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Stone consolidation experiments in rock art outcrops at the Côa Valley Archaeological Park, Portugal

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SUMMARY: The Côa Valley Archaeological Park (PAVC) is home to an impressive assembly of prehistoric open-air rock art. To evaluate the possibilities of carrying out conservation work in the rock art panels, experimental interventions in non-engraved schist outcrops were commissioned in 2003 to three different Portuguese stone conservation companies. Together with another experimental intervention done in 1995 when a dam was being built in the Côa River, we propose to assess the stone consolidation materials and techniques that were used on both occasions as well as their adaptation and evolution in the overall environment where they were applied.

KEY-WORDS: rock art conservation; consolidation of rock outcrops.

INTRODUCTION

The Côa Valley Archaeological Park was created in 1996 with the specific mission of "managing, protecting and organizing for public visits, including the setting up of museum facilities, the monuments included in the special protection zone of the Côa Valley"[1]. The Côa river valley, situated in North-eastern Portugal, possesses one of the largest collections of open-air rock art anywhere in the world. The imagery ranges from the Upper Paleolithic just until the contemporary era, being the Iron Age, Neolithic or Historic periods other important epochs in the Côa Valley ultra-millenary rock art engraving tradition. Most of the figures were engraved in schist outcrops, although we can still observe some limited number of paintings and engravings done into granite bedrock. Since the most ancient motifs have an important aesthetic and scientific value, UNESCO has decided in 1998 to include the Côa Valley Pre-Historic rock art sites in the World Heritage List[2].

The engravings were inscribed onto moderately metamorphic schist outcrops of very regular surfaces resulting from well-developed tectonic joints (Fig.1). The rock high resistance to weathering allowed for the conservation of such delicate engraved motifs for a very long period; in fact, some of the most ancient ones were dated back to some 25000 years BP[3].

The authors had the opportunity, in other occasions, to describe the conservation problems affecting the engraved outcrops[4,5] as well as describing in detail the PAVC Conservation Program[6] or the efforts done to monitor the evolution of the weathering dynamics at work[7]. Therefore, leaving readers references that might prove helpful in further readings on the subject, the following analysis will be focused on the pilot conservation experiments done in recent years in Côa valley. The tested outcrops have no engravings, yet they have

conservation problems similar to the engraved ones. We also believe to be worthwhile examining a less recent translocation experience in which a large part of a schist outcrop was consolidated *in situ*, then cut from the bedrock and, finally, moved to a different location. Although with very different objectives, recent and older experiments will be examined concurrently since both may provide valuable insights on the way the applied stone consolidation materials are behaving within the natural environment in which they were employed.

Figure 1 - Aspects of the rock art panels and their geomorphologic setting. Engraved surfaces (above) are well developed and very smooth, constituting perfect panels. Most panels are engraved in surfaces from a same and very penetrative joint family (below) that runs for long distances in sub-parallel orientation. Notice the sharp edges and the dismantling process progressing from the borders inwards directly affecting the engravings

GENERAL OVERVIEW OF THE CONSERVATION PROBLEMS

Schists are the main lithotype present in the Côa Valley region. They are fine-grained and very compact, sometimes presenting intercalated thin layers of slightly coarser varieties of greywacke-type. In the vast majority of cases, the engravings were incised upon the surfaces of very smooth tectonic joints (Fig. 1). These all belong to the same tectonic family with large continuity running in sub-parallel surfaces for very long distances.

The engraved outcrops are scattered throughout vast and diversified areas along the slopes of the Côa river valley and of some of its tributaries. These slopes frequently present local instability problems but large landslide incidents occur quite rarely. In general, the geomorphologic evolution occurs through localized instability events that trigger block falls. Chemical alteration is slow, yet a progressive physical disintegration of the schists is pervading all the exposed outcrops. The condition of the rock art engravings can be considered, on itself, as quite reasonable, considering the extremely long term of their exposure. Taking into account the age of engravings, this clearly testifies the extreme resistance of the schistous materials to chemical weathering. The weathering dynamics that more directly affects the engraved surfaces is related to physical processes set in motion by wetting and drying episodes, further worsened by the pronounced anisotropy that characterizes the Côa valley schists. All the engraved surfaces possess widespread and dense network of deep fissures that weaken the rock material. Close to larger fractures and on the edges of the engraved outcrops, physical weathering is more easily observable, fissures are more widely open and mechanical weakness is more critical. Rock erosion is more active here and loss of material may progressively affect the engraved motifs. In spite of the reasonable good condition of rock art motifs still surviving, the signs of block dismantling and localized losses show that an undetermined number of motifs has been naturally lost, either completely or in part.

The extensive fissure networks that generally affect the engraved surfaces are an important factor in the outcrops structural solidity that, at the same time, facilitates its chemical alteration. In another lithological type, this fact would have more harmful consequences implying also more detailed attention. Fortunately, in the present case, given the very slow chemical alteration rates, further intervention regarding this matter is not necessary, fact that permits to keep the conservation needs at a very low intrusive level.

The engraved outcrops are in a very chaotic condition, with disconnected blocks, sometimes approaching toppling situations, open and closed fractures, erosion gaps, etc. Since they are located at the foot of rather steep slopes, all weathering mechanisms contribute to rock weakening and may easily trigger the uphill progression of natural instability phenomena. Although local climate has been quite favourable to the conservation of the rock art, mainly due to the prevailing warm and dry conditions, in summer temperatures may rise to more than 40º C in the bottom of the valley and daily thermal amplitudes may reach 10º to 15º C[5]. Thermal dimension change is another factor to take into consideration. As a result of all these conditionings, the aim of the interventions to be undertaken is to provide better stability conditions to the whole outcrop and to slow down, as far as possible, the evolution rate of the above-described weathering and erosion dynamics. Likewise, the main objective of the pilot interventions described below was to provide additional stability to the deeply

fractured outcrops and to test and select solutions that could be suitable for the future conservation actions to be carried out in the engraved outcrops.

THE 1995 EXPERIMENT

Brief account of the Côa recent history

When the first rock art panels were found, probably as early as in 1991[3], a large dam was under construction near the mouth of the Côa River. As further discoveries were being made the archaeological community became aware of the importance of the findings, realising that the continuation of the dam's construction would result in the flooding of the vast majority of the rock art already found. This issue was widely debated within the Portuguese but also international public opinion, although, right from the start[3], Prehistory experts warned about the extraordinary value of the rock art panels just discovered. The debate focused on the big investment already undertook by the, at the time, totally state owned electricity company - EDP - and the loss that the flooding of the rock art panels would represent in terms of the exceptional aesthetic and scientific values that were already recognized. At a certain point in 1996, the Portuguese Government took the extraordinary decision, even in international standards, to stop the dam construction, assuming the burden of compensating the expenditures already incurred in a bulk estimation of more than 100M€.

Later on, when UNESCO inscribed the Côa Valley in the World Heritage List, the value of the engravings was generally accepted by the Portuguese public opinion. Nonetheless, from its discovery in 1991 till 1996, 5 years of incertitude on what was to be the faith of the Côa Valley rock art passed by and proposals on how to conciliate the better of the two worlds – constructing the dam while trying to preserve (at least some of) the rock art – were put forward. Among them, EDP suggested that the most representative identified panels could be removed from the area to be flooded. The idea was to create some sort of thematic park where some of the most exceptional rock art outcrops would be relocated and, as far as it was possible to guarantee, placed in an optimum conservation environment. Although the idea had some merits, the archaeological community rejected it on the grounds that dislocating the rock art would signify the loss of its original context that is largely granted by its relationship with the surrounding landscape[8]. Nevertheless, in June 1995, HIDRORUMO (an EDP subsidiary company) performed an experiment in which a large piece of an un-engraved outcrop was cut from its original position and relocated in a new location. The experiment was thus undertaken to prove that it was technically possible to dislocate the rock art panels from the impounding area without loosing its integrity, although in charge technicians have raised doubts on the overall feasibility and conceptual justification of such endeavour[9].

The HIDRORUMO experiment

Although EDP was solicited by the authors to provide data regarding the experiment the relevant information was not delivered by the time this paper had to be written. Therefore, our description is based on the news that appeared in a newspaper of national audience, Correio da Manhã[9] and in the EDP Journal[10], both dated June 1995. In the absence of a more technical report, these two articles provide a reasonable amount of general information on the experiment.

The displacement action was executed by SWECO, a Swedish company that has in its curriculum the relocation of the Temple of Ramses in Abu Simbel threatened by the construction, in the 1950's, of the Assuam dam. After studying the general conservation condition of the un-engraved block to be moved as well as its geomorphologic features (mainly the orientation and width of fractures), epoxy resin and what was described as "special cement"[10] – probably, by looking at it now, a reinforced Portland based mortar – was injected in the existing fractures. In a second step diamond drill bits were used to perforate several openings that ran across the total width of the block. Steel extendable bars where then introduced throughout these openings and sealed with epoxy resin and Portland cement. Two big hook-like bars were also fitted on the top of the block allowing a crane to move it once it had been cut away from its core. Finally, a diamond saw cutter separated the (6 tons, 2,5 m high, 1,5 m long and 60 cm width) block from the original bedrock, allowing it to be moved to the location where it now rests (Fig.2).

Figure 2 - Aspects of the translocated block. Notice on the right the saw cut surface and the mortar filling of the rock joint

About 13 years have elapsed since the block was cut and moved to its present location and the information on the evolution of the block provides some hints on the appropriateness of consolidation solution and on the behaviour of the interface between the artificial materials and the schistous rocks.

A detailed analysis of the dislocated block reveals that it is in a good conservation condition. There are no apparent losses of fragments, the materials used to consolidate the weaker parts of the block are still in place and no harmful effects were identified in the adjacent rock. As far as we can evaluate, the intervention carried out more than a decade ago as definitely contributed to the stability of the block.

A close examination revealed that the epoxy material has turned yellowish and opaque, constituting an aggressive aesthetical change. The used mortars show no major alteration, both in colour and texture. On the other hand, mortar and resin still form separate but coherent solid unities, with no visible loss of fragments. Their strengths seem to have not significantly changed, as well.

STONE CONSOLIDATION EXPERIMENTS IN THE CÔA VALLEY ROCK ART OUTCROPS

Intervention methodology

After its creation, one of the Park's chief priorities was to gain a more comprehensive knowledge of the Côa Valley rock art conservation issues. Different Portuguese and international experts were called in to give their advice, including one of the co-authors (JDR). Following provided recommendations[3] it was deemed as necessary to carry out some pilot-experiments on the several steps that might constitute a typical intervention in an engraved outcrop. These experiments were suggested to be implemented in outcrops without engravings but with conservation problems similar to the engraved ones. Since there is little knowledge and few references to open air rock art conservation in schistous substrates, this was considered a most prudent approach. This methodology would allow some latitude and freedom in experimenting materials and techniques without risk for the engraved outcrops that are waiting to be conserved. Foremost, it has been the philosophy of the Conservation Program to gather a comprehensive understanding of the overall conservation steps, including the identification and characterization of possible direct and side effects that could be anticipated in future active conservation interventions to be carried out in the rock art outcrops. The leading idea is to prepare the ground for the decision makers to proceed as far as possible with "risk-free" actions, avoiding those measures that have shown to be incompatible or more risky to the engraved surfaces.

To carry out these pilot experiments, the PAVC invited three Portuguese companies with experience in stone conservation. To the best of our knowledge, there are no companies with expertise in the conservation of open-air rock art in schist outcrops. Hence, the aim was also developing local skills to tackle the challenges that future conservation interventions in the Côa valley rock art will present.

The three contractors were given some terms of references, although accepting that they were entitled to take proactive actions based on their own evaluation of the site conditions. Contractors were warned about the importance to solve the problems related to the access and movement of water on the "engraved" surfaces and active actions to solve the problem were requested. Considering that the main fractures form an interconnected system, the solutions that would lead to retain water inside the outcrop would be inconvenient and, thus, the solutions that prevent water from penetrating the interior of the outcrop and create direct and easy drainage paths were to be preferred. The improvement of the mechanical stability of the outcrop was also asked to be implemented, specially acting on the boundary of the outcrops, reducing the action on the "engraved" surface to the possible minimum.

Interventions

Contractors were given a specific area in the sites of Canada do Inferno (COMPÓSITO, Lda.), Penascosa (IN SITU, Lda.) and Ribeira de Piscos (NOVA CONSERVAÇÃO, Lda.). Each company chose an engraved outcrop to be the model to be taken into consideration when carrying out the intervention tests. Subsequently a "similar" non-engraved outcrop was selected for implementing the pilot experiments, bearing in mind the conservation problems identified in the engraved outcrop (same kind of fractures, toppling condition, loose blocks, etc.). The experiments were carried out in 2004.

Contractors were asked to accurately identify and map the degradation forms and to carry out a simple cleaning operation for better identification of the relevant problems to address. The differences between the sites and the composition of the teams lead companies to follow distinct action paths, an approach that revealed an interesting cause-effect relation. A few examples of the solutions developed by the contractors are shown in Fig. 3.

Figure 3 - Aspects of solutions proposed by the contractors. Bridging a large gap to avoid excessive water infiltration (upper left); details of the mortar filling of wide fracture gaps (upper right and lower left) and detail of the filled gap after a flooding episode (lower right).

The main focus of the intervention in Penascosa had to do with the completion of several studies, emphasising the need for a methodological proposal to analyse the geotechnical stability of the rock slopes. Although somewhat exaggerated for the greatest part of the small engraved outcrops, this approach might prove helpful when larger outcrops are concerned. Another proposal considered the implementation of monitoring systems to measure the evolution of the most prominent weathering dynamics that affect the engraved outcrops.

The intervention in Canada do Inferno started by trying to stabilise some large blocks that presented themselves in a toppling position by (re-)placing them to what probably would have been their primitive situation. Since this is a quite intrusive intervention that requires the use of difficult-to-manage logistics, namely heavy appliances, its application should be considered only in a very limited number of outcrops. Nevertheless, this demonstration showed that when the need to improve the stability of a given outcrop exists, this is a possible solution. In specific cases, when a whole engraved motif is disseminated by different blocks in toppling positioning, it might be justifiable to move the block(s) into their virtual 'original' position. To determine precisely what that position could have been, a possible key-factor is to reconnect the detached traits of the engraved motif.

Also worth mentioning was the implementation of drainage paths, fracture filling, attachment of loose blocks and consolidation of disaggregating surfaces. The proposal put forward to seal fractures deserves in-depth scrutiny. On the other hand, if filling fractures might be a solution to be implemented in the majority of cases, it has to be fully demonstrated that the applied mortars don't contribute themselves to an excessive retention of water on the inside of the treated outcrops. As already pointed out, the drainage capacity of the outcrop must be one of the basic concerns of any intervention, especially of those that have a more intrusive nature like, for instance, the sealing of fractures.

The approach followed in the Ribeira de Piscos site had the analysis of the condition of the two chosen outcrops as a starting step. Models of instability were identified and a detailed record and documentation system was created. The presentation in layers of the data resulting from the observation of the alteration state is quite elucidating. On itself, it may also be useful to define specific actions to be taken in the analysed engraved outcrop. Likewise, the way in which the alteration state was documented, as well as the recording of the intervention work carried out in the pilot outcrop are quite clear and suggestive. Several conservation interventions were tested, namely drainage and flood protection, outcrop covering with "reinforced soil", and the multilevel filling of openings between blocks with layers to fit different objectives (to drain, impermeabilise and regularise). The way in which the large openings between the treated outcrop and the massif were sealed is quite interesting. The main concern was to allow the free flowing of drainage water at the base of the openings. Again, emphasizing that this point will be crucial in future interventions, we are not in position to conclude on how effective these solutions have proved to be.

DISCUSSION

In general terms the three contractors followed approaches with some common points: all of them used non-aggressive mortars to seal off fractures and gaps, trying to avoid water infiltration and reinforcing the stability of the outcrop. Regular monitoring done by the Côa valley authority since the execution of all three interventions did not reveal any significant changes in the applied materials. At the same time, no noticeable hastening of weathering dynamics in the three outcrops was detected. Up to now, the interventions carried out can be considered as successful from conservation and stone consolidation viewpoints. Further aesthetic and principles issues pertaining the undertook interventions were discussed elsewhere[11]. Nevertheless, even from a strict technical perspective, it is relevant to reckon how intrusive were the interventions and whether more "friendly" alternatives could have been applied.

The intervention in Penascosa was very minimal in terms of conservation actions and, therefore, when seen from a reasonable distance to the outcrop (2 to 3 m) it is hard to identify the intervention. The followed option implied only to apply mortar on the side areas of the outcrop to prevent water from circulating inside the outcrop and consequently very little information on possible conservation actions can be extracted from it.

The other two interventions followed a more incisive approach, by directly addressing the treatment of fractures present on the surface of the outcrops. One of the mortars used in Canada do Inferno reveals some kind of biological colonization with areas progressively acquiring a green colour. In the Ribeira the Piscos site, the intervened outcrop was covered, at the very end of the intervention, with loose small schist fragments, grinded from slabs that were laying on the ground. The objective was to give a more natural finishing touch to the outcrop. Although they were slightly bonded with rock, most of these fragments have already disappeared.

One of the objectives of the Ribeira de Piscos intervention was also that occasional flooding would help to give a more natural appearance to the treated outcrop. Floods deposit sediments that in turn became the needed soil for smaller, in a first phase, and then higher plants to root. Since the trial interventions were executed at least one major flood has occurred. However, this flood has not lasted for too long, and, consequently, the amount of sediment deposited was minimal. Therefore, the Ribeira de Piscos outcrop still possesses a somewhat unnatural looking. However, assessing the behaviour of the applied materials and of the treated outcrops when exposed to such a stressful event was also one of the objectives of the interventions. Of the three interventions only the Canada do Inferno outcrop was not located in an inundation area. After the end of the flood and consequential lowering of water levels, an analysis of the other two sites revealed that both treated outcrops behaved well and that no loss of materials, both in the rock and applied materials.

On the other hand, all three interventions have not deliberately tried to emulate the rock characteristics (tones, colours, textures, etc.) in what concerns the applied mortars, option that will help to more adequately monitor the evolution of the applied materials. Nonetheless, considering future interventions on engraved outcrops we consider that a certain mimetic degree, adjustable according to the specificities of each case, between rock surface visual and palpable characteristics and applied materials should be enforced.

CONCLUSION

The decision to promote the pilot tests has proved to be an adequate strategy at this stage of the preparatory works. The experiments helped to find solutions to several problems that a real intervention will necessarily have to face. The most relevant actions concerned the structural stability of the engraved panels, an operation that can be considered under the framework of a consolidation approach. The basic objective is to solve instability situations that frequently occur in the periphery of the blocks and following the eroded fractures. The solutions tried to confine the fragments that were about to detach as well as to avoid the infiltration of runoff water. In this domain, contractors were asked to adopt solutions to seal water inlets and to leave outlet areas open to easy drain the infiltrated water. In spite of the intensive microfissures network, massive consolidation of the rock matrix was not considered as necessary. In fact the rock is in good condition with no need to introduce any consolidant that would oblige to face all the known shortcomings of consolidation in a long term perspective. Confining of large openings that are causing the progressive loss of

engraved areas fits the concept of minimum intervention and allows the Park authority to adapt its strategy and to use more intrusive actions only when new data will demonstrate that no softer solutions are able to solve the problems.

The evaluation carried out has shown that the applied materials are behaving well and that the interventions have not caused an increase of the weathering evolution dynamics in the treated outcrops. Of some relevance is also the data delivered by the analysis of the HIDRORUMO experiment, since this intervention has been performed over a decade ago. Nevertheless, an extended and continued monitoring of the evolution of the applied materials and techniques within the environment in which they were applied will further reinforce these findings, thus contributing to a full validation of the proposed solutions.

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