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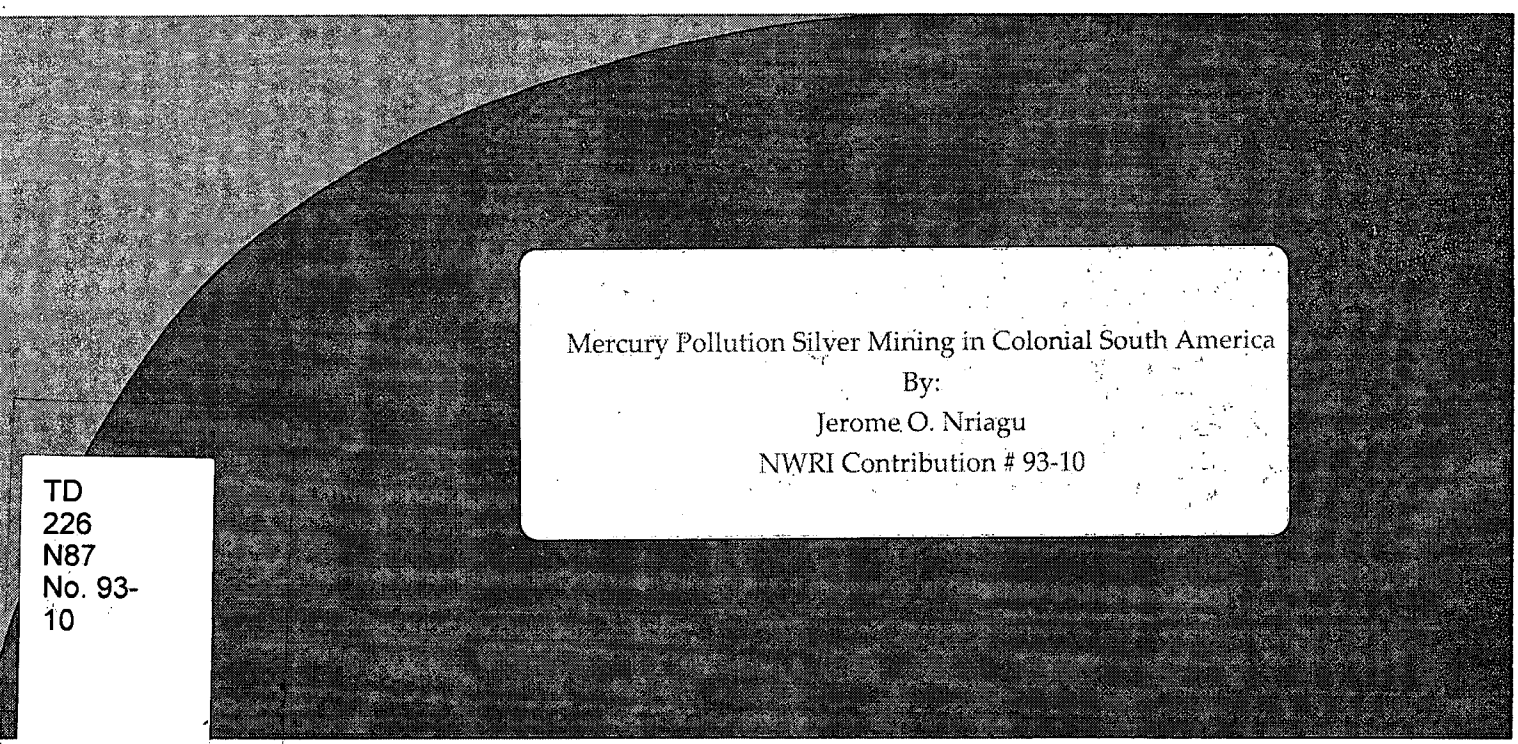

Mercury Pollution Silver Mining in Colonial South America

By:

Jerome O. Nriagu

NWRI Contribution # 93-10

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Historical

MERCURY POLLUTION FROM SILVER MINING IN COLONIAL SOUTH AMERICA

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Abstract

The development of the *patio* (amalgamation) process into an industrial scale operation in 1554 stimulated the production of mercury at unprecedented levels for over three centuries. Most of the mercury went to the silver mines of Spanish American where the recovery of 1.0 kg of silver entailed the loss of 1.5 kg of mercury. The annual loss of mercury averaged 527 t/y (range 292-1085 t/y) between 1580 and 1820 and increased to 875 t/y in post-independence times.. About 60-65% of the mercury was released to the atmosphere implying that the silver mines were the dominant source of atmospheric mercury pollution especially before the Industrial Revolution. The cumulative discharge of mercury from 1580 to 1900 when the patio process was in common used is estimated to be 196,000 tonnes. The continuing recycling of this large mass of mercury may partly be responsible for the high background levels of mercury in the global environment.

MANAGEMENT PERSPECTIVES

Beginning from about 1570, South and Central America established a hegemony on the silver market which lasted for over 300 years. The primary impetus for the massive silver output was the introduction of a cheap and simple technology -- the *patio* or mercury amalgamation -- into silver production which was ideally suited for the low grade ores and some unique ore minerals (such as argentite and cerurgyrite) common in the region. The new technology, often regarded as one of the most remarkable inventions of Ibero-America, also solved the eternal problem of fuel scarcity which had plagued the resource extraction industry. While the patio process supplied the silver that financed fueled the European economy, it also left an unparalleled legacy of massive mercury pollution which is still leaking into the global environment.

For most of the silver mines of Spanish American, a rule of thumb was that the recovery of 1.0 kg of silver entailed the loss of 1.5 kg of mercury. The annual loss of mercury averaged 527 t/y (range 292-1085 t/y) between 1580 and 1820 and increased to 875 t/y in post-independence times.. About 60-65% of the mercury used this way was released to the atmosphere implying that the silver mines were the dominant source of atmospheric mercury pollution especially before the Industrial Revolution. (other sources = ? /yr) The cumulative discharge of mercury from 1580 to 1900 when the patio process was in common used is estimated to be 196,000 tonnes. The continuing recycling of this large mass of mercury may partly be responsible for the high background levels of mercury in the global environment. Drawing the attention of the scientific community to the need for a detailed assessment of the long-term dispersal of the massive mercury reservoir in the silver mining centers of South America remains an objective of this report.

Atmosphere?
(add Canadian Contrib)
Hg to Arctic
Great Lakes etc

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Although the priniciple of amalgamation had been known and employed since ancient times (**8-9**), its development into industrial scale operation was first made in New Spain (now Mexico) in 1554 by Bartolome de Medina (**3**). In its original cold form, the amalgamation was done on a large, flat stone-paved surface (the *patio*). The finely pulverized ore (*harina*) was piled in heaps (*montones*) of 1-1.5 metric tonnes on the patio and mixed with salt (about 1.0 kg per *quintale,* roughly 50 kg, of ore) and water to form the *ripaños* (mud). Lime was added if the mixture turned "hot" but if no heat was generated the *magistral* (roasted copper or iron pyrites) was used. Mercury was then mixed in, typically at a rate of 3-6 kg per quintale of ore and the mixture spread out as large cakes (*torta*) up to 85 m across which was treaded at intervals by men, horses or mules. The reaction of the mercury and silver took 3 weeks to 5 months depending on the ambient temperature, the nature of the ore and the refining skills of the *azoguero* or *beneficiador*. At high altitudes where the temperature is lower, such the Potosi mines located in the Andes mountains, the reaction was often speeded up by warming the mixture in large stone tanks (*cajones*) or the copper-bottomed tubs invented by Alonso Barba in 1590 (**10**). The finished cakes were shovelled into a large vat (*tina*) equipped with beaters to separate out the silver amalgam (*pella*). Excess mercury was expelled

be consistent

from the *pella* in canvas bags and the amalgam heated in a retort (*capellinas*) to free the silver and recover some of the mercury.

The patio process and its various adaptations made it possible for large amounts of ores containing as low as 15 oz silver per tonne of ore to be extracted profitably, a performance unmatched by any of the smelting techniques being used in Europe at that time. It remained unchallenged in South America for over 300 years; as late as 1870, about 71% of all the Mexican silver was still being produced by this process (7). Although it was supplanted by the "barrel amalgamation" or Born process in the late 19th century, the technological nexus between silver and mercury was not severed until cyanide amalgamation was introduced around 1900 (see Ref. 7).

An adequate supply of mercury was unquestionably the key raw material in the refining of silver by patio amalgamation. Three sources furnished virtually all the mercury used in Spanish America, the order in terms of volume supplied being Almaden in southern Spain, Huancavelica in central Peru and Idrija in modern Slovenia (**9, 11-12**). In general, the mercury from Huancavelica went to South America, New Spain got her supplies from Almaden, and Idrija was tapped to make up any shortfalls from the two principal sources.

Considerable quantities of mercury were needed to sustain the massive output of silver from the Spanish American mines and the great cycles of silver production were closely linked to the supply and price of the mercury (**9, 11**). Although some of the mercury used to extract the silver was recovered, a large fraction was generally wasted in the process because of the crude equipment and conditions. Until the middle of the 18th century, a rule of thumb was that 1.5 kg of mercury was lost for every kg of silver produced (**5, 7, 9, 11**). The ratio (or *correspondencia*), however, could be as low as 0.85 kg Hg/kg Ag for impoverished ores and as high as 4.1 kg Hg/kg Ag for very rich ores (**4-7, 9-13**). Because of depressed mercury price during 1760-1810, the loss of 2.4-2.9 kg Hg per kg of silver produced became common in many mining districts (**9**). The

correspondencia for the colonial silver mines were quite similar to the current loss of mercury associated with gold extraction in the Amazon of Brazil estimated to be in the typical range of 1.3 to 1.7 kg per kg of gold recovered (**14-16**).

Since nearly all the mercury produced in Almaden and Huancavelica went to the silver refineries in South America, the loss of mercury can been estimated using the production figures from these two sources and the recorded imports from the Indrija mines (see **7, 9, 11-13**). The coincidence in the upsurge in mercury pollution with the discovery of the Huancavelica mines in 1563 was not by accident. During 1556-1560, about 9 t/y of mercury were discharged and by 1570-1575 the wastage had exceeded 86 t/y (**1**). Between 1580 and 1820, the calculated losses (Figure 1) varied from 292 to 1085 t/yr with the average being 527 t/yr. By comparison, the input of mercury into the Amazon associated with the current gold rush is reported to be 90-120 t/yr (**14, 17**). The cumulative loss of mercury in South America between 1570 and 1820 is estimated to be 126,000 tonnes, from Figure 1.

Total silver production in South and Central America between 1820 and 1900 is estimated to be 99,400 tonnes, based on the compilations by Moshide (**18**), Croshaw (**19**) and Lamey (**20**). Assuming the ratio of mercury lost to silver produced to be 1:1 (less than the ratios in colonial times) and that 70% of the silver was recovered by the patio process and its modifications (see above), the cumulative discharge of Hg during the 80 years is estimated to be 70,000 tonnes. From the total figure, the average discharge rate in post-independence times is estimated to be 875 t/y. For the duration of over 300 years, from 1570 to1900, when the patio process was in common use, the total discharge of mercury from silver mining in South and Central America is estimated to be 196,000 tonnes, an impressive figure indeed.

Although mercury was used in numerous silver mines, the most sustained losses occurred in the 7 important silver mining regions of South America and the 16 major centers in Central America (Figure 2). An intriguing question is, what has happened to

the unprecedented quantities of mercury discharged in these silver mining areas? The old Spanish literature is virtually silent on the ecological and human health effects of what would have been severe mercury pollution (**3, 4, 10, 13**). One would hope that this report will encourage some investigation of the long-term dispersal of the massive mercury reservoirs in the old silver mining centers.

It would seem reasonable to assume that 10% of the mercury supply was lost during transport and storage (**4, 21**). In general, about 25-30% of silver, and implicitly the mercury as well, was left behind in the residue (**7**). The balance of the mercury lost (60-65%) would have been released to the atmosphere during (a) the burning of the mercury amalgam, (b) the amalgamation process on the open patio floor or in heated cauldrons, and (c) the squeezing of the *pella* (amalgam) to remove the excess mercury. The fraction estimated to be emitted to the atmosphere in colonial times is comparable to the 65-83% figure for current recovery of gold in the Amazon (**14-15**).

From the data shown in Figure 1, the atmospheric fluxes of mercury from the silver mining in colonial South America during 1587-1820 are estimated to be 180-705 t/y, the average being 316-342 t/y. Since the anthropogenic sources released much less than the current 910-6200 t/y Hg (**22**), it clear that the silver mines were the main source of atmospheric mercury pollution in those days especially before the Industrial Revolution. For the period of 1570 to 1900, the cumulative amount of mercury emitted to the atmosphere from the silver mines is estimated to be 118,000-127,000 tonnes. A sustained deposition of mercury from such a large source would have been more than enough to significantly affect the mercury budgets of many target ecosystems in the region.

The importance of this "new" source has not been considered in previous discussions of the global and regional cycling of mercury (**23-24**). It may, in fact, explain the elevated mercury levels found in the Antarctic snowfields and in the marine environment of the Southern Hemisphere (**25-28**). Also, under the hot tropical condition

especially in Mexico, any mercury in the abandoned mine wastes or deposited in the aquatic sediments remains liable to be methylated and released to the atmosphere (29-30). And any deposited mercury can subsequently become mobilized and the grasshopper-like behavior can result in the same mercury being cycled through the atmosphere for a long time. It is therefore possible that the Spanish American silver mines were partly responsible for the high background concentrations of mercury now being reported in the global environment.

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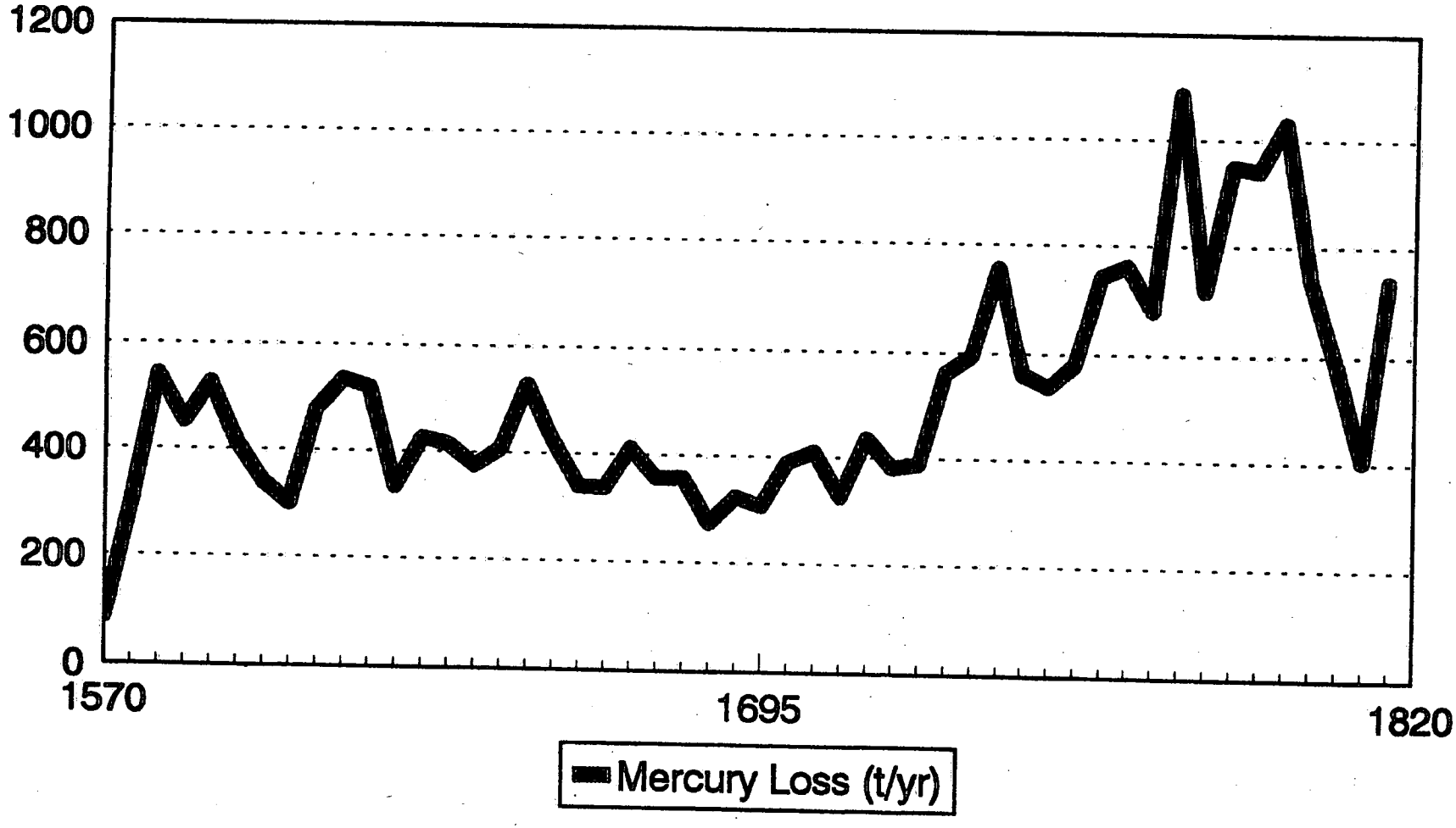
FIGURE CAPTIONS

Figure 1. Mercury losses from the refining of silver in colonial South America. Virtually all the mercury produced from the Huancavelica and Almaden mines went to the silver mines of South America; the consumption and discharge of mercury each year is derived from the mercury output by the Huancavelica mines, 85% of the output by the Almaden, and any imports from the Idrija mines. Based on various compilations especially those in refs. 2-7, 9-13.

Figure 2. Major silver mining centers in colonial South and Central America (based on refs. 3, 12, 19)

Mercury discharge from silver mining in Colonial S. America



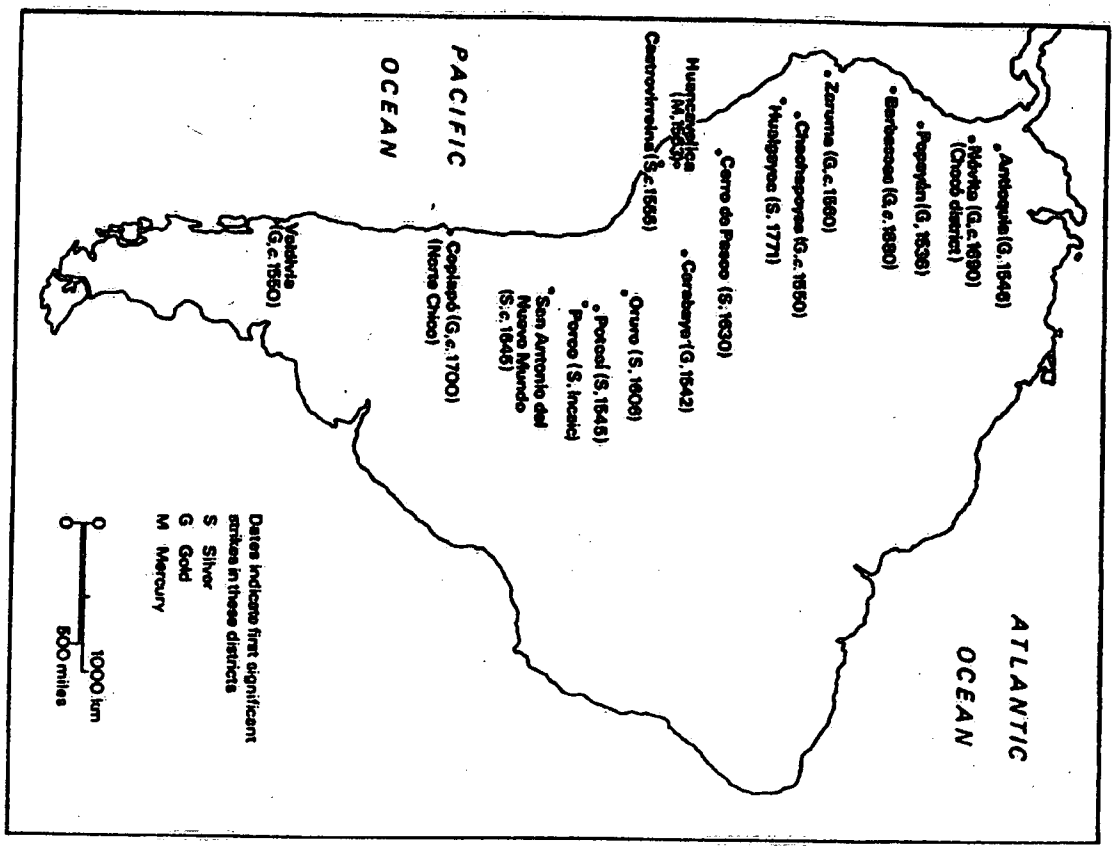
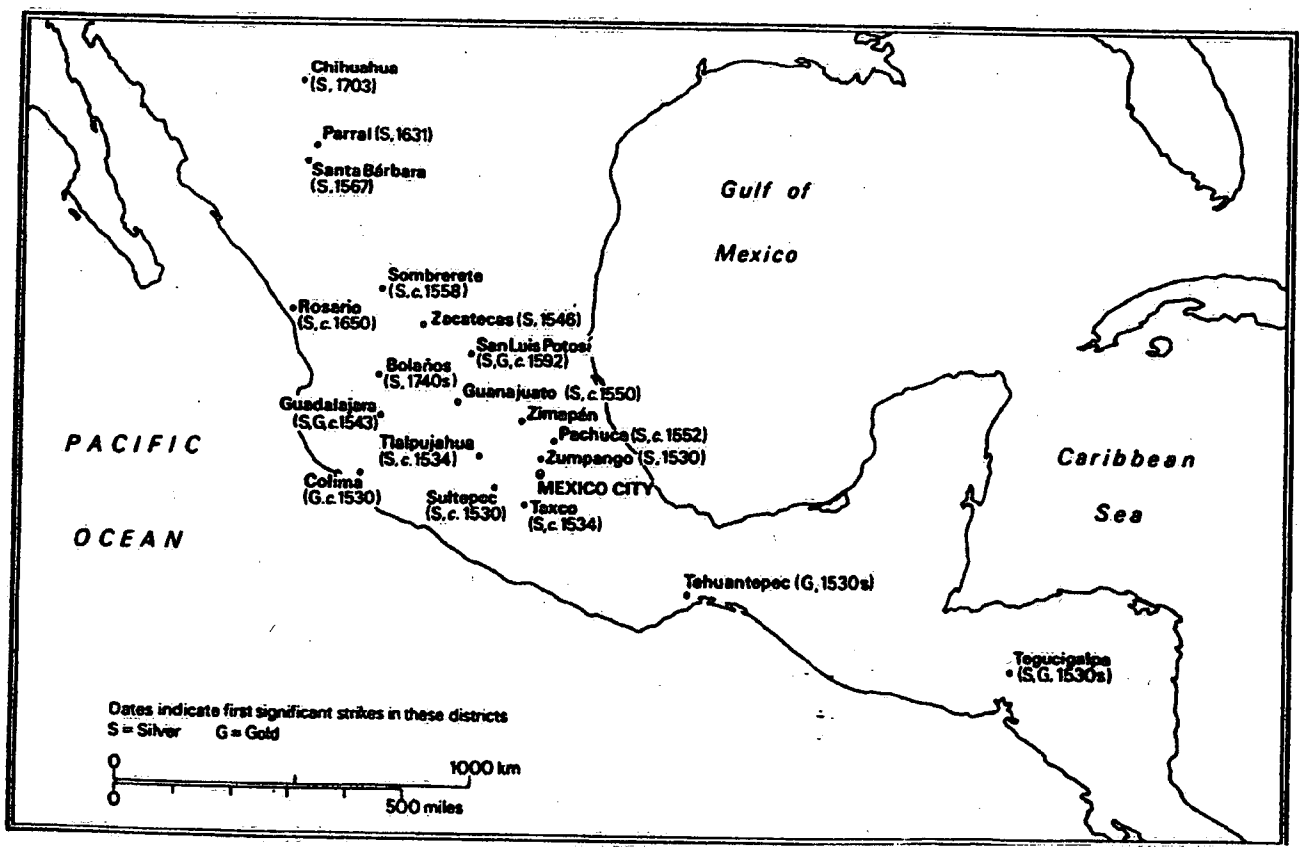

PACIFIC
OCEAN
ATLANTIC
OCEAN
Antioquia (G, 1546)
Nóvita (G.c.1690)
(Chocó district)
Popayán (G, 1536)
Barbacoas (G.c.1680)
Zaruma (G.c.1560)
Chachapoyas (G.c.1550)
Huallgayoc (S, 1771)
Cerro de Pasco (S, 1630)
Huancavelica
(M, 1563)
Castrovirreina (S.c.1555)
Carabaya (G, 1542)
Oruro (S, 1606)
Potosí (S, 1545)
Porco (S, Inciaic)
San Antonio del
Nuevo Mundo
(S.c.1645)
Coplapó (G.c.1700)
(Norte Chico)
Valdivia
(G.c.1550)
Dates indicate first significant
strikes in these districts
S Silver
G Gold
M Mercury
1000 km
500 miles

Fig. 2


Chihuahua
(S, 1703)
Parral (S, 1631)
Santa Bárbara
(S, 1567)
Gulf of
Mexico
Sombrerete
(S.c.1558)
Rosario
(S.c.1650)
Zacatecas (S, 1546)
San Luis Potosí
(S,G,c.1592)
Bolaños
(S, 1740s)
Guanajuato (S, c.1550)
Guadalajara
(S,G,c.1543)
Zimapán
Pachuca (S,c.1552)
Tlalpujahua
(S.c.1534)
Zumpango (S, 1530)
Colima
(G.c.1530)
MEXICO CITY
Sultepec
(S.c.1530)
Taxco
(S,c.1534)
PACIFIC
OCEAN
Caribbean
Sea
Tehuantepec (G, 1530s)
Tegucigalpa
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Dates indicate first significant strikes in these districts
S = Silver G = Gold
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Revised: Feb. 8, 1993

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For most of the silver mines of Spanish American, a rule of thumb was that the recovery of 1.0 kg of silver entailed the loss of 1.5 kg of mercury. The annual loss of mercury averaged 527 t/y (range 292-1085 t/y) between 1580 and 1820 and increased to 875 t/y in post-independence times.. About 60-65% of mercury used this way was released to the atmosphere implying that the silver mines were the dominant source of atmospheric mercury pollution especially before the Industrial Revolution. The cumulative discharge of mercury from 1580 to 1900 when the patio process was in common used is estimated to be 196,000 tonnes. The continuing recycling of this large mass of mercury may partly be responsible for the high background levels of mercury in the global environment. Drawing the attention of the scientific community to the need for a detailed assessment of the long-term dispersal of the massive mercury reservoir in the silver mining centers of South America remains an objective of this report.

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Using 60-65% of the historical consumption data (see Figure 1), the atmospheric fluxes of mercury from the silver mining in colonial South America during 1587-1820 are estimated to be 180-705 t/y, the average being 316-342 t/y. Since the anthropogenic sources of the period released much less than the total 910-6200 t/y Hg by present-day industries (**22**), it is clear that the silver mines were the dominant source of atmospheric mercury pollution especially before the Industrial Revolution. For the period of 1570 to 1900, the cumulative amount of mercury emitted to the atmosphere from the silver mines is estimated to be 118,000-127,000 tonnes. A sustained deposition of mercury from such a large source would have been more than enough to significantly affect the mercury budgets of many target ecosystems in the region.

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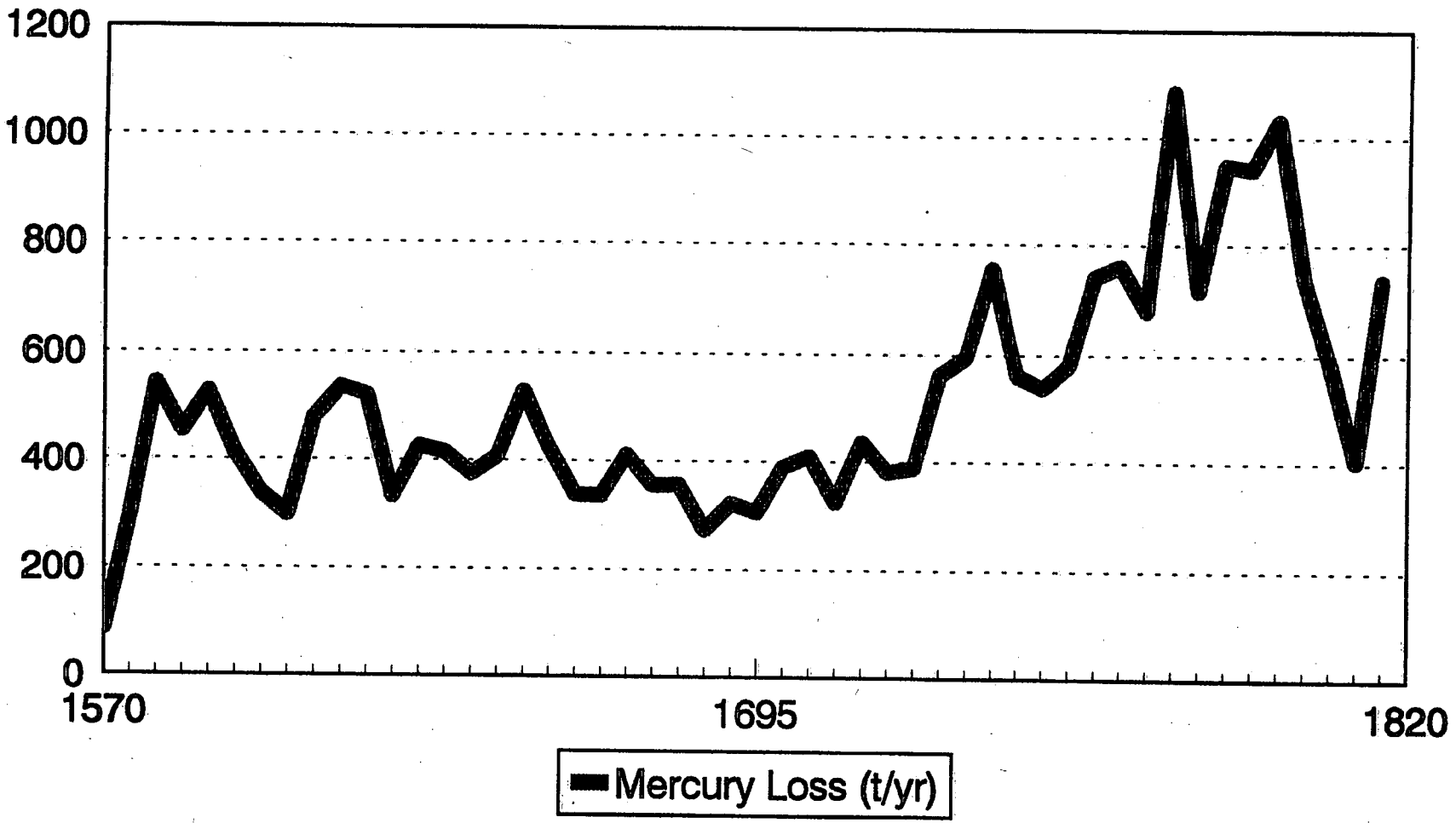
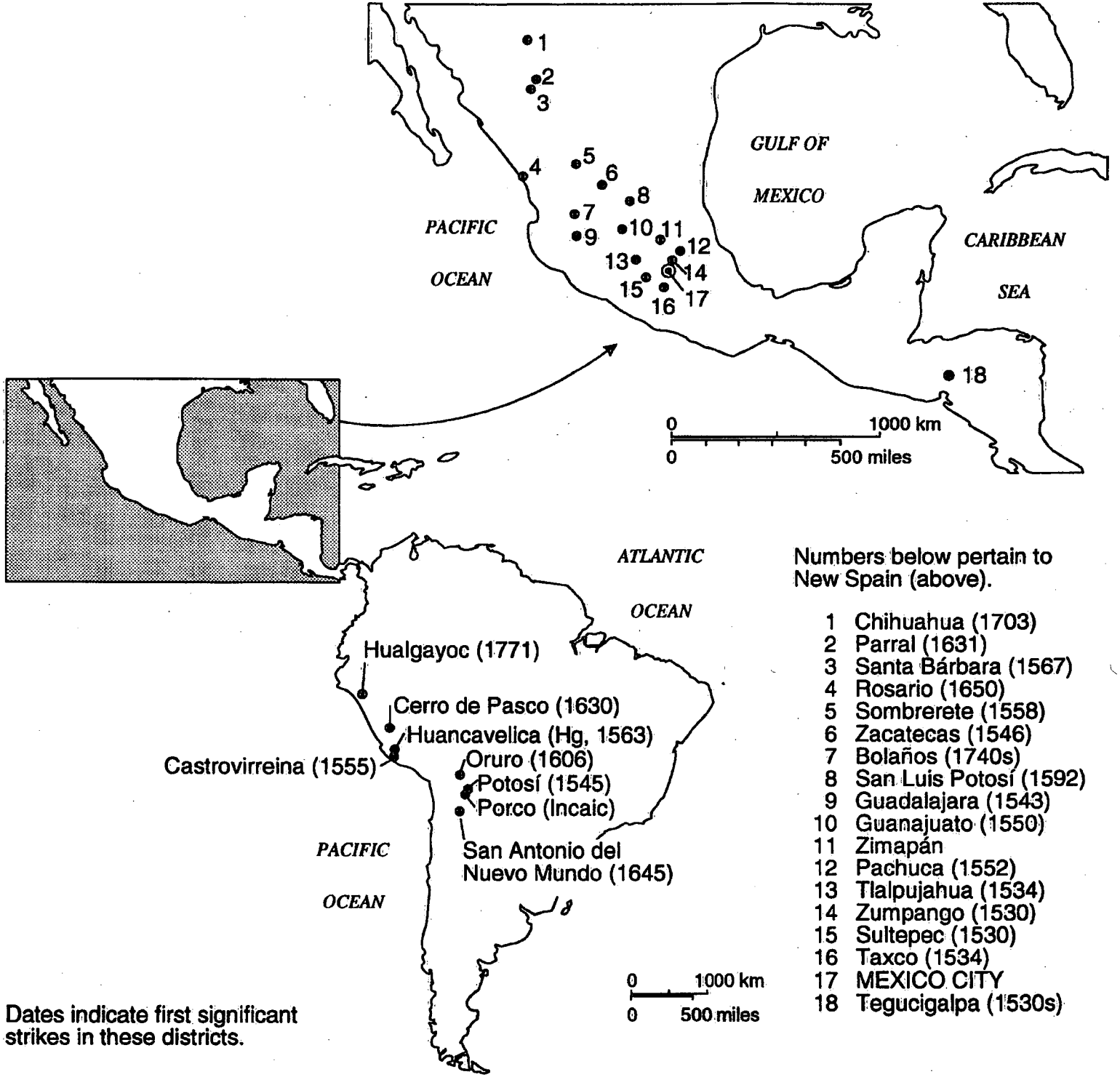
FIGURE CAPTIONS

Figure 1. Mercury losses from the refining of silver in colonial South America. Virtually all the mercury produced from the Huancavelica and Almaden mines went to the silver mines of South America; the consumption and discharge of mercury each year is derived from the mercury output by the Huancavelica mines, 85% of the output by the Almaden, and any imports from the Idrija mines. Based on various compilations especially those in refs. 2-7, 9-13.

Figure 2. Major silver mining centers in colonial South and Central America (based on refs. 3, 12, 19)

Mercury discharge from silver mining in Colonial S. America





Dates indicate first significant strikes in these districts.

Numbers below pertain to New Spain (above).

1 Chihuahua (1703)
2 Parral (1631)
3 Santa Bárbara (1567)
4 Rosario (1650)
5 Sombrerete (1558)
6 Zacatecas (1546)
7 Bolaños (1740s)
8 San Luis Potosí (1592)
9 Guadalajara (1543)
10 Guanajuato (1550)
11 Zimapán
12 Pachuca (1552)
13 Tlalpujahua (1534)
14 Zumpango (1530)
15 Sultepec (1530)
16 Taxco (1534)
17 MEXICO CITY
18 Tegucigalpa (1530s)

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