PREVENTIVE CONSERVATION
PRACTICE, THEORY AND RESEARCH

Preprints of the Contributions to the
Ottawa Congress, 12-16 September 1994
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PREVENTIVE CONSERVATION PRACTICE, THEORY AND RESEARCH

Edited by
Ashok Roy and Perry Smith

Published by
The International Institute for Conservation of Historic and Artistic Works
6 Buckingham Street, London WC2N 6BA
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THE CONSERVATION OF THE CUEVA DE ALTAMIRA

J.A. Herráez, M.A. Rodriguez and E. de Alvaro

ABSTRACT
Considerable, but intermittent, efforts in terms of studies and treatments have been expended by those responsible for the conservation of the Cueva de Altamira. Apart from the control of visitor numbers to a level compatible with the preservation of the important palaeolithic paintings and engravings scattered throughout the cave, the conservation of the site requires the study and continuous observation of the natural ecosystem which has enabled this art to survive for more than 14,000 years. The planning of an appropriate preventive conservation strategy has focused, in the first stages of the current project, on basic installations such as the electrical wiring, the lighting system and security devices, and a data-acquisition system for the continuous monitoring of various environmental factors. The conditions inside the cave make considerable technical demands on complex equipment, which has been designed with a view to maximum functionality and minimum impact on the cave.

1 INTRODUCTION
The Cueva de Altamira is a natural cave formed by karst activity in stratified limestone interspersed with thin layers of clay. It is situated in a hill near the town of Santillana del Mar (Cantabria, Spain), in a rural spot with agrarian and tourist activities. The cave (Fig. 1) takes the form of a wide gallery — except for the end part, known as the Cola de Caballo, which is very narrow and of difficult access — broadening out at various points, and approximately 300 metres long.

The cave was rediscovered in 1868 when a hole opened up because of nearby quarrying. In 1879, Marcelino Sanz de Sautuola and his daughter, María, discovered the paintings immediately provoking a great controversy among researchers about their authenticity. This question was resolved at the end of the nineteenth century with the discovery of other caves with rock art in France.

Although there are paintings and engravings made directly on the stone surface all through the Cueva de Altamira, there are two areas of particular importance. The first, and better known, is the Sala de los Pólicos, where there is a painting of a herd of bison surrounded by other animals, mainly horses and deer (Fig. 2). The paintings were done with mineral pigments — except the black which was obtained from vegetal charcoal (this has allowed its dating by means of $^{14}C$) — and without the use of any kind of organic binding medium. The other special area in the Cueva de Altamira is the so-called Cola de Caballo, where there is a series of sketches in black pigment, notably three animal masks which define a space with a clear symbolic meaning.

Fig. 2 Sala de los Pólicos: female bison.

In the Cueva de Altamira, besides the cave paintings, there is an important archaeological site of the Upper Palaeolithic era. The two phases of activity represented are the Solutrean, with a $^{14}C$ date of 18,540 B.P. [1], notably a series of shoulder blades engraved with female deer-heads, very similar to those engraved along the walls of the cave; and the Magdalenian, with $^{14}C$ dates between 15,910 [2] and 14,480 B.P. [1], the period in which most of the paintings on the ceiling of Altamira were done.

1.1 Conservation of the paintings: 1979-1977
From the discovery of the paintings in 1879 until the present day, various types of activity have taken place inside the cave, both to secure its stability and to make it fit for tourist visits. All these modifications have irreversibly changed the environmental equilibrium that has preserved the site for more than 14,000 years.

The most important interventions, between 1924 and 1935, were the application of hydraulic cement to the fissures in the roof of the Sala de los Pólicos, where there were large cracks (probably due to the work of the quarry mentioned above); the installation of false walls and pillars throughout the cave; and, in particular, the walls closing off the Sala de los Pólicos and the lowering of the floor to facilitate access.

In 1941, new false walls and timber cladding were erected in the Sala de los Pólicos, the latter producing biological contamination that is still visible today in the paintings. The wooden structure remained until 1960, when the floor was lowered further and the walls closing off the Sala were extended to their present arrangement. In this way, the original volume of the Sala, 3,000m$^3$, was reduced to the 300m$^3$ of today (Fig. 3). As a result of these modifications, the physical, chemical and biological factors that determine the condition of the paintings behave very differently to the way they did originally [3].

During the 1960s and 70s, with the tourist boom in Spain, the Cueva de Altamira became an important attraction, involving a massive influx of visitors (Fig. 4). This, together with the modifications made to the cave and the scant interest of the authorities of the time in its conservation, brought about a situation which seriously threatened the preservation of the paintings.

1.2 Research: 1977-1983
From the early 1970s on, various researchers reported on the deterioration of the paintings, with the result that in 1976 a
Committee of Investigation was set up to study their condition. As a consequence, the cave was closed to visitors in 1977 and a research project was initiated in conjunction with the University of Santander.

This project was divided into three phases. The first focused on the definition and characterization of the natural ecosystem of the cave. The second aimed to investigate the influence of visitors to the cave, under a regime of restricted numbers. These two phases continued until 1983, when the contract with the University of Santander ended. The third phase, which was never completed, involved re-opening with a controlled number of visitors and assessing the measures adopted by continuous monitoring of environmental parameters.

In 1982, public visits began again with a fixed quota of visitors based on the provisional conclusions of this project. In 1990 the automatic recording system, which had never worked properly, ceased to function.

1.3 Research: 1990-1993

In 1990, scientists from the Instituto de Conservación y Restauración de Bienes Culturales (ICRBC) of the Spanish Ministry of Culture prepared a programme of work in connection with a new research project that will extend our knowledge about the physical, chemical and biological mechanisms of the ecosystem, and make it possible to control the conservation of the Cueva de Altamira. This programme of work involved collaboration with the Consejo Superior de Investigaciones Científicas (CSIC), and a list of urgent action. This included the cleaning of the cave and the removal of the old electrical system, since this posed a serious risk of fire.

Both these were accomplished during 1993, resulting in the removal of almost one tonne of electrical wiring and six tonnes of various materials abandoned in the cave.

2 DESCRIPTION OF THE ECOSYSTEM

From a physical point of view, the Cueva de Altamira is an ecosystem consisting of a natural cave in a limestone mass, so that, in spite of the artificial modifications to which it has been subjected (Fig. 3), the stability of the structure is dependent on geological and hydrogeological processes. The only means of air exchange with the exterior is the entrance, closed by a metal door with orifices that allow some ventilation. This isolation from the outdoor environment gives an atmosphere which is very stable but also very sensitive to any disturbances. The slight fluctuations which are natural to the ecosystem are related to factors of the external climate (insolation, precipitation, wind and so on). On the other hand, the more important disturbances are related to the occupation of the cave, from the opening of the door until it is closed after the last person has left.

The surface of the terrain above the cave is covered with vegetation and protected to some extent from activities which could cause contamination, disruption or vibration of the soil. Situated in the north of Spain, at a short distance from the coast, the area is characterized by a temperate and humid climate, with a mean annual rainfall of 1,200mm.

2.1 Microclimatic characteristics and conservation problems

According to data from earlier studies [4, 5], the most relevant characteristic of the cave microclimate is the stable temperature of the air and the rock surface. This moves in a narrow band around 14°C, while the relative humidity fluctuates between 96 and 98%. The differences between the various zones of the cave are very small, and consequently the convective movements of the air masses are very weak.

Most of the internal surfaces are permanently bathed with water, since there are numerous points of infiltration.

In these conditions, the principal mechanisms of deterioration of the paintings and engravings are:

(a) Precipitation or dissolution of calcium carbonate which can either obscure the paintings or cause the dissolution of the supporting rock, depending on the thermohygroscopic conditions and the levels of carbon dioxide in the air of the cave.

(b) Deposition and precipitation of transported or dissolved materials in the infiltrating water.

(c) Loss of pigment due to the washing action of infiltrating water.

(d) Loss of paintings due to reduction in the cohesion of the pigments and/or their adhesion to the rock, produced by
swelling and shrinking caused by changes in moisture content and temperature.

(e) Growth of microorganisms that can obscure and degrade certain components of the pigments and the supporting rock.

(f) Cracking or loss of fragments due to mechanical movement, vibration or collapse.

3 PROJECT FOR CONSERVATION OF THE CAVE

The approaches to the project are both theoretical and practical since, although the design of the equipment involves great technical difficulties, experience proves that it is more difficult to instil the attitudes required for preventive conservation.

There are some data on the microclimate of the cave from as early as 1930 [6]. Since then, data have continued to be collected, but in a rather episodic manner. In connection with the studies which began in 1976, recording equipment was installed in the cave to allow the systematic acquisition of data on air temperature, relative humidity and carbon dioxide levels. A short time later this equipment was modified and complemented with a data-acquisition system for measuring and recording data on the temperature of the rock surface. The most recent studies, during the period 1979-83, were achieved with this continuous recording equipment and various apparatus and monitors for point measurements. From then on, following the adoption of measures derived from these studies relating to the number of visitors to the cave, automatically recorded data were stored routinely, without being adequately analyzed, due to a lack of technical staff for this task. The equipment deteriorated through lack of maintenance and eventually it became obsolete.

Although the effort expended on this research was considerable, it seems that the institutions responsible for the conservation of the cave considered that their work was then complete. This attitude, only too common in those with political responsibility for the conservation of cultural property, is incompatible with preventive conservation. Efforts are reduced to sporadic measures, consisting in this case of closing the cave or restricting the number of visitors. Having failed to adopt the recommendations proposed by the team of investigators [7] on the need for continuous monitoring, we have now reached a point where, although the recommendations of the latest studies are rigorously applied, there is a lack of the objective data necessary for the conservation of the cave and its rock art.

Against this background, equipment has been designed for the current project that will allow the investigation of the key mechanisms which affect the conservation of the cave in general and its paintings and engravings in particular, with continuous monitoring of certain environmental factors and assessment of the effectiveness of the present regimen of visits.

Other fundamental aspects developed in the project have been the installation of an adequate electrical infrastructure and lighting system, and changes to the exterior installations; consideration has also been given to the use of the land on the surface in the area which affects the cave. All these aspects, including the urgent action mentioned above, have been integrated in the present project, giving it a holistic emphasis which, in the opinion of the authors, should be the focus of preventive conservation.

4 CRITERIA FOR THE DESIGN OF EQUIPMENT

The complexity of the conservation of a natural ecosystem like the Cueva de Altamira makes it necessary to collect a large quantity of data on a variety of factors, many of which require continuous and simultaneous monitoring. The acquisition of these data requires, also, an assembly of different kinds of sensors and devices, either standard or adapted, selected from the choices offered by current technology. On the other hand, the conditions inside the cave, with a relative humidity constantly near saturation, limit the function and durability of these devices. The positioning of the sensors and the installation of the wiring are considerations which in other cases may be secondary but at Altamira it is very important to get the system working correctly and avoid an adverse impact on the cave.

As a result of these complications, a system has been designed to record various microclimatic, hydrogeological and structural features of the cave which will allow us to investigate and monitor the dynamics of the ecosystem. The data collected will form the basis of further study programmes, for example of the biological factors.

4.1 Possibilities for expansion

To provide for possible expansion of the monitoring capabilities, which may be required by new studies, a fundamental design requirement for the equipment has been a sufficiently large and versatile data-acquisition system and its connection network. The aim is to equip the cave with a suitable infrastructure that will avoid overload and inadequate capacity within a short period of time.

4.2 Ease of use

Another aspect given particular attention is the ease of use of equipment which is technically complex and involves the handling of a large volume of data. Software has therefore been custom-designed to work on two levels: one basic, to carry out the recording and sorting of the data, the other more elaborate, with automatic analysis of certain factors or sets of factors. This structure allows access to the data required for each type of study, as well as automatically displaying the relevant parameters for conservation. In this way an attempt is made to ensure that the information supplied automatically is intelligible to staff without specialized training.

4.3 Possibilities for communication

A third essential requirement was to provide the system with the capacity for communication and remote operation. The location of the site and the lack of specialized personnel in situ have led in the past to the routine collection of data that were not analyzed, until the equipment finally ceased to function through lack of maintenance.

Communication by computer modem allows access to data at any time, and from whichever research centre is in charge of carrying out a particular investigation.

It is essential for those responsible to recognize that it is no use making available good equipment if nobody is in charge of analyzing the information collected.

4.4 Accessibility and reversibility

The installation of the equipment has been carried out according to criteria very different from those adopted in the past. The system of sensors and its cabling, the only components installed inside the cave, have not been hidden nor has any attempt been made to make them look like the rock. On the contrary, they are visible and accessible. This achieves a double purpose: their accessibility facilitates maintenance, and they could be easily dismantled and moved without damaging the cave.

As far as maintenance is concerned, it is essential to plan a programme for calibration of the sensors and general supervision of the installation. This is especially important in the damp conditions inside the cave.

5 DESCRIPTION OF THE EQUIPMENT

The equipment for environmental monitoring consists of the following components:
(a) A central registration unit for a system of data acquisition, with an initial capacity of 100 channels, but capable of almost unlimited enlargement, and a computer to control the logger, with a modem card for communication by telephone line.

(b) Software specifically designed for the conservation needs of the cave.

(c) Sensors of maximum quality and precision to monitor the fundamental parameters in relation to the processes of deterioration described above: temperature and relative humidity of the air; surface temperature of the rock; carbon dioxide content of the air; ventilation; movement of blocks of rock; flow of infiltrating water. (All the electronic components of the sensors have a protection factor of IP65.)

(d) For the monitoring of external conditions there is a meteorological station which sends data to the logger on the temperature and relative humidity of the air, precipitation, wind speed and direction, insolation, soil temperature, atmospheric pressure and so on.

(e) The sensors are connected by means of cabling with suitable insulation and all the sensors have an output signal intensity converter (4-20mA) to avoid loss of signal.

(f) Most of the sensor devices are supported on the conduit for the cabling, and the link to the measuring point is achieved by means of special supports, avoiding potential damage to the rock.

(g) To stabilize the current and avoid possible short breaks in supply, the equipment has been isolated from the commercial electricity network by means of an uninterrupted supply unit.

(h) The colorimetric monitoring of the paintings is achieved, at present, by means of a series of portable monitors, until some means of automation can be provided.

6 CRITERIA FOR THE LIGHTING SYSTEM

6.1 Conservation
Maximum levels of illumination do not exceed those which were used previously (10 lux on average). This level is quite sufficient, given the nature of the site and the process of visual adaptation before visitors enter the Sala de Polícrions. Ultraviolet radiation does not represent a problem for the conservation of the paintings at this light-level.

Heat emission is reduced to a minimum by the use of better lighting, better distribution of lights, and high-quality auxiliary devices. Central monitoring of flux and time of exposure will allow us to assess the effect of the lighting system on changes in the environmental conditions within the cave.

Special attention has been given to the positioning of the lights because the previous system, with lights half-hidden in turns of the path and so on, caused local proliferation of certain microorganisms (bacteria and algae).

6.2 Function
The minimum requirements of the system answer the following needs:

(a) Safe passage. The level of natural dampness and the ingress of water, together with the physical structure of the cave, make this a relatively perilous area to enter. It is necessary to ensure good visibility along the various paths.

(b) Appreciation of the larger spaces. The cave is of considerable length, and at intervals there are spaces of large volume. Fortunately, these are not of great importance, apart from some paintings and engravings at human height, so it is sufficient to give an overall impression of space.

(c) Specific lighting of certain paintings and engravings which are normally shown to visitors.

(d) Adequate vision in the Sala de los Polícrions. The most important paintings are concentrated here and the lighting requires special attention.

6.3 Visual comfort
Three fundamental aspects have been considered:

(a) Taking into account the location of the Sala de los Polícrions (Fig. 1), near to the entrance of the cave where visual adaptation takes place, there must be an adequate variation in the gradients of illumination in this zone. A short pause at the beginning of the path can help this adaptation.

(b) The lights must have as high a chromatic reproduction index (CRI) as possible. It seems ill-advised to have an incandescent lamp in a traditional luminaria; considering the nature of the space, the levels demanded and so on, new ranges of compact fluorescent lamps with a CRI slightly above 90 are the chosen solution.

(c) Removal of glare, or reduction to a minimum. This consideration is particularly important in the Sala de los Polícrions.

6.4 Aesthetics
It is very common at this type of site to seek to create a theatrical effect by using redegrade placing of lights, coloured bulbs and so on. In fact, that is what the previous system was like. In some caves it can look good, but not at Altamira. Therefore, two requirements were set:

(a) The system should be as light as possible.

(b) The colour must provide sufficient contrast with the general tonality, while at the same time being neutral.

6.5 Versatility
The infrastructure of the system should have the capacity to support any additional wiring demanded by new equipment and services. The spotlights for the large spaces should have at least two degrees of freedom.

6.6 Stability
Bearing in mind the environmental conditions in the cave, all the materials of the new system must be physically, chemically and biologically stable.

6.7 Reversibility
As with the rest of the equipment, the installation of the lighting system must avoid the risk of damage to the cave and allow easy dismantling if necessary.

7 DESCRIPTION OF THE LIGHTING SYSTEM

7.1 Infrastructure
The electrical installation runs along a conduit, more than 250m in length, which also houses the cabling for the sensors of the data-acquisition system. This conduit is visible, supported on small rods fixed in the floor, and only the branches which cross the principal path and those in the Sala de los Polícromos are buried. There are power points every 25m. The conduit also carries the lighting system for the signs and other services.
7.2 Sala de los Polícramos
A luminaire has been specially designed for this space, equipped with a compact fluorescent lamp, with high-frequency loading that allows regulation of the illuminance. It is also equipped with a special asymmetric reflector, due to its positioning and the very irregular surface of the ceiling.

Glare is avoided by the use of a glass which incorporates micrometric oblique laminae. From most angles of observation the surface appears dark.

According to studies carried out [8], the palaeolithic inhabitants used a strong light with a colour temperature of 1600K, produced by the combustion of bone marrow and tree bark, for illumination during the execution of the paintings. Bearing this in mind, we have tried, within the possibilities offered by modern lighting, to approximate this by using lights with a warm tonality.

7.3 Large spaces
In the largest spaces of the cave (the Gran Sala and the Hoya, Fig. 1) three directional spotlights with compact fluorescent lamps (26W) have been installed. The beams are directed towards the ceiling, giving adequate light for the whole area with minimal power.

7.4 Signs
The conduit extends along the path used for public access. On one side, 7W fluorescent lamps with appropriate reflectors are set in at 7m intervals. In this way, average values of illumination of 3-4 lux are achieved. In dangerous transit areas such as steps and so on, the distance between lights is reduced to 5m, giving values of 5-6 lux.

7.5 Lighting of details
The illumination of three motifs normally shown to visitors is envisaged:

1. The large engraved horse on one side of the Sala de los Muros, lit with a spotlight with a compact fluorescent lamp (26W), giving a more or less raking light.
2. The painted horse in the corridor which joins this room to the Gran Sala, with frontal illumination by a spotlight with a 60W PAR (parabolic) lamp and a narrow beam (12°); this spotlight is mounted on a bracket fixed to the conduit.
3. The bison in the Hoya, illuminated in a similar way to the painted horse.

7.6 Alarm system
Telephones have been installed in clearly marked watertight boxes, for communication with the outside world in case of emergency.

7.7 Emergency system
The electrical system is equipped with a one-hour uninterrupted power supply and acoustic warning of its operation inside the cave. The conduit also supports the signs indicating the way out.

7.8 Technical data of the lights
The type and photometric curves of spotlights have been defined by means of in situ tests, because of the impossibility of doing reliable calculations.

All the spotlights are painted black and have a protection factor of at least IP55.

The total capacity of the lighting installation is 763W, with 105W (which can be regulated) in the Sala de los Polícramos.

8 CONCLUSIONS
This project has a number of objectives. The first is that closer study of the functioning of the ecosystem will serve to define a theoretical model which can be used to predict certain phenomena and evaluate their impact on the conservation of the cave, its paintings and engravings.

On the other hand, the clear testimony of the paintings which have been preserved for a period of 14,000 years is sufficiently significant to set these objectives in their right perspective. It seems, therefore, that the chief objective must be adequate control of the impact of visitors, methods of study, environmental management and so on. The more ambitious, and controversial, challenge is to define the possible ways of intervening to minimize the effect of the natural processes of deterioration which undoubtedly affect and have affected the paintings and engravings during such a long period of time.

Having said this, it can be argued that the most ambitious objective is to convince those responsible that this project does not represent an end in itself but an approach which requires continuous development.

ACKNOWLEDGEMENTS
We would like to mention here colleagues who, although they are not involved in the current work, have contributed to the development of the project: José A. Lasheras, Director of the Museo y Centro de Investigación de Altamira; Irene Arroyo, biologist, Angel L. Sousa, architect, and Concepción Cirujano, restorer, all of ICRBC; and Manuel Hoyos, geologist, of CSIC.

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