

The Unesco **Courier**

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SCIENCE IN THE SERVICE OF ART





TREASURES
OF
WORLD ART

160

Lebanon

Baal the Storm God

This bronze statuette (18.5 cm high) was unearthed during excavations at the ancient Mediterranean seaport of Tyre, renowned in ancient times for its far-flung commerce, its purple-dyeing industry, and its people's cultural and intellectual activities. The figure, dating from around the middle of the second millennium BC, depicts Baal, God of the Storm in the Canaanite pantheon. A wide diversity of religions, technologies and art styles met and flourished in Tyre, which attracted in turn Phoenicians, Assyrians, Greeks, Romans, Byzantines, Arabs, Crusaders and Ottomans. In December 1979 the United Nations recognized the archaeological site of Tyre as part of the "world heritage". Unesco is actively supporting the International Committee which is now, in close collaboration with Lebanon, working to safeguard the remains of this great city of Antiquity.

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Cover

Science is today proving to be a powerful instrument in the service of art, enabling specialists to analyse ancient creative techniques, unmask fakes, date archaeological finds, and even chart the currents of cultural transmission. Another notable example of the close association of art and modern technology is the conservation of cultural property, a new discipline which is being fostered and encouraged by Unesco. Photo shows a statue of a seated Ariadne from Myrina, now in the Louvre Museum, Paris. In background is equipment used in thermoluminescence, a technique which enabled the statue's date (first half of 2nd century BC) to be scientifically confirmed.



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Photo © Laboratoire de Recherche des Musées de France, Paris



Detail from statue of queen Nefertari is taken from a photogrammetric survey of the façade of the small temple of Abu Simbel.

Science in the service of art

by Magdeleine Hours

ART and Science are two terms which have been set apart by a long history of opposition. The former was identified with "creation", the product of human sensibility; the latter was considered to lead to the "discovery of the laws of nature".

Twentieth-century man has seen the growing impact of scientific and technological development gradually change the pattern of his daily life. In the world of the arts, among both students and artists alike, this phenomenon produced a defence mechanism and a feeling of apprehension—although the importance of the sciences as a source of inspiration for twentieth-century art is undeniable.

However, in the last thirty years, the world conscience has so often been aroused by the extent of the destruction of works of art and by the need to preserve the artistic and cultural heritage, that a new alliance has emerged between scientists and those whose task is to study and conserve the artistic heritage.

In Europe the close links between science and art were formed as early as the eighteenth century: in Paris through the activities of the Encyclopaedists Fontenelle, Charles, Diderot and others; then in London through the work of Humphry Davy. During the nineteenth century, research was more sporadic, but both the French chemist and microbiologist Louis Pasteur and the German physicist Wilhelm Roentgen applied their own scientific methods of analysis to the study of works of art. On 6 March 1865 Pasteur wrote: "There are circumstances in which I clearly see that the alliance between science and art is both possible and desirable, with the chemist and the physicist sitting at your elbow and informing you..." Thirty years later in 1895, Roentgen discovered X-rays, and, working in Munich, attempted to take the first X-ray photograph of a painting.

Half-way through this century the world's great museums created their own laboratories, and universities began to use their facilities and in some cases to enlist their research workers to discover the

origins of objects and their date, and to establish the technology with which they were made. Initially it was thanks to the properties of electro-magnetic waves that historians and curators found themselves equipped with techniques for studying works of art which vastly increased the power of the naked eye. Through ultra-violet rays it was possible to detect and photograph those places, hitherto invisible, where an artist had made changes in his work or returned to it after an interval. Infra-red rays and X-rays enable us to penetrate wood and canvas, go back in time, and rediscover unsuspected steps in the act of creation.

These methods have shed some light on the techniques used in creating a work of art, but they yield less information in this field than procedures which have been developed to analyse the materials used by artists and craftsmen of former times. Methods of physical and chemical analysis, which even a few years ago were seriously handicapped because they required a sample of the object to be removed, are now so highly developed that only a tiny sample (of the order of a few microgrammes) need be taken. In the case of the nondestructive technique of X-ray microfluorescence, no sample at all is needed. Analytical techniques are now so accurate that they not only reveal the secrets of materials but pinpoint their origin. In this way the mysterious invisible power of radiation is enabling us to chart the trade-routes of ancient metallurgy (see page 17).

While spectrometry and nuclear methods cast light on the unfolding story of objects and sites, dating procedures permit us to situate objects in time. A number of dating systems are currently in use, carbon-14 being increasingly successful since it now requires the destruction of less and less organic material. Thermoluminescence has made it possible to date ceramics, and dendrochronology the age of wood, while for questions of prehistory, the dating of bones and the system of racemizing amino-acids are yielding important information.

The dialogue which has now been established between the exact and the

human sciences in art and archaeology is akin to that which exists between pure science and medicine. It is to be hoped that the various international initiatives in this field will lead to a standardization of scientific methods which would have beneficial consequences for the exchange of information, the conservation of the artistic heritage and the campaign against forgers, as well as providing historians and archaeologists with new and more accurate criteria for dating objects and relating them to their environment.

In the exploration of the past there is room for two methods of analysis, two approaches which should lead to the same goal: the unity and the broadening of the concept of culture. For there is today a real danger of a split between scientific culture and the human sciences. If this hypothesis of a divided universe became widely accepted, it would mean the end of "Culture". And so we should do all we can to promote ever closer co-operation between the exact and the human sciences. Such an effort is bound to meet obstacles and it will call for efforts on every side, but it is the only way, in our opinion, towards a new humanism. ■

MAGDELEINE HOURS, of France, is head curator of her country's National Museums, and has directed the French Museums' Research Laboratory since 1946. Madame Hours was Commissaire Général of a major exhibition, "The Secrets of the Great Masterpieces—Science in the Service of Art", which was held in 1980 at the Grand Palais in Paris. The exhibition presented a series of outstanding works of art and also displayed the spectrum of methods of scientific examination, analysis and dating which are today being used in the study and conservation of works of art. Over 60 laboratories and almost a hundred research workers were involved in the work of the exhibition, for which a 330-page catalogue was prepared comprising a description of the works shown, scientific notes on the methods used in connexion with them, and an explanatory list of scientific techniques in current use. On the following pages we present specially chosen extracts from this catalogue. We express our thanks to the authors, the Réunion des Musées Nationaux, and Madame Hours herself, for authorizing us to publish them.

Lascaux

Saving a sanctuary of prehistoric art

THE prehistoric painted cave of Lascaux is situated near the little town of Montignac in the Périgord region of south-west France. The whole area is rich in prehistoric sites, but it is in the limestone cliffs which run beside the winding course of the Vézère river that the ancient rock shelters and caves are most abundant.

The Lascaux cave was discovered on 12 September 1940 by four children from Montignac while they were playing among the pines and chestnut trees on a steep slope above the river a kilometre or two outside the town.

The opening of the cave, barely 80 cm square, was half hidden beneath a layer of dead leaves. It plunged vertically into the hillside, ending in a pile of debris and rubble.

In the next few weeks, the undergrowth surrounding the entrance was cleared, and an enormous pit several dozen metres wide was dug in front of the hole. The excavations provided virtually direct access to the grotto which, because of the animals depicted on its ceiling and walls, was to become known as the Hall of Bulls.

Access to the cave had probably never been easy. After the last of the cave artists had left, rocks falling from the roof gradually piled up and sealed off the grotto for thousands of years. Air currents and water infiltrating through the debris caused little damage, except possibly during the period at the end of the Ice Age, when geologists believe that the calcite hollows known as *gours* were formed. The calcification of the surface of the cone of rubble, the formation of stalactites, and the infiltration of sand and clay washed down by glacial meltwater must have consolidated the barrier at the entrance. Studies would later show the importance of this barrier in preserving the frescoes on the walls of the cave. The roof of the limestone vault, between six and eight metres thick, was covered by a layer of impermeable clay. As a result, the paintings, including the "unicorn" situated less than ten metres from the original passageway, remained in a perfect state of preservation.

The listing of the site as a historic monument on 27 December 1940 enabled the French authorities to intervene on what was a piece of private property, and the owner was wisely persuaded to erect a wooden door at the entrance to the cave. However, this was mainly to prevent uncontrolled access by the public, not to preserve the grotto's "microclimate", the significance of which was still unsuspected.

Major operations at Lascaux did not begin until World War II was over, and it was not until 14 July 1948 that, with a stone staircase, a bronze door, an entrance hall and a paved pathway through the grotto which had been equipped with protective barriers and lighting, Lascaux was opened to the public.

The scenes portrayed in colour on the brilliant white calcite crust are a supremely beautiful and impressive display of Palaeolithic art, with their remarkably skilful use of the relief of the cave walls to depict animals caught in mid-movement, and their highly individual mixture of perspectives and profiles. The conservation of the frescoes called for scrupulous care and constant supervision.

In July 1955, the curator noticed that during peak visiting periods condensation coloured by pigments from the frescoes was dripping from the walls and ceiling. Scientific investigation established that this was caused by the carbon dioxide exhaled by the visitors.

In 1958, an air conditioning system was installed. The air in the cave was sucked through a filter to remove dust, decarbonated, and cooled to a constant temperature of 14°, while the humidity was kept close to dew point (95-98 per cent). This electronically regulated system was hooked up to a turnstile which recorded the number of visitors entering the cave.

It proved so successful in eliminating condensation and purifying the atmosphere that the owner was authorized to keep it running at

full power at the height of the summer tourist season, when on some days over a thousand visitors filed through the grotto.

In September 1960, the curator noticed a green spot, so tiny as to be scarcely perceptible, on the ceiling of the cave. Despite the application of a treatment recommended by the Pasteur Institute, tests the following year showed that more spots had appeared. And so, in March 1963, the Minister of Cultural Affairs, André Malraux, appointed a special committee of scientists from a wide range of disciplines to investigate the problem and propose solutions. It took over ten years of dedicated efforts and close collaboration between scientists from over a score of laboratories before the frescoes were finally saved.

The closure of the cave, on 20 April 1963, was no solution to the problem. The colonies of microscopic plant organisms which were the source of the danger continued to spread, and within a few months had increased from three to 720. Laboratory tests revealed the presence of many species of algae, as well as growths of ferns, mosses and fungi. Shock treatment was clearly required to eliminate these sources of pollution.

After making sure that the paintings would not be harmed, the scientists rid the cave of bacteria in the air by spraying the cave with



Photo © Institut de Photographie Scientifique et Médicale, Faculté de Médecine, Marseilles, France

antibiotics. The algae on the walls, which had by now spread out into 1,350 colonies, were gradually destroyed by spraying with solutions of formalin, in concentrations of 1:10 on the cave floor, 1:20 on the bare rock, and 1:200 on the paintings. After two years of treatment, the micro-organisms had been totally wiped out, but in order to prevent further contamination, visits were limited in number and duration, and the intensity of the lighting was considerably reduced. Regular analysis of the bacteria and the algae in the atmosphere and on the floor of the cave, and inspections of the walls and ceiling have made it possible to limit precautionary measures against new outbreaks to a minimum.

Scarcely had the biological attack been repulsed, however, than a new threat to the paintings materialized. The right-hand wall of a smaller cave which leads out of the Hall of Bulls and is decorated with stags, began to disappear under a fine crust of calcite crystals. The same thing began to happen, to a lesser extent, to the unicorn in the main grotto.



Photo © Archives Photographiques Paris/SPADEM

Left, the head of a huge, four-metre-long bull at Lascaux. The mysterious, three-pronged sign in front of the bull is thought to be a symbol of the male sex. The visitors who thronged Lascaux during the fifteen or so years that it was open to the public disturbed the delicate microclimate of the cave which had for thousands of years preserved intact this amazing gallery of prehistoric art. The cave became excessively humid and crystalline formations such as the calcite crystal (opposite page) began to appear. The only way to combat this "white sickness" was to re-create the original microclimate and this unfortunately involved closing the cave to the general public.

After examining the formation of the calcite crystals by means of microphotography, the scientists undertook a comprehensive examination of the entire structure and climate of the cave, using various other ultra-modern hydrological and geological techniques. The outline of the cave, and its relation to the surface of the hillside, were plotted in detail. The soil was analysed and, by means of a vertical photogrammetric survey carried out every 5 mm, contour lines were established for all the painted areas. The pigmentation of the paintings was examined in depth and content, and the temperature of the soil was studied by infra-red radiometry. At the same time, the temperature at various points on the cave walls was measured to within 1/100th of a degree, and the volume of the enclosed space was accurately determined (1,778 m³). Aerodynamic studies were carried out to detect the existence of microclimates through data provided by electronic equipment which recorded in minute detail the temperature, humidity, carbon dioxide content and barometric pressure.

The processing of all the data obtained over several years led the scientific committee to decide on a course of action designed to preserve as far as possible the "natural" climate of the cave, and more particularly to prevent changes in temperature, humidity and carbon dioxide content.

Air entering the cave is now chilled; excess carbon dioxide of natural origin is tapped at its source (the so-called "Wizard's Well") and pumped out of the cave. Partitioning of the cave into several compartments also helps to stabilize the temperature (at 13°), humidity (at 98 per cent), and carbon dioxide content (at 1 per cent). No more than five visitors, who must be bona fide scientists, may enter the cave on any one day. The cave is completely sealed on two days each week.

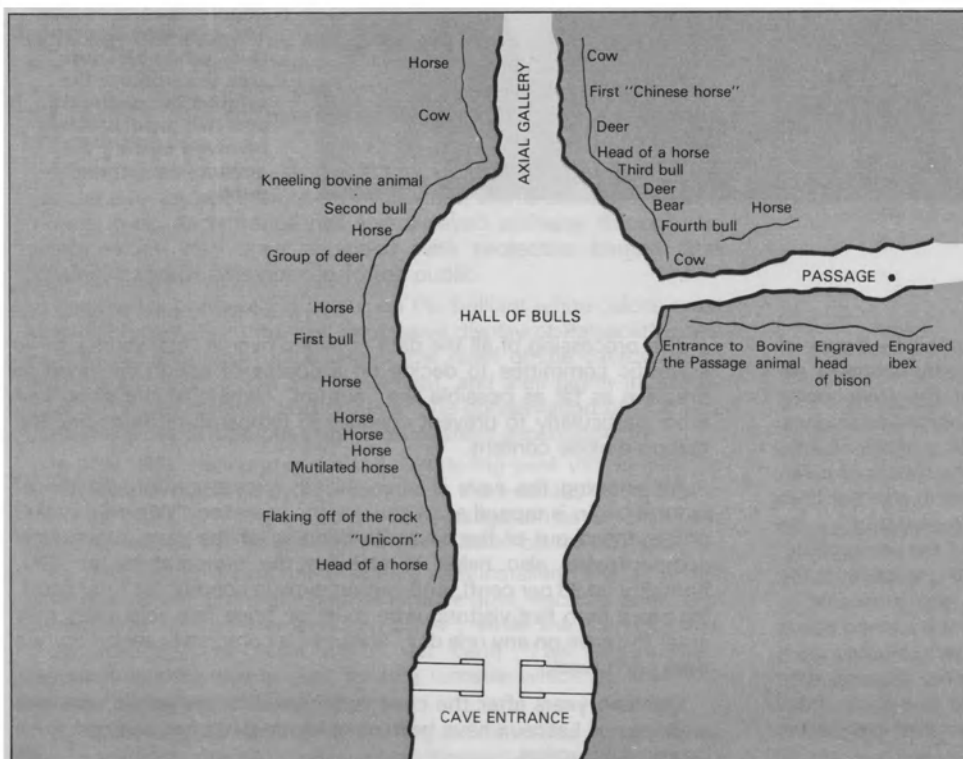
Eighteen years after the cave was closed to the public, the wall paintings of Lascaux have been saved from what had seemed to be certain destruction. ■



Photo © Archives Photographiques Paris/SPADEM.

Above, general view of the Hall of Bulls, and, opposite page, the reconstruction presented at a recent exhibition at the Galeries Nationales of the Grand Palais, Paris. Below, a plan of the Hall of Bulls.

The hall of bulls



THE Hall of Bulls forms the heart of the Lascaux cave complex. Its form and prolific painted decoration make it a masterpiece of prehistoric art. From 1963 to 1975, twenty-five French laboratories worked together with the historic monuments authority and prehistorians to save the site. Their efforts constitute an outstanding example of how science can serve art.

Although the grotto was saved, its condition remained fragile. A balance had to be carefully maintained between the temperature, humidity and carbon dioxide content. This balance was precarious, and visits now have to be strictly limited.

To enable a wide public to appreciate the beauty of Lascaux, a life-size facsimile of the Hall of Bulls was constructed for the *Science au Service de l'Art* exhibition held last year at the Grand Palais, Paris. The facsimile was produced with the collaboration of the French National Geographic Institute which had previously made a photogrammetric survey of the cave. This made it possible to reconstitute the contours of the Hall of Bulls to an accuracy of a quarter of a centimetre.

Plan © Skira publishers. From *Lascaux*, by G. Bataille

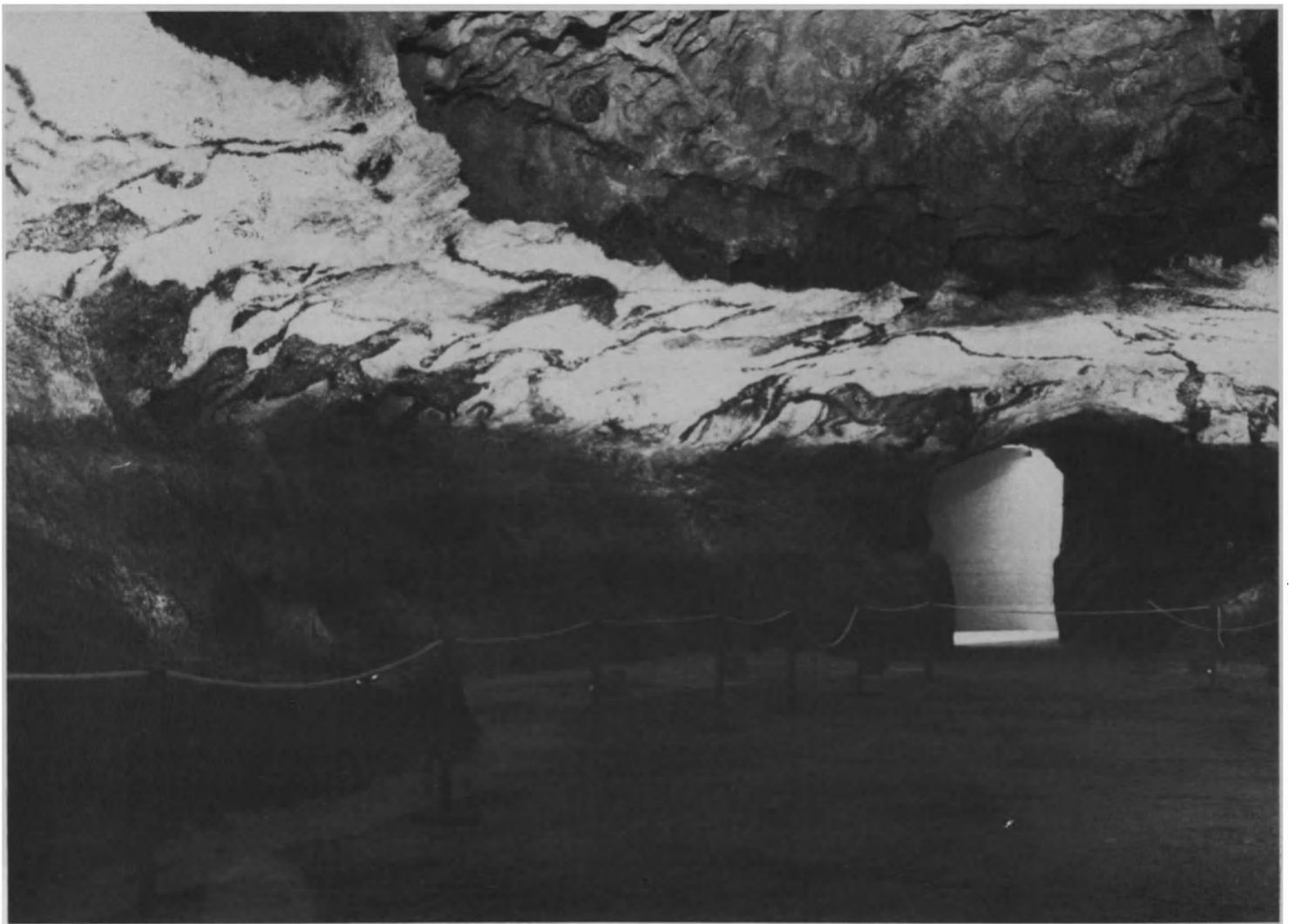


Photo J. Rochaix © Kodak-Pathé, Paris

Reconstituted masterpieces of early man

Using the data from the Institute's survey, a firm specializing in the construction of theatre sets began the difficult task of building an artificial cave. A team of specialists made twenty-six unit modules, each module comprising a frame with five vertical and seven horizontal sections in plywood at intervals of twenty-five centimetres.

The modules were then filled in with expanded polystyrene blocks to reconstitute the cave's macrorelief. Each block was then modelled to obtain the microrelief of the rocky sides of the cave. The polystyrene surface of the blocks was protected by a layer of latex and then a mixture of polyester resin and fibre glass was sprayed on, forming a resistant, fireproof layer about five millimetres thick. This plastic structure faithfully moulds the underlying cast, but without adhering to it.

This polyester structure held by the wooden frame was then removed from the polystyrene blocks and covered with an ochre and red coating mixed with sand, gravel and resin to give the overall impression of a limestone and calcite surface. The

areas which were to receive the reproductions of the frescoes were painted white. The twenty-six fireproof modules were then assembled by screwing them on to a raised platform which resembled the sloping floor of the cave.

So far so good! A replica of the Hall of Bulls now existed. But how could photographic enlargements of the wall paintings be placed on the uneven surface of the walls? To attempt a photographic reconstitution in relief of the Lascaux paintings seemed to be to defy the laws of photography and physics. A team of experts from the Kodak-Pathé research laboratories at Vincennes, near Paris, came up with the following ingenious solution to the problem.

The technique they evolved is new and consists of transferring by a decalcomania process a photographic image, previously stripped of its original paper base, on to any type of surface (wood, stone, metal, fabric, plastic, plaster, etc.). Transfer is achieved after a treatment which makes the stripped film elastic. The resulting gelatin layer is only a few microns thick and features the amaz-

ing property of not distorting laterally when stretched.

Strange as it may seem, when this layer of film containing the photographic information is transferred it faithfully moulds onto the boldest relief without changing the true density of the original colours. Added to the exact reproduction of colours and the details of the photographic technique is the realism of the underlying relief.

The photographic enlargements to be transferred to the walls were printed from twenty-five colour negatives provided by the French National Geographic Institute, keeping to the original dimensions of the Lascaux paintings. This required fine optical adjustments. Allowances also had to be made for any variances in density and colour from one image to another after processing.

One of the problems was to calculate and assemble the photographic prints as a flat mosaic. The prints had to fit together perfectly despite the inevitable distortions due to picture-taking angles which were aggravated by the overhanging concave sides of the cave.



1

The Hall of Bulls (continued)

2



3



Once printing had been completed on colour paper the actual transfer of the images to the cave face had to be prepared. The first operation consisted of calculating the colour photo assembly on a 1:6 model. Using this "puzzle" the original mosaic was cut up into about 200 quadrangular prints. Each print position was carefully identified on the final layout and a standard 60×80 cm size adopted to facilitate subsequent automation of operations.

The cut-out prints were pasted emulsion face down onto decalcomania paper—ordinary paper comprising a layer of water-soluble gelatin. The photographic image was then peeled off its original base in a special machine which dissolves the resin underlayer, isolating the photographic emulsion from its paper base. After drying, the layer which holds the picture is thus affixed to the decalcomania paper which is easily removed by wetting.

Each print was then pasted with an adhesive on to the area marked out for it. The paper was easily removed with wet sponges and brushes so that only the photographic image remained pasted to the artificial rock face and its myriad indentations.

Once the enlargements had been transferred, retouching had to be carried out to compensate for any imperfections during the decalcomania process, particularly at the junction of the modules. Lastly, the tints of the paintings had to be harmonized with the adjacent rocks.

The realism of this three-dimensional photographic reproduction of the Hall of Bulls was heightened by low-temperature air-conditioning and music evoking the sound of dripping water. ■



1) Assembling the plywood framework of the artificial cave.

2) A section of the artificial cave is eased into position.

3) The photographic prints of the wall paintings being assembled as a flat mosaic.

4) Assembling the lifesize enlargements.

5) and 6) The delicate process of transferring the photographs to the modules of the artificial cave walls.

Photos 1, 3, 4, 6. Pertuisot © Kodak-Pathé, Paris

Photo 2: J. Roचाix © Kodak-Pathé, Paris

Photo 5 Courtoix © Kodak-Pathé, Paris

Pages 9-11: photographic reconstitution of the wall paintings of the Hall of Bulls, Lascaux, produced by means of a process of photographic transfer in relief perfected by the Kodak-Pathé Research Centre for the Musées de France for the exhibition *La Vie Mystérieuse des Chefs-d'Oeuvre, la Science au Service de l'Art* (Secrets of the Great Masterpieces, Science in the Service of Art), organized by Madame Magdeleine Hours

The scientific investigation of painting

Painting is a form of creativity which has developed in a historical context. It is both the result of an act—putting brush to canvas—and the fruit of reflexion. No factor in this process should be overlooked, for each step is a contribution to the making and hence the understanding of masterpieces. Science can help us here in three fundamental ways: by shedding light on history, by revealing the technology used by artists and craftsmen, and by helping to ensure that their works are preserved for posterity.

The contribution of scientific investigation to art history is essential. This does not mean, however, that the new approach should be granted privileged status, to the detriment of connoisseurship and the traditional methods of art criticism (the opposition between scientist and humanist is a thing of the past), but simply that the properties of various kinds of radiation and the resources of modern physics are today enriching our perceptions of works of very different styles and periods.

Studies to establish the authenticity of paintings may call for the use of powerful apparatus such as the electron probe microanalyser and sophisticated techniques such as X-ray microfluorescence. These techniques are used to analyse the technology of the artist and his period, the materials he used and the way they have aged, as well as providing information about dating and artistic techniques. The proliferation of fakes and the skilfulness of forgers has put us on our guard, and in the search for truth the results being obtained from a whole range of methods and the information being subsequently stored in computers, are helping us even more than heavyweight equipment.

Methods for dating paintings are currently being studied all over the world, but they are still at the experimental stage and it is too early as yet to bank on their efficiency.

Finally, scientific analysis is playing a crucial role in the conservation of paintings. We can only conserve what we thoroughly know, and for the health of a work of art, like that of a human being, a laboratory diagnosis must precede treatment.

LABORATORY examination of Rembrandt's *Portrait of a Young Man* made it possible to rediscover the picture's basic structure and to compare its characteristics with those of other works by Rembrandt.

Two types of investigation, one global, the other detailed and highly specific, were conducted from the surface of the painting down to the deepest layers, in order to discover the techniques used by the artist. X-ray photography revealed the original sketch for the portrait and the overall construction of the composition, while detailed analysis of a small cross-section sample disclosed what materials the artist used, the layers in which they were applied and the technology involved.

The X-ray picture (below right) shows an earlier composition of a woman leaning over a cradle, which the artist had overpainted. It

Rembrandt's *Portrait of a Young Man*, dated 1658, Louvre Museum, Paris.



I. X-ray of a Rembrandt

also shows that the features of the young man's face have been broadly outlined in white lead with the large brush and firm strokes that were characteristic of Rembrandt's work at the end of his life.

Microscopic study of a small cross-section removed from the central part of the picture during restoration work confirmed the presence of more than one painting: eight different layers of paint could be observed, four belonging to the lower composition and four to the more recent one. The cross-section also showed that the underlying painting was completed, for traces of varnish are visible between the layer of white depicting the woman's veil and those depicting the young man's garment.

Analysis of the cross-section by an electron probe microanalyser made it possible to identify all the elements of which the paint is composed. With the aid of X-ray

An X-ray image of the painting reveals its underlying structure and the bold wide brush marks typical of Rembrandt's technique. The X-ray also brought to light the presence of an earlier painting of a woman seated beside a cradle.



II. True or false?

X-RAYS and analytic studies have also proved valuable in distinguishing fakes from authentic works. One painting which was authenticated in this way is the *Virgin of the Annunciation*, an early 15th-century work by the Italian artist Taddeo di Bartolo (photo top left, overleaf).

The X-ray photograph (photo top right, overleaf) shows a clear image of the composition and of the wood panel on which it is painted. The poplar panel is in a good state of preservation, despite a knot in the wood at the level of the Virgin's chest, which has been filled in with an opaque substance which does not let X-rays through. The panel consists of two separate lengths, joined together with a substance which is also opaque.

To make the support smoother and to level out knots in the wood, a canvas was incorporated into the gesso, the substance with which the surface was prepared for painting. A large piece of this canvas covers the whole of the lower part of the panel below the Virgin's eyes. The entire surface of the panel was prepared for painting, including those parts not covered with paint.

The X-ray image of the painting has a very low density, for the elements in the painting materials (earths, lapis lazuli and lacquers) have a low atomic mass. The details of the face, the hair and the veil covering it, as well as folds in the dress, have been painted in with a soft brush and very fluid paint rapidly applied. A faint tracery of fine parallel cracks, perpendicular to the grain of the wood, has had an effect on the material used.

An infra-red photograph also showed up the artist's elegant, flowing style. In places, the lines of the drawing itself can be seen, especially in the hair, the face, the hands, the folds of the garments and the strip of veil on the bosom. Some deterioration can be observed in the cloak.

Study of the painting materials shows that both the substances and the technology involved correspond to the suggested period and origin of the picture:

- The dressing applied to the panel consists of a gesso made up of calcium sulphate and size, applied in two layers and in which a canvas is included.
- The blue of the Virgin's cloak consists of coarse grains of lapis lazuli crystals. These are covered by a layer of Prussian blue, evidence of an early restoration of this part of the picture.
- The red of the robe is a mixture of madder lacquer and white lead.
- The coloured layer has been applied with an egg tempera.

All these features are consistent with the tradition of Italian painting at the beginning of the fifteenth century, as described

minutely by Cennino Cennini in his *Libro dell'Arte*. The rediscovery of this treatise, published in Italy in 1821 by Cavaliere Tramboni and translated into French in 1858 by the painter Victor Mottez, gave rise to a series of fake Italian primitives.

The *Virgin and Child* (photo bottom left), another painting on wood closely related in its general style to the Siennese school of the 15th century, has been shown to be a fake. Several formal details in this painting are hard to reconcile with its presumed period and origin.

In a case like this, scientific analysis using optical and microchemical methods can provide data which may confirm or refute results obtained by the historical and aesthetic criteria used by the art historian.

X-ray photography is undoubtedly one of the most useful methods of authenticating pictures. It reveals the structure of the work in depth, the sketch outlined by the artist and any anomalies that may exist, thereby making it possible to compare the painting with evidence obtained from fully authenticated works.

Clearly the X-ray photograph (bottom right) is very different from those of works of the 15th century. The X-ray image of the composition is practically invisible; there is a vague outline of draped folds on the shoulder and sleeves which can no longer be seen in the picture in its present state. The most interesting information provided by the X-ray is a large network of premature and artificially-induced cracks. These are of an entirely different nature from the tracery of fine cracks indicative of age which covers the surface of genuine primitives.

An infra-red-ray photograph (not shown here) restored the original form of the cloak's drapery, subsequently hidden by a layer of repainting. It was also possible to see damage to the face which had later been repaired. The photo showed that the picture had been extensively restored, and this was confirmed by study of the layers of painting materials.

Microchemical analysis revealed, in fact, that there were anachronisms in the composition of the paint. Cross-sections showed that the application of the paint of the pseudo-Siennese Virgin followed the traditional pattern with the colours being applied over a thick white gesso. However there were several anomalies:

- The white imprimatura overlaying the gesso on the entire surface of the picture is made up of a layer with a base of lithopone, a mixture of zinc sulphide and barium sulphate which only came into use after 1875.

- Lithopone is also present in the flesh-coloured layers. It should be noted, however, that these were traditionally made up of a layer of pink on a layer with a green earth base.

- The red paint has a cadmium base only used since the 19th century, and the yellow has an antimony base. Antimony was a pigment known in Antiquity but which did not come into use again until the 18th century.

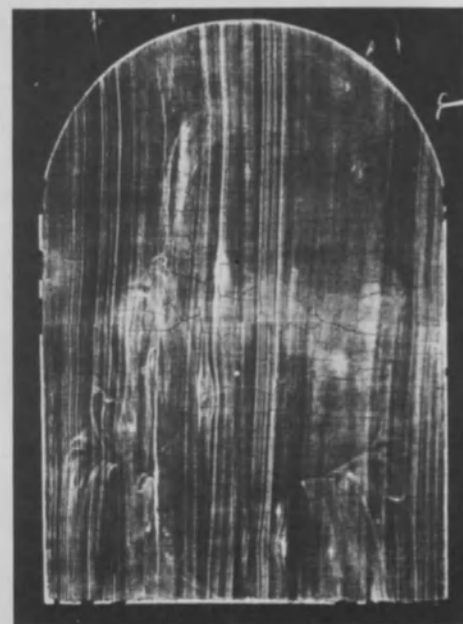
This evidence is sufficient to show that the picture could not have been painted earlier than the end of the 19th century.

In addition, cross-sections of the yellow of the Child's robe and of the red of the Virgin's robe revealed that the paint had

penetrated into the cracks of the imprimatura layer. This suggests that the latter was artificially dried before the layer of colour was applied.

Finally, the binding agent in the paint is a distemper—with or without the addition of some oil—which is chemically quite different from the egg tempera that one would expect in a painting of this period.

Thus, although the picture has undergone considerable restoration and although the painter was skilful enough to use a technique resembling that of primitive painters of the 15th century, the presence of recently adopted pigments uniformly and, therefore, mechanically ground, makes it extremely easy to identify as a fake. ■



Above, *Madonna*, by the Siennese painter Taddeo di Bartolo (1362-1422), now in the Petit Palais Museum, Avignon. The X-ray image reveals features characteristic of the Siennese school of the early 15th century.

Right, forged *Virgin and Child*, in the style of the Siena school. The X-ray image, with its lack of density, is quite different from those obtained from genuine paintings of the period. Chemical analysis revealed the presence of lithopone, a white pigment not in use before 1875.

Photos © Laboratoire de Recherche des Musées de France, Paris



Heat treatment unmask a sham Zapotec

IN the past few years stylistic studies of pre-Columbian objects in some of the world's major museums have brought to light some puzzling findings.

Thermoluminescence (see article page 21) and optical microscopy are two scientific techniques that have been used to solve the problems arising from these discoveries. The former revealed that some of the objects in question were of recent manufacture; the latter pinpointed where the objects had been made.

Photos above and right show two of forty terra-cotta statues belonging to the Musée de l'Homme in Paris and to the Royal Museums in Brussels which were studied in this way. They are both examples of the Zapotec style named for the Zapotec Indians of what is now southern Mexico. One is an authentic archaeological specimen; the other was made in relatively recent times.

Photo above shows the head of an old man which forms part of a large terra-cotta object symbolizing the cult of an elderly god. The god is depicted as an old man whose tall headdress surmounted by plumes was a brazier in which copal was burned in his honour.

Photo right shows an anthropomorphic urn representing the god of corn. The figure holds an ear of corn in each hand and the headdress is also decorated with ears of corn. These great anthropomorphic urns are characteristic of Zapotec civilization. They were often found in tombs and sometimes in temples.

Thermoluminescence makes it possible to distinguish between ceramics fired several centuries ago and those produced recently.

Measurements were made with a forty-milligramme sample of powder to determine its natural thermoluminescence, on the one hand, and, on the other, its artificial thermoluminescence after it had been irradiated in a laboratory.

The results obtained enabled specialists to calculate the amount of radiation deposited in the ceramic material since it had been fired: the old man's head had absorbed about 300 rads, a dose commensurate with an "archaeological object"; whereas the dose absorbed by the corn god was no more than 17 rads. It was therefore possible to conclude that the corn god was made recently, and even to date its manufacture to the beginning of the 20th century.

Examination of thin strips from ancient and modern Zapotec objects through a polarizing microscope revealed the following facts: several different clays had been used, but all contained, in varying proportions, a type of mineral found in a zone of the Oaxaca valley where the Zapotec civilization developed, and in particular at Monte Alban, the main site of this civilization. It can thus be assumed that both ancient and recent objects were produced in the same area.

Microscopic examination has also revealed that a number of modern objects, mainly large anthropomorphic urns, were probably produced in the same workshop. The ceramic pastes used in these objects are remarkably uniform and contain the same minerals, of identical size and in equivalent proportions, set in a base of yellowish, clayey paste.



X-ray microfluorescence and a Merovingian treasure

X-RAY microfluorescence is a spectrometric technique which can be used to analyse the constituent elements of any material. The spectrometer consists of a source of X-rays which "excites" the material to be analysed, a detector which measures the radiation emitted, and two analysers which divide the radiation into rays.

This apparatus is particularly well adapted to the needs of museological research. Its results rank between those produced by the electron probe microanalyser and those yielded by classic X-ray fluorescence spectrometers.

X-ray microfluorescence makes it possible to analyse, directly and without causing the least damage, all types of objects and archaeological materials, whether they are conductors (metals) or nonconductors (ceramics, glass and organic compounds), and whatever their shape or size. It can thus be used both with large-scale works of art (paintings or archaeological specimens), or with tiny samples of powder, glaze, solder, encrustations, corrosion, patina or painting materials.

Using this technique, direct analysis can be made of tiny areas of an object, ranging from a tenth of a millimetre to a dozen millimetres in diameter. If specially adapted,

it can be used to analyse samples only a few dozen microns in diameter. In this case, the sample must be preserved, for since the sensitivity and precision of X-ray microfluorescence are constantly improving, it is useful to be able to complete preliminary analyses later on.

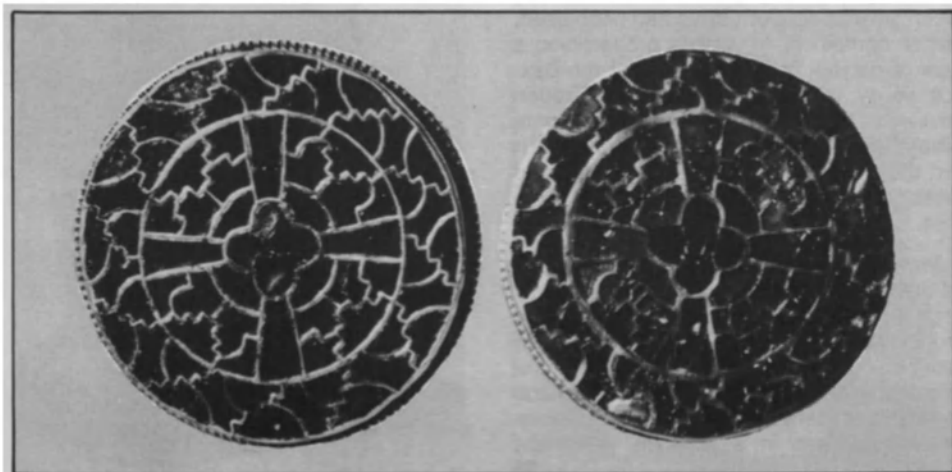
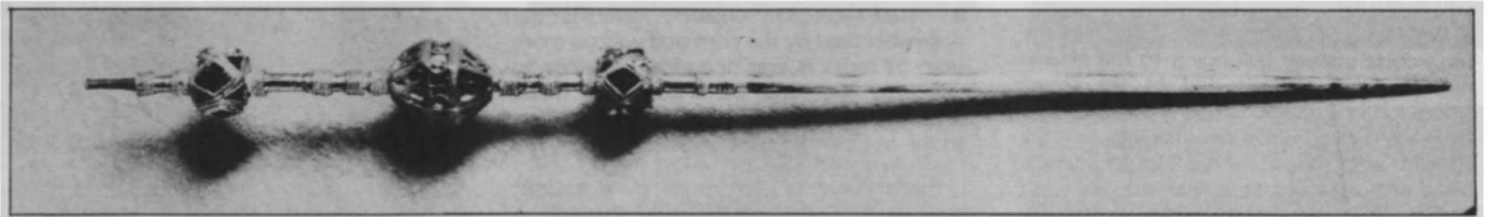
This non-destructive technique, recently developed by the French Museums' Research Laboratory, proved its worth in analysing the treasure of Queen Aregunda, wife of the Merovingian King Chlotar I (c. 497-561 AD), whose tomb was discovered at Saint-Denis in 1959 by Michel Fleury. This is the only Merovingian royal tomb which has ever been identified, except for that of Childeric I, discovered at Tournai in 1654. Queen Aregunda's tomb contained a rich store of precious objects.

A painstaking laboratory study was made of the treasure, which consists of a pair of pins, ear-rings, a long pin, two round fibula, a signet ring, ornaments for a belt, garters and shoes, and gold sleeve bands.

The state of the objects was such that it was impossible to take samples, and analysis of the gold or silver alloys of which they were made was carried out directly on the surface using X-ray microfluorescence. The analysis was effected at several points on each of the jewels in order to obtain

quantitative results, taking into account possible changes in the surface composition due to deterioration of the gilding and niello-work.

The results showed that each pair of objects was made of a different alloy, whereas the objects in each pair were made of the same alloy. Examination through a binocular magnifying glass also showed that the workmanship of one object in each pair was highly skilful, while the other revealed an inferior level of craftsmanship. It could be deduced from this that each pair of objects was from the same workshop (since the composition of the alloy was the same) but that one item in each pair had been made by the master craftsman and the other by an artisan. ■



Gold and silver pin encrusted with garnets. It was buried near the Queen's breast.

These two circular gold clasps encrusted with garnets fastened Queen Aregunda's silk tunic at the neck and waist.

Photos © Gilbert Mangin, Nancy, France.

Ancient metallurgy

The computer is turning up a mine of information

METALLURGY is a field in which, more than any other, close cooperation has developed between specialists in the exact and social sciences, who have built on the multidisciplinary foundations laid by the remarkable work of the metallurgist Cyril Smith at the Massachusetts Institute of Technology.

Extractive and chemical metallurgy, which is linked to the nature and origin of mineral ores, is one of the new lines of archaeological research that have developed over the last fifteen years thanks to the rapid evolution of spectrometric, atomic and nuclear techniques.

Ores of different geographic origins have a different chemical composition characterized either by the proportion or by the nature of the impurities which reflect the geology of the various rock formations. Archaeological research is concerned either with metallogeny, that is the processes through which ore is transformed into metal, or with the analysis of their trace elements and the magnitude of the lead isotopes. The purpose of this research is to discover indicators which then make it possible to determine the origin of archaeological objects.

Such multi-disciplinary research, in which analysts, archaeologists and geologists cooperate, deals with archaeological prospection of ancient copper, silver, gold, tin, lead and antimony mines. It is being carried out in many parts of the world, notably by in-

stitutes in the United States, Europe, the Soviet Union and Japan.

The metallurgy of processing and manufacture, which investigates the actual making of objects, is a more traditional line of research. X-ray photography can reveal assembly and smelting techniques, while investigation of thermal, mechanical and chemical processing, which modify the crystalline structure, requires elementary analysis of the metal, or microscopic examination of a metallographic section, along with dilatometric or thermal analysis. [Dilatometry is the measurement of changes of volume caused by thermal or chemical effects.]

Examination through a microscope of the metallographic structure discloses the technological past recorded by the metal.

This method, which has been used in metallurgy for over two centuries, makes it possible, among other things, to explain the role of carbon in the crystallization of the steel in damascene swords, which are decorated with peculiar markings produced during manufacture.

Physical metallurgy establishes relations between the physical properties of a metal obtained by mechanical, thermal or chemical effects on the crystalline structure. Very delicate technology—such as the electron microscope, electron-, neutron- and X-ray diffraction, the electron probe microanalyser or the ionic microprobe—is used to carry out these physical measurements.

With such ultra-modern equipment researchers can now understand the transformation processes of metal; it is possible to identify an effect of corrosion and discover its origin. Research on deterioration in metals, and in particular in ancient alloys, has increased our understanding of slow corrosion processes and



The "vase à la cachette" discovered on the citadel of Susa, Iran, in 1908. Beside it are the copper and alabaster objects it contained. The vase, 51 cm high and 20 cm in diameter, dates from approximately 2400 BC.

contributed to the conservation of metal objects. Thus the practical experience acquired by artisans in Antiquity and the natural ageing of metals are a source of scientific information which applies both to art works and to the most up-to-date industrial activities.

The technical research applied to art both for obtaining data and processing them is helping the exact sciences to interpret the history of metallurgy itself, together with its techniques. Thus, for example, extensive research carried out on finds such as the "vase à la cachette" ("the treasure-trove jar") has enabled specialists to draw up a map of the ancient trade routes for copper and tin.

The "vase à la cachette" is in fact the treasure contained in two large jars, one undecorated, the other painted, together with its lid, which were discovered on the site of the Susa citadel in 1908 by the mission led by the French archaeologist Jacques de Morgan. The treasure includes crude metal—the residue from five crucibles, weapons, and tools for making copper vessels similar to those found in the "royal tombs" of Ur—as well as alabaster jars and cylindrical seals. The latter which are either of local style or imported from Mesopotamia, confirm not only the date as being approximately that of the first Ur dynasty (between 2500 and 2350 BC), but the links which united Susa, one of the main cities of Elam (the plain of present-day Khuzistan in south-west Iran) and the land of Sumer (see map).

Susa, a city with a culture related to those of Mesopotamia and the Iranian plateau, was in fact the meeting point of the routes crossing the plateau, along which were dispatched the raw materials and finished products necessary to the powerful States of the alluvial plains.

Highly advanced copper metallurgy is known to have existed in Elam as early as the beginning of the fourth millennium. It spread to Mesopotamia right at the end of this period and especially during the third millennium. Yet both these regions are without any natural mineral resources. The raw materials necessary to the artisans of the Mesopotamian cities could have come from a number of areas, such as Anatolia, the Iranian plateau, where metallurgy had been developed as early as the fifth millennium, or the mountains of Oman, to mention only the nearest.

How can we establish what really were their sources of supply?

The use of physical and chemical parameters as a means of identifying the mines and the manufactured objects that originated from these mines has made it possible to establish the relationship between mineral resources and metal objects. And, by assigning to each group of archaeological objects its original ore, it has become possible in turn to determine precisely where the various cities obtained their copper.

One of the techniques used to analyse the composition of microsamples of native coppers and ores collected during prospection in Iran, Oman and Afghanistan, as well as the composition of finished objects from Susa, such as the "vase à la cachette", is spark source mass spectrometry. This technique has made it possible to conduct simultaneous quantitative analysis of more than 30 different chemical elements in each sample.

Computer processing of the data thus obtained has enabled us to reconstitute the chemical transformations that take place in the course of the ore's conversion into metal and to check that the geochemical features

of the original ore are present in the manufactured object.

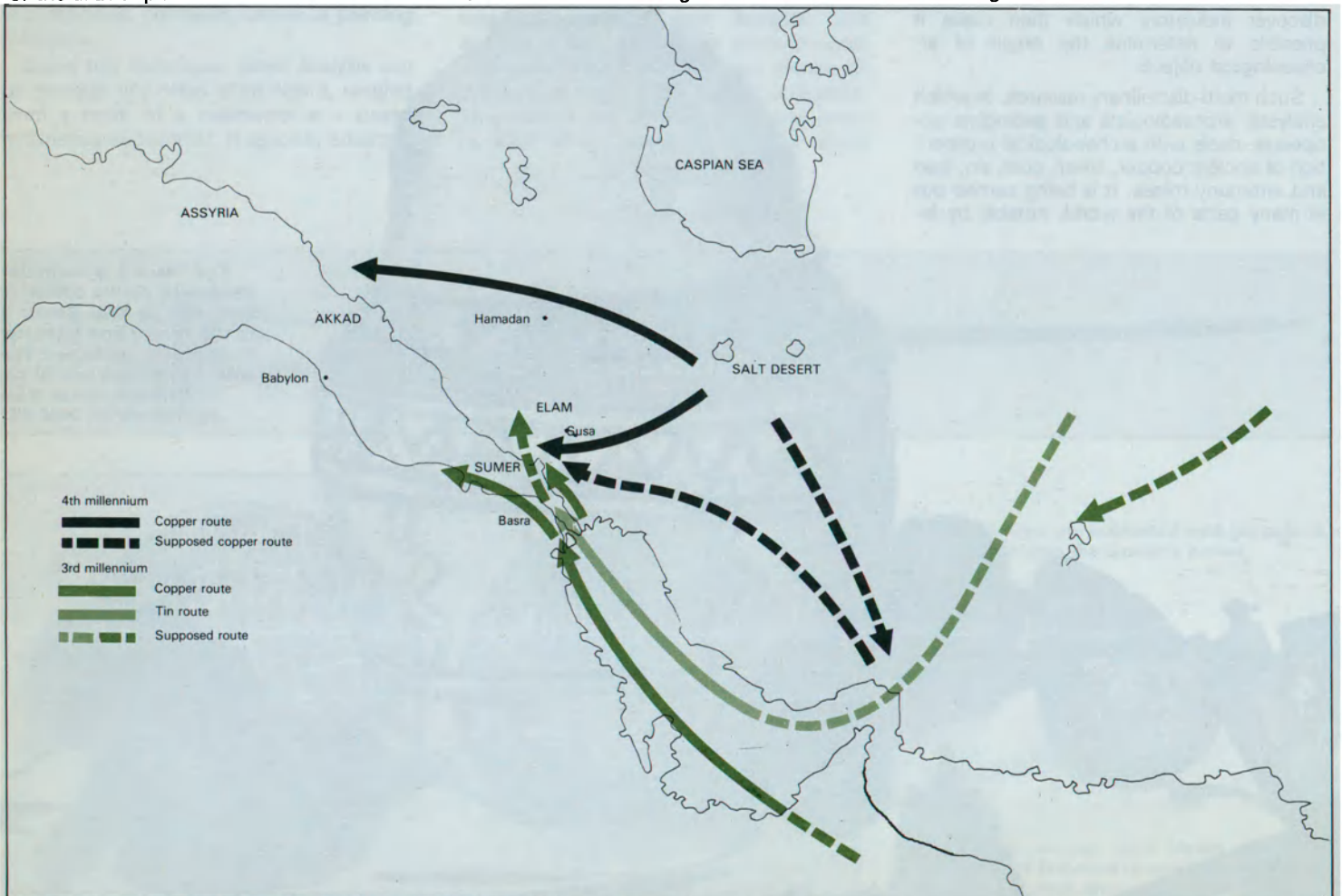
Thus despite the changes that occur when the ore is reduced and the objects are cast, the correlation of the different chemical elements and their respective distribution are seen to correspond before and after the pyrotechnical transformation.

This use of computers to chart the evolution of concentrations of trace elements and minor elements has enabled us to refine research on the "ore-object relationship" and to establish a connexion between certain ores and groups of objects which, otherwise, would have gone unnoticed.

Throughout the study great attention has been paid to the consistency of the results both from the technological and historical viewpoints. Basic information about ancient mining sites—the dates when they were worked and the mineral resources they yielded—as well as detailed analysis of various residues and remains of metallurgical activity (such as casting ducts and the walls of furnaces), have all been taken into account. Moreover, precise methods of identifying elements added to copper ore to increase its fluidity during casting or to serve as alloys have been developed.

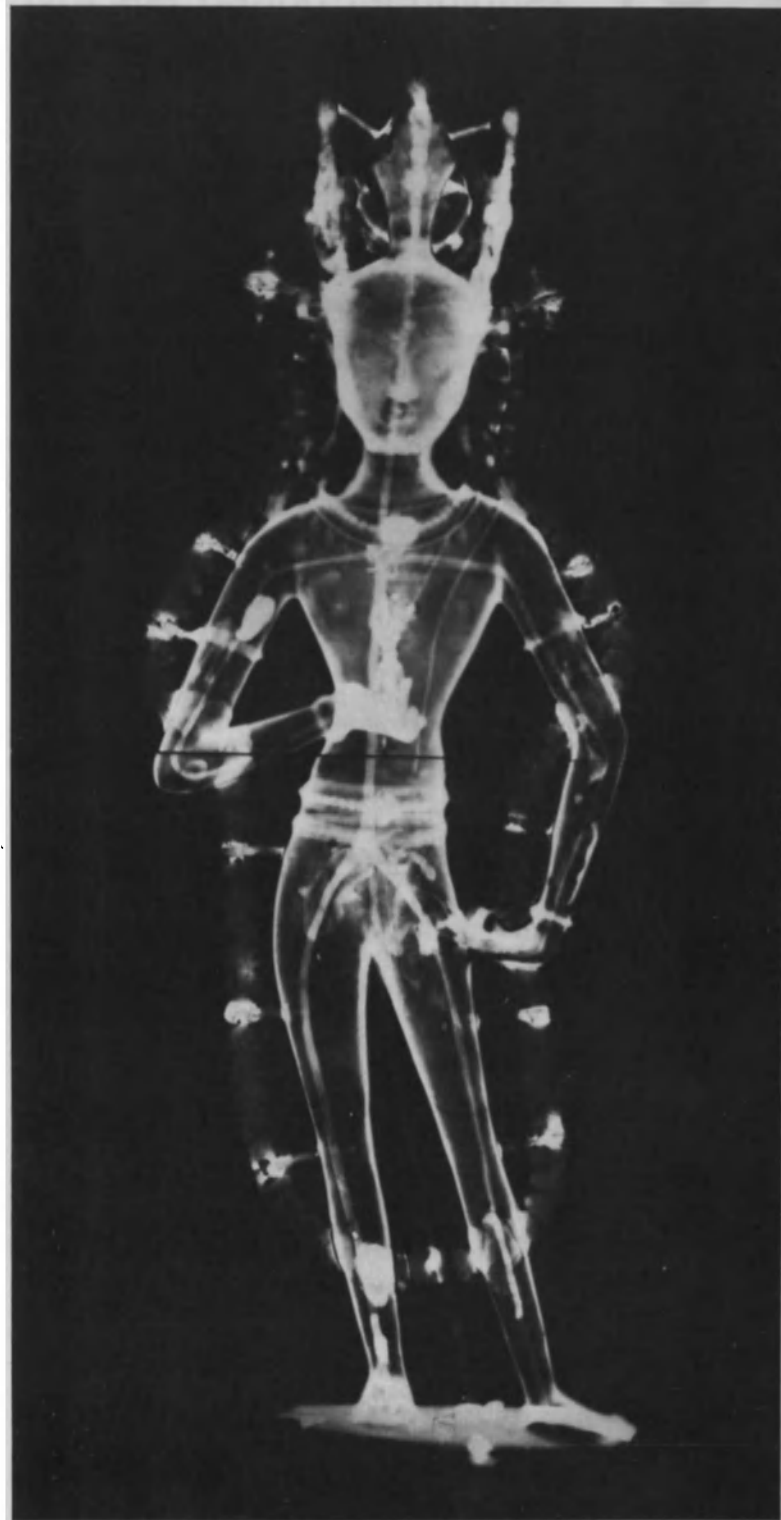
The combined use of elementary analysis and the techniques of data analysis has produced new information on the supply sources of copper and tin in the Middle East during the fourth and third millennia before the Christian era.

In the fourth millennium, most of the copper came from the Iranian plateau. But an important change took place at the beginning of the third millennium when new trade links were established along the Gulf and, from then on, the copper used in Mesopotamia came from the mountains of Oman, the Magan of ancient Sumerian texts. ■



Map Unesco Courier. Source *La Vie Mystérieuse des Chefs-d'Œuvre*, Editions de la Réunion des Musées Nationaux, Paris

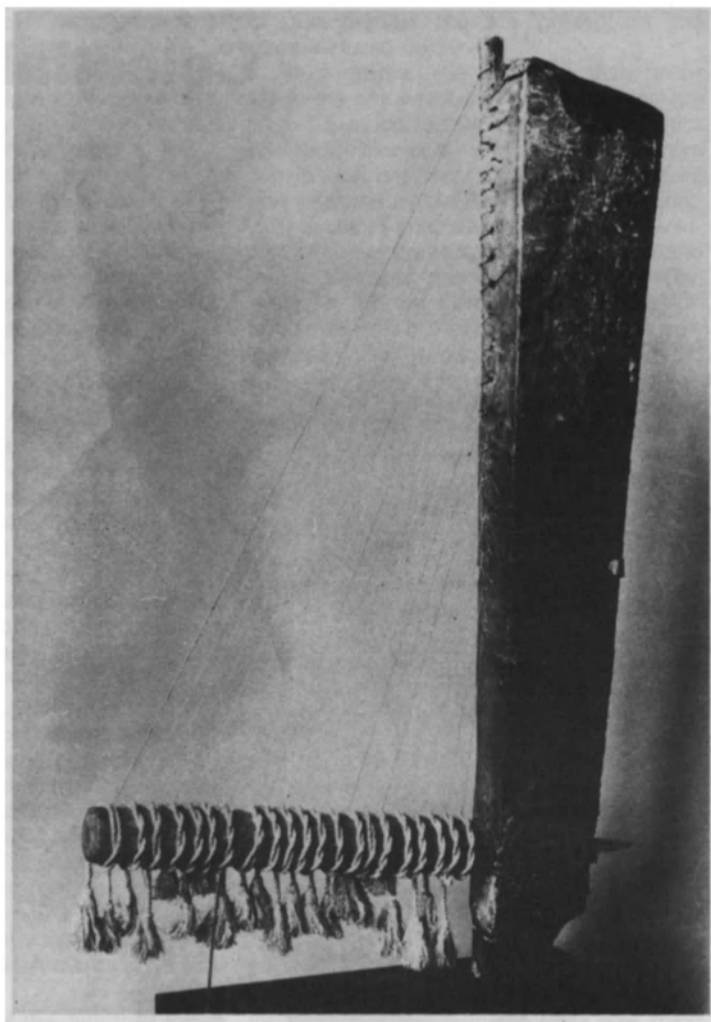
Celestial radiance



Photos © Laboratoire de Recherche des Musées de France, Paris

12th-century replica of an 11th-century Tibetan brass statue of Vajrapani, a celestial Bodhisattva ("Buddha-to-be"). The X-ray image reveals the internal structure of the statue as well as the method of casting used.

Anatomy of a harp



X-RAY examination of musical instruments is basic to understanding the technology, invisible from the outside, which has a direct bearing on their acoustic qualities: the shape and roughness of the holes in a wind instrument, for example, or the form and structure of the sound board of string instruments.

The structural changes which each instrument has undergone in the course of its history are also very important since, in addition to providing historical data, they can make it possible to reconstitute the sound originally produced by the instrument.

Among Egyptian musical instruments, the harp has always been a particular favourite; its shape and dimensions have varied considerably. The instrument shown above dates from sometime during the first or second millennia BC, and is in a perfect state of conservation. The harp, now in the Louvre, consists of a vertical sound box (1.10 metres high) entirely covered in green leather, and a console (cross-piece) made from a cylindrical bar of wood set at an angle of 85 degrees to the sound box. Twenty-one strings are wound around the console, and cords with a tassel at the end enabled the player to tune the instrument.

Visual examination does not reveal the various elements of the sound box—the essential part of the instrument—but X-ray photography has enabled specialists better to understand the form and structure of this type of instrument.

In profile, the sound box is shown to be a massive piece of wood hollow from the top down to the level of the console. The upper part is closed by an oval piece of wood set in between the sides of the sound box. Fixed to the sound box is the suspension rod to which the strings are attached. It tapers towards its lower end, just above the console.

The two sides of the sound box are maintained apart by five small, intricately-worked cross-pieces about 7 cm high. These dovetail-shaped wedges are set at regular intervals in the sound box, which is reinforced by two vertical ribs from one to two centimetres thick. The small piece of wood jutting out from the top of the sound box on the left may have been a support for a symbolic figure similar to those found on certain musical instruments.

X-ray photography shows that the base of the sound box hidden beneath the leather has an outline slightly different from what is visible from the outside. Moreover, a small piece of wood has been add-

ed to reinforce the base on which the instrument rests, but this in no way alters its character.

The different components and their position have enabled specialists to compare the harp with one formerly preserved in Berlin. The Berlin harp was in a very bad state of conservation, but after detailed study a copy of it was made on which it was possible to play. The copy and the original harp, which have since disappeared, were described in a published study, and it is interesting to note that there is a close similarity between the harp in the Louvre and the Berlin instrument. Both reveal a relatively sophisticated technology, and could even have been produced by the same instrument-maker.

To understand a musical instrument, all its aspects must be considered: how it was made, how it works, its acoustics and its aesthetic appearance.

The X-ray photographs show that the techniques used in making this Egyptian harp were advanced. Detailed analysis of its shape shows that the "aesthetic ideology" of ancient Egyptian harp-makers was based on proportions similar to those used in architecture. The harp's outline is that of a specific geometrical figure whose measurements are absolutely proportionate to the "Royal Cubit" (52.35 cm), a unit of length used in ancient Egypt.

This type of instrument consists of two parts: an "instigating" system, represented here by the strings, and a "resonance" system, represented by the sound box.

The design of the sound box with its dove-tail-shaped cross-sections and that of the console and their respective positions show that the mechanical problems had been mastered. The strings could vibrate once they had been stretched and the sound box was "flexible" enough to change shape temporarily.

Greater amplitudes of vibration in the lower ranges are required to make the sound appear homogeneous to the ear. This was done by making the lowest-pitched string four times longer than the highest one, for the aim was not to achieve sounds of great intensity but sounds which were warm and mysterious. This explains why a leather sound board was used instead of a wooden one. In order to bring the whole of the board into play, the wooden rod to which the ends of the strings are attached was placed under the leather. Acoustically, the system is appropriate and effective.

Art, archaeology and the atom

Nuclear dating techniques and how they work

by Bernard Keisch

ONE cannot possibly overemphasize the importance of carbon-14 dating in the fields of art and archaeology since its discovery shortly after World War II.

The importance of the method was recognized immediately and, in 1960, earned for its discoverer, Willard F. Libby, the Nobel Prize.

The reasoning behind the method is this. The earth is being continually bathed in cosmic radiation. One product of that radiation, a quantity of neutrons, reacts with nitrogen in the upper atmosphere to produce carbon-14.

Since the flux of neutrons has been nearly constant for the last several thousand years, the rate at which carbon-14 has been produced by this means has been just as constant.

The carbon-14 atoms react chemically with oxygen to form carbon dioxide, which eventually mixes, throughout the atmosphere, with ordinary carbon dioxide. (Ordinary carbon atoms contain 6 protons and 6 neutrons and are not radioactive.) Carbon dioxide in our atmosphere is incorporated into living tissue by growing vegetation. Animals that eat vegetation, and the animals that eat vegetarians, etc., also eventually contain carbon-14.

The end result is that all living things must contain carbon-14 in the same concentration that occurs in the atmosphere during their lifetime. But carbon-14 has a *half-life* of about 6,000 years, and when an organism dies and ceases to participate in the biosphere, its carbon-14 supply is no longer being replenished by freshly produced carbon-14 through the food chain. The concentration of carbon-14 in its tissues thus begins to decrease.

The nature of radioactivity is such that we may express the rate at which a radioactive substance disappears in terms of its half-life. In this case, it means that after 6,000 years, one-half of the carbon-14 atoms will have disappeared. After a second 6,000 years, half of that remaining after the first 6,000 will have disappeared, or *three-quarters* of the original number will be gone.

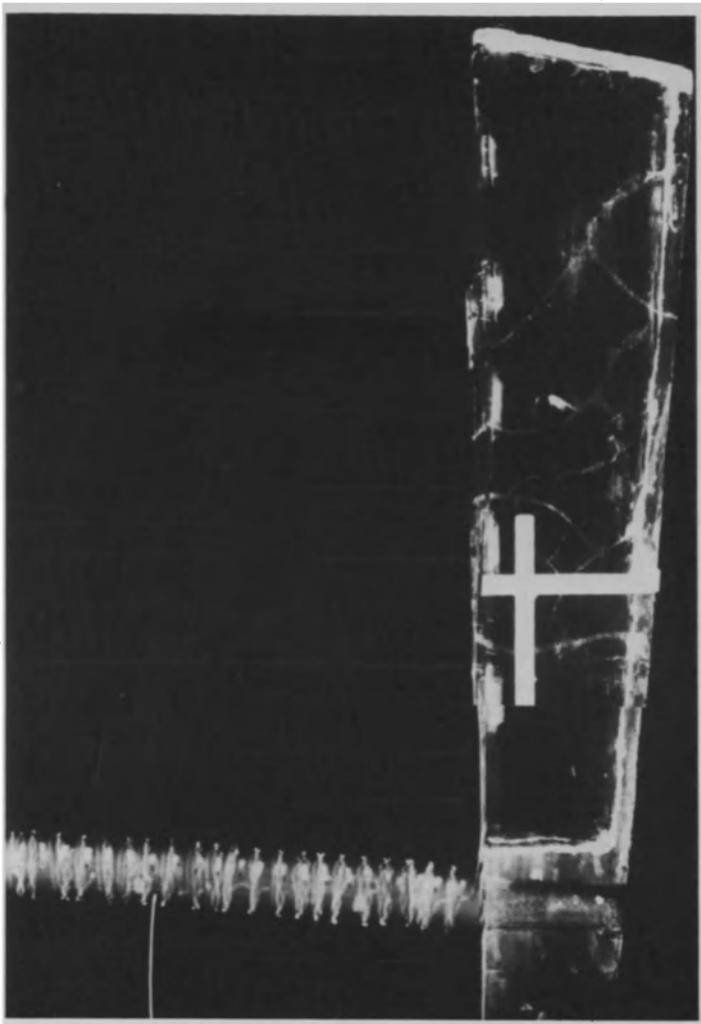
Up to about 1900 the concentration of carbon-14 in our atmosphere and biosphere was such that the radioactivity of each gramme of carbon was about 15 disintegrations per minute (dpm). This way of expressing radioactivity, dpm per gramme, is called "specific activity". Put another way, for our present case, 15 dpm per gramme means that in among the 50 thousand million million atoms of carbon-12 in 1 gramme, there are about 650 thousand million atoms of carbon-14 of which 15 "disappear" by radioactive decay each minute.

Thus, 6,000 years after an organism dies, the carbon-14 specific activity will be 7.5 dpm per gramme; in 12,000 years, it will be 3.75 dpm per gramme, and so on. By using large samples (if they are available) and efficient instruments for measuring the radioactivity, it has been possible to date objects made of wood, for example, that are as much as 50,000 years old. Most carbon-14 dating, however, is done on objects that are no more than 10,000 to 15,000 years old.

Most of the objects dated by this method are made of wood. It is also possible to date objects of bone, textiles, ivory, and iron. (It is possible to date iron because iron contains a few per cent of carbon which, in old samples, came from wood charcoal.)

Another method for the dating of ceramics, radiation-induced thermoluminescence, was first used by George C. Kennedy in 1960.

BERNARD KEISCH, U.S. radiochemist, has specialized in the applications of nuclear technology to the identification of works of art. This article has been adapted from material appearing in his study *Secrets of the Past: Nuclear Energy Applications in Art and Archaeology*, published by the Office of Information Services of the U.S. Atomic Energy Commission.



Photos © Laboratoire de Recherches des Musées de France, Paris

Analysis of the sound range by "acoustic spectrography", that is, the "response curve" obtained by tapping at each extremity the longest, medium and shortest string, shows in each case a difference in the degree of "freedom" between the two points.

The end nearest the leather has a lower pitch than the console end. The timbre has therefore two different frequency areas similar to those of the "human voice".

The harpist used to tune his instrument by stretching the strings to the point where the sound corresponded with the ideal of the day; fine-tuning was done later. He changed the pitch according to the "scale" of the piece he happened to be playing. It seems likely that the twenty-one strings covered three octaves of seven notes which could be adjusted at will.

The workmanship that went into making the harp, its physical characteristics and results of the acoustic studies all point to a high degree of technical sophistication. The acoustic study, however, is not entirely conclusive since the instrument is not in a state to be played; the strings do not have the proper tension, the leather has lost its elasticity and the handle has probably been altered. The conditions in which the instrument was tuned and played have inevitably changed.

However, the X-ray photographs and readings from the "response curve" would make it possible to construct a model on which a real study could be made. ■

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These texts originally appeared in the catalogue of the exhibition "La Vie Mystérieuse des Chefs-d'OEuvre. La Science au Service de l'Art" (Secrets of the Great Masterpieces—Science in the Service of Art), which was published by Les Éditions de la Réunion des Musées Nationaux, Paris (1980) under the direction of Madame Magdeleine Hours. They have been extracted from articles, notes and graphics by: Magdeleine Hours, Max Sarradet, Suzy Delbourgo, Jeanne Gautier, Michel Fleury, Juliette Liszak-Hours, Christian Lahanier, Pierre Amiet, Thierry Berthoud, Lola Faillant-Dumas, Florence Abondance, France Drilhon, Emile Leipp.

► This method was eventually refined by workers at Oxford University and at the University of Pennsylvania and has become an extremely valuable tool. One reason why it is so valuable is that bits of pottery (called potsherds), which are quite durable, are almost always found at "digs", or archaeological sites.

The method itself is based on the principle that radiation distorts the electronic structure of insulating materials and so stores energy within the material. This process may be likened to the stretching of a spring. When the material is heated to a certain temperature the forces holding the electrons "out of place" begin to "loosen", the structure relaxes as a stretched spring would, and the stored energy is released. This released energy is emitted in the form of light.

The radiation that produces this deformation comes mainly from naturally radioactive materials like uranium, thorium, and potassium, which are present in the pottery in low concentrations. The soil in which the pottery was buried also contains naturally radioactive material that affects the pottery in the same way. Cosmic radiation also contributes to the radiation "damage".

As time passes, more and more energy is stored in the material and thus the system acts like a clock. The clock is started at "zero", which is the last time the material was heated to the temperature at which the system "relaxes" (a process called annealing). In the case of pottery, this is the time when the pottery was baked as the final step in the manufacturing process.

To read the clock for a potsherd years after it was started, one must know or measure at least three important things.

1. How much radiation "ran the clock" since it was started. This information is obtained by measuring the radioactive constituents of a sample of the potsherd and the soil in which it was buried, estimating the small contribution of cosmic radiation, and calculating an annual radiation dose.

2. The amount of energy stored in the sample must be measured. To measure this, a small amount of very fine powder taken from the sample is spread in a very thin layer and attached to a block of metal. A light-measuring device (called a photomultiplier) is set up so that it faces the samples. The metal block is then electrically heated so that its temperature (and that of the sample) rises slowly and steadily. The temperature and the light emitted are continuously measured and recorded to give a thermoluminescence curve. Any material that is heated begins to emit light, or glow, when it gets hot enough. The trick here is to measure the *extra* light emitted by the pottery.

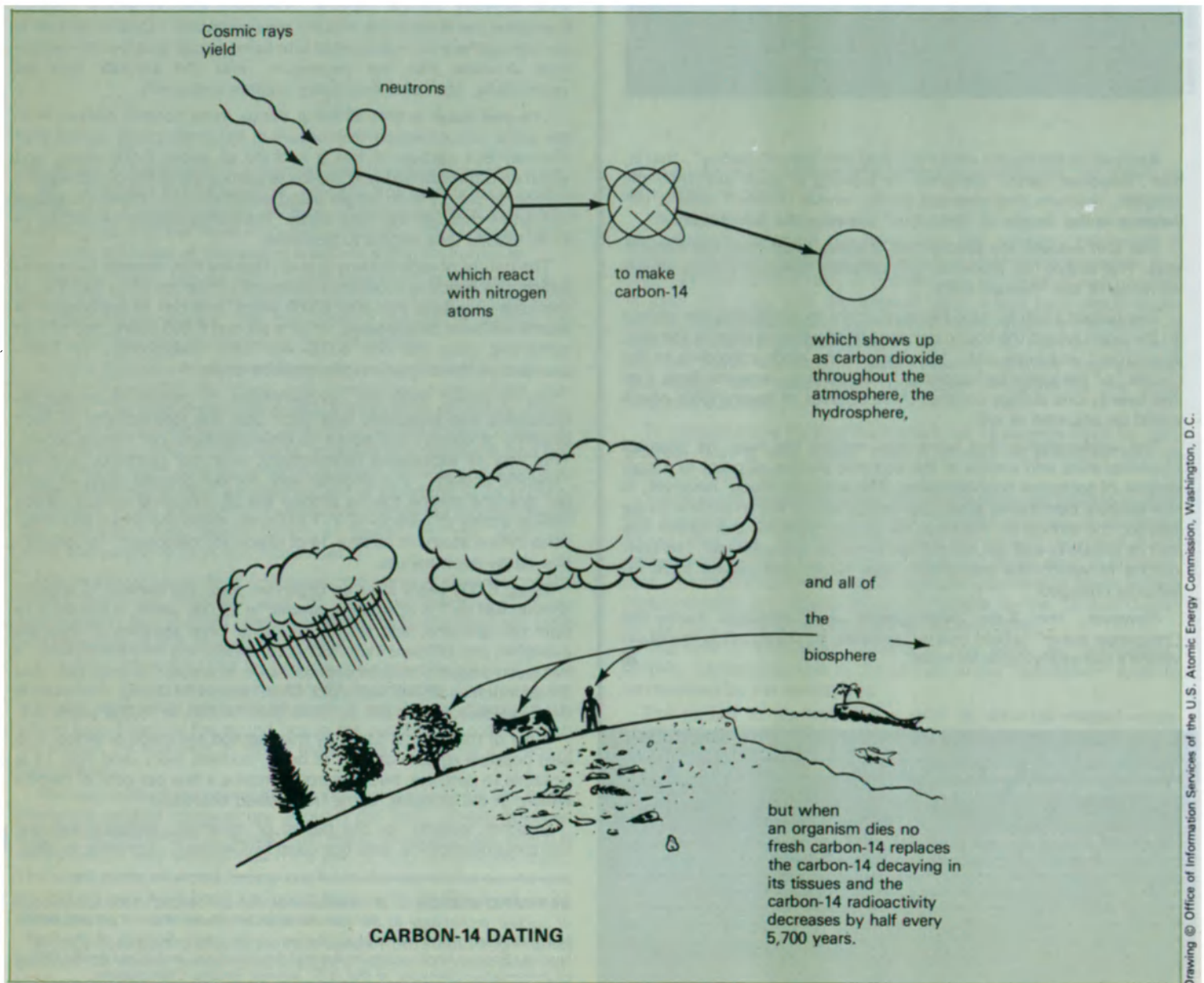
3. The susceptibility of the sample for radiation induced thermoluminescence. This is determined by measuring the artificially induced thermoluminescence produced by irradiating the sample with a *known* quantity of radiation after the original measurement is complete.

Relating these three factors in an equation gives the age of the piece.

It takes careful work and attention to detail to obtain an accurate date by this method. For example, the sample must be powdered carefully because grinding it too hard and fast may heat it enough to emit light prematurely. Nevertheless, the techniques have been worked out, and quite a number of dating problems have been solved in this way.

Other ceramic items besides potsherds can and have been dated. Terra-cotta statuary and ceramic figures have also been analysed, and forgeries have sometimes turned up.

■ Bernard Keisch





Genuine fakes

Dating by thermoluminescence has revealed the curious case of the "genuine fakes". In China under the Tang dynasty (618 to 906 AD) ceramic goods for burial with the dead were a popular status symbol and to meet the demand for them the potters of the day adopted a form of mass production known as piece-moulding. Separate moulds were made, for example, of a horse's head, legs and body which were cast independently for later assembly. Many such figurines were unearthed during railway construction work at the end of the 19th century. A number of moulds were also found which local craftsmen were quick to exploit, creating wares of impeccable style which, before the introduction of thermoluminescence dating techniques, were indistinguishable from genuine Tang period objects. Of these two white clay prancing horses, the one below is a ninety-five-year-old "genuine fake", while the one above was made by a Tang potter some 1,300 years ago.



Photo © Smithsonian Institution, Washington, D.C.

Gamma-ray 'fingerprints'

This 18th-century brass cock was made by the Benin people in the part of Africa that is now Nigeria. It was constructed of two parts, the bird itself and the base, and a question was raised as to whether the two parts were made by the same people. To solve this problem recourse was had to a technique known as neutron activation analysis. This is an extremely sensitive analytical technique by which it is possible to detect and measure the trace elements that occur in almost every substance. The concentrations of trace elements in a substance constitute a "fingerprint" by which the source of a substance can be identified. A sample is placed in a nuclear reactor and bombarded with neutrons. Some of the elements in the sample become radioactive and give off gamma rays. The graphs superimposed on the photograph of the cock are the gamma-ray spectra obtained when samples taken from the two parts were activated by neutrons in a reactor. Notice how similar the shapes of the two spectra are. Each peak represents a gamma ray of a particular energy and can be identified as coming from a particular element in the brass. The height of each gamma ray is related to the quantity of that element present. In all, seven elements were identified and found to be in almost identical concentrations in the two parts of this sculpture. This tends to prove that the two parts, although made separately, were made at the same time and place.

A rogues' gallery of fakes

by Stuart J. Fleming

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THE history of forgery and imitation goes back many centuries. The Roman appreciation of Greek Classical sculpture in stone and bronze prompted extensive imitation that is now extremely difficult to detect, while blatant forgery of early silver coins from many cultures in the Empire was recorded in verse by the Roman poet Phaedrus during the reign of the Emperor Augustus.

Coinage has always been a prime target for debasement because of the immediate financial rewards that result. We find early examples of counterfeiting amongst the subject peoples of the Roman Empire, particularly in Britain. Around AD 198, during the reign of Severus, the silver *denarius* was already debased by the addition of about 42 per cent copper, but imitators took the devaluation much further. We also know from excavated clay moulds impressed from original coinage that the folk of Whitchurch in Somerset (U.K.), during the last quarter of the third century AD, produced their own silver *antoniniani* once official minting in the area had ceased.

Attitudes to fakes and the reasons for their existence have changed many times in the past. Roman materialism seems to have been very akin to that of our present genera-

tion while in the medieval era there was a greater interest in an item's subject matter than its age.

The year 1524 marks the earliest documentation of forgery amongst European paintings, in Pietro Summonte's discussion of the activities of a Neapolitan artist, Colantonio, some seventy years earlier. A portrait of the Duke of Burgundy was so well reproduced that the merchant-owner from whom the original had been borrowed accepted the return of Colantonio's version without suspicion.

A little more than a century later there began a saga that remained untold until 1871. A work commissioned from Hans Holbein the Younger, in 1525, *The Madonna as Protectress of Jacob Meyer, Mayor of Basle, and his Family*, passed through several hands before reaching an Amsterdam dealer, Le Blond. Then the "Madonna" developed a split personality.

STUART J. FLEMING, a British physicist who is currently scientific director of the University Museum, University of Pennsylvania, is an internationally recognized authority on thermoluminescence dating of ceramics and bronzes. This article has been extracted from his book *Authenticity in Art: The Scientific Detection of Forgery*, published by the Institute of Physics, London and Bristol, in 1975.

One version (probably the original) eventually entered the Ducal collection at Hesse. A second version was pawned to a firm of Venetian bankers and found an honoured place in the Dresden Collection in 1743. Only when the two panels were brought together in the last century did the second version proclaim its seventeenth-century style by comparison with the original. The copyist (possibly Bartholomeaus Sarburgh) felt he had to introduce some "improvements", the figures becoming smaller and the architectural surround more dominating. Current taste demanded more space of movement and a colour scheme of deeper, richer tones.

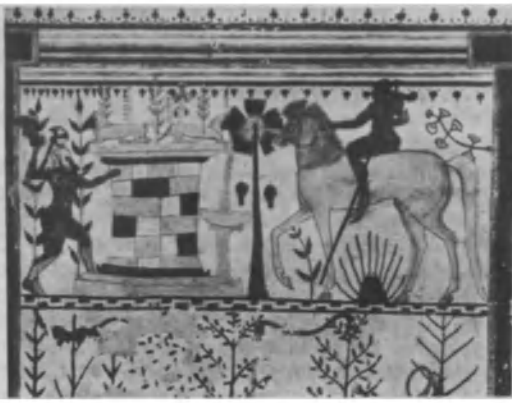
Some later case histories kept their secrets for a much shorter time. Luca Giordano, at the end of the seventeenth century, found himself in court for painting in the style of Durer. The work, *Christ healing the Cripples*, bore the renowned "AD" monogram prominently enough while Giordano's own signature was concealed elsewhere in the picture. Oddly enough he was not found guilty, as it was judged that he could not be blamed for being able to paint as well as the German master. The more recent court judgement of one year's imprisonment on Han van Meegeren, in 1947, for his "Vermeer" imitations was scarcely more severe.



Photos © Stuart J. Fleming, from *Authenticity in Art*, Institute of Physics, London and Bristol



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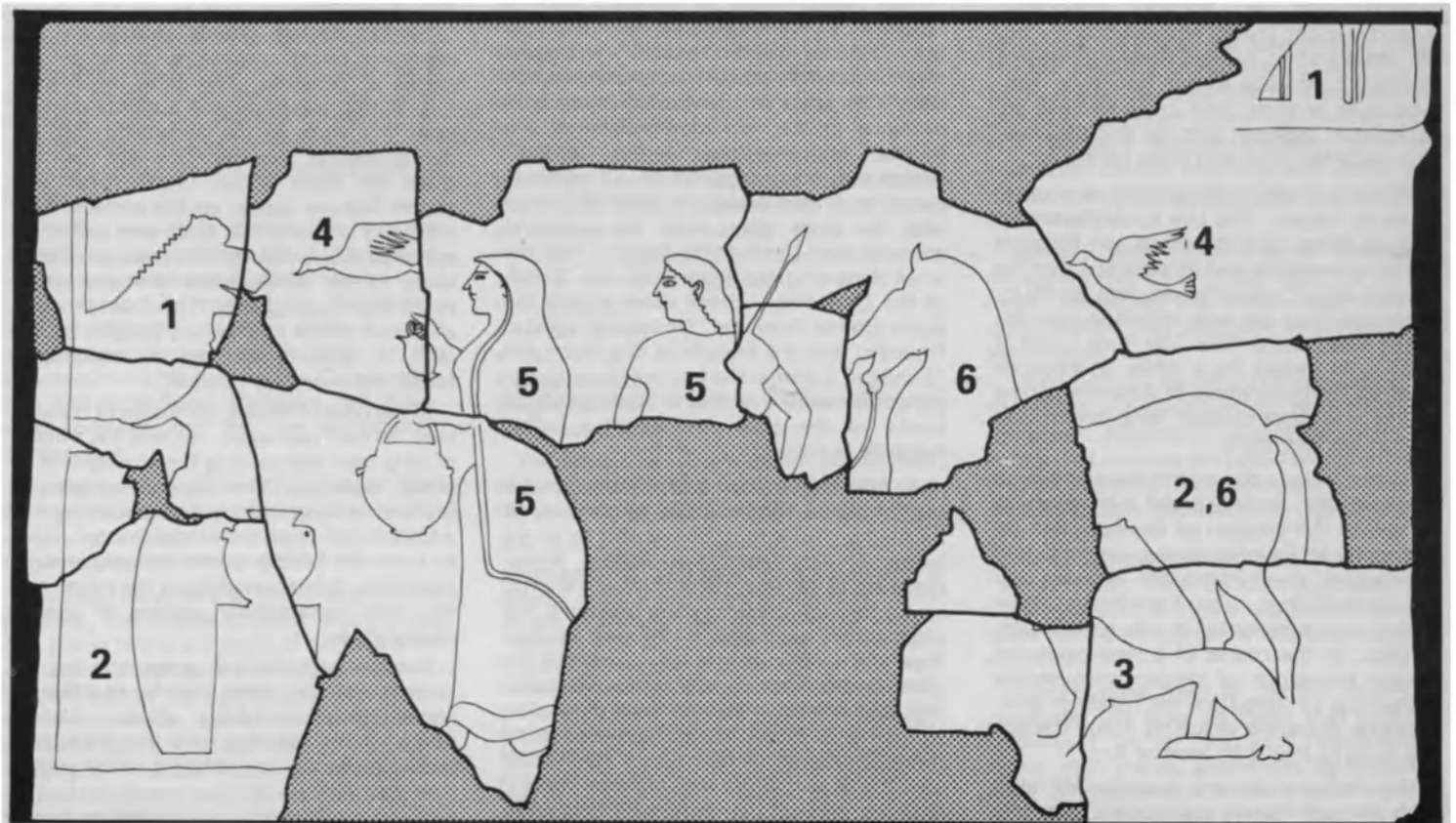


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Opposite page below, a pastiche (or forgery) of an ancient Etruscan wall-painting on a terra-cotta slab. Each element in the work is the copy of a detail from an authentic piece of Etruscan art, and the forgery, which seems to display a remarkable unity of conception, is actually a kind of jigsaw puzzle of different motifs (below). The painting depicts Troilus, son of King Priam, and his sister Polyxena, about to fall into an ambush laid by Hercules. (The forger cunningly showed only part of the chequered fountain, letting it be supposed that it was completed with another, missing, plaque, with Achilles lurking behind it.) Photos above show the origins of the different motifs used in the pastiche: 1) Detail from a clay altar from Corinth; 2) Fresco from the Etruscan "Tomb of Bulls" at Tarquinia (Italy). Detail shows Achilles waiting to ambush Troilus; 3) Banquet scene painted on a Greek wine-jar; 4) Detail of fresco from "Tomb of Augurs" at Tarquinia; 5) Terra-cotta wall-plaque of "female figures" unearthed at Banditaccia (Italy); 6) Decorative frieze on funeral urn from Tarquinia (detail).



Forgeries fall into three main categories. The first of these, fakes without a model, is rare. The path to acceptance can be made easier if the subject chosen has some connexion to a legend or a fragmentary documentary reference. The fourteenth century provides us with one of the better-known examples of a fake based on a legend. Political manoeuvres against the Knights Templars in 1306 included a claim that they worshipped an idol called Baphomet. The production of these idols (small mis-shapen stone figures covered in meaningless inscriptions) probably dates from the time when this story was popular, in the literature of the Gothic revival.

Fakes designed to fit in with genuine documentary evidence include some remarkable wholesale inventions of a complete, spurious artistic style, such as that of the Obotrites (a Slavonic tribe from the Mecklenberg region later over-run by the Huns) and of the Moabites who came to public attention in 1869 with the discovery of a genuine inscription related to their King, Meshah.

Archaeological material has been particularly susceptible to this kind of forgery. Gustav Wolf, in 1907, announced the discovery of cremations among Danubian peoples who first raised cattle and farmed in the region of Wetterau in the fourth millennium BC. The unearthing of about a hundred of these graves led to the revision of academic belief that skeleton burial was the custom of those times. Finely-pierced flint tools, notched bone implements and carefully arrayed necklace beads all helped to compound a funerary assemblage. Wolf, in his autobiography, gave full credit for the finds to his co-excavator, Bausch, and died oblivious of the fact that he had been deceived by that very man.

The Old Stone Age and Neolithic cultures offer great potential to the forger because of the simplicity of workmanship required and the ready availability of media (flints, shales, antler bone and cave-wall rock) all ready for embellishment in hitherto unacknowledged ancient styles. Hieroglyphs cry out for interpretation, our fascination increasing in direct proportion to our ignorance. New languages emerge; new cross-linkages are established between cultures and the situation becomes more and more confused.

Runic inscriptions have been particularly prone to forgery. The Ura Linda Chronicle, with its notion that the Finns and Magyars are blood relations and its assertion that the Frisians are a Chosen People, was readily incorporated into the early racialistic attitudes of the Nazi Party in 1933. The Rune Stone of Minnesota served, for a while, as evidence of a Viking occupation of America by the end of the tenth century, long before Columbus set foot there.

Similar unique documents have appeared intermittently, including the last words of Moses to the children of Israel written on leather by an Egyptian scribe, Unianus, and scripts of a "new" Phoenician historian called Sachuniathon. The Frenchman, Vrain Lucas, was a specialist in this type of production. In the course of a long career he forged thousands of original manuscripts purporting to stem from the hands of an illustrious gathering including Julius Caesar, the Apostle Paul and Joan of Arc.

We find scarcely any examples of fakes with no such literary associations, possibly

because forgers realize that they will not fit into any art historian's "data-bank" and are therefore liable to immediate rejection.

Alterations and additions to a work supply our second category of fakes. We might mention, as an example, a painting with figures in the style of the seventeenth-century Dutch painter Philips Wouwerman superimposed upon a genuine landscape by his near contemporary Jan van Goyen. The presence of both artists' monograms suggested the work was a joint effort but it now seems probable that the parts of the painting attributed to Wouwerman are the work of one Robert Griffier.

Simple anthropomorphic sketches on bone and small sculptural reliefs executed on stone can endow Neanderthal man with unexpected skills while similar schoolboy rock-carvings have been known to rise to the status of national treasures.

The third and most common form of forgery is that of pastiche, that is to say, an object that derives its detailed units from a variety of similar elements in authentic material. Our illustrations (pages 24 and 25) show this process for an "Etruscan" painting on a terra-cotta slab, the authentic form of which would have decorated a niche of a tomb. The scene is that of Troilus, son of Priam, leading his horse to water, accompanied by his sister, Polyxena. The fountain is only shown in part so that we could anticipate the existence of a further plaque, to be mounted to the left, displaying a treacherous Achilles waiting to pounce upon the unsuspecting prince.

This legend is depicted in a fresco from the "Tomb of Bulls" at Tarquinia in Italy which provides the main theme and, in detail, is the source of the fountain chequering. Polyxena enters the scene via a frieze of this ambush that appears on the Corinthian "Timonidas" flask, but she now has the shawled dress-style of the females on a plaque excavated at Banditaccia, near Cerveteri.

The reined horse is derived from a funerary urn from Tarquinia with many of the outlines and muscle emphases reproduced with almost mathematical precision. The same accuracy of drawing is in evidence in the lion mouth-piece of the fountain and the upper border "tongue" design that occur together on a Corinthian clay altar. Fresco details are faithfully copied with the birds taken from the wrestlers' scene in the "Tomb of the Augurs" and the small decanting jug taken from the "Tomb of the Lionesses". Greek vases supply the water pitcher (from the "Onesimos" bowl in Brussels) and the crouching dog (from the "Eurytios" krater in the Louvre). Every component is readily available in photographs of books of the past two decades, often helpfully in colour.

An alternative source of information for the would-be forger is the showcases of museums. This is most convenient for single leaves of illuminated manuscripts; three-dimensional objects, parts of which are not visible through the front glass partitions, are often poorly executed. In the past engravings and woodcuts proved a valuable inspiration both for transfer into easel paintings and extension into an extra dimension as marble or terra-cotta statuary and stone reliefs. Similarly, medals supply small-scale versions of portraiture that translate well into stone reliefs of grander proportions while

offering less risk of anachronism in costume and hair styling.

Slavish plagiarism is rare. It only appears at all commonly in the field of drawings, where it was common practice of the leading studios of the past to give each apprentice old prints to copy as part of his education. The eighteenth-century English painter Sir Joshua Reynolds produced "Guercino" sketches with consummate ease. Michelangelo deliberately set out to deceive his master, Ghirlandaio, by copying a head, smoking the surface of the paper to simulate the effects of ageing, and exchanging his product for the original. Raphael, whose popularity was at its zenith in the nineteenth century, has been copied repeatedly even to the extent of enlarging small folio details into full-scale cartoon elements.

Surfaces often need major treatments to give them the necessary antique appearance. Cracking of a paint surface is an ageing effect that follows from the pigment or priming layers being too rigid to cope with the stretching of the flexible canvas or panel support. Once the oil medium has dried a simple rolling-up of a canvas will simulate this cracking quite well.

Other "recipes" include application of a heavily-contracting varnish or stiff glue to break up the picture's surface. Alternatively, some kind of heat treatment followed by rapid cooling causes shrinkage of the support at too great a rate to be taken up by the paint layers. For paintings on wooden panels the paint break-up usually runs parallel to the fibre structure of the wood and so the pressure directions require some deliberation. A final brush with soft highlights the damage.

A "fly-blown" appearance can be produced by stippling some areas with a stiff-bristle brush in a matching colour to create an illusion of antiquity. Swiftly applied restoration, damp-staining and blotching of paper, rim-chipping of pottery and the use of worm-eaten wood are all stock-in-trade skills of the ambitious faker.

Similar ageing effects giving an appearance called *craquelure*, occur in the glazes of ceramics. The glaze ingredients fuse during kiln-firing and a glassy coating seals the pores in the underlying clay. If, during cooling, the clay cools less than the glaze the latter is put under stress and coarse fissures appear on the surface. This crackling is due to kiln treatment and in no way indicates antiquity. The passage of time leads to the development of many more, much finer crazing lines. This must be quite a difficult effect to simulate, judging by the rarity of good *craquelure* on established fakes, but examples do exist.

In the case of metals, corrosion of the surface, termed patination, records the effects of long-term exposure to the atmosphere or burial moisture. The copper content of bronzes oxidizes to form amorphous cuprite which, in turn, reacts with carbonated water to form the familiar green encrustations of malachite. Other impurities in the metal, like tin, may preferentially oxidize to give a silvery sheen.

Sulphur and chlorine, present in the attacking moisture, each give rise to different characteristic tarnishing effects. Unfortunately, the softening tone that patination produces on the raw, shining metal seems

The principles of conservation

by Bernard M. Feilden

THE conservation of cultural property demands wise management of resources and a good sense of proportion. Perhaps above all, it demands the desire and dedication to see that cultural property is preserved. In this sense, two familiar maxims are pertinent: "Prevention is better than cure" and "A stitch in time saves nine".

Modern long-term conservation policy concentrates on fighting the causes of decay. Natural disasters such as floods and earthquakes cannot be prevented, but by forethought the damage can be greatly reduced. Industrial development cannot and should not be halted, but damage can be minimized by combatting waste, uncontrolled expansion, economic exploitation and pollution.

Despite the difference in scale and extent, the underlying principles and methods of conservation are the same both for movable and immovable cultural property.

There are, however, important logistical differences. First, architectural work entails treatment of materials in an open and virtually uncontrollable environment. Whereas the museum conservator-restorer can generally rely on good environmental control to minimize further deterioration, the architectural conservator cannot. He must allow for the effects of time and weather.

Secondly, the scale of architectural operations is much larger, and in many cases methods used by museum conservator-restorers may be found impracticable due to the size and complexity of the architectural fabric.

Thirdly, and again due to the size and complexity of architectural conservation, the various measures of conservation must be carried out by contractors, technicians and craftsmen, while the museum conservator-restorer may do most of the treatment with his own hands. Communication and supervision, therefore, are important considerations for the architectural conservator.

Lastly, architectural conservation must take place within the context of a historic structure, and take account of its site, setting and physical environment.

For both movable and immovable cultural property, the objects chosen for treatment and the extent and nature of the treatment are based on values and priorities which inevitably reflect each different cultural context. For example, a small wooden domestic structure from the beginning of the 19th century in Australia would be considered a national landmark because it dates from the founding of the nation and because so little

Australian architecture has survived from this period. In Italy, on the other hand, with its thousands of ancient monuments, a comparable structure would have a relatively low priority in the overall conservation needs of the community.

Whatever form of conservation treatment is adopted, the following standards of ethics must be rigorously followed. First, the condition of the object, and all methods and materials used during treatment, must be clearly documented. Second, historic evidence should be fully recorded, and must not be destroyed, falsified or removed. Third, any intervention must be the minimum necessary. Fourth, any intervention must be governed by unswerving respect for the aesthetic, historical and physical integrity of cultural property.

Interventions should be reversible, if technically possible, or at least not prejudice a future intervention whenever this may become necessary. They should not hinder the possibility of later access to all evidence incorporated in the object, and should allow the maximum amount of existing material to be retained. If additions are necessary, they should be less noticeable than original material, while at the same time being identifiable. Conservator-restorers who are insufficiently trained or experienced should not undertake such interventions without competent advice. However, it must be recognized that some problems are unique and have to be solved from first principles on a trial-and-error basis.

Seven "degrees" of intervention can be identified, but in any individual conservation treatment, several degrees may take place simultaneously in various parts of the "whole". The seven degrees are:

- prevention of deterioration
- preservation
- consolidation
- restoration
- rehabilitation
- reproduction
- reconstruction

Prevention of deterioration (or indirect conservation). Prevention entails protecting cultural property by controlling its environ-

ment, thus preventing agents of decay and damage from becoming active.

Prevention thus includes control of humidity, temperature and light, as well as measures to prevent fire, arson, theft and vandalism. In the industrial and urban environment it includes measures to reduce atmospheric pollution, traffic vibrations and ground subsidence due to many causes, particularly abstraction of water.

Preservation deals directly with cultural property. The object is to keep such property in its existing state. Damage and destruction caused by humidity, chemical agents, and all types of pests and micro-organisms must be stopped in order to preserve the object or structure.

Maintenance, cleaning schedules and good management aid preservation. Repairs must be carried out when necessary to prevent further decay. Regular inspections of cultural property are the basis of prevention. When the property is subjected to an uncontrollable environment, such inspections are the first step in preventive maintenance and repair.

Consolidation (or direct conservation). Consolidation is the physical addition or application of adhesive or supportive materials into the actual fabric of cultural property, in order to ensure its continued durability or structural integrity. In the case of immovable cultural property, consolidation may entail, for example, the injection of adhesives to secure a detached mural painting to the wall. Movable cultural property, such as weakened canvas paintings and works on paper, are often backed with new supportive materials.

In many cases it is wise to buy time with temporary measures in the hope that some better technique will evolve, especially if consolidation may prejudice future conservation work.

Restoration. The object of restoration is to revive the original concept or legibility of the object. Restoration and reintegration of details and features are based on respect for original material, archaeological evidence, original design and authentic documents. The replacement of missing or decayed parts must integrate harmoniously with the "whole", but must be distinguishable on close inspection from the original so that the restoration does not falsify artistic or historic evidence.

Contributions from all periods must be respected. All later additions that can be considered as a "historical document" rather than merely a previous restoration, must be preserved. When a building includes superimposed work of different

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periods, only exceptional circumstances can justify revealing the underlying state: when the part removed is widely agreed to be of little interest and when it is certain that the material brought to light will be of great historical or archaeological value, and when it is clear that its state of preservation is good enough to justify the action. Restoration also entails superficial cleaning, but with full respect for the patina of age.

Rehabilitation. The best way of preserving buildings is to keep them in use, a practice which may involve what the French call "mise en valeur", or modernization and adaptive alteration.

Adaptive re-use of buildings, such as utilizing a medieval convent in Venice to house a school and laboratory for stone conservation, or turning an eighteenth-century barn into a domestic dwelling, is often the only way that historic and aesthetic values can be made economically viable.

Reproduction entails copying an existing artefact, often in order to replace some missing or decayed, generally decorative, parts to maintain its aesthetic harmony. If valuable cultural property is being damaged irretrievably or is threatened by its environ-

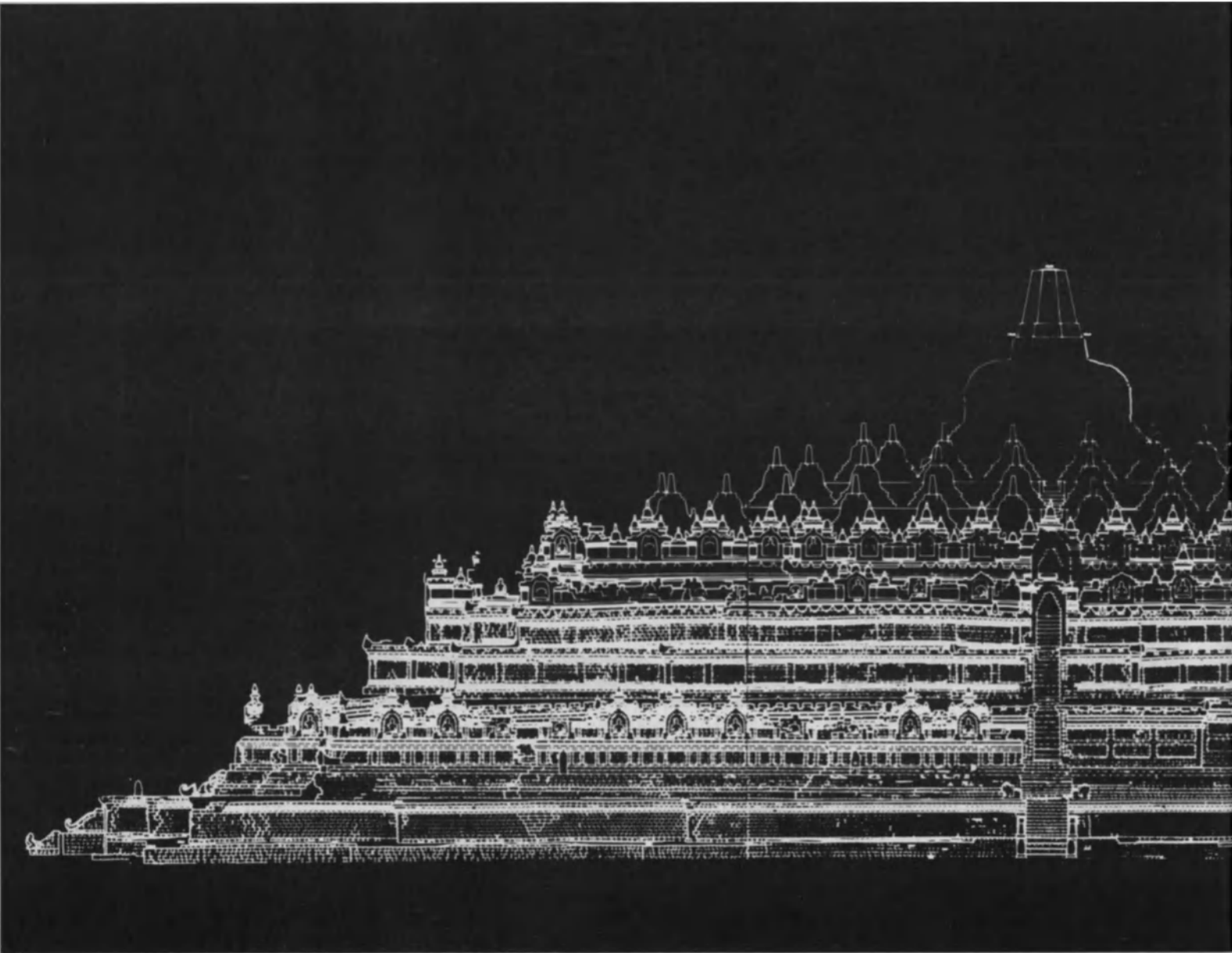
ment, it may have to be moved to a more suitable environment. A reproduction is thus often substituted to maintain the unity of a site or building. For example, Michelangelo's famous sculpture of David was removed from the Piazza della Signoria in Florence to a museum to protect it from the weather. A good reproduction took its place.

Reconstruction of historic buildings and historic town centres using new materials may be necessitated by disasters such as fire, earthquake or war, but reconstructions cannot have the patina of age. As in restoration, reconstruction must be based on accurate documentation and evidence, never on conjecture.

Moving entire buildings to new sites is another form of reconstruction which is justified only by overriding national interest. However, it entails some loss of essential cultural values and the generation of new environmental risks. The classic example is the temple complex of Abu Simbel, which was moved to prevent its inundation by the Aswan High Dam (see *Unesco Courier*, February-March 1980).

■ Bernard M. Feilden

Photo © Kodak-Pathé-National Geographic Institute, Paris. From the exhibition *Le Fil des Pierres*, Photogrammetry and Conservation of Documents



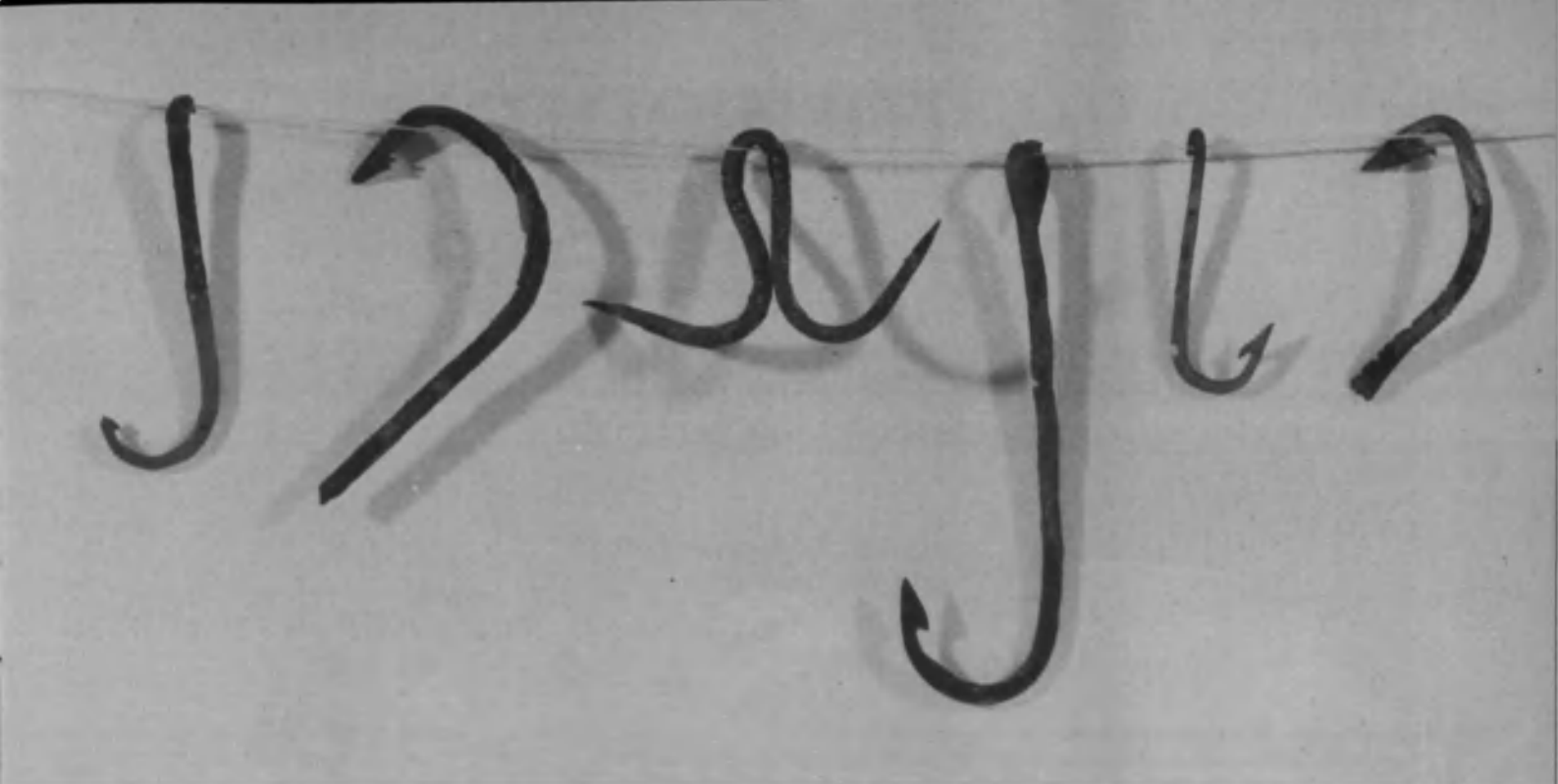


Photo © Borély Museum, Marseilles, France

Miniature and monumental



Left, façade of the temple of Borobudur, on the island of Java, Indonesia. The temple dates from the 9th century and is the world's biggest and most complete ensemble of Buddhist bas-reliefs. The image was produced by photogrammetry, the process of using photographs for measurements in surveying. A decade ago, at the request of the Indonesian Government, Unesco launched an international campaign to save Borobudur, whose foundations had been undermined by 12 centuries of exposure to torrential monsoon rains and whose galleries had subsided as a result of the seismic disturbances which are common in this region. It was decided to dismantle the temple stone by stone, and rebuild it on a specially designed concrete structure which would withstand earthquakes and allow rainwater to drain away. Before work could begin, a survey was carried out by France's National Geographic Institute. Because of the size, complexity and pyramidal shape of Borobudur, many parts of the temple were not visible in photos taken from ground level. Consequently, 180 additional pairs of stereoscopic photos were taken, as well as 35 shots from a helicopter. In this way an exact survey of the monument's volume was made, along with an estimate of the restoration work that would be necessary to save it. Above, six Bronze-Age fish-hooks (between three and five centimetres long) unearthed in the South of France and preserved in the Borély Museum, Marseilles. Even the humblest everyday object can provide precious evidence of past ways of life.

A museum in a suitcase

Three-dimensional 'replicas' of works of art,
produced by the astonishing technique of holography

by Ivan G. Yavtushenko
and Vladimir B. Markov

THE technique of producing holographic images was first advanced in 1949 by a Hungarian-born British physicist, Dennis Gabor. However, his method proved unusable for lack of a suitable light source. Not until the development of the laser as a source of coherent light was further progress possible.

The breakthrough came in 1962, thanks to the work of American scientists Emmett Leith and Juris Upatnieks, and a Soviet scientist, Y.N. Denisjuk. Leith and Upatnieks took the laser as their source of light and, working with a modified version of Gabor's method, proved it possible to record and reconstruct a three-dimensional image of any light-reflecting object. Meanwhile, Denisjuk's fundamental work established the principle of the complete reconstruction of the light field created by a real object.

What is holography and how does it differ from conventional methods of recording images? Non-holographic techniques use a lens to produce an image of the subject on light-sensitive material, and of course, the original three dimensions are then converted into two. Holography consists of recording the light field emitted by the subject—the same field as is normally perceived by the human eye.

The theory of the technique of holography may be described as follows. As in photography, one needs a light source, a photographic plate and, of course, an object. The layer of photosensitive emulsion is comparatively thick—about 10 microns. The object is illuminated by the light of a laser; the reflected light falls on the plate. However, in contrast to ordinary photography, the plate is also illuminated by reference light rays from the same source. These two beams of light combine, and are registered by the photographic plate, which is called the hologram.

The image is reconstructed by placing the hologram as before and directing onto it a similar source of light. The effect of this upon the structure recorded on the hologram is to produce light beams which are an exact replica of those reflected by the original subject, so that the viewer sees a three-dimensional copy of that subject. (Denisjuk's holograms can even be viewed with a pocket flashlight.)

This description of the recording and reconstruction of the image is the key to the origin of the word holography, which Gabor coined from two Greek words: *holos*, meaning "complete", and *graphein* meaning "to write". In other words, it is a method of recording all the information about the light field emitted by a real object.

It is the hologram's ability to produce an exact optical copy of the subject which suggested that it might be widely used in museology.

There are many ancient objects which, for a variety of reasons, cannot be displayed: perishable items that need special storage, or those unique antiquities for which unusual security arrangements are required. This problem can largely be overcome by exhibiting holographic replicas of such objects. Again, it is no secret that particularly valuable items found in provincial areas usually find their way to large central museums. Holograms could well be made of them and placed in provincial museums, providing exact replicas which could advantageously replace laborious castings. Equally important is the potential use of holograms in establishing the origin and identity of objects and determining their age and state of preservation. Optical replicas may now be used in this research, rather than perishable or particularly valuable originals.

Holography holds out exciting prospects for museums in the organization of exhibitions. There are many exhibits which must be viewed from several angles, or at least from two opposite sides. This is especially true of coins or medals, since the designs on the obverse and the reverse sides are different. Such items as chalices and goblets also fall within this category. Holograms containing every detail of the structure of such items can be produced by taking circular reflective holograms. But this is an extremely difficult procedure: a simpler method is to take two-sided reflective holograms. The latter technique employs a single plate to record separate holograms of the obverse and the reverse of the subject, which must be done in such a way that when reconstructed the images exactly coincide.

The first phase in this process is to take a hologram of the "obverse" side. The exposed plate is then turned round, and a second exposure is taken of the "reverse" side of the same subject. In order to avoid an overlap between the images, it is essential that the exposure be taken with the light striking both the subject and the plate at obtuse angles. When processed, this hologram is set up and illuminated from both sides, so reconstructing an image of both the "obverse" and the "reverse" of the object.

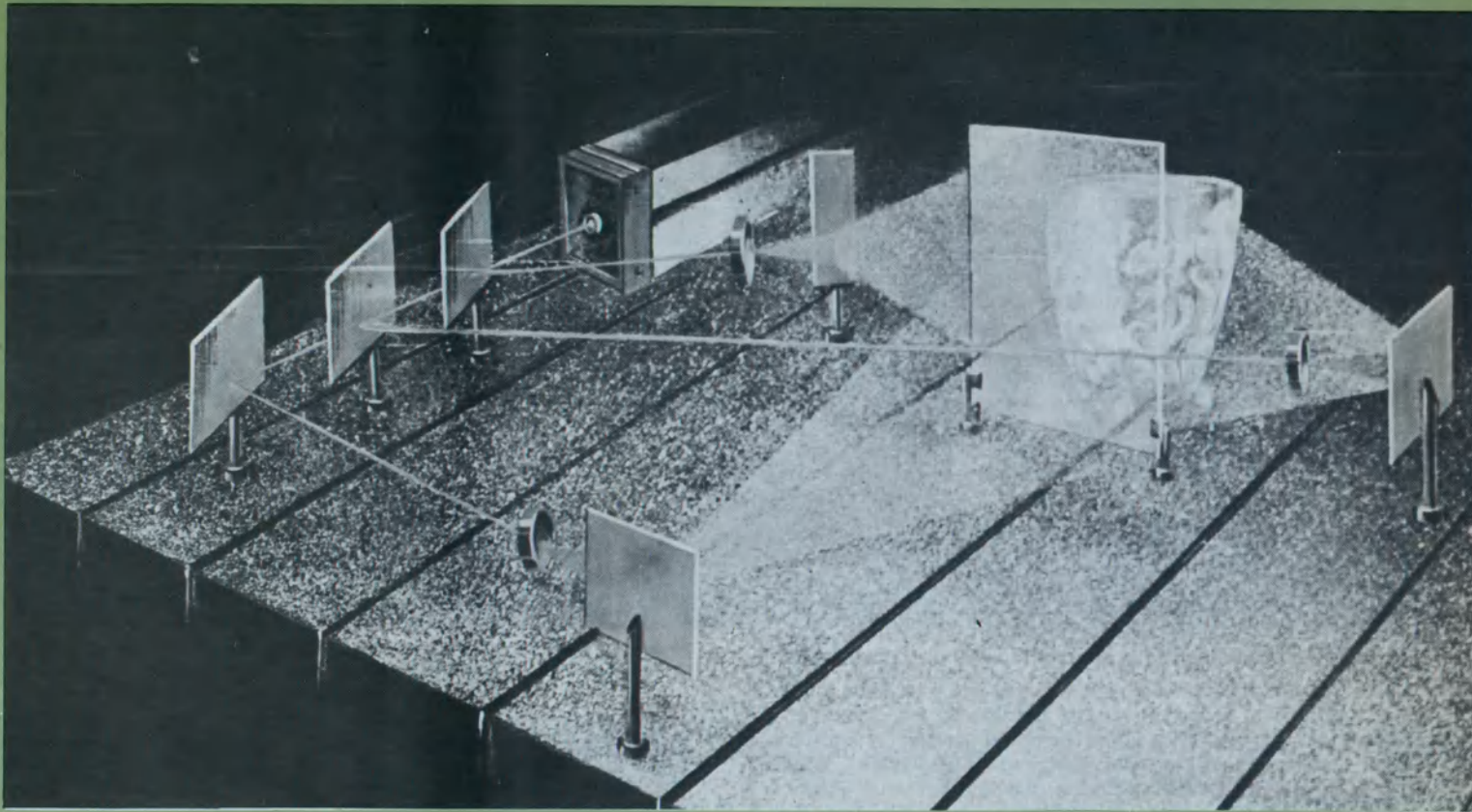
A further use of holograms in museology arises from their ability to reconstruct pseudoscopic images. This method holds particular advantages in those frequent cases where the mould of a seal or a die is too ill-preserved to be used for casting, since an image can be produced of the article which the mould was used to make. The technique is as follows. The exposed and processed hologram is rotated through 180 degrees in relation to the light source, and a beam is directed onto it. The image thus produced is a pseudoscopic copy of the mould—in other words, an image of the real article.

Enlarged or scaled-down three-dimensional images of real objects can also be produced, these methods being particularly appropriate where small objects are to be displayed, or for showing the minor details of a large exhibit. Lastly, the applications of holography are not restricted to historical objects, but may include holographic portraits of contemporary figures, or holographic views of interiors.

One highly successful use of holograms is in travelling or permanent exhibitions, which can quite easily be set up in any locality. This is confirmed by the fact that such exhibitions have been organized in Moscow, Kiev, Yalta, Simferopol, Sebastopol and other Soviet towns and cities. The international exchange of these exhibitions is arousing strong interest. One sign of this is the popularity of an ex-

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Artist's impression of the arrangement of components in a holographic set-up (above) for the production of a hologram of a vase, and (below left) for the reconstitution of a three-dimensional image of the vase from the hologram. Below, simplified diagram of a hologram production lay-out.



Photos © The Ukrainian SSR National Commission for Unesco

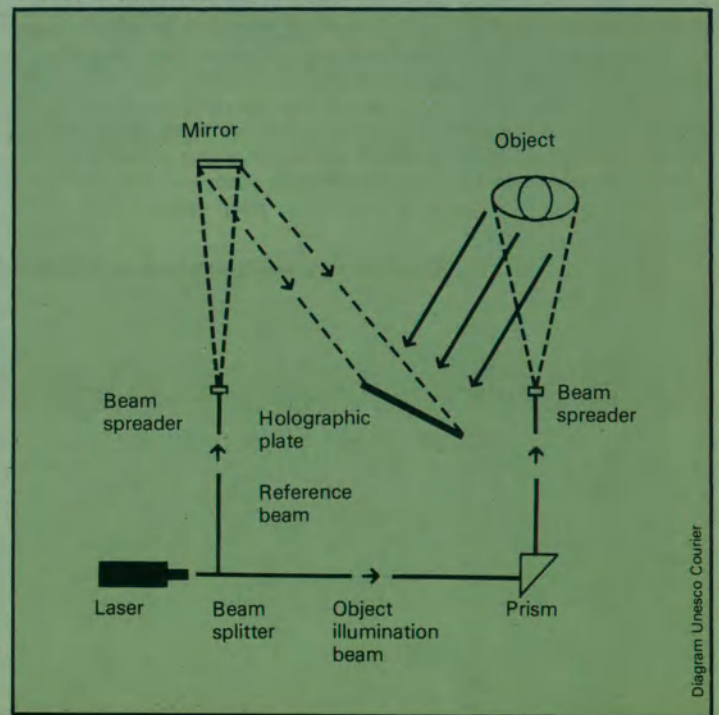


Diagram Unesco Courier

hibition of holograms of historical objects from Ukrainian museums, which has been shown in Belgrade, Yugoslavia, during the twenty-first session of Unesco's General Conference; at the "OPIEM" international conference on holograms in Strasbourg, France; at the Intercamera-79 exhibition in Prague, Czechoslovakia; and at exhibitions in Finland, the German Democratic Republic and elsewhere.

Holography provides enormous potential for the establishment of special thematic exhibitions combining items from several museums. It is notoriously difficult to bring together, for example, the *objets d'art* of antiquity, or collections of Scythian gold, which are housed in museums scattered throughout the world. Yet a specialized exhibition of holograms could be arranged on any such topic, and would prove extremely popular not only among specialist historians or art experts, but also with the general public, since it would bring together articles from a given historical period.

Another possibility would be to arrange for the centralized production and sale of original souvenirs in the shape of holographic replicas of rare ancient objects. These would find a ready market, and would be excellent publicity for museums both at home and among foreign tourists.

In view of the enormous number of exhibits, this list of possible museological applications is sufficient evidence that research institutes alone could not cope with the volume of work involved. This is why the Ukraine, for example, has taken steps to associate both physicists and museologists in attempts to provide global answers to a number of problems. As a first step, holographical laboratories have been set up at the museums themselves. The Applied Holography Laboratory of the Institute of Physics of the Ukrainian Academy of Sciences provides them with scientific and technical advice, trains their experts, and also develops new holography techniques. It is intended that these museum laboratories should produce holograms of all the rarer objects in their collections, and firstly of their perishable articles or those which require special storage or security.

The particular way in which the image is produced in holography gives rise to extensive applications in the field of science and technology. One such application is holographic microscopy. The chief fault of existing microscopes is that a sharp image can only be obtained of the part of the subject on which the instrument is focused, while the rest of the image is out of focus and so lacks definition.

The study of objects which are unstable in time is even more difficult, since the microscope must continually be adjusted. The holographic microscope enables three-dimensional images to be frozen at any point in time for subsequent study in detail. Such instruments are particularly efficient in the study of small suspended particles (aerosols) or of transparent objects. For instance, a holographic microscope has been used to produce a three-dimensional image of a neuron with a diameter of less than 0.001 millimetres.

Among the most rapidly developing applications is holographic interferometry, a technique which draws upon a single hologram's ability to record several successive images. The first exposure records the image of the object at rest: the object is then subjected to an external stimulus, and a second exposure is taken. If a supplementary beam is directed onto the hologram, both images are reconstructed simultaneously, and the light beams thus formed are mono-directional. Since these beams are coherent, interference occurs, and the resulting image is covered with light and dark patterns. This interferential structure, which varies according to the nature of the external stimulus, may be used for such purposes as determining the topology of the subject, identifying deep-seated defects, or comparing two subjects.

■ Ivan G. Yavtushenko and Vladimir B. Markov

Right, holographic exhibition in the Ukrainian Museum of History, Kiev. Itinerant holographic exhibitions open up immense possibilities for bringing the treasures of the world's great museums to the attention of a worldwide audience, at very low cost and with no risk to the treasures themselves. It has been estimated, for example, that the entire contents of a major exhibition in Moscow, "The treasures of the State Museum of History", could be recorded full size on 110 holographic plates measuring 60 by 80 centimetres each, all of which could be packed into a crate of just one and a half cubic metres.

Below, Shermazan Kakichashvili, head of the optical research laboratory of the Cybernetics Institute of the Academy of Sciences of the Georgian SSR (at left of photo) looks at a circular hologram of himself. Illuminated by a laser beam, the hologram is mounted on a turntable which, when turned, shows his head in profile, from behind and full face.



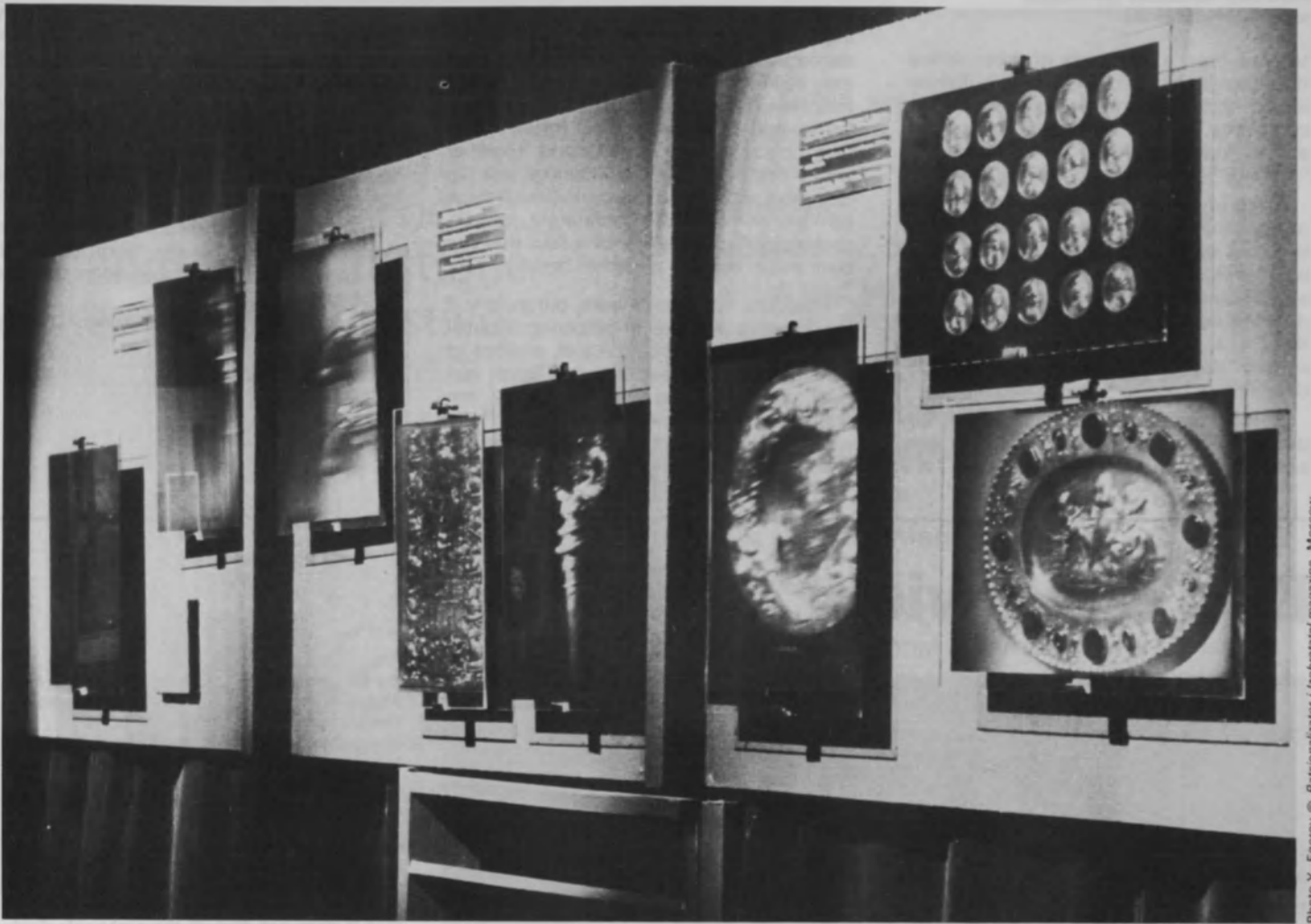
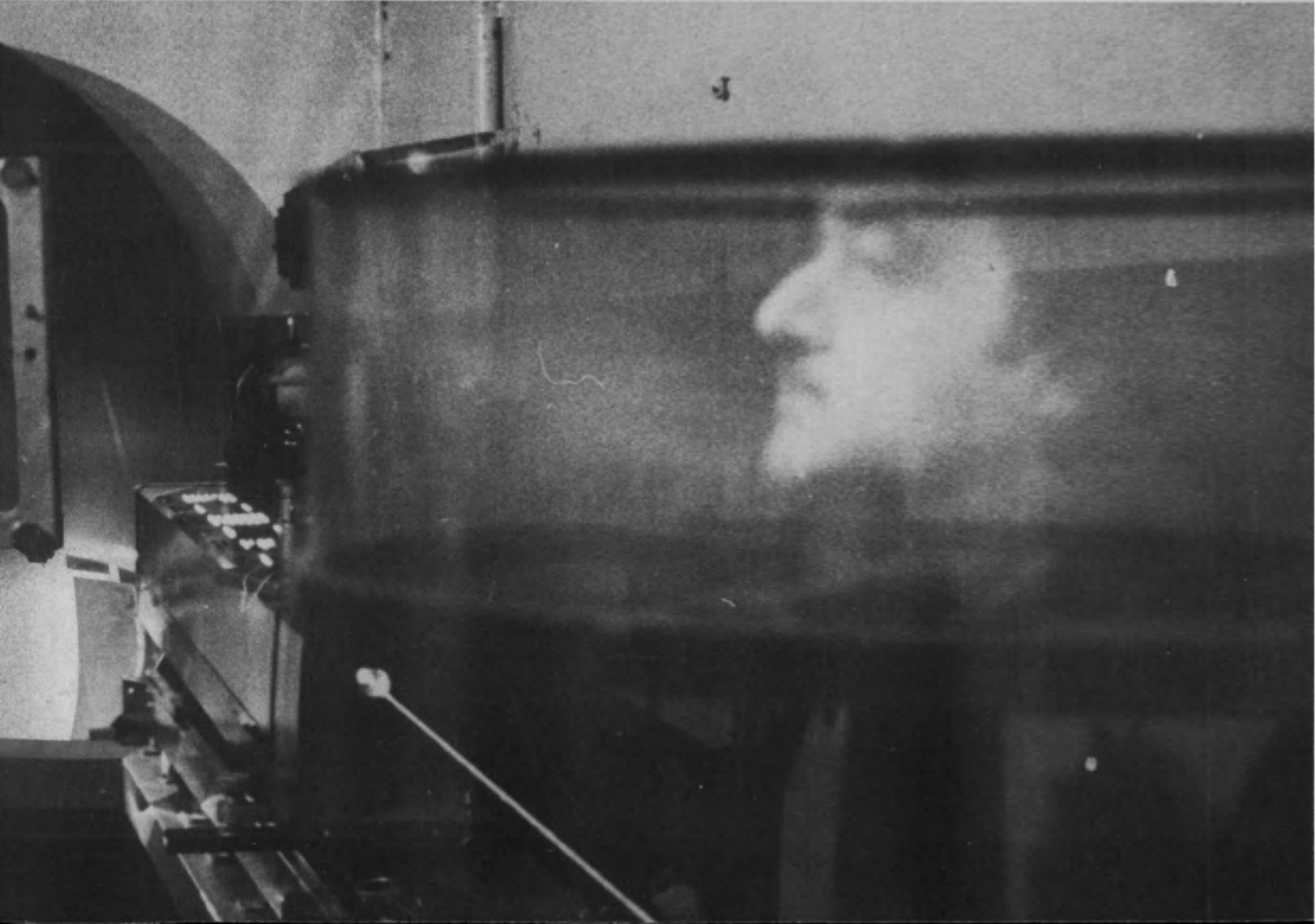


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Photo V.S. Zhydtchenko © The Ukrainian SSR National Commission for Unesco



ROGUES' GALLERY OF FAKES

(continued from page 26)

to have been to the taste of other civilizations besides our own. Vasari, in his discussion of technique in the Renaissance era, comments on the desirability of artificial ageing treatments such as oil-blackening, "pickling" in vinegar and even varnishing.

Silver often carries a slight purplish tinge owing to chloride corrosion. However, this is a slow reaction compared with oxidation or chlorination of any copper present so that alloyed systems like those encountered in debased coinage usually suffer these reactions first. Chemical induction of artificial surface degradation poses no particular difficulty.

Despite the simplicity of the notion few deliberate artificial treatments offer the faker a better reward than burial of his work for a

year or so to allow nature to begin the "ageing" process. Although this requires patience and a steady nerve (someone else may accidentally dig up the forgery before the market is ripe) the method remains an effective one. Even the slightest traces of surface concretions or roots marks together with a degree of "natural" damage and the inevitable softening in decorative brightness can only be helpful in generating a good archaeological provenance for a fake that has been subjected to a period of burial.

This does not always work, particularly if the forger is careless in preparing a burial spot. In 1905 the Abbé d'Aguel, anxious to demonstrate that trade between Egypt and Gaul dated back to Neolithic times, announced the discovery of a number of finely-worked flint implements and weapons. These, according to the Abbé, had been

dug up from the sealed sedimentary limestone layers on the Ile de Riou, off the Marseilles coast. Experts soon became concerned that the surfaces of the objects had a bright, almost lacquered appearance—the kind of surface patination found on objects which have been exposed for long periods to a dry desert atmosphere, not on articles buried in limestone for thousands of years.

The material was certainly authentic and Egyptian but its voyage from Egypt to France had been rather more recent than the Abbé claimed.

■ Stuart J. Fleming

Bird's eye view of the past



Aerial photo (left) taken on a winter's day above Warfusee in northern France shows the plan of a large Roman Villa. It illustrates how airborne archaeology can locate historical sites which may be concealed from the eye of the earthbound archaeologist by centuries of farming activity. Such faded imprints of the human past can be detected by aerial archaeology at certain fleeting moments of the day and at certain seasons, as after winter ploughing. One advantage of this method is that it does not disturb the archaeological site, whereas a badly executed piece of excavation may cause irremediable damage. Surveys being carried out by aerial archaeologists and covering entire regions are today making a major contribution to the recording and protection of the archaeological heritage.

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Museums full of people admiring works of art that are not there may one day be commonplace, thanks to holography, a revolutionary method of creating three-dimensional representations of objects of such perfection that the viewer has the impression that he is looking at the objects themselves (see article page 30). Photo shows a third-century-BC mask of Silenus, the companion of the god Dionysus, discovered in the Ukraine in 1935, as presented at the permanent holographic exhibition at the Ukrainian Museum of History, Kiev.