

The Ancient Molinete, Plants, and Mercury Efficiency in Present-Day Artisanal Gold Mining, Northern Perú

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Abstract

The *molinete*, a smaller version of the *quimbaleta* or Inka mill, was also used to crush gold ore in the ancient Andes and its present-day use, though limited, continues. It consists of a large, movable upper stone, or *chungo*, and a lower, stationary stone, or *muscha*, that has a depression to seat the *chungo*. Each stone may weigh approximately one ton. The worker is seated and rocks the *chungo*, by foot on the lower, water-lubricated *mushca*. The weight of the *chungo* and back and forth motion crushes the ore thereby releasing the gold grains into the muddy slurry to which mercury is added to form a gold-mercury amalgam. After the amalgam is recovered, it is squeezed in a cloth to recover excess mercury, and then it is burned to volatilize the remaining mercury leaving an anthropogenic gold nugget. Spot geochemical sampling for Inductively Coupled Plasma (ICP) analysis of the *molinete* gold ore indicated average ~43 ppm Au and post-amalgamation mud contained average ~33 ppm Au which indicates an efficiency of ~23%. Local plants such as *pegorondo* or *mur-muncho* were added to the muddy slurry in the *muscha* depression to aid amalgam recovery and help lubricate *molinete* movement; however, the use of these plants has been discontinued since the 1940s. Most importantly, since mercury is used with *molinetes* and *quimbaletes* to recover gold at artisanal gold processing sites today, then, the documented use of these artisanal ore-crushing mills in the past is consistent with mercury use for gold amalgamation in pre-contact Perú.

Keywords

Amalgamation, Mercury, Molinete, Perú, Plants

1. Introduction

The *molinete* is an ancient artisanal stone crushing mill (Larco Hoyle, 1945, 2001) and it is a smaller version of the ancient *quimbalete* or Inka mill (Petersen, 2010; Brooks, 2025). The purpose of the *molinete* is comminution, or crushing and pulverizing the ore, thereby releasing the gold for separation, chemical treatment, and recovery (Thrush, 1968). Synonymous regional terms for these artisanal ore-crushing mills include: *bimbalete* or *bambalete*, which comes from an indigenous word meaning shake or move from one side to the other while staying in the same place (Petersen, 2010); *piruro* or drum-wheel (Petersen, 2010); *chancadora* (Larco Hoyle, 1945, 2001); and *maray* (de Nigris & Riart, 2013). Jaw crushers, also called *chancadoras*, have a similar role in initial ore processing in Perú's present-day open-pit copper-gold mines.

Artisanal mills were widely used in the past and descriptions are numerous, for example: Agricola (1912); Atlas (2000); Barba (1923); Bargalló (1955, 1969); Brooks (2025); Costa et al. (2009); Florsch et al. (2015); Kaptan (1982); Olaechea (1901); Petersen (2010); Rivero y Ustariz (1857); and Romaña (1908). These mills have been found at pre-contact mining sites in Argentina, Bolivia, Chile, and Perú (Ahlfeld & Schneider-Scherbina, 1964; Larco Hoyle, 1945, 2001; Petersen, 2010). A review of Andean crushing mills and sites is provided in de Nigris & Riart (2013) and mechanics of these mills is discussed in Florsch et al. (2015); however, neither study acknowledges the essential use of mercury (*azogue*), without which gold could not be recovered from the muddy slurry in the *muscha*, for example, in La Rinconada, Perú (Cuentas & Velarde, 2025).

Given that there are only two ways to produce industrial amounts of gold—the oldest is amalgamation and the other is cyanide, which only dates to the 1880s in the US (Craig et al., 2001), then mercury amalgamation must be considered as key to archeological studies of ancient gold production. However, most archaeologists resist this logic and provide no evidence of alternative methods. Hard geochemical evidence for pre-contact use of mercury for gold amalgamation is based on comparison of the high mercury content of pre-cursor alluvial gold (>5000 ppm Hg) and the low mercury content of artifact gold (<20 ppm Hg) resulting from burning (*refogado*) the gold-mercury amalgam to volatilize the mercury (Petersen, 2010; Brooks et al., 2013).

Approximately 1.5 tons of gold per month are produced from Perú's small-scale gold mines that use artisanal methods that include the ages-old technique of gravity separation and mercury amalgamation (Ahern, 2016; Al-Hassan & Hill, 1986; Brooks et al., 2007; Cánepa, 2005; Chauvin, 2018; Larco Hoyle, 1945, 2001; Soto-Viruet, 2018). The abundant alluvial gold sources (Noble & Vidal, 1994; Atlas, 1999; Atlas, 2000) in Perú likely provided the tons of gold used by Atahualpa as ransom for his release from the Spanish before his execution in 1533.

2. Using the Molinete

The *molinete* consists of a movable, upper stone, or *chungo* and a lower, station-

ary stone base, or *muscha*, that has a depression to seat the *chungo*. These stones may weigh one ton, or more, each. The worker, or *moledor*, is seated (**Figure 1**) and rocks the *chungo* with his feet (**Figure 2**) or may be aided by ropes attached to the *chungo*. In the 1940s smaller rocks encircled the *muscha* in order to help contain the muddy mixture (**Larco Hoyle, 1945, 2001**). Water is added to the *muscha* which helps the initial gravity separation of the heavier gold from the ore. Mercury is then added to the *muscha* and amalgamates the millimeter-sized or smaller gold particles. To recover the amalgam, a rock is propped under the *chungo* for safety. The amalgam is squeezed in a cloth to recover excess mercury and then burned to volatilize the mercury leaving an anthropogenic gold nugget.

Mercury is commercially available in Perú (**Brooks et al., 2007**) (**Figure 3**). And in the past, mercury was available from mercury occurrences in Perú that include mines such as Chonta and Huancavelica (**Arana, 1901; Petersen, 2010; Giles, 1990; Brooks, 2020**).



Figure 1. *Molinete* workplace, Pataz, northern Perú.



Figure 2. Worker seated at *molinete*, Pataz, northern Perú.



Figure 3. Commercial mercury used at *molinete* work site, Pataz, northern Perú.

3. Plants and Gold Recovery

Artisanal gold that is recovered today using plants or other non-mercury methods is referred to as “green gold” however, the use of plants as a part of gold processing dates to Roman time at Las Médulas, Spain. The gold washing tables, called *agogae*, were lined with moss or heather, locally called *brezo* [*Ericaceae*], which helped trap the fine-grained gold particles (Fernández-Lozano et al., 2021). The plants were removed, cleaned, and mercury was added to amalgamate the trapped fine-grained alluvial gold particles. This is mechanically comparable to the legendary Golden Fleece and the use of animal skins or specialized carpets and mats that are similarly used today to trap the fine-grained gold in sluice boxes.

In Chocó, western Colombia, artisanal miners use plant leaves, commonly called *cedro playero* to aid the final separation of the fine-grained gold and platinum from the lighter waste material (Castillo, 2007) and mercury is not used. The plant leaves are crushed by hand and the frothy liquid is mixed in water to make a flotation foam that is added to the gold pan. The heavier gold sinks as a heavy-mineral separate from the lighter minerals that cling to the foam. The plants were identified as *Balso* [*Ochroma pyramidale*] and *Malva* [*Hibiscus furcellatus*] (Brooks et al., 2015). Chocó gold miners were awarded a United Nations environmental award for producing green gold (Silva Herrera, 2010; Brooks, 2014).

Near Tulpo, northern Perú, the use of plants in gold-processing was documented in the 1940s by Larco Hoyle (1945, 2001) and the local plant names include: 1) *pegorondo*, which helps clean the mercury of impurities, and 2) *murmunchito*, which forms a viscous mass to capture the gold and also help lubricate the movement of the *molinete*. Other plants listed include: *el shinac*, *shirac* [*Iochroma umbellata*] (Figure 4), *la verbena* [*Verbena litoralis*] (Figure 5), *el cuiguyum* [*Solanum glutinosum*] (Figure 6), and *el negush negush*. Only some of the listed plants were found in the field and the other local plant names given in

Larco Hoyle (1945, 2001) were not cross-referenced in Flora of Perú (MacBride, 1936a, 1936b). However, the use of plants with *molinetes* has been discontinued since the 1940s.



Figure 4. *Shirac* [*Iochroma umbellata*], northern Perú.



Figure 5. *La verbena* [*Verbena litoralis*], northern Perú.



Figure 6. *El cuiguyum* [*Solanum glutinosum*], northern Perú.

Agricola (1912) describes a unique mercury retorting process in which mercury is retorted from cinnabar in a closed work area or hut that contains a shrub or small tree. The mercury is retorted from cinnabar, the common ore of mercury, and the vapor condenses on the cooler plant leaves and can then be collected.

4. Sampling

A *molinete* site near Pataz was sampled to determine the efficiency of mercury amalgamation. Samples were taken of the gold ore and the mud resulting from *molinete* processing with water and mercury. It is important to indicate that the *molinete* process is ongoing with little clean-up other than perhaps a spray with a hose after the amalgam is removed and therefore, the mud from the first step mixes with ongoing mud output from the *molinete* process. Spot samples obtained from each step were analyzed by ICP (Inductively Coupled Plasma) and fire-assay for gold content and results from spot sampling at the Pataz site are given on **Table 1**. The samples were taken as available and there is no continuity between samples of: 1) ore, and 2) mercury-bearing mud on **Table 1**. Spot samples (~400 g each) were taken at each step given below:

Step 1: gold ore is crushed by the *molinete*, ~23% of the gold, as a gold-mercury amalgam is removed from the mud during this step

Step 2: remaining gold-mercury containing mud flows out of the *molinete*, there is no further treatment to recover the remaining gold or mercury.

Table 1. Molinete geochemical sampling, Pataz, northern Perú.

	PE251 Au ore	PE252 Au ore	PE253 after Hg	PE254 after Hg	PE255 after Hg
Au (0.003)	6.46	79.5	55.7	31.4	12.0
Ag (0.3)	0.3	7.0	11.7	7.1	6.5
Al (300)	44,004	34,941	21,788	32,669	20,137
As (2.0)	4028	294	2142	918	376
Bi (5.0)	<5	10	41	25	<5
Ca (300.0)	2013	3562	5186	9404	3252
Ce (1.0)	31	10	9	12	13
Co (1.0)	14	53	143	81	21
Cu (1.0)	34	114	1302	915	498
Fe (300)	32,653	158,228	>250,000	167,557	67,956
Hg (0.5)	3.8	6.7	>100	77.9	>100
K (300)	35809	3878	7036	10715	3722
La (1.0)	16	7	7	8	8
Li (2.0)	<5	15	<5	6	12
Mg (100.0)	3787	25,731	8760	11,746	9323
Mn (5.0)	248	753	216	287	710
Na (100)	5214	140	601	970	326
Ni (1.0)	9	15	11	8	20
Pb (3.0)	19	1056	4338	3409	1934
S (30)	13,719	91,121	175,367	102,647	19,043
Sb (2.0)	7	7	7	3	3
Sc (1.0)	8	16	6	9	9
V (3.0)	29	115	31	43	115
Zn (3.0)	22	687	2364	1736	1166

Multi-element ICP analyses in parts per million (ppm) (detection limit given to right of element, in parentheses); American Assay, Sparks, NV [ICP-I04AB28, Au-fire assay]. Sample Descriptions: PE251 Au ore, rusty, quartz vein breccia, abundant pyrite and sulfides; PE252 Au ore, rusty, mafic rock, with quartz breccia, abundant pyrite; PE243 mud after *molinete* crushing and addition of Hg; PE254 mud after *molinete* crushing and addition of Hg; PE255 mud after *molinete* crushing and addition of Hg.

5. Elements of Interest

Gold—Two spot samples of the gold-bearing ore were sampled and the gold content of the two samples was 6.46 ppm and 79.5 ppm for an average gold content of 43 ppm gold (Table 1). After amalgamation, spot samples of the outgoing

molinete mud ranged from 12 ppm to 55.7 ppm gold for an average gold content of 33 ppm gold indicating that mercury removed ~23% of the gold during amalgamation. In Perú, a study of artisanal gold recovery using the *quimbalete* indicated that ~20% of the gold was recovered by amalgamation (Brooks, 2025) and in Colombia, a similar field study showed that <19% of the gold was recovered by amalgamation (Torkaman & Viega, 2023).

Silver—Two spot samples of gold-bearing ore indicated very low silver content of the ore.

Mercury—Two spot samples of the gold-bearing ore contained 3.8 ppm and 6.7 ppm mercury indicating the base level of mercury in the primary gold deposit. After amalgamation the mercury content of the outgoing *molinete* mud samples was predictably higher, from 77.9 ppm to >100 ppm mercury. The gold-mercury-containing mud from the *molinete* process goes untreated and may create an environmental risk, whereas the mud from the *quimbalete* process is treated with cyanide to recover the remaining gold (Brooks, 2025).

6. Conclusion

Perú is the leading gold producer in South America and ~1.5 tons of gold per month are produced from Perú's numerous small-scale gold mines that use age-old indigenous methods that include the use of *molinetes*, gravity separation in water, and mercury amalgamation. However, mercury is lost to the environment from amalgam burning as a vapor as well as residual mercury in the mud resulting from the *molinete* process. Amalgamation with a *molinete* removes ~23% of the gold and the gold remaining in the mud is not recovered. Present-day artisanal *molinete* technology and the use of mercury to produce gold is key to understanding past gold production in the pre-contact Andes.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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