Muriel Mauriac

Lascaux
The history of the discovery of an outstanding decorated cave

Introduction

The casual discovery of Lascaux cave by four teenagers, Marcel Ravidat, Jacques Marsal, Simon Coencas and Georges Agniel in September 12, 1940, during troubled time, have changed the perception of modern man about prehistoric times. This discovery, immediately considered as a major event, offered the world a cave free of any exploration, arousing the enthusiasm of the international scientific community but also of the general public (Fig. 1&2). However, its opening to the public and the incredible excitement it generated, rapidly destabilized its fragile natural environment. From crisis to solutions, Lascaux will be a place of many experiments that have willy-nilly turned it into a laboratory for the conservation of decorated caves. Thus the story of its preservation will greatly improve our knowledge about these complex environments.

Fig. 1. Testament of the popular success of the first visits to Lascaux: Visitors of all ages flock to the cave entrance. © DR

Presentation of the Lascaux cave

The Lascaux cave is located in Montignac, a town in the Dordogne, an extremely rich region for prehistoric sites. For instance, we can mention as guidelines the *Abri de Cro Magnon*, the cave of *Font de Gaume*, the rock shelters called *Laugerie Haute* and *Laugerie Basse.* Many archaeological remains are today exhibited at the National Museum of Prehistory in Les Eyzies-de-Tayac. If the conditions presiding over the discovery of Lascaux, a cave located on a plot owned by a private owner, the Comte de la Rochefoucauld, aroused enthusiasm, the exceptional quality of the paintings, the freshness of the colours and the richness of the artistic representations - about 2000 with more than 900 figures - certainly explain the immediate impact and fascination that the cave arose. It was quickly considered as a World Heritage masterpiece. The State immediately

Fig. 2.Hall of the Bull, october 1940. In the center, with arm extended, Count Begouën and Abbot Breuil. Seated in the foreground, two young inventors: Jacques Marsal (profile) and Marcel Ravidat (front).
Work is in progress to lower and even out the ground surface in the cave to facilitate visitor access. © DR

recognized its outstanding heritage value by protecting it as a Historical Monument, in December 27, 1940, just a few months after its discovery. Its placing in 1979 by UNESCO on the World Heritage List, with 14 other prehistoric sites and decorated caves in the Vezere Valley, is the achievement of this recognition (Fig. 3).

The hill on which Lascaux is located is a butte of the Upper Cretaceous limestone plateau of the region (Fig. 4). A little apart from the decorated sites concentration we know today and located around Les Eyzies-de-Tayac, the Lascaux cave is situated in a limestone geological setting at the interface of the Upper Coniacian and Lower Santonian (Fig. 5). Its originality lies in its location -shallow depth-, its small volume and its high rate of CO2. This has be pumped quickly to limit the risk of precipitation of calcite on the walls, to avoid dissolution of carbonate substrates by forming carbonic acid, but also for the convenience of visitors.

The cave is divided into several autonomous spaces. About 250 meters long, it opens onto the Hall of the Bulls, prolonged by the Axial Gallery, then on the right, a side Gallery called the Passageway is followed by the Apse. To the left of the Apse is the Nave, the Mondmilch Gallery then the Chamber of the Felines. Finally, at the bottom of the Apse is the Shaft (Fig. 6).

According to its areas, the cave has various mineralogical characteristics. There is a wide variability of surface - a dozen - especially in terms of hardness, grain size, reflectance. These differences are distributed between the Hall of the Bulls and the Axial Gallery on the one hand, and the Passageway, the Apse, the Nave and the Shaft, on the other hand. In the first sector, the figures are on calcited limestone surfaces too hard or too irregular to be engraved. The walls are adorned with paintings realized by pigments application and also spray technique (Fig. 7& 8). In contrast, in

Fig. 3. Map of prehistoric sites of the Vezere Valley.
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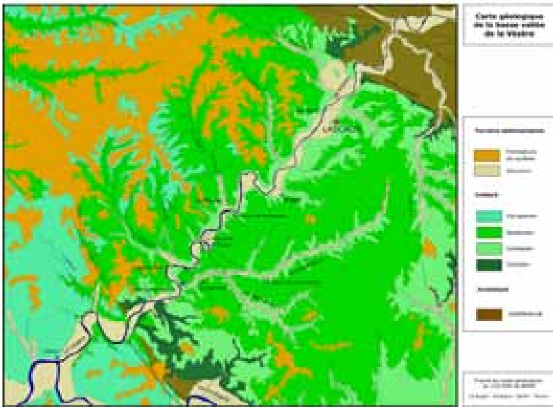

Fig. 4. Geological Map of the lower Vezere valley.
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Fig. 5. Geological Map of the Lascaux hill. © B. Lopez - Université Bordeaux 1-Laboratoire Ghymac

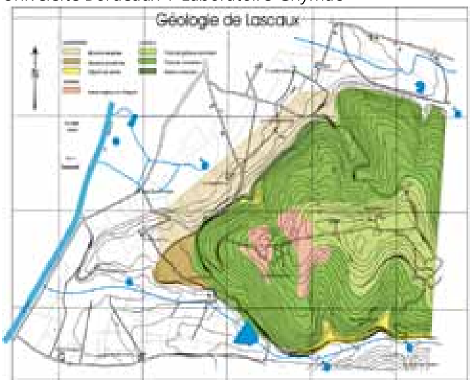


Fig. 6. Lascaux plan. © MCC-CNP

the second area, the limestone surfaces, not covered with calcite or locally calcited over, are soft surfaces. The works are engraved and painted by spray technique (Fig. 9&10). It is worth noting that the very nature of supports may explain the conservation status of some works, already damaged at the time of the discovery.

Prehistoric artists beautifully adapted to the physical characteristics of the walls to take better advantage of them (Fig. 11). Some even speak of "participant cave" to explain the distribution of works in the cave. Those different mineral surfaces have resulted in a perfect adaptation to media paintings. The techniques were also adapted to the nature of the substrate such as engraving on soft limestone surfaces or projecting pigment onto calcited surfaces. The important archaeological material discovered by André Glory at the foot of the walls attests to the multiplicity of the techniques used.

The pigments used, iron oxide for red, brown and ocher, and manganese oxide for blacks present a great diversity especially in the Hall of the Bulls and the Axial Gallery (Fig. 12). Between 1996 and 2005, hundreds of microscopic samples were lifted to study the colors and the methods used. These analyses performed by the C2RMF laboratory have shown the great geological diversity of the different families of oxides used (pyrolusite,

Fig. 7. Axial Gallery. Second and Third Chinese Horses. © MCC-CNP

Fig. 8. Axial Gallery, The Confronted Ibexes. © MCC-CNP

Fig. 9. Nave, Black Cow. © MCC-CNP

Fig. 10. Apse, Yellow Horse. © MCC-CNP

Fig. 11. Axial Gallery, The Upside-Down Horse. © MCC-CNP

manganite, romanechite in particular). The pigments were expertly prepared from blocks of raw material used without being heated.

If among all the figures horse represents 60% of the bestiary, it is the aurochs, which only represents about 4% of the bestiary, that was chosen for the most spectacular figures, especially the fourth bull on the right wall that measures 5.5 meters. This aurochs is considered as one of the largest representation of prehistoric animals (Fig. 13).

In the weeks that followed the discovery, some work was carried out by the owner who wanted to open the cave to the public to promote prehistoric art awareness and had to facilitate access to the cave. The discovery hole through which the four young boys had accessed this treasure was then modified for the first time (Fig. 14&15). But it is from 1947 that the owner undertook significant work carried out without any real archaeological monitoring: monumental entrance arrange-

Fig. 12. Axial Gallery, Ceiling. © MCC-CNP

Fig. 13. Hall of the Bull, Fourth Bull. © MCC-CNP

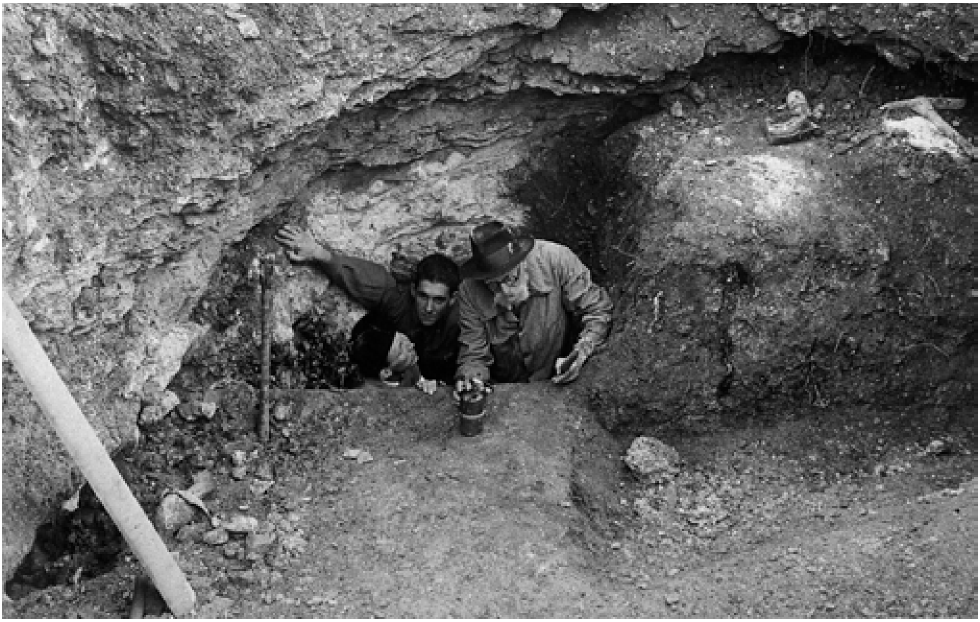


Fig. 14. Lascaux cave, entrance of the cave. Count Begouën. © DR

Fig. 15. Entrance of the cave by 1940. Count Begouën, Jacques Marsal and Marcel Ravidat, Professor de Fribourg, Paul Fitte, Abbot Breuil, Abbot Sainsaulieu, Maurice Thaon, Léon Laval, René Barotte. © DR

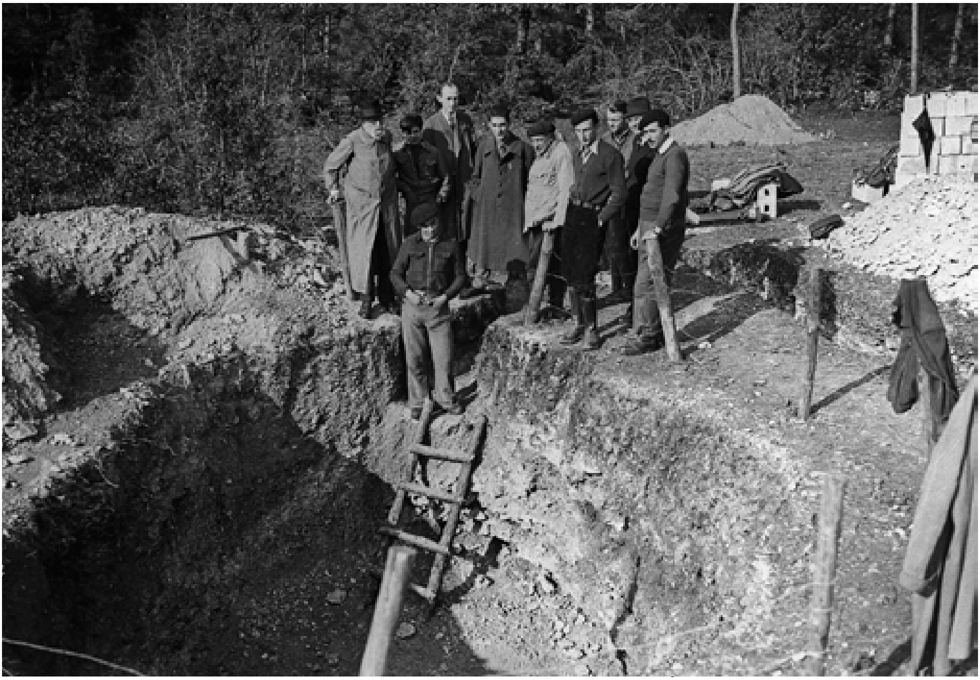


Fig. 16. Lascaux cave. Significant terracing work to enlarge the entrance. © DR

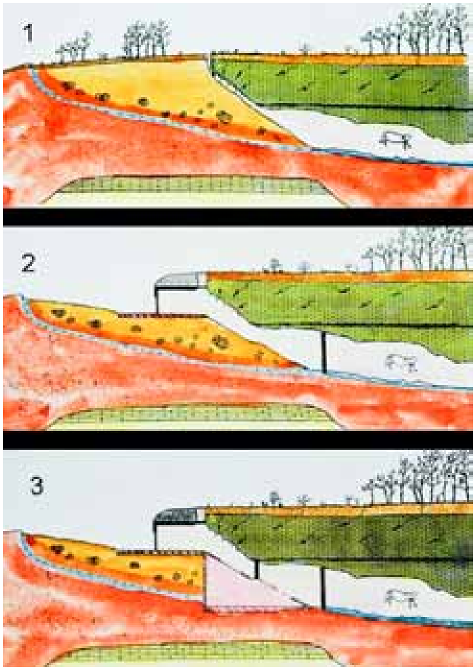


Fig. 17. Schematic longitudinal cross-section of the cave at differents periods. © MCC-CNP

Fig. 18. Passageway. Vestiges of a painted Horse where corrosion has a long time ago,damaged the surface. © D. Bouchardon-LRMH

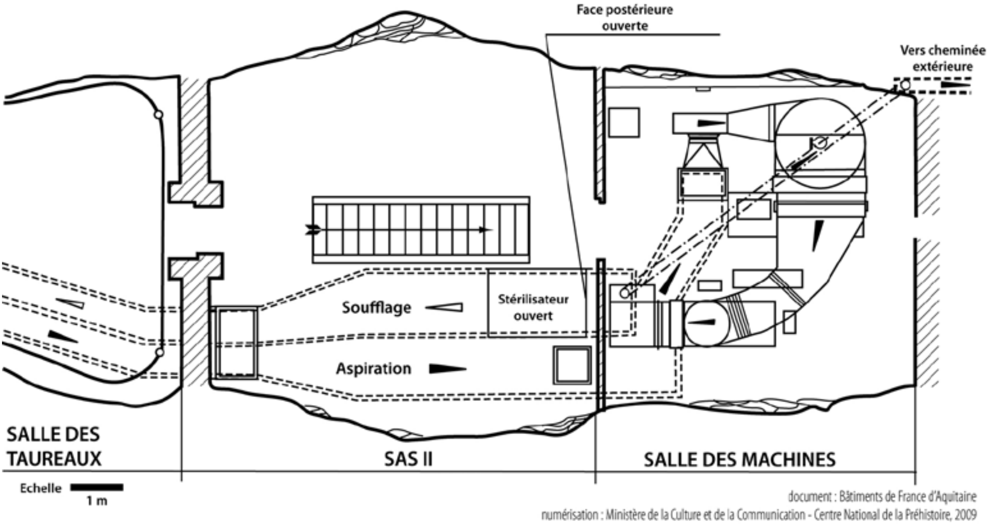


Fig. 19. Plan of the machine installed in Lascaux cave in 1957- 1958. © MCC-STAP24

of the porch (fig. 17). Several tons of sediments were then either removed out of the cave, or thrown into the Shaft where they were extracted in 1958 by André Glory. After these substantial "improvements", Lascaux was opened to the public July 13, 1948.

Due to its characteristics, the cave quickly proved fragile and its fame increased its vulnerability. Indeed, the huge interest it aroused, the desire to show this masterpiece to an ever increasing number of visitors - up to 1800 a day - the changes carried out, including the modification of the discovery hole, soon represented a threat to its conservation, with sudden and sometimes dramatic episodes, disrupting the conditions under which the cave had been up to his discovery. Further work was decided, having drastic effects on the cave environment and therefore on its climate and biological balance. Conservation problems soon appeared.

The difficult conservation of the cave from 1948 until its closure in 1963

It would be wrong to imagine that for more than 18,000 years the cave had remained in a stable climate. During its early history, it underwent alterations, particularly in the Right Gallery such as the Passageway, where the paintings, as could be observed since its discovery, have mainly disappeared. Figures have vanished, leaving place to engraving and pigment remains on the eroded walls (Fig. 18). The old alterations of some walls and some pigment disappearance as in the Passageway may be explained by air convection associated with the flow of water that had invaded at a time the "gours". Recent analyses conducted at the Atomic Energy Commission in Saclay give a possible dating for the growth of the "gours" calcite elements: between 9530 and 6635 BP or between 8518 and 5489 BP. It would seem that the "gours" have been water for a rather long time.

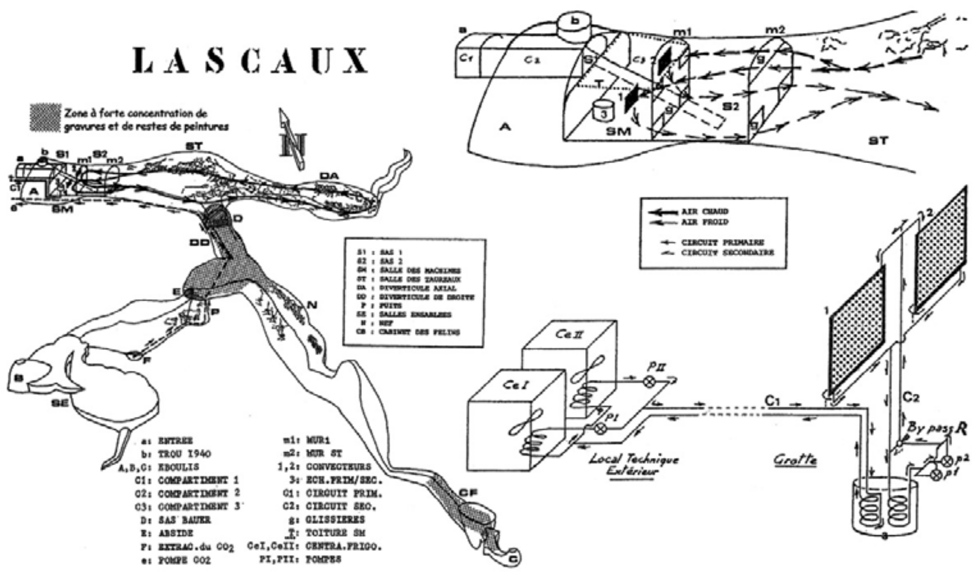
By 1949, the presence of algae was reported and two Airlocks were arranged to create a buffer zone between the cave and outside. In 1955, the intermittent water condensation on the walls, a high temperature and a high level of CO2 worried the officials in charge of the cave for the conservation of parietal art. This added up to the inconvenience created by the CO2 high rate for visitors, especially numerous that year: nearly 30 000.

In 1955, evidence of damage appeared on the walls. The cave then knew by 1957-1958 a new phase of development work. The aim was to restore the climate balance disrupted by the flood of visitors, especially during summer when the cave received over 1800 people a day. At the request of the Historical Monuments Department, and under the supervision of the Chief Architect of Historical Monuments Yves-Marie Froidevaux, an impressive atmosphere regeneration system was installed in 1958 in the Machine Room. Located upstream from the decorated part of the cave, it was under the entrance strairway, instead of the debris cone (Fig. 19). This system had been dismantled in 1966 after the 1962-1963 first bioclimatic crisis.

Developed to reduce C02 excess, the system was supposed to optimize the air renewal in the visited parts of the cave, extracting the stale air and reinjecting regenerated air through underground pipes. Thermal regulation of the cave was maintained at 14° C. But these improvements brought about the destruction of the debris cone and led to a very important sediment removal -over 70 meters of galleries were concerned but without reaching the Chamber of the Felines nor the Shaft-. The work that deeply changed the volume of several sectors and especially that of the Passageway, was managed with an archaeological monitoring retrospectively judged insufficient. Thus, 440 m3 of sediment were removed, that is to say about 1,200 tons. Recruited by the Minister of State for Cultural Affairs to study and make tracings of the decorated walls and to supervise the earthworks, André Glory Glory traced and drew more than 1400 engraved figures without touching the walls. In addition, he made numerous cross-sections of the passages. Despite limited equipment and human resources, he thus collected a huge and precious amount of information. During this work André Glory discovered a number of portable objects, 112 flints, 13 nucleus, 2 bone needles including one with its eye, a few scattered fragments of charcoal that were C14 dated, remains of reindeer and stag bones, grinding stones and the famous lamp preserved today at the National Museum of Prehistory in Les Eyzies-de-Tayac. Part of the archaeological layer of the cave however had irretrievably been destroyed.

The work to stabilize the climate of the cave proved to be insufficient, since in 1960 the curator of the cave, Max Sarradet, reported the appearance of green stains on the walls, which would increase between 1962 and 1963 with the presence of colonies of algae in the

Fig. 20. Plan of the machine installed in Lascaux cave in 1965. © MCC-CNP



Hall of the Bulls and the Axial Gallery. He also pointed out the formation of a calcite veil developing due to condensation and over-frequentation.

Faced with this alarming situation, the proliferation of green stains and the appearance of a white calcite veil, André Malraux, Minister of Cultural Affairs, appointed in March 1963 a "Committee for the Study and Preservation of the Lascaux cave". The Committee's task was to identify a set of parameters that determined the climate and microbiological balance of the cave. The Committee, which would meet until 1976, imposed in April 1963 to the Count de la Rochefoucauld, the owner, the closure of the cave to the public. The analysis carried out revealed a large microbial diversity, with *Chlorococcales, Bracteacoccus sp*, as the main type of algae. To curb microbiological growth, the Committee advocated a cure based on sprays of antibiotic solutions and the use of formalin solutions at different concentrations onto the floors and walls. A basin with formoldehyde in water where visitors had to disinfect their shoes completed this treatment. The appearance of worrying limestone concretions (a light veil of opaque white calcite) led the Committee to set up the daily monitoring of climate measures and to remove the machine "Froidevaux", deemed inappropriate. In 1965, a new climatic regulation system, with static batteries installed in the Machine Room (secondary circuit) and refrigeration units located outside the cave (primary circuit), was implemented. This artificial cold point that replaced the natural cold point linked to the debris cone, allowed moisture from the air to condense, when too abundant, on the batteries and not on the walls. It was also supposed to maintain the air convection in the cave (Fig. 20).

From its discovery to its closure in 1963, the cave was thus subject to many evolutions due to its adaptation to the visits and to the conservation works realized, sometimes at the expense of its archaeological integrity.

The improvement of the Lascaux site

The closure in 1963 overnight prevented access to one of the most famous prehistoric sites, thus challenging an economy fully connected with the touristic exploitation of the site. The conditions for conservation of the cave and its apparent stability allowed the Committee to permit visits to small groups, 5 people a day, 5 days a week for 35 minutes. But this was quite insufficient to deal with the popular success of the site. After acquiring the cave from the Count de la Rochefoucauld, on January 3 of 1972, the State allowed him, in consideration of the closure forced upon him, to make a facsimile of the cave. However, the financial cost of such a project did not allow the Count de la Rochefoucauld to complete it and it was in fact achieved by the Dordogne General Council with the help of the State. The operation was entrusted to the Régie Départementale du Tourisme of the Dordogne, transformed into a semi-public company in the late 1990s, SEMITOUR, which still remains the facsimile's owner. The partial reproduction of the cave, the Hall of the Bulls and the Axial Gallery, now worldwide known as "Lascaux II", was built and inaugurated in 1983 on the Lascaux hill, a few steps from the original cave.

But this generous idea to offer an alternative to the closure of the original cave has shown its limits with an annual attendance of the site between 250 000 and 300 000 visitors. This influx of visitors implied the construction of tourist facilities, and it is a works project of the reception building, in 2002, which led the public authorities to design a program to "sanctuarize" the Lascaux hill. The natural environment around the cave is indeed essential to the preventive conservation of the site: the flow of visitors attending "Lascaux II" and all developments affecting the archaeological soils have to be controlled. The Dordogne General Council and the town of Montignac have clearly expressed their desire to achieve, in close cooperation with the services of the State, a comprehensive protection of the Lascaux hill. It is in in this context that the creation of a bypass road to ban the flow of cars from the hill is currently under review. The project to "sanctuarize" the Lascaux hill plans to expand the State property with the acquisition of the plots involved in the catchment area from which polluted waters can reach the cave. It also plans to move the parking area to the foot of the hill.

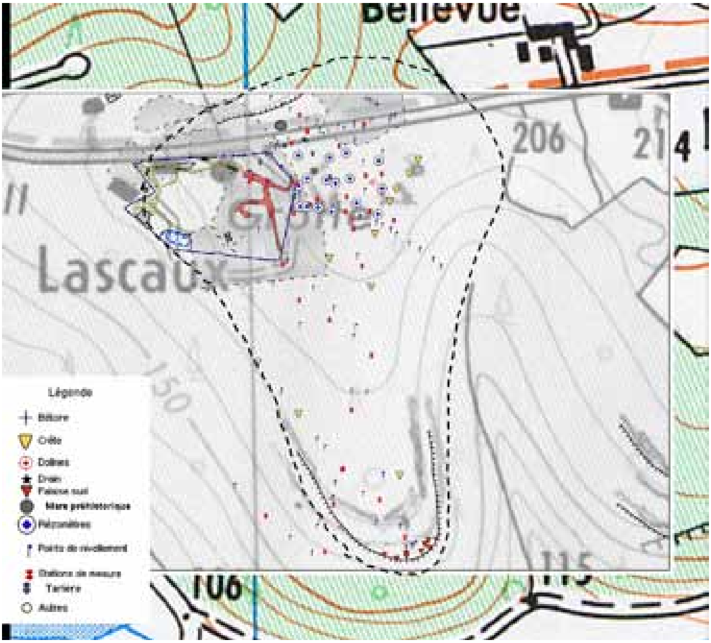


Fig. 21. Plan of the Lascaux impluvium.
© Laboratoire 12M

In July 2003, the Scientific Committee established in 2002 on the occasion of the 2001 bioclimatic crisis learnt that work was undertaken in the immediate vicinity of the cavity by SEMITOUR, the operator that manages the "Lascaux II" facsimile. The Committee was very concerned over the risks due to such work for the conservation of the original cave which is not a closed environment. Aware of the fact that the cave must have a better protected and controlled environment, the Committee proposed the creation of a special Sanitary watch committee. Since november 2003, the Prefect of the Dordogne coordinates all services whose activities might concern the Lascaux hill and the cave's integrity. It is within this context that the will to "sanctuarize" the Lascaux hill has been formalized in order to implement a global protection adapted to this unique site.

The prerequisite was to have a thorough understanding of the complex geological setting of the cave. The I2M Laboratory of the Bordeaux University carried out a study to define the groundwater basin which concerned the cave (Fig. 21). This study showed that the catchment area from which polluted water could reach the cave was larger than the land originally acquired by the state. As a result, the service of Historical Monuments undertook a policy of acquisitions of additional plots to better control the land related to the cave.

The measures developed to sanctuarize the hill are part of an ambitious project to create in Montignac, at the foot of the Lascaux hill, a Rock Art International Center. The Center will provide a full reproduction of the Lascaux cave through a complete facsimile and virtual rendition of it. This project, supported by the French State, the Aquitaine Region and the Dordogne General Council, could come to fruition by the years 2015-2017. The infrastructure related to Lascaux II could then be displaced and the remaining facsimile used as a teaching aid in relation to the new center. A bypass road in order to remove the road passing close to the cave is already under consideration. The strong will of the State to "sanctuarize" the Lascaux hill therefore means considering this site as a whole. The conservation of Lascaux is taken into account through a series of measures implemented inside the cave but also outside. Paradoxically, if the Lascaux cave is worldwide known for its paintings and also for its various microbiological crises, it is also one of the least studied caves from an archaeological point of view. Its anthropisation since 1940 and the facilities realized especially in the 1950's have removed much of the archaeological material. Considering the hill as a whole may offer a better understanding of Lascaux's human environment, the site having only undergone limited archaeological research.

Through the example of Lascaux II, we see that actions taken on behalf of heritage conservation and enhancement can meet limits and it is not always easy to predict collateral effects. This is what some call the "Lascaux syndrome," the ill of a pioneering site which had arisen a huge passion for an ever increasing crowd and whose preservation may be threatened by too many visitors number or measures that could appear retrospectively inappropriate.

The 2001 crisis

The appearance in 2001 of a fungus: *Fusarium solani*

In the mid-1990s, some equipment installed during the first crisis showed signs of aging limiting their effectiveness for those materials were not provided for prolonged use over time. This is the case of the climatic assistance machine installed in 1965, as shown by Jean-Michel Geneste, appointed curator of the Lascaux Cave in 1992 in his report on the sanitary condition of the site produced in 1994, *Lascaux : Etat des lieux*. Based on this report, the restoration of the too old installations was decided in 1996 by the site managers. Between 1999 and 2000, the old climatic assistance machine was replaced under the control of Philippe Oudin, Chief Architect of Historical Monuments.

Several weeks after the end of this work, fungal contamination had developed on both floors and benches in the "Airlock 2", at the entrance of the Hall of the Bulls and in the Machine Chamber, on the newly installed equipment. The causes of this sudden proliferation may result from the combination of different factors such as the confinement of the cave during the work period - a bulkhead isolated the Hall of the Bulls from the "Airlock 2", inadvertent introduction of organic materials during the work and also a possible resistance to biocide acquired by microorganisms after repeated applications. A source of contamination was found in the piping insulating materials and in the new machine structure. All these materials were immediately removed. However, this removal modified the initial properties of the new machine and adjustments had then to be made to align the capabilities of the machine to the needs of the cave for climatic assistance. It is worth noting that for almost 12 years now, the machine has kept the cave in a satisfactory climatic regime.

Simultaneously with this work, in the Hall of the Bulls, from April to June 2001, was undertaken the treatment of lichens already identified and observed by the Research Laboratory of Historical Monuments (LRMH) since January 1998. Treatments were carried out by a restorer of murals. But during summer 2001, a sudden proliferation of fungus *(Fusarium solani, Glyomastix)* was detected (Fig. 22).

Fig. 22. Nave. Development of white mycelium on a bench in 2001. © D. Bouchardon-LRMH

Fig. 23. Axial Gallery. Compresses applied on white mycelium on a sloped surface. © D. Bouchardon-LRMH

The rapid spread of mold on the floors and the benches led the Research Laboratory of Historical Monuments (LRMH), after having identified the micro-organisms, to set up a treatment with quaternary ammonium *(Vitalub)*. The treatment was performed according to the LRMH recommendations by spraying the solution or applying it with dabs (Fig. 23). Because the fungicide used was degraded by a bacteria associated with *Fusarium solani, Pseudomonas fluorescens*, an antibiotic, *polymexine*, had to be occasionally added to the treatment. But these micro-organisms had became particularly resistant to treatments commonly used in such situations and the first results were not satisfactory. In order to eradicate the spread of *Fusarium solani* it was decided in October 2001 to "sterilize" the soil by spreading lime. A check of the hydration and carbonation of the lime and a control of the impact of the particles were done at the same time. A weekly chronicle was kept up to link the climatic parameters to the observed phenomenon and also to locate the treatments performed and the possible changes identified. Chemical treatments were supplemented by mechanical manual eradication, carried out by restorers.

Given the complexity of the problem, the Ministry of Culture created in 2002 a new scientific committee including curators, biologists, hydrologists, climatologists. Headed by Marc Gauthier, *Conservateur Général du Patrimoine*, the committee directed its action towards a necessarily long research of the causes of the contamination phenomenon and of what constituted the cave's structural fragility. The committee also sought to assess the impact of the works undertaken and to consider how to avoid the return of such an incident. Once the *Fusarium* crisis got under control, the Scientific Committee established, in 2003, a *Global research and intervention project* to maintain the sanitary equilibrium of the cave. The reduction of fungal development led the Committee to propose in its program to give up biocide treatments (such as quaternary ammonium sprayed on infected surfaces for two years) in favour of a "mechanical" action on visible micro-organisms. Since 2004, a team of restorers has been responsible for observing the condition of the walls with a very pre-

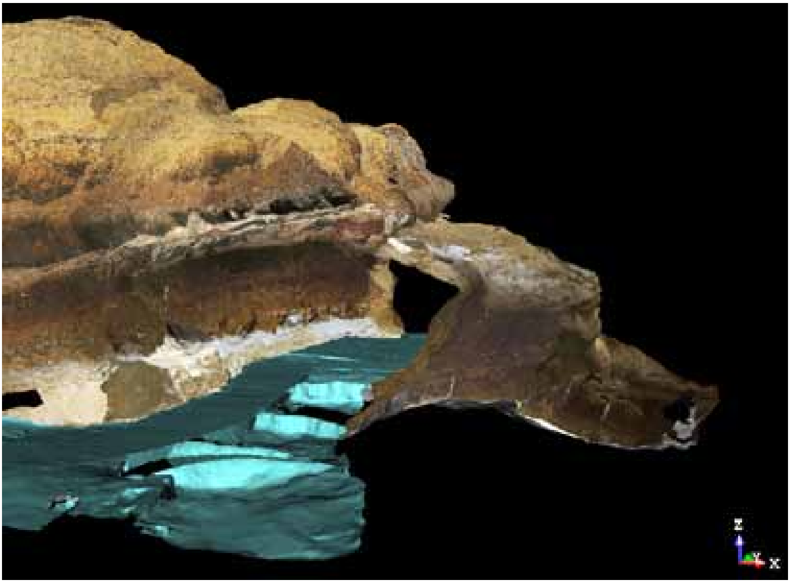
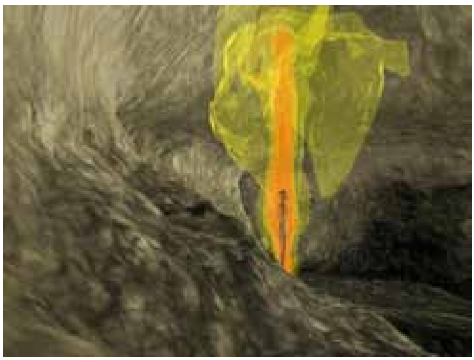


Fig. 24. *Screenshot of 3D representation of the Hall of the Bull. Cabinet Pérazio © MCC-DRAC Aquitaine*

cise analytical grid and to remove manually, with compresses, visible micro-organisms in all accessible areas without ever touching the decorated field. The Committee also asked archaeologists to carry out the extraction of the lime covering the soil since October 2001.

Under this *Global project* the Committee developed innovative assessment tools serving the cave's conservation. To have regular informations on the contamination development and on the regression observed in the cave, the Committee proposed to make a 3D scan laser assessment of the cave, a work assigned to Perazio Cabinet in 2003 (Fig. 24). It still serves as a basic georeferencing for all observations in the cave and it permitted to develop a predictive numerical model for preventative conservation, called the *Lascaux Simulator*. In June 2005, as part of a quadripartite agreement involving the Ministry of Culture and Communication, the EDF Research and Development Foundation, the CNRS and the University of Bordeaux (I2M laboratory), a research program named *"Lascaux Simulator"* was developed. This useful tool for research is used to predict the supposed impact on the cave conservation of disturbances due to air flow changes, of possible materials brought into the cave (scaffolding, bulkhead) or the impact of human combined presence for a better distribution of the time (Fig. 25). The *Simulator* had improved the understanding of climate changes in the cave, in conjunction with climate change outside. The visualization of temperature and speed profiles on a cross-section of the Hall of the Bulls and the Axial Gallery has shown a temperature inversion, with a cold spot in the upper part of the cave in 1981 and a cold spot in its lower part in

Fig. 25. Simulation of thermal impact associated with the presence of man in the Hall of the Bulls. © Thétis, 12M, CNRS-Université Bordeaux



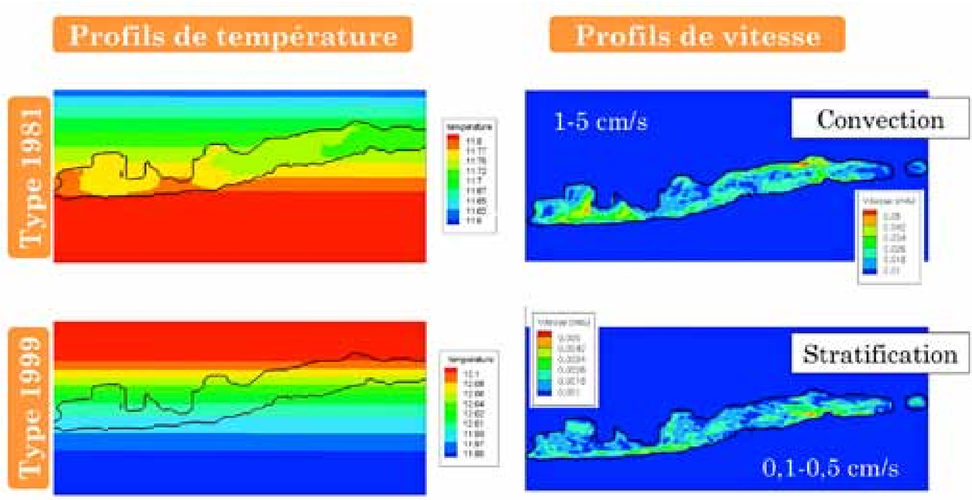


Fig. 26. Screenshot of the Lascaux Simulator showing changes in the air cirdulation speeds and temperature between 1981 and 1999. © MCC-CNP

1999. This inversion resulted in a stratification of the air, with a speed intensity divided by 100 in the late 1990s (Fig. 26).

This multidisciplinary modeling had also permitted to identify sensitive areas, especially by specifying the air and moisture conditions transfer in the different areas of the cave. It is important to say that the conclusions and possible recommendations from the *Simulator* are always correlated with in situ measurements and human observations. The temperature and humidity influence, the rate of carbon dioxide or the air speed in terms of their influence upon the walls can be both studied using the measurements given by the sensors in the cave and the *Simulator* calculations.

The appearance of “black spots” in 2006

Given the difficulty to monitor objectively the state of wall surfaces, the Scientific Committee decided to carry out a complete condition report of the cave, in order to provide an exhaustive inventory that could be used as a reference over time (Fig. 27). Carried out by a team of restorers helped by a geologist and a photographer, the work should have been pursued by a dynamic condition report to monitor possible changes. However the new appearance of fungus by spring 2006 had cancelled this monitoring project. These “black spots” (Fig. 28) had appeared and developed only in the Right Gallery. They are concentrated in the Passageway and the Apse ceilings where traces of painting exist but also where there remains a huge number of engravings and also on the Nave walls. By July 2007, the “black spots” locally reached the decorated walls in the Nave, especially the Black cow horns and the antlers of the Deer, at the entrance of the Apse. It is probably significant to note that the fungus grew preferentially in the Right Gallery, an already weakened area at the time of the discovery of the cave, an area where the substrate is a soft and powdery limestone.

In November, 2007, to stop the progression of the observed “black spots”, the Scientific Committee validated the principle of a biocide treatment on the affected areas, followed by a closing off of the cave for three months so it might “rest”. After preliminary tests, the treatment was achieved in January 2008 according to a protocol established by the LRMH. After that rest, the monitoring carried out in late March (ATP monitoring - Adenosine Tri Phosphate) showed that among the eleven selected areas under observation, nine showed a fairly sharp reduction in metabolic activity, which was an overall positive result. Moreover, the level of atmospheric pollution was lower.

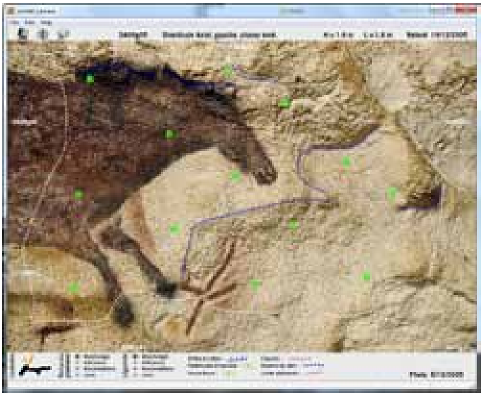


Fig. 27. Screenshot of the condition report of the cave. © MCC-CNP

Fig. 28. Passageway. "Balck spot" at the ceiling, septembre 2011. © MCC-DRAC Aquitaine

After this period of rest, the team responsible for the cave monitoring continued its work in all sensitive areas in order to assess any changes or modifications. From these observations, the manual removal of micro-organisms was made under archaeological supervision, provided it was safe for paintings and engravings. Thus, with the agreement of the cave curator, a manual cleaning of visible micro-organisms on the lower parts of the non adorned walls was realized. The residual organic deposits were aspirated with an injector extractor developed in 2004 by the LRMH, the *Grégomatic*.

In summer 2008, if the Hall of the Bulls and the Axial Gallery remained very stable, it was not the case of the Right Gallery which was still affected by the phenomenon of "black spots", particularly the ledges of the Apse, where despite regular cleaning, micro-organisms were present.

Objections had arisen within the scientific community about the relevance to treat or not to treat these fungus chemically. The Scientific Committee decided, during its meeting of July 2008, to carry out an impact study, in order to evaluate the appropriateness of pursuing the treatments and their impact upon the walls. Four zones were selected in the Passageway, each with different characteristics, related to the rock support (cracks, morphologies...), the archaeological sensitivity (close to engravings and / or traces of pigments) and visible microbiological colonization (appearance, thickness, recent developments). Manual cleaning tests and spraying of biocidal product were thus realized on the "black spots" located in those four zones. This impact study had two objectives. First, to evaluate the effectiveness of coupling manual cleaning and chemical treatment compared to the chemical treatment alone. On the other hand, to collect data on the possibility of manual intervention in an adorned area with a well known fragile limestone substrate. Two particularly sensitive areas were selected to be superficially cleaned with a very soft brush without any biocide treatments. In the two other zones, a biocidal treatment was carried out in addition to cleaning. The aim was to associate the more or less extensive manual elimination of "black spots" to a biocide treatment and then to compare the results in relation with areas that had been exclusively manually cleaned. Samples for microbiological analysis were lifted on three occasions, in the concerned areas: before the restorers cleaning, after cleaning and before the biocide treatment, and finally after three weeks of post treatment rest.

In view of the support fragility in this area, the Scientific Committee entrusted the Centre National de la Préhistoire (CNP) to conduct an archaeological survey of the decorated walls concerned (Fig. 29). Correspondingly, a mapping of the substrate fragility of the ceiling was carried out by the restorers to assess the impact of any mechanical action on the ceiling of the Passageway and the feasibility of their intervention. The cleaning was undertaken within an evaluating protocol, implemented

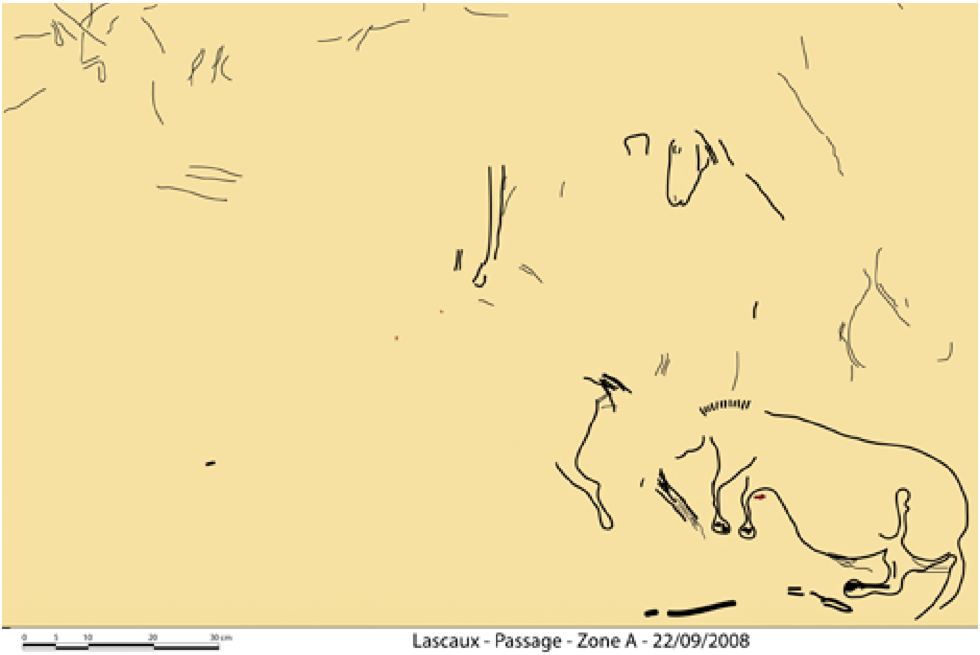


Fig. 29. Passageway. Archaeological survey of the decorated walls concerned by the impact study. © MCC-CNP

before and after each intervention: measurements of the adenosine triphosphate (ATP) and epifluorescence microscopic analysis, reemission spectroscopy measurements, identification of populations according to molecular method, analysis of the residues recovered during the cleaning operation. These evaluations were conducted by the Laboratoire de Recherche des Monuments Historiques (LRMH) in close partnership with the microbiologists of the Scientific Committee.

For the Ministry of Culture and Communication, this very strict protocol of intervention developed in this impact study was fully part of an old politics. The principle of reversibility has been the basis of any work on cultural property in France for many years. As to biology applied to conservation, the first guiding principle is to ensure the effectiveness of a treatment regarding the elimination of pathogenic micro-organisms with a maximum safety for the substrates. Those two principles formed the basis of the impact study that was conducted in the Passageway.

This study showed that to be really effective on this type of fungus, biocide treatments should be supplemented by a manual cleaning. But in fact, any manual cleaning on the engraved or painted areas should be avoided for such actions would certainly and irreversibly damage the walls.

Diverging positions appeared. Some microbiologists were favourable to biocide treatments to remove all micro-organisms and biological reservoirs of contaminants. Others considered that the repeated use of these products might bring about a selection of the most resistant micro-organisms, but also that some of them could feed on organic residues that the nature of the walls did not allow to clean without a huge risk of alteration. Thus, the Scientific Committee decided not to treat the cave chemically. As a result, since the latest treatments carried out in January 2008, the cave has not been treated with biocides. Monitoring of the visible micro-organisms is regularly ensured by the team of restorers and the cave staff. Tracings on paper and photographs help to understand the evolution of the dark spots.

Since 2009, the overall level of contamination of the cave has been relatively stable and the restorers responsible for its monitoring have not noticed any changes in the location of contaminated areas. The increase of the "black spots" that appeared in 2006 has slowed sharply since 2009. The color of many "black spots" faded from black to grey. The few new ones on the ceiling of the Passageway and the Nave are rather pale grey spots or extensions of former spots as small points.

To better understand the evolution of these "black spots", recently identified as a new species within the genus *Ochroconis Scolecobasidium*, the relevant sectors have been regularly monitored since December 2007 by the restorers in charge. If the last monitoring of the cave shows the appearance of very few new spots, the records of accumulated spots show encouraging results with a very sharp slowdown in their evolution. If visible microorganisms are still present in some areas, particularly on the ceiling of the Passageway, of the Apse and of the Nave, very few new spots have appeared.

Recent research programs

Following the 2001 microbiological crisis, research programs were set up by the Scientific Committee to determine the origin of the phenomenon, to rigorously understand the site perturbations and to possess a reliable exhaustive inventory of the cave. A multidisciplinary research project on *"the impact of physical parameters of the atmosphere and substrate on the development of micro-organisms"* was decided by the Committee. This international project associated experts in microbiology (Institut National de la Recherche Agronomique – INRA - Dijon and the Laboratoire de Recherche des Monuments Historiques - LRMH), experts in physics of the atmosphere (Consiglio Nazionale delle Ricerche Istituto di Scienze e del Clima dell'Atmosfera - ISAC-CNR of Padova) and experts in transfert properties of rocks (LRMH). Established in 2006 for a period of three years, it initially involved three control areas at the entrance of the Axial Gallery. The aim was to dynamically follow microbial contamination changes in the affected areas and to correlate these changes with physical and microclimatic parameters measured continuously at the surface of the wall and the stone substratum. The observations tended to confirm the hypothesis that microclimatic conditions on the surface of the walls were essential to control microbial growth at the air-mineral substratum interface.

However but fortunately for the cave, the changes that had affected the microclimate were too low to change the surface colonization which remained broadly stable. The absence of visible micro-organism developments on the observed surfaces prevented the scientists from crossing climate and microbiological data. Therefore, in July 2008, a reorientation of the program was decided by the Scientific Committee. It concerned two new areas located at the beginning of the Nave, under the Panel of the Imprint. These areas were chosen according to the nature of the substratum, the first one rather argillaceous without visible fungal contamination, the other, rather sandy and covered with a large clay sediment, the kind of substratum colonized by "black spots". This research program was presented to the Scientific Council in spring 2011. But once again, the climate stability during this second phase did not allow us to reach the initial objectives. Under these conditions, the Scientific Council did not support the continuation of this research program which will not be extended.

In parallel with this study, a new research program was set up in the course of 2009. Led by the Institut National de la Recherche Agronomique – INRA in Dijon and the Instituto de Recursos Naturales y Agrobiologia of Seville, the program *"Microbial ecology of Lascaux cave"* aimed to better understand the micro-organisms responsible for contamination through the study of their metabolic needs. Rather than eliminating apparently dominant species, the approach developed through this program was to consider the microbial communities as a whole and to consider their balance in order to act on the environment that could encourage the emergence of imbalances. This program that just ended was also presented to the Scientific Council in spring 2011. The Scientific Council who is favourable to its con-

Fig. 30. Hall of the Bulls. Detail of vermiculations on a non decorated wall. © MCC-DRAC Aquitaine

tinuation must now define the content of the scientific project to be set up.

In October 2009, the limited presence of vermiculations was reported in the Hall of the Bulls. This natural occurring phenomenon observed in other caves had been previously mentioned at Lascaux. These few millimeters deposits dispersed over very small areas are the consequence of a complex transportation of sediment particles (Fig. 30). To better follow the possible evolution of the phenomenon, a weekly visual control by persons working at the site was set up and a photographic monitoring is done regularly. To detect any new appearance, seventeen photographic coverages were conducted on the concerned areas from october 2009 to january 2012. This comparative monitoring showed that during that time the phenomenon evolved very little: very few new vermiculations were observed.

Although the type of deposits in the cave is very common, there is very little scientific data published on it. Thus, the French Ministry of Culture asked the new Scientific Council, appointed in February 2010, to define the contents of a research program on this phenomenon. Under the chairmanship of Pr. Yves Coppens, appointed by the Minister of Culture and Communication, Frederic Mitterrand, the Scientific Council proposed a study conducted by a consortium of researchers to define the scientific knowledge on vermiculations, to establish their mineral and microbiological characterization and a mapping of the areas at risk and at last, to follow the possible development of the phenomenon. The researchers involved in this program should submit the first scientific results to the Council by the spring of 2012.

New tools for monitoring the cave over time, an important issue in the perspective of preventive conservation approach of the cave, are being developed. Since 2010, a partnership between the Ministry of Culture and Communication and the Ecole des Mines d'Alès has allowed us to set up a methodology to detect and evaluate any changes in the appearance of walls through chromatic measurements. Phenomena like visible microbiological growth or mineral deposits such as a light veil of calcite can lead to disorders that must be detected as soon as possible and the changes quantified. As part of this partnership, a data acquisition technique, adapted to the underground environment, is being developed. Calibrated pictures are realized and exploited in terms of usable image analysis. This technique allows the researchers to highlight and to monitor changes on the wall surfaces, whether mineral or organic, and to assess their possible extent in time on colorimetrically calibrated images.

Conclusion

Lascaux cave is a living environment, fragile and sensitive to changes that needs to be disrupted as little as possible. Unfortunately, the heavy interventions made by man since its discovery in 1940 are irreversible. In front of this masterpiece in the history of art, we understand the concern of the scientific community and the general public, supported by media, arising from the crisis in 2001. However, the threat of a downgrading by UNESCO in July 2008 faded away because of the obvious scientific and financial efforts of the French Ministry of Culture, facing the complexity of such a site. If we will not be able to recover the initial balance of the cave, everything is still done to stabilize the situation. Moreover, it is important to highlight that all the data acquired in Lascaux for many years represent a great contribution to the preservation of rock art heritage throughout the world, which can be regarded as a major positive element in the Lascaux crisis. As the Curator of the cave since 2009, it is my duty to strictly implement the conservation principles identified in collaboration with the Scientific Council.

Fig. 31. Axial Gallery. Cow with Collar. © MCC-CNP

Muriel Mauriac,
curator of the Lascaux cave
muriel.mauriac@culture.gouv.fr

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