Archaeology International No. 13/14, 2009-2011, 76-83 DOI: http://dx.doi.org/10.5334/ai.1318

The Production of Silver in South America

Thilo Rehren*

Silver plays important roles in pre-Columbian, colonial and modern South American societies. Case studies covering the production stages, and spanning nearly two millennia, provide examples of the complexities of silver metallurgy. Ethnographic evidence from Bolivia demonstrates the function of the pre-Columbian *huayrachina* furnace, adapted to the environment of the High Andes, while an archaeological site in southern Peru exemplifies the small-scale, probably domestic, processing of silver slag across major socio-political changes. The transition from indigenous to European technology is another complex aspect of South American silver metallurgy and highlights the importance of studying technology in its social and economic contexts. We can see the co-existence over several centuries of a large-scale state-run silver industry, based on the patio process (and requiring a long-distance network to provide silver ore, mercury, energy and supervision), alongside a small-scale European high-temperature silver extraction (using fuel-intensive 'dragon' furnaces), and a surviving indigenous technology based on *huayrachina* furnaces.

The mineral wealth of South America is legendary, for its gold that fuelled the early dreams of the European invaders, the emeralds from Colombia and the diamonds from Brazil that dazzled the aristocracy and newly rich in Europe, Western and South-East Asia, to the more mundane copper and iron ore driving today's global commodity boom. Silver, by comparison, has been less visible in the public perception, both in the past and more recently, although South America is still the world's largest producer of this metal and has been so for centuries. Throughout the 16th and 17th centuries, South American silver financed in a complex global economy the trade between Asia and Europe. Having finally lost its traditional role as a coinage metal and more recently as the basis for photographic film, it now oscillates between an industrial metal used for electronics and other practical uses, a hoard of wealth (particularly in India), and a medium of speculation on the international metal markets. But what about the role of silver in pre-contact societies in South America? We know that silver had been used for at least a millennium before the conquest, and that in the later cultures it was held in juxtaposition to gold, like the moon and the sun, and its use restricted to the elite of the Inca Empire. But what do we know about the production of silver? Namely, where, how and since when was it smelted from its ores?

The best evidence for the early use of silver are, of course, archaeological silver finds; however, these are rare and not well published, so that an authoritative statement about its distribution and consumption is hardly possible. What is apparent is that

* UCL Qatar,
PO Box 23689, Education City, Doha, Qatar
th.rehren@ucl.ac.uk

This paper is an English version of a text originally published (2011) as 'Zur frühen Gewinnung von Silber in Südamerika', in Slotta, R. and Schnepel, I. (eds) *Schätze der Anden - Chiles Kupfer für die Welt*, Bochum: Deutsches Bergbau-Museum, 257-264.

across the length of the Andes silver played a major role. Some evidence for this comes from the tales of the conquerors – and the tax and cargo lists from the ports on both sides of the Atlantic. An illustration of the abundance of silver in the Inca Empire is given by the account of the capture of the last Inca, Atahualpa, in late 1532. The ransom paid for his release was defined thus: a room measuring 7 x 5m was to be filled to half its height of 5m with gold, and twice over to its entire height with silver. It took two months to deliver the loot, before Franscisco Pizarro had him killed regardless. Nine Spanish furnaces were then busy for three months melting down the metal, casting 11 tons of gold – and twice as much in silver ingots. The veracity of this report is difficult to establish, and much of the gold may well have been *tumbaga,* the copper-rich alloy made to look like gold through surface treatment. Certainly more reliable are tax lists, e.g. for Seville, Spain's main port for treasure ships. These show that between 1531 and 1660, c.155 tons gold and 17,000 tons silver were landed – that is more than one hundred times in weight silver than gold, and hence also much more in value. Much of this was, of course, the result of European mining in both Bolivia and Mexico, but the story about Atahualpa does show that, already before the arrival of the Europeans, silver played a major role among the metals of South America. This paper aims to provide a brief overview of recent research into pre-Columbian silver production – about which we know more than the production of either gold or copper.

Tracing pre-Columbian silver production

Several serendipitous discoveries over the last decade have enabled us to start to piece together a comprehensive picture of silver metallurgy in pre-Columbian South America. It has to be stressed that this is still very much a pastiche of culturally and chronologically disparate elements and observations, and that a high-resolution picture for individual regions or periods is as yet far away.

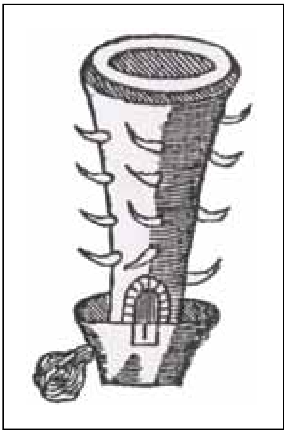

Fig. 1: A *huayrachina* silver-smelting furnace in the Bolivian Andes (after Barba 1640).

Having said this, the various elements will be presented in their technological sequence, covering a substantial part of the comparatively complex metallurgy of silver.

Smelting silver

The metallurgy of silver begins with the smelting of its ores. We can assume that the earliest smelters had easy access to native silver, a relatively common occurrence in many surface outcrops of silver-bearing veins. This only needed to be melted and cast into shape, leaving little if any archaeological trace of its production. At some point, though, the metallurgists had to resort to more complex silver ores, either intergrown by nature with lead minerals, or using added lead as an aid in smelting. The function of the lead in this is to collect the finely dispersed silver from the ore, almost like a selective sponge, and to separate it from the worthless gangue components. For this to work, the silver content in the ore can be as low as a fraction of one percent by weight; and lead as a collector is indispensible for this process.

The smelting of lead-rich silver ore in the Andes is in early reports always connected with a particular furnace type, the *huayrachina* (**Fig. 1**).[1,2] The *huayrachina* furnace with its numerous small openings depended on a strong and permanent wind flow, and was

Fig. 2: A *huayrachina* smelting furnace in use for lead production near Porco, Bolivia (photo B. Mills).

therefore always placed in particularly wind-exposed settings. That much was known; but little archaeological evidence for *huayrachinas* had been published, and the technology seemed extinct since the last reported sightings in the late 20th century. Unexpectedly, fieldwork by Dr Mary Van Buren, and her team from Colorado State University, in the vicinity of Porco, near Potosi in southern Bolivia, located an on-going tradition of some local people to smelt lead-rich ores in *huayrachinas,* as for instance Don Carlos Cuiza (**Fig. 2**).[3] A detailed investigation of some of Don Cuiza's smelts formed the basis of Barbara Mills' BSc dissertation and Claire Cohen's PhD thesis at the UCL Institute of Archaeology.[4] One of the key aspects of this research is that the *huayrachina* is exceptionally fuel-efficient, albeit at the expense of an incomplete metal yield.[5] This low metal yield, manifest in numerous metal droplets trapped in the incompletely molten slag, is due to the relatively low operating temperature of the furnaces. However, this makes perfect sense in view of the mineral wealth of the region and the scarcity of fire wood – the furnaces operate at c.4,000m above sea-level, well above the tree line. The furnace charge consists of c.2/3 galena, lead sulphide, and 1/3 cupellation hearth material, recycled waste of an earlier step in the silver production rich in lead oxide and thus the ideal complement to the sulphur-rich galena. Don Carlos only smelted for lead metal in his *huayrachinas,* but our investigation of older *huayrachina* fragments, widely scattered in the region, showed that silver-rich ore was previously smelted – as is evident from the silver-rich droplets of metal in the slag, often visible to the naked eye.

The origins of this furnace type are difficult to date, as there are hardly any excavated pre-Columbian *huayrachinas* known; it is apparent that the technology is restricted to the high altitudes of the Andes, located on saddles or slopes with strong erosion and no build-up of datable archaeological sediments. However, the *huayrachinas* are widely reported by the earliest chroniclers as an unusual furnace type and have noth-

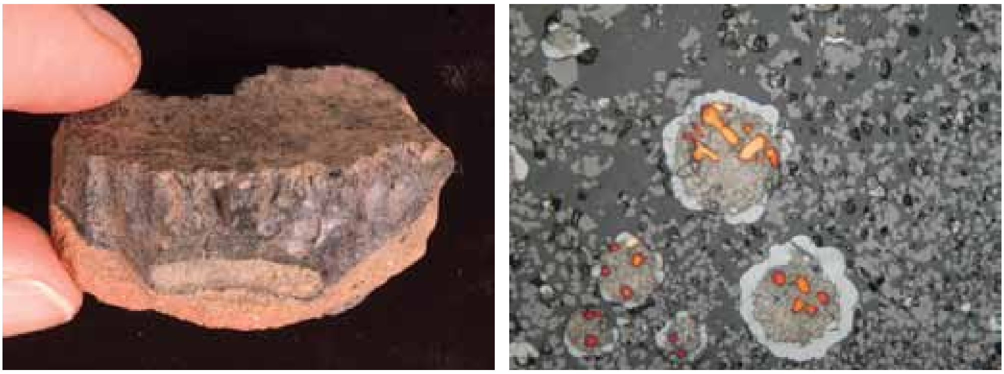

Fig. 3 a-b: Crucible fragment containing silver-rich slag, excavated from a pre-Columbian workshop by Lake Titicaca, Peru (photo 3a C. Schultze).

ing in common with the European furnaces later introduced by the Spanish; it is safe to assume an indigenous origin for them.[5,6] What is remarkable is that this technology has persisted to this day, even if very much marginalised and conducted in secrecy, in the face of half a millennium of colonial and modern attempts to centralise and control silver production under the aegis of the government of the day.

The antiquity of the indigenous processing of complex sulphur-rich silver ores has recently been shown by Carol Schultze, who carried out her PhD research at the University of California in Los Angeles on an archaeological site at the shore of Lake Titicaca in Peru. She was able to demonstrate through deep soundings that, for well over a millennium in this workshop complex, silver-rich slags were processed in small crucibles (**Fig. 3, a-b**).[7] On-going research, undertaken jointly with the Institute of Archaeology, has demonstrated the likelihood that metal droplets extracted from smelting slag were re-melted to obtain larger lumps of metal, ready to be further processed elsewhere to extract the pure silver.[8] One can imagine that this slag rich in metal droplets formed in *huayrachinas,* somewhere high in the mountains, near the mines, where a steady wind blew. We can assume that this secondary crushing and hand picking of metal prills occurred as a regular part of the *chaîne operatoire* of indigenous silver production, from the earliest layers dated to the 1st century AD right down to the Spanish conquest, and beyond. Such an activity would most elegantly compensate for the seemingly inefficient metal yield of the *huayrachinas,* without the need for additional fuel but using well-established mechanical means of crushing and grinding for most of the labour. Studies of lake sediments elsewhere in Bolivia point to a long-lasting pre-Columbian silver production across a wide region,[9] suggesting that this technology was not an isolated instance.

Cupellation

The first product of the silver smelting furnace is silver-rich lead whenever lead is used as a collector for noble metals; 'silver-rich' in this context often means not more than one percent of silver in 99 percent of lead metal, although it can of course be much more if the ore is rich enough. Whatever the case may be, lead and silver have to be separated first, before the pure silver can be worked into artefacts or alloyed with copper for further working. This separation of lead from silver is carried out through selective oxidation of the less noble lead metal, in a process known as cupellation. The argentiferous lead is kept molten in a shallow hearth, and a constant blast of air across its surface burns off the lead to lead oxide, litharge, while the noble silver remains at the end as pure metal, the regulus. In the Old World, this process is


Fig. 4 a-b: Out-building on a farm near Porco, Bolivia, containing a hearth for silver cupellation (photo 4b B. Mills).

known at least from the Early Bronze Age onwards[10] and was vividly described by Pliny the Elder, who compared the separation of litharge from silver with that of oil from water, a very apt comparison for the separation of two immiscible liquids by their different densities.[11]

As a result of Dr Van Buren's work and with the co-operation of Don Carlos Cuiza, we were able to observe first-hand the indigenous silver cupellation. The cupellation hearth, hidden in a small out-building on his farm, is prepared from the ash of a local plant called *llareta* or *Yareta* (*azorella compacta*) (**Fig. 4 a-b**).[5] The fuel is llama dung, available in abundance on the farm and sufficient in its heat generation. Subsequent analysis of the cupellation hearth material in London showed that it is much richer in sulphur than its European counterparts and had a significant silver content, indicative of incomplete silver recovery.

It is noteworthy that H. Lechtman, in her fundamental survey of Andean metallurgy (1976),[14] published numerous disk-shaped cakes of cupellation hearth material from Middle to Late Horizon Ancón. Among the characteristics mentioned by her is their high sulphur content; this might suggest that this is a common feature of pre-Columbian Andean metallurgy which has survived to this day, in parallel with half a millennium of the more oxidising practice introduced by the Europeans.

Synthesis

Viewing these individual studies in a broader (hypothetical, partly ahistorical) context shows that each step of the *chaîne operatoire* has its short-comings and limitations; however, taken together, they combine to form a sequence of nearly perfect silver recovery optimised for fuel efficiency. The first smelting in the *huayrachina* takes place at a relatively low temperature, resulting in an incomplete separation of metal and slag; the silver losses here are minimised by crushing the slag and hand-picking the metal prills for re-melting in small crucibles. The cupellation of the argentiferous lead occurs in a closed hearth, again ideal to conserve heat and minimise fuel consumption; this results in higher sulphur retention and increased silver loss into the hearth material. Recycling the cupellation hearth material into the initial *huayrachina* smelting does, however, capture this residual silver during the next cycle of the process. This systematic recycling of cupellation hearth material explains why so little of it is known archaeologically; even today's indigenous silver smelters told us that they regularly collect cupellation hearth material 'from the mountains' to add to their smelting charge.

The European influence

The transition from the indigenous *huayrachina* furnaces, with their limited production

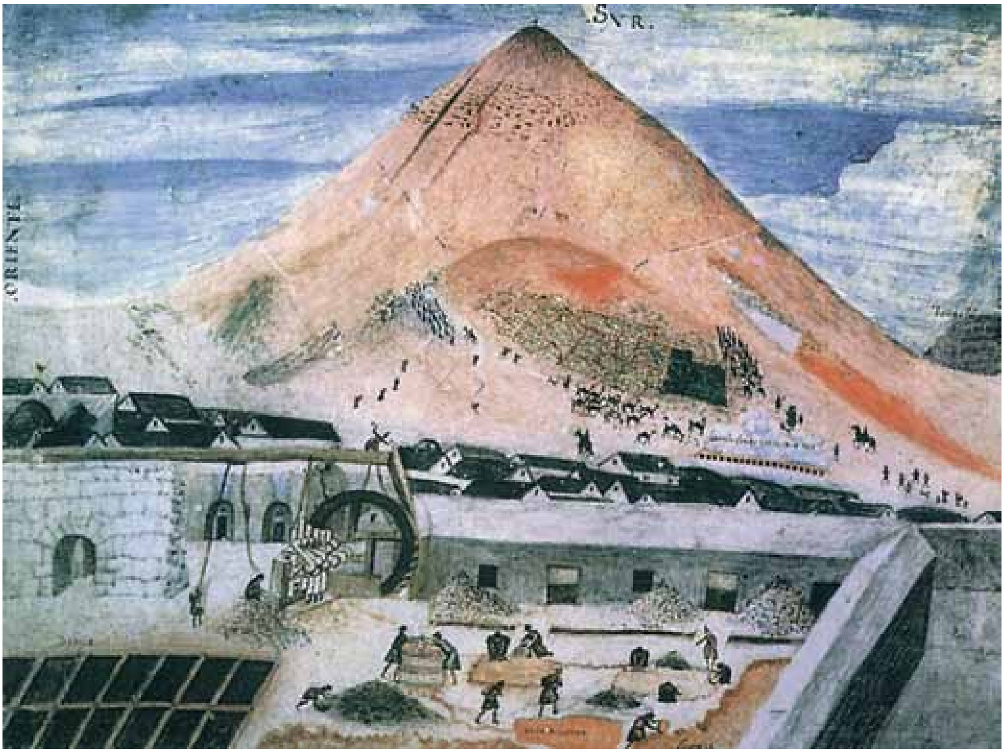

Fig. 5: The European silver production landscape at the Cerro Rico, Potosi, as shown by an unknown artist in 1584. In the foreground the beneficiation of ore in preparation for the patio process is visible.

volumes and dependence on rich ores, to the European amalgamation technology of the patio process in 1570 is well known and historically documented, particularly for Potosi (**Fig. 5**).[12,13] Less well-known are the numerous small European furnaces producing silver for centuries, probably at a relatively small scale and possibly in private ownership. The best historical source for these is Alonso Barba's (1640) *Arte de los Metales*, which provides a comprehensive overview of European metallurgical practice in South America some 150 years after the conquest. In this work, he presents the various furnace types in operation, the most remarkable of which are the 'dragons': hemispherical furnaces with a long chimney and adjacent fireboxes (**Fig. 6**).[6] Near Porco, some of these furnaces are well preserved (**Fig. 7**), and the investigation of the slag from these showed that they – like the *huayrachinas* – worked sulphur-rich ores, but with a much better fused slag and hence, most likely, a much higher fuel consumption. We do not have exact data to prove this, but it is reasonable to assume that this is a direct reflection of an attitude directed to short-term profit maximization, at the expense of a long-term and sustainable economy adapted to the ecosystem of the High Andes.

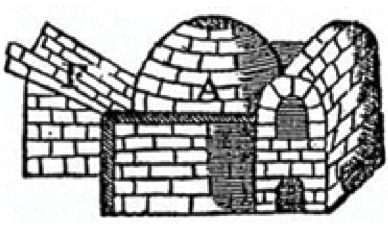

Fig. 6: 'Dragon furnace' for silver smelting in the Bolivian Andes (after Barba 1640).

Fig. 7: Remains of a well-preserved 'dragon furnace' near Porco in southern Bolivia.

Summary

The studies sketched here demonstrate how much archaeometallurgical knowledge is still to be gained through further research in the field and the laboratory. Luckily, most of the archaeological sites are situated in remote and inhospitable regions, preserving them despite the harsh environmental conditions. We see clear evidence for an indigenous metallurgy well adapted to the scarcity of fire wood and comprising a sequence of inter-related operations which in the end result in an efficient exploitation of the natural resources. Its roots can be traced back for nearly two millennia, and some of it persists to this day in a clandestine but regularly conducted operation. The use of European-designed 'dragon' furnaces is less well-documented and offers rich potential for further research. Both of these pyrometallurgical traditions operated for centuries side-by-side with the 'cold' patio process promoted by the government to exploit even poor silver ores. Thus, we see three separate metallurgical traditions operating in parallel, each occupying its own particular economic and environmental space.

References

1 Peele, R. (1893) 'A primitive smelting furnace', *School of Mines Quarterly* 15, 8–10.

2 Pfordte, O.F. (1893) 'Ancient method of silver and lead smelting in Peru', *Transactions of the American Institute of Mining Engineers* 21, 25–30.

3 Van Buren, M. and Mills, B.H. (2005) 'Huayrachinas and Tocochimbos: traditional smelting technology of the southern Andes', *Latin American Antiquity* 16, 3–25, http://www.jstor.org/stable/30042484.

4 Cohen, C. (2008) 'The Winds of Change: an archaeometallurgical study of silver production in the Porco-Potosi region, southern Bolivia, AD 1500 to 2000', unpublished PhD Thesis, UCL Institute of Archaeology, London.

5 Cohen, C., Rehren, Th. and Van Buren, M. (2009a) 'When the wind blows: environmental adaptability in current day silver production within the Bolivian Andes', in J.F. Moreau, R. Auger, J. Chabot and A. Herzog (eds) *Proceedings ISA 2006, 36th International Symposium on Archaeometry, 2-6 May 2006, Québec City, Canada,* Québec: Centre interuniversitaire d'études sur les lettres, les arts et les traditions, 465–75.

6 Cohen, C., Rehren, Th. and Van Buren, M. (2009b) 'An archaeo-metallurgical study of the use of European furnaces in colonial Bolivia', in *Archaeometallurgy in Europe II, 2nd International Conference, 17-21 June 2007, Aquileia, Italy: Proceed-*

ings, Milano: Associazione Italiana di Metallurgia, 529–40.

7 Schultze, C., Stanish, C., Scott, D., Rehren, Th., Kuehner, S. and Feathers, J. (2009) 'Direct evidence of 1,900 years of indigenous silver production in the Lake Titicaca Basin of Southern Peru', *Proceedings of the National Academy of Sciences of the United States of America* 106, 17280–3, DOI: http://dx.doi.org/10.1073/pnas.0907733106.

8 Rehren, Th. and Schultze, C. (2010) 'Indigenous silver production at Lake Titicaca, Peru, from 1900 BP to 400 BP' (presentation at the 38th International Symposium on Archaeometry, Tampa, Florida).

9 Abbott, M.B. and Wolfe, A.P. (2003) 'Intensive pre-Incan metallurgy recorded by lake sediments from the Bolivian Andes', *Science* 301, 1893–5, DOI: http://dx.doi.org/10.1126/science.1087806.

10 Pernicka, E., Rehren, Th. and Schmitt-Strecker S. (1998) 'Late Uruk silver production by cupellation at Habuba Kabira, Syria', in Th. Rehren, A. Hauptmann and J. Muhly (eds) *Metallurgica Antiqua. In Honour of Hans-Gert Bachmann and Robert Maddin,* Bochum: Deutsches Bergbau-Museum, 123–34.

11 Rehren, Th. and Klappauf, L. (1995) '... ut oleum aquis. Vom Schwimmen des Silbers auf Bleiglätte', *Metalla* 2, 19–28.

12 Bakewell, P. (1997) 'Technological change in Potosi: the silver boom of the 1570s', in P. Bakewell (ed.) *Mines of Silver and Gold in the Americas,* Variorum: Brookfield, 75–95.

13 Probert, A. (1997) 'Bartolomé de Medina: the patio process and the sixteenth century silver crisis', in P. Bakewell (ed.) *Mines of Silver and Gold in the Americas,* Variorum: Brookfield, 96–111.

14 Lechtman, H. (1976) 'A metallurgical survey in the Peruvian Andes', *Journal of Field Archaeology* 3, 1–42, DOI: http://dx.doi.org/10.1179/009346976791547995.