THE EVOLUTION OF GREEK BRONZE STATUARY
FROM THE ARCHAIC TO THE HELLENISTIC-ROMAN PERIOD: NEW EVIDENCE ON THE ANCIENT MANUFACTURING TECHNIQUES

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WORKING ON THE RIACE BRONZES

In 1972, two complete bronze statues were casually found and recovered from the sea bottom, in front of the hamlet of Riace Marina (Calabria, Italy). No wreck was identified in the nearby areas (Lombardi Satriani & Paoletti 1986; Formigli 1984). The statues (labelled Riace A and B) range among the few existing Greek originals dating to the Vth century BC. Most scholars agree that statue A was made around 470-460 BC, while statue B is slightly later (ca. 440-430 BC) (see La Rocca 1996). The find of the two statues awakened a great popular and media interest. The bronzes were sent to Florence, where they underwent a long restoration, eventually recovering their beauty. During this intervention, the conservators attempted the removal of the original casting core still trapped inside, correctly realizing that the permanence of the inner clay might have endangered, in future, the conservation of the bronze walls. The lead pivots below the feet were removed, and long steel bars with different functional extremities were used as chisels for excavating the cores, starting from the heads and the lower legs. When this stage came to a stop, as the clay was too compact, the conservators used pressure water and then hydrogen peroxide (130 volumes per liter) for further crumbling its mass. Kilograms of clay residues were extracted in form of liquid slurry, mud and relatively small lumps without precise locational information (see Formigli 1984; Micheli & Vidale 1998). At a certain point, this process, too, exhausted its utility. The statues were declared empty, or almost completely emptied; they were erected and successfully exhibited in Florence, Rome and finally displayed in Reggio Calabria.

In the early eighties, the Istituto Centrale per il Restauro, Rome (ICR) started a major program of analysis centered on the structure, composition and state of conservation of the two greek masterpieces. This time, microcameras, videorecorders, digital technology and remote-controlled microsurgical tools were available. The cavity inside the statues was visually explored and recorded as it were an archaeological site. It was found that the residual clay cores (about 72 kg for statue A, and 56 for B, mainly present in the legs and the torsos) had caused a strong corrosion of the inner bronze wall. It was decided to completely remove this material. At the same time, the core material would have been the subject of an intensive characterization study (Lombardi & Vidale 1998). Finmeccanica, a leading industrial italian group, sponsored the whole project. An archaeologist and four conservators, both from ICR and the Archaeological Superintendency of Calabria, worked together for almost three years in Reggio Calabria, microexcavating the cores with the constant aid of microcameras operated with remotedly-controlled mechanical supports, designed for this purpose, and monitors. Many tools and mechanical devices were directly inspired by medical video-endoscopic surgery. The process was followed by a central computer station, capable of acquiring digital pictures and attaching to them excavation notes. The location of each extracted sample was recorded with centimetric coordinates. Many fragments of the cores were extracted from the available small openings and refitted together, in order of reconstructing as much as possible of the original clay interior. Microexcavation proceeded in a tomographic fashion, i.e. recording stratigraphic cross-sections of the cavities and their clay fillings at intervals of 5 cm. A total amount of about 80 cross-sections were so obtained; the data base also includes about 80 hours of films and thousands of digital pic-

tures. Fortunately, enough of the cores was left to reveal unexpected and very complex microstratigraphical patterns. This evidence, as we shall see, questions the theories so far generally accepted on the nature of the techniques used by ancient greek craftspeople for making bronze statues in the Vth century BC (Micheli - Vidale, 1994; 1998).

THE THEORY OF INDIRECT LOST-WAX CASTING OF LARGE BRONZES IN THE 5TH CENTURY BC

Among the first scholars to pay attention to ancient bronze casting techniques prominent was the figure of the German archaeologist and craftsman Kurt Kluge. In his reconstruction, the earliest technique used in ancient Greece was casting within sand moulds impressed with wooden carved models. He also supposed that, in an evolutionary perspective, sand casting after a wooden model was technically connected to the making of *sphyrelata,* the early sculptures made of bronze sheets hammered and nailed onto wooden cores (quoted in Mattusch 1988: 23-25). This idea was rooted in his personal experience and skill as a bronzesmith, because sand casting, in the XVIIIth and XIXth centuries, was a widespread, efficient industrial bronzeworking process. Also, such hypothesis appeared to be supported by the columnar look of the lower part of the Delphi Charioteer, whose original model, according to Kluge, could have been carved out of a trunk of a tree. Kluge's reconstruction, furthermore, included the notion that direct lost-wax casting procedures became the most common technique in the Vth century BC, to be replaced by indirect procedures during the hellenistic-roman period.

For about 25-30 years, Kluge was the only authority on this subject. After the second world war, scholars were able to travel abroad and had direct access to greek bronze sculptures; new bronze statues were also recovered. It was soon realized that the Delphi Charioteer had been cast in pieces with a lost-wax technique. The idea of sand casting being an evolutionary stage of greek bronze statuary had to be abandoned, and with it Kluge's reconstructions, as a whole, fell into discredit (see Mattusch, 1988: 22). Then, archaeologists tried to develop a new interpretative model on the evolution of greek bronze statuary.

It was such rejection that ultimately brought about the theory of the use of the indirect casting method in the Vth century BC. Interestingly, still in 1975 C.C. Mattusch, in her PhD thesis, although contesting the old sand casting hypothesis, followed the general outline of Kluge's theory, and considered the indirect process a variant of the direct procedure, introduced in an unknown moment but certainly common in the hellenistic period (1975: 1-11). Gradually, in the following years, C.C.Mattusch and other authors gave more and more importance to the hypothesis of an early use of indirect techniques (see the sequence of the following papers: Mattusch, 1975; 1982; 1988; 1990; Bol, 1985; Rolley, 1988; 1990; 1992; Haynes, 1992; Heilmeyer, 1993; Mattusch, 1994; 1996). An argument frequently used for support this view is the archaeological evidence, since the VIIIth century BC, of a moulding process for the serial casting of appliques on large archaic bronze cauldrons dedicated as temples offerings (for example, Kyrielis 1990; Heilmeyer 1993).

In 1992, D. Haynes felt confident enough to state that the idea that direct lost-wax casting preceeded in time indirect casting was "...no more than a romantic prejudice unsupported by any evidence" and accused K.Kluge of romantic overtones in proposing it (Haynes 1992: 34, note 1). In some recent works, C.C. Mattusch implicitly states that indirect lost wax casting was the only technique used in the Vth century BC (1994: 789; 1994a; 1996), stating that it directly spread from the archaic moulding techniques. Indirect casting techniques, according to the same author, could be somehow combined with direct procedures. She thinks that even the two Riace bronzes were made with waxes moulded after the same "rough model", with secondary modifications, refering also to the strong similarity between the herm from Mahdia and a specimen at the Getty Museum (1994: 795; 1994a). This idea was rejected with reason by C. Rolley (1990: 407). The circularity of the arguments proposed for supporting the use of moulds in the man-

ufacture of such life-size statues is self-evident: the use of moulds would be demonstrated by the close match between various measurements, but when there are discrepancies, this is because the soft waxes could be easily modified after moulding!

Indirect casting, allowing serial reproduction of statues, according to Mattusch and other authors, would have been adopted and diffused in the course of the Vth century BC. Her views are shared by W.-D. Heilmeyer (1993), who seems to view the adoption of the indirect casting process as a plain case of linear technical evolution gradually promoted by the need of improving the technical and economical standards of the production cycle. Most of these papers and books seem to have accepted, more or less explicitly, a comparison with modern manufacturing techniques, in particular the idea that, once the wax panels have been moulded after the model and reassembled, their inner cavity was filled by clay in liquid or semiliquid form, resulting therefore in a homogeneous, amorphous clay mass. Thus, the inner structure of the casting core would represent a critical technological indicator.

THE INFLUENCE OF FORMIGLI'S PALEOTECHNOLOGICAL ANALYSIS OF THE RIACE BRONZES

Reviewing the available literature, it is evident that a turning point in the gradual acceptation of the indirect casting theory was the publication in 1984 of the reports on the conservation of the Riace bronzes in Florence, in particular of the contribution by E.Formigli on the manufacturing techniques of the two statues. Formigli, in fact, listed a set of 5 indicators which, in his opinion, demonstrated the use of an indirect process. These indicators were respectively: a) the presence of round depressions in the interior of the feet of the statues, suggesting that wax had been pressed into moulds from inside; b) the fact that the middle toe in all four feet had been separately cast and then soldered, in order (he suggests) of avoiding complex undercuts during moulding; c) the fact that in the right leg of statue B the iron bar touches the inner bronze walls, as it had been blindly inserted into an amorphous semiliquid mass; d) the fact that the inner cores are reduced and not oxidized; e) a strange statement, according to which, as the thin sections of some core lumps showed a distinctive band orientation, the clay had been pressed in "dens-fluid" state into wax moulds (Formigli, 1984: 107). Formigli's interpretation of the thin sections was so ambiguous that, later, D.Haynes (1992: 35) could quote it stating that "Analysis of the structure of the core materials of these two statues has shown conclusively that it was poured into the mould in a semi-liquid state and left to set". Thus, a structure made of parallel slabs came eventually to be described as an amorphous water-laid mass. This conclusion represents a complete twisting of material evidence.

Without entering into a detailed discussion (presented in Micheli - Vidale 1998), we think that these indicators are unconsistent. The middle toe of the feet - an old subject in archeometallurgy - might have been separately cast because of the location of a casting canal, and might have no relation at all with moulding. As we shall see, the bar was not inserted at all in a semiliquid mass; the inner cores we extracted from the statues are both oxidized in some large areas, and reduced in others; if the cores have a stratified, band-like inner structure, this is because they were applied in preformed slabs, as revealed by our excavation (see below), and not spread in a not better described "dens-fluid" form. The depressions in the interior front of the feet, finally, might be simple protuberances in the hand-modelled inner core of the direct casting process.

In other words, it was Formigli's "demonstration" which was unsupported. Probably, his interpretation was biased by the observation of contemporary casting techniques, and by the firm belief, shared by many collegues, that great artists such as Polykleitos and Pheidias would have not run the danger of destroying their unique plastic models with a direct procedure. In contrast, on the base of the evidence nowadays available, we would better agree with T. Karaghiorga (1988: 45) that the direct lost-wax process, in which the positive model was destroyed together with the outer mould, is a distinctive

characteristic of classical greek bronzes, granting the unicity and originality of each image, were it secular or divine.

The problem was that the work of Formigli, in other aspects, is just excellent - doubtless the best technical report on bronze statues ever published. As a consequence, also his weak arguments in favour of the indirect process were acritically accepted by art historians and archaeologists. Nobody seems to have seriously asked himself or herself why, if such was the technique used in the past, there is no actual evidence of water or gravity-laid sedimentary structures in the known casting cores; and, perhaps more important, how could the bronzesmiths deal with the problems of drying a core completely encased in wax, as well as counteract the effects of the expected shrinkage of the clay core (a mixture of special gypsum and grog with no shrinkage is used nowadays by contemporary bronze casters).

THE ARCHAEOLOGICAL EVIDENCE FROM THE INTERIOR OF THE RIACE BRONZES

In contrast with the highly speculative arguments so far reviewed, the microexcavation of the casting cores of the Riace statues showed that legs and torsos had been formed by rolling around the iron bars and superimposing concentric preformed slabs of variable thickness and composition. There is no evidence of homogeneous clay masses resulting from pouring liquid or semiliquid clay. The slabs are tempered with substantial amounts of animal hair, apparently carbonized in the casting process; in statue B the innermost layers applied onto the iron bars are thicker, porous and more heavily tempered, while the outermost clay sheets, often corresponding to finer details such as the ribs or muscular expansions, are almost free from hair and not porous. This demonstrates that the function of the animal hair is not, as previously supposed, to create pores for the absorbtion of gases generated in casting, but to re-enforce the structure of clay slabs, like in modern fiberglass. In our experiments we found that slabs tempered with hair are stronger and more handly than untempered ones.

There is evidence of microlayers of slip laid between the clay slabs, possibly brushed as a glue while constructing the core, sheet after sheet; also, there are finger impressions from outside towards the center of the core, consistent with the hypothesis of a free hand modelling through a concentric slab construction process. Our data suggest that torso and legs were separately formed and then assembled before the application of wax panels onto the inner model. It is very unlikely that such concentric slab structure was built as a filling of a preexisting structure made of moulded wax panels, as the innermost structure is plainly concentric and continuous, and the evidence of post-forming corrections is very limited (Micheli & Vidale, 1998). Our experimental replicas of the process suggested that such concentric slab construction technique is expedient, effective and easy to learn (Micheli & Vidale, 1984).

Incidentally, if we are right, and this was the technique normally used by ancient greek bronze sculptors, it is possible that the famous treatise by Polykleitos, besides centering on linear measurements and scaling, included also simple rules for gradually obtaining fixed three-dimensional proportions by adding slabs of a given thickness. When we described and showed the concentric slab technique to contemporary bronze sculptors, they reacted negatively, as their own modelling technique is completely different, and, like other contemporary craftspersons, they are attached to the idea of a precise continuity of tradition with a prestigious past. It is important to stress the need for new, highly controlled microexcavations of casting cores of bronze statues datable to the archaic, classic and hellenistic periods, for building an archive of comparable information, now missing. More experiments will also be needed before a sound conclusion is reached. For the moment being, we consider such concentric slab constructed cores as likely evidences for direct lost-wax casting techniques. We expect, in contrast, that in the future the examination or excavation of casting cores of bronze statues made with the indirect process will reveal cores built with sequences of irregular lumps or slabs manu-

ally applied into the wax cavities. We also expect that the sections of these cores will show major building interfaces in correspondence of the assemblage joints among the original moulded wax panels. An example is provided by the tomography of the casting core of a Renaissance bronze copy moulded after a roman statue, the Praying Youth of Berlin (Heilmeyer, 1996: Taf. 62). Tomography clearly shows that a bivalve-like wax structure (front and rear of the figure) was filled by applying onto the symmetric cavities thick irregular slabs and lumps of clay. In all plates published by Heilmeyer such layers and interfaces appear to extinguish themselves at the joints. The resulting pattern contrasts with the continuous, concentric layering of the cores of both Riace bronzes, and might be taken as a preliminary model of what an indirect casting core should look like.

OTHER EXAMPLES OF CONCENTRIC SLAB CONSTRUCTED CORES

Actually, we have not been the first ones to observe such concentric core structures in ancient greek bronze statues, and to relate them to the direct casting techniques. For example, W.-D.Heilmeyer (1985; 1993; see also Formigli & Schneider 1993: 76), after a pioneering tomographic examination of the Kythera head, found in its residual casting core similar structures, and concluded that it had been cast with a direct technique, as clay cores introduced in liquid form would have been distinguished by a different structure. A similar concentric slab structure had been noticed and excavated by the greek conservators which cleaned the interior of the famous *kouros* from the Piraeus find, as described by C.C. Mattusch (1988: 78). Also in this case, the finer layers were found at the contact of the inner bronze wall, while the innermost slabs were coarser.

Even earlier was the inner microexcavation of the casting core of the Getty's Youth, considered by some authors an original by Lysippos (Frel, 1982). The microexcavation of the core was carried out with great care and intelligence: it revealed some purposeful alterations of the neck and the right arm, and a concentric structure involving materials and inclusions such as layers of loam and sand, glue, pebbles, potsherds, ivory fragments and even a certain amount of pistachio nut shells (Frel, 1982: 11). Later, this work was just ignored. May be because of the scarcely academic implication of Lysippos chewing pistachios and spitting the shells into his clays, or because Frel considered the statue a direct casting, the microexcavation of the Getty Youth has been rarely or not at all quoted in the following literature.

In summary, when the cores of bronze statues were actually excavated or investigated, concentric slab construction, in each case, turned out to be the forming technique in use, and this cannot be a simple coincidence. The evidence for this type of casting cores apparently extend from the beginning of the Vth to the middle of the IVth millennium BC, and, if the Piraeus *kouros* dates back to the end of the VIth century BC, as proposed by some authors, such technique could be even earlier. Until the proposed correlation between such structures and the direct casting process will be questioned on material grounds, providing reliable alternative explanations, the hypothesis of the exclusive or prevalent use of this process in the Vth century BC should be given the proper attention.

CONCLUDING REMARKS: DATING THE INTRODUCTION OF THE INDIRECT CASTING PROCESS

The microexcavation of the cores of the two Riace bronzes thus suggests that, in contrast with what assumed and so far published by the conservators in Florence and by the majority of the specialists who followed them, the Riace bronzes were made with a direct lost-wax casting process, i.e. by hand-modelling the inner core onto the iron supporting bars found on their interior, and not using moulds for reproducing an original finished model, as it would have been the case with the indirect casting process. If we are right, again, the implications are manifold and important: in fact, the theory nowadays prevailing, according to which indirect lost wax casting was widely used by Greek bronze-

smiths in the Vth century BC, is based, to a great extent, just on the interpretations proposed in the seventies at Florence on the inner cores of our two statues. These interpretations are now untenable. Also, in this light, the bronzesmiths modelled a slightly thinner, not proportioned human figure in clay and coated it with wax slabs; this wax layer was then worked in its details, to be coated with the outer mould and destroyed by melting before casting, so that no finished model of the statue survived outside. The casting technique normally used by ancient Greek bronze sculptors in the Vth century BC did not involve the possibility of serial casting.

Although the principles of moulding and casting of replicas were well known and mastered by greek bronzesmiths since centuries, such techniques were applied to the manufacture of large statues only when the market required it. When did this happen? There are statements by Pliny (*Naturalis Historia*, 35, 153) and by Lucian (*Zeus Tragoikos*, 33) which comfortably place this innovation between the midth of the IVth century BC and the IInd century AD, i.e. in the hellenistic-roman period. The few examples of moulds and plaster casts so far found in archaeological excavations fall in the same time range. Bronze statues begun to be reproduced by moulding and perhaps manufactured in series only when new emerging families, particularly in late republican and early imperial Rome, became suddenly very rich and demanded growing amounts of bronze images for imitating the richer aristocracies and displaying their newly acquired status. This happened in the context of the late hellenistic kingdoms and the expanding power of Rome, both home and in the eastern mediterranean basin. Thus, we would go back to the original hypothesis by Kurt Kluge and the earlier paleotechnologists: another argument for stating that, in the recent past, many good, old-time ideas have been dumped too hurriedly.

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ΠΕΡΙΛΗΨΗ

Η ΕΞΕΛΙΞΗ ΤΟΥ ΕΛΛΗΝΙΚΟΥ ΜΠΡΟΥΝΤΖΙΝΟΥ ΑΓΑΛΜΑΤΟΣ

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Τα δύο μπρούντζινα αγάλματα, που βρέθηκαν στην θαλάσσια περιοχή της Riace Marina (Καλαβρία Ιταλίας) το 1994-95, έχουν αποτελέσει το αντικείμενο ενός πρωτοποριακού έργου συντήρησης.

Καθώς περιείχαν αντίστοιχα περίπου 70 και 50 kg από τους αρχικούς πυρήνες χύτευσης (από άργιλο), έπρεπε να ανασκαφθούν εσωτερικά με μικροεργαλεία, έτσι ώστε να αναδειχθεί και να συντηρηθεί με χημικά μέσα το εσωτερικό μπρούντζινο τοίχωμα.

Μικροκάμερες, τηλεχειριζόμενα εργαλεία και ψηφιακή επεξεργασία εικόνας εφαρμόστηκαν για την τεκμηρίωση και την εξαγωγή από το εσωτερικό των αγαλμάτων των υπολειμμάτων των αργιλικών πυρήνων.

Η "μικροανασκαπτική" διαδικασία αποκάλυψε εσωτερικές μικροδομές απρόσμενης πολυπλοκότητας. Σε αντίθεση με τις κρατούσες απόψεις σήμερα, διαφαίνεται πως και τα δύο αγάλματα -κατά πάσα πιθανότητα- κατασκευάστηκαν με την άμεση "τετηγμένου κηρού" μέθοδο, χωρίς την διαμεσολάβηση των τεχνικών χύτευσης που απαιτούνται από την έμμεση "τετηγμένου κηρού" μέθοδο.

Τα ευρήματα λοιπόν που υπάρχουν σήμερα, μας δίνουν την ευκαιρία να αναθεωρήσουμε τις απόψεις περί σταδιακής και γραμμικής εξέλιξης των αρχαίων Ελλήνων μπρούντζινων αγαλμάτων, οι οποίες ήταν γενικά αποδεκτές έως τώρα.

Ο Γερμανός λόγιος και τεχνίτης Kurt Kluge μπορεί –πιθανόν- να μην είχε και τόσο άδικο.