

CT SCANS IN ART WORK APPRAISAL

by Dr Marc Ghysels

Since the late 1970s, CT scanners have probed patients' bodies to help identify the causes of their illnesses. Just as the technique of computed tomography imaging revolutionized the practice of medical diagnosis in its time, its contemporary use in the art world could ultimately change the way some works are appraised.

The quality and reliability of the images produced by a CT scanner – also called a computed axial tomography scanner or a CAT scan – literally « undress » the art work and reveal its internal structure.

The CT scanner, or « CT », as it is more briefly known, provides a more accurate measurement of the density of the component parts of the object under examination, thereby dissociating parts that are usually merged on a conventional X-ray film. It therefore has its place among the various scientific disciplines used to clarify the history of art works: manufacturing techniques, initial functions, later uses, preservation, etc.

In conventional radiology, the X-ray beam projects onto the film the accumulated shadows of the component parts of the object it goes through. Low-density areas are completely masked by the shadow of denser parts. CT avoids this drawback by enabling each part to be viewed separately. The principle is to record a series of « slices » or sections of the object. The images are recorded in digital format and special image processing software is used to construct sections on any spatial plane desired. The sections can be combined to give a global view of the object and the transparency of the component parts can be modified at will. These operations reveal valuable information about the object's background:

- manufacturing techniques, showing for example, whether pottery was modeled from a clay coil, turned on a wheel or stamped,
- natural damage, such as oxidation, erosion, or cracking,
- repairs: impregnation, infiltration, gluing of chips or fragments, etc.,
- restoration: a clear and accurate reconstruction of the damaged parts,
- even the tricks used in assembling the piece.

The technique of CT scanning, when combined with a pertinent interpretation of the images obtained, is a powerful diagnostic tool which can provide proof of the inner state of an art work. Although it can help establish the history of the piece, when used in conjunction with other techniques of observation and analysis, it is not a dating test.

Like all sophisticated equipment, the CT has its limits. It was designed principally to examine the human body so the three-dimensional objects scanned must not exceed a diameter of 50 cm or the weight of a man. Although a medical CT can handle most materials, an industrial CT should be used for metal items. CT scanning of antiquities is not recent: in 1979, the year when the Nobel Prize for Medicine was awarded to Allan M. Cormack and

A - Baule mask, Ivory Coast. Wood, 29 cm. The X-ray film and CT scan show no anomalies in this case, but provide an excellent example of the two imaging techniques before approaching more complex cases.

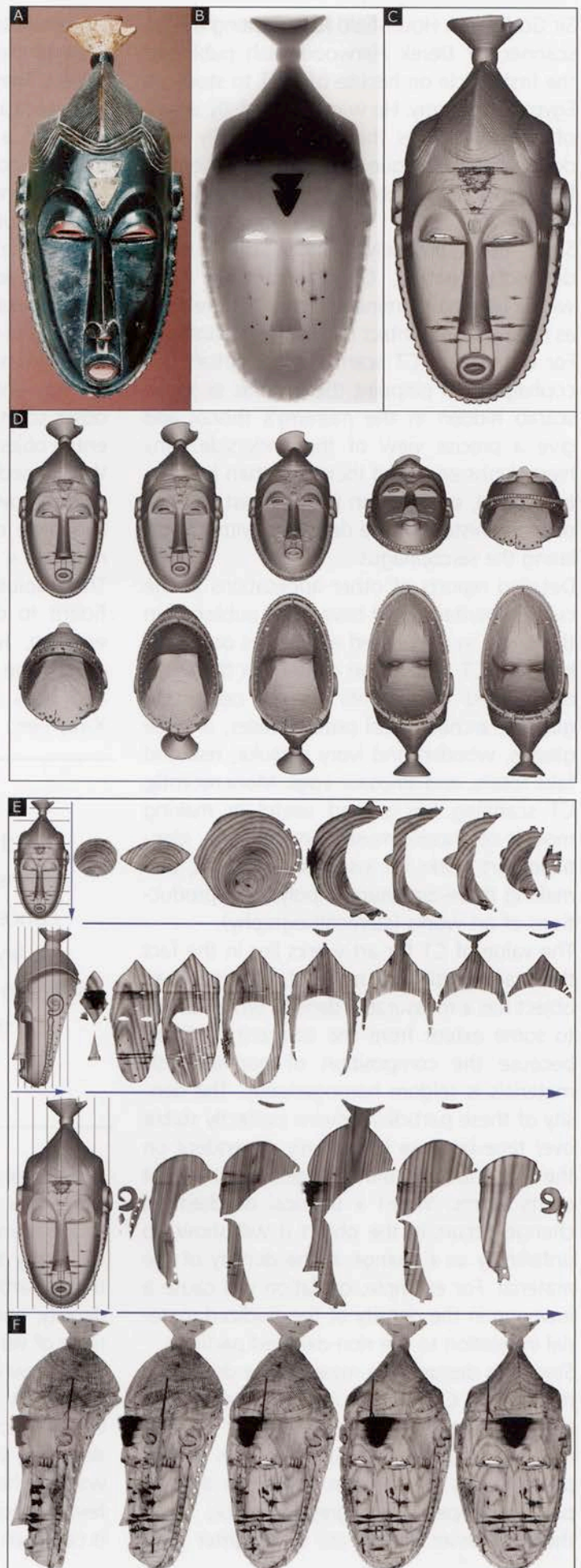
B - Conventional X-ray film. The little black dots on either side of the nose are nail tips. © KIK-IRPA Catherine Fondaire, Brussels

C - CT: opaque three-dimensional view (3D).

D - CT: opaque 3D views. The mask has been rotated on a horizontal axis, to obtain observations from different angles.

E - CT: thin sections taken on the three spatial planes. The growth rings in the wood are clearly visible, as are the nail tips and metal triangles on the forehead which have caused distortion in the images due to the diffraction of the X-rays on the crystalline structure of the metal.

F - CT: translucent 3D views taken while the mask was rotated around a vertical axis, bringing out the grain of the wood.



Sir Godfrey N. Hounsfield for inventing the CT scanner, Dr Derek Harwood-Nash published the first article on his use of a CT to study an Egyptian mummy. He was already fully aware of the advantages that this essentially non-destructive technique had to offer scientific fields such as Egyptology, Paleontology and Archeology.

Since then, precisely because of its non-destructive nature, CT scanning has been widely used to examine objects from the past, as it leaves them intact for future generations. For example, a CT scan of an Egyptian sarcophagus can pinpoint the ceramic or stone scarab hidden in the mummy's thorax and give a precise view of the underside. Any hieroglyphs engraved there can then be photographed, enabling an Egyptologist to decipher the history of the deceased without violating the sarcophagus.

Detailed reports of other applications in the cultural heritage field have been published in the press, in specialized magazines or on the Internet: CT scans have assisted in the study of stringed instruments (violins, cellos and guitars), archeological pottery vases, antique glasses, wooden and ivory netsuke, real and fake fossils, and dinosaur eggs. More recently, CT scanning has proved useful in making models of ancient musical instruments, identifying art works for insurance purposes, and making three-dimensional polymer reproductions of art works (stereolithography).

The value of CT for art works lies in the fact that each particle of material making up an object has a measurable density, which differs to some extent from the adjacent particles, because the composition of non-synthetic materials is seldom homogeneous. The density of these particles remains perfectly stable over time because it is mainly dependent on the concentration and average atomic weight of its atoms. When a physical or chemical change occurs in the object it will show up unfailingly as a change in the density of the material. For example, oxidation will cause a lowering in the density of the oxidized material in relation to the non-oxidized particles. Since it is designed to measure the density of matter, the CT is particularly appropriate for detecting any change in the state of a material. The result of the examination is usually presented as an image in which the densest particles appear dark grey or black, while those of lesser density are of a lighter grey.

Unfortunately, these images, displayed in a scale of greys, do not always speak for themselves! They must be interpreted, just as, in the medical field, a radiologist is needed to interpret a scan of the spinal column, for instance, to see whether or not the vertebrae are fractured. The quality of this interpretation obviously depends on several criteria such as the quality of the CT, its initial calibration, the adjustment of the parameters used for the examination, and the type of algorithm used to construct the images.

Apart from its non-destructive character, the CT has another substantial advantage over other scientific tests in that it examines the entire object rather than just a sample.

When used under optimal conditions, its resolution power, that is the minimal diameter of a particle of material for which the CT can measure a density value, is about 0.05 mm. This resolution power is therefore largely sufficient to detect, for instance, a crack in a wooden, ivory, pottery or stone sculpture, even if the crack is invisible to the naked eye and does not show up on a conventional X-ray film.

In the tribal art field, ritual stigmata, fetishes or magic charges are sometimes concealed inside the sculpture or under a layer of condensed organic matter, and non-invasive investigation may shed light on their nature and original function.

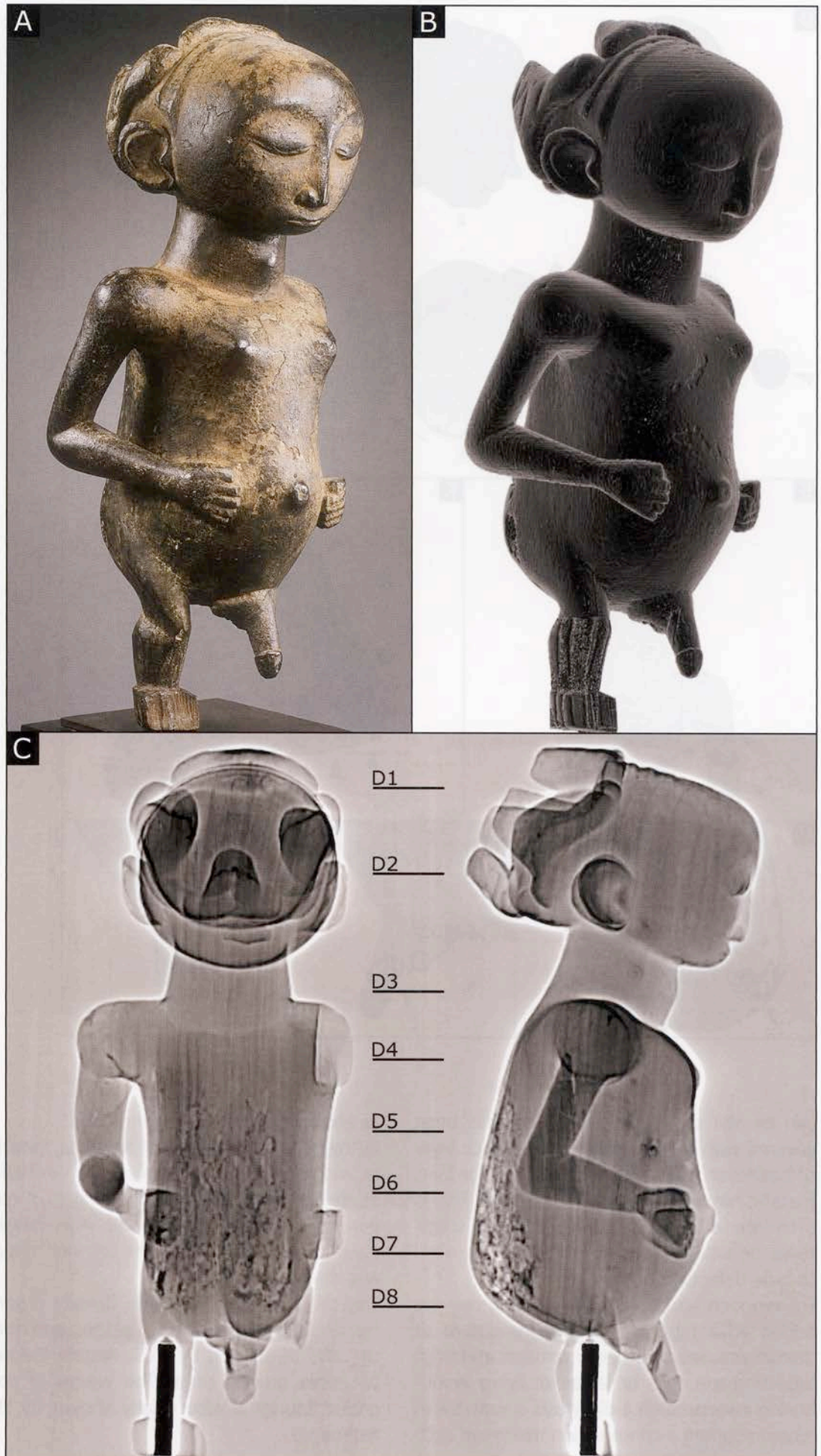
Sculptures in Wood and Similar Materials

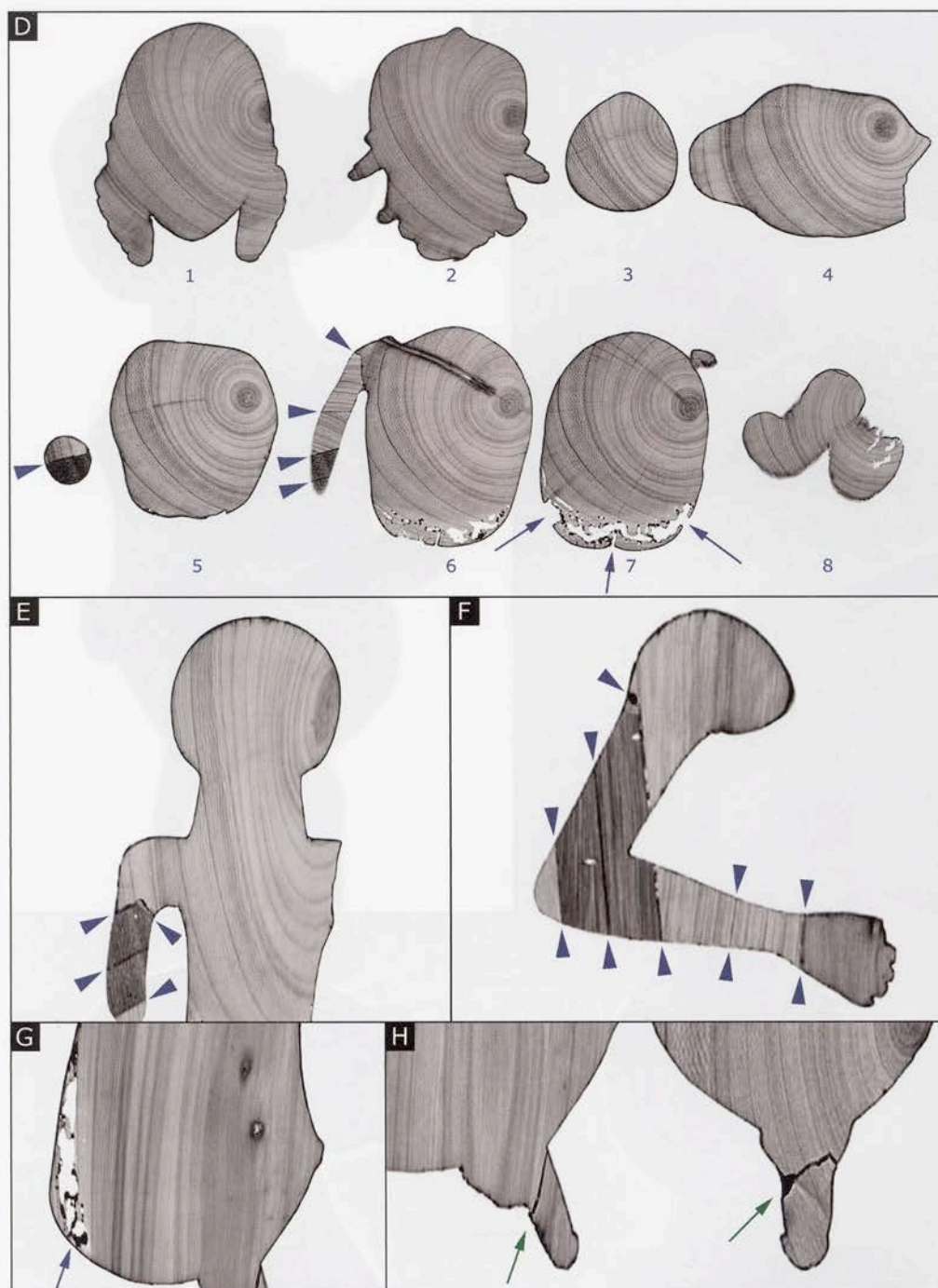
Wood is an ideal material for studying with a CT, firstly because it is an organic material that is partly dehydrated and therefore of low density, and secondly because it has growth rings of varying density, arranged in a regular pattern which is disturbed by the least tampering. A CT study of growth rings in a wooden sculpture can be a valuable aid for detecting the assembly of different pieces of wood, whether they are of the same or different species, as well as any gluing or breaks; it can even be used to identify the species. It

A - Hemba
ancestor statue,
D. R. C. Wood,
H.: 45 cm.
© Photo
Hughes Dubois,
Paris-Brussels.

B - CT: opaque
3D view.

C - Digital X-ray
films from front
and side.





D - CT: eight thin axial sections (see markers on Figure C). The sections through the arm show traces of glue (arrowheads) between separate blocks of different species of wood. Both the density of these blocks and the direction of the growth rings differ, proving that the piece has been restored. The sections through the lower back show termite damage (arrows).

E - CT: frontal section showing the join between the original statue and the restored piece.

F - CT: curved section which unrolls the arm from shoulder to wrist, showing the five blocks of wood simultaneously.

G - CT: lateral section of the torso, through the navel and the middle of the back, which is riddled with termite galleries.

H - CT: right-angle sections centered on repairs to the penis. The black line across the base is a layer of glue (arrows).

can be still done if the sculpture has been covered with opaque varnish, or a thick layer of patina or paint, even if the latter contains metallic pigments such as white lead. This is often the case for polychrome wood sculptures, on which paint and patina may be used to hide defects.

For wooden sculptures, CT scanning has the added advantage of showing the extent of damage caused by borer or termites and even detecting the eggs or larvae of living wood-boring insects. Such a diagnosis is valuable in recommending a conservation treatment such

as anoxia in a nitrogen environment.

In the tribal art field, ritual stigmata, fetishes or magic charges are sometimes concealed inside the sculpture or under a layer of condensed organic matter, and non-invasive investigation may shed light on their nature and original function.

Objects made of other low density organic matter such as plant fibers, leather, and horn, can also be studied by a CT, despite the lack of visible growth rings. The weave of concealed fabrics is also clearly shown by this technique.

Ivory and Bone Sculptures

Bone and ivory are the densest organic materials. Yet they can easily be CT scanned because the size of the piece is usually within acceptable bounds.

A CT scan of the Burmese ivory stupa, illustrated further on, reveals its mysterious contents: a standing statue of Buddha, finely carved by removing the debris through the openwork screen. The Buddha and the screen were carved from a single piece of ivory, as is proven by the unbroken root canal which runs through the entire sculpture. Indeed, the ivory comes from a hypertrophied incisor, necessarily innervated during the elephant's lifetime.

A close study of the Ekoi head, illustrated further on, shows a human skull under the layer of antelope skin. This suggests that it dates from a period prior to the British protectorate

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in Nigeria (late 19th century). Moreover, an anatomical study of the skull shows that teeth from a carnivorous mammal have been inserted in the upper jaw, giving the head a particularly frightening aspect as tradition demands. Lastly, an examination of the frontal sinuses reveals a magical charge, containing some metal, hidden under the bony wall of the sinuses and covered with clay and antelope hide. It is probably because the charge was completely invisible that it was not removed before the head reached the European market.

Terracotta Sculptures

Of all the materials examined, terracotta is the one for which the CT yields the most information on manufacturing techniques.

Since clay is initially soft, it keeps a trace of everything it has been in contact with before firing, whether it is the stand on which it was

modeled, the potter's fingers or tools. Because of its relatively adhesive nature, fresh clay sometimes incorporates dust or residue of varying density. These marks enable the radiologist to trace the sequence of steps in the creation of the work and to pinpoint any inconsistencies. A plausible explanation must be found for these inconsistencies, in a field where fakes are legion, as was confirmed by many of the experts recently interviewed by Thomas Fuller.

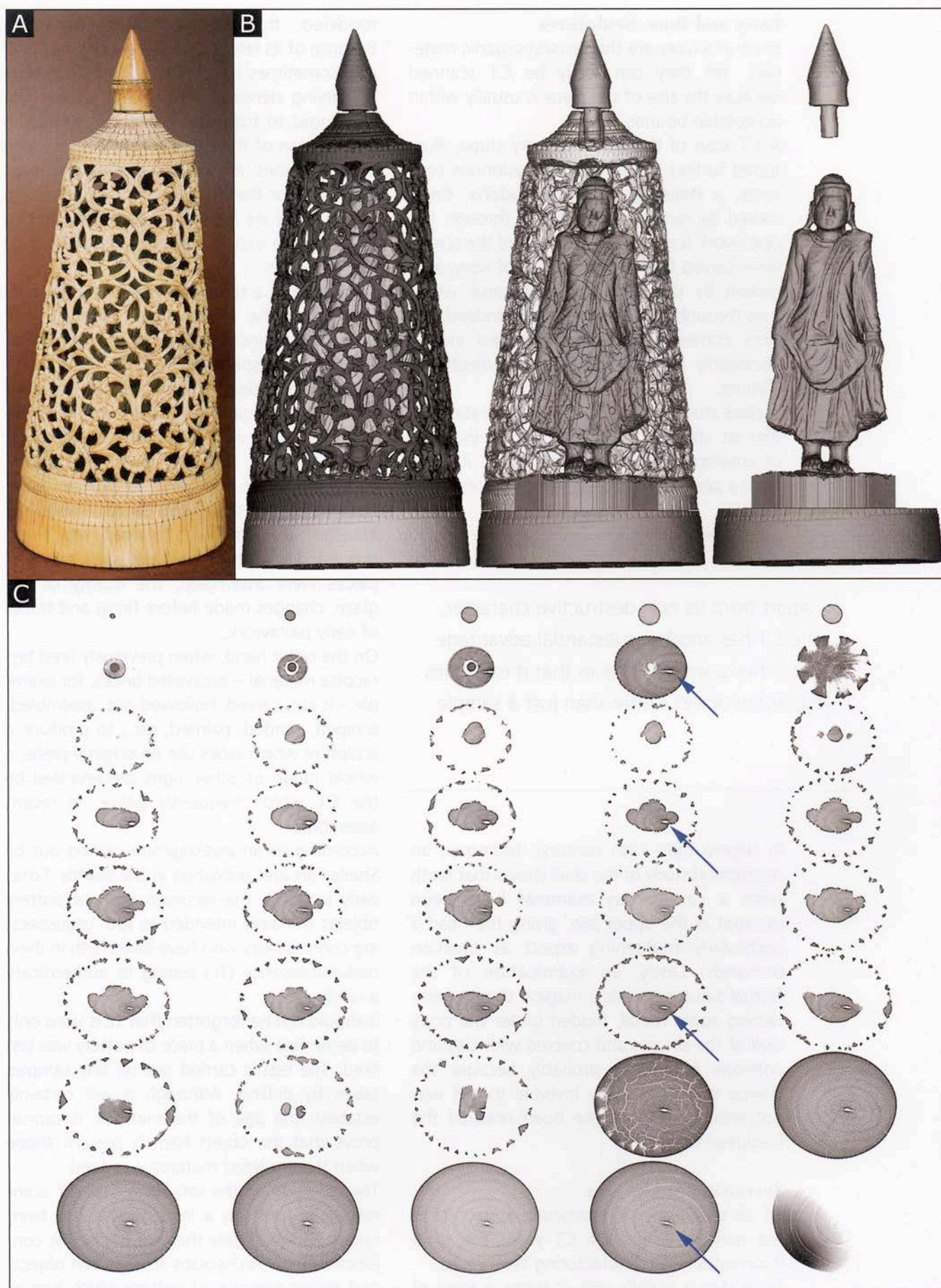
A CT scan of a terracotta object also permits a study of the granulometry of the metal flecks it contains as well as of its overall density. Generally speaking, both the granulometry and global density of the clay are constant in the same sculpture, as the artist theoretically shapes his work from the same stock of clay. Moreover, the CT gives information about the metal or organic supporting structures used by the artist during modeling, whether or not they survived the firing process. Lastly, it reveals the way stamped pieces were assembled, the quality of the glaze, changes made before firing and traces of early paintwork.

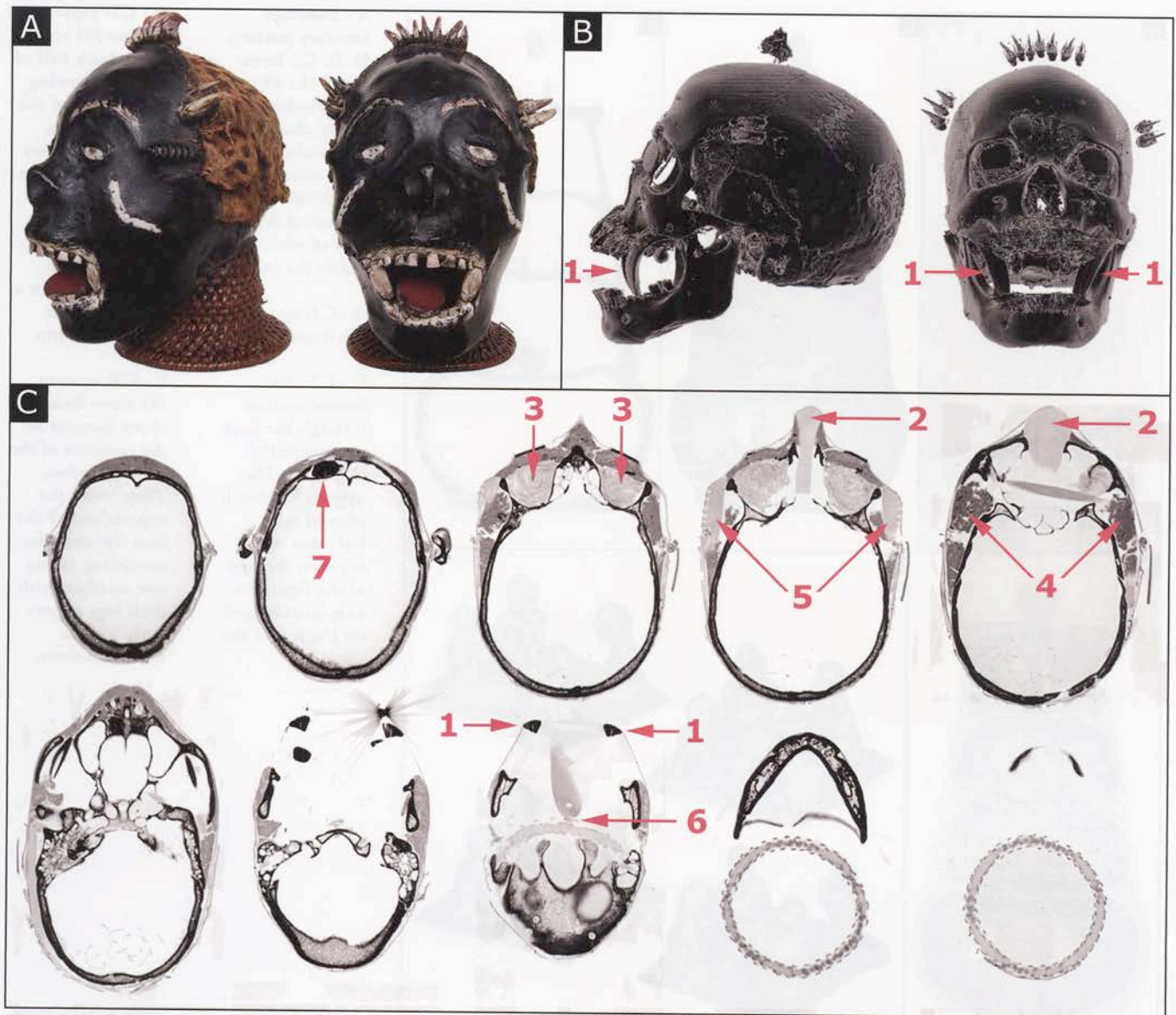
On the other hand, when previously fired terracotta material – excavated bricks, for example – is cut, carved, hollowed out, assembled, scraped, sanded, painted, etc., to produce a sculpture which looks like an original piece, a whole range of other signs are revealed by the CT which frequently prove its recent assembly.

According to an investigation carried out by Sheila Farr and published in the *Seattle Times* early in 2003, the reconstruction of pottery objects is mainly intended to fool unsuspecting connoisseurs who have blind faith in thermoluminescence (TL) testing to authenticate a work.

It should not be forgotten that TL is used only to determine when a piece of pottery was last fired. The test is carried out on tiny samples taken by drilling. Although it will certainly establish the age of the material, it cannot prove that the object had its present shape when the analyzed material was fired.

The question of the influence that CT scanning may have on a later TL test has been raised. To investigate this, we worked in conjunction with Archéolabs to scan ten objects and eleven samples of pottery which had all been age-tested by thermoluminescence. The TL tests were repeated under the same condi-





A - Stupa (chedi), Mandalay, Burma/Myanmar, 19th century. Ivory, H.: 18 cm.

B - CT: 3D views of the openwork stupa, cut (virtually) into 3 separate volumes, which enables the Buddha to be studied separately from the screen. By rendering the screen gradually translucent and finally transparent, we obtain a view of the Buddha that the artist never saw.

C - CT: a series of thin axial sections which show the precision of the work of hollowing out the ivory and the lack of restoration. They also show the root canal, in the form of an oval hole visible in the centre of each section (arrows), running from the tip to the base of the stupa, thereby proving that it was carved from a single piece of ivory.

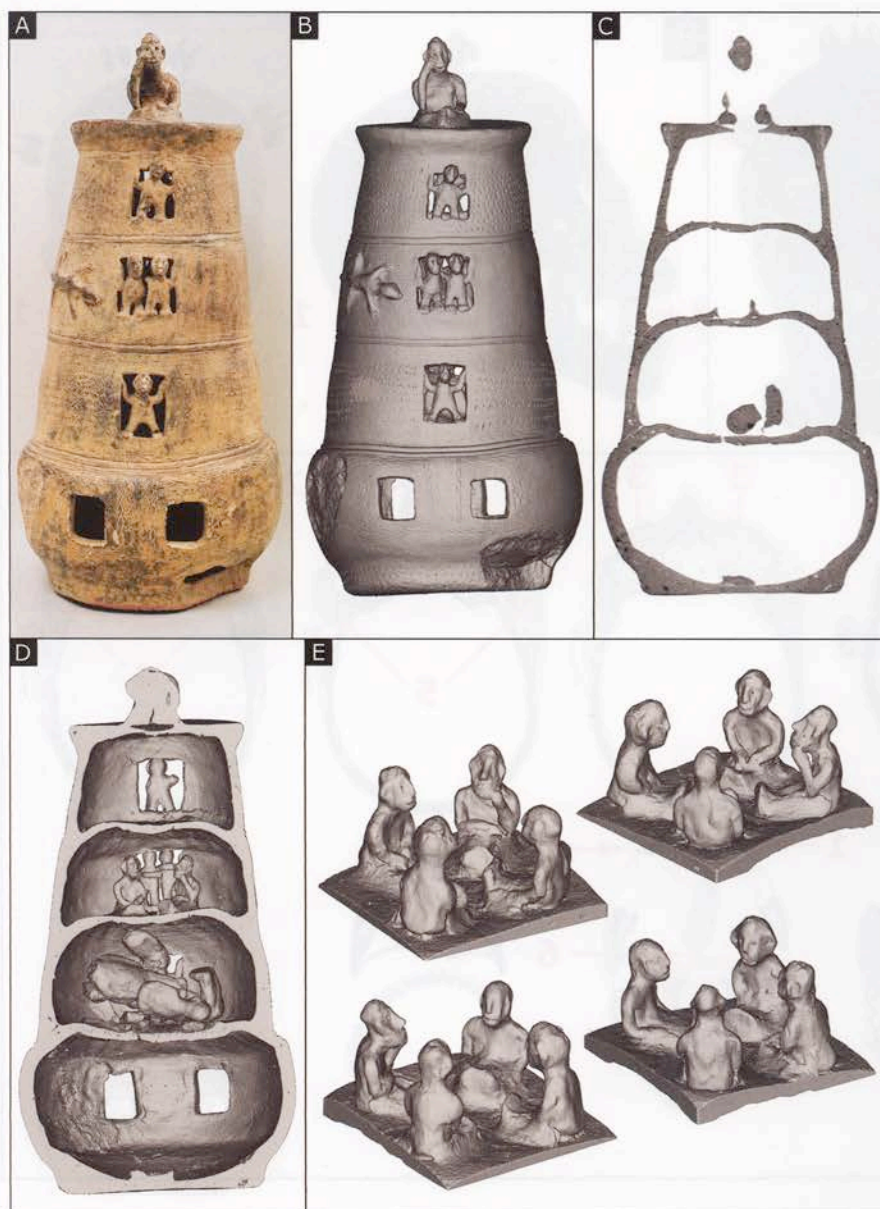
A - Ekoi mask, Nigeria, 19th century. H.: 26 cm.

B - CT: 3D views in which the structures of lower density than bone have been erased, revealing that the incisors of a carnivorous animal (1) have been inserted in the upper jaw of a human skull.

C - CT: a selection of thin axial sections which illustrate the original technique used to make the mask:

the nasal cartilage was replaced by a piece of carved wood (2) and covered with antelope skin; the eye sockets (3) were filled with cloth; the temporal fossae were filled with clay (4) and sticks (5), finely carved to give the impression of scarification, were inserted under the taut antelope skin. The articulated wooden tongue is attached to the top of the wickerwork by a fiber ligature (6). The

cavity of the right frontal sinus is filled with a magic charge (7), covered in turn by clay and antelope skin.



A - Bakongo funerary pottery, D. R. C., Terra-cotta, H.: 49 cm. The windows are partly obstructed by standing figures, which makes it difficult to give a detailed description of what is inside the pot.

B - CT: opaque 3D frontal view.

C - CT: thin frontal section through the four superimposed chambers. The upper chamber is pierced with a hole that opens between the legs of the figure sitting cross-legged on the top of the pot.

D - CT: exploded opaque 3D view of the back half of the pot, showing the content of the four chambers. From the bottom up, the first chamber contains a bed, the second, fragments of figures, the third, figures sitting in a ring, while the fourth is empty.

E - CT: opaque 3D views from above focused on the contents of the third chamber. They reveal the expressions of the four figures, who are sitting facing one another, with their legs apparently hidden under blankets.

A - Pre-Columbian jaguar vase, Peru. Polychrome terracotta, H.: 18 cm. Distinguishing feature: the eyes and teeth are made of lapis lazuli.

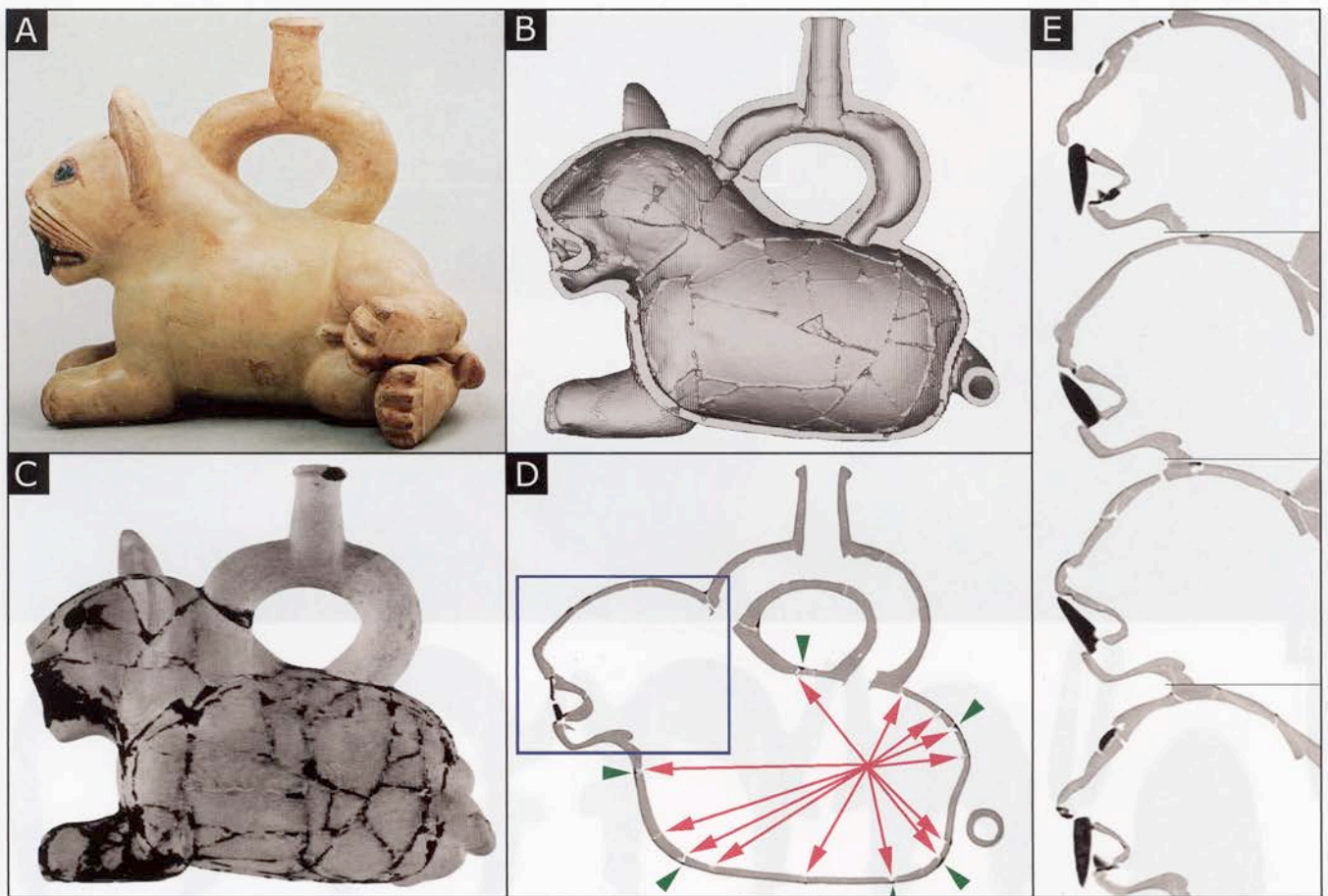
B - CT: opaque 3D view of the inner right side of the vase which shows a network of glue joints holding together more than a hundred fragments of terracotta.

C - CT: opaque 3D lateral view. The terracotta has been rendered translucent to reveal, in black against a grey ground, the use of

high-density resin to fill the joints on the outer surface of the restored vase. This means that the polychrome coating, except for the ears, has been applied recently.

D - CT: thin lateral section showing the low-density glue between the breaks (red arrows) and the high-density resin on the outer surface (green arrow-heads).

E - CT: thin lateral sections, centered on the head (box in figure D), showing clearly that the sculptor had not fashioned



sockets into which the four lapis lazuli teeth could be slotted after firing. On the contrary, holes were later drilled in the mouth to receive the teeth, held in place by low-density glue and high-density resin. Although the vase has been heavily restored, this trick has given it a more attractive appearance.

tions, after the CT scan, although Archéolabs was unaware of the X-ray exposure the specimens had received. The findings showed that the age determined by TL, both for the ten objects and the eleven samples, was the same as before they went through the CT.

This experiment therefore confirms unpublished experiments made by other laboratories indicating that CT scanning antique terracotta, under appropriate testing conditions, in no way modifies the TL results.

Stone Sculptures

No literature has yet described CT scanning of monolithic sculptures. The reason for this is probably to be found in the apparent incompatibility between the relatively low penetrating power of the X-rays used in medical CT (compared with industrial CT) and the high density of the stone.

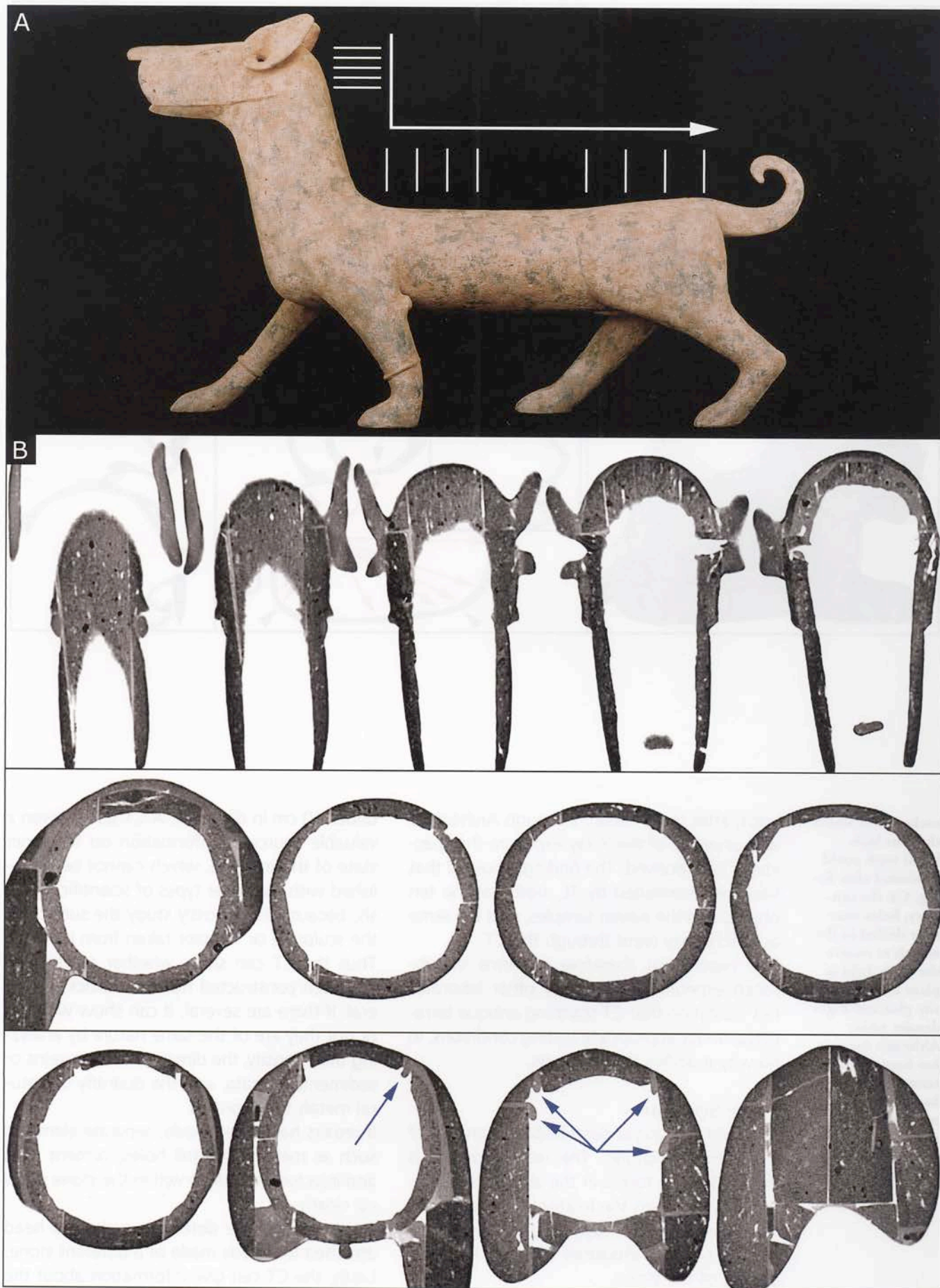
Yet experience shows that medical CT scanners are powerful enough for stone sculptures

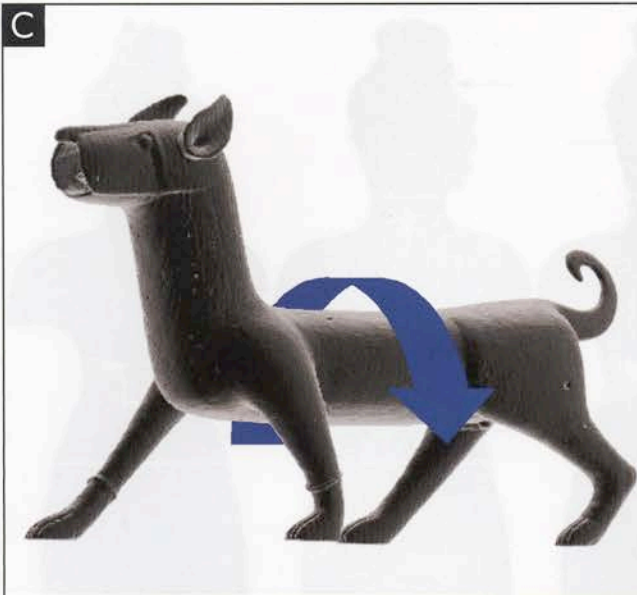
under 40 cm in diameter. A CT scan is even a valuable source of information on the inner state of the material, which cannot be established with the other types of scientific analysis, because they mostly study the surface of the sculpture or samples taken from it.

Thus the CT can show whether a sculpture has been constructed from one block or several. If there are several, it can show whether or not they are of the same nature by analyzing their density, the direction of their veins or sedimentary strata, and the quantity of natural metals they contain.

If repairs have been made, separate elements such as metal rods, drill holes, cement joins and injected resin deep within the stone show up clearly.

Fakes can also be detected, such as a head attached to a body made of a different stone. Lastly, the CT can give information about the outer crust and even find deep-lying causes for surface anomalies. Thus a crack running





A - Dog, China. Terracotta, H.: 58 cm. Thermoluminescence (TL) analysis gave an age of 2000 years ($\pm 20\%$) and an analysis of the chemical composition of the terracotta revealed no anomaly.

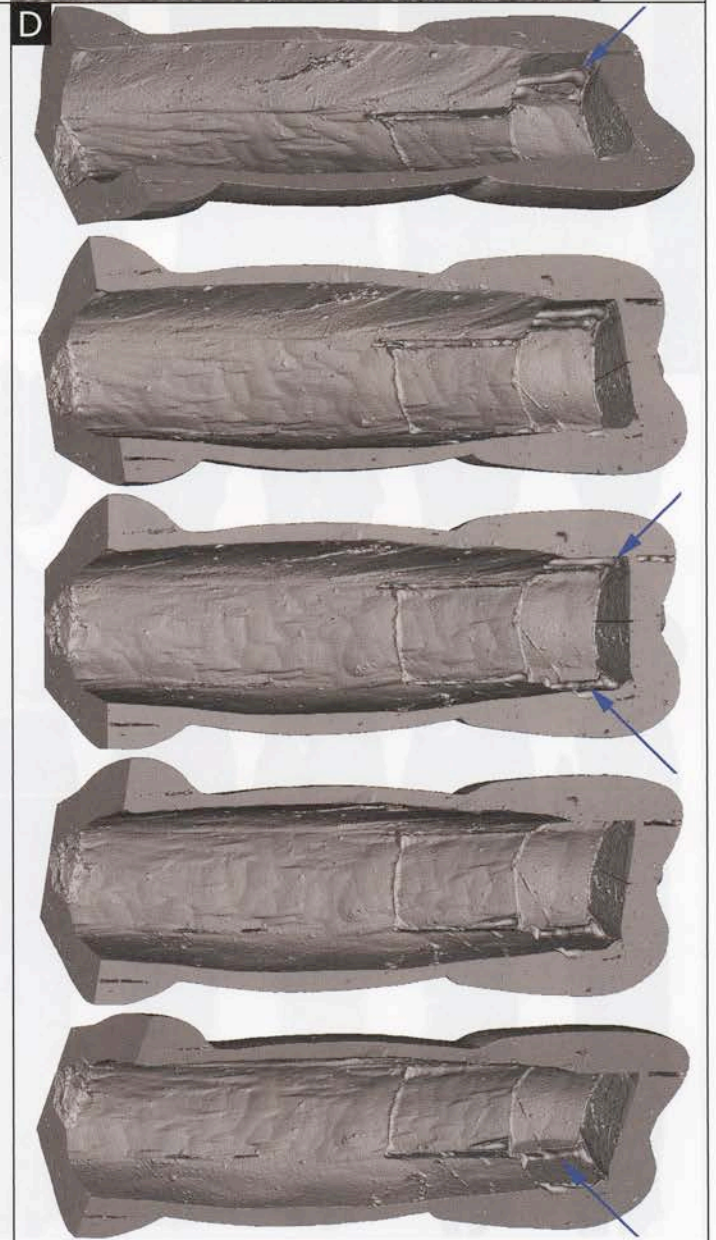
B - CT: thin axial sections through the head, the forequarters and hindquarters (markers shown in Figure A). They reveal that the main tubular structures are composed of terracotta slabs. The CT scan emphasizes the different density of the slabs, proving that the dog has been assembled. The bulging cement joints inside the statue, which are of lower density and therefore lighter, show up clearly (arrows). The technique of assembling terracotta slabs cut out

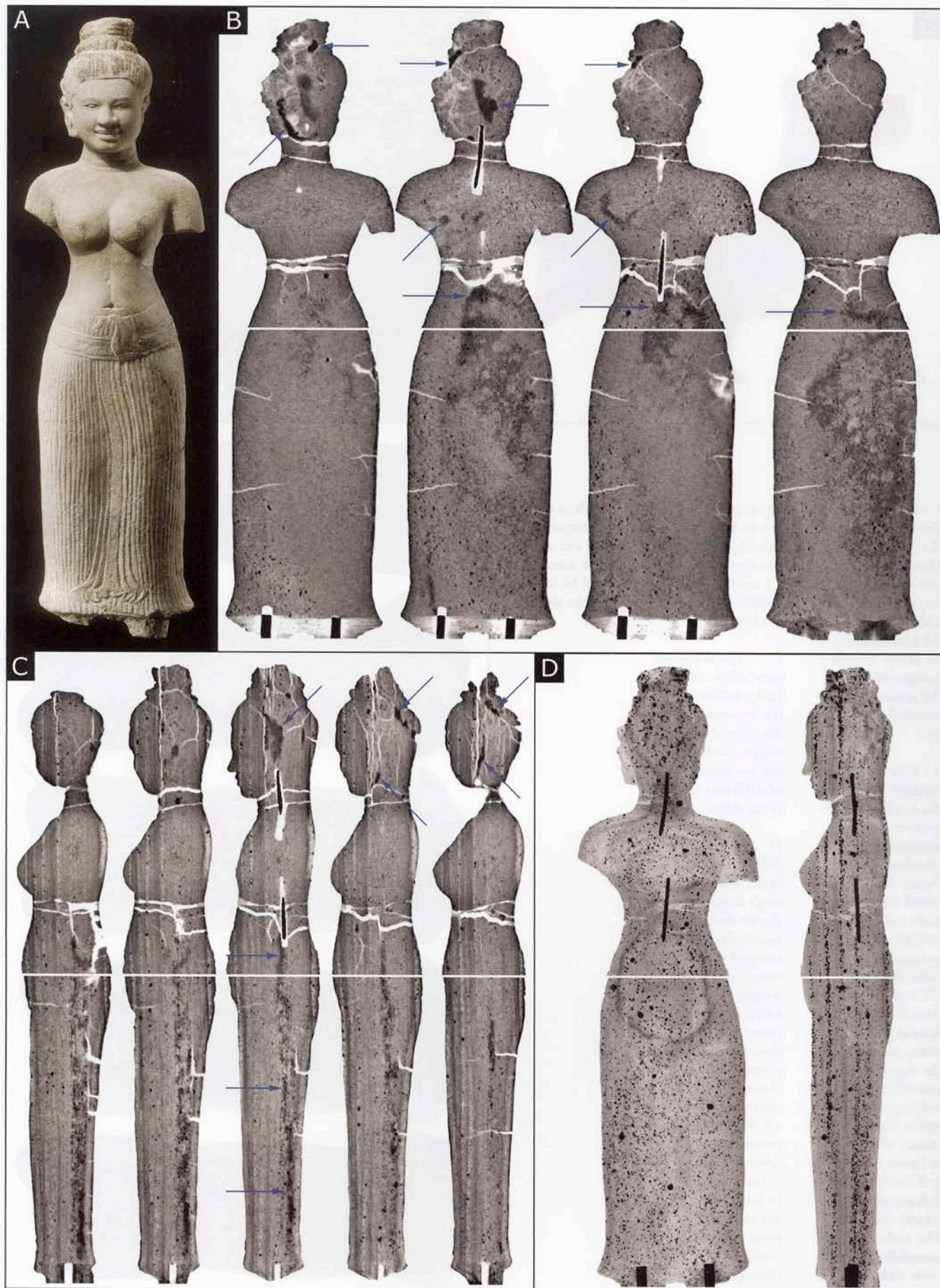
of excavation bricks and then carving them into a sculpture gives TL results compatible with an ancient piece.

C - CT: a flattened view of the dog's body, following the movement of the curved arrow, which confirms the juxtaposition of different terracotta slabs.

D - CT: inclined 3D views of the inner wall of the dog's body. It shows that the terracotta has been scraped out to ensure that the weight of the finished sculpture is comparable with that of an antique piece. There are also dribbles of cement (arrows) on the inner curves of a trapdoor cut in the animal's back. Indeed, although the inside of the head and the neck could be reached through the open

mouth, a temporary trapdoor had to be cut out so that a scraper could be inserted into the dog's belly.





A - Khmer goddess in Banteay Srei style, Cambodia, second half of the 10th century. Sandstone, H.: 63 cm.

© Photo Roger Asselberghs, Brussels

B - CT: four thin frontal sections. They reveal the repair of breaks at the neck and waist by means of two metal rods sealed with cement in central drill holes. The dark patches are due to resin (arrows) injected into the cracks in a friable rock to ensure better conservation. The horizontal white line represents the border between the CT scans of the upper and lower parts of the statue (idem for the following figures).

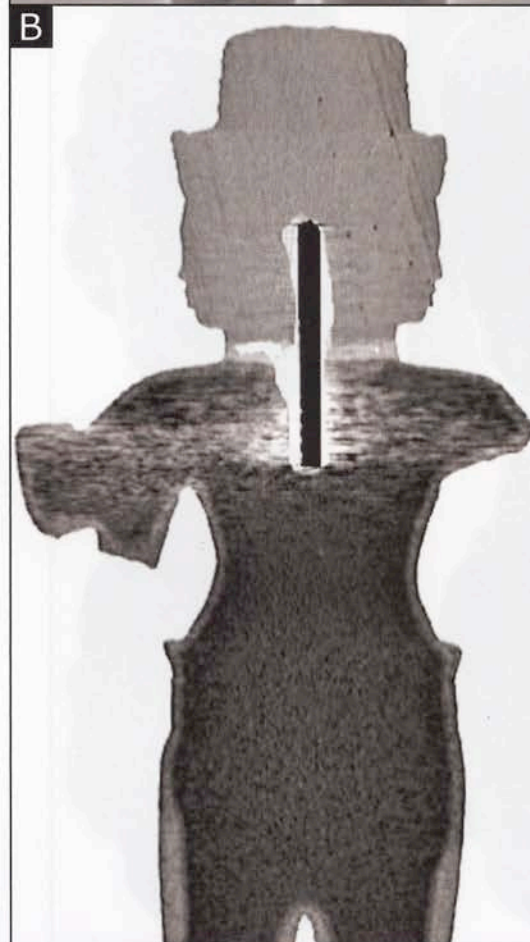
C - CT: five thin lateral sections, which confirm the sedimentary nature of this ferruginous sandstone, as the geological strata of varying density are oriented vertically. The black dots correspond to iron oxide nodules. Despite the breaks at the neck and waist, the continuity of the strata in the three fragments of sandstone glued together proves that the original statue was made from a single piece of stone. These sections also show the areas of injected resin (arrows) and the cracks in the rock which show up as irregular white lines in the head.

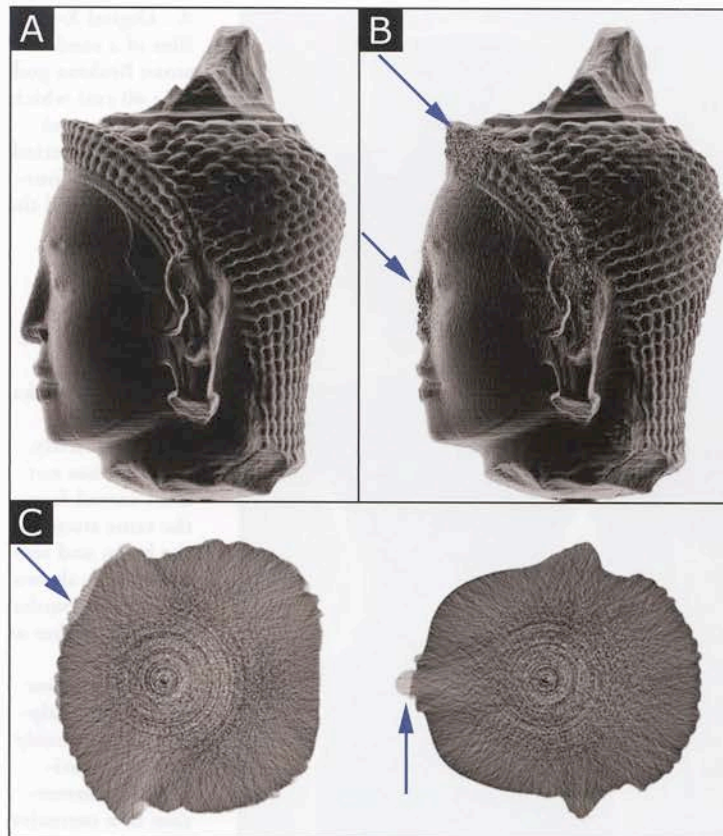
D - CT: frontal and lateral 3D views. The sandstone has been rendered translucent. In the frontal view, apart from the metal rods, the iron oxide nodules seem to be scattered at random. In the lateral view, the sedimentary nature of the rock and the monolithic character of the sculpture are confirmed because this time the nodules are aligned in the geological strata.



A - Digital X-ray film of a sandstone Brahma god (H.: 40 cm) which shows a central metal rod inserted between the four-faced head and the body.

B - CT: a thin frontal section which, unlike the X-ray film, exposes two tricks used in its construction: firstly, the head has not been carved from the same stone as the body, and secondly, as is shown by the pale border which is thicker at the hips and thighs, the lower part of the sculpture was probably artificially oxidized by immersion in a corrosive solution to give it the appearance of an antique object.

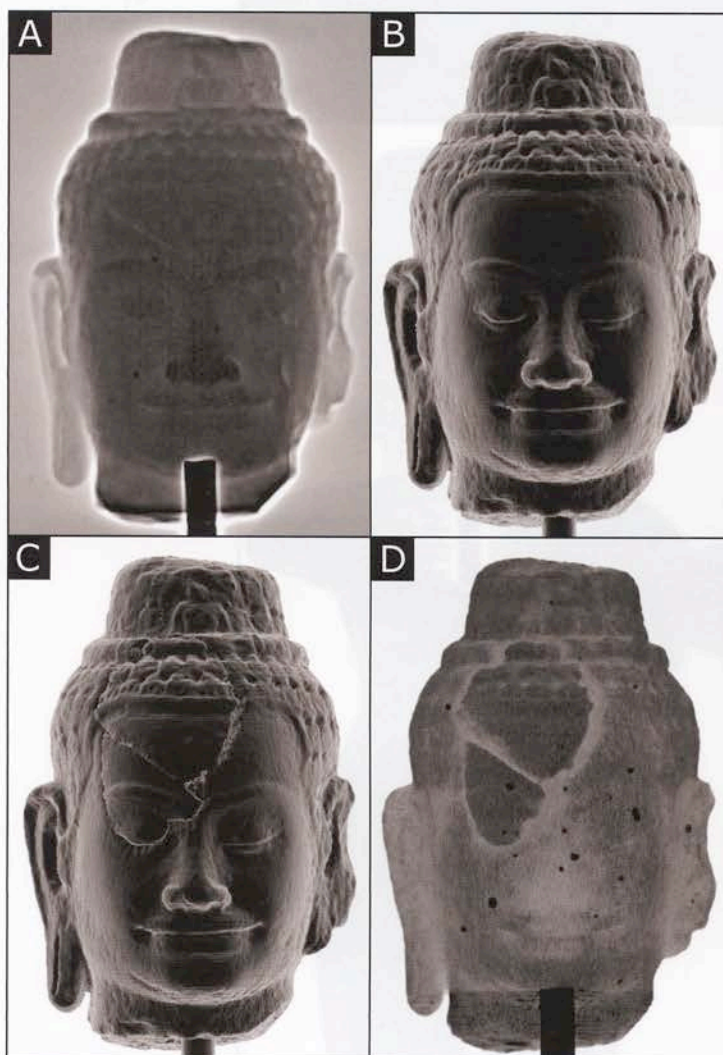




A - CT: 3D opaque view of the head of a Khmer Buddha, Cambodia, 13th century. Sandstone, H.: 45 cm.

B - CT: the same 3D view after adjustment of the display of visible densities to erase the restored part of the nose and diadem (arrows), thus simulating the appearance of the statue before restoration.

C - CT: two thin axial sections, one through the restored part of the diadem and the other through the nose, bringing out the difference in density between the sandstone and the material used for the restoration (arrows).



A - Digital X-ray film of another Khmer head, Cambodia, 13th century. Sandstone, H.: 19 cm. There seems to be an anomaly on the forehead.

B - CT: opaque 3D view.

C - CT: the same 3D view, after modification of the display of visible densities, reveals a fake repair of damage to the right eye and forehead.

D - CT: the same 3D view, once the sandstone has been rendered translucent, reveals that, in fact, those repairs have not been made with the original stone. The restoration has been done with fragments of a different type of stone. The black dots indicate iron oxide nodules.

around the statue does not necessarily mean that the stone has been broken and glued together again, but may be due to the natural erosion of an oxidized sedimentary stratum.

Conclusion

When a collector is interested in an art work, one of his primary concerns is to establish its authenticity. This is based on several subjective factors (experience, pedigree, expert opinion) to which are progressively added, depending on the importance of the work, criteria based on a number of scientific studies: stylistic analysis, thermoluminescence or carbon 14 dating, a dendrochronological study, spectroscopic or microscopic analysis, etc. Alongside these technical tests, which focus mainly on the visible parts of the work or on a few samples, CT scanning is an absolutely non-destructive test that has the advantage of describing the inner state of the object, examined this time as a whole. CT scanning – or computed tomography – can therefore provide valuable information about an art work's background by:

- revealing its contents,
- showing how it was made,
- clearing up doubts about its general condition,
- generalizing the findings of one-off analyses,
- revealing the nature and extent of restoration work,
- supporting a conservation report,
- detecting fakes.

CT scanning is thus a valuable aid for people with various interests in art, such as collectors, dealers, art experts and historians, museum curators, anthropologists, ethnologists, paleontologists, stringed instrument makers, and scientific archivists, but it can also be of use in a wider context, in restoration workshops, auction rooms, legal offices, insurance companies, and even forensic science laboratories.

Inner Vision

An exhibition of CT scans of art works, entitled « Inner Vision » will be held at the Belgian Antique Fair from 6 to 15 February 2004.

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