Batán Grande: A Prehistoric Metallurgical Center in Peru

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There is widespread interest in the technological and cultural dimensions of central Andean metallurgy, which, as Lechtman (*1*) has forcefully argued, constituted one of the major independent metallurgical traditions of the world. This interest is an extension of our general concern with the interplay between technological innovations and culture and society as a whole. Our current understanding of prehistoric central Andean metallurgy relies heavily on ethnohistorical descriptions of Inca techniques (*2*) and inferences drawn from laboratory analyses (*3–7*). The metallurgical activities that have thus far been documented through excavation have been confined primarily to those carried out in limited workshop settings within large settlements whose primary functions were not metallurgical (*8, 9*). These studies have given us a rather fragmented and limited understanding of central Andean metallurgy. Lechtman (*1*) has pointed to the urgency of in-depth archeological studies of mining-metallurgical complexes, particularly on the north coast of Peru and in the altiplano (high plateau) of the Peru-Bolivia-Chile border region, the two suspected metallurgical centers of the central Andes.

Summary. Recent archeological fieldwork on the north coast of Peru permits a preliminary reconstruction of a prill-extraction copper and copper alloy smelting process heretofore undocumented in the New World. The process was applied on a large scale during the late pre-Hispanic period. This study provides strong support for the claim that central Andean metallurgy constituted one of the major independent metallurgical traditions of the world.

Since 1978, as part of a long-term investigation into the unique Batán Grande Archeological Complex, situated in the small La Leche Valley on the north coast of Peru (*10–12*) (Fig. 1), a team of researchers has been studying a major interlinked prehistoric mining and metallurgical complex at Cerro Blanco and Cerro de los Cementerios (Fig. 2). The numerous elaborate tombs in Batán Grande are widely known for the immense quantity, variety, and beauty of their metal funerary objects (*3, 6, 10, 13*). In fact, most of the spectacular prehistoric gold objects attributed to Peruvian sources and now in museums around the world were most likely looted from tombs there. We had thus suspected a long metallurgical tradition in the Batán Grande region. On the basis of data accumulated since 1978 from the Cerro Blanco–Cerro de los Cementerios complex, we examine here the technological and the broader cultural dimensions of the northern component of central Andean metallurgy. These data make possible a preliminary reconstruction of an industrial-scale, prill-extraction copper smelting process heretofore undocumented in the New World.

Geology-Mineralization and the Cerro Blanco Mine

The Leche and Lambayeque rivers flow through a region of unusual geologic complexity. Outcrops within a 50-kilometer radius of Batán Grande vary from Precambrian metamorphics to Tertiary volcanics (*14*). Quaternary alluvium has been deposited at the base of the Andes Mountains, creating a broad coastal plain that obscures structural relationships between the relatively wide continental shelf and Paleozoic sediments of the foothills sector. Multiple Mesozoic-Cenozoic intrusives associated with the emplacement of coastal batholiths have invaded these sediments. Toward the headwaters of these rivers, major thrust faults separate the sedimentary sequence from a great thickness of Tertiary volcanics comprising the Andean highlands. As a consequence, a wide variety of ore and lithic materials was available to the prehistoric inhabitants from their immediate surroundings.

Batán Grande is located at the northern extremity of the Peruvian metallogenic province in a little-studied area (*15*). Copper mineralization throughout the Lambayeque region is not conspicuous but is now known to be rather extensive (*16*). There is a rich prehistoric copper mine (*16*) near the eastern flank of Cerro Blanco, within sight of the modern settlement of Batán Grande (Fig. 2). Indications of a Colonial smelter beneath a modern crushing mill and concentration plant at Cerro de los Cementerios attest to the long-term productivity of this mine.

Ore at Cerro Blanco is a complex of copper-lead-zinc oxides and sulfides associated with a small Tertiary granodiorite intrusion. This eroded igneous dome produces great sheets of exfoliating rock that spall off on all sides to form an apron of large boulders and talus. The main ore bodies occur in gouge zones of a concentric fault network radiating outward from the pluton. Discoloration along the contact zone suggests that a gossan cap may have developed; but, if so, it has not survived weathering during the Pleistocene.

Although the overall characteristics of the Cerro Blanco ore are similar to the Lowell-Guilbert model (*17*), the metallization episode did not produce a typical copper porphyry. Instead, we find well-defined veins and shoots cutting through gangue rock consisting of brecciated and marbleized cherty limestone and shale, believed to be equivalent to the Permo-Carboniferous Copacabana formation (*18*). Veins tend to be strata-bound and well defined in the limestones. Other veins consist of mineralized breccia and fault gouge and are probably penecontemporaneous.

Prehistoric miners followed the discovery vein (3 by 17 meters) ore downward a short distance until it soon pinched out. Eventually, they pried out all the ore along the strike of this vein, working several meters inward into the hillsides where they encountered a much larger transverse vein. This steeply plunging (41°) ore body was worked at its highest level by the prehistoric miners, who left a narrow trench with near

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vertical sides where the discovery vein was removed. Elsewhere on the surrounding hillsides are numerous small prospecting pits where the Indians carefully broke out copper ore by using methods similar to those documented in northern Chile (*19*). We can still see where they squirmed into narrow crevices and left behind large triangular hammerstones (about 20 centimeters long and 10 to 12 centimeters at the widest point) with battered ends that were probably held with two hands and used in conjunction with wooden wedges. Fire quenching (*20*), if known, was not used, probably because of the porous fabric of the ore and country rock.

Colonial and modern owners made irregular excavations at three deeper levels, removing so much ore that it is difficult to establish zonation on the basis of the mineral suites. However, thin-section analysis of tailings indicates that a complex differentiate was present with the common oxides and sulfides of copper predominating (*21*). Secondary enrichment occurs in the form of thin coatings of azurite and malachite on breccia.

The Metallurgical Center of Cerro de los Cementerios

The site (Fig. 2) is located southeast of the modern village of Batán Grande and roughly 3 kilometers north of the Cerro Blanco mine. The fact that a relatively straight, ancient road 2 to 2.5 meters wide links these places suggests their contemporaneity and functional interdependence. Near the mine, the road is partially dug into the hillside, and the outer edge is built up with fieldstones used to maintain a level surface. Prehistoric ceramics with paddle-stamped designs were found embedded in the road surface and downslope. Prehistoric occupation of Cerro de los Cementerios was limited to its north and west slopes, although several stone structures were built along the mountain ridge. A dry riverbed and parallel ancient canal skirt the northern base of the Cerro.

Another conspicuous, raised, banked road, 2 to 2.5 meters wide and over 1 kilometer long, dominates the north slope of Cerro de los Cementerios. It originates at the eastern edge of sector I (*22*), traverses sector II, and passes the base of a major T-shaped stone platform with a commanding view of the northwestern sector of the Cerro (sector III). This physical linkage of the sectors implies a synchronous, functional relation. The road would have been more than adequate to have supported caravans of llamas for the transport of ore, fuel, or metal products (*23*).

In sector I, north of the road, lies a gently sloping alluvial surface. Near the center of the fan are a cluster of adobe and stone compounds of varying size and internal organization. There is definite architectural unity with respect to their placement, configuration, and construction format that contrasts with the dis-

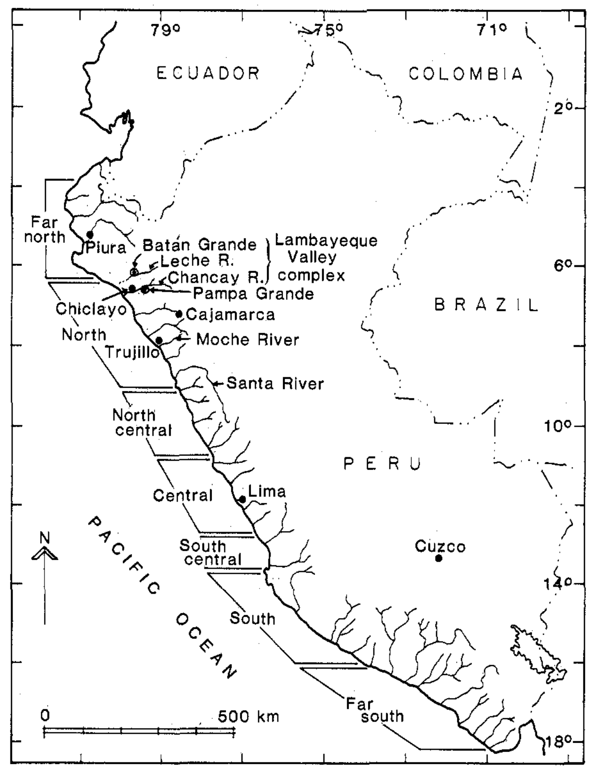


Fig. 1. Map of Peru showing the geographic-cultural subdivisions of the coast and the location of the Lambayeque Valley complex and Batán Grande.

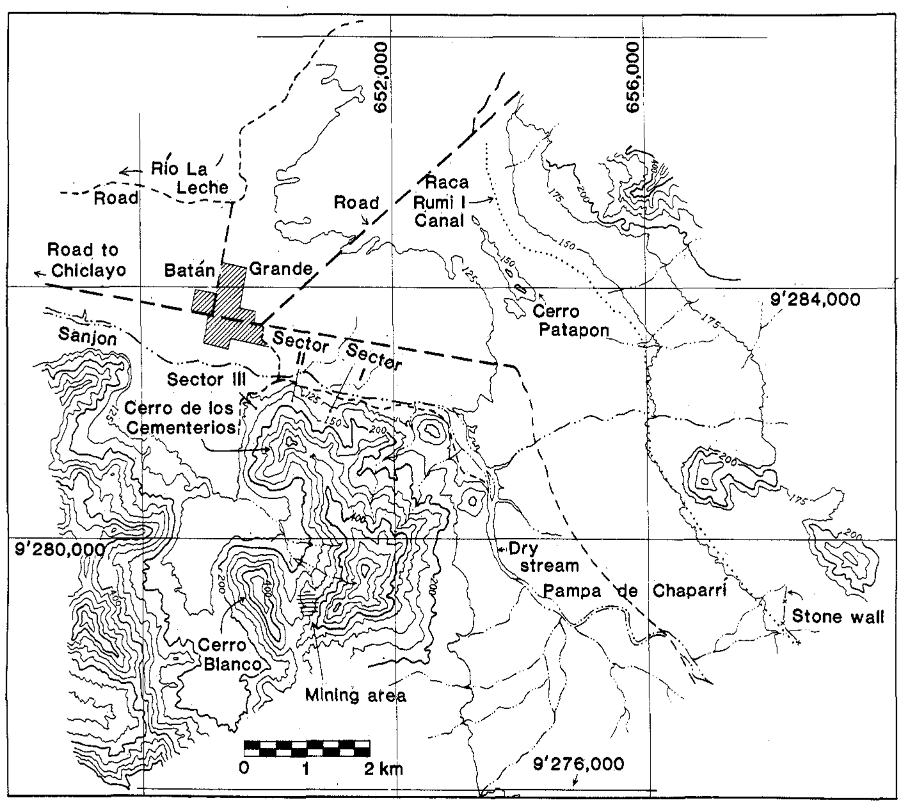


Fig. 2. Topographic map of the area surrounding the present-day community of Batán Grande, showing the location of Cerro de los Cementerios and Cerro Blanco. The contours are in meters. The two ancient roads discussed in the text are not shown on this map.

persed, irregular masonry structures in sectors II and III. We suspect that a block of rooms on the western edge of the sector may have housed the metallurgists who worked in sector III.

On the terraced slope of sector II above and below the road are numerous structures of unmodified fieldstones arranged in complexes, each with access to the road through its curb wall. These may have been additional residential structures.

The most important area of the site is the northwestern base of the Cerro (sector III), where three parallel, north-south platform mounds are situated. These platforms are on natural promontories built up further with rubble and refuse fill, often three or more meters tall, including thick lenses of llama dung within rectangular chambers. All the platforms were apparently used intensively as cemeteries and have been badly looted in recent years. Sherds recovered from the fill and backdirt from looting show a wide range of ceramic styles, including Wari Norteño, late Classic Lambayeque, Coastal Cajamarca, Chimu, and Chimu-Inca. A time range of about A.D. 700 to 1532 is suggested.

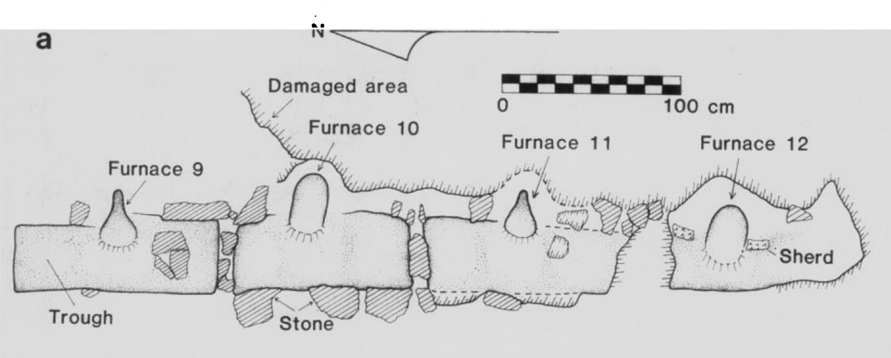
The ceramics associated with the smelting areas in sector III investigated thus far are predominantly Chimu-Inca and, to a lesser degree, Chimu and Provincial Inca. The presence of intrusive burials with Chimu pottery in groups of interlinked, well-built rectangular rooms buried within platform mounds and in their immediate vicinity attests to pre-Chimu occupation in sector III. The overall organization and construction style of these rooms are clearly different from those associated with metallurgy during Inca times. Although the fill that buried these rooms contains metallurgical debris, particularly crushed slag, thus far no definite evidence of in situ metallurgical activities within these pre-Chimu rooms exists.

Other lines of evidence are indicative of pre-Chimu metallurgical production at Cerro de los Cementerios. The site of Huaca del Pueblo Batán Grande, 1.75 kilometers northwest of sector III, yielded evidence of small-scale copper smelting—a small amount of scoria, a tuyere (the ceramic tip of a blowtube) fragment, and a piece of hematite—on a floor, dated to about A.D. 800 to 850 [based on an A.D. 870 ± 65 date (SMU-899) for the immediately overlying floor].

To obtain a picture of the depositional and occupational history of sector III, we excavated a trench 7 meters long and 2 meters deep, down to bedrock. The trench showed that this was a locus of intense metallurgical activity for many years. Thick lenses of crushed slag alternate with numerous plastered floors associated with charcoal, slag, troughs, and walls. A radiocarbon sample from the very bottom of the stratigraphy yielded a date of A.D. 1010 ± 40 (P-3121). Another sample from the middle of the stratigraphy was dated to A.D. 1140 ± 40 (P-3119). A third sample was derived from a furnace cut by a later terrace wall and subsequently covered by a floor. This dated to A.D. 1170 ± 50 (P-3120). One of the most recent furnaces yielded a date of A.D. 1500 ± 60 (Beta-2591), in perfect agreement with the Chimu-Inca ceramics. Overall, metallurgical activity in sector III spanned at least 500 years from about A.D. 1000.

The gentle slope surrounding these platforms in sector III, an area measuring about 200 by 150 meters, was the focus of large-scale smelting and related activities. The concentration of metallurgical evidence is overwhelming here, although ore fragments, slag, and *batanes* (large, tabular mortar-like stones used in conjunction with *chungas* or rocking stones) also occur, dispersed in small concentrations in sector I. Additional remains are also visible in various looters' pits in sector III. For example, the fill of the westernmost platform contains vitrified sherds and tuyere fragments, and at least six smelting furnaces were noted in profiles of looters' pits dug into the central platform-cemetery. There is no definite evidence of metallurgical activities in the eastern platform-cemetery; however, crushed slag in the construction fill indicates that abundant slag drifts had accumulated before the platform was constructed.

Slightly south and east of the central



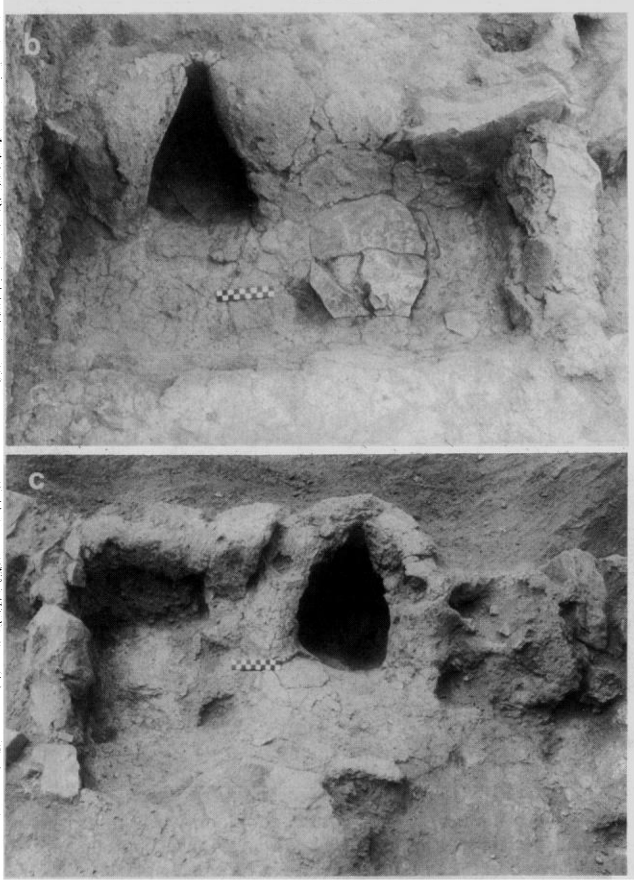


Fig. 3. (a) Plan view of a well-preserved set of furnaces exposed in excavation area 5, sector III, Cerro de los Cementerios. (b and c) Furnaces within the set, showing the different states of preservation and variation in the construction details.

platform are numerous low mounds defined by low adobe and stone walls. Varying densities of metallurgical debris cover much of this area. The area also contains the heaviest concentration of *batanes* at the site. Within an area with a radius of 25 meters, 12 *batanes* are visible on the surface, most measuring about a meter in diameter and deeply worn and polished from use. Numerous *batanes* have been removed from the site within the past 50 years. Those that are now present at the site probably represent only a small portion of the original number (*24*).

Sector III is ideally suited for smelting; the wind direction is constant, and the wind blows predictably every afternoon. It would have dispersed noxious smelting fumes and increased draft for the furnaces. Based on her extensive survey in the central Andes, Lechtman (*16*, p. 41) concluded that the "critical element in the location of such [smelting] installations was not the proximity of ore or fuel, but the strength and direction of the wind." Fuel, ore, and workers can be transported, whereas wind remains an uncontrollable variable. The selection of Cerro de los Cementerios as the locus of large-scale metallurgical production, however, appears to have been influenced by a number of factors. The Cerro occupies a "central place" among the various communication routes, fuel sources, and prehistoric mines thus far identified within the valley. Within 10 kilometers from the Cerro, there are five mines, four on the northern margin and one (Cerro Blanco) on the southern margin. All the mines yielded copper ore, although the Cerro Blanco mine is disproportionately larger than the others. The contemporaneity of these mines has not yet been established, but the inferred longevity of the Cerro de los Cementerios occupation allows for some temporal overlap. The Cerro also has direct access to all areas of the valley as well as two major side valleys that lead to the adjoining Lambayeque Valley to the south. The major north-south road that Pizarro and his men followed on their way to Cajamarca passes slightly west of the Cerro.

Experiments have shown that the amount of fuel consumed in primitive copper smelting is several times greater than the amount of ore consumed (*25*). This suggests that proximity to fuel may have taken precedence over proximity to ore in determining the location of a smelting operation. The dense and extensive (some 70 square kilometers) subtropical thorn forest just north and west of the site may well have supplied much of the charcoal fuel (*26*).

Industrial-Scale Smelting

The limited excavation at Batán Grande in 1980 and more extensive excavation in 1981 focused on sector III, the suspected center of industrial-scale smelting. Thus far we have excavated, partially or in entirety, 24 smelting furnaces in sector III. Most furnaces were located on the basis of surface indications, including slag and heat-discolored mud used for the construction of the smelter, and examination of looters' pits, which often cut through furnaces and their associated features. On the basis of the first ten or so furnaces discovered, we established a set of criteria for predicting the location of furnaces. For example, with a few exceptions, furnaces are organized in rows of three or four, which are aligned north-south. Typically, adjacent furnaces are separated by about 1 meter. With several exceptions, individual furnaces are oriented east-west, perhaps to take advantage of the strong, predictable east-west afternoon winds (*27*). Furthermore, they are invariably associated with ground slag and tuyere fragments. Most of the excavated furnaces are situated on the eastern side of the crest of a U-shaped basin, the slope of which is largely covered by a series of low, narrow terraces built on and retaining up to 2 meters of metallurgical debris and earth intercalated with floors.

The application of these criteria and the recognition of a furnace wall exposed in a small looter's pit led to an excavation of a row of four well-preserved furnaces in excavation area 5 of sector III (Fig. 3). Extending the excavation to elucidate the broader association of this furnace set led to the discovery of a stratigraphically more recent row of four furnaces.

We estimate that there are upwards of 100 furnaces remaining within this sector, despite the heavy toll taken by modern looting. Air photos taken in 1949, before the onset of modern looting, showed various rectangular compounds with regular divisions that are now difficult to discern. In light of this evidence, we can speak confidently of an industrial-scale smelting operation in sector III.

Smelting furnaces: construction and organization. The 24 excavated furnaces show definite morphological unity despite varying stratigraphic levels (about A.D. 1200 to 1532). A typical example may be described as follows. Seen from above, the furnace is pear-shaped (Fig. 4). The narrow end is built up to form a primitive chimney and lies deeper than the wide end, which forms a shallow, flaring apron. The chimney is formed by setting the narrow end into a low terrace step, the riser of which is steeply angled, running from the widest part of the furnace's wide end up to the point of inflection at the pear's waist. The chamber inside the chimney narrows to a slot at the apex of the furnace. Typical dimensions are 30 to 35 centimeters from the tip of the narrow end to the outer edge of the apron, 25 centimeters from the deepest part of the furnace to the top of the chimney, 10 centimeters across the widest part of the chimney slot, and 25 to 30 centimeters across the widest part of the furnace, which is at the bottom of the terrace step.

The relatively small size and peculiar shape of the furnace appear to have been based on the constraints of lung-powered draft, the necessity for a reducing atmosphere for smelting, efficient ventilation (including perhaps amplification of wind draft), and heat retention. The physical strain of an individual's having to blow air continuously and forcefully without the benefit of bellows underlies the difficulties associated with attaining and sustaining sufficiently high temperatures for efficient smelting (typically 1100° to 1200°C).

The interior surfaces of the furnaces were lined with highly refractory gritty mud with a melting point of over 1300°C (*28*). Some furnaces had been relined up to three times, a strong testimony to their prolonged and intense use. Although most furnaces show only slight blackening of their interior surfaces, some show more serious damage—a crusted "waterline" 8 to 10 centimeters above the lowest point of the furnace with disintegration of the lining above that line. The linings of all furnaces were heat-reddened to a depth of 5 to 10 centimeters. Some furnaces, after their use was discontinued, were intentionally filled with stones and earth. One had been cut in half by a later furnace. Pieces of furnace lining were used in the construction of basins associated with later furnaces.

The furnaces in rows are linked by troughs, roughly 40 centimeters wide and 20 to 30 centimeters deep, lined on the bottom and sides with tabular stones and plastered with clay (Fig. 3). These troughs are subdivided at regular intervals (100 to 140 centimeters) by narrow, mortared stone partitions. Each furnace is situated in the middle of a subdivided trough. The resultant basins (about 40 by 40 by 20 to 25 centimeters) on both sides (north and south) of the furnace appear to have held charges, or materials raked

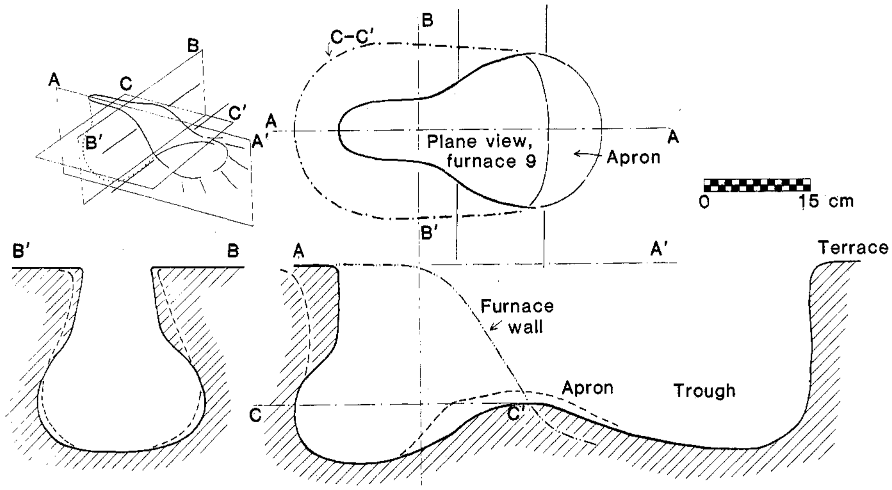


Fig. 4. Plane and sectional views of furnaces 9 (——) and 11 (- - -), respectively, in excavation area 5, sector III, Cerro de los Cementerios.

out of the furnace, or both. Some of these basins were still filled with charcoal and ash with bits of flux and slag.

It is apparent that smelting generated considerable debris. For example, close to furnace 1 we found a deposit best described as an industrial midden, which contained numerous 1-centimeter pieces of hematite and various sized limonitic concretions (a dense, iron-rich ore, partially heat-altered with adhering flecks of charcoal, slag, and powdery yellow limonite). These iron compounds are commonly found associated with furnaces and are clear evidence of fluxing (to facilitate the separation of metal and slag). A body of the iron ore needed as flux occurs on the western slope of Cerro Cabeza de León, 4 kilometers west of Cerro Blanco. This ore body was recently mined commercially and may well have been exploited prehistorically.

The midden also contained tuyere fragments, slag, and "thumbprint scoria." The latter number upwards of two dozen and are the most common item in the midden. They are of particular interest as we believe they are rare "fossilized" evidence of air blasts into the furnace from blowtubes. These masses of incompletely smelted ore, charcoal, and flux, fused together by slag, are formed around a void shaped like a thumbprint. The depression in the material is covered at one end and open at the other. Whole samples vary in size but are typically 4 centimeters in length. The jet of air from the tuyere would blow a depression in the semifused charge, chilling and solidifying it.

Three whole tuyeres and numerous broken fragments (Fig. 5) were recovered from the surface and excavation in sectors I and III. Our study of some 100 tuyere fragments indicates that the diameter of the hole through which air was blown is highly consistent, about 0.8 ± 0.1 centimeter at the distal end. All but one, which is squarish, are cylindrical with the proximal half tapered, presumably for easy insertion into a cane or other perishable shaft. Although such shafts may have burned during use, the tuyeres could simply have been reinserted further into the shaft. Many show noticeable heat discoloration and cracks near the distal end. One fragment recovered from the industrial midden described above was plugged with slag; evidently, tuyeres were not meant to touch the fused charge.

The architecture associated with the furnaces is typically impermanent. The scarcity and nature of the rubble as well as the construction of the wall foundations indicate that most walls were narrow and weak. In fact, the paucity of postholes and roofing materials indicates that smelting occurred within a simple, partially roofed veranda-like construction. Much of the associated construction was probably of wattle-and-daub or similarly perishable partitions, serving not as structural supports but as room dividers or shields that protected workers from furnace heat and fumes. The need to vent noxious fumes from smelting and the importance of maximizing afternoon winds called for partial enclosures with good ventilation. Several thick, solid masonry walls may have demarcated the boundaries of individual work units.

Prill-extraction smelting technique: tentative reconstruction. In sector III, a battery of furnaces set into hillside terraces was fanned by wind and lung power. The flaring apron and pear shape of the furnaces facilitated the use of blowtubes. As the ore was reduced, copper droplets, called prills, formed in the unwanted slag residue. Apparently the slag remained so thick and viscous throughout the smelting operation that the copper prills remained trapped in its matrix, unable to sink to the bottom of the furnace and coalesce into ingots. It is possible that, occasionally under ideal conditions, ingots may have formed at the bottom of the furnace, but the quantity of ground slag accumulated in sector III suggests that the ideal conditions were rarely met. When the furnace cooled, the slag was apparently cracked and the *batán* and *chunga* were used to extract the prills. The rocking action of a heavy *chunga* would easily shatter the brittle, vitrified slag (as a quick field experiment showed) to the consistency of coarse sand, leaving the pinhead to pea-sized malleable prills rolling free in the depression of the *batán*, ready to be collected.

Ground slag is ubiquitous in our sector III excavations. In situ *batanes* are invariably associated with considerable amounts of ground slag, in some cases enough to create small but noticeable mounds. A trench in excavation area 1, sector III, revealed in situ evidence for slag grinding, a mud plaster construction that appears to be a work pedestal for a *batán*. The pedestal with a cavity (40 centimeters in diameter and 20 to 30 centimeters deep) where a *batán* once sat and the associated crushed slag make up a low mound some 7 meters in diameter and 1.5 meters high on the slope of the U-shaped metal production area mentioned earlier. The pedestal was built atop a hard, concreted layer of crushed slag that gradually tapered off toward the base of the mound. The presence of 1 meter of laminated crushed slag beneath the hardened slag layer argues that there was formerly a *batán* in the same location. This accumulation of slag and the extensive use of slag in architectural fill attest to the intensity and continuity of prill-extraction activity in sector III.

Prills thus recovered are too small to be made into anything larger than beads; the next step in the metal industry of Cerro de los Cementerios must have been the remelting of the prills to consolidate them into ingots or castings. This remelting process at the Cerro is not yet well documented. One logical procedure would be to set a ceramic or clay crucible containing prills in charcoal fuel within a furnace capable of reaching 1083°C, the melting point of copper. When the fuel was consumed, one would be left with an ingot (*29*). However, we have not found associated with the furnaces or on the surface any clay or ceramic vessels that could have served as crucibles. The vitrified or slag-coated sherds, commonly found in the smelting areas, show forms and surface modifications not typical of crucibles. These sherds, typically of thick (1.0 ± 0.3 centimeters) utilitarian redware, are quite flat and large (as wide as 22 centimeters) and usually show slag adhering to their margins and edges. We suggest that these sherds were used as readily available, removable covers for the furnace openings. Such covers would allow more effective retention of the necessary reducing atmosphere and would yet readily accommodate blowtubes and recharging for the furnace. The slag adhering to the sherds may have resulted from unintentional contact with the slag inside the furnace.

The nearly pure charcoal content of some of the excavated furnaces may represent fuel for ingot formation. On the other hand, a more plausible explanation would be that the charcoal represents the initial charge of fuel for preheating the furnace prior to the addition of a smelting charge of mixed ore, flux, and fuel. In addition to the furnaces containing pure charcoal, in excavation area 4, sector III, we unearthed a cluster of three large (40 to 50 centimeters in diameter) inverted ceramic urns partially filled with a layer of pea-sized charcoal 10 to 15 centimeters thick (Fig. 6). Loose ashy soil surrounded the urns, which were partially buried below the associated floor. The inverted mouths of these vessels were incompletely sealed with adobe bricks, perhaps intentionally to allow for limited air circulation. Although the poorly preserved floor surface does not permit a definite interpretation, the three inverted vessels appear intrusive. The proximity of the furnaces to the urns makes it difficult to use the furnaces. One explanation may be that the urns were used for roasting sulfide ore in preparation for subsequent smelting (*30*). Four additional inverted urns containing charcoal have been located, one in excavation area 5, sector III, and the others in sector I.

Nine prills (six found loose and three embedded in slag) surface-collected from sector III are being studied by proton-induced x-ray emission (PIXE). Preliminary results show that all the prills contain arsenic in quantities between 0.5 and 6.4 percent. The two ingots from sector I were found to contain 2.0 and 2.8 percent arsenic. This range is similar to that noted by Lechtman (*1, 16*) for Peruvian north coast arsenical copper artifacts. The presence of arsenic in prills, which are primary smelting products, indicates that arsenic-bearing compounds must have been included in the initial smelt rather than added at some later stage.

Fig. 5. Variation among tuyeres recovered in sector III, Cerro de los Cementerios.

Behavioral and Cultural Considerations

Metallurgical production is a complex, hierarchically structured activity systemically related to various other aspects of a culture. Thus we must also consider the cultural contexts in which metallurgy functioned.

The existence of limited scale metal workshops within large multifunctional settlements away from mines or smelting sites raises the possibility that the smelting and ingot production occurred at sites that were separated from those producing finished metal artifacts made by techniques such as cold-hammering, annealing, gilding, fusion-welding, and plating. Although separate areas (for example, sectors I and III) of Cerro de los Cementerios may have been differentiated to deal with these phases of production, we hypothesize that the site was a major regional supplier of copper and copper alloy ingots and possibly cast implements. Interesting in this regard are data from the principal Moche V site of Pampa Grande (about A.D. 600 to 700) in the neighboring Lambayeque Valley. There, Shimada (*8*) excavated a metal workshop consisting of an interlinked set of three small rooms with a well-built stone, mud-lined hearth, a strip of copper, a trough-shaped ceramic mold with a copper oxide "waterline" on its interior, and two sets of faceted stones. One set of highly polished stones was apparently used in conjunction with a flat, polished anvil placed atop a low bench. Hammering may have been done here. The second set of stones consists of rectangular blocks with perpendicular corners and perfectly flat faces covered by fine striations; perhaps they were used for cutting and shaping. Despite intensive surveying and excavation at the site, no smelting or ore-processing areas were found. This finding suggests that metal was imported to the site either as ingots, roughly cast blanks, or other stock forms.

A number of preliminary observations can be made pertaining to the labor force involved in the metallurgical activities in sector III. The smelting operation was a multifaceted activity that entailed carrying ore, fuel, and flux; keeping furnaces going; preparing charges; raking out the resultant products and cleaning the furnaces; transporting slag to grinding areas to be crushed; and extracting copper prills. Rows of three or four furnaces could have been tended by individual work units consisting of perhaps six to eight persons; this arrangement would allow two persons to provide air blasts with blowtubes at each furnace, if we assume the simultaneous use of all furnaces. The flaring apron of each furnace would allow two or possibly three blowtubes to be used simultaneously. We must also consider the possibility of sequential or staggered use of the furnaces. Although continuously supplying air with only human lung power is taxing and may have required a rotation of laborers, we may be underestimating the capacity of ancient metalworkers. A modeled Moche vessel (*31*) shows four men blowing air into a circular furnace using long blowtubes. Each worker holds the blowtube to one side of his mouth as if he were inhaling air from the other side.

The grinding of slag and the recovery of copper prills may have been done by other labor units distinct from those in charge of the furnaces. Slag grinding with *batán* and *chunga* is not a particularly physically taxing or time-consuming task. The recovery of prills is a tedious task that requires time and patience but no special skills or strength. This task could have been performed by women, elders, or children. The Inca state allocated work quotas to heads of households who were assisted in fulfilling these obligations by any able-bodied members of the household.

The proximity of grinding areas to the furnaces suggests that these activities were closely coordinated. In excavation area 1, two in situ *batanes* (each about 80 centimeters in diameter) surrounded by ground slag occur in an area adjacent to the furnaces (Fig. 7). This proximity of *batanes* and furnaces was repeatedly observed in sector III. All phases of the metallurgical activities, charging of the furnace, grinding of slag, extraction of prills, and production of ingots, seem to have occurred in a set of interlinked rooms manned by the same labor unit.

Significant to the question of administrating metallurgical production in sector III are our excavations in a small, square masonry compound at the center of the U-shaped area with furnaces and on a major T-shaped, masonry, two-level platform with a commanding view of the entire sector. The compound is a solid and well-built construction, unlike the architecture in the metallurgical areas. The formal internal division, the central placement in relation to the metallurgical areas, and the absence of metallurgical debris, domestic refuse, and artifacts on the floors lead us to infer an administrative function. The small number of ceramics found are largely Provincial Inca. No high-status Cuzco-Inca style ceramics were found, an indication that administration at this level may have been entrusted to local leaders with sworn loyalty to the Inca. Location and size support the idea that the area was used by a small number of low-ranking officials engaged in the day-to-day supervision of metallurgical production in the sector, coordinating procurement and the transportation of ore, flux, and fuel. The architecture and artifacts suggest that neither the metalworkers nor the administrators enjoyed high status or material privilege. This interpretation is in accord with the documented Inca principle of indirect administration that assured continuity of local pre-Inca administrative infrastructures (*32*).

The T-shaped platform in sector III provides a glimpse of a Chimu (pre-Inca) administrative unit. This structure consists of a stone platform built atop a larger one with a long, steep masonry ramp. A row of four 1-meter-square stone cubicles is situated at the center of the upper platform. The cubicles were empty. Small quantities of valued goods, such as copper and copper alloy ingots, may have been stored in these cubicles. A low U-shaped construction facing the cubicles corresponds to the Chimu "*audiencia*," a structure that was frequently used to control strategic points such as access to storage areas and that has been interpreted as the physical representation of the Chimu state administration (*33*). Several other aspects of the platform argue that its occupants performed an important administrative function: its high visibility, its direct access to the raised masonry road that linked all three sectors of the site, and the impressive masonry platform set high above the rest of sector III.

We have the impression that what mattered most was the production of specific quantities of specific metal products. Variation in attendant behavior, artifacts, and architecture was of secondary importance. For example, de-

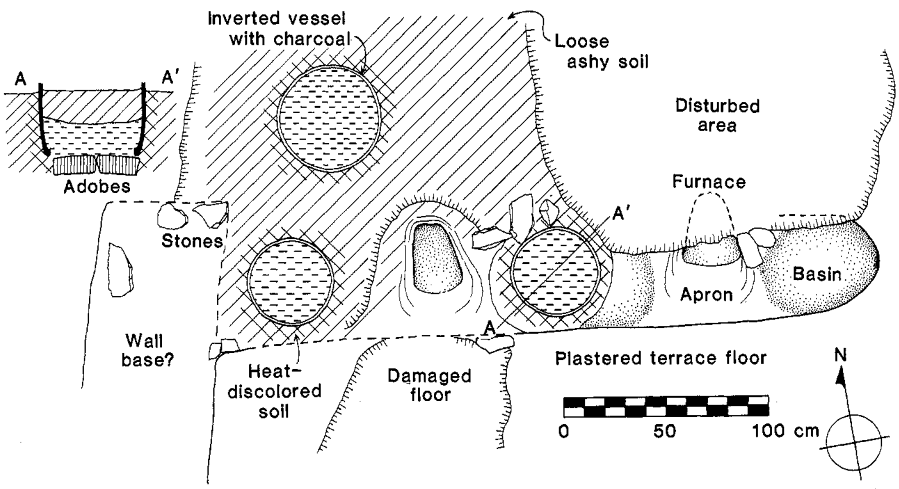


Fig. 6. Distribution of furnaces and inverted urns with charcoal contents in excavation area 4, sector III, Cerro de los Cementerios.

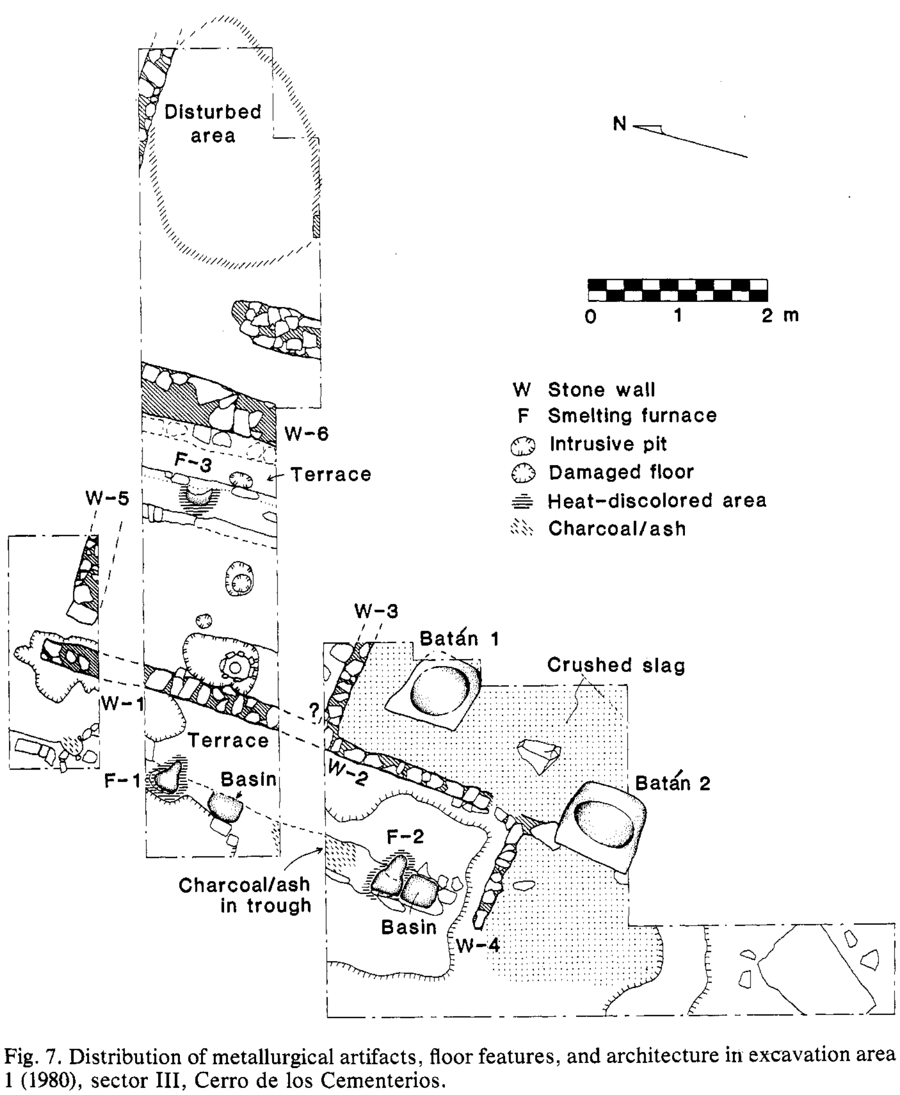


Fig. 7. Distribution of metallurgical artifacts, floor features, and architecture in excavation area 1 (1980), sector III, Cerro de los Cementerios.

spite a basic similarity in the overall shape of tuyeres, there is considerable morphological variation without apparent functional correlation. We suggest that the tuyeres had to be replaced frequently and that they were produced locally by the individual work units involved in smelting. Furnaces, troughs, and associated architecture also show no rigid standardization.

Conclusions

We have made good progress toward defining the technological and cultural dimensions of prehistoric metallurgy at Cerro de los Cementerios in Batán Grande. Data from our fieldwork have made possible a preliminary reconstruction of a prill-extraction copper and copper alloy smelting technique heretofore undocumented in the New World (*34*) and its large-scale application during the late pre-Hispanic occupation of Cerro de los Cementerios. The pear shape of the furnace, with its primitive chimney, the refractory mud that lined the furnace and allowed for its repeated use, the thorough grinding of slag by *batanes*, and the efficient recovery of prills represent a unique set of solutions to the physical and behavioral constraints that all copper industries must contend with. Various lines of evidence indicate that this newly documented technology evolved locally from at least A.D. 800 to 900 (*35*). The organization of the furnaces and associated features, including their architectural setting, argues for production by the masses, with a battery of smelters, each producing small quantities of copper and copper alloy products at a time. The great number of furnaces, however, suggests that the total production was quite large.

Future research objectives at the site include the study of ore sources, smelting charges, and the ingot and artifact distribution through trace element analysis. The evolution of the Batán Grande smelting technology remains to be clarified by further excavation. The administration of the Cerro de los Cementarios metallurgical production must also be placed in its regional context.

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20. The term refers to the rock-shattering technique of alternate fire setting and water quenching.
21. D. Warburton, personal communication.
22. We subdivided the site into three sectors on the basis of topographical features and the organization and distribution of visible architecture. Sector I corresponds roughly to the eastern third of the site, sector II to the central third, and sector III to the western third.
23. A considerable amount of camelid remains was recovered from our excavations in sector III. We suspect that large male llamas, which are known to carry burdens weighing up to 45 kilograms, were used for ore transport. A large empty rectangular stone enclosure beside the road near the Cerro Blanco mine may have been used as a llama corral.
24. In her 1981 survey of *batanes* in the village of Batán Grande and at the site, P. Carcedo (personal communication) recorded 23 and 20 in sectors I and III, respectively, and 20 still in use or present in the village. Because of easier access to sector III, we suspect that most *batanes* were removed in historic times from that sector.
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26. Nonagricultural use of this adjacent fertile floodplain is documented in (*11*). The trees that characterize this forest (*Prosopis chilensis*, *Acacia macracantha*, and *Capparis angulata*) produce excellent charcoal.
27. There are four known furnaces oriented north-south with the narrow end pointing north. Two are shown in Fig. 5.
28. Experimental firing of a piece of lining taken from furnace 2, excavation area 1, sector II, conducted by S. Epstein and W. Romanow showed that it began to fuse between 1300° and 1350°C. Thus, even if the ancient metalworkers attained temperatures sufficient to make slag flow, the furnaces would not have been damaged. The absence of vitrification on these furnaces confirms that smelting was carried out well below the melting point of the lining.
29. S. Epstein recovered two plano-convex arsenical copper ingots on the surface in the southeastern corner of sector I, an area without any evidence of metallurgical activities but with sherds contemporaneous to those in the smelting area of sector III (Chimu, Chimu-Inca; about A.D. 1400 to 1532). Three similar ingots are on display in the Brüning Regional Museum in Lambayeque. C. B. Donnan [*Archaeology* **26**, 289 (1973)] and Caley and Easby (*5*) illustrate similar ingots.
30. Surface survey and excavation at Cerro de los Cementerios have failed to locate any significant concentration of ore, particularly the low-grade ore that would be expected from sorting. Because the mine and site are separated by a distance of 3 kilometers, we believe that ore sorting and crushing were carried out at the mine.
31. This vessel, which shows what seems to be annealing, is illustrated and discussed by Donnan (*29*).
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34. Prill-extraction copper smelting industries have been reported from the third millennium B.C. occupation of Tepe Hissar in northeastern Iran [V. C. Pigott, S. M. Howard, S. M. Epstein, in *Proceedings of the Seminar on Early Pyrotechnology* (Smithsonian Institution and National Bureau of Standards, Washington, D.C., in press)] and at Timna, in the Negev Desert [H. Bachmann, in *Archaeo-Metallurgy* (Monograph 1, Institute for Archaeo-Metallurgical Studies, London, 1978), pp. 21–23; B. Rothenberg, *Timna: Valley of the Biblical Copper Mines* (Thames & Hudson, London, 1972); in *Archaeo-Metallurgy* (Monograph 1, Institute for Archaeo-Metallurgical Studies, London, 1978), pp. 1–15].
35. Lechtman (*1*) observes that tin bronze, characteristic of the southern component of Andean metallurgy (as opposed to arsenical copper, characteristic of the northern tradition), was adopted throughout the extensive domain of the Inca Empire. However, data from Cerro de los Cementerios shows strong continuity in the technology and production of arsenical copper, even during Inca control of the site. In addition to the difference in alloys, the two traditions apparently developed different smelting technologies. La Encrucijada in northwest Argentina is one of the few investigated smelting sites within the southern tradition [L. Rodriguez, in *Pre-Columbian Metallurgy of South America*, E. P. Benson, Ed. (Dumbarton Oaks Research Library, Washington, D.C. 1979), pp. 203–207]. The furnaces there are typical *huayras*, as described by Lechtman (*16*).

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