

COLOMBIA MERCURY INVENTORY 2011

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Abstract

Colombia has many occurrences of cinnabar, the ore of mercury, and in the ancient Andes, mercury was mined, retorted from cinnabar, and used for small-scale gold mining. However, La (Nueva) Esperanza, Dept. Caldas, Colombia's most well-known mercury mine, closed in the 1960s.

Mercury is acknowledged as a global contaminant by the U.S. Environmental Protection Agency, the U.S. State Department, the United Nations Environmental Program, and many other world organizations and Colombia is one of the top three users of mercury in the world. The Government of Colombia is concerned about environmental contamination from mercury releases and has attempted to reduce the use of mercury for small-scale gold mining from 140 t/yr to 70 t/yr. The United Nations Industrial Development Organization (UNIDO) planned to invest \$US1.7 million dollars to help reduce the use of mercury in Colombia.

In 2011, Colombia imported mercury from Mexico (23 t) and Spain (21 t) and the mercury was used for small-scale gold mining, chlor-alkali production, and neon lighting. In Remedios, Dept. Antioquia, in north-central Colombia, and Dept. Chocó, western Colombia, alluvial gold (Au-Ag-Pt) is produced by mercury as well as non-mercury "green gold" methods. Many of the gold shops where the gold-mercury amalgam is burned have water traps to capture the mercury that is volatilized when the amalgam is burned. In Remedios, simple ball-mills, or entables, also use mercury to amalgamate the fine-grained alluvial gold before burning. Collaboration with Japanese researchers and the efforts of Universidad Nacional de Colombia (CIMEX) scientists in Medellín has resulted in reduction in the use of mercury at intermediate-sized gold mines in Depts. Nariño and Antioquia. In Dept. Chocó, the use of mercury with dredges and sluices, which also cause increased sediment load in the rivers, has decreased.

There is one mercury-cell chlor-alkali plant in Colombia and some of the mercury is recycled in-plant. Mercury imported in fluorescent and CFLs, dental amalgam capsules, thermometers, batteries, light-up kid's shoes and toys commonly ends up in the wastestream and is not recycled. Some mercury-containing material may be encapsulated and then placed in landfills. Increased gold prices, to >\$US1,500 per troy ounce in 2011, continue to drive the use of mercury and the rise in mercury prices to >\$US3,000 per 34.5 g flask.

Key words: mercury, gold, green gold, environment, retorting, amalgamation

Resumen

En Colombia, se encuentran muchos afloramientos de cinabrio, la mena de mercurio. En tiempos prehispánicos, el mercurio fue usado para la minería de oro a pequeña escala y el cinabrio fue usado en rituales funerales. La mina principal de mercurio en Colombia, La (Nueva) Esperanza, Departamento Caldas, fue cerrada en los 1960s.

Pero hoy día, agencias internacionales como el U.S. Environmental Protection Agency, el U.S. State Department, y el United Nations dicen que el mercurio es un elemento muy tóxico al medio ambiente y al ser humano. Colombia es uno de los tres líderes mundiales en el uso del mercurio. A causa de los efectos del mercurio en el medio ambiente y en el ser humano, el gobierno Colombiano quiere reducir el uso de

mercurio, de 140 t/a hasta 70 t/a. UNIDO (United Nations Industrial Development Organization) quiere invertir \$US1.7 millones para reducir el uso de mercurio en Colombia.

En 2011, Colombia importó mercurio de México (23 t) y España (21 t) para uso en minería a pequeña escala, producción de cloro, y lámparas con neón. En Remedios, Departamento de Antioquia, en el norte de Colombia y en el Departamento de Chocó en el oriente, se usa mercurio para agarrar oro (Au-Ag-Pt) y también se usan métodos sin mercurio para producir “oro verde.” Muchos de los talleres de oro tienen trampas, con agua, para retener los vapores de mercurio después de quemar (refogar) la amalgama (Hg-Au). También, en Remedios, Departamento Antioquia, se usan entables, con mercurio para amalgamar el oro fino de los aluviones. Estudios realizados por científicos japoneses e investigaciones de los científicos de la Universidad Nacional (Laboratorio CIMEX) en Medellín han dado como la disminución del uso del mercurio en minas de oro a mediana escala en los Departamentos de Nariño y Antioquia. En el Departamento Chocó, el uso de mercurio con las dragas, que también dejan muchos sedimentos de grano fino en los ríos, se ha reducido. En Colombia, hay solamente una planta de cloro que también usa y recicla mercurio. Colombia no tiene plantas de reciclaje para productos como lámparas fluorescentes, amalgama dental, termómetros, juguetes, y zapatos de niños. Por consiguiente, la mayoría de los residuos con mercurio se disponen en la basura o quizás en los rellenos sanitarios. También, hay evidencia de la explotación de oro en minería a pequeña escala para financiar las actividades de los grupos al margen de la ley. A causa del incremento en los precios de oro, >\$US1500 por onza troya en 2011, se incrementó el precio de mercurio llegando a un valor de >\$US3000 por frasco (34.5 kg).

Palabras claves: mercurio, oro, oro verde, medio ambiente, refogado, amalgamación

INTRODUCTION

In 2001, the Global Environment Facility funded studies of mercury use for small-scale gold mining in 6 countries from 3 continents. In 2004, in Buenos Aires, Argentina, a United Nations Environmental Programme-Chemicals (UNEP-Chemicals) workshop indicated a need for data and information on the use of mercury for small-scale gold mining in South America, human health issues, mercury releases, and regional mercury pollution. Minimizing mercury contamination in the Amazon Basin was the theme of meetings held in Rio de Janeiro, Brazil, in December 2004 and in Lima, Perú, in February 2005. In 2007, the U.S. Department of State documented the reduction of mercury emissions in the U.S. and indicated that the United States should take a leadership role in addressing global mercury risks (U.S. Department of State 2007).

In response to the need for mercury information, the U.S. Embassy, Lima, Perú, proposed an in-country mercury inventory. Perú is a leading producer and exporter of mercury, produced as a byproduct from its gold-silver-copper mines—and mercury is also imported and used for small-scale gold mining (Brooks *et al.* 2007). Perú is the leading producer of gold in Latin America and produced approximately 164,000 t of gold in 2010, of which, approximately 19,000 t,

or 12%, came from small-scale gold mines (Gurmendi 2010, table 1).

In 2008, after successfully applying mercury emission reduction technology in gold shops in Brazil, the U.S. Environmental Protection Agency (EPA) brought its technical experience to Perú (Habegger *et al.* 2008). The EPA partnered with the U.S. Embassy, Lima, the U.S. Geological Survey (USGS), and Peruvian Government officials and now Perú has become a regional leader in reduction of mercury emissions from the gold shops. Perú's byproduct mercury is now voluntarily shipped to Germany for stabilization with sulfur, as artificial cinnabar, and storage in salt mine repositories (DELA GmbH 2011).

International trade data showed that Colombia imported a total of 84 metric tons (t) of mercury in 2011, mainly from Mexico (23 t), Spain (21 t), and the U.S. (14 t) (table 1) (Brooks 2012); this is a 26% decrease from the 113 t imported in 2010. Site visits and interviews provided information on the use and disposition of mercury for small-scale gold mining and other applications.

Colombia also imports mercury-containing batteries, electronics and computers, compact fluorescent lamps (CFLs), standard fluorescent lamps, and thermometers.

Table 1. Colombia Import Statistics, Mercury, 2006-2011.

(Data provided by U.S. Embassy, Bogotá, Colombia, from Global Trade Information Services, Inc., accessed April 26, 2012 via <http://www.gtis.com>.) a. Data in metric tons (t) b. U.S. dollars

Colombia Import Statistics							
Commodity: 280540, Mercury							
Annual Series: 2006 - 2011							
Partner Country	Unit	Quantity					
		2006	2007	2008	2009	2010	2011
World	T	62	71	79	130	113	84
Germany	T	2	6	9	9	39	3
Hong Kong	T	0	0	0	0	0	3
Italy	T	0	0	0	0	0	0
Japan	T	0	0	0	0	3	11
Kyrgyzstan	T	0	0	1	0	4	9
Mexico	T	3	12	13	25	5	23
Netherlands	T	22	28	25	48	25	0
Peru	T	4	0	0	0	0	0
Russia	T	0	3	3	0	0	0
Spain	T	27	9	19	14	31	21
United Kingdom	T	0	1	1	0	0	0
United States	T	4	12	7	34	7	14

Table 1b

Colombia Import Statistics						
Commodity: 280540, Mercury						
Annual Series: 2006 - 2011						
Partner Country	United States Dollars					
	2006	2007	2008	2009	2010	2011
World	1,154,001	1,225,399	1,598,880	2,403,778	3,440,470	5,352,251
Germany	33,442	88,267	167,283	166,802	1,215,033	210,590
Hong Kong	-	-	-	-	-	210,257
Italy	193	417	224	196	-	-
Japan	-	-	-	-	108,226	766,482
Kyrgyzstan	-	-	30,861	-	81,235	537,190
Mexico	63,427	218,214	237,052	462,401	188,184	1,533,333
Netherlands	407,748	452,270	515,606	808,428	659,333	-
Peru	26,792	-	-	-	-	-
Russia	-	58,851	71,706	-	-	-
Spain	536,263	163,060	402,652	298,983	947,988	1,131,429
United Kingdom	-	16,462	30,012	-	-	3,207
United States	86,136	227,858	143,483	666,968	240,470	959,762

In 2011, Colombia imported approximately 10,481,769 units of a wide variety of fluorescent lamps (does not include CFLs) (table 2); however, none of the mercury contained in these lamps (a minimum estimate of ~1 t), and in other products such as batteries, computer electronics, or dental amalgam is recycled. Some of that mercury-containing waste may be contained in landfills; however, much of the mercury contained in fluorescent lamps, which may be easily broken, or in mercury-containing dental amalgam, may ultimately be released to the environment.

FOCUS ON COLOMBIA

Colombia was selected for this inventory because:

- Colombia has numerous cinnabar, mercury, and placer gold-silver-platinum occurrences (Mutis Jurardo 1983)
- Colombia has a long history of ancient and colonial mercury production and use for small-scale gold mining (Restrepo 1884; Fetzer 1938; West 1952; Wokittel 1958a,b; Brooks *et al.* 2011)
- Colombia is an important importer and user of mercury for small-scale gold production (Viega 1977, 2010)
- guerilla and paramilitary groups are using the gold from the small-scale mines in Colombia to finance their operations
- Colombia has a growing gold-silver-copper exploration sector (Delgado 2010a), and therefore, the potential for byproduct mercury production
- Dept. Antioquia, one of the main gold-producing regions of Colombia, with 15,000 to 30,000 small-scale miners, may release 50-100 t of mercury annually to the environment from numerous small-to-medium scale gold mines that use mercury (Metal-Pages Ltd. 2010; Viega 2010).

Mercury's chief use in Colombia is for small-scale gold mining—placer gold (with silver, as electrum) and platinum, specifically in Dept. Chocó, Colombia, were the main source of precious metals used by ancient Colombians (Bergsöe 1937; Macdonald 1960; Boyle 1979, p. 333; Scott & Bray 1980; Bray 1988) and these alluvial occurrences still account for a significant portion of the approximately 53,600 kg of gold, 15,300 kg of silver, and 990 kg of platinum produced in Colombia in 2010 (Wacaster 2011). Mercury used in batteries, chlor-alkali production, dental amalgam, fluorescent lights, neon lights, switches, and thermometers, can be recycled or landfilled (Brooks & Matos 2005); however, only a

small amount of the mercury used for small-scale gold mining is recycled—most is released to the environment as mercury vapor from burning the mercury-gold amalgam to recover the gold, or the mercury is lost directly into the rivers and streams at the mines.

Human Health

Exposure to mercury and mercury vapors released from burning the mercury-gold amalgam is a significant environmental and human health concern (Brooks *et al.* 2007, figure 2). Effects include brain, kidney, and nerve damage, blindness, memory problems, irritability, and tremors (ATSDR 1999; Gutierrez de Salazar 2010). Miners and gold shop workers with these symptoms are said to be mercury-intoxicated, or *azogado* (from *azogue*, an Arabic word for mercury that is commonly used in South America). Anecdotal effects may also include anemia, diarrhea, excessive salivation, hair loss, heart irregularities, loose teeth, premature aging, and sexual dysfunction (Catorce 6 2007; Sertox 2010; Flores 2011; Millan 2011; Siegel 2011). A researcher indicated that approximately 15 mercury-related kidney transplants take place in the gold mining town of Remedios, Dept. Antioquia, each year (Delgado 2010b). The high incidence of craniofacial malformations in children born in gold-mining areas in Dept. Bolívar, Colombia is possibly linked to mercury exposure; however, other environmental causes must also be considered (Berrocal Revueltas *et al.* 2003).

In ancient Perú, the health hazards of mercury were understood by the Inka (~AD 1200-1533) who recognized that exposure to mercury during cinnabar mining and mercury retorting would cause the ancient Peruvian miners “to shake and lose their senses” and, therefore, the use of mercury declined (Larco Hoyle 2001, p. 135). At about the same time in Europe, Agricola (1556/1912) described methods for retorting mercury and workers were warned to turn their backs to the sweet smelling mercury fumes that would loosen their teeth. A number of health disorders were related to mercury exposure and, in the 1950s, “dancing cats” were evidence of the nerve damage in cats that had eaten mercury-contaminated fish from Minamata Bay, Japan (D'Itri & D'Itri 1977; Aronson 2005).

Because of the mercury released during small-scale gold mining along the Dagua River, Colombia, university researchers have documented high levels of mercury in fish in Buenaventura Bay where the Dagua empties into the Pacific Ocean (Kraul 2011). Hair mercury analysis was carried out on 219 people, mainly fishermen, who consumed fish from streams that were downriver from one of Colombia's small-scale gold mining areas in Dept.

Table 2. Colombia Import Statistics, Fluorescent Lamps, 2006-2011.

(Data provided by U.S. Embassy, Bogotá, Colombia, from Global Trade Information Services, Inc., accessed April 26, 2012 via <http://www.gtis.com>.), units of straight fluorescent lamps b. U.S. dollars

Colombia Import Statistics							
Commodity: 8539311000, Tubulares Rectos							
Annual Series: 2006 - 2011							
Partner Country	Unit	Quantity					
		2006	2007	2008	2009	2010	2011
World	NO	0	6,548,685	7,017,169	5,938,499	7,581,239	10481769
Argentina	NO	0	-	-	-	28	0
Belgium	NO	0	233	7,890	200	5,329	26228
Brazil	NO	0	347,707	578,837	629,384	396,299	361835
Canada	NO	0	6,338	63,856	70,359	234	5
Chile	NO	0	1	-	-	-	0
China	NO	0	1,284,611	1,861,036	1,799,453	3,600,564	6016356
Denmark	NO	0	-	-	2	24	0
Ecuador	NO	0	-	-	2,000	-	134
France	NO	0	5,746	5,616	4,825	788	905
Germany	NO	0	1,203,546	1,169,646	109,672	423,193	1473678
Hong Kong	NO	0	240	42,200	94,620	6,402	23990
Hungary	NO	0	154,204	214,711	247,305	141,676	10744
India	NO	0	-	66,000	-	-	0
Indonesia	NO	0	-	-	-	11	3246
Italy	NO	0	5,456	223	310	134	1097
Japan	NO	0	3,226	361	909	4,946	599
Korea South	NO	0	1	-	-	-	0
Luxembourg	NO	0	-	-	22	-	0
Mexico	NO	0	376,035	507,765	385,093	18,456	19758
Netherlands	NO	0	154,855	45,026	229,522	254,130	399233
Panama	NO	0	-	11,016	-	20,000	0
Peru	NO	0	-	8,500	7,560	9,690	8
Poland	NO	0	29,167	10,818	36,637	8,314	375
Reunion	NO	0	-	-	-	118	0
Romania	NO	0	1	-	-	-	0
Slovakia	NO	0	-	4	-	-	0
Spain	NO	0	-	3	3,187	5,520	6222
Sweden	NO	0	4	1	-	-	0
Switzerland	NO	0	-	-	292	2	18
Taiwan	NO	0	3,850	-	10	1,419	0
Thailand	NO	0	-	750	17,208	1,255	3000
United Kingdom	NO	0	3,374	723	81	266	2754
United States	NO	0	2,970,090	2,422,187	2,299,848	2,628,991	2131584
Uruguay	NO	0	-	-	-	53,450	0

Colombia Import Statistics						
Commodity: 8539311000, Tubulares Rectos						
Annual Series: 2006 - 2011						
Partner Country	United States Dollars					
	2006	2007	2008	2009	2010	2011
World	-	5,656,566	6,142,130	5,527,906	5,394,099	7,212,519
Argentina	-	-	-	-	225	-
Belgium	-	1,396	21,545	254	15,279	45,343
Brazil	-	176,791	340,978	454,123	240,175	227,619
Canada	-	6,038	82,719	93,802	1,538	39
Chile	-	111	-	-	-	-
China	-	1,060,400	1,263,913	1,040,028	1,782,830	2,900,726
Denmark	-	-	-	502	1,015	-
Ecuador	-	-	-	4,586	-	325
France	-	28,084	19,387	8,330	2,277	4,297
Germany	-	1,003,281	942,197	178,302	380,050	1,215,553
Hong Kong	-	989	25,568	47,391	18,625	32,273
Hungary	-	258,699	339,700	293,349	185,082	11,220
India	-	-	28,781	-	-	-
Indonesia	-	-	-	-	669	5,541
Italy	-	7,233	1,073	1,864	1,515	2,682
Japan	-	13,281	16,855	10,833	29,113	12,552
Korea South	-	15	-	-	-	-
Luxembourg	-	-	-	51	-	-
Mexico	-	292,812	426,824	424,729	38,288	49,630
Netherlands	-	392,698	86,413	379,442	419,255	728,806
Panama	-	-	22,328	-	8,022	-
Peru	-	-	16,870	5,150	8,985	651
Poland	-	53,337	28,197	72,739	18,890	1,337
Reunion	-	-	-	-	11,359	-
Romania	-	264	-	-	-	-
Slovakia	-	-	289	-	-	-
Spain	-	-	727	5,435	10,670	6,270
Sweden	-	175	5	-	-	-
Switzerland	-	-	-	1,252	716	1,390
Taiwan	-	2,030	-	6	14,627	-
Thailand	-	-	1,531	19,633	2,136	5,617
United Kingdom	-	17,572	15,060	3,151	7,423	19,576
United States	-	2,341,362	2,461,171	2,482,957	2,157,779	1,941,075
Uruguay	-	-	-	-	37,558	-

Chocó. The data indicated higher levels of mercury in samples from the fishermen that were significantly different when compared to the control groups, and the fishermen also suffered from headaches, irritability, memory loss, metallic taste, and oral lesions (Olivero *et al.* 1995).

In the San Juan district, Dept. Chocó, a study of the blood, hair, and urine of 70 people who were exposed to metallic mercury or mercury vapors as a result of small-scale gold mining and related activities indicated that 9 subjects were not contaminated, 56 were contaminated, and 4 showed signs of chronic mercury intoxication (Medina Mosquera *et al.* 2011).

Near Santa Marta, a coastal town in northern Colombia, the mercury content of sediments and fish muscle from two species was determined. High mercury concentration was found in sediments near the sewer discharge from a closed chlor-alkali plant and high mercury concentration was also found in omnivorous fish species when compared to bottom-feeding species (Alonso *et al.* 2000).

Mercury may also be a part of some Caribbean and Latin American cultural and religious practices. In Colombia, mercury may be used in amulets for good luck (Margarita Gonzales, environmental geologist, Ministry of Mines and Energy, Bogotá, oral communication, February 24, 2010). These uses may also include burning mercury in a candle or sprinkling mercury on the floor and can result in high levels of indoor mercury (Riley *et al.* 2001).

Government Efforts and Legislation

Colombia is a significant importer of mercury that is used mainly for small-scale gold mining and chlor-alkali production. In 2007, the Colombian Government, in collaboration with the United Nations Industrial Development Organization (UNIDO) announced a plan to invest US\$1.7 million, over a 5-year period to reduce the use of mercury from approximately 140 t to 70 t annually (El Colombiano 2007).

Through Decree 1594 (1984) Rules of Natural Resource Management, the Government of Colombia established strict limits on mercury in water. Studies were carried out to reduce mercury releases from small-scale gold mining and specific recommendations were put in place in Depts. Antioquia, Caldas, Cauca, Cordoba, and several other Departments. A Government study indicated that a number of common mining practices actually increased mercury releases in the mining areas, these included: unknown character of the mineralogy of the deposit, open-circuit amalgamation, disproportionate

use of mercury, use of low quality mercury, and lack of knowledge of clean-gold recovery methods. Researchers have since attempted to teach and apply clean-gold technology methods (Ministerio de Ambiente 2007; Ministerio de Minas y Energía 2007).

In a similar study of the use of mercury and cyanide for small-scale mining, recommendations included elimination of toxic substances in mining, use of clean-gold technology, and most importantly, relocation of the gold shops, where the amalgam is burned, away from urban areas (Unidad de Planeación Minero Energética 2007).

In 2009, Colombia was one of a number of countries to sign a legally binding treaty with the United Nations Environmental Programme to reduce mercury contamination. At a follow-up session in Japan in 2011, objectives included: increased awareness and exchange of scientific information; reduced international mercury trade; reduced mercury supply; treatment of mercury waste; and contaminated site remediation (United Nations Environment Programme 2011).

Under a new competitive process beginning in 2013, Colombia will award mining concessions and in the first year, 20% of mineral lands set aside by the Government will become available; including concessions that contain gold, silver, coal, and other resources. Colombia's mining code will be revised so as to revoke titles for assets that have been improperly explored or developed. The revised code, due before the Colombian Congress in July 2012, will also give the Colombian Government more power to shut down illegal miners, many of whom use mercury or otherwise contribute to environmental degradation, and destroy their equipment (Gordon 2012).

On November 2, 2012, the President of Colombia signed Decree 2261 against illegal mining (Decree Against Illegal Mining 2261, 2012). The main objectives of Decree 2261 include: 1) license requirements for importation of heavy machinery and chemical substances; 2) regulations on the possession, storage, and transportation of mercury, cyanide, and arsenic; and 3) import permits are for a maximum of two years. This Decree will regulate mining and its negative effects on the environment at the national level instead of leaving control to local administration.

Minerals, Guerilla, and Paramilitary Groups

The President of Colombia has taken a strong position against small-scale gold mining because, similar to the siphoning of funds in the Congo from small-scale columbium-tantalum (col-tan) mines (Vick 2001), gold from Colombia's numerous gold occurrences (Lozano

& Pulido 1987) has been used to fund the operations of paramilitary and guerilla groups (al Jazeera 2011; Mining Journal 2011a; Albiñana 2012).

In 2002, guerillas in Colombia numbered approximately 18,000 and now that number is down to approximately 8,000 as the President of Colombia has led a crackdown in central Colombia which is also an important small-scale gold mining region (The Economist 2011). Turf wars have erupted for control of the mining areas and leaders of the two main groups, FARC (Fuerzas Armadas Revolucionarios de Colombia) and ELN (Ejército de Liberación Nacional) reached a cease-fire and established an agreement over control of small-scale mining in the border areas between northeastern Dept. Antioquia, southern Dept. Bolivar, and northwestern Dept. Santander (El Tiempo 2012b).

In 2011, The Colombian Chamber of Mining estimated that the mining industry will lose US\$560,000 as small-scale miners are forced into supporting the guerilla groups. Security “fees” and mining equipment “taxes,” as much as US\$4,500 per bulldozer, are extorted from the small-scale miners by FARC, the Oficina de Envigado, the Paisas, the Rastrajos, the Urabeños, or other groups. With gold prices at almost US\$1,500 per troy ounce in 2011, the local population is attracted to the profit and simplicity of small-scale gold mining: however, these miners have no protection from the Government and are obliged to pay protection fees to the guerilla groups, and then, the miners are marginalized for their alleged support of the rebel groups (Lopez-Gamundi 2011; Kosich 2011). As an example, in an effort to control small-scale or illegal mining, 110 miners were charged with environmental crimes and their bulldozers, tractors, dredges, and 100 kg of mercury were seized in 6 Departments in Colombia through early 2011 (America Economia 2011).

Mercury Reserves

The Government of Colombia maintains no stockpiles nor mercury reserves; however, for comparison, 4,436 t of mercury are held the U.S. Department of Defense and 1,329 t of mercury are held by the U.S. Department of Energy (Brooks 2012).

Mercury-cell technology is used by Brinsa S.A. (Dept. Cundinamarca, Colombia) to produce salt, cleansers, chlorine, and caustic soda; however, the amount of mercury in the cells, or stocks on hand, was not available. An unknown amount of mercury was also on hand at dental supply shops, dentists’ offices, laboratories, museums, neon lighting shops, and importers in Colombia (figure 1).



Figure 1a. Quimicos Campota mercury for sale



Figure 1b. Quimicos Campota Almaden (black) EEUU (gray)

OCCURRENCES OF CINNABAR AND MERCURY IN THE REGION

Cinnabar mining and mercury retorting date to 1000 BC in Mexico (Langenscheidt, 1986; Consejo de Recursos Minerales 1992, p. 27; Martino *et al.* 1992, p. 82) and Barba & Herrera (1988) describe cinnabar mining, processing, and details of the ancient ceramic vessels used to retort mercury at San José Ixtapa, Querétaro, Mexico. In Central America, cinnabar occurrences are also known (Roberts & Irving 1957) and native mercury was found in a tomb in Belize that dates to AD 900–1000 (Pendergast 1982). There are also cinnabar and mercury occurrences in Bolivia (Barba 1640/1923; Ahlfeld & Schneider-Scherbina 1964); Chile (McAllister *et al.* 1950; Ruiz Fuller 1965); Ecuador (Truhan *et al.* 2005); and Perú (Petersen 1970/2010; Nuñez & Petersen 2002); one of the world’s largest cinnabar occurrences is at Huancavelica, Perú (Arana 1901; Yates *et al.* 1955; Brown 2001).

Cinnabar and Mercury Occurrences in Colombia

In the early 1800s, cinnabar samples were given to German explorer Alexander von Humboldt and cinnabar was supposedly found near Monserrate, near Bogotá (Ibáñez 1919). Cinnabar was also described from Dept. Tolima (Scheib 1922).

Cinnabar and mercury occurrences in Colombia are numerous: Depts. Antioquia (4), Boyaca (2), Caldas (12), Cauca (2), Cordoba (1), Nariño (7), Quindio (2), Risaralda (1), Santander (5), Sucre (1), Tolima (4), and Valle (2) (Lleras Codazzi 1930; Mutis Jurado 1983; Lozano 1987). And, of the above occurrences, native mercury was specifically indicated in Depts. Caldas (5), Nariño (3), Quindio (1), Santander (1), and Tolima (2) (Mutis Jurado 1983).

However, there was only limited mercury exploitation in Colombia through the 1940s (Wilson 1941), and, in 1948, Mina La (Nueva) Esperanza, Aranzazu, Dept. Caldas, was opened and its mercury (figure 2) supplied Colombia. The mine is now closed and there is no small-scale mercury production in the region. Geochemical exploration for a variety of metals including gold, silver, and mercury also took place in Depts. Quindio and Tolima (Lozano *et al.* 1984a,b) and occurrences of anomalous concentrations of mercury in soil throughout Colombia were compiled by Ingeominas (2003).

In 2012, only one company, Icobandas, S.A., in Popoyán, was listed as providing mercury ore in Colombia (Mining1 2012).

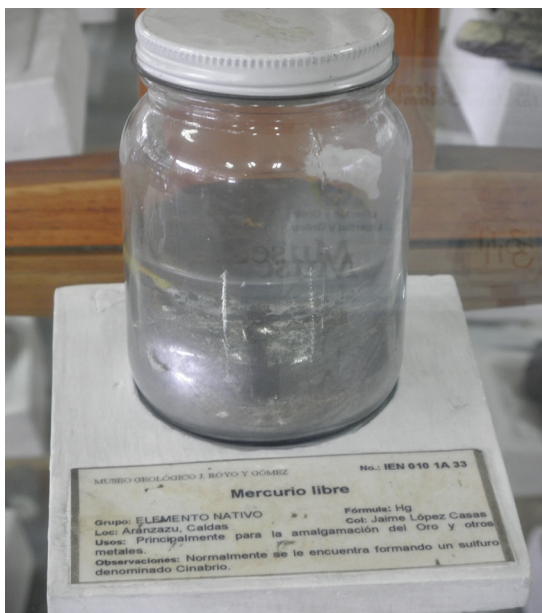


Figure 2a. Native mercury



Figure 2b. Mina La Esperanza quartz vein with cinnabar

Mercury Occurrences as Gold Exploration Targets

Gold mineralization was discovered at the Manhattan mercury mine in California, U.S.A., in 1978. The discovery of the gold mine resulted from exploration directed at mines and hot springs with mercury mineralization in precious metals districts. The exploration program included surface mapping and sampling to detect ore-grade gold mineralization, drilling of 400 holes, and metallurgical test work. The mine was described as a mercury-bearing, epithermal hot-springs gold deposit that contained 3,000,000 troy ounces of gold, and in 1982, annual production was 250,000 troy ounces of gold. In the early 1990s, when the price of gold was \$360-\$380 per troy ounce, mine life was predicted to be 20 years (Gustafson 1991).

Therefore, given the number of mercury occurrences in Dept. Caldas (12), including the La (Nueva) Esperanza mercury mine, regional alluvial gold occurrences, Colombia's ancient and modern gold production, and the proximity to the Marmato gold mine, then exploration and sampling at these mercury occurrences, may result in new gold targets and discoveries.

Ancient Use of Cinnabar and Mercury

Early man's mining and use of cinnabar and mercury date to 8,000 years ago in Turkey (Barnes & Bailey 1972). And, in South America, at the Museo Gustavo Le Paige, San Pedro de Atacama, northern Chile, several gold artifacts (500-900 A.D.) are covered with a red ochre (cinnabar?). In ancient Perú, blood-red cinnabar was mined and used as a decoration on gold masks (Gordus & Shimada 1995); as a pigment (Petersen 1970/2010, p. 80; Bonavia 1985; Brooks *et al.* 2008); as a cosmetic for the elite Inka women (Brown 2001); and for funeral preparations (Shimada & Griffin 2005).

Mercury was used by the Moche (100 B.C.-A.D. 750) to amalgamate placer gold in northern Perú (Larco Hoyle 2001) and Cabrera La Rosa (1954) proposed that ancient Peruvian miners retorted mercury from cinnabar for mercury-gold amalgamation. Isotopic data on mercury in lake sediments indicate that cinnabar mining at Huancavelica, Perú, began around 1400 BC and that production peaked at approximately 500 BC and again at AD 1450, corresponding: 1) to the heights of Chavin and Inca rule, respectively, in the region (Cooke *et al.* 2009), and, 2) a peak in Inca gold mining (Petersen 1970/2010).

In contrast, even though cinnabar is widely available in Colombia (Mutis Jurardo 1983), thus far, there is only limited evidence of its use as a decorative pigment in ancient Colombia. For example, there are no clear descriptions of cinnabar associated with ancient Colombian burials described by Rojas de Perdomo (1985) nor Reichel-Dolmatoff (2005); however, Silva Celis (1981) provides the following details from an ancient burial near Soacha [translation]:

“Among the scattered bones, appear fragments of larger bones (femur, tibia, humerus) and skulls corresponding to adults and the surfaces of these bones have been colored with a red mineral ochre.

There is another instance of the application of a red mineral substance to Chibcha cadavers. An example of this is from a pre-Columbian cemetery that was excavated several years ago near Soacha. There, in rectangular tombs, were found the bones of three skeletal females and two new-borns, all with limbs extended in exact anatomic position. These bones also showed the red pigment exactly as those at the Infiernito site. As at Soacha, at Villa de Leiva, there is also a red material on the bones. The natural decay of the soft tissue, which was once covered with a red mineral powder, has resulted in the red material now being in direct contact with the bones. There are several references to this cultural practice in the pre-Columbian tombs at Tinjacá, Tunja, and Sutamarchán.

The funerary custom of painting the body with a red mineral substance was also noted by Father Pedro Simon and was used for those who had died from fever, dysentery, in battle, or women who had died in childbirth. Additionally, the face was painted red and the tomb was perfumed.

The Chibchas also used the color red as a sign of grief or mourning as was done for the death of Chief Nemequene. Colored cloaks were worn and the face was painted red in sympathy and mourning for the deceased king. The practice of partial or total painting the body with red ochre before or during

the burial was also practiced widely by native Americans.”

In the above, even though cinnabar was not specifically identified, the use of cinnabar, because of its toxicity and preservative qualities (Sax 1984, p. 1,756), has similarly been described from ancient burials in Turkey (Barnes & Bailey 1972), Greece (Maravelaki-Kalaitzaki & Kallithrakas-Kontos 2003), and Perú (Shimada & Griffin 2005). Therefore, because of the association of cinnabar with other ancient burials, it would be useful to obtain samples of Silva Celis' (1981) *red ochre* material for mineralogical identification by x-ray diffraction.

Many gold funeral masks from Perú are decorated with cinnabar (Carcedo Muro & Shimada 1985); however, no cinnabar is present on the many gold funeral masks, or other gold artifacts, on display at the Museos del Oro in Bogotá, Cartagena, or Santa Marta. Perhaps cinnabar simply was not widely used in ancient Colombia? Or if used, perhaps the cinnabar was removed during preparation? A photograph of a winged pre-contact copper-gold figure from the Museo del Oro, Bogotá, shows reddish stains and splotches that *may* be cinnabar (figure 3; Plazas & Falchetti 1985, p. 53).



Figure 3. Copper-gold pendant (3.038 Museo del Oro, Bogota)

Native mercury was available, for example, at Mina La (Nueva) Esperanza (Lozano *et al.* 1984b), and old (*antiguas, viejas amalgamadoras*) workings are indicated in Dept. Santander; however, it is not clear if these are pre-contact or colonial (Mutis Jurardo 1983).

And, in the 1750s, mercury was used to amalgamate ore from the gold-platinum placers in Dept. Chocó, Colombia (Juan & de Ulloa 1748/1807, p. 606).

Geochemical studies of ancient gold artifacts from Perú, Ecuador, and Colombia all indicate similarly low levels of mercury, less than 20 parts per million (ppm), whereas alluvial gold may contain from 1,000 to 10,000 ppm mercury and amalgam may contain as much as 300,000 ppm mercury. This comparative research indicates that mercury was used to amalgamate and burn (*refogado*) gold from small-scale mines in the ancient Andes, and the mercury content of the amalgam was greatly reduced by applying heat from a *soplete*, or blowtorch, much as is done today at small-scale gold mines in Colombia, Ecuador, Perú, and Venezuela (Brooks *et al.* 2011).

Mercury Production

Mercury is retorted from, or is found as a native metal in association with cinnabar [HgS]. It is a scarce metal that is silvery and liquid at room temperature in elemental form. It averages 0.05 ppm in the Earth's crust. Mercury's chemical and physical properties, isotopes, and other properties are given in DeVito & Brooks (2005).

The more common ore of mercury, cinnabar, is dark-red and soft, and may be associated with low-sulfidation epithermal mineral deposits worldwide; this is a type of hydrothermal mineral occurrence with a specific suite of minerals that forms at depths of less than 1 km and at temperatures of less than 300° C. Mercury ores may be found disseminated in fine-grained or brecciated volcanic rocks near volcanic centers, fossil hot springs, and intrusive rocks and may be any age from Silurian to Tertiary (Rytuba 1986).

Cinnabar may be mined by underground or open-pit methods, typically from depths of less than 350 m. There are numerous mercury occurrences in Colombia and the most well-known is Mina La (Nueva) Esperanza, Aranzazu, Dept. Caldas (Lozano *et al.* 1984b), which is now closed (figure 2).

In general, mercury ores may contain from 0.1 to more than 2% mercury; however, most economic ores contain more than 1% mercury. The ore is crushed, screened, and then heated in a retort or furnace with limited ore beneficiation. During retorting, mercury is released from the cinnabar, the mercury vapors cool, the mercury condenses, and is then collected. Other specialized methods include leaching, dissolution, and electro-oxidation (Nowak & Singer 1995). Mercury occurrences, as cinnabar, are known worldwide.

Byproduct Mercury Production

In 2011, world mine production of mercury was approximately 2,000 t and China was the leading producer (1,500 t) followed by Kyrgyzstan (250 t). However, mercury may also be produced as a byproduct from processing precious and base metal ores, for example, in Chile (100 t) (Brooks 2012). And of these occurrences, most byproduct mercury is produced from epithermal gold-silver-copper occurrences that may be found above a regional subduction setting as in the southwestern U.S. or western South America.

At Barrick's Pierina gold mine, near Huaraz in northern Perú, and at Newmont's Yanacocha gold mine, near Cajamarca, northern Perú, the gold-silver ore, which also contains mercury, is milled and then leached with cyanide to remove the metals. In the zinc precipitation process, also known as the Merrill-Crowe process, mercury is also precipitated with the gold and silver onto the zinc, and some of these precipitates may contain in excess of 20% mercury (Washburn & Hill 2003). A carbon-based extraction system is then used to recover the dissolved metals. The gold-silver-mercury amalgam, or Merrill-Crowe precipitate, is then sent to a large, on-site retort for step-heating, which will volatilize and remove the mercury from the gold-silver ore. The volatilized mercury cools, condenses, and then passes into a tank that is periodically tapped, and the mercury is drained into a 1 metric ton (t) container. The container sits in a larger, water-filled pan that will trap any droplets of mercury that may splash during tapping. The container has a 2-to 3-centimeter (cm) layer of water inside that keeps the mercury from volatilizing at ambient temperatures. The byproduct mercury may then be transferred to flasks for export and sale, and the gold-silver concentrate moves on for further treatment.

A number of health and safety measures are in place at the on-site retorts which are separate from other mine operations. The mercury flasks are drop-tested for security and measured for standard dimensions. After the flasks are filled, the mercury may then be chemically tagged, and the flask caps are double-sealed. The filled and sealed flasks are placed in a larger steel container, which has also been drop tested for security (Brooks *et al.* 2007). The container is then bolted shut before shipment and export of the mercury.

Since 1927, the common unit for measuring and pricing mercury has been the "flask," which was set to conform to the system used at Almaden, Spain (Meyers 1951). One flask weighs 34.5 kg, and 1 t of mercury contains approximately 29 flasks. The flask itself is a screw-top, welded-steel container that is approximately the size of

a 2-liter soft drink bottle. Examples of U.S. and Spanish flasks are shown in figure 1.

Potential for Byproduct Mercury Production in Colombia

In 2011, mining exploration spending in Colombia increased and Foreign Direct Investment (FDI) in Colombia more than doubled, to US\$14.4 billion, up from US\$6.8 billion in 2010, largely because of a campaign against paramilitaries and gangs that made it safer to do business. In percentage terms, Colombia's FDI of 211% was a regional leader; Chile's FDI increased by 16% and Peru's FDI increased by 8% (Gordon 2012).

- Colombia has an established gold-platinum sector (Engineering and Mining Journal 1994; Sutill 1994; Hernandez 2007; Berry 2010; Mining Journal 2011a; El Tiempo 2012a) and is now experiencing a mining boom. Newly found, and future gold-silver, epithermal deposits in Colombia, generated by regional subduction of the Pacific plate under the South American plate, and therefore comparable in regional tectonic setting (Bailey *et al.* 1973, p. 410) to byproduct-mercury producing precious metals mines in Perú and Nevada, will have the potential to produce byproduct mercury that will have to be managed.
- The growth in Colombia's mining sector is also indicated by the opening of a specialized assay lab in Medellín; previously samples were shipped to the U.S. or Perú (Chavez 2012).
- In the field, mercury-gold amalgam may contain as much as 300,000 ppm mercury; however, when the gold is burned, the mercury content is reduced (Brooks *et al.* 2011). Therefore, when the gold obtained from the small-scale mines is processed in the metallurgical laboratory, there may also be the potential for mercury recovery and sale.
- Even "green gold" that has been mined from alluvial sources without the use of mercury, contains mercury that must be removed from the gold; this mercury may also be recovered and sold. For example, alluvial "green gold" samples from Remedios, Dept. Antioquia and Quibdó, Dept. Chocó contained 208 ppm Hg and 575 ppm Hg, respectively, and an alluvial platinum sample from Quibdó contained 551 ppm Hg (table 3). The high mercury content of these samples may be the result of mercury released from centuries-old small-scale mining, detrital mercury from mercury occurrences, or from regional volcanism.

Mercury in Coal

Colombia is a significant global supplier of coal, yet in general, South America has only limited coal resources (Alvarado 1980). Mercury, arsenic, and other metals are contained in trace amounts in coal, and may be released into the environment when the coal is burned in a coal-fired powerplant. The quantity of mercury contained in coal is typically small and it is not produced; however, the volume of coal that is burned yearly indicates that tons of mercury may be released—this is a concern for the global environment and human health. Coal-fired powerplants in the U.S., for example, may release ~48 t of mercury annually (Gugliotta 2004).

Because of global concern for mercury emissions related to coal-burning, the U.S. Geological Survey, in cooperation with many of the world's coal producing countries initiated the World Coal Quality Inventory. Therefore, 16 samples from Colombia were obtained and analyzed for major, minor, and trace elements. The elements of concern for human health related to air pollution from coal-fired power plants, specifically arsenic and mercury, are low in the Colombian coal samples and half of the mercury values are below detection limits. With respect to mercury and arsenic content, Colombian coal does not appear to present any potential environmental or human health problems (Tewalt *et al.* 2006).

MERCURY PRICES

In 2001, the price of mercury sold in the U.S. was approximately \$155 per flask and in 2006 mercury sold for US\$670 per flask (Brooks 2010); however, by the end of 2011, the price of a flask of mercury on the global market was close to US\$3,500 or higher (Mining Journal 2011b).

At stores that supply the small-scale gold miners in Colombia (figure 4), mercury may be sold in 1 kg, or smaller, quantities and profit from this practice increases the overall value of the flask of mercury. The quality of the mercury may vary, from 99.9999% purity from recyclers and mercury dealers in the U.S., to recycled mercury with a dirty appearance. Prices vary widely depending on purity or perceived country of origin, for example, Spanish mercury typically demands a higher price (Brooks *et al.* 2007). Information on mercury prices is provided in the site visits.

Table 3. Geochemical Analyses (ICP) of Gold, Platinum (alluvial), and Cinnabar (vein) from Colombia.

	Rau	Qau	Qma	Qpt	Qind1	Qind2	Azz
Ag	308	415	7	107	2	9	0
Al	33.300	1.710	26700	19.300	33.600	23.500	55.800
As	1	680	410	5100	31	11	290
Au	552.000	819.000	15.700	248.000	62	424	2
B	4	3	3	760	6	13	12
Ba	8	7	100	11	93	67	7.600
Bi	3	0	11	3	3	3	0
Ca	34	30	816	1.810	3.700	8.300	22.100
Cd	0.7	0.9	05	8.5	0.4	1.2	2.2
Ce	1.350	10	310	20	450	250	20
Co	1.6	0.9	114	21	43.4	38.2	16.4
Cr	15	16	3.010	5.470	350	260	95
Cu	180	227	176	6.740	77	1.420	391
Dy	0	0	2	9	1	0	0
Er	0	0	3	6	5	4	1
Eu	0	0	0	0	0	0	0
Fe	1.680	1080	305.000	20.400	346.000	317.000	85.400
Ga	2	2	39	7	38	32	22
Gd	0	0	53	11	14	12	6
Hg	208	575	45	551	10	12	5.620
Ho	0	0	0	1	0	0	0
In	0	1	0	10	0	0	0
Ir	2	2	0	844	0	0	0
K	10	0	21	31	3060	1.560	9.650
La	0	0	0	1	5	2	2
Mg	12	17	2.360	388	3.610	2.580	7.910
Mn	2.130	3	4.340	149	1.150	747	238
Mo	0	2	7	1	6	1	4
Na	82	49	52	381	2.010	1.850	17.600
Nb	2	0	116	4	21	4	10
Nd	0	0	25	11	29	25	6
Ni	4	5	60	102	73	61	77
Os	0	1	0	70	2	3	0
P	4	22	175	37	816	308	896
Pb	28	9	106	5.720	20	24	3
Pd	2	24	34	1.960	0	0	0
Pr	0	0	0	1	1	0	0
Pt	452	585	4.860	147.000	0	0	0

	Rau	Qau	Qma	Qpt	Qind1	Qind2	Azz
Rb	0	0	18	0	8	7	0
Re	0	0	0	0	0	0	0
Rh	8	3	61	2.150	0	0	0
Ru	0	1	7	154	3	3	5
S	7	67	340	188	407.000	427.000	69.200
Sb	10	49	12	104	15	18	125
Sc	0	0	13	1	3	2	2
Se	0	4	3	0	7	1	0
Sm	0	0	5	4	8	6	2
Sn	1.300	340	80	2.340	3	4	0
Sr	1	0	2	2	101	46	148
Ta	0	0	0	0	0	0	0
Tb	0	0	0	0	9	6	10
Te	9	2	34	18	59	61	5
Th	0	2	128	60	119	134	43
Ti	49.300	2.590	143.100	69.200	6.670	6.350	2.250
Tl	0	1	3	1	2	3	1
Tm	0	0	0	2	0	0	0
U	0	0	31	1.040	55	49	20
V	6	11	1.080	39	297	66	84
W	7	1	2	365	5	2	0
Y	0	0	0	30	6	3	1
Yb	0	0	1	6	2	1	0
Zn	6	3	175	41	63	679	53
Zr	325.00	3.240	13.500	10.300	240	760	50

Rau-alluvial “green gold” concentrate, Remedios, Dept. Antioquia

Qau-alluvial “green gold” gold concentrate, Quibdó, Dept. Chocó

Qma-very magnetic concentrate, Quibdó, Dept. Chocó

Qpt-alluvial platinum concentrate, Quibdó, Dept. Chocó

Qind1-black, alluvial pan concentrate (jagua), Quibdó, Dept. Chocó

Qind2-black, alluvial pan concentrate (jagua), Quibdó, Dept. Chocó

Azz-quartz vein with cinnabar, pyrite, cutting volcanic rocks with propylitic alteration in Quebrada Chupadero, La (Nueva) Esperanza mercury mine, Aranzazu, Dept. Caldas

Because of security concerns, samples were obtained in shops in the respective towns and not in the field. Inductively Coupled Plasma analysis, in parts per million (ppm), by American Assay Laboratories, Sparks, NV



Figure 4. Remedios mercury for sale

In 2006, the price of gold was US\$600 per troy ounce (Kitco 2006); however, by February 2012 the price of gold was above US\$1,700 per ounce (Kitco 2012). The increased mercury price, from 2006-2011, has largely been driven by: 1) the increased gold price, 2) a diminishing supply of mercury from traditional sources (Brooks & Matos 2005), and 3) European and impending U.S. mercury export bans. Average mercury and gold prices for 2006-2011 are compiled on table 4.

Table 4. Mercury and Gold Prices, 2006-2011.

	2006	2007	2008	2009	2010	2011
Mercury/fl	\$670	\$530	\$600	\$610	\$1,070	>\$1,850
Gold/oz	\$605	\$699	\$873	\$974	\$1,227	\$1,570
Gold/kg	15,683	15,482	34,321	47,837	53,605	55,900

Mercury prices in dollars per flask (fl); gold prices in dollars per troy ounce; and production data are given in kilograms (kg). Data available from U.S. Geological Survey Yearbooks for mercury and gold and the U.S. Geological Survey Mineral Industry of Colombia 2011.

One flask of mercury weighs 34.5 kg, and 1 t of mercury contains approximately 29 flasks. The flask itself is a screw-top, welded-steel container that is approximately the size of a 2-liter soft drink bottle.

MERCURY USES IN COLOMBIA

The chief uses of mercury in Colombia include small-scale gold mining, chlorine-caustic soda production, dental amalgam, and neon lighting. Mercury is also imported as a component in some batteries, fluorescent lamps, and children's light-up toys. In 2011, the main sources of the 113 t of elemental mercury imported into Colombia were Mexico (23 t), Spain (21 t), and the U.S. (14 t) (table 1) (Brooks 2012). Mercury may have been transshipped clandestinely from other locations in South America such as Ecuador, Guyana, Perú, or from Europe (Fialka 2006; Simpson & Walsh 2012). In 2011, the main sources of the 10,481,769 units of all sizes of mercury-containing fluorescent lamps imported into Colombia

were China (57%), the U.S. (20%), and Germany (14%) (table 2).

Overview of Small and Medium-Scale Gold Mining

Mercury has been used for small-scale gold mining in Perú at least since the time of the Moche (100 B.C.-A.D. 750; Larco Hoyle 2001) and the widespread use of mercury for small-scale gold mining continues today (Brooks *et al.* 2007). It is estimated that more than 200 t of mercury are released annually through small-scale gold mining throughout Latin America (Viega 1997).

The simplest method of amalgamation is with a wooden gold pan or *batea* (Ahlfeld & Schneider-Scherbina 1964). The gold-bearing sediments, either from alluvial

sources or from vein occurrences that have been crushed, are washed directly in the stream or river until only the heavy minerals, including gold, platinum (mainly in Dept. Chocó, Colombia), and magnetite, as “black sand” remain. At this point, mercury is added, which amalgamates with only the gold. The gold-mercury amalgam may then be removed for burning (*refogado*, in Perú) which volatilizes most of the mercury leaving the gold as a lump or “sponge” or “pepita” which is then sold.

In one “green gold” method, the gold-black sand concentrate is first dried and the magnetite is removed with a magnet. The concentrate is then placed on an inclined pan or saucer, is gently tapped to cause any remaining magnetite grains to fall away leaving a gold concentrate; however, this “green gold” gold may also contain mercury (575 ppm Hg; table 3). Typically, the alluvial gold produced by non-mercury methods can be easily recognized—the grains are individual, mm-sized, and somewhat flattened-rounded (figure 5).



Figure 5. Green gold

In Colombia, green gold may also be produced using alternatives to mercury that may include plant juices from *cedro playero* (Castillo Espitia 2007), *yaruma*, and in Tadó, the liquid from plants commonly known as *balso* (*Malachra ruderalis*) and *malva* (*Quararibea* sp.) are used in place of mercury. In Peru, plants known as *murmuncho* and *cuiguyum* are also used (Perú) (Larco Hoyle 2001). In the *aventadero* method, gold-bearing sands are dried, tossed into the air, which leaves a gold concentrate (Petersen 1970/2010). In some parts of Perú, carpet or donkey skins may be placed in the sluices and streams to trap the fine-grained gold (Walter Sologuren, geologist, Compañía Minera Poderosa, S.A., Lima, oral communication, October 31, 2008); however, the gold may then be further concentrated using mercury.

At medium-scale gold mines, the sediments may be collected directly from the streams, or in some mining operations, front-end loaders may dump the gold-

bearing sediments in grizzlies, or dredges (*dragas*) may remove sediment from the river bottom, and the gold-bearing sediments may then be treated once the larger rocks and stones have been removed (al Jazeera 2011). Traditionally, the fine-grained gold-bearing sediments from the river bottom may be run across a mercury-coated table, and in addition to the mercury released during this practice, the sediments are then dumped into the river which adds to silting and contamination of the waterways. However, at an alluvial gold project in El Bagre, Antioquia, the dredges reportedly do not use mercury and may actually recover some of the mercury released by small-scale miners (Dias 2012).

In Colombia, gold ore may also be treated in ball-mills in shops known as *entables* (figure 6); mercury is added to the sediments in the ball-mill, the mixture is tumbled, and then the amalgam is removed and burned to volatilize the mercury and recover the gold. This final burning (called *refogado* only in Perú) helps the gold dealer gauge the purity of the gold, set a price and, most importantly, the gold is always visible to the dealer and to the miner. The doré from the gold shop in Remedios, Dept. Antioquia, for example, is then taken to Medellín (C.I. Fundación Escobar S.A., Calle 33 no. 43-78) for further refining and parting of the gold and silver.



Figure 6. Remedios entable hospedaje above

Until recently, and with the advent of “green gold”, the amount of small-scale gold produced was a reasonably useful index in estimating mercury use. To produce a given quantity of small-scale gold, two to three times as much mercury may have been used (Roskill Information Services, Ltd. 1990; Cánepa 2005). Regardless, after the mercury is used, very little is recovered or recycled and the mercury that is recovered may be cleaned using a variety of methods that include: electricity from 12-volt batteries; lemon juice; paper towels; soap; or

toilet paper. After Spanish mercury, recycled mercury is a distant second choice for gold amalgamation in the field; however, most of the mercury used for gold amalgamation, regardless of its origin, is released as mercury fumes during burning/retorting, or is otherwise lost to the environment and is not recycled.

Mercury-gold amalgamation may still leave fine-grained gold in the tailings. These tailings may then be treated with cyanide for further gold recovery and the miner receives no profit from the gold recovered from this secondary process.

Small-scale gold mining is a global activity, the processes are similar, and mercury is widely used. Therefore, The Global Mercury Project has published “Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners” (Veiga & Baker 2004) and a “Manual for Training Artisanal and Small Scale Gold Miners” (Veiga *et al.* 2006); the purpose of these books is to introduce cleaner and healthier small-scale gold mining and extraction technology.

Site visits

Remedios, Dept. Antioquia–Remedios is one of many gold-mining towns in Dept. Antioquia and it is approximately 4-5 hours by road, northeast of Medellín.

- Mercury (*azogue*) was available for sale (figure 4) for CP280,000 (US\$160) per kg in a small, unmarked, plastic bottle. Because of its dirty appearance, this mercury may have been recycled locally, and at this price, a flask of mercury (34.5 kg) would be worth as much as CP10,100,500 (US\$5,500).
- Two gold-shops in Remedios were visited. Both had ceiling fans, and both had covered, vacuum-vented retorts with small doors through which the amalgam was placed for burning; however, one of the shops vented the mercury vapors from gold burning directly above the shop. And, at the other shop, there was a vacuum system for running the mercury vapors through water, capturing the mercury for resale, and a mask and protective equipment for the worker were on hand. The dealers buy both “green gold” as well as gold treated with mercury.
- One *entable* was seen and directly above, was a small hotel (figure 6).
- At another gold shop, recycled mercury, if available, sold for CP150,000 (US\$85) per kg.
- In order to establish the mercury content of “green gold”, one sample from Remedios was submitted for

Inductively Coupled Plasma (ICP) analysis (table 3). The mercury content of this “green gold” is 208 ppm; however, the mercury content of this gold is not primary—the alluvial gold may have been exposed to mercury released from a variety of sources (Brooks *et al.* 2011).

Quibdó, Dept. Chocó–Quibdó, the capital of Dept. Chocó, is approximately 1 hour by air, west-northwest of Bogotá. Chocó is known for its biodiversity and for its long history of small- and medium-scale gold-platinum mining. The gold-bearing, Río Atrato forms a backdrop to the city (figure 7). Pre-contact platinum artifacts in museum collections indicate that ancient Colombian miners and craftsmen, using blowpipe technology, achieved temperatures sufficiently high to smelt platinum (1764°C; Petersen 1970/2010)—a technology not used in Europe until the late 1800s (Bergsøe 1937; McDonald 1960; Scott & Bray 1980; Bray 1988).



Figure 7. Quibdo gold panning w/o mercury

- In 2010, the United Nations awarded Chocó miners the Seed Award for their exemplary production of “oro verde” (green gold), efforts to reduce the use of mercury in the region, attention to conservation, and the elimination of mining practices such as the use of backhoes and dredges that pollute and destroy the streams (Silva Herrera 2010). Even as the market moves toward “green gold”, the jungle in Chocó is already pock-marked with craters where gold-bearing sediments were extracted (Posada 2011).
- A huge sign at the airport in Quibdó promoted environmentally responsible mining and the elimination of mining practices such as dredges or sluices that use mercury and contaminate the streams with mercury and increased sediment (figure 8). Several unused gold dredges were beached along the banks of the Río Atrato (figure 9).



Figure 8. Quibdo responsible mining



Figure 9. Rio Atrato draga

- There were no signs advertising the sale of mercury in Quibdó.
- There were 12 to 15 gold-platinum shops along or near Calle 26 (figure 10). At Promineral S.A., where both amalgam, “green gold”, and platinum were bought, a vacuum retort system was used to trap mercury vapors from the amalgam and a mask and gloves for the lab manager were visible and clearly had been used (figure 10). Twice yearly, the lab manager’s hair, blood, and urine were tested for mercury and the results were normal; he had worked at the shop for 8 years. The

dealer had approximately 1 kg of gold (figure 5) and 1.5 kg of platinum on hand.



Figure 10a. Quibdo gold-platinum shop



Figure 10b. Retort



Figure 10c. Water tanks

- Green gold is typically loose, mm-sized, and sub-rounded to flattened (figure 5), whereas gold processed using mercury usually has a sponge-like appearance.
- Mercury was available, though not advertised, and a flask (also called a *pipa*), if available, was estimated to

sell for CP13,000,000 (US\$7,500)—the shop managers clearly preferred not to talk about mercury.

- An attempt was made to visit a large mine approximately 12 km south of Quibdó, along the road to Pereira; however, two armed guards would not permit entrance nor photographs. The mine was called the Colombo-China Mine (Au-Pt); a few days after my visit to this mine, the road from Quibdó to Pereira was closed by FARC.
- Gold was mined from the Rio Atrato riverbanks in Quibdó using only a wooden gold pan (*batea*) and no mercury (figure 7). The black sand-gold concentrate was allowed to dry and the black sand was removed with a magnet leaving “green gold”.

One of the world’s largest platinum nuggets, 11.6 kg, came from Chocó and a 536.7 g nugget (R4244), also from Chocó, is on display at the Smithsonian, Washington, DC. Chocó platinum also contains iridium, palladium, rhodium, and osmium (Petersen 1970/2010). An alluvial platinum concentrate contained 147,000 ppm platinum, 248,000 ppm gold, 844 ppm iridium, 1,960 ppm palladium, 2,150 ppm rhodium, and 70 ppm osmium (table 3).

As of yearend 2010, platinum sold for CP2,938,300 (US\$1600) per troy ounce; iridium sold for CP1,175,300 (US\$640) per troy ounce; palladium sold for CP973,300 (US\$530); rhodium sold for CP4,517,700 (US\$2,460); and ruthenium sold for CP367,300 (US\$200) (Loferski 2010). The platinum-group metals, aside from their use for jewelry, resist chemical attack, have stable electrical properties, and may be used in catalytic converters, electrodes, and other applications.

Analysis of a green gold sample from Chocó indicated 575 ppm mercury (table 3); however, as with the green gold sample from Remedios, the mercury content of this sample cannot be considered primary. The green gold produced in the region has likely been exposed to mercury released from pre-contact mining, colonial mining, or other sources (Brooks *et al.* 2011).

Elevated neodymium (11-29 ppm), a rare-earth element, was found in 4 samples from Quibdó (table 3); however, it was not present in the Quibdó alluvial gold sample. Nickel content ranged from 5 ppm to 102 ppm and ruthenium (154 ppm), commonly associated with platinum, was also elevated in one of the Quibdó samples (table 3).

Marmato, Dept. Caldas—Marmato is an important gold-silver occurrence that is approximately 50 km north of Manizales, Dept. Caldas, and 80 km south of Medellín,

Dept. Antioquia. The gold is hosted in pyrite found in veins in a porphyritic, Miocene dacite-andesite stock with several phases, including stockwork and breccias.

- Small-scale, alluvial gold mining at Marmato dates to 500 BC, well before the arrival of the Europeans, and Marmato is probably Colombia’s most well-known gold occurrence. The name roughly translates to pyrite, an iron sulfide, known as fool’s gold.
- Part of the property is held by Gran Colombia Gold (Toronto, Canada), who hopes to have an open-pit mine; however, the other part has been owned and worked by local, small-scale gold miners for generations. In order for the open-pit operations to proceed, the small-scale miners are facing displacement and this is a source of conflict between the international company and the local small-scale miners (al Jazeera 2011). Marmato has the potential for bulk mining with an indicated resource of 6.6 million troy ounces of gold (Mendoza 2011).
- At Marmato, gold occurs as electrum (gold-silver) in pyrite found in mm to m-sized veins, with minor native gold. The small-scale miners crush the ore in ball-mills, then the heavy minerals, mainly pyrite, are separated on a Wilfley Table, and then the concentrate is treated with cyanide to recover the gold. Parting of the gold from the silver takes place elsewhere and mercury is not used at Marmato.

La (Nueva) Esperanza, Dept. Caldas—Mina La (Nueva) Esperanza is north of Aranzazu (Lozano 1987), had three levels, and the mine site included a concentration plant. The ore was not retorted, but was crushed, and then centrifuged to concentrate the native mercury. The country rock is a metamorphic complex and the ore was typically found in veins (figure 2) cutting the metamorphic rock and associated with a Tertiary igneous complex (Rivera, 1969a,b). The mine is approximately a 2 hour hike down a very steep ravine, the northeast-trending Quebrada Chupadero, and quartz-cinnabar veins with sulfides are present in the stream (Hubach 1951). The volcanic host rock shows propylitic alteration and a sample from a quartz-cinnabar vein gave 5,620 ppm mercury and 2 ppm gold (table 3).

In order to expand mercury production in the region, regional sampling programs were carried out at Esperanza (Williamson 1967) and at nearby El Mico (Rivera 1969a); however, production at Esperanza began to decrease [November 1967, ~32 flasks; December 1967, ~23 flasks; and in January 1968, ~14 flasks] and the mine finally closed in the late 1960s (Hubach 1951; Wokittle 1958a; Lozano *et al.* 1984b; Antonio Rivera, retired mine geologist, oral communication, May 15,

2012). The mine is now caved-in, the area is heavily overgrown, and there is a strong sulfur smell from the mine drainage. There are a number of cement columns and supports that mark the site and there is no small-scale cinnabar mining or retorting in the area.

Even in the 1950s, there was concern for the mine worker's health at La (Nueva) Esperanza and the effects of *mercurialismo* that resulted from inhalation of mercury vapors. Therefore, a number of recommendations were made that included: 1) effective ventilation of the mine, 2) avoid any heat sources in the mine that would volatilize mercury, 3) workers should use masks or cover their mouths with towels soaked in cold water, 4) wash hands and shower frequently, and 5) gargle with manzanilla tea (Wokittle 1958a).

Maps—La (Nueva) Esperanza does not appear on the map, but is on Plancha 187 [(Plancha Antigua) 187-IV-D, 1:25,000, 1961], accessible by a dirt road northwest of Alegrias, which is north of the town of Aranzazu, on Plancha 206-1-B [scale 1:25000, 1963]; both of which are available from Instituto Geografico Agustin Codazzi, Bogotá.

Medium-scale mining and examples of gold recovery without mercury

Llanada, Dept. Nariño—JICA (Japan International Cooperation Agency, Tokyo) and Ingeominas, Bogotá, began technological collaboration in the 1990s in order to bring sustainable, mercury-free mining methodology to the gold mining district of Llanada, Dept. Nariño. JICA is an Incorporated Administrative Agency (Act No. 136, 2002) with the aim of promoting international cooperation, sound development of Japanese and global economic goals by supporting the development, recovery, and economic stability of developing regions (JICA 2003; Ingeominas 2008).

- At the El Canada mine, Dept. Nariño, gold is found in fracture-filling quartz veins, both as native gold (with silver, as electrum) and associated with arsenopyrite and sphalerite.
- Ore treatment includes crushing and then the material is passed across a Wilfley Table and the gold-bearing heavy concentrate is sent to Cali for further processing.
- Ore is also treated with cyanide, the metals are precipitated onto zinc (Merrill-Crow process), and the precipitate is then sent to the smelter.
- Mercury is not used.

CIMEX Laboratory, Medellín, Dept. Antioquia—At the Instituto de Minerales CIMEX, at the Universidad

Nacional de Colombia, in Medellín, researchers have demonstrated a mercury-free technology for gold recovery. The ore that comes from the mines is crushed and moved through a series of tanks with chemicals that have physical properties very similar to soap and alcohol and are biodegradable. The process is called “flotation-foaming” and is based on the fact that gold can be made to repel water, and float, while other minerals are attracted to the water in the tank, and sink. The addition of air bubbles into the tank produces the foam that helps concentrate the gold. However, this flotation process only works with ore that has native gold and not with ore where the gold is associated with pyrite. The gold recovered by this flotation method can then go on directly to the smelter (Universidad Nacional de Colombia 2011).

Chlor-alkali Production

The Brinsa S.A. chlor-alkali plant, near Zipaquirá, is approximately a 1 hour drive from Bogotá. Through the U.S. Embassy, Bogotá, a plant briefing and tour were arranged and the following information was provided by Hugo Lasso (manager, Brinsa S.A., February 24, 2010); however, no pictures were allowed. Brinsa products include caustic soda, chlorine, cleaners, swimming pool chlorine, salt, and sodium carbonate. The brine for chlor-alkali and salt production (Refisal) is obtained locally, but not from the Zipaquirá mine. The Zipaquirá region is known for its salt deposits, is a tourist destination, and hosts an underground cathedral carved in salt.

Brinsa is a member of the Washington, DC-based Chlorine Institute; however, they are not members of the regional CloroSur organization. The Zipaquirá plant has 36 mercury cells (ICI/14H3) used for electrolytic production of chlorine and caustic soda from the saline brine that is passed over the mercury. Approximately 3 mm of mercury is contained in the bottom of the cell which is approximately 15 m long and 1.5 m wide. The anode is a titanium grid and chlorine gas is captured in plastic tubes and compressed. The mercury traps the sodium, as a Na-amalgam, which is moved away for treatment and recovery of the caustic soda, and the mercury is then recycled back into the cells. The floor under the cells is well-kept and contains a sump to capture any droplets of mercury which are then processed and put back into the cells; these droplets are caught in soapy water. All workers and visitors must have respirators, eye shields, and hard hats.

In the storehouse were approximately 55 “American” style flasks (Spanish flasks are distinctive and have flat shoulders and have “Almaden, Spain” embossed on the collar, see figure 1) of mercury. The mercury was

purchased from Lambert Metals International Ltd., a London, UK-based mercury distributor who purchases U.S. mercury; Lambert has offices in Belgium, the Netherlands, and elsewhere (Fialka 2006; Simpson & Walsh 2012).

Because of economic reasons, there are no plans for Brinsa to convert to the more costly mercury-free membrane technology. Information was not available on the tons of mercury in the plant, nor annual purchases. Plant workers are tested annually for heavy metals in their urine, as well as tests for potential effects of mercury intoxication that might include damage to the nervous system.

Dental Amalgam

Dentists have used amalgam, which contains mercury and other metals, since 1833 (Talbot 1882) and modern amalgam contains mercury (50%), silver (34-38%), tin (12-14%), copper (1-2%), and zinc (0-1%) (Davis 2003). The combination of silver and mercury, both biocides, substantially reduces the risk for further decay in the amalgam-filled teeth.

In the U.S., amalgam is sold in pre-measured capsules that are opened in the dentist's office just before use and the American Dental Association discourages the use of bulk mercury for amalgam preparation (American Dental Association 2006). Approximately 30 t/yr of mercury is used in the U.S. and used or discarded amalgam from collection devices, or traps, in dental offices may be processed to recover the mercury, silver, and other metals (Lawrence 1995). Depending on the size of the filling, amalgam fillings may last from 2-20 years (Dr. John Mercantini, dentist, Reston, VA, oral communication, December 12, 2004). There are no data on the amount of mercury that is recycled from dental amalgam in the U.S.

Site visits were made to dental supply stores in the Chapinero district, Bogotá (Deposito Dental Sosa Hermanos, Cra. 14A, no. 60-95; N.S. Dental, Cra. 14A, no. 60-61; Unidental, Cra. 14A, no. 61-19), the dental faculty at the Universidad Nacional, Bogotá, and a dental office in Quibdó. In Chapinero, there are numerous dental supply shops, dental clinics, and training facilities. Mercury is available in pre-mixed amalgam capsules and the capsules are imported from the U.S., Australia, or Canada. In only one shop was a small bottle (100 g) of mercury available for sale, for approximately CP25,000 or US\$13. There is no sale of dental "traps" to catch the amalgam residue that might be spit out of the patient's mouth. Therefore, silver and mercury both go into the sewage system. The leftover

capsule and amalgam material that has not gone into the patient's mouth are treated as hazardous waste and may be sent to the landfill.

At the Universidad Nacional de Colombia, Bogotá dental school, information was provided by Dra. Maria Clemencia Rodriguez, Director of the Universidad Nacional de Colombia dental school, and faculty members Dr. Norberto Ramirez and Dra. Martha Ujueta (oral communication, February 24, 2010). Ceramic material is now generally preferred, however, in the Public Health System it is obligatory to use mercury amalgam; however, it is rare to buy a bottle of mercury. Mercury is available in pre-measured capsules that contain a droplet of mercury, which when the capsule is crushed in the amalgamator, combines with the copper-tin-silver powder in the capsule to make the dental amalgam. Non-biologic-contact mercury material is put in hazardous waste containers for hazardous waste disposal. Ecocapital Internacional S.A., in Bogotá (Ecocapital Internacional S.A. 2010) and New Stetic S.A., in Medellín (New Stetic S.A. 2011) provide information on disposal and recycling procedures for dental and other medical waste. Extracted teeth, with mercury amalgam, are also collected as biological hazardous waste and are sent to Ecocapital. There was a black market for gold teeth robbed from cadavers.

Both university faculty and the dental office in Quibdó (Dr. Wilmer Lozano Córdoba, Oralsalud S.A., Calle 28, no. 1-110, February 22, 2012) indicated declining use of amalgam in preference of cosmetically-appealing resin or ceramic fillings. In Quibdó, there had been requests to remove amalgam and the waste material was simply thrown into the trash or into the drain. Amalgam capsules were available in Quibdó from suppliers in Medellín; however, no country source was indicated.

Advances in bio-compatible ceramic materials for fillings, as well as esthetic reasons, have diminished the use of mercury amalgam (Meriño 2010). University researchers have found that dentists and their staff are also exposed to mercury in the office setting; however, the use of gowns, face shields, and gloves has reduced the risk to the dental staff (Ruiz 2009).

Other Mercury-Containing Products

Mercury-containing products include batteries, computers and electronics, fluorescent and CFL lamps, and thermometers. Some children's light-up toys, shoes, and even some toothbrushes may use mercury or mercury-containing batteries, but specific data on the large quantity of toys and other battery-containing imports were not available. None of the mercury

contained in these products is recycled and the products are landfilled or incinerated and the mercury may ultimately be released to the environment.

Batteries—There are many sizes, shapes, and varieties of everyday-use batteries, and batteries may also be used in kid's light-up shoes and toys. Mercury oxide is used in varying amounts, especially in "button" batteries; however, alkaline batteries generally have the lowest mercury content. Cadmium-mercury batteries have been widely used in watches, calculators, cameras, and hearing aids (Battery-Index 2003; Mercury in Batteries 2004). In Perú, inexpensive "button" batteries that were sometimes swallowed by children were blamed for blindness and other health problems (El Comercio 2002; 2003).

Button batteries used for calculators, watches, and other uses may come from China and Indonesia and are routinely sold in multi-battery packs in stores near Calle 21 and Carrera 9 in Bogotá. Some of the packages indicate that lead and mercury are used in the battery and that the battery should not be disposed of in the trash. Some used batteries may reach a collection bin (figure 11), but whether or not the mercury from the used batteries is recycled is unknown.



Figure 11. Bogota Panasonic recycling.

There was no information on battery imports into Colombia. According to Environment Canada (2007), batteries may contain from 5-25 milligrams (mg) of mercury as mercury oxide. Given an average battery weight of 5 g for all battery styles (Shenzhen Tech 2007), a minimum of 5 mg of mercury per battery, and given

a zero recycling rate for batteries, then a minimum of approximately 1 t of mercury will ultimately be released after the imported batteries are put into the trash.

The Swiss company Batrec, which was founded in 1989, is Europe's leading recycler of mercury-containing materials and it processes more than 3,000 t/yr of batteries and other materials (Beck 2004). The Mercury Recycling Group, which is the largest recycler of mercury in the United Kingdom, has tripled its recycling capacity in response to European environmental legislation (Metal-Pages Ltd. 2004). Environmental legislation in Europe has resulted in the European Union Battery Directive which is expected to result in a \$640 million market (Vollrath 2006).

Computers and Electronics—Electronics and computers may be recycled in order to recover the arsenic, copper, lead, mercury, and others metals that can be harmful if dumped, unencapsulated, into a landfill. For example, on its model MA6, Gateway Inc., includes a label indicating that the display lamp contains mercury and should be disposed of in accordance with local, state, and federal laws. It is estimated that 20-50 million metric tons of electronic waste are generated worldwide. In the U.S., approximately 1 billion personal computers have been retired—these computers contain cadmium, chromium, lead, and approximately 180 t of mercury (Zhang 2011).

Thus far, there is no recycling of computers in Colombia (figure 12). For security reasons, used U.S. Embassy computers are destroyed and the metals, including gold in the hard-drives, are not recycled. Used computers and electronics may be passed from one agency to local schools or refurbished and resold in Bogotá and some used computers may also be resold so that the gold contained in the microprocessors may be recovered.



Figure 12. Univ Nacional computers

Fluorescent and CFL Lamps—In the U.S., reclamation of mercury from spent fluorescent lamps and mercury-vapor lamps began in 1989 and mercury is also reclaimed from compact fluorescent lamps (CFLs). Originally, these lamps contained as much as 10-20 mg of mercury (National Electrical Manufacturers Association 2003; Environment Canada 2007); however, now the CFLs contain less than 5 mg of mercury and some have as little as 1.2 mg (Von Ahn 2007). Fluorescent lamp packages in the U.S. have an information panel that has the symbol for mercury (Hg) and a statement that the lamp contains mercury and should be disposed of in accordance with disposal laws.

Traditional fluorescent lamps and the newer CFLs are widely promoted and used in Colombia and, in 2011, approximately 10,481,769 units of fluorescent lamps of all types (excluding CFLs) were imported (table 2). A site visit to Home Center in Bogotá (February 27, 2012) showed that this total included a wide variety of wattages (8-100 watts) and lengths. CFLs and circular lamps were also in stock and were made mostly in China. Some of these packages indicate that mercury is used in the lamps (<5 mg Hg); however, most do not, and there is no warning that mercury is toxic or that the lamps should be recycled.

Import data did not provide weight of the fluorescent lamps imported in 2011, therefore, it is estimated that perhaps 1-2 tons of mercury may have been imported as a component of the lamps. Regardless, since there is no recycling of fluorescent lamps in Colombia, all of the mercury will be released to the environment when the lamps are ultimately broken. For example, fluorescent lamps at the McDonalds (Septima and Jimenez, La Candelaria, Bogotá) are simply discarded in the trash. In a poster *¿Qué se recicla y qué no?* [What can and cannot be recycled] provided by the Gobierno, Seguridad y Convivencia, Alcaldía Local de La Candelaria, Bogotá, bulbs (*bombillos*) and fluorescent tubes (*tubos fluorescentes*) are included in the list of materials not to be recycled. Therefore, these lamps end up broken (figure 13), or in the trash and, enroute to the landfill, are likely broken and the mercury is released. Aside from mercury, these lamps can be recycled to recover the aluminum end-caps, glass, as well as rare-earth elements (REEs) that are contained in the white powder in the lamps (Molycorp 2011).

Skin-lightening Creams—Mercury-containing skin preparations have been used for many years, for example, the use of mercury compounds to treat syphilis (Cole *et al.* 1930). However, chronic exposure to organic or inorganic mercury can damage the brain, kidneys, or the fetus. Inorganic mercury, such as ammoniated mercury,

is the active ingredient in some skin-bleaching creams (Marzulli & Brown 1972) and these skin-lightening creams have been used in many parts of the world in order to obtain a lighter skin-tone by inhibition of pigment formation. These preparations have been widely sold in parts of Asia, the Middle East, and also in Mexico. For example, health officials in Texas (U.S.) have warned of a mercury-laden face cream available in Mexico that is sold online, and thus far, 20 people have tested positive for elevated levels of mercury (Allford 2011). For example, see: Piel Mas Blanca (Lighter Skin) <http://pielmasblanca.com/?hop=dgoogle> (accessed September 7, 2011). In a research report, Al-Saleh & Al-Doush (1997) provide the names, mercury content, and country of origin of more than 30 skin-lightening creams used mainly in the Middle East; one sample from Lebanon contained 5650 ppm mercury. At present, there is no data on imports or use of these creams in Colombia.



Figure 13a. Univ Nacional eight foot fluorescent



Figure 13b. Broken lamp

Thermometers and Medical Equipment—In Colombia, mercury-containing thermometers are readily available and cost approximately CP1,800-2,200 (US\$1.00-1.25) and digital thermometers are also available for approximately CP11,000 (US\$6.50). Some of the mercury-containing thermometers were imported from Germany and others are simply embossed “U.S.A.” No data was available on the quantity of mercury-containing thermometers imported into Colombia in 2011. However, most of these thermometers will ultimately be broken, thereby releasing the mercury in the home, hospital, or to the environment.

Mercury-containing blood pressure devices are also imported from Germany (Rudolf Riester GmbH & Co., <http://www.riester.de>) and are widely sold and used in Colombia; however, neither mercury thermometers nor mercury-containing blood pressure measuring devices are used at the U.S. Embassy/Bogotá. There is minor use of mercury compounds in some vaccines (Dr. Christina McDaniel, Medical Officer, U.S. Embassy/Bogotá, oral communication, February 22, 2010).

Mercury used in thermometers and in blood pressure devices may be recycled; however, at present, there is no collection or recycling of any mercury-containing medical equipment in Colombia.

Other Mercury Uses and Releases

Cremation—Mercury fumes may be released from dental amalgam fillings during cremation and in the U.S., crematoriums may emit as much as 145 kg/yr of mercury (Chea 2007). In the United Kingdom, a study indicated that approximately 11 kg of mercury were released from one crematorium chimney in one year (Mills 1990).

The Cremation Society of Great Britain indicated that there are 17 crematoria throughout Colombia (Cremation Society of Great Britain 1999) and approximately 45% of burials in Bogotá are cremations. However, cremation is not common in other parts of Colombia (Claudia Castillo, Operations Director, Funeraria Gavira, Bogotá, oral communication, February 24, 2010). In Colombia, dental amalgam is not removed and this indicates a potential mercury release during cremation. The Director also indicated that pacemakers are removed because they may explode; Au-containing teeth are not removed; cadavers that have had treatment with certain radioactive materials are not cremated; titanium implants such as hip replacement and other metals are separated from the cremains and are kept at the crematorium after the cremation is completed; and there are no filters on the crematory stacks.

Fireworks—Studies in Stockholm, Sweden, in 1996 showed that airborne levels of mercury, cadmium, lead, and other metals, used to provide specific colors, were 4-5 times higher than normal after a fireworks display (Fireworks 2007). There are approximately 7 fireworks shops in Bogotá that appear to be clandestine. One guard indicated that their fireworks were imported and was unwilling to provide any other information.

Laboratories—High school, university, and other laboratories may have stocks of mercury on hand in bulk, as geologic samples, or in thermometers and hygrometers (figure 2). Releases of mercury are a concern because mercury readily volatilizes at room temperature (Putman 1972); however, there was no information available on the quantity of mercury held in laboratories in Colombia.

Landfills—By law, each municipality in Colombia must have at least one sanitary disposal site; however, larger cities, such as Bogotá, Cali, or Medellín, may have more than one site. In Bogotá, Rellenos de Colombia S.A., landfills mercury and other hazardous waste. Their containment cells are 20 m wide at the base, 20 m deep, and the cells have a volume of 20,000 m³ or a containment capacity of approximately 24,000 t (Mauricio Cardozo, Rellenos de Colombia S.A., chemical engineer and technical director, oral communication, February 26, 2010). Cell stratigraphy includes placement in clay with 3 layers of geomembrane, alternating clay layers, and lixiviation channels are tested monthly. Decreto 4741 (Republica de Colombia, Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Decreto No. 4741, Dec. 30, 2005, 25 p.) provides definitions, classification, and other documentation related to handling of hazardous materials. Hospital waste, cyanide waste, pigments, and specific metals such as beryllium, lead, zinc, and mercury are included. Mercury content of the lixivate may not exceed 0.2 mg/L.

Mercury-containing lamps are crushed, residue is filtered through carbon filters, and the broken glass is encapsulated in cement. Other materials including batteries, thermometers, mercury flasks, and amalgam are also encapsulated and then placed in the cell. Mercury contaminated soil is treated with sulfur in order to stabilize the mercury. Workers at Rellenos are given urine/blood texts annually, as well as before hiring and upon termination.

Neon Lights—Neon and argon/mercury are used as fill to provide color in “neon” lighting, and out of 44 lamp styles listed on one website, 37 of these used argon/mercury fill (Depue 2001; Lite Brite Neon 2007). These lamps may last 7-10 years or longer. In the argon-

mercury tubes, a droplet of mercury is added to the glass tube, and when the current passes through the tube, the mercury is vaporized and provides color.

A visit to Zano Electricos (Manuel Zambrano, owner, Carrera 12 No. 20-1, Bogotá) indicated that only a droplet of mercury was used in the lamps; perhaps ~1 kg of mercury was used per year. Mercury was purchased from Químicos Campota y Cia Ltda. (Calle 13, No. 13-27, San Victorino, Bogotá) where a 1 kg container cost CP310,000 (US\$175). Químicos Campota's current stock of mercury was from Mexico; however, the salesman indicated that previously, their mercury had also been imported from Spain (figure 1). There is no information on the number of neon shops in Colombia nor on the mercury in stock at the neon or chemical vendor's shops.

Paint—Until about 1990, mercury-containing paint was used to control mold and mildew in the U.S. (Brooks & Matos 2005). A site visit to Home Center, a major home supply center in Bogotá, indicated that Pintuco (Compañía Global de Pinturas S.A.) provides a household paint with an anti-mold, anti-mildew ingredient and mercury-based anti-mold, anti-mildew paints are not used.



Figure 14. Antique mirror with mercury...Quinta de San Pedro Alejandrino

Antique Mirrors—Mercury has been used for antique barometers, clock pendulums, organs, and the backing for antique mirrors (U.S. Environmental Protection Agency 2012). During the 16th century, an amalgam of 25%

mercury and 75% tin was used as the reflective mirror backing; however, after the 1840s, mercury-tin was no longer used as the reflective surface. These antique, mercury-backed mirrors may still be seen at the Quinta de Bolivar (Bogotá), Hotel Casa de las Palmas (Cartagena), and the Quinta de San Pedro Alejandrino (Santa Marta) (figure 14). Mercury mirrors are usually well-preserved and should not be a concern (NEWMOA 2011).

CONCLUSIONS

Mercury has been mined and used for ancient and modern small-scale gold mining in Colombia and the region. Mercury releases occur from small-scale gold mining, gold processing, and from broken fluorescent lamps, batteries, and dental amalgam that are put into the waste stream without reclamation or recycling of the mercury. Much of the mercury used for gold mining, chlor-alkali production, and the mercury contained in these other mercury-containing products could be recycled. However, at present, there are no recycling facilities in Colombia nor is there legislation in place, or pending, which would require tracking or recycling of mercury and imported mercury-containing products.

Colombia has been an important gold, silver, and platinum producer, as well as a user of mercury for small-scale mining, and Colombia is now positioned to become a significant producer of precious metals and also has the potential to become a regional leader in mercury stewardship. Colombia's mercury-containing waste, with appropriate legislation, could be sent to recycling centers worldwide for reclamation and recycling of the mercury.

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In response to increasing international concerns about mercury and human health, the principal investigator, in collaboration with Camilo Cardozo from the Economic Section of the U.S. Embassy, Bogotá, Colombia, and Prof. Thomas Cramer of the Universidad Nacional de Colombia, Bogotá, has herein compiled information on mercury in Colombia. This research was funded by the J. William Fulbright Foreign Scholarship Board, Washington, DC, and administered by Fulbright Colombia, Bogotá.

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POSTSCRIPT

A project that will ban the use of mercury is about to become law in Colombia. “In five years mercury will be banned from use for gold mining and its use in industrial applications will be banned in 10 years.”

Augusto Posada, Presidente de La Comisión Quinta de Cámara de Representantes

June 6, 2013, Colprensa, Bogotá, Colombia

APPENDIX

Colombia, Mercury, and Mexico: Reclamation of Spanish Colonial Mercury at Zacatecas, Mexico

Mexico has approximately 27,000 t of mercury reserves and produces 15-20 t of reclaimed mercury annually (Castro Diaz 2008). In 2011, Mexico became the leading exporter of mercury to Colombia (23 t)(table 1); however, Mexico has a long history of mercury mining that dates to 1000 BC (Langenscheidt 1986; Consejo de Recursos Minerales 1992). Ceramic retorts for retorting mercury from cinnabar were found at San José Ixtapa, Querétaro (Barba & Herrera 1988).

In Mexico, from the mid-1500s to 1900, mercury was imported from Spain, and some from Huancavelica, Perú, to be used to amalgamate silver using the patio process (Martino *et al.* 1992; Crozier 1993) in Zacatecas, a very important silver center since the 1530s. The mercury-containing waste rock from the amalgamation process was left in tailings around Zacatecas and Pedernalillo Dam is one example. It is estimated that 13,000-34,000 metric tons of mercury were discarded in the extraction of Ag and only about 5% of the mercury has been recovered (Ogura *et al.* 2003). Similarly, Colonial silver mining at Potosí, Bolivia relied mainly on Huancavelica mercury for ore treatment and contamination from that

mercury still poses an environmental hazard (Robins 2011).

The waste from Pedernalillo Dam is brought in by truck and then dumped into one of the 5-7 swimming pool-sized leach tanks (*pilas*). Approximately 7,000 t is dumped into the leach tank and the “shallow” end of the tank is then dammed with dirt. Rotation is about 1 week, that is, the *pila* is filled on Monday, then, after treatment with CaS_2O_3 , the material is removed the following Monday. Some of the plants also treat fluorescent lamps.

Homemade CaS_2O_3 (not cyanide) is flushed onto the tailings to leach Hg, Au, Ag, and other metals. The pregnant solution is piped into the plant and the metals are precipitated onto copper wires and copper scrap. Then, the metal sludge is shaken and removed from the copper scrap and this material is allowed to settle and moves through four 2m x 2m x 1m concrete tanks.

The metal sludge then goes into one of six 2m x 30cm half-cylinder containers which are placed horizontally into the retorts. The retorts are sealed and heated to 480°C for ~24 hours, with no one present during retorting. The Hg vapor moves through a tube, condenses, drops into a water-filled tank behind the retort room wall and then the reclaimed Spanish colonial mercury, originally from Almaden, can be tapped and cleaned for sale (figure 15). Gas is used to fire the retorts and retorting takes place over the weekend in the ventilated retort room.



Figure 15. Almaden mercury Mexico

This is a family business and has operated for ~100 years, and produces ~15 t of mercury per year, or about 1-1.4 t per month. The mercury is sold to Argentina, Colombia, and other countries and the Au-Ag residue remaining after retorting goes to Industrias Peñoles S.A.B de C.V. in Torreon, Mexico, for recovery of Au, Ag, and other metals.

For this study, geochem samples (Inductively Coupled Plasma) were taken: 1) from silver amalgamation waste at Pedernalillo Dam, 2) from mercury-contaminated amalgamation waste before treatment (201 ppm Hg), 3) from waste after treatment (12 ppm Hg), and from the precipitate from the pregnant solution (2200 ppm Hg). The owners estimated that 650 g of Au and 265 kg of Ag could be recovered from one ton of sludge/precipitate. The silver content of the mercury-contaminated soil before treatment was 87 ppm, after treatment, 13 ppm and the precipitate contained 316 ppm Ag; data are compiled on table 5. For comparison the Ag content of an ore sample from the Fresnillo Mine contained 680 ppm Ag.

Treatment of Au ore with CaS_2O_3 may be a sound alternative to small-scale gold mining methods that rely on mercury or cyanide.

Northeast of Zacatecas, at San Felipe de Mercurio, approximately 6 hours away, small-scale cinnabar mining and retorting produces about 2 t per week of mercury and there are also mercury occurrences in Durango, near Mapimi. In Querétaro, near Sierra Gorda, there are as many as 200 cinnabar mines some of which are producing mercury (Chavez 2011; Flores 2011).

Table 5. ICP Analyses of Mercury-contaminated Soil, Mercurio del Bordo, Zacatecas, Mexico

	B1001 tailings	B1002 cabezas	B1003 colas	B1004 precip
Ag	9	88	13	316
Al	11.000	19.510	27.100	4.370
As	75	204	36	22
Au	<2	<2	<2	3
B	<20	<20	<20	<20
Ba	206	154	464	60
Bi	<3	<3	<3	<3
Ca	22.400	12.200	11.400	183.000
Cd	5.7	40	17.9	9
Co	12	22	19	4
Cr	43	91	79	16
Cu	116	435	457	22.280

	B1001 tailings	B1002 cabezas	B1003 colas	B1004 precip
Fe	25.500	45.300	44.100	7.410
Ga	<10	<10	<10	<10
Hg	18	201	12	2.200
K	1.410	2.220	2.890	1.820
La	15	9	11	4
Mg	6.960	15.200	13.000	3.820
Mn	530	882	862	296
Mo	1	<1	<1	10
Na	438	325	377	1.800
Ni	28	63	55	9
P	924	446	484	164
Pb	474	1.850	1390	126
S	849	4.460	965	184.604
Sb	9	36	29	8
Sc	<5	9	9	<5
Se	<5	<5	<5	10
Sr	48	33	40	684
Th	<3	<3	<3	<3
Ti	172	755	1.390	216
Tl	<5	<5	<5	<5
U	<8	<8	<8	<8
V	66	80	84	18
W	<2	<2	<2	<2
Zn	815	4.590	2.941	145

B1001–Pedernalillo dam soil, Spanish colonial amalgamation tailings

B1002–*cabezas*, Hg-contaminated amalgamation tailings before treatment with CaS_2O_3

B1003–*colas*, Hg-contaminated soil after treatment with CaS_2O_3

B1004–precipitate, from black, dried material above outflow channel for pregnant solution

Inductively Coupled Plasma analysis, in parts per million (ppm), by American Assay Laboratories, Sparks, NV

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