existing means of exploiting porphyry type deposits – enormous deposits of diffused metals at very low concentrations. Given their size, porphyries produce enormous quantities of gold and silver. Take for example Goldcorp's Peñasquito project at Mazapil (Zac.). It is estimated to generate 17.8 million ounces of gold, 1 277 million ounces of silver as well as important amounts of marketable zinc and lead.[63] The precious metals alone will fetch $33 172 800 000 at today's market prices.[64]

Environmentally-speaking the impacts of open-pit mining are directly related to the scale of the operations which are, in turn, related to the extremely low grades of ore

[61] Average value of ore grades in contemporary Mexican open pit projects: 2.1 gr/tonne; high: 13.4 gr/t; low: .18 gr/t. On the "invisible gold rush" and open-pit porphyry mining see W. Petruk, *Applied Mineralogy in the Mining Industry*, (New York, Elsevier Science BV, 2000), 124.
[62] MICLA database.
[63] Goldcorp In. Peñasquito Project Technical Report (December, 2007), 16.
[64] Calculated on basis of a gold ounce at $930, and a silver ounce at $13.

worked in these deposits. The Peñasquito mine is located on the same mineralization zone that has 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."[65] Given gold concentrations as low as 1.8 parts per billion, Goldcorp will have to excavate and process truly astronomical quantities of the Sierra Madre in order to extract the $33 billion of gold and silver that it has left. 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 which will also be moved in the process. At the end of the project's estimated 21 year cycle, Goldcorp will have moved close of a trillion tonnes of ore, created two large open pits (the larger measuring 4.5 kilomters in diameter and close to 1.5 in depth), and disturbed large swaths of the Mazapil valley for tailings piles, waste rock piles, cyanide heap leaching pad, processing plants and the other remaining infrastructure for the mine. It is a form of mass terra-forming of unprecedented proportions.

These efforts carry important environmental costs, both for the local environment as well as for environments in other parts of the globe. The movement of so much physical mass requires enormous amounts of mechanical energy. In the case of Peñasquito, 25 769 628 MJs per day will be used to run the mine's drills, haul trucks, crushers, mills and grinders. To put this in historical perspective, a single Komatsu haul truck consumes as much energy during a single shift as an entire colonial mining

[65] S.G. Lasky, "How Tonnage and Grade Relations Helps Predict Ore Reserves," *Engineering and Mining Journal*, (April, 1950), 81-5.

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. Given that energy for open pit mining principally comes in the form of diesel, and given the quantities involved, large gold mining corporations such as Barrick Gold have moved to purchase oil companies to reduce and stabilize their energy costs.[66] The environmental impacts generated by the extraction and processing of the fuel consumed by Mexican open pit mines are borne in oil fields and refineries across the world. Hydroelectricity continues to supply important energy inputs to open pit mining but here too environmental consequences are distanced from the mine itself.

In the immediate vicinity of the mine, the generation of waste rock and tailings creates the potential for acid rock drainage on a mass scale. Heavy metals such as arsenic accumulate at similar scales and can escape into local ecosystems and hydrologies. At the same time, the operation of open pit mines requires large volumes of water – again measured in the tens of millions of liters – on a daily basis to run solutions through the leach pads or other extractive processes. Since many of the open pit mines in Mexico are situated in semi-arid highland areas this 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 themselves quite toxic or fatal if they accidentally come into contact with people or animals.

4. Observations and Discussion

[66] CP Newswire, "Barrick Gold Bids to Acquire Cadence Energy for C$350M"

I would like to make some observations about the temporal and spatial patterns of mining-driven environmental change in Mexico. They form a conclusion of sorts, one that raises at least as many issues as it settles.

Over the course of five centuries of mining in Mexico the scales of energy use, mass displacement and precious metal production rose in a step-wise manner. These increases mirrored by matching declines in ore grade that dropped many orders of magnitude over this same period. Indeed, these trends seem to provide a broad historical confirmation of Lasky's Law. These trajectories did not translate neatly into patterns of environmental change. Take the case of energy, a key input in mining which had, in its different configurations, tremendous impacts on the land. As Mexican mining moved from system to system, so too did techniques and ways of organizing production. Thus the consumption of heat energy dropped significantly with the advent of new processes such as cyanidation, heap-leaching. These used chemical reactions and mechanical energy to substitute the work done by charcoal heat. Moreover, energy use became increasingly efficient over time. In colonial smelting, for instance, large amounts of heat energy were dissipated. Improvements in furnace design reduced such losses. A rough measure of these trends comes when we measure the amount of energy expended to process a given tonne of ore in the three systems. (See table 2) The gains in efficiencies offset the increase in the scale of energy consumption over time.

The play of time was itself a key variable in exploring the issue environmental comparatively. Recall the durations of each system - the colonial system, 350 years; the industrial system 100 years; and the contemporary system might very well play out over the next forty or so.[67] At which point the Sierra Madre really will be exhausted of its wealth. This means that the intensity of mining-driven impacts are going up. On the other hand, the duration is dropping significantly. The question to be explored is whether the resilience of ecosystems greater when the impact is of low intensity of but long duration or if anthropogenic demand is of high intensity but short duration? Constant wood cutting and associated soil erosion occurring over the centuries of the colonial system may have changed (degraded?) local landscapes more profoundly than its successors. Or one could argue it the other way: that the diffused nature of impact allowed constant vegetative and ecological restoration.

Played out over the long-term, the spatial dynamics of show some interesting patterns that may helpfully frame further discussion of mining-driven environmental change. In the colonial system fuel and other imputs (with the exception of mercury) came from the areas contiguous to the mines. The high demand for heat energy led to irradiating rings of deforestation that spread out from the mine. But since there are many mines and each mine is very small, the overall picture is one of hundreds of these deforestation circles scattered across the Sierra Madre.

As Mexican mining passed into the industrial and open-pit system the geography of impact split. On the one hand, significant environmental impacts were externalized away from the mines. Energy inputs ceased to come from local forests but rather coal depositis,

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[67] Assuming no new large mineralization zones are found (a safe assumption) and an average term for an open pit mine of ca. 15-20 years. These estimates are entirely speculative of course.“Asking a historian to predict the future is like driving with your rear-view mirror” – M. McLuhan.

oil fields, power plants, and hydroelectric dams that could be hundreds of kilometers away or, increasingly, across the globe. Likewise, the emissions and pollutants generated by the treatment of Mexican silver and gold were increasingly released away from the mine. On the other hand, as we move forward to the industrial and contemporary systems the number of mines drop even as they became larger and accumulated ever greater quantities of heavy metals and suplhides to their local environment. The spatial configuration moved towards networks extending ever-further out from a shrinking number of mines, networks that increasingly secure necessary inputs (and their environmental costs) from afar while simultaneously intensifying impacts in the immediate vicinity of the mine – a kind of "enclave economy as ground zero" image.

Table 2: Comparative environmental impacts by mining system.				
	Mass displaced (ore tonnes/day	**Energy consumption (MJ/day)**	**Energy consumption (MJ/tonne)**	**Ore grade ratios**
Colonial	0.48	105 000	242 827	1~3:100
Industrial	1350	156 720	116	6: 1 000 ~1.5:1 000 000
Contemporary	130 000	25 800 000	206	2.1: 1 000 000 ~1.8: 10 000 000

<table>
<tr><th></th><th><u>Colonial and Early National</u>

Sierra Madre from Oaxaca/Chiapas to Sonora/Chihuahua
453 mines across 18 mining districts (1774)
1023 mines across the same districts (1884)</th><th><u>Late 19th and 20th centuries</u>

401 mines across the same districts (1903).</th><th><u>Contemporary</u>

341 mining projects across the same districts (2007)</th></tr>
<tr><td>Deposits & Ore grades</td><td>Placer and ore veins.
Grades (gr/tonnes):
<u>Silver</u>
Median: 1 500
Av’g: 6 970
High: 120 000
Low: 104</td><td>Ore veins, copper porphyries.
Grades (gr/tonnes):
<u>Silver</u>
Median: 2 326
Av’g: 4 566
High: 14 394
Low: 120</td><td>Porphyries.
Grades (gr/tonnes):
<u>Silver Gold</u>
Median: 145 1.2
Av’g: 175 2.1
High: 394 13.5
Low: 85 0.4</td></tr>
<tr><td>Techniques</td><td>Tunnel mining, mechanical grinding, mercury amalgamation & smelting</td><td>Industrial underground mining:pneumatic drills, dynamite, electric hoists, rail cars, aerial tramways cyanidation-flotation & smelting, steam and electric power.</td><td>Open pit, fuel and electric power, cyanide heap leaching, cyanidation-flotation & smelting.</td></tr>
<tr><td>Energy (MJ/day)</td><td>Maldonado mine and smelter Cerro de San Pedro, SLP (17th)
Processing: .48 tonnes ore/day.
<u>Mechanical (Extraction, haulage, milling):</u>
8-36 individuals @ 3.66 MJ/day = 30 – 132
8-16 oxen @ 28 MJ/day = 224 - 448
15-35 mules @ 14.64 MJ//day = 220 - 512
1 watermill (4 kW) = 117
<u>Heat (smelting and refining): 105 209</u>
Total: 105 800 – 106 418 MJ/day</td><td>ASARCO’s Santa Barbara mine, Parral, Chihuahua
Processing: 1350 tonnes/day.
Est. powr consumption = 224 775 MJ/day (@ 46.24Kwh/T)[68]

Central power plant – American Crossley gas plant
Hydro-electricity from La Boquilla Dam</td><td>Goldcorp’s Peñasquito project, Mazapil, Zacatecas
Processing: 130 000 tonnes/day
Drilling: 7 035 948
Hauling: 14 871 600
Sandvik Crushers: 207 360
EGL SAG Mills: 1 581 120
Secondary grinding: 2 073 600
<u>Smelting[69]: 45 000 ~ 54 000</u>
Total: 25 814 628 ~ 25 823 628 MJ/day</td></tr>
<tr><td>Law & the State</td><td>Limited staking (3/individual); claims follow veins over short distances; no surface or water rights; foreigners excluded; 20% royalties; state assists and controls key inputs such as Hg and labour recruitment.</td><td>Unlimited claims; land and expropriation rights; foreign ownership; perpetuity of tenure; state investments in geology and mining engineering.</td><td></td></tr>
<tr><td>Environmental impacts</td><td>Deforestation
Mercury emissions
Lead emissions</td><td>-Mercury emissions.
-Tailings contamination: As, Pb, Zn
-Acid Rock Drainage
-Sulphide emissions during smelting.
-Water contamination and hydrological disruption
-Secondary impacts: hydroelectric dams, coal prod.</td><td>-Tailings contamination: As Pb, Zn
-Acid Rock Drainage
-Sulphide emissions during smelting.
-Water contamination and hydrological disruption
-Secondary impacts: hydroelectric dams, fossil fuel production</td></tr>
</table>

68 F.W. McQuiston and R.S. Shoemaker, Gold and Silver Cyanidation Plant Practice Monograph.

69 Using Smil’s figures of 12.5 ~ 15 GJ/t metal produced. Daily metal Au & Ag production est. 3.6 tonnes.