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Biodeterioration:

an applied case for rock art in the Ventania Hill System
(Buenos Aires, Argentina)

Biodeterioração:

um caso prático na arte rupestre do Sistema Serrano de Ventânia
(Buenos Aires, Argentina)

ABSTRACT: From 2004, we have been studying the transformation processes in caves and rockshelters with rock art in the Ventania Hill System, Buenos Aires Province, Argentina. This research involves controlled observations, discriminating records and study of geophysical, geochemical, biological and anthropics agents of deterioration. Thus, the presence of microorganisms forming biofilms on rocky surfaces, the activity of arthropods, and the occurrence of higher animals, cause alterations of cave art; added factors include microclimate alteration, presence of water infiltration, cracking, rock exfoliation and superficial accretion of glasses, among others. In this work we present the results of preliminary studies on biodeterioration (defined as any undesirable change in the conditions of a material caused by biological activities) in four sites. Surface samples were collected and counts of the different microbial pollutants that form biofilms were made.

Key words:
biodeterioration, biofilms, rock art, Ventania Hill System, preservation.

Introduction

This work is a study of transformation processes made through observations, discriminating records and sampling of different deterioration agents: geophysical, geochemical, biological and anthropical. In the Ventania Hill System (southwestern Buenos Aires province, Argentina), a total of 28 sites

(caves and/or rock shelters) have been recorded that present some type of art rock. Some of these sites were selected to research and compare the consequences of deterioration caused by biological agents, as well as geophysical and geochemical factors. These analyses included making "in situ" microbial cultures and collecting five samples from different archaeological sites located within caves and rock shelters. This approach considers rock art in direct relationship with its environment, given that the rock surfaces are integrated into the landscape structure, where topographical elements have been used to recreate a new rock landscape, in addition to the structurations arising from organizational aspects of the societies that made the rock paintings. This environment results form both cyclical and linear processes, as well as from the structural properties of the sites, understood on the basis of the interrelationship between past and current societies and the biogeophysical and biogeochemical agents that affected them. This determines the landscape visibility of the sites and of particular designs, taking into account the deterioration processes that could alter these manifestations after their creation.

Background

The first systematic works in the studied area began in the 1980 decade, with the studies made by Madrid and Oliva 1994; Consens and Oliva 1999, Oliva 2000. Recently, Oliva and Algrain (2005) proposed a characterization of the motifs present in different sites with rock art in Ventania, based on morphological aspects, and compared them to other types of archeological records, relating specific aspects of the representations to their location, as well as with symbolic elements of indigenous societies (Oliva 2006). More specifically, a report of the situation of deterioration of rock art sites was presented by Oliva in 2000, in which he considered both natural and cultural causes for this phenomenon. In 2001, Oliva and Sánchez reconstructed, by means of computerized techniques, the location of the cave art motifs in a sector of the "Gruta de los Espíritus" ("Cave of Spirits", a cave that has suffered intensive vandalic attacks including *graffiti*)

Work methodology

Among the works made in Argentina related to the study of agents of deterioration of rock art, Rocchietti and collaborators (1999) have studied the geomorphological processes of deterioration at the sites in Cerro Intihuasi, Córdoba, Argentina; they observed different events related to the record of light in the sites, the effects of water on the rock mass and the surface, eolic

action associated to the geomorphological structure of the sites, and the geodynamics associated to processes of compositional change, displacement and collapsing hazard of the granitic blocks (Bolle 1999; Rocchietti *et al.* 1999). On the other hand, in the "Parque Arqueológico y Natural de Cerro Colorado", Bolle and collaborators evaluated the progressive degradation of rock paintings with the goal of implementing a management plan for this archeological park that would take into account factors such as: nature of the rock, water filtrations, soluble salts, climate, microorganisms, animals, and presence of tourists (Bolle *et al.* 1995)

As part of the "Programa de Documentación y Preservación del Arte Rupestre Argentino" (Program for Documentation and Preservation of Argentine Rock Art), organized by the Instituto Nacional de Antropología y Pensamiento Latinoamericano, through several projects: Patagonia Centro Meridional (Cueva de las Manos, Cerro de los Indios, Santa Cruz province), Comarca Andina at Parallel 42º, La Pampa province, Antofagasta de la Sierra, in Catamarca province, Ischigualasto, in San Juan province, and Cerro Cuevas Pintadas, in Guachipas, Salta province, Wainwright's (1985) proposal for the record of natural and cultural deterioration factors for each particular case has been applied, with the goal of generating a diagnosis of the preservation state of each site and starting plans for the management and programmed interventions in these sites (Bellelli *et al.* 1997; Podestá *et al.* 2000, 2004; Rolandi *et al.* 1996)

In 2004 began to make comparisons with observations from previous years (Oliva 2000), creating adequate methodological tools to record the environmental, biological and cultural deterioration agents for the sites located in caves and rock shelters of Ventania (Gallego 2005; Gallego and Oliva 2004, 2005; Gallego and Panizza 2005). For this first stage, some of the methodological criteria of the classification proposed by Wainwright (1985) were used, while adapting the scheme to the particular circumstances of the archaeological record in the Ventania Hill System.

Studied Sites

The Ventania Hill System is located between 37° 25' - 38° 30' South latitude and 62° 48' - 61° 20' West longitude. This system is shaped like a northwest-southeast directed arc, rising clearly from the surrounding flatlands. It is formed by strongly folded Paleozoic rocks, with the addition of Tertiary red highly cemented conglomerates and some Quaternary materials including Pleistocene cobbles, clayey and loessoid sediments, and silts intercalated with calcareous tosca (Harrington 1947, 1980; Suero 1972)

Within the universe of 28 known rock art sites for the Ventania Hill System, monitoring has started at eight caves and rock shelters with diverse degrees of deterioration. This monitoring is being carried out by means of controlled observations at different times of the year, made with the purpose of achieving an accurate representation of all the agents that participate in the deterioration process, and comparing seasonal variations of this phenomenon.

The studied sites are: Alero Corpus Christi (rock shelter), Cueva del Toro (cave), Cueva Parque Tornquist (cave), Cueva 2 Parque Tornquist (cave), Cueva 3 Parque Tornquist (cave), Cueva 2 Arroyo San Pablo (cave), Cueva 2 Valle Intraserrano (cave) and Cueva 3 del Valle Intraserrano -La Sofía 7 (cave)- (Consens and Oliva 1999; Gallego 2005; Gallego and Oliva 2004, 2005; Madrid and Oliva 1994; Oliva 2000, 2006)(Figure 1)

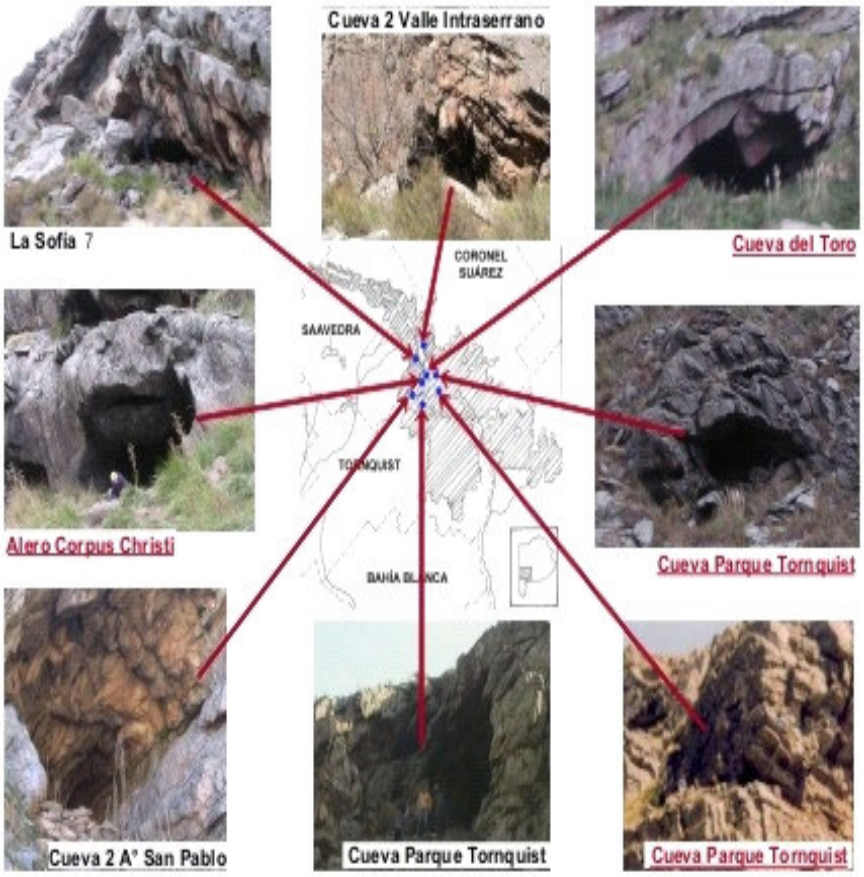

Figure 1. Studies sities

Deterioration Agents

Geophysical and Geochemical agents

Phenomena of cracking, exfoliation, saline wear, carbonation and iron oxidation were observed in all the caves, affecting both the sectors with and without art rock. Solar radiation, eolic erosion and water infiltration were recorded in six of the eight caves (Guiamet et al. 2006). In one of the remaining caves (Cueva 3 del Valle Intraserrano -La Sofía 7-) only water infiltration was noted, and in the other (Cueva Parque Tornquist) none of these agents were present. Manganese oxide was also present in all the caves except for Cueva 2 Arroyo San Pablo.

Although some deterioration agent is present in all the studied caves at the sectors with rock painting, not all cases involved a direct effect on the motifs themselves.

These agents not only affect the sites through exfoliation of the rock surface, but also by infiltration of interstitial and capillary water, deposition of salts and other minerals, thus creating favorable conditions for the establishment of microorganisms (Bednarik 1995; Brunet *et al.* 1995; Van Grieken *et al.* 1998; Wainwright 1995; among others). These deterioration factors can also derive from the activities of bacteria that metabolize nitrogen, iron, sulfur or manganese; these activities may significantly aid in the deterioration of rock surfaces, and in some cases, the associated rock paintings (Bednarik 1995; Brunet *et al.* 1995; Myers and Taylor 1974; Soleilhavoup 1979; Van Grieken *et al.* 1998). For this reason, it is probable that other deterioration agents occur wherever there is water infiltration (Gallego and Panizza 2005)

Biogeophysical and biogeochemical agents

In all the caves studied, the action of lichens, algae and mosses was observed, as well as grasses and ferns, at both the walls and roof of the caves and rock shelters (Table 1).

Higher animals are also agents of biogeochemical and biogeophysical deterioration at the studied sites. Among the animals recorded within the cave microenvironment, bats predominate. The guano produced by these mammals is highly acidic, and can promote the accumulation of certain minerals on the rocks that form the cave, altering their chemical composition; in addition, they alter the mesoclimate of the cave (Gallego and Oliva 2005; Gallego and Panizza 2005). Birds are second in importance; both nesting

activity and guano were recorded. As previously mentioned, guano damages the rock paintings due to its high acidity; changes in mesoclimate may affect the preservation of the rock paintings (Shahack-Grossa *et al.* 2004)

SITE	algae, lichens, mosses	Grasses, ferns	Bushes	Cattle	Bats	Other mammals	birds	Arthropods
Cueva 2 Valle Intraserrano	X	X		X			X	X
Cueva 3 Valle Intraserrano	X	X		X				X
Cueva Parque Tornquist	X	X			X			X
Cueva Parque Tornquist 2	X	X	X					X
Cueva Parque Tornquist 3	X	X					X	X
Cueva del Toro	X	X			X			X
Cueva 2 Arroyo San Pablo	X	X		X		X	X	X
Alero Corpus Christi	X	X		X			X	X

Table 1 Biological agents recorded in the sectors with cave paintings at each site.

With respect to the presence of other animals within the caves, rodents were recorded on the basis of indirect signs (fecal pellets). Other mammals that could interfere with the preservation of these sites include wild cattle (horses) that occurs in the Parque Provincial Ernesto Tornquist; a special shine observed on the rock walls of the shelters is probably due to these animals rubbing against these surfaces; horse manure was also recorded (Gallego and Oliva 2005; Gallego and Panizza 2005)

Arthropods, mainly arachnids, coleopterans and hymenopterans, were also recorded at all the studied sites. These agents cause soiling of the rocky substrate, which could damage the paintings, although no specific effects were recorded during the controlled observations (Gallego and Panizza 2005)

Biodeterioration

The biodeterioration of materials is caused by several agents, including the metabolic products and extracellular polymeric material (EPM) excreted by microorganisms such as bacteria, cyanobacteria, fungi, yeasts, algae and lichens, which form a thin layer called *biofilm*. EPM acts as glue or agglutinating substance for environmental particulate matter, thus enhancing the disfiguring effects of *biofilm*. Biodeterioration is conditioned by environmental factors such as relative humidity, temperature, as well as by natural and anthropogenic pollution. Different types of organisms occur together with the abovementioned microorganisms, including lichens, mosses, vascular plants and arthropods (Martínez 2002; Gómez de Saravia 2001; Guiamet 2001)

The present study included "in situ" microbial cultures made from five samples corresponding to the sites Cueva del Toro, Alero Corpus Christi, Cueva Parque Tornquist and Cueva 2 Parque Tornquist (Gallego *et al.* 2006)

The "in situ" microbiological samplings were made using Envirocheck Contact YM (R) slide cultures on the rock surface, which allow the quantitative assessment of surface microbial load (Figure 2). Given the cultural worth of these rock paintings and the serious preservation issues at these sites, the samples were carefully extracted and placed in sterile containers for laboratory processing.

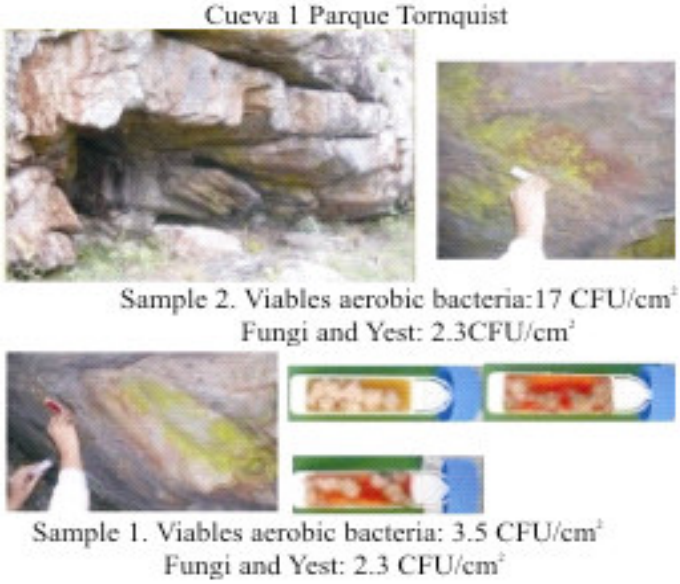

Figure 2. Sampling and culture "in situ". Growth results.

These studies represent the first microbial surveys in the area; there are no antecedents for these procedures. This technique has been applied to investigate the microbial flora present in the *biofilms*. In 1999, the invasion of lichen populations onto rocks that supported rock paintings was recorded at the site Cueva 2 Parque Tornquist. After that, in 2005, the new surveys showed progressive increase of the deterioration.

The samples were taken by holding the plate margin and contacting the investigated surface using firm uniform pressure. This procedure was performed for both sides of the slide cultures. Each sample was identified with site, date and hour; in all cases, the test was performed before any kind of cleaning procedure was made. The slide cultures were later incubated at room temperature during 72 hs. for bacterial growth, and five days for fungi and yeasts (figure 2)

Results

These first microbiological studies indicate, according to the counts of colony forming units obtained from the slide cultures, the greatest abundance of microorganisms occurs in Cueva Tornquist 2. The other sampled sites show varied degrees of microorganism development that fall within the normal standard values for open locations (Gallego *et al.* 2006).

It is important to consider that all microbial biofilms growing on rock surfaces, whether formed by algae, lichens, bacteria, yeasts, fungi and/or other microorganisms, are capable of altering the chemical and mineralogical composition of this substratum and therefore participate in the deterioration of the rock paintings. These *biofilms* may also cause physical changes of pore size of the rocks, fissures and mechanical fractures, chemical instability, surface decoloration, as well as acidic and oxidoreductive modification, resulting in weakening of mineral structures and deterioration of the rock paintings. On the other hand, the complex hydrological characteristics of these caves and rock shelters also contribute to the formation of *biofilms*, mostly through alterations of capillary and interstitial water infiltration, the resulting cracking and exfoliation of the rock, and the deposition of salts and other mineral components (Martínez 2002; Videla 2001; Gómez de Saravia 2001)

Discussion and Final Considerations

The agents act as taphonomic selectors for the visibility of the representations, given that rock art, like any other element of the archaeological record, is a taphonomic remanent (Bednarik 1994). This means that a large part of the

rock art corpus is altered or eliminated through time by diverse processes, produced by environmental, biological and cultural factors. As a general rule, in most sites only a remnant sample of the entire rock art may have survived to the present. All the quantificable characteristics of art are the result of, first, taphonomic processes, and second, the artistic production of past societies. These processes are not casual or random; they are favored by certain techniques, pigments or types of paintings, locations, type of rock support, and climate, among others (Bednarik 1994)

The importance of the factors considered in this work lies in the fact that rock art is directly related to its environment, since the rocky surfaces that are the support for the representations are integrated in the landscape structure, where topographic elements have been used to recreate a new rock landscape. This environment is the result of climate changes and their influence on the hydrology of the sites, as well as of their structural properties, interpreted in terms of the interrelation between the intervening biological agents.

This determines the visibility of the sites and in particular, of the representations, considering the effects of the taphonomic processes that caused alterations after the generation of these representations.

For this reason, some criteria related to the location of the sites and the representations were taken into account. One of these is the orientation of the opening of the caves and shelters; on the basis of the controlled observations, those sites oriented to the north-northwest are exposed to greater eolic erosion given the predominant winds in the area; however, no differences in erosion could be recorded within the sites because the location of the representations is variable without a consistent pattern from one site to the next. Also, the altitude of each cave and shelter studied, as well as other orographic features of the area, were considered because, as discussed above, these characteristics determine a series of local climatic variations or mesoclimates, that may differ from the average conditions of surrounding areas and provide favorable conditions for the action of certain taphonomic selectors inside the caves and rock shelters (Gallego and Panizza 2005)

To sum up, in the sites of this hill system that were studied in this work, diverse deterioration agents were recoreded, most of which do not directly affect the paintings. The results of the "in situ" microbial cultures show bacterial load in all the *biofilms* that occur on rock surfaces of these sites (Gallego and Oliva 2005; Gallego and Panizza 2005; Gallego *et al.* 2006). The mechanisms involved in this biodeterioration of rock surfaces, and therefore

of the rock paintings, range from production of acidic metabolites, microbial activity that forms complexes of surfactanting substances and also of some structural components, biological alteration of these components, to microbial deterioration through mechanical effects (Videla 2001; Resende 2001)

It is noteworthy that at the site Cueva 2 Parque Tornquist, the count of colony forming units (CFU, total viable aerobic bacteria) was 17 CFU per cm^2. This leads to consider some particular characteristics of this cave, such as its higher location with respect to the remaining sites (above 700 m asl). On the other hand, the amplitude of the valleys in this area of the hill system (as shown in the photograph), coupled with the relative humidity index of this environment, favors the formation of contaminating *biofilms* over the paintings (Gallego *et al.* 2006)

It is not advisable to eliminate these microbial biofilms in the studied cases (i.e. Cueva 2 Parque Tornquist) because the products that are commonly used for this purpose, such as commercially available fungicides or ammonia hydroxide, may contaminate the rock surface and cause decoloration of the paintings (Bolle 1995; Rosatto 2001). Similarly, removal of lichens is not advisable because they may cause even greater deterioration of the paintings (Podestá *et al.* 2004). For this reason, until now the activities performed have been limited to identification of the microorganisms in order to assess their advance over the rock paintings, but with no direct actions towards their elimination.

As previously mentioned, rock art is harmonically integrated to its surrounding environment. For this reason, the presence of *biofilms* is sometimes negative, because the rhizomes penetrate the rock and maintain a high humidity level that contributes to the deterioration of the substrate; on the contrary, in other cases *biofilms* have positive effects because they can protect the rock and rock paintings from the attack of other climatic agents that may be more damaging, integrating the painted motifs into the microenvironment of the site (Bolle 1996; Podestá *et al.* 2004)

These microbiological studies will continue with the goal of achieving a better understanding of the interrelationship between the different factors that affect the process of *biofilms* formations, the consequent biodeterioration and their role in the alteration of rock paintings. For these purposes, other types of sampling will be performed to allow typification of the bacteria, cyanobacteria, algae, fungi and other aerobic and anaerobic microorganisms present in the caves and rock shelters. The identification of these organisms will provide a more complete perspective of how damaging they could be, and of possible techniques to clean the rock substrates without affecting the paintings.

It is worth noting that these controlled observations of the biological, environmental and cultural agents of transformation of these archaeological sites are aimed at emphasizing the study of the integrity of the archaeological record on a regional level. For this reason, we do not interpret the archaeological record as a reflection of the cultural behavior of past societies, but neither do we understand this record as a distortion of this past behavior. The complex amalgam of elements that make up the archaeological record is the remnant of the action of cultural systems integrated to larger natural systems in a constant dynamic interrelationship, and their resolution will depend on the factors that participate in this systematic mechanics (Binford 1981; Goldberg *et al.* 1993). As many authors agree, the approach used to establish relationships between the evidences and the possible cultural behaviors is what makes possible to infer, understand and/or reconstruct the human behaviors that could have caused them (Binford 1981, 1988; Goldberg *et al.* 1993; among many others)

The application of this taphonomic logic as approach to compare and analyze the agents that participate in different art rock sites will help to obtain a view of the state of conservation of the sites with rock art in the Ventania Hill System, to generate protection policies that entail adequate management of this cultural heritage.

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RESUMO: Desde o ano 2004 vêm-se realizando estudos sobre os processos de transformação em cavernas e abrigos sob rocha que apresentam arte rupestre no Sistema Serrano de Ventânia, província de Buenos Aires, Argentina. Estas pesquisas são efetuadas mediante a realização de observações controladas, de registros discriminados e estudos de agentes de deterioração geofísicos, geoquímicos, biológicos e antrópicos. Assim, a presença de microorganismos formando biofilmes sobre as superfícies rochosas, a participação de artrópodes, a presença de animais superiores, provocam alterações sobre a arte, acrescentando-se a este fato, a alteração do microclima, a presença de infiltrações de água, rachaduras, esfoliação da rocha e acreção superficial de cristais, entre outros. Neste trabalho apresentam-se os resultados dos estudos prévios realizados sobre a biodeterioração (definida como qualquer modificação indesejável nas propriedades de um material produzida pela atividade vital dos organismos) em quatro sítios e foram obtidas amostras da superfície dos mesmos. Foram realizadas contagens dos diferentes contaminadores microbianos formadores de biofilmes.

Palavras-chave: biodeterioração, biofilmes, arte rupestre, sistema serrano de Ventânia, conservação.

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