Chapter 16
Discussion: Mineral Resources and Prehispanic Mining

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My discussion primarily addresses the second half of this book (Chaps. 7–14) that presents case studies of Prehispanic mining, the process of extracting a wide range of minerals from the earth, commonly metallic ores for smelting and decorative purposes. Richard Burger comments on the first half that relates more closely to quarrying, a type of mining that in archaeology commonly refers to the extraction of dimension, or architectural, stones for construction and decorative purposes and non-crystalline and microcrytalline minerals and rocks for tool making. My comments are thematically organized and written from the vantage of personal knowledge and experience garnered over 3 decades on diverse aspects of the integrated process of Prehispanic mining and metallurgy in the Andes, particularly on the north coast of Peru.

Preliminaries: Why Has not Prehispanic Mining Received the Attention It Deserves?

This book effectively reminds us that Andean civilization past and present has been inseparable from mining and quarrying. These activities and their products have played integral parts during much of the human existence in the Andes up to this day. The early Holocene mining of hematite and goethite (reddish pigments) at San Ramón 15, a site dated to cal. 10,200 and 11,500 BP that Salazar et al. (Chap. 7) have documented, is a striking case in point. Dynamic and complex geological processes have given birth to impressive mineral diversity and wealth throughout much of the Andes, particularly in the highlands of the modern nations of Bolivia, Chile, and Peru. Today Chile and Peru rank among the largest global producers of economically

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important metals as copper, gold, lead, silver, tin, and zinc (see e.g., Cavanagh 2011; Cavanagh and Glover 1991; Slotta and Schnepel 2011). Contributed chapters in this book discuss additional metallic ores (hematite and mercury). Not surprisingly, there is a close correlation between the availability of appropriate ores and the development of sophisticated, versatile, and innovative metallurgical traditions in the Prehispanic Andes (e.g., Lechtman 1976, 1979, 1988). The geological processes also account for the availability of a multitude of igneous dimension stones (ranging from andesite, diorite, granite, and rhyolite) that were extensively utilized by the Tiwanaku and Inca for their justly famed constructions and stelae (see Chaps. 3 and 4).

Given the long-standing and widespread importance that mining and quarrying and their products have held in the Andes, why have not they received much attention from archaeologists? This is the question I have pondered for many years. Was it the perceived rarity of Prehispanic mines? In her influential work, Lechtman (1976) did not identify conclusively (clearly she was very cautious) any Prehispanic mines during her macro-scale mine survey. Subsequently, Oehm (1984: 27) concluded that the Cerro Blanco copper mine adjacent to the town of Batán Grande in the mid-La Leche Valley on the north coast of Peru (Shimada 1994; Shimada and Craig in press; Shimada et al. 1982) was the only credible Prehispanic mine in Peru identified up to that point in time. Were Prehispanic mines truly as rare as these conclusions implied?

These questions and conclusions are even more baffling given that scientific investigation into Prehispanic Andean mining had an early and propitious start (see below) and Andean archaeology has had a long-standing interest in paleoenvironmental reconstruction and natural resource management (Shimada and Vega-Centeno 2011).

True, there are various practical difficulties that hamper our efforts as discussed in Chap. 13 by Van Gijseghem et al. and others (e..g., Eerkens et al. 2009; Lechtman 1976; Núñez 1999; Shimada 1994) such as disturbances or even obliteration of ancient mines by more recent, often larger scale exploitations. Owners jealously control access to their mines and surrounding areas by fencing and/or armed guards, effectively preventing us from examining them. Mineralized areas where mines are likely to be found are in rugged, mountainous terrains outside of typical archaeological study areas, thus requiring separate surveys. In addition, the widespread political violence during the 1980s and 1990s clearly constrained our ability to conduct surveys in such areas in Peru (Shimada and Vega-Centeno 2011). From an Old World perspective, Bloxam (2011: 149) lists other factors that have contributed to ancient quarries and mines being neglected by archaeologists and the broader public: their material remains are generally mundane, nonmonumental, and often scattered over large areas and "are still rather peripheral to archaeological research as they are often seen in a limited, usually technological, context." The last factor is particularly influential and relates to what I consider to be a basic, conceptual problem that has hindered advances in archaeological investigation of ancient mines. I consider it below by means of a summary discussion of earlier pioneering studies.

Antonio Raimondi (1826–1890), a natural historian/scientist from Milan, Italy, who arrived in Peru in 1850, laid a sound empirical foundation by publishing valuable detailed information and observations from his many field trips throughout Peru

(accompanied by numerous meticulously prepared maps and other illustrations) in the first three volumes of the encyclopedic series on the geology (especially mineralogy and mining) of Peru that he conceived and named *El Perú* (Raimondi 1874, 1876, 1880; Villacorta 2004). His 1878 publication (Raimondi 1878) offers a rather complete inventory of mineral sources and resources of Peru. His effort to properly contextualize mines by discussing their social and technological dimensions as well as challenges they face (e.g., Raimondi 2004 [1887]) still serves as a standard against which to measure our modern anthropology of mining and other technologies.

A generation later, the fortuitous discovery of a remarkably well-preserved Prehispanic miner, the so-called Copper Man, inside a collapsed copper mining shaft at Chuquicamata in what is today the Far North Coast of Chile in 1899 (Bird 1979) and at least one other well-preserved, mummified corpse, presumably of miner, at the same mine (Mead 1921; see detailed discussion by Figueroa et al. in press) provided valuable information and insights into labor intensive, manual mining techniques using simple equipment that included hafted stone hammers, hoes or shovel-like hafted tools, and tightly woven baskets.

These important developments, however, did not spawn follow-up studies until the 1970 publication of *Minería y Metalurgia en el Antiguo Perú* (2010 [1970]) by the German-born Peruvian geologist, Georg Petersen. Although many archaeologists did not properly appreciate it, its importance to the subject at hand lies in the fact that he embraced a very broad vision of mining—from the identity and locations of numerous minerals utilized to mining methods and tools. The temporal–spatial and topical coverage of his book closely matches that of this book, except for the social and symbolic dimensions. He attempted to integrate (1) mining and metallurgy, (2) field and laboratory works, and (3) mineralogical, archaeological, historical, and ethnographic data. His conceptual holism (a nascent form of which was already seen in the works of A. Raimondi) in treating mining and metallurgy as phases of a single productive process is noteworthy.

Subsequent pan-Central Andean survey mostly of then-known and accessible ancient mines and metallurgical sites and systematic and detailed archaeometric analyses of collected samples by Heather N. Lechtman (1976) represented an important expansion and refinement of the line of investigation that Raimondi (1876, 1878) initiated and Petersen (1970) refined. Lechtman (1976, 1988) provided much empirical support of the logical connection between locally available ores and smelted metals thereby effectively reminding us of the importance of examining mining and metallurgy (or more broadly, different facets and stages of a given production system) as an integrated whole. The same systemic conception underlies what I have called a "holistic approach to craft production" (Shimada 1985, 1994; Shimada and Craig in press: Shimada and Wagner 2007) that entails a balanced, interdisciplinary investigation of the raw materials (including their acquisition), production technology, organization and personnel, and utilitarian and symbolic use and significance of products. In essence, it is an attempt to broadly contextualize production systems.

The above, integrated conception seems logical enough, but in actuality, I believe many archaeologists treat raw material acquisition and the subsequent stages of the production (including products) as analytically distinct and independent, *prioritizing*

attention on the *finished (more familiar) products*. While Andean archaeological literature is replete with studies dealing with crafting, its products and their roles in the political economy, studies that give due attention to raw material acquisition (i.e., mining-quarrying) as *an* integral *part of a production process* are quite rare. I argue that it is this conceptual problem, the disarticulated treatment of the production process and system, together with other factors mentioned above, that largely explain why mining and quarrying have not received the attention they deserved from archaeologists.

The preceding discussion was intended to provide an intellectual context and basis for assessing the significance of this and one other new publication that focus much deserved attention to Prehispanic mining and quarrying. The latter is an upcoming special issue of the Chilean journal, *Chungará*, presenting the proceedings of the First International Meeting on Prehispanic Mining in the Americas held in Chile in November, 2010. These publications effectively showcase a new generation of archaeological investigations of varying scale and intensity exploring diverse aspects of mining. They reinforce the point that the presumed rarity of Prehispanic mines reflects not true paucity but insufficient archaeological attention (Shimada 1994), particularly on the south coast of Peru and in the adjacent South-Central Andes (the Titicaca Basin and the adjoining *altiplano* and coastal valleys) that have long been known for their mineral wealth, innovative and advanced metallurgy, and/or broader cultural developments. With multiple, concurrent projects working in these areas, we anticipate important synergetic advances and testing and refinement of existing views (e.g., Lechtman and Macfarlane 2005). Encouragingly, many of the projects in this volume are keenly aware that mining is only the first stage and facet of what is in reality a multistage, multifaceted, and multisite production system and have accordingly adopted a long-term, multi or interdisciplinary and regional approach (see below).

Methodological Challenges and Solutions

This volume focuses on "archaeological research at primary deposits of raw materials extracted through mining or quarrying in the Andean region." Although it is not one of its stated goals and archaeological study of Prehispanic mining is still young in terms of formalization, sophistication, and intensity, we need to better resolve various basic methodological challenges.

Locating Prehispanic Mines

How do you locate and date ancient mines? These are the challenges faced by all contributors. As for the first question, some contributors are explicit about the methods they employed. Vaughn et al. (Chap. 8) and Van Gijseghem et al. (Chap. 13), for example, both relied heavily on information culled from modern local informal and

itinerant miners. The turquoise and chrysocolla mines discussed by Salazar et al. (Chap. 12) and Cantaturri (Chap. 9), respectively, were discovered prior to their investigations and thus the pertinent discovery methods not mentioned. For Reindel et al. (Chap. 14), mine surveys and investigations were an integral part of their ambitious coast-highland transect of Nasca and Palpa drainages aimed "to reconstruct settlement shifts as influenced by climatic variations … . " Mine location was not an end in and of itself; mining and their products were instead conceived as a means of documenting the "changing patterns of movement of people and goods over time." Discoveries of mines of different periods described in other chapters, on the other hand, were the result of more focused archaeomineralogical surveys.

Given that archaeologists rarely have a comprehensive, in-depth knowledge of the natural resources of their study areas (Shimada 1998), local informants such as miners, hunters, and herders are the most accessible sources of pertinent information (see Shimada and Craig in press). At the same time, as with any informants, we should be mindful that all are not equally knowledgeable, reliable or open-minded, or willing to share what they know. It is prudent to interview a range of informants and show them good specimens of what you seek.

It is surprising that local information sources are not complemented by independent and/or larger, regional scale approaches such as the search for mineralization sources. On coastal Peru, eroded Cretaceous igneous intrusions that mineralized the surrounding areas can be easily recognized by their conical form (often called *panes de azúcar*) either on remote-sensing images and/or in the field. Accordingly, specific areas can be targeted for intensive mine surveys. "Floats" or ore fragments in dry streambeds that indicate minerals of interest originating somewhere upstream can be used to narrow the survey area (Shimada and Craig in press). While many authors of this volume have adopted a broad landscape approach to Prehispanic mining particularly its symbolic dimension, we should consider the possibility that Prehispanic miners recognized the critical connection between readily recognizable mineralization sources (e.g., igneous intrusions) and the occurrence of desired minerals. Such sources could well have been considered *huacas* for their form and association with valued minerals.

For locating mines, elsewhere I have emphasized the value of identifying and tracing roads that head to rugged, uninhabited mountainous terrain (Shimada and Craig in press). This approach offers the important advantage of allowing us to identify mines, campsites, and production sites at termini and along the way that operated synchronously. Although questions surrounding the transport of dimension stones concern Ogburn (Chap. 3) and Janusek et al. (Chap. 4), no one discusses them in regard to extracted ores, presumably because of the small scale of mining. These issues, however, may be pertinent for the period of intensified and larger scale mining in the Ica valley mentioned by Van Gijseghem et al. (Chap. 13). Vacant enclosures along the roads leading to Prehispanic mines in the Batán Grande area have been interpreted as corrals for llamas used in ore transport and as an indication of intensity and organization involved in mining (Shimada and Craig in press).

As all the mining chapters note, *preserved and securely dated* Prehispanic mines—regardless of the mineral extracted—were generally small in scale and

shallow in depth with no winzes (vertical or steeply inclined shafts between different levels for access and/or ventilation) or stopes (step-wise excavations to extract ore from steeply inclined veins; Shimada and Craig in press). Miners also carefully and selectively traced high-grade veins resulting often in irregular trenches and pits and relatively small accumulations of gangues and tailings. The small size of gangues and their relatively limited weathering distinguish them from the surrounding landscapes. This point, in combination with sinuous access roads, irregular prospection and mining pits and trenches, and associated artifacts and constructions, can help us identify ancient mines. There is no single effective means of discovering Prehispanic mines and, in essence, I recommend a multipronged approach that utilizes combinations of the aforementioned methods.

The small size of identified prehistoric mines does not mean, however, that there were no large Prehispanic mines. It is more likely that mines with large, high quality ore deposits did exist but were subsequently reworked to the point we cannot no longer ascertain their Prehispanic origins. Consider the case of the impressive Chuquicamata copper mine (until recently, the world's largest open-pit copper mine) in the Atacama region of north Chile and the fortuitous preservation and discovery of Prehispanic miners and their tools discussed earlier. We should consider the distinct possibility that mines that have been securely dated to the Prehispanic era only present us with *a truncated vision* of the true variability and that the economically, politically, and symbolically most important mines have been lost to our study.

Speaking of the scalar variability of Prehispanic mines, Van Gijseghem et al. (Chap. 13) adopt a typology proposed by Eerkens et al. (2009) that consists of "prospecting sites," "extraction sites" (mines and mining camps), and "production sites." As with any typology, it imposes some sense of the existing variability and order out of the data amassed, but also raises some issues. For example, a relatively small pit that in terms of modern mining standards might represent a mere prospecting pit may well have been an extraction site that was initiated but soon abandoned for some reason. In addition, an extraction site close to a production site could well have been worked on a daily commuting basis and may not been associated with any "mining camps." Reindel et al. (Chap. 14) in their coast-highland transect of the Nasca-Palpa drainage point to the rarity of mining camps. The distinction between the first two categories can be nebulous and should not be based on size or the presence/absence of associate structures. The quality, extent, and ease of extraction of the ores should be considered, together with the correspondence between the extracted minerals and what were actually utilized in the associated production site. New data from the Inca site of El Abra adjoining a turquoise mine (Salazar et al. [Chap. 12])—what might be classified as a mining camp in this typology—suggest that at least some lapidary work using gold sheets and mined turquoise may have been conducted there, blurring the mining camp-production site distinction. Use of this typology requires caution. Our understanding of ancient mines, regardless of their scale and intensity and the identity of minerals extracted, *cannot be adequately achieved without basic knowledge of associated production site(s).* In the case of Sicán copper-arsenic production, the placement of smelting sites appears to have been primarily dictated by their proximity to mines supplying the necessary ores and secondarily,

to a labor force and fuels (Shimada and Merkel 1991; Shimada and Craig in press). Importantly, well-defined roads connected mines directly with some of the documented smelting sites. While logistical and financial constraints make it difficult to concurrently search for both mines and production sites, the contributors to this volume must not lose sight of the integrated nature of mines and production sites.

Dating Mines

Reliable dating of Prehispanic mines is a persistent and challenging task due to: (1) the limited range and number of diagnostic artifacts (probably reflecting the basic simplicity of the mining tool kit and nature and status of personnel involved) and datable organic remains; (2) disturbance from later human exploitation; (3) the effects of taphonomic processes including downslope movement and animal activity (e.g., bats). Fire-setting or -quenching to aid in ore extraction would leave datable charcoal and soot, but the technique appears not to have been employed in Prehispanic mining (see comments by Reindel et al. [Chap. 14]; also Shimada and Craig in press).

As with locating Prehispanic mines, their dating is also best approached in a multipronged manner (Shimada and Craig in press). The presence or absence of abandoned or broken stone hammers (as detailed by Salazar et al. [Chap. 7] in their discussion of the Archaic hematite mine of San Ramón 15), straight audits (horizontal entrances to mines), stopes and winzes, as well as the distinct marks that steel tools leave on walls are ways of distinguishing Prehispanic from Hispanic/modern mining. For more precise dating, we have to rely on associated artifactual and architectural remains. An extension of this method is to examine features found along associated roads. A dating method that may be productively employed in dating ancient mines that do not have associated artifactual or architectural remains is optically stimulated luminescence, or OSL, dating (Aitken 1998; Murray and Olley 2002), that can date unexposed sand that may have accumulated inside or at the mouths of mines. The method measures the amount of ionizing radiation that sand grains emit to estimate the last time they were exposed to light.

Research Methods and Organizations

Analytical Methods

This volume, with a few exceptions, does not concern itself much with analytical methods used in mineralogical or chemical compositional determination of extracted minerals. Janusek and his colleagues (Chap. 4) summarize their use of the ever more popular portable X-ray florescence spectrometer complemented by X-ray diffraction analysis. Schultze (Chap. 11) passingly speaks of scanning electron microscopy (energy-dispersive X-ray spectroscopy?) in her discussion of

evidence for silver extraction in the northern Lake Titicaca Basin. Reindel et al. (Chap. 14) mention their use of lead isotope analysis for provenience and their distribution study of metal objects in the Nasca-Palpa drainage. The same technique would be very much applicable to Schultze's (Chap. 11) study of silver mining and the political economy of its products as its purification requires the mixing of silver-bearing with lead containing ores.

Chapter 10 deserves careful attention as it is built upon the results of inductively coupled plasma (ICP) analysis. Brooks and Schwörbel (Chap. 10) summarize known recovery and concentration methods in the Andes past and present, including panning of placer gold and mercury amalgamation-*refogado* processing (burning to volatilize mercury) of vein gold that is often finely disseminated in quartz. It is for the recovery of the latter type that amalgamation is widely employed throughout the world. In support of their claim for pre-Incaic mercury amalgamation, the authors adduce varied lines of evidence including ethnohistorical accounts. Pre-Incaic use of cinnabar, reddish mercuric sulfide (HgS), as a pigment has long been known and recent isotopic analysis of sediments from a lake near the famed Huancavelica mercury mine (Cooke et al. 2009) suggests cinnabar mining started around 1400 BC R. Larco (2001: 135) emphatically argues that the Mochica (aka Moche; ca. AD 100–750/800) already knew and employed this method, but his evidential basis is quite weak.

Their case, however, rests primarily on ICP results of pre-Incaic gold alloy sheet metal objects from Peru and Colombia. They argue that the significantly lower mercury contents detected by ICP on these samples (<100 ppm with an average of ca. 10 ppm) in comparison to naturally occurring mercury levels on modern placer gold samples (i.e., 1,000 to 10,000 ppm) "can only be explained by heating and volatilization of the mercury" presumably used for amalgamation.

Their explanation is quite plausible, but not entirely convincing yet. As the authors acknowledge, the placer gold samples they used as the comparative baseline may have been contaminated with mercury from modern gold mining and processing upstream. It would be useful to have a comparison of surface and interior mercury contents by means of a microprobe analysis of cross-sections of both gold and sheet metal samples. Additionally, we cannot ignore the potential effects of alloying and sheetmetal preparation on the mercury contents of the analyzed sheet metal samples, which are gold–silver–copper–arsenic alloys (see Table 10.3 in Chap. 10 by Brooks and Schwörbel). The extent of volatilization and lowering of mercury concentrations from numerous cycles of heating and hammering conducted with furnaces readily capable of achieving temperatures over 1,100 °C (Shimada et al. 2007) should be properly evaluated. Experimental testing is urged.

This volume also offers additional new data on *pre-Inca* gold mining that has received far less attention than the resultant gold *objects.* Reindel et al. (Chap. 14) briefly address gold mining on the south coast, noting that in Nasca times gold was clearly the desired ore to be mined and that placer gold was not available on the south coast (Stöllner 2009). These views are reinforced by the findings by Van Gijseghem et al. (Chap. 13) at Mina Zurita in the Ica valley that seems to date to Nasca 1/Proto Nasca. The technological and organizational details of gold extraction at these sites, however, are not yet available.

Productive Research: Multi- Versus Inter-Disciplinary Approach

"The archaeologist who works alone is a species in danger of extinction," so declared Killick (2008: 58) some year ago to impress upon us that the knowledge and expertise required to conduct cutting edge archaeological research had expanded beyond the capacity of a single individual archaeologist and that a well-integrated collaboration with relevant specialists was essential. While Andean archaeology appears to be prospering, this prophetic statement cannot be readily dismissed particularly for those interested in the exploitation and management of natural resources and their broader significance. In fact, we should ask whether our research on various aspects of Prehispanic mining is productively organized and conducted with pertinent expertise and knowledge. The authorship and the contents of constituent chapters indicate that there is a good deal of variation in the manner and extent to which specialists of diverse fields have participated in attaining results reported.

Most chapters are the result of some degree of *multi*disciplinary collaboration with one or more specialists in some facets and stages of the research, often postfieldwork examination or analysis of samples collected by archaeologists who may not have been properly trained to undertake the task alone. What we should strive for, however, is maximum integration of specialists, ideally from the conception and design of research to field implementation and onto the final publication of results. Bringing to bear different but complementary perspectives, knowledge and expertise to the widest range of research activities, particularly in fieldwork, is what is meant by an *inter*-disciplinary approach (also called trans- or cross-disciplinary) that offers valuable synergy and a stimulating in situ question-and-answer and self-corrective process (Shimada 2011). These are far from original recommendations (see e.g., Buikstra 1991), but deserve to be repeated as they are often not heeded.

In this regard, two projects stand out: those of the "Andean transect" by Reindel et al. (Chap. 14) and Mina Primavera by Vaughn et al. (Chap. 8). The former is unique in having the unparalleled long-term and wide-ranging (including "archaeo-scientific") support of the German Archaeological Institute (DAI), a federal research institution dedicated to comparative studies of ancient civilizations worldwide. The Nasca-Palpa project forms part of a global study of the transformation from sedentism to complex society and focuses on "trans-disciplinary investigation" of the interrelationship among settlement, economy, and environment (Reindel and Wagner 2009). Thus, their investigations of mines and quarries are nested within two broader sets (regional and international) of research issues and aims and conducted by archaeologists working closely in and out of the field with appropriate specialists (two co-authors, Stöllner and Gräfingholt are members of other research institutes, the German Mining Museum and the Institute of Archaeologic Sciences [Ruhr University] both in Bochum). Although their chapter has a preliminary character, with their trans-disciplinary character, we can anticipate in the near future a much more comprehensive picture of regional mines and quarries, their products and significance. In essence, they should be able to properly *contextualize* mining and quarrying through their investigation into the broader environmental, sociopolitical, and technological conditions and processes. They have already shown a

significant correlation between the prevailing climatic conditions and settlement pattern; i.e., coastal occupation is emphasized during periods of relative humidity while the occupation shifts toward higher elevations during periods of relative dryness. Whether mining and quarrying activities mirror this pattern is not clear.

The complementary Mina Primavera project directed by Vaughn in the adjacent Ingenio valley is an outgrowth of his "Early Nasca Craft Economy" project (2002–2007). These two projects have a clear logical thread as the mine was discovered in the process of locating sources of raw materials used in the manufacture of well-known polychrome Nasca ceramics. The Mina Primavera project is thus clearly focused on a comprehensive understanding of the technology, organization, and significance of the Nasca crafts. It is similar to the Nasca-Palpa project in applying an interdisciplinary approach and aiming to contextualize the hematite mine that was primarily exploited during the Early Nasca phase. Vaughn and his colleagues (Chap. 8) make a strong case of interconnection between mining, on the one hand, and the ebb and flow of Cahuachi as the primary Nasca ceremonial-civic center together with the concurrent shift of emphasis from polychrome textiles to polychromic slip-painted ceramics that extensively utilized hematite, on the other. Hematite exploitation at the mine declined significantly after this period. The authors should test the quality of the hematite that remains in the mine to dispel the possibility that its disuse owes to the qualitative decline or exhaustion of hematite.

As expected, contributing chapters of the book present a wide range of analytical methods and approaches that, in general, await refinement and formalization.

Interpretive Models and Interpretations

Chaîne opératoire (Operational Sequence) and Technological Choice

The editors of this volume justly observe that, "Regardless of the materials that originate in mines and quarries, many of the technological considerations that an ancient miner must face are shared." Solutions to the shared tasks and challenges have been described in terms of the two related concepts of *chaîne opératoire* and technological choice formalized by Leroi-Gourhan (1993; also see Dobres and Hoffman 1994; Edmonds 1990; Schlanger 1994; Sellet 1993) and Lemmonier (1992, 1993; see also Sillar and Tite 2000), respectively. As used in this volume, the concepts typically refer to specific technical steps and sequences and the associated decision-making processes by which raw materials such as clays, ores, and microcrystalline minerals are chosen and physically and/or chemically shaped and transformed into desired products (artifacts) and used. The documented steps and sequence, in turn, form the basis to examine the factors that shaped or guided specific decisions and steps (e.g., inherent limitations and potential of the raw materials selected, and the expectations of users and social value of finished products) as well as interrelationships between steps, pertinent equipment, knowledge and skill,

and other issues. They can chart the directions of our inquiries at different levels of abstraction and map specific technical steps and cognitive processes of their social actors, including the symbolic significance of their own acts and products.

In this book, for example, Tripcevich and Contreras (Chap. 2) discuss how obsidian knapping choices relate to intensity of use, while Roddick and Klarich (Chap. 5), from an ethnoarchaeological perspective, examine factors shaping the selection of raw materials for pottery production. Salazar et al. (Chap. 7) discuss the criteria for selecting appropriate rocks for making stone hammers for Archaic hematite mining. Ogburn (Chap. 3) and Janusek et al. (Chap. 4) describe the inherent material and symbolic factors that may have influenced the selection of dimension stones. Schultze (Chap. 11) combines excavation, settlement survey, archaeometric, ethnohistoric, and other lines of evidence to propose a partial *chaîne opératoire* for silver extraction.

These and other discussions of the *chaîne opératoire* and technological choices in this volume are in general preliminary or partial in character and based only on one or a few case studies. An exception is the similar operational sequences (five stages) of chrysocolla mining activities that Cantarutti (Chap. 9) documented at five mining areas in the Los Infieles area of central Chile. They are, however, based on limited or no excavations of primary extraction and/or production sites that are situated at different points of the *chaîne opératoire.* Clearly, the nature and plausibility of inferences at different levels of abstraction as well as the interconnections between technical and social factors and acts hinge on how securely and thoroughly the specific technical steps and sequences of the *chaîne opératoire* were established. I find many of the behavioral and organizational inferences found in this book necessitate *logical leap-frogging.* Various chapters speak of the significance of copper, silver, and chrysocolla to the political economy and prestige economy of associated polities such as the Tiwanaku, Ica, and Inca without adequately establishing such critical factors as the organization and management of their production sites, productive outputs, and the contexts and manners in which products were utilized. The social and symbolic values of raw materials and products cannot be assumed based on their presumed rarity, labor cost, and other variables (see e.g., Helms 1993).

The establishment of a *chaîne opératoire* and discussion of technological choices need to be based more on pertinent empirical data from primary context excavations and archaeometric and experimental testing of excavated evidence (Shimada and Wagner 2007; Shimada and Craig in press) than on inferences or assumptions built on ethnohistoric, ethnographic, and/or modern material scientific data. A solid empirical basis is essential in coping with interpretive problems stemming out of the principles of multiple solutions (that there are multiple solutions to any given problem), equifinality (that a given end state [product] can be reached by different potential means and/or pathways), and functional equivalence (that two or more items that differ in specific aspects can serve basically the same function or have the same basic meaning). Detailed documentation of specific technical steps and sequences and an in-depth understanding of the limitations and potential of raw materials are prerequisites to understanding why specific solutions or pathways were selected.

Formulation of a well-documented, working model of craft production with its material, behavioral, social, and ideological correlates and ramifications such as the one illustrated here (Fig. 16.1) requires a thorough contextual understanding of the

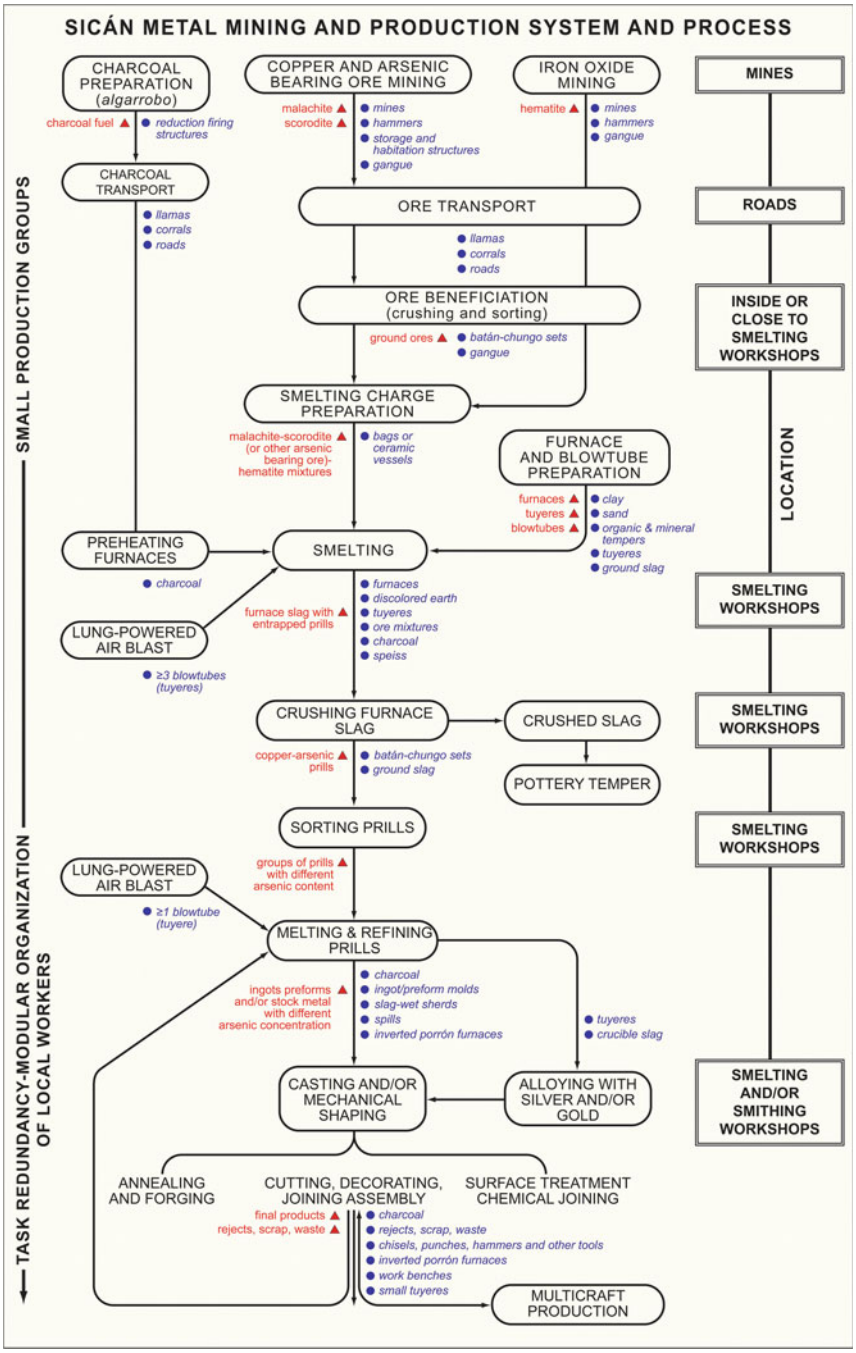

Fig. 16.1 Working model of Sicán metal mining and production system and process. Prepared by Izumi Shimada and Steve Mueller

production. Such understanding, in turn, results from long-term, interdisciplinary, regional research that actively searches and focuses on multiple sites that will illuminate the different facets and stages of a given production process and system (Shimada and Wagner 2007; Shimada and Craig in press).

In spite of the above criticism concerning the preliminary and/or partial understanding of the *chaîne opératoire*, there are various projects that hold much promise for establishing a comprehensive and referential *chaîne opératoire.* Silver smelting and concurrent multimineral extraction in Puno Bay in the northern Titicaca Basin that Schultze (Chap. 11) describes is such a case. The area seems to have already provided varying quantities and qualities of evidence that together suggest the presence of much, if not all of the *chaîne opératoire* for Prehispanic silver smelting. Just as exciting is the distinct possibility that there are sites relatively close to each other (or even within same sites) that together form a case of multicraft production or co-production (Shimada 2007), a type of "synergistic co-evolution … between a variety of mineral industries" and perhaps even copper and silver production. Multicraft production refers to the "concurrent practice of multiple crafts by different individuals or groups, each specialized in one or more craft, in the same or in a series of adjacent spaces," whereas co-production describes a form of multicraft production "in which artisans specializing in different crafts … collaborate in the design and manufacture of products...." (Shimada 2007: 5–6).

To fulfill the potential this area holds, however, Schultze (Chap. 11) needs to improve the dating of mines and other pertinent contexts, and better establish the association of key material evidence through excavations, among other tasks. The specific steps and sequences involved in silver purification should be empirically established rather than simply applying the knowledge and understanding of historical or modern silver extraction methods. In-field collaboration with pertinent specialists should also help identify relevant mineral and metallurgical remains. Only then, will her discussion of another type of synergistic co-evolution, that of co-evolution between ritual practices and mineral craft industries, as well the political economic significance of the products of these crafts be convincing.

Ritual and Symbolic Significance of Mines and Minerals: Lo Andino (Invariable Andean Beliefs and Worldviews)?

Following documentation of ritual offerings of *Spondylus princeps* at Prehispanic mines in the Batán Grande area and an associated smelting site (Shimada 1994: 54; Shimada and Merkel 1991; Shimada and Craig in press), I urged more attention be paid to the ritual and symbolic aspects of mining and associated metallurgical activities (Shimada in press). Salazar et al. (Chap. 12), Cantarutti (Chap. 9), and Vaughn and his colleagues (Chap. 8) show that ritual activities at and the significance of mines cross-cut time, space, and the nature of the mineral extracted (turquoise, chrysocolla, and hematite). In fact, most chapters discuss not only the sacred character and ritual significance of mines, but also how they relate inseparably to the landscape and in process acquire importance.

Most contributors seem to have been inspired by ethnohistoric accounts of the Incaic conception of sacred landscape and, to a lesser degree, by Ingold's (2000) dwelling perspective of the landscape. For example, Salazar et al. (Chap. 12) and Cantarutti (Chap. 9) discuss Inca exploitation of turquoise and chrysocolla in northern and central Chile, respectively. In the process, they argue for the critical role of Inca state religion and rituals in displaying and legitimizing their appropriation and restructuring of the physical and symbolic (sacred geography) resources of each area. Their arguments are based on inferred rituals atop the nearby ridge or nearby elevations and "wide spread Andean beliefs" or ethnohistoric accounts of the Inca's conception of the sacred landscape.

The zeal with which some authors pursued the documentation and interpretation of the ritual significance of mines, particularly by invoking Inca and ethnographic beliefs and ritual practices raises serious methodological and theoretical concerns. While I strongly endorse their exploration into the ritual, symbolic, and sociopolitical dimensions of mines and mining, I find it problematical that Van Gijseghem and his colleagues (Chap. 13) directly apply "general principles on mining and landscape in the Andes" culled from ethnohistoric and ethnographic information from Peruvian and Bolivian highlands to the Early Nasca and later Ica situations in the Ica valley. They point out that the "extraction of a mountain's substance" is conceived as "a profound transgression," a violation of mountain's sanctity, and that "mining is fundamentally dangerous" physically and supernaturally. They cite ethnographic accounts of beliefs that unpredictable and powerful spirits or devils (*supay*) reside in mines and that miners' and mine owners' (or political leaders') must make offerings to minimize accidents and other risks that accompany mining.

To what extent do these beliefs reflect their Prehispanic and pre-Inca counterparts, particularly given the fact that many of the preserved and known Prehispanic mines were relatively small, and nearly always shallow, open pits posing little risk to the miner? Of course, the "Copper Man" described earlier does indicate that Prehispanic mining was by no means risk-free. At the same time, historical mining that went to the unprecedented depths starting early in the colonial era (e.g., Bakewell 1984; Young 1994) brought concomitant risks to miners and constant struggles for improved working conditions. Have beliefs in mines and mining remained unchanged in spite of significant changes in its practices and numerous accidents and deaths over 450 years? The invariability of beliefs and practices or "general principles" needs better substantiation.

Their accompanying discussion of metal symbolism and the argument that "the social and political capital that comes with metal manufacture, ownership, and exchange" (applied to the Late Intermediate Ica) are again based on extrapolation of data and views from different areas and times (heavily based on the Incaic situation; e.g., Lechtman 1993, 2007). Unfortunately, there is a minimum of data for and understanding of *local* Ica metallurgical production and associated symbolism to judge if the Incaic situation is indeed applicable here. To infer socially and historically specific symbolic behaviors by reference to those of other cultures is a problematical approach. Overall, I urge greater caution in applying ethnohistorical and ethnographic information and insights.

Conclusions

Nearly 2 decades have passed since I wrote a critical overview of Prehispanic Andean mining and metallurgy. This book is strong testimony for how many advances have been made since then in archaeological investigation of Prehispanic Andean mining. Various of the recommendations and criticisms I made back then—for example, broadening of our conception of mining and minerals to be studied (Shimada 1994: 67) and attention to the ritual and symbolic aspects of mining (Shimada in press)—are now being addressed. This volume showcases many of the new generation Andean and Andeanist researchers and their emerging results. I can state emphatically that the subject of Prehispanic Andean mining is finally coming to receive attention it deserves. Contrary to the widespread tendency in archaeometallurgy to focus on the technical analysis of finished metal products, this book is definitely broader and anthropological in its aims, the issues it targets, and the analytical and interpretive models it adopts. Particularly notable in regard to the last is its use of the *chaîne opératoire* and technological choice concepts, and attempt to illuminate how mining and minerals were embedded in other aspects of Prehispanic Andean life including the physical and symbolic landscapes and political economy of social elites involved. The last point serves to remind us of the inherent danger of the reductionist/rationalist thinking that seems widespread in regard to the strategies for acquiring minerals (including those used for lithics). At least Inca practices tell us that concern with time and labor costs were often secondary to political and symbolic factors.

At the same time, there remain many unresolved issues and tasks. For example, while it is very welcome that attention is now being paid to a wide range of minerals, we (more likely, our archaeological colleagues) need to better educate ourselves so that minerals are properly analyzed and/or correctly identified (e.g., sodalite misidentified as lapis lazuli and/or turquoise distinguished from chrysocolla). In addition, we need to continue searching for Prehispanic sources of diverse minerals as has been done for obsidian. For cinnabar, there appears to have been at least one important pre-Hispanc source in the south highlands of Ecuador (Loma Gashuin near Azogues; Truhan et al. 2005). Where are the sources for the turquoise and chrysocolla that were extensively utilized for decorative purposes in pre-*Inca* times? In other words, we still face the basic task of improving our knowledge of mineral sources.

Reflecting the recent nature of many of the research projects represented, this book has a definite preliminary character. Likewise, the methods and broader approaches employed can and should be refined and formalized so that research aims can be effectively attained. Although it is not within the purview of the book (or the studies represented within) to deal with the entire production process and system (e.g., mining-metallurgy) including products and their use and significance, its focus on "primary evidence for raw material extraction" has resulted in a series of tenuous and highly speculative visions of how mining and quarrying articulate with other aspects of Prehispanic Andean life, particularly world views and political economy.

The sort of holistic vision and comprehensive *chaîne opératoire* I have sought to define takes many years of focused, interdisciplinary teamwork. What I find exciting about this book is that many of its contributors are ready to pursue, if not already well into pursuing, similar goals and making lasting contributions to Prehispanic Andean craft production studies and beyond. I hope the criticisms and suggestions presented here help in this pursuit.

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