



Martinón-Torres, M; Uribe-Villegas, MA; (2015) Technology and culture in the invention of lost-wax casting in South America: an archaeometric and ethnoarchaeological perspective. *Cambridge Archaeological Journal*, 25 (1) pp. 377-390. [10.1017/S0959774314001164](https://doi.org/10.1017/S0959774314001164). Downloaded from UCL Discovery: <http://discovery.ucl.ac.uk/1464460>

ARTICLE

Technology and Culture in the Invention of Lost-wax Casting in South America: an Archaeometric and Ethnoarchaeological Perspective

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Abstract

The invention and spread of lost-wax casting in South America is not amenable to explanations based on the concepts of practical or prestige technologies. Here we propose an alternative model to explain this phenomenon, based on a combination of technical analyses of Colombian metalwork and ethnographic information. A crucial element of our argument is that we should not focus on the cast objects or the casting process only, but rather we should consider the role of wax in this innovation. We will develop the claim that the use of wax may have been culturally just as important as the metals, and that perhaps metals were used in a process of transformation that required the use of wax, as opposed to wax being simply the medium to make gold objects more beautiful. The focus on wax and its symbolic role may help explain both the invention and the adoption of the new technology, thus subsuming these two categories that those studying innovations tend to separate heuristically.

Introduction

Histories of technology have thankfully moved away from deterministic explanations that saw pragmatic ‘necessity’ as the mother of all inventions, and the history of mankind as a unilinear evolution to more efficient problem-solving (Pfaffenberger 1992). The origins of metallurgy, for example, have been explained as resulting from a concern with aesthetics that exploited the colours and textures of the new materials (Smith 1982), rather than as the product of the quest for tools and weapons. Similar arguments have been raised to explain the origins of glass (Nicholson 2007) or iron smithing (Rehren *et al.* 2013). The earliest fired-clay objects were non-functional and broken during their manufacture (Vandiver *et al.* 1989), and the individually crafted, highly ornate earliest pottery in the Near East has also been explained as a form of ‘aesthetic labour’ (Wengrow 2001). Not only pyrotechnological materials, but other innovations from domestication to slavery have been described as ‘prestige technologies’ that primarily sought to display and aggrandize status (Hayden 1998). In other words, it can be argued that none of the above innovations were really necessary from a utilitarian viewpoint, but they were embraced because they satisfied broader social needs, generally related to ostentation, imitation and status display (or biased cultural transmission, cf. Henrich 2001). By and large, the archaeological record shows that only after becoming cost-effective, safe and reliable do new technologies spread more widely

across social sectors and are put to utilitarian uses (Hayden 1998; Kandler & Steele 2010; Killick 2001; Kingery *et al.* 1986; Schiffer & Skibo 1987;1997).

All of the above studies on innovation offer explanations for the 'adoption' of the new technologies (i.e. their uptake and spread in a given context), but most often they leave the 'invention' unexplained (i.e. the actions and circumstances that led to the discovery of the new technology in the first instance) (Torrence & van der Leeuw 1989). The latter, when not explained as resulting from cultural transmission (again an 'adoption' rather than an 'invention'), is explicitly or implicitly attributed to experimentation ranging from serendipity to problem-oriented trial-and-error (see e.g. Wertime 1964 for a classic theory on the development of metallurgy as interdependent with ceramic technology). Paving the way for future work, Schiffer (2010) has proposed a more formalized list of alternative models that may help explain the triggers for invention in specific contexts, although many of his examples are derived from modern inventions whose contexts can be reconstructed in greater detail than usually afforded by archaeology.

Hypothetically, the emergence of lost-wax casting technology in South America might at first appear amenable to the 'aggrandizer' explanatory framework (Hayden 1998). It is hard to envision how this technology could have resulted from a chance discovery, but it would seem reasonable to suggest that the innovation was based on experiments sponsored by emerging elites that sought ways of producing more sophisticated metal forms, which would in turn allow for more conspicuous forms of consumption and social display. When the archaeological record is examined, however, it is hard to find support for these explanations. Although many artefacts were used in ceremonial acts, there are also numerous artefacts made by the lost-wax method—and particularly Muisca votive metalwork—which were not meant to be seen by others (i.e. no social display). Some of the shapes would conceivably have been achieved more easily using alternative technologies (i.e. no practical need) and, more often than not, it can be argued that the appearance of the end product was not a prime preoccupation (i.e. no concern with aesthetics of the 'finished' item). Furthermore, the use of this technology appears to have remained strongly embedded in symbolic behaviour for over a millennium (i.e. not spreading primarily as a cost-effective resource).

In this paper, we lay out an alternative explanation for the emergence and adoption of lost-wax casting in South America. A crucial element of our argument is that we should not focus on the cast objects or the casting process only, but rather we should consider the role of wax in this innovation. The challenge, of course, is that the wax model was lost during the making of the objects, and any wax remains are very unlikely to be preserved at production sites. On this issue, however, instrumental analyses of the metalwork and an assessment of the ethnoarchaeological record can provide invaluable insights. We will argue that the success of lost-wax as an innovation had more to do with the cultural significance of wax than with a concern with efficiency or the appearance of objects ultimately cast by this technique. We will develop the claim that the use of wax may have been culturally just as important as the metals, and that perhaps metals were used in a process of transformation that required the use of wax, as opposed to wax being simply the medium to make gold objects more beautiful. Interestingly, the focus on wax and its symbolic role may help explain both the invention and the adoption of the new technology, thus subsuming these two categories that those studying innovations tend to separate heuristically (see also Schiffer 2010, who further subdivides the innovation process into invention, development, replication and adoption).

The following sections will begin with a brief overview of the earliest evidence of lost-wax casting in South America. We will then focus on highlights derived from the technical study of Muisca metalwork, which substantiate the points made above. Subsequently, we will summarize ethnoarchaeological work, particularly on the indigenous U'wa of the Eastern Highlands, that enriches our understanding of the cultural and symbolic importance of wax in the region, and thus lends further support to our interpretation. We will end by briefly exploring the applicability of this model beyond the Muisca.

The origins of lost-wax casting

Notwithstanding numerous variants, the essence of lost-wax or investment metal casting involves the following steps:

1. using beeswax, an accurate model is created of the object that one seeks to cast;
2. also made of wax, a funnel-shaped piece may be attached to the model, as well as, where needed, several 'feeders' or wax threads that connect various parts of the model to the funnel;
3. a mixture of charcoal dust and fine clay is used to cover the model, and successive layers of stiffer clay are applied until a complete mould is formed around the model, almost totally encasing the wax but leaving at least one opening, at the point of the funnel;
4. through gentle heating, the wax is melted out, thus obtaining a hollow mould with the negative impression of the object to be cast connected to the exterior through a funnel-shaped opening;
5. finally, molten metal is poured into this void and,
6. after cooling, the mould is broken to retrieve the metal object.

Normally, the goldsmith could then proceed to cut the cast feeders and sprue cup, as well as performing other finishing touches (Fig. 1).

<INSERT FIGURE 1 NEAR HERE>

The scarcity of absolute dates associated to metalwork makes it difficult to chart precisely the origins of lost-wax casting in South America. The earliest metal objects hitherto found on the continent are some hammered gold beads recovered in Peru and dated to c. 2100 BC (Aldenderfer *et al.* 2008). While the southern Andes progressively became a 'metallurgical region' with a shared tradition dominated by hammered objects, it has been proposed that Lower Central America and most of present-day Colombia may have been home to an independent focus of metallurgical invention, given the different styles and predominance of cast artefacts in this area. According to Plazas (1998), lost-wax casting technology may first have been developed in the Zenú and Quimbaya regions of northern and central Colombia around the early first millennium BC. This proposal is based on the early dates obtained on carbon-rich core material from a few zoomorphic, ceremonial objects, which were manufactured by lost-wax casting of gold alloys. These dated objects were cast using 'false cores' that were extracted after casting, resulting in hollow objects. While these early dates are not without problems (Plazas 1998), the sheer abundance of lost-wax cast artefacts in the region is coherent with an origin of the technology in the area. From this focus, the technology is thought to have spread towards the Eastern Highlands of Colombia, the Isthmus and West Mexico, where cast objects in different alloys are increasingly frequent from the mid to late first millennium AD.

While we await further absolute dates, at present we can only attempt to disentangle the origins of the lost-wax innovation by trying to comprehend the technology in its social and environmental context, ideally within a technological tradition. This may not help narrow down the *when*, but it should help further our understanding of more interesting questions such as *why* and *how*. With this purpose in mind, we shall largely concentrate on the metalwork produced by the Muisca of the Eastern Highlands of Colombia. There is no evidence to suggest that the Muisca would have been among the earliest users of lost-wax casting—in fact, objects of 'Muisca style' are typically dated to after AD 700. However, our focus is justified by the relatively richer information available from this region, including ethnohistorical texts, relevant ethnographic records and recent analytical studies. Based on this and the somewhat more explicit traits of this metallurgy, we can formulate new hypotheses about lost-wax as an innovation, whose applicability to other regions is briefly addressed at the end of this paper.

The Muisca goldsmith as a wax sculptor

The Muisca were a Chibcha-speaking group that inhabited the Eastern Highlands of Colombia when the Europeans encountered them in 1536 (Fig. 2). Most Muisca villages had chiefs and priests, who had some privileges but were also responsible for the welfare of their communities (Langebaek 1995; 2005; Langebaek *et al.* 2011). Economic activities comprised agriculture, pottery, metalwork and textile production, salt and emerald mining and specialized trade (Lleras-Pérez 1999, 32)—not least to ensure the supply of gold and beeswax for metalwork, as well as cotton, shells and feathers, amongst other commodities (Langebaek 1987a, 139–46). Human sacrifices, votive offerings and psychotropic consumption occupied a central stage in religious rituals—activities in which metal artefacts played a key role (Lleras-Pérez 1999, 32).

<INSERT FIGURE 2 NEAR HERE>

Muisca metalwork includes alloys covering the whole range of proportions between copper and argentiferous gold. The objects fall under two broad functional categories: adornments (including crowns, nose-ornaments, ear-pendants, necklaces and breastplates, sometimes found as burial goods) and votive offerings. The latter are far more abundant, though this impression may be at least partly skewed by the fact that ornaments could have been more exposed to plundering by Europeans. Votive offerings usually take the form of a group of small anthropomorphic figurines or *tunjos*, often contained in a ceramic vessel and accompanied by other metal objects representing scenes, animals, staffs or hallucinogen trays, sometimes together with non-metallic materials such as emeralds, ceramic beads or even colonial glass (Lleras-Pérez 1999, 101–15; Fig. 3). Based on the iconographic, technical and stylistic study of metal objects, we have established that all the objects in a given offering were generally made in a single manufacturing event, at the same workshop and, often, with a single metal batch. In each case, the iconography is coherent among the objects, with many or all of them being related, for example, to hallucinogenic consumption, war, birth or human sacrifice. This is consistent with ethnohistorical records indicating that votive assemblages were made on specific commission and offered soon after, seeking divine support for a well-defined need (Uribe-Villegas 2012; Uribe-Villegas & Martín-Torres 2012a,b; Uribe-Villegas *et al.* 2013).

<INSERT FIGURE 3 NEAR HERE>

We cannot be certain of whether the same craftspeople made both body adornments and votive objects. European sources distinguish between *plateros* (literally ‘silversmiths’ or jewellers), who were tolerated, and *santeros* (‘saint’ or idol makers), who were prosecuted as heretic (Langebaek 1987b)—but this segregation could either have deeper roots or simply reflect different responses to European impositions. Both types of artefacts are almost invariably made by the lost-wax technique, but adornments sometimes include large series of identical objects created with the help of a stone matrix, whereas votive figures are always unique. Furthermore, unlike votive items (see below), ornaments typically show evidence of finishing work to improve appearance, as well as occasional signs of repair.

Several factors derived from the examination of these artefacts lead us to contend that the process of making a votive offering by lost-wax casting was at least as significant as the end product itself (cf. Uribe-Villegas *et al.* 2013 for further images; publication of further analytical details is currently under preparation). The first is the very fact that, with very few exceptions, every metal object was cast using the lost-wax technique and in a single pour. While in some cases it seems reasonable to argue that the technique was a cost-effective solution to achieve complex shapes, the manufacture of some objects or object features by this method seems unnecessarily complicated. Particularly illustrative of this point are the dangling nose-

rings and other pendants that sometimes appear hanging from extremely small loops in the figurine crowns. Detailed examination of these pendants often reveals the 'stumps' left after cutting the cast feeders that would have supplied the metal to these elements during casting (Fig. 4). For a pendant to remain free to move after casting, the charcoal-clay mix would have to be applied extremely carefully to the wax model, to ensure that the wax loop and the wax dangler itself remained separated. Other elements of the figurines, such as the elaborate headdresses or staffs they sometimes carry, or the several figures making up the more complex scenes, could conceivably have been made by casting-on in several steps, or cast separately before assembling them together mechanically or through soldering. However, these techniques are only very rarely—if ever—documented in the artefacts. Instead, goldsmiths opted for the likely more time-consuming, and certainly more risky, practice of always casting the entire artefact in a single pour (Fig. 5).

<INSERT FIGURES 4 & 5 NEAR HERE>

A second factor supporting the cultural significance of the making process is the 'unfinished' appearance of many of these objects, together with the occurrence of casting errors. Very frequently, casting feeders have not been removed after casting, or only cursorily so (Fig. 4). Remains of the charcoal-clay mix used to make the mould are left filling corners and crevices, sometimes obscuring the intricate detail of the original waxwork (Figs. 4 & 6). Object surfaces are very often textured from the large dendrites that formed during a very slow metal cooling, most likely in a pre-heated mould; this was surely necessary to prevent the freezing of the very thin metal mass before it filled all the details in the mould, but no attempt is made subsequently to enhance the surface appearance through cleaning or polishing (Fig. 6). In the same vein, many of these objects show what most would call casting errors: for example, voids in areas of the figurines, or flashes of metal in spaces where the mould likely cracked during casting (Figs. 4 & 8). However, these are never 'retouched', even if this might require little more than trimming, polishing or hammering. There are examples of more severe casting errors, where the original model is hardly recognizable, which in other contexts would have led to the object ending up recycled in the melting pot. The Muisca, however, include these peculiar artefacts in their offerings, alongside those that would today rank as better casts (Fig. 7). Importantly, all of these 'errors' or 'imperfections' are related to the casting stage. The modelling of the wax (and the moulding of clay-charcoal), on the contrary, seems to have been extremely meticulous, to such an extent that the fineness of the detail can only be truly appreciated under a microscope (Fig. 8). It is hard to overestimate the work involved in crafting the models employing wax coils of diameters well below one millimetre, to achieve the accurate and detailed representations in some of the extant figures.

<INSERT FIGURES 6, 7 & 8 NEAR HERE>

Thirdly, another fact worth highlighting here is that these offerings were not meant to be seen or displayed. Not only were they most likely deposited almost immediately after manufacture, but the artefacts were offered in containers or otherwise covered, and placed in remote locations. Remains of cotton left in the surfaces of some of these, as well as ethnohistorical sources (see Falchetti 2003), indicate that sometimes the gold figures were even wrapped in textiles, so they would not be visible at all. This aspect of the ritual, together with the 'unfinished' state alluded to above, reinforces the impression of the somewhat lesser importance of the end product's appearance, compared to the manufacturing process. Considering these observations, it might be argued that cultural customs dictated that the making process should be perceptible in the finished product, perhaps materializing the process of transformation—which would justify the 'unfinished' appearance. This may well be part of the explanation and it would justify, for example, the feeders or mould remains left in some *tunjos*, as well as the small ingots or *tejuelos* included in some offerings (e.g. Fig. 3). But it cannot be the whole story, as it would hardly explain why blatant miscasts were

kept with the offerings rather than recycled or repaired. Similarly, it might be tempting to think that the metal was not an important element of the manufacture and materiality of an offering—perhaps just a way of making wax more durable. This, however, is unlikely to be true: as we have argued elsewhere (Uribe-Villegas 2012; Uribe-Villegas & Martín-Torres 2012a), the composition of the alloys employed seems to have been specifically decided, probably when the offering was commissioned; in some cases, a wide spectrum of alloys was deliberately chosen, resulting in a rainbow of yellow to reddish tones (even if these were not subsequently cleaned to enhance their striking appearance). Rather than actual colour hues, these various alloys may have reflected different combinations of ‘colour energies’, as suggestively understood by some Amazonian indigenous groups (Reichel-Dolmatoff 1978; 1981). If we add to this the fact that gold had to be obtained through trade, the cultural and economic value of the metal would seem unquestionable.

Whatever the case, the making of Muisca votive goldwork conveys the impression of a technological arena that was strongly bound by cultural constraints: the objects had to be made by the lost-wax technique and in a single pour; the waxwork had to be sculpted to perfection, often to the extent that details would not have been readily perceptible to the naked eye; lastly, repairs or other finishing touches on the metal were not desirable or acceptable. Clearly, any understanding of this sociotechnical phenomenon will require a consideration of Muisca ritual customs and beliefs, and of the symbolism of metals and transformation processes—but also, crucially, a closer look at wax.

Bees and wax among the U’wa

The study of indigenous communities that survived the European conquest can provide useful reference models that, with due caution, may help understand the archaeological record. Of particular relevance here are the U’wa, a Chibcha-speaking community that still inhabits some areas in the Sierra Nevada del Cocuy of the Eastern Cordillera of the Colombian Andes—thus geographically, culturally and linguistically connected to the Muisca. Ann Osborn (2009) carried out a detailed analysis of the ritual ecology of this community, articulated in the chanted myths that enshrine and perpetuate their ancestral traditions and regulate the ritual, political and economic seasonal activities that guarantee social stability and cosmic equilibrium. Building on this work, Ana Maria Falchetti (1997; 2001; 2003; Falchetti & Nates-Parra 2002) has focused on the symbolism of gold, and the important role stingless bees and bees’ products play in the cosmologies and ritual behaviour among the U’wa. She went on to suggest that some of the symbolic associations of bees and wax may have permeated the significance of gold metallurgy in general and lost-wax casting in particular. Falchetti’s pioneering work thus deserves credit as the first attempt to connect the ethnography of bees with the archaeometallurgy of goldwork—a proposal that can be developed here in the light of the more detailed examination of archaeological artefacts.

According to U’wa mythology, bees are the daughters of the sun and they carry the essence of life itself. They were created by deities to quench the ‘thirst’ of the U’wa and satisfy their need for fertility and germination. Like humans, bees are creatures with social structures whose behaviour is controlled by seasonal cycles. Chewing-thinking is a creative process shared by bees and deities. Female bees are understood to chew ‘yellow earth’ (which may be identified with gold) and produce female ‘embryo seeds’ and ‘basic original matter’, whereas male bees chew pollen and wood, and produce wax.

Bees produce wax of highly variable texture, colour, purity and malleability. Together with honey, wax products are consumed or otherwise present in several rituals associated with fertility, protection, and social order. Deities gave ownership of wax to certain clans only, who are responsible for their trade. Both male and female principles and materials are necessary to create the hive. Inside it, the generation of wax and honey is seen as a magical embryonic transformation. Falchetti noted suggestive parallels between the bee hives and the lost-wax moulds used to produce goldwork. Like the hives, these moulds are composed

of a hollow space encased in a hardened material, and connected to the exterior through a channel. Perhaps significantly too, bees often make their hives inside gourds—the same receptacles used as containers for the lime to be chewed together with coca leaves.

The points succinctly summarized above highlight the crucial symbolic role that wax may have played in the production of metal artefacts. Besides requiring extensive selection and handling of this precious material (both symbolically and economically), wax could be perceived to be turned into gold inside the mould, in a process of transformation and subsequent birth. This might explain the lack of finishing touches, as the newly born object might be expected to have all the necessary qualities for its own development. In this sense, the offering vessel where the objects are placed may again be understood as another receptacle where further transformations could occur, under the protection of cotton or other textiles, which in U'wa ritual represent male protection for germination (Reichel-Dolmatoff 1981, 29; Falchetti 2003, 370–72). It is even tempting to interpret the spectrum of colours displayed by some offerings as related to the rainbow, which is again connected to fertility (Falchetti 2003, 372).

It should be acknowledged that the U'wa, while connected to the Muisca, cannot be claimed to be direct descendants. In fact, they are thought not to have produced goldwork themselves, but they obtained it by exchange with neighbouring communities that may well have included the Muisca (Falchetti 1997; 2001). Wax remains a symbolically important material to current U'wa, but there is no evidence of its use for artistic work. However, the Muisca and the U'wa 'shared cultural and ideological elements' (Falchetti 2003, 368), and U'wa mythology is so suggestive of the ritual importance of wax, and so fitting to explain the patterns identified in Muisca metalwork, that its importance cannot be ignored. Thus beeswax and metal together seem to reinforce their mutual value in a complex set of relationships that tied both materials and communities symbolically but also economically, contributing to the survival of both. The making of a metal artefact by lost-wax casting would thus be a materialization of these ties, in a process where both wax and gold were essential components. From this perspective, the choice of lost-wax as a new technology is understood as a form of action that is intimately bound in ritual behaviour. This—and not the practical technical advantages it could bring in some cases—is seen as the foremost factor explaining its inception and prevalence. Indeed, this ritual embeddedness may also justify the conservativeness of the technology from its early roots until well after the European contact (as shown, for example, in Muisca offerings that include European glass but remain traditional in the approach to goldwork: see Fig. 3).

Conclusion

This paper has put forward a different theoretical framework and substantive data that may help understand the inception and prevalence of lost-wax casting technology in some areas of South America. We argued that, among the Muisca, the making process and the use of wax were as essential as the end product; we also contended that there were strict cultural constraints affecting the manufacture of votive metalwork, as exemplified in the exclusive use of lost-wax in single pours, the scarcity of finishing touches and the disregard towards casting errors, in contrast to the pulchritude of the waxwork. Drawing on the U'wa cosmology and ritual behaviour, we found possible explanations for the symbolic importance of wax, as a precious material associated to cosmological order, fertility and health. On this basis, it seems unquestionable that the adoption of lost-wax casting technology among the Muisca responded primarily to ritual stimuli related to fertility and order, and not to practical needs. Similarly, the concept of 'prestige technology' seems inappropriate for an innovation devoted to the production of votive offerings that were generally not made to be seen by others. When proposing his distinction between practical and prestige technologies, Hayden (1998, 15) acknowledged in passing that 'perhaps there remains a useful category of nonprestige ritual or social artifacts' that was neither a prestige nor a practical technology. The present study thus confirms that, for the Muisca at least, offerings indeed fall outside those broad

categories. Considering that votive offerings constitute a cross-cultural practice, we should not underestimate this arena as a possible context for technological innovations.

There are no grounds to claim that the Muisca invented lost-wax casting—as opposed to adopting it from potential inventors in the broader Colombia. Thus, to what extent can we relate the very discovery of this technology to symbolic behaviour too? The metalwork of other lost-wax casters of Colombia reflects different regional trajectories that may not seem as explicit as that of the Muisca in revealing the importance of wax and the cultural constraints that regulated the manufacturing process. However, ethnographic and ethnohistorical sources from several regions attest to a widespread reverence for bees and wax among other indigenous communities around Colombia, including the Kogi of Sierra Nevada de Santa Marta in the North (Preuss 1993), the Desana (Reichel-Dolmatoff 1978) and Barasana of the Amazon basin (Hugh-Jones 1988) or the Andoke of the Japurá River (Jara 1996). Worthy of special mention is a myth collected among the Emberá of the Isthmus area (Isacsson 1993, 75–85), which recalls a shamanic metamorphosis into melted beeswax before returning to normal human state. In the Chocó language spoken by the Emberá, the etymology of the term used for beeswax has been argued to evoke ideas of change into an esoteric cosmic mind (Isacsson 1993, 79). Thus, while we note the unquestionable cultural diversity that lies beneath the superficial impression, the ethnographic record overwhelmingly supports the symbolic importance of wax in the region of present-day Colombia and, thus, its key role in lost-wax casting. Further work on archaeological collections beyond the Muisca should be warranted to ascertain this point.

In a similar vein, the association of metalwork to ideas of transformation and birth is widespread in Pre-Columbian societies of lower Central America and present-day Colombia, in a broadly shared cultural code that has given rise to overarching interpretive schemes about this metallurgical region (Falchetti 2003; 2014; Reichel-Dolmatoff 1981). Against this background, in a region of metal-using societies in revered contact and familiarity with bees and wax, who distinguished different wax products and used them for a plethora of symbolically loaded activities, envisioning the invention of lost-wax casting becomes more plausible.

Wherever the discovery took place, initial experimentation must have been related to ritual behaviour involving materials and skills that were all valuable. The very ritual embeddedness of wax, encoded in conservative ancestral traditions, would preclude its use in a mere search for innovations perceived as pragmatic solutions for practical problems. Hence, overall, both the inception and the adoption of lost-wax casting must have been triggered by symbolic behaviour that favoured the combination of wax and metals in a broader set of practices and beliefs that ensured social order. Of the various models posited by Schiffer as possible contexts favouring inventions, the one that best fits this scenario is that of the ‘material-stimulated inventions’ (Schiffer 2010, 246–7). According to this model, inventions often take place when a new material enters a given sociotechnical context, especially in contact areas. Considering that both wax and gold were traded among Pre-Columbian communities, it is conceivable that lost-wax casting was discovered by a community that became in contact with either metals or wax (or both) through exchange with their neighbours. If this is the case, the experimentation and discovery would have taken place soon after the entrance of metal in the social system. We should therefore expect to keep finding lost-wax casts among the earliest goldwork made in the region: whether metallurgy was transferred from the South or truly invented, lost-wax casting could have resulted from the ‘material stimulus’ of the new material in a cultural background where wax was both available and ritually important. This model would also explain why we document invention in a context of ritual behaviour—an arena that, by definition, tends to be conservative and repetitive in its practices.

It remains to be tested if similar concepts may also help explain the inception of lost-wax in other regions of the world. In the Near East, Wertime (1964, 1262) saw an evolutionary progression that involved the sequential discoveries of smelting, alloying and piece-mould casting, before culminating in lost-wax casting technology—but the reality is likely to have been more complex. A more recent review of early lost-wax metalwork in the Old World placed much emphasis on the versatility of this technique to facilitate the production of new forms, but it acknowledged that often the products were ‘not practical’ (Davey 2009). In the Indian subcontinent, where several craft traditions involving lost-wax casting have survived to this day, ethnographic records highlight the role of this technique as a way to give ‘permanence’ to otherwise perishable figurines made of string, straw or wax. In some areas, the modelling of the wax mixture does not start until canonical prescriptions are drawn from divine inspiration (Reeves 1962; Ghose 1981; Horne 1987). Clearly, the topic deserves further research combining technical study, ethnoarchaeology and a closer look at the contexts, functions and uses of objects cast by the lost-wax method.

We hope that this study will help raise awareness that the study of inventions and innovations in archaeology can benefit from approaches that complement those focused on placing dots and dates on a map, that there is more to human nature than ostentation and imitation, and that the history of technology is much richer than a linear quest for either efficiency or beauty.

Acknowledgements

We are indebted to the staff at the Museo del Oro in Bogotá, Colombia, for their essential support, especially to Clara Isabel Botero, Roberto Lleras, Lucero Gómez, Clark Manuel Rodríguez, Juanita Sáenz Samper and Jose Socarrás. We would also like to acknowledge Paul Craddock for his helpful comments. This research was supported by a British Academy grant (SG-54242).

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Marcos Martínón-Torres is Professor of Archaeological Science at the UCL Institute of Archaeology, where he co-ordinates an MSc in the Technology and Analysis of Archaeological Materials and supervises several research students working on ancient materials and technologies. His research interests include material culture and technology, the applications of science to archaeological problems and the interplay between archaeology, anthropology, science and history. Some of his current projects focus on pre-Columbian metallurgy in America and the logistics behind the making of the Chinese Terracotta Army.

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Figure captions

Figure 1. Schematic drawing of some of the main steps in the manufacture of a metallic tunjo by the lost-wax technique.

Figure 2. Map of Colombia with an indication of the main goldworking regions, including the Muisca in the Eastern Highlands.

Figure 3. Complete offering from Tocancipá, including the ceramic offering vessel, numerous ceramic beads, fragments of emerald and glass, as well as four metallic tunjos, two small metal ingots or tejuelos, and a gold nugget.

Figure 4. Three tunjos from the Gutiérrez offering. Each figure, including all their elements, was cast in a single pour. The earrings received the metal through feeders that connected them to the figure shoulders, and the 'stumps' left after cutting these feeders can still be seen (one of them is indicated by an arrow). The two figures on the left still carry the casts of the main feeders attached to their feet, as these were never cut. Remains of charcoal and clay from the mould are still visible in some areas, such as the necklace of the left figure or the eyes of the middle one. The tallest figure is c. 17 cm in height.

Figure 5. Scanning electron microscope image of two tunjos from Suba, showing detail of the wax work on their faces and headdresses, and the very similar design of all the elements making them. All of these parts were stuck together in wax before casting in a single pour. A casting flash is visible at the neck of the figure on the left, while a casting void appears in the shoulder of the figure on the right. Small blebs of metal are noticeable in various places. These are likely remnants of air bubbles trapped in the mould material, subsequently filled with metal but never filed off in the finished object.

Figure 6. Two of the three very small figurines from the Carupa offering. Their arrangement shows that both figures were modelled as a single wax piece and cast together, before snapping the object quite crudely. The image on the right shows a high-contrast detailed view of one of them under the scanning electron microscope. Here one can appreciate the rough fracture at the top, the remains of charcoal and clay from the mould left in several crevices, and the dendritic texture resulting from a very slow cooling.

Figure 7. A miscast tunjo included in the Suba offering. Composite image from micrographs obtained in the scanning electron microscope.

Figure 8. Tunjo from the Suba offering representing an adult carrying a baby. The image on the left shows casting flashes left on the figure, especially around the neck, as well as imperfections in the casting of feet where the metal was insufficient. In contrast, the scanning electron microscope image on the right shows a detail of the baby, demonstrating the fineness of the wax coils employed to manufacture the original model.