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Metallurgy in Southern South America

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The Andes represent the largest source of mineral wealth in the Americas and the birthplace of New World metallurgy. Metallurgical exploitation of these resources occurred for millennia prior to colonial contact, as testified by numerous artifacts of gold, silver, and bronze. Prior to the arrival of Spanish conquistadors in 1532 AD, indigenous South Americans smelted silver ores, hammered gold sheets, and annealed copper alloy sheets, independently of technologies that, by then, were highly developed in the Old World. Despite this extensive history, we know astonishingly little about the development of metallurgical techniques through time.

Today we learn about ancient metallurgy primarily through three sources of information. The first is the collection and analysis of artifacts recovered from archaeological excavations. However, looting of archaeological sites is pervasive and as a result the archaeological record is incomplete (Jones and King 2002). This means that the archaeologist often works with either a small fraction of the original material, or with artifacts that have been removed from their original context. Moreover, looters frequently “restored” looted artifacts, severely limiting what information can be drawn from their appearance (Shimada and Griffin 2005). The second source of information comes from historical and ethnographical data collected at the time of conquest. For recordkeeping purposes, Spanish conquistadors documented the looting of Inca palaces and exploitation of Inca mines (Lechtman 1976). Useful as these archives are, they tell us little about those peoples who preceded the Inca. Moreover, the Spanish were primarily concerned with the acquisition of gold and to a lesser extent silver. They make little mention of copper and copper alloys, even though these represent the foundation of Andean metallurgy. The third method is that of archaeometry. Archaeometry is the application of scientific methods to archaeological sites or artifacts. In the Andes, the most common archaeometric analysis employed is a compositional chemical analysis (Lechtman 1999, 2002). Recently, scientists have also utilized geochemical analysis of lake sediments to track atmospheric pollution from smelting. This method was used to establish the onset of smelting at the town of Potosí in the highlands of southern Bolivia (Abbott and Wolfe 2003). This method provides an independent record of the timing and intensity of smelting for the region. However, as with the previous approaches, it has its limitations. It cannot answer which group specifically was smelting or how it was used or valued by ancient South Americans, and is restricted to regions, which contain continuous sedimentary environments suitable for analysis (i.e., lakes, swamps, bogs, etc.). Despite the limitations of each of these methods, by studying them in concert, it has become apparent that indigenous South Americans possessed extensive knowledge in acquiring metals from various ores and also in combining and working metals into elaborate artifacts. Here, we review the major findings related to the procurement and smelting of nonferrous ore bodies in the southern Andes and the manufacture and use of various alloys as tools and objects of adornment within indigenous South American culture.

Smelting

Nonferrous metal ores have been smelted in South America for approximately 2,500 years. The earliest evidence to date for smelting activity in southern South America comes in the form of copper slag from the Wankarani site in the highlands of Bolivia dating between 900 and 700 BCE (Ponce 1970). Slag, also known in the Andes as *scoria*, is the waste or by-product of smelting. Often this is all that remains for the archaeologist to find as an indication of metallurgical activity (Van Buren 2005). Very little research has been conducted on the metallurgy at Wankarani and to date little is known about what type of metal artifacts were being produced and how the control of metal resources was governed.

To the southwest, additional evidence for early smelting comes from recent research at the Ramaditas site in the Guatacondo Valley of northern Chile (Graffam 1994, 1996). Here, excavations have revealed evidence that copper smelting and sheet metal working (*repoussé*) began near the first century BCE. This finding confirmed that not only does metallurgy date back in excess of 2,000 years in northern Chile, but that this activity was often carried out independent of the presence of a large formalized state or Empire (Graffam 1994, 1996). Northern Chile contains abundant ores of copper and the exceptionally arid environment allows excellent preservation of artifacts. This makes Chile an ideal locality to conduct future metallurgical research.

On the *altiplano* of southern Bolivia, a silver deposit known as Cerro Rico de Potosí was once the world's richest silver mine. Legend attributes the discovery of silver at Potosí to the penultimate Inca ruler, Huayna Capac, in the mid-fifteenth Century AD. However, this date was recently challenged by the discovery of much earlier metal pollution in a nearby lake that can only be explained by local smelting activity (Abbott and Wolfe 2003). During smelting, trace metals are released into the atmosphere and are subsequently deposited into the lake environment through precipitation and dry atmospheric deposition. As soils, algae, and sediments accumulate at the bottom of the lake, they preserve these atmospherically derived metals. Natural archives, i.e., lake sediments, are sensitive enough to pick up even preindustrial emissions (see Renberg et al. 1994). Lake sediment cores (tubes of sediment recovered vertically from the bottom of a lake) were collected from a high alpine lake downwind of Cerro Rico de Potosí. Geochemical analysis of the sediments revealed a long history of smelting activity beginning shortly after 1000 AD, 400 years prior to the supposed discovery of silver! The use of this method to track metallurgical activity has only just begun and research is currently underway to understand the chronology of smelting throughout the Andes.

The final source of information on indigenous smelting at Potosí comes from a combination of historical archives and ethnoarchaeological research. Given its richness, Potosí was the central focus of colonial mining for years after conquest. As a result of this attention, a written chronicle of smelting techniques in use at Potosí exists. For example, between 1545 and 1572 AD, Inca silversmiths under colonial rule using indigenous furnaces conducted all silver production. Three different types of furnaces were recorded by the Spanish during this time as they worked Potosí and the nearby mine of Porco. The first type of furnace was simply a pit dug into the ground that reduced ores rich in silver. The second type was a small, and sometimes portable, reduction furnace called a *huayara*. These charcoal-fired, wind-drafted furnaces were lined with clay and were often placed on mountaintops to take advantage of strong winds. As such, they were prone to destruction by any number of natural forces (e.g. landslides, earthquakes) and to date none have been recognized in the archaeological record. Recently, however, a huayara has been found still in use today in Bolivia (Van Buren 2005). This is an important discovery, which promises to contribute a great deal toward the understanding of ancient smelting techniques and their remains in the archaeological record. The third type of furnace was a *tocochimpu*, which was normally used to refine silver in combination with argentiferous galena or *soroche* (lead sulphide). Cieza de León was one of the first Spanish chroniclers to describe the use of soroche at Potosí and documented its use as a flux to enable extraction of silver from even low-grade ores. Future research combining historical archives, archaeological and ethnoarchaeological research is sure to illuminate lingering questions regarding the spatial and temporal homogeneity of smelting technology in the southern Andes.

Despite these advances in the smelting of ores, direct analysis of the metal artifacts themselves is the most common analytical approach. The most frequent analysis performed is that of a compositional analysis which determines the relative proportions of the metals which make up an artifact. This has shown that the vast majority of Andean artifacts are composed of alloys. Alloys, rather than pure metals, are pervasive in both Old and New World metallurgy for three reasons. First, occurrences of pure copper, silver, and gold do not commonly occur in any large quantity. Second, alloys have the benefit of often being harder than objects made of native metal, as is the case with silver and gold (Lechtman 1996). Third, by combining one or more metals, the melting temperature of those metals is lowered, which facilitates the smelting of ores. This is important as all pre-Columbian metallurgy was done without the use of bellows and had to rely on natural drafts to aerate furnaces.

The most common alloys found in southern South America have been those of arsenic–copper (arsenic bronze), tin–copper (tin bronze) and ternary alloys of copper, arsenic and nickel. There is also evidence that the Inca alloyed bismuth in bronzes recovered from the site of Machu Picchu (Gordon and Rutledge 1984). Alloys composed of copper–gold (a binary alloy sometimes referred to as tumbaga) and copper–silver–gold (a ternary alloy) have also been found, though not in the same quantity as copper alloys (King 2000). The precious metal artifacts that are found normally occur as items of personal adornment (e.g., discs, bracelets, rings, and pendants) associated with individuals of high social status, and as religious or ceremonial items (Olsen Bruhns 1994). Because of the extensive looting which has taken place in Peru, both recently and during colonial times, few precious metals remain and our understanding of them remains comparatively sparse. Here we focus our discussion on the appearance and distribution of copper alloys as they represent the backbone of Andean metallurgy. We then highlight two examples in which indigenous South Americans altered the appearance of copper-gold and copper-silver alloys to give them the appearance of precious metal.

Bronze Alloys

Arsenic bronze was the earliest alloy to be utilized in both northwest Argentina and southern Peru. In northwest Argentina, arsenic bronze was in use by 400 AD and its use continued until colonial conquest. This bronze alloy was used both for tools (axes, chisels, and wedges) and finer domestic items (awls, needles, bracelets, and tweezers) (González 1979; Fester 1962). In southern Peru the earliest evidence for arsenic bronze metallurgy occurs at the site of Pikillacta in the Lucre Valley circa 600 AD (Lechtman 1997). This occurs during the influence of the pre-Inca Empire known as the Wari, which controlled the area from approximately 600 to 1000 AD (McEwan 2005). These arsenic bronze artifacts are normally represented by domestic items or tools (Lechtman 1997). Naturally occurring alloys of copper and arsenic are readily available in the high Andes of central/southern Peru and would have been accessible to native South Americans. Therefore, arsenic bronze metallurgy characterized the time period between 400 and 1000 AD in southern Peru and northwest Argentina.

In contrast, in Bolivia there is a paucity of both natural alloys and artifacts made of arsenic bronze. Rather, tin bronze and copper–arsenic–nickel alloys seem to have been the metals utilized. The earliest occurrence of this alloy in Bolivia is found on the Bolivian *altiplano* around 600 AD (Lechtman 2002). Tin bronze was favored for ornamental rings, while copper–arsenic–nickel appears to have been preferred for needles, nails, and chisels (Lechtman 2002). The tin for tin bronze appears to have been obtained from the rich "tin belt" of the *altiplano*, where it primarily occurs in the mineral cassiterite (tin oxide). No source has yet been found for the copper–arsenic–nickel alloys. Therefore, tin-based bronze metallurgy in northern Bolivia appears to have begun around 600 AD. This is broadly contemporaneous with the widespread use of arsenic bronze metallurgy in nearby southern Peru and northwest Argentina. Future research is needed to understand what, if any, interaction was occurring between Bolivia and southern Peru at this time of florescence of the copper industry.

Traveling north and forward 200 years to 800 AD, the site of Batán Grande represents early arsenic bronze metallurgy along the north coast of Peru. Previously undocumented in the New World, Batán Grande is a prehistoric metallurgical center situated in the La Leche Valley (Shimada et al. 1982, 1983). Smelting here began circa 800 AD and continued until just prior to the Spanish conquest. Though small quantities of copper ore are locally available, arsenic bearing minerals are not. However, the highlands of northern Peru are rich in arsenic bearing minerals; this fact has led Lechtman (1991) to argue that highland miners might have provided coastal smelters with the necessary arsenic.

The mechanism for this highland-coastal exchange, be it social, economic, or otherwise, has yet to be adequately explained.

Batán Grande was also the site of a large-scale cosmelting operation heretofore undocumented (Lechtman 1999). During cosmelting, a mix of both the sulfides (the primary ore minerals) and oxides (the secondary or the weathered alteration product of sulfides) were charged into the furnace. This mixing need not be deliberate and yielded clean, coherent copper–arsenic alloy ingots (Lechtman and Klein 1999). Cosmelting represents a dramatic improvement in smelting operations while eliminating noxious arsenic fumes that might otherwise have been generated.

Moving forward to the mid-fifteenth century AD, the Inca Empire implemented the use of tin bronze for domestic and household metal items throughout Peru, Bolivia, northwest Argentina, and northern Chile. This widespread occurrence of tin bronze associated with the Inca Empire has been dubbed the so-called "Tin Horizon" (Costin 1989; Lechtman 1996; Lechtman and Klein 1999; Owen 1986). The tin would have been prepared as sheet stock and then could be dissipated through the Empire where it was added to local alloys of arsenic bronze or simply added to local copper to form tin bronze (Cositn 1989; Lechtman 1976). Adding tin to existing bronze technology improves the workability of the metal and increases the hardness of the finished product (Costin et al. 1989). The Inca represent the culmination of metallurgical development in native South American history until the conquest of the Spanish in 1532.

In summary, two loci of bronze based metallurgy can be distinguished for the southern Andes. This appears to be a direct result of differences in local resources (arsenic-copper deposits in southern Peru and northwest Argentina versus tin–copper deposits in northern Bolivia). The situation changes with the establishment of the Inca Empire, after which tin bronze becomes the domestic metal of choice throughout the Andes.

Precious Metals

Although artifacts made of bronze alloys are the most commonly found during archaeological excavation, gold and silver remained the most prized metals during Inca and pre-Inca times as well (Costin et al. 1989). For the Inca, gold was endowed with spiritual and symbolic meaning and was believed to be the rain of the sun, while silver was the rain of the moon (Jones and King 2002). However, artifacts composed purely of silver or gold are extremely rare. Considerably more common are alloys containing a mixture of copper and gold or silver. After the Spanish conquistadors took control of Peru, they began to melt down what they believed to be golden objects. To their surprise, they discovered that these "golden objects" were in fact composed of copper alloys and had only very thin surfaces of gold. This was because locally available resources, combined with sophisticated alloying techniques were used to produce golden surfaces on alloys containing small percentages of precious metals (Lechtman et al. 1982).

Experimental archaeology has been especially important here in determining how Andean cultures manipulated alloys to accentuate desired qualities. Two of the best examples of native abilities were the processes of electrochemical replacement plating and depletion gilding. In electrochemical replacement a copper alloy is given an extremely thin and even surface coating of sliver or gold. To accomplish this, silver and gold were dissolved in an acidic or corrosive solution (Lechtman et al. 1982). A copper artifact was dipped into this solution, and a chemical reaction would occur that resulted in a very thin and even "plate" or surface coating of silver or gold. In addition, the specific color of the object could be altered simply by varying the relative amount of silver or gold in solution (Lechtman et al. 1982). Depletion gilding was used on alloys of copper-silver-gold. Here, naturally-occurring chemicals are used to separate the gold from the silver, leaving a surface of the desired precious metal. These are just two of the techniques in which native South Americans manipulated the appearance of metal artifacts in order to achieve a surface of silver or gold. These technologies appear to have been developed by the Moche (100 to 800 AD) on the north coast of Peru and remained a northern phenomenon until the rise of the Inca Empire in the mid-fifteenth century. At this time the Inca Empire relocated the northern metallurgists to Cuzco to serve at the Inca capital. Further research is needed to document fully the full range of both Inca and pre-Inca alloying techniques.

In short, a wide variety of metallurgical techniques were used by Andean cultures, and considerable skill was demonstrated in the manipulation of nonferrous ores. By integrating the fields of archaeology, ethnohistory, and geology a great deal can still be learned about these cultures' use of metals.

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Meteorology in China

Li Di

Chinese meteorology, here referring to the traditional meteorology which was used in China, has many unique characteristics. Although China began to adopt Western meteorological knowledge as it was introduced in the seventeenth century, Chinese traditional meteorology lasted 250 years. Chinese meteorology can be described from four aspects.

Knowledge About Meteorological Phenomena

The Chinese recognized some meteorological phenomena 3,000 years ago. In the inscriptions on borns or tortoise shells of the Shang Dynasty (ca. sixteenth to eleventh century BCE), there were some words meaning rain, frost, snow, thunder, lightning, rainbow, etc. The Chinese identified the relationship between the rain and rainbow;