NATURAL PROCESSES IN THE DEGRADATION OF OPEN-AIR ROCK-ART SITES: AN URGENCY INTERVENTION SCALE TO INFORM CONSERVATION

ANTÓNIO PEDRO MARTINS DA MOTA BATARDA FERNANDES

A thesis submitted in partial fulfillment of the requirements of Bournemouth University for the degree of Doctor of Philosophy

July 2012

Bournemouth University

ABSTRACT

António Pedro Martins da Mota Batarda Fernandes

Natural Processes In The Degradation Of Open-air Rock-art Sites: An Urgency Intervention Scale To Inform Conservation

Open-air rock-art forms one of the most widely distributed categories of prehistoric material culture with examples recognized across the Old and New Worlds. It is also one of the most threatened features of human heritage and is susceptible to accelerated decay as a result of anthropogenic and natural processes. Much attention has previously been given to the impact of identifiably human activities and their mitigation, but the aim of this research is to redress the balance and focus on understanding the short-, medium-, and long-term impacts of natural processes. The main objectives of research are to identify open-air rock-art natural degradation causes, create a suitable method to assess the state of conservation of any given engraved outcrop of the Côa Valley rock-art complex and develop a urgency scale for conservation interventions. The urgency scale will be established by thoroughly examining a sample of the most – in terms of conservation – representative engraved outcrops. Since more than one thousand outcrops with rock-art still subsist today, it would be impossible to examine them all. Therefore, a sample comprising outcrops that possess most, if not all, of the variables that might affect stability and conservation state will be chosen. Some of the issues to consider are weathering and erosion of outcrops, or slope gradient and aspect of the hills where these are located. Such phenomena as biological colonization, rainwater percolation or chemical exchanges at surface level will also be analyzed. The expected end result of research is the creation of a method to determine the condition of outcrops and to identify methodically those in most urgent need of conservation. As a result, informed conservation action plans can be systematically tailored to suit specific natural conditions. Moreover, conservation interventions can be prioritized within a total universe of 1000 outcrops with rock-art.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

Research presented here has it roots more than a decade ago when the author was hired as a staff archaeologist by the Côa Valley Archaeological Park to develop a Conservation Program for the Côa Valley open-air rock-art. Fresh out of University, the author faced an overwhelming task that was, nonetheless, enthusiastically embraced: understanding and dealing with the threats that endanger the endurance of the rock-art. The serene yet irresistible allure of the rock-art and 'its' landscape made the author gain a passion for the dramatic twists and turns of the vale punctuated here and there by the artistic expressions of yore.

The first step in the endeavor was to carry out a Master Course in Managing Archaeological Sites at UCL's Institute of Archaeology, gain research skills and debate available options on how to strike a balance between public visits and the conservation and preservation of the Côa rock-art sites. It was argued that the 'site-friendly' public visits system in place has proven to strike a fair balance between the two ends of the preservation/public-needs spectrum. But the Master's thesis dealt only with the human agency part of the equation regarding the endurance of the rock-art. Hence, the Conservation Program attempts to manage human-based threats to the continued existence of the rock-art but also to monitor, understand and deal with, if and when necessary, the natural degradation processes impacting the conservation of this outstanding prehistoric artistic ensemble. To that regard, different level monitoring procedures were implemented, research on the several concerned variables was initiated and pilot conservation tests were carried out in rock outcrops not featuring rock-art imagery.

Research presented here is thus the next logical step in the improvement of the Conservation Program as the development of methodologies for condition assessment and ranking of outcrops in worst condition is instrumental to inform and prioritize future conservation work. Research is going to be of help in better understanding natural degradation processes laying out the basis for future conservation interventions also aiding in choosing the best suited methodological, logistical, ethical, and theoretical options for the (long) road ahead. If the most ancient rock-art in the Côa is some 25,000 years old, can it survive another 25,000 years more, now that it has been awaken from its prolonged sleep?

ACKNOWLEDGEMENTS

In Norway the author would like to thank Karin Tansem for the warm welcoming and useful discussions in Alta; to Alta Museum for providing for the stay of the author during his visit to the site; the whole conservation team (namely Eva Ernfridsson and Kjartan Gran) at Ausevik with whom the author had many insightful discussions. A very special thanks is due for Trond Lodoen who ‘opened doors’ to many sites (especially Vingen) and for the invitation to participate in conservation work at Ausevik also providing financial assistance through Bergen University towards that end. The many discussions on management, conservation and interpretation of Norwegian but also European rock-art with Trond Lodoen have been quite illuminating and helpful. The Hillary Williams Travel Scholarship, Bournemouth University, paid the author’s airfare when visiting Norwegian rock-art sites.

In Brazil the author wishes to thank Mila Simões de Abreu, Chris Buco and Maria Conceição Lage for useful discussions and mainly for making the author feel at home. The guide Giordano Macedo was been very helpful regarding information on the conservation work carried out in the Serra da Capivara National Park rock-art sites. Fundação para a Ciência e a Tecnologia provided airfare for the visit to Brazil.

In Arizona the author wishes to thank his good friends Evelyn Billo and Robert Mark for ‘bed and breakfast’ during his stay in Northern Arizona but mostly for showing the wonderful Chevelon Steps site and for useful discussions on rock-art management and conservation issues in the Southeastern USA besides pointing him in the right direction (not Vegas). The author wishes also to thank Flagstaff and Winslow Chapters of the Arizona Archaeological Association and Deer Valley Rock-art center for lecture invitations. Ronald Dorn was most kind and patient when explaining the Rock Art Stability Index, natural weathering processes active in the North-American Southeast as well as rock-art management issues. The author whishes also to thank Karin Ransden for offering a place to stay while in Phoenix and Katherine Neustadt for arranging it.

In South Korea the author wishes to thank the Northeast Asian History Foundation for the kind invitation to participate in the Congress commemorating the 40th anniversary of the discovery of the Bangudae Petroglyphs, which enabled the author to visit that rock-art site.

At the School of Applied Sciences, Bournemouth University, the author would like to thank his fellow postgraduate research students especially to Niels Brouwers for all the help in getting to know the School and Bournemouth. The author would also wish the thank the following staff members: Paola Barbuto who instructed the author in thin section preparation, microscope and SEM analysis; Jeremy Pile for helping in finding relevant references and providing useful information on slope gradient measuring, porosity analysis and petrological characterization and mostly especially to the late Professor Chris Wood who offered tremendous help in all Geology related matters and in planning research methodology.

Research has been partially funded by FCT – Fundação para a Ciência e a Tecnologia. DEM data was supplied by Instituto Geográfico Português (www.igeo.pt). Climate data was provided by Instituto de Meteorologia (www.meteo.pt), Agência Portuguesa do Ambiente (www.apambiente.pt) and Sistema Nacional de Informação de Recursos Hídricos (www.snirh.pt). Pedro Guimarães kindly allowed the use of some of his photos in Annex A. The author whishes to thank Joana Marques for all the help during common fieldwork outings and for relevant discussions and data on lichen colonization and how it affects the Côa Valley rock-art, to Luís Domingues for invaluable help in sorting out the meteorological data and to José Delgado Rodrigues for offering the foundations of research methodology and in helping the author gain a better understanding of natural weathering processes affecting the Côa Valley rock-art.

In the Côa Valley, the author whishes to thank all staff members at the Côa Valley Archaeological Park for all the help given to the author in the last decade developing the Park’s Conservation Program. Special thanks go to Luís Luís for tending to the Park’s weather station and collecting data while the author was gone; to Fernando Barbosa for the magnificent drawings of the Côa Valley rock-art; to Manuel Almeida for photos used in Annex A; to Mário Reis for supplying the location coordinates of the Côa Valley rock-art outcrops, allowing the use of many of his photos to help better illustrate research presented here but especially for all the demanding but at all times fruitful discussions on the conservation, spatial distribution and interpretation of the Côa Valley rock-art; to the former director of the Park, Fernando Maia Pinto, for hiring and believing in the author; to the former director of the Park, Alexandra Cerveira Lima, for all her support; to the current director of the Park, António Martinho Baptista, for the use of many of his photos to help illustrate research presented here, support and for always pointing new ways to look at and interpret the Côa Valley rock-art and lastly to the president of the board of trustees of the Côa Foundation, Fernando Real, for all his help and support towards completion.

Finally, the author wishes to thank his research supervisor, for all the help in steering research in the right direction, for all the discussions on how to develop research methodology, identify natural processes in rock-art degradation and general support in the form of the many paperwork that needed to be filled and signed. But mostly the author whishes thank Tim Darvill for always keeping calm and optimistic regarding the completion of research, a composure that much helped the author to also remain collected and focused (albeit not always!) and for proofreading sections of the text presented here. The author is thankful to his father, José António Batarda Fernandes for the financial help towards the conclusion of research; to his mother, Guilhermina Mota and her husband, António Tavares Lopes, for all the financial help, for being there for Leonor and Tiago when the author has not able because writing up and editing do take time, and lastly for being a supporting pillar of the whole family. Ultimately, the author whishes to thank his better half Fernanda for all her patience, affection, support and stoicism in putting up with long absences from home, especially in a period in which two young humans appeared in this world. To his two sons, Leonor and Tiago and to all his family with love, the author dedicates these volumes: only when you put your mind and heart in to it is it possible to accomplish! The sky is the limit…

AUTHOR'S DECLARATION

The list on Physical weathering processes present in Chapter 5 (Section 5.3.2.) has been taken, as mentioned in the body of the text, from an unpublished report to the Côa Valley Archaeological Park authored by Rodrigues (1999). Sections 4.2. and 4.3. in Chapter 4 partially feature, as mentioned in the body of the text, material published before by the author (Fernandes 2004; 2007).

“What is stored in the petroglyphs is not written in any book or to be found in any library. We need to return to them to remind us of who we are and where we came from, and to teach our sons and daughters of it.”
Herman Agoyo (All-Indian Pueblo Council Chairman in 1988). Quoted in Welsh and Welsh (2007, 106)

Chapter 1. Introduction: Rock-art, Open-air rock-art and the Côa Valley

1.1. Introduction

One of the great achievements of archaeological investigation across the world in the past half-century as been the recognition and recording of rock-art covering the whole span of human existence from the Pleistocene through to modern times (Bahn 1998; Clottes 2002). At the same time this presents a challenge for the future as protecting, conserving and managing these remains is neither simple nor straightforward. The research reported in this thesis concerns rock-art in just one situation, open-air sites, in relation to one set of conservation issues, natural processes. Attention focuses on the Côa Valley in northern Portugal, a World Heritage Site with a wealth of recently recorded open-air panels that can be used as a case study to inform the construction of an urgency scale to guide and prioritize interventions for conservation management. Such an urgency scale, it is argued, may be of use at other sites across the world.

In this introductory Chapter consideration is first given to the general character, definition, and significance of rock-art for archaeological research and public archaeology before focusing more explicitly on open-air rock art. The rock-art of the Côa Valley is then introduced and briefly described, its conservation discussed, and the broader aims and objectives of this research unfolded.

1.2. Rock-art in context

According to the International Federation of Rock-art Organizations, rock-art is everything inscribed or painted on rock surfaces possessing no utilitarian use (IFRAO 2008, 130). This wide definition therefore comprises motifs made by pecking, engraving or painting, whether of prehistoric or historic date, located in caves, natural shelters or the open-air and from cup marks or ‘plain’ drawings and paintings to the exquisite works present in the Lascaux or Altamira caves of France and Spain. Although there may be some discussion regarding the full scope of the precise wording, this is a definition widely accepted by rock-art researchers (but see also Bahn 1998; Clottes 2002).

What can be classified as (prehistoric, historic, or contemporary) art would require discussion at this point. However, defining (rock-) art can be a thorny task (as any post-modern reading on the matter will *subjectively* reveal) and is beyond the scope of the present research. Rather, the above-mentioned definition put forward by

IFRAO is an attempt to establish some common ground for characterizing rock-art. Nevertheless, can't (rock) art in itself (also) possess a utilitarian use dimension? For instance, it might provide, even if not entirely consciously intended, a sense of identity, and thus social cohesion, to the individual, people or society that created it. On the other hand, the author is aware of the possible pitfalls of using contemporary concepts when analyzing the cultural manifestations of other non-contemporary, non-western or not westernised societies. The issue has been hotly debated, namely with the concrete use of the word and concept 'art' when referring to rock-art. Moro-Abadía and González Morales (2007) offer a review of the old (and, in the author's opinion, pointless) discussion about the application of the word 'art' to cultural expressions such as rock-art in other societies. This is why some researchers prefer to use different terms for rock-art such as 'petroglyph' or 'pictograph' (for a review on the subject, see Chippendale *et al.* 2006). It is impossible to completely become the *Other* (especially when this *Other* is parted from the present by a few tens of millennia) and therefore the concepts (and corresponding words) available to us today are the only ones that can be used, without losing sight of the fact that in studies of history or prehistory only interpretative *hypothesis* can be formulated. Nonetheless, for an interesting discussion on the contemporary Western concept of 'art' as opposed to that of modern primitives see Tim Ingold (2000) who suggests in the paper "*Totemism, animism and the depiction of animals*" that there is no division between ecology and art as both form part of a meaning that reveals itself (and it is not *represented*) thus granting deeper understanding of the world. Additionally, Heyd (2007) offers some insights into the possibility of creating an aesthetic appreciation through cross-cultural etiquette for rock-art. In light of this discussion, the present author is quite happy to use the word 'art' for 'rock-art', hyphenating the two words as Chippendale and colleagues (2006) propose. The author comes from a European, 'Western' social context and thus belongs to a culture that uses the term 'art' for the concept of 'art'.

In fact, this whole introductory Section on rock-art, and on the (mostly prehistoric) rock-art of the Côa Valley is being constructed using today's words, conveying contemporary ideas and concepts. It is impossible to ascertain whether there is any correspondence between today's concept, ideas, and words and those used in the prehistoric past by those who created and viewed the panels in the first place. Researchers, when cataloguing rock-art, describe what they are seeing: a bulky four-legged creature with big ears and a long trunk is usually an elephant. But it is not known whether the concept (concept and not word) ‘elephant’ existed among ancient communities and, if it did, whether it exactly matched what today is meant when using the word ‘elephant’ in relation to the concept ‘elephant’? As Paul Bahn states,

> "If it looks like an elephant, and every single person who sees the depiction recognizes it as an elephant, then one can be reasonably sure - albeit never completely certain – that it is what the artist *intended us to see*" (2010a, 61-62, author's emphasis).

As the English researcher notes, although it is impossible to be one hundred percent confident, the intention of the artist was to depict an elephant that could be recognized by viewers when looking at the image. It is suggested therefore, that since (prehistoric) rock-art was not done by Martians or by any other existent species, it must have been done by our direct ancestors, with whom we possess many traits in common (namely the same large brain and, more importantly, a special fondness for and necessity of graphical expression). It can be proposed that the human species is capable of envisaging many concepts and emotions that are essentially universal across time and space. For instance, Howell (1991) draws attention to the elemental constants of human life (sex, death, mourning, birth) while Pinker (2002) references a list containing about 100 universals of human behaviour common to all cultures.

As others have pointed out (Bahn 2002; Lorblanchet 2007), it is believed that rock-art, as with any other product of human activity, anywhere and at any given moment, has manifold and overlapping meanings. In today’s world of ‘*Homo globalis’*, it is common sense, perhaps a truism, to state that explanations are complex before they become simple and vice-versa. Nevertheless, many times in science, and rock-art studies are no exception, new or ‘recycled’ theories (see Bahn 1997, 2001) are presented as the ‘new-all-explaining-mantra’ since they were produced with the intent of disproving or replacing existing ideas and theories. Indeed, too often, competing interpretative theories appear irreconcilable in their eagerness to explain. Nevertheless, existing interpretative proposals may and should be used together (depending on the specific circumstances of each case, evidently) to try to build and enhance our *contemporary* understanding of prehistoric rock-art, since precise original meaning is lost in the depths of human time.

Against this background, the author considers rock-art to be one of the most significant windows to have into the spiritual, social or economic life of our ancestors as well as to their mindset. The importance of the ancient imagery inscribed in rock walls is twofold. On one hand, rock-art provides important data that can be used in scientific attempts to characterize prehistoric or historic land-use, settlement patterns, migration waves, religious and spiritual belief systems, the role of different individuals in society, visions of the environment and its components, dating human occupation in certain regions, pinpointing the emergence of art, abstract thought, and storytelling, and thinking about (proto)-writing systems, to list just a few (see also Anati 2000; Bahn 2002; Dowson 2009; Gabora and Kaufman 2010; Lewis-Williams and Dowson 1999). On the other hand, rock-art undeniably possesses aesthetic qualities which make most imagery works of art and a few of them, true treasures of Art History (see for instance Clegg and Heyd 2005; Moro-Abadía and González Morales 2007).

It is quite remarkable that of the countless millions of rock-art motifs that have been discovered, so many possess such an incredibly aesthetic allure, even by today's standards. This outstanding feature of rock-art proves the merit of Ellen Dissanayke's label "Homo Aestheticus" for our species (Dissanayake 1992): prehistoric imagery has such a powerful appeal today, despite being produced by societies that have disappeared long ago. Rock-art sites such as Lascaux cave (Ruspoli 1987), Drakensberg (Lewis-Williams 2003), Serra de S. Francisco (Gutiérrez Martinez 2010) or Uluru (or, as it was baptised by Westerners, Ayers Rock) (Mountford 1965), and the Côa Valley to name just a few are living confirmation of the bond ancient rock-art can have with present populations. Pablo Picasso has stated that "if a work of art cannot live always in the present, it must not be considered at all" (quoted in Barr1946, 270). Worldwide, the millions of visitors that every year experience rock-art sites demonstrates that this ancient art form is still very much alive and appreciated today[1].

Surprisingly then, today's supposedly comprehensive Histories of Art only feature very general accounts of early art in their introductory chapters, as for example with Gombrich's highly acclaimed *"The Story of Art"* (1995), Honour and Fleming's "*A World History of Art"* (1999) or Janson and Janson's "*History of art"* (1997). Generally speaking, it seems art historians gladly leave the analysis of

[1] For instance, the Côa Valley Archaeological Park has received more than 200,000 visitors to the rock-art sites open to the public in the vale since opening in 1996 (Fernandes *et al.* 2008).

prehistoric art to archaeologists and researchers in connected fields. These scholars, more interested perhaps in understanding the social, cultural and economic contexts of rock-art production, in attaining the mere monographic description of motifs or in postulating the all encompassing explanation theory of rock-art, devote only fleeting attention to the highly relevant and original characteristics of prehistoric rock-art such as those considered below for the Côa Valley rock-art. For that reason, highly original and relevant traits of rock-art typically pass unnoticed in mainstream humanities research, as for example the presence of particular scenes, depictions of movement, direct archaeological context, or the rarity of obvious themes (Sanchidrián 2005).

Aesthetic value is another (and thornier) issue to address although rock-art, by definition, falls within the aesthetic appreciation realm as already recognized. Therefore, researchers have investigated the ways in which such an appreciation can be characterized by reaching the conclusion that rock-art possesses universal stylistic canons that can be objectively categorized and compared (Clegg and Heyd 2005; Heyd and Clegg 2008; Lamarque 2005; Morphy 2005).

Issues of aesthetic quality and aesthetic value partly underpin the interest directed at rock-art conservation but they are dimensions mainly excluded from the core of this research. Rather, in focusing here on a major gap in our knowledge pertaining to natural processes as they relate to the conservation and management of rock-art in open-air situations, it is important to recognize the importance of rock-art *per se* both in the academic world and in society in general as this dictates the resources that will be put into place to try to prevent the physical disappearance of this valuable but fragile heritage.

1.3. Open-air rock-art

Open-air rock-art panels are found throughout the world and their conservation is an international problem. Date range, site characteristics and geological context are very diverse. In Europe, rock-art imagery has survived since the Upper Palaeolithic (the Côa Valley but also many other sites, see Bahn 1992; Bahn 1995), the Neolithic (as in Northumberland, UK: Sharpe *et al.* 2008) and the Bronze Age (as in Alta, Norway: Tansem and Johansen 2008) as well as from more recent historic times. Elsewhere, emphasis tends to focus on whether rock-art panels are prehistoric or not. Among the former, some of the most well-known imagery is that made by aboriginal or First Nation groups in Australia (for instance in Kakadu National Park: Sullivan 1991), North America (the Coso Range, California: Whitley and Dorn 1987), South America (Serra da Capivara National Park, Brazil: Nash 2009), Asia (Altai, Russia: Kubarev *et al.* 2004) and Africa (Tassili n'Ajjer, Algeria: Coulson and Campbell 2010). Because individuals painted or engraved rock faces in their own local environments, rock-art can be found on almost every kind of rock type (schists, granites, sandstones, etc.).

By definition, open-air sites comprise all rock-art that exists outside of caves or constructed monuments, which possess very specific conservation problems mainly related to the disruption of a 'closed' delicate environmental equilibrium such as that associated with opening of decorated caves to the public. In general, open-air rock-art sites comprise panels that exist on exposed rock surfaces that are open to the sky such as cliff faces, outcrops, and glacial boulders.

Because of their outstanding universal value, many rock-art sites have been inscribed in the World Heritage List (WHL), as with most of the sites mentioned above. Today the WHL includes 33 rock-art sites (a small minority consisting of caves) and 43 on the so-called Tentative List (Sanz 2008)[2]. On the other hand, a preliminary review points to the worldwide existence of more than 70,000 rock-art sites comprising some 45 million images (Anati 2004), although some commentators believe this estimate to be far too conservative (see, for instance, Malotki 2007, 6).

On a world-wide scale, open-air sites are extremely significant since they vastly out-number rock-art panels located in caves not least because the prerequisites needed to produce open-air panels (i. e. an external rock surface) are readily available in nature. A certain Eurocentric approach that has dominated rock-art studies, together with what was perceived as the 'less spectacular' characteristics of open-air rock-art (weathered motifs can be difficult to perceive), has meant that, generally speaking, less interest has been devoted to such sites. Nevertheless, work on open-air sites always starts by first paying attention to the documentation and interpretation of the rock-art, then to its protection from human agency issues, and finally to its protection from natural causes of degradation. The situation has only begun to change in the last decades with the worldwide realization of the role of rock-art (and the past in general)

---

[2] A detailed examination of the inventory provided by Sanz (2008, 59-62) reveals that in some of the listed sites the principal criterion for inclusion in the WHL was not the existing rock-art but rather combined cultural and natural features. Nevertheless, even if rock-art was not the main reason for inscription, it is now a significant part of the overall significance of these scheduled properties. In other cases (such as Rapa Nui Island, Chile or Petra, Jordan), the property does not appear as it could be easily classified as rock-art as, for instance, it is categorized by the above-cited IFRAO definition.

in providing social cohesion to communities, countries or particular ethnic groups. This was partly because of a politically correct approach that tries to signal the importance of non-Western pasts and the political desire to provide time depth to life in a specific country or region. Moreover, in the last few decades, archaeological sites have become major attractions and rock-art is no exception. All this, together with the interesting revenues tourism generates in the generally rather underdeveloped areas where rock-art sites still exist means that more attention is being dedicated to the conservation of open-air sites. (Anati 1983; Anati *et al.* 1984; Deacon 2006; McManamon and Hatton 2000; Soleilhavoup 1991-1992, 1998).

One outcome of these changing fields of interest has been the investigation of open-air rock-art sites that encompassed, on the one on hand, their aesthetic and scientific significance and, on the other, human impact issues. Regarding scientific relevance, if one outcrop possesses a more important assemblage of motifs, its conservation will be more urgent than another with less significant motifs. As for human agency issues, considerable work has been done. There are plenty of cases from all over the globe pertaining to the management of heritage sites in general (Hall and McArthur 1996; 1998, for instance, provide an overview of the most relevant current heritage management issues). The current approach to managing rock-art sites tries to balance the need to preserve the art with the pressure arising from tourism and economic development. Among the most well-used strategies are management planning for impact reduction, access restriction, seasonal closure, guided tours only or the construction of pathways, fences, and interpretation facilities (Jacobs and Gale 1994; Lambert 1989; Ward and Ward 1995). However, as will be explained in the course of this thesis, human factors are only part of the problem so far as management and preservation issues are concerned; natural processes represent an equally important field for consideration not least as their impact is medium and long-term.

1.4. Rock-art in the Côa Valley, Portugal

The Côa Valley is located in North-eastern Portugal, in an area with several frontiers, including the border with Spain, but also the administrative, regional, natural and socio-economic divisions between the provinces of Beira Alta and Trás-os-Montes e Alto Douro (see Figure 1, Figure 2 and Figure 3). The rock-art has been discovered during the survey work undertaken during construction of a large dam (Carvalho 1994). Subsequent survey and documentation work confirmed the wealth of the site

(Zilhão 1997) and justified the Portuguese Government's decision to abandon the construction of the dam (Baptista and Fernandes 2007).

Within the wider context of Western Europe Upper Palaeolithic (UP) rock-art, the Côa Valley possesses distinctive characteristics that contribute to its unique significance. In fact, several researchers have called the finding of the Côa open-air rock-art a revolution in our understanding of Upper Palaeolithic art (Bahn 1995; Clottes 1998; Sacchi 1995; Scarre 1998; Zilhão *et al.* 1997). Until the discovery of the Côa, it was believed that the artistic manifestations of prehistoric Europeans were paintings found exclusively within caves, with a few exceptions that confirmed the rule. Now, specialists believe that painting in open-air and cave rock-art sites were originally equally common, albeit that most of the former have not survived into modern times because of their exposed locations. This also helps to explain why in the Côa only engravings exist today, with the exception of a few paintings located in natural shelters, namely in the Faia site. Among other relevant characteristics, it should be highlighted that the Côa Valley has the highest concentration in Europe of open-air Ice Age rock-art.

As of January 2010, a total of 960 of panels with rock-art had been identified in the Côa Valley grouped in 57 different clusters (Mário Reis, personal communication)[3]. However, 36 records will not be considered in the present study since they correspond to rock-art motifs inscribed in walls and on stones that now compose walls or to isolated mobile art finds. Hence, the total of known rock-art outcrops in January 2010 was 924 (see Table 1 and Figure 4 and Figure 5). Moreover, as detailed below (Conservation of the Côa Valley rock-art section), the sites located in granite and quartzite terrains besides those that are currently submerged due to the waters of the Pocinho dam (see Chapters 4 and 5) will not be included, regarding the aim of the PhD, in the universe of study. This fact lowers the total to be included in the present study to 822. Nevertheless, all rock-art outcrops known in January 2010 (924) will be included in the overarching description of the Côa Valley rock-art that

[3] It should also be noted that the total of rock-art outcrops presently known in the Côa Valley increases almost every month as Mário Reis, the staff archaeologist in charge of rock-art survey, regularly makes new finds. Hence, it was decided to carry out the present PhD project considering the data available in January 2010 since it would be extremely confusing to keep adding new outcrops to the study universe. As a further note, it should be mentioned that the total of rock-art outcrops known at the time of writing this footnote (May 2012) is well above 1000 (Mário Reis, personal communication).

will immediately follow since all belong to this vast artistic complex located in North-eastern Portugal.

Imagery from the Pleistocene is to be found in 450 outcrops, corresponding to 42 percent of the total identified rock-art outcrops, and scattered along 36 different sites. At this point, it is difficult to accurately determine the total number of UP motifs but these are estimated to be around two thousand (Baptista 2009, 130). Imagery that has reliably been dated to the Upper Palaeolithic is grouped in two distinct phases: the Gravettian-Solutrean archaic phase that spans the period 25,000 BP to 18,000/17,000 BP and the Magdalenian phase covering a period from 15,000/14,000 BP until the end of the Upper Palaeolithic, about 11,000/10,000 BP (Aubry and Sampaio 2008; Baptista 2009). Imagery from the Neolithic, Chalcolithic, Iron Age, historical and contemporary periods has also been identified (Baptista 1999; Baptista 2009) (see Figure 5 and Figure 6). Of all this, only the prehistoric period rock-art was inscribed by UNESCO in the World Heritage List (UNESCO 1999).

The Pleistocene Côa Valley rock-art has a clearly defined internal logic and structure. Some have drawn attention to the fact that the most ancient Solutrean-Gravettian rock-art in the valley may be understood as an open-air ‘sanctuary’, possessing well-marked distinct ‘pilgrimage’ paths (specifically established by differently themed, placed or oriented motifs) leading to different ‘shrines’ (Baptista and García Díez 2002). Hence, rock-art would have functioned as a means of creating (or ‘humanizing’) the landscape. According to Baptista (2009, 166-171), this more ancient period generally corresponds to predominantly pecked and abraded motifs located in the most ample fluvial beaches available in the Côa (Canada do Inferno, Rêgo da Vide, Fariseu, Ribeira de Piscos, Quinta da Barca and Penascosa). This group of sites constitutes what he calls the archaic sanctuary. As for Magdalenian motifs, most were executed in the fine-line incision technique. The majority are concentrated in the mouth of the Côa area, although they also appear, in small numbers, at the above-mentioned sites containing older representations. In Pleistocene times, anthropomorphic motifs appear only in this later Magdalenian artistic period.
During this older phase, the Côa Valley could have been a meeting place for different groups where goods were traded and intergroup ties were strengthened (Luís and García Díez 2008). One of the ways these ties could be reinforced was by carving, in a structured fashion, meaningful motifs in the outcrops thus constructing a landscape which through repeated creation acts might have turned into a ‘sanctuary’. It is

supposed that the Côa was an area richer in food resources than other locations in the region, especially during the summer or in extremely dry years, due to a nearly constant flow of water (Aubry *et al.* 2002). Therefore, the Côa, besides its hypothetical role as a sanctuary, could also have been an area where groups would find almost constantly subsistence resources. Indeed, as that affluence impressed individuals they felt ‘obliged’ to ‘consecrate’ this particular part of the physical world by impregnating it with their symbols. This dedication would also be part of the landscape creation process. Available data suggests that the major change in spatial organization of decorated rocks between the Gravettian-Solutrean archaic phase and the Magdalenian has to do with a northwards dislocation, towards the Côa’s mouth, of the central nucleus of the ‘sanctuary’ (Baptista 2009, 171).

As visible in Figure 6, the Pleistocene rock-art sites are located on both banks of the Côa, with predominance for the left margin, and on some of its (mostly left bank) tributaries. In the later case, the majority of these sites are very close to the main valley. There are also a few sites located in both banks of the Douro, again with predominance for the left bank. Due to local geomorphology, after the mouth of the Côa, the Douro follows a northbound course that makes it, in way, a sort of continuation of the Côa, for the short length where rock-art is still present. In this stretch of the Douro, sites are only located on the left bank. Before the Côa’s mouth, sites in the Douro are to be found in both banks. It should be noted that of all the Côa Upper Palaeolithic sites only a quarter (9 sites) are located on the right bank of the Côa (6 sites) and of the Douro (3 sites). Regarding altitude, more than half (299) of the Pleistocene outcrops are located on, or very close to, the foot of steep slopes (therefore, near or on the edge of the waterways), having an elevation between 110m and 200m (see Figure 7). The average altitude of the outcrops is 188 m. A more suitable characterization of the spatial distribution reality of UP outcrops concerning elevation is perhaps given by median altitude of 160m.

Among of the most relevant characteristics of the Côa Valley rock-art is the tradition of engravers (sometimes of different ages, but mostly during the Upper Palaeolithic) superimposing new motifs upon existing ones (Baptista 2009, 142) (see Figure 8). The author has proposed elsewhere (Fernandes 2008a)[4] that it is intriguing why, out of a total of many thousands of outcrops that existed in the region during the

---

[4] Available at http://www.arte-coa.pt/Ficheiros/Bibliografia/1322/1322.pt.pdf.

Upper Palaeolithic, only 1000 were selected for engraving. It was suggested that there was a deliberate culture-oriented choice of outcrops perhaps because of 'idiosyncratic' qualities of the selected outcrops seen at the time. These qualities could have been tone, texture, prominent location, or the existence of fractures. More recent insights, in fact a 'by-product' of this research, makes it possible to suggest adding to this hypothetical list, factors such as the aspect of slopes where the outcrops are located and of the outcrops themselves (Fernandes 2010b)[5]. A more recent study (Aubry *et al.* 2012) somewhat contradicts this suggestion, albeit not entirely as will be discussed in Chapter 6.

Another relevant characteristic of the Côa Valley Pleistocene rock-art is the representation of the natural motion of animals (Baptista 2009, 146-154; Luís and Fernandes 2010)[6]. Although the representation of movement can be found in imagery from other Western Europe Upper Palaeolithic sites (Azéma 2005; Rusinowski 1990), the Côa possesses a large quantity of such representations visible in different techniques. In fact, to name just a few, the addition of a second or even third head to an animal suggests the partial motion of a body part (in this case, the head, see Figure 9 and Figure 10). In other examples it is the whole animal that moves suggesting its motion through a timeline representing narrative. In these cases there is not only the representation of different individuals of the same species but also of the same individual in diverse positions. For instance, Figure 11 may portray the same goat climbing through a slope leaping from one rocky outcrop to another. Technically speaking this is nothing less than the invention of motion pictures or the idea of cinema.

One last feature regarding the whole corpus of rock-art in the Côa worth mentioning is what is known as the 'Côa Valley ultra-millenary artistic tradition' (Luís 2009, 130). In spite of the existence of some hiatuses between the archaic Upper Palaeolithic period and today when no rock-art was created (for example the Middle Ages), the fact is that people from many ages left the traces of their passage through the vale as inscriptions on the local schists and, to a lesser degree, granites. There are, of course, obvious formal, thematic and even technical differences between the rock-arts of, say, the Upper Palaeolithic and the Iron Age (which will be addressed below)

---

[5] Available at http://www.arte-coa.pt/Ficheiros/Bibliografia/1329/1329.pt.pdf.
[6] Luís and Fernandes paper available at http://www.artecoa.pt/Ficheiros/Bibliografia/1412/1412.pt.pdf.

but the practice itself is persistent (see Figure 12). Therefore, when the term ‘ultra-millenary artistic tradition’ is used, it should not be inferred that there is formal continuity since the Upper Palaeolithic. Conversely, the term refers to the fact that there is a long-lived tradition extending throughout different ages of people resorting to the rocky walls to inscribe or paint artistic motifs.

As for the thematic, formal and technical characteristics of the prehistoric Côa Valley rock-art, it can be said that it closely follows the great rock-art traditions of each particular age in Western Europe prehistoric art. Albeit the existence of some regional quasi-unique particularities such as the above-mentioned depiction of motion, in the Côa we find depictions of large mammals such as aurochs, goats, horses and deer (the four most represented species in the Côa). Motifs were done by pecking, abrasion (see Figures above) or fine line incision (see, for instance, Figure 13 and Figure 14) and using artistic canons to portray anatomical details of animals, similar to those used in other prehistoric art areas of Western Europe (Baptista 1999; Baptista 2009; Sanchidrián 2005). Following these traditions, among the least depicted motifs we find animals such as fish (see Figure 15), chamois, and the human figure and there are no representation of birds or elements of the natural world such as the sun, moon, plants, waterways, or mountains. Because of poor survival in open-air context there are very few painted motifs. Cold-climate mammals that are now extinct that can be found at sites of the same period in France (namely in Perigordian caves) such as mammoths, wholly rhinoceros, and the megaloceros are absent from the Côa since climate was milder during the Upper Palaeolithic in this southern region of Europe (Zilhão 1995). Although not many Pleistocene open-air rock-art sites have been found in the Iberian Peninsula, those that have been identified share many characteristics with the Côa. The Sabor and Ocreza rivers (Baptista 2009, 190-235), for instance, in Portugal, and Siega Verde (Alcolea González and Balbín Behrmann 2007) or Domíngo García (Ripoll López and Municio González 1999) in Spain are among such sites (see Figure 16). However, because of the quantity of panels the Côa Valley constitutes the most important and most extensive Upper Palaeolithic open-air rock-art site in Europe.

The open-air rock-art site of Siega Verde should be noted as being the ‘twin’ site to the Côa Valley. In fact, in 2010, UNESCO extended the classification of World Heritage Site status enjoyed by the Côa since 1998 to also include Siega Verde. The overall property inscribed in the World Heritage List is now designated as

“Prehistoric Rock Art Sites in the Côa Valley and Siega Verde” (UNESCO 2010b). The site is located a few kilometers from the border with Portugal in the municipality of Ciudad Rodrigo, Spain. It occupies a relatively minute area on both banks of the Águeda River, which, like the Côa River, also runs from South to North and is a tributary of the Douro River.

Unlike Côa, which holds motifs from other periods, at Siega Verde only representations from the Upper Palaeolithic have been identified so far. Both sites involve the use of engraving as the main means of executing the motifs, so overall the rock-art in Siega Verde is stylistically and technically akin to the Côa Valley (and Western European) Upper Palaeolithic rock-art. As in the Côa, motifs depict large quadrupeds, namely horses (which account for half of the depictions), deer, aurochs and goats (Alcolea González and Balbín Behrmann 2007, 519-20). Among the specificities of the site, the cited Spanish authors refer the rare depictions, in the context of Upper Palaeolithic art in the Iberian Meseta, of bisons, reindeer, and felines (Alcolea González and Balbín Behrmann 2007, 523).

The Côa rock-art that can be attributed to the Neolithic, Chalcolithic and Bronze Age also follows the themes, formal characteristics, and execution techniques of prehistoric art of the period in neighbouring areas of Portugal and Spain (Baptista 1983-1984; Sanchidrián 2005). The art becomes more schematic and the human figure assumes great relevance. Geometric symbols are also noteworthy. Engraved imagery from these periods is pecked and abraded (Baptista 1983). Another trait is the existence of a quite high, proportionally speaking, number of painted motifs, a fact that may result from the preferential choice of the walls of more protective natural shelters to paint figures (Baptista 1999, 158-66) (see Figure 17 and Figure 18). In fact, the vast majority of painted motifs known in the Côa belong to these periods and together account for less than 5 per cent of the whole known corpus of Côa Valley rock-art. These panels have not been extensively researched to date.

Iron Age art is the second most important period in the Côa Valley, not only because it is second in number of motifs represented, to the Upper Palaeolithic but also because of the quality of many figures (see Figure 19) and the relevant data that can be extracted from them. Imagery from this period was all engraved in the fine-line incision technique, with the exception of some motifs that were also (quite finely) abraded (see, for instance, Baptista 1999, 179). Thematically speaking, the human figure, namely the warrior, sometimes on horse, together with war and hunting apparatus, such as spears, swords or shields, gains visibility (Baptista 1999, 167-81) (see Figure 20 and Figure 21). The art is thus the expression of a proto-state warrior society that had in fighting and raiding activities, invading its neighbouring tribes' territory, an important activity. The warrior, especially if accompanied by a horse, would be positioned at the top of social scale. The Iron Age in Portugal spans the first millennium BC; at the end of this period, the Iberian Peninsula is conquered by Rome. It is interesting to consult classic sources, namely the geographer Strabo, regarding his description of the tribes that occupied the Côa Valley (Luís 2008). He portrays a fierce tribe called the Lusitanians that other sources mention took many years to be conquered by the Romans (Martín 1989). If one compares Strabo's description of the Lusitanian warrior attire and weaponry with Iron Age Côa representation of human figures, the similarities are astounding (Luís 2008, 421) (see for instance the footman in Figure 21). Therefore, the Côa Valley Iron Age rock-art is the only known self-representation of the Lusitanians, a prehistoric population group that has been used, namely by Portuguese political regimes, to establish a 'mythical' identity for Portugal (Fabião 1996).

Historical and modern engraved motifs can also be found in the Côa. Historical imagery comprises religious and anthropomorphic representations from the seventeenth and eighteenth centuries (Baptista 1999, 182-3) (see Figure 22). Modern figures consist of representations of daily life (for instance, a steam locomotive passing the bridge over the Côa's mouth), animals, and mythical historical occasions (such as a fight between the Kings of Portugal and Castile near to the Castle of Guimarães, the legendary birth place of Portugal – see Figure 23) that can be referred to as 'naïve' art. Some modern engravers also cut their name in the rock. These motifs were done in the 1940s and 50s by the owners (and/or their sons) of the watermills that, at the time, were situated on the banks of the Côa. It is interesting to note that these engravers noticed the ancient prehistoric imagery (although they could not have imagined its age) and chose not to superimpose their work over older motifs instead using nearby empty rock surfaces (Luís and García Díez 2008). Lastly, there are also quite a number of motifs that because they are uncharacteristic or just loose lines fall into a category labelled as 'Undetermined' (Baptista and Reis 2008, 143).

1.5. Approaching preservation and conservation of the Côa Valley rock-art

Critical here is a distinction between the terms ‘preservation’ and ‘conservation’, as they will be used throughout this thesis. Although the two terms are often seen as having an intertwined meaning (see for instance Bednarik 1996; Brink *et al.* 2003; Herráez 1996), this author considers there is an important distinction between the two concepts (see Fernandes 2007, 72-3). The term ‘preservation’ is here applied to all actions that indirectly (that is, without directly intervening in the fabric of a heritage element) aim to address menaces to the perpetuation of that heritage asset (in this case, rock-art). Most of these menaces have an anthropogenic origin, or are greatly enhanced by human intervention on the land from the micro-scale (e.g. over-visiting at a heritage site that subsists in a delicate and interdependent natural equilibrium) to the mega-scale (e.g. climate change). Thus, heritage management strategies are created and implemented to try to inhibit human impacts from accelerating natural weathering or natural decay processes at work at a given site besides preventing the destruction of heritage assets due to vandalism or economic growth (farming, infrastructure building or urban development). On the other hand, the term ‘conservation’ is proposed to include all the ‘hard’ interventions brought to bear on heritage assets with the aim of prolonging their ‘natural’ physical lifetime. Therefore, actions such as stabilization, consolidation, and cleaning (either built, ruins, or rock-art) represent conservation actions. It is more than a matter of linguistics. Although different words might be used, it is suggested that such a distinction is made not only for clarification and systematization questions but also in relation to the theory, methodologies and techniques behind each concept which are quite different and ultimately rest in different spheres of academic tradition.

1.5.1. Preservation of the Côa Valley rock-art

When the first rock-art panels in the Côa Valley was found, a major dam was being built on the river. In fact, it was the archaeologist hired by the power company that was building the dam that discovered the first engraved outcrop, Canada do Inferno 1 (see Figure 24). Although only made public in 1994, the find probably occurred in 1991 (Baptista and Fernandes 2007, 263). The discovery rapidly provoked a political controversy since the government stance was quite ambiguous: while forced to admit the importance of the find because of its extreme rarity as an example of Upper Palaeolithic open-air rock-art in the European tradition, the dam was seen as fundamental to energy production and the regulation of flood regimes in the Douro hydrological basin (of which the Côa is part). The controversy quickly reached the international community as renowned international rock-art specialists backed the chronological attribution of the rock-art to the Upper Palaeolithic first proposed by Portuguese archaeologists (but see Jorge 1995). On the other hand, the power company (then partly owned by the Portuguese State) hired three different rock-art researchers to carry out a blind test in order to try to date the engravings. Direct dating of engraved rock-art (where, unlike the case with paintings, no organic material is present) is a field of knowledge still in its infancy and "the application of several dating methods remains unresolved" (Pope 2000, 842). Thus, results from the Côa blind test were quite unreliable and were not accepted by the international scientific community (see Baptista and Fernandes 2007, 267; Zilhão 1995). Ultimately, after fierce controversy during the 1995 election campaign, in which the Côa was one of the central issues debated, and a subsequent government change, it was decided to stop construction of the dam and create, in 1996, the Côa Valley Archaeological Park (Parque Arqueológico do Vale do Côa – PAVC). The Park was charged with the duty of managing, preserving, and presenting to the public the Côa Valley rock-art (Zilhão 1998). Two years later, in 1998, the Portuguese government's decision to preserve the engravings *in situ* proved its merits when UNESCO, in one of the fastest scheduling processes ever, decided to include the Prehistoric rock-art sites in the Côa Valley in the World Heritage List (UNESCO 1999).

The first issue to consider in rock-art management is human impact. Since its creation in 1996, the Park has mainly devoted its efforts to controlling aspects of human agency that could endanger the survival of the rock-art. The strategy was to attempt to control what is most readily controllable, that is, the impact of human activities on the rock-art landscape. Because of its rapid creation, the Park was established without a Management Plan that would regulate the economic use of the landscape. Therefore, a provisional regulatory scheme was set up which meant that the PAVC had effective control over the 200 square kms it manages. Tourist visits to the rock-art sites are subject to a control system. The economic exploitation of the landscape (quarrying, farming, etc.) is controlled by legal norms of which the PAVC is the enforcer. All major projects that might affect the landscape (roads, gas pipelines, etc.) are subject to early consultations with the Park that also follows construction work *in loco* (Fernandes 2004). In 2002, a comprehensive Management Plan was ready for approval. The plan definitely established (and enhanced) the temporary protective measures set out at the time of the Park's creation (Pau-Preto and Luís 2003). Right from the start, there has always been an overarching objective guiding the Park: understanding the global environment in which it is located in order to delineate the best-suited measures to counter all threats to the long-term preservation of the rock-art (Zilhão 1998). Hence, preservation-related issues (preservation understood as it was explained above) were not addressed in any detail in research reported here. This was not because preservation issues are not important but because for the time being they are sufficiently covered by the Management Plan and by the protection efforts now established in the Côa Valley.

1.5.2. Conservation of the Côa Valley rock-art

Following the definition offered above, the focus of this research is conservation of open-air rock-art. As it will be discussed (Chapter 5) natural processes play a critically important and rather understudied role in the long-term security of rock-art and yet are not well covered by archaeological research. Even among related disciplines such as geomorphology and geology, the study of weathering and erosion dynamics of stone in its natural context has been driven by issue-based approaches such as physical, chemical, or biodeterioration decay. These have made useful contributions to the overall understanding of such dynamics and informed conservation work, but there is more to do and especially in relation to the combined impacts of these processes. Therefore, trying to holistically understand and address all the degradation dynamics is not an issue unique to the Côa Valley Archaeological Park. Although each case has its own specific overall context, the work reported here has significant implications for other sites; in this sense, the Côa Valley is a relevant case study. The methodology, research issues, and results will be of use to rock-art managers and conservators worldwide. Importantly this work will enhance our comprehension of natural degradation processes and contribute to the development and implementation of sound and informed conservation actions at open-air rock-art sites.

As part of an integrated management philosophy, the author has been developing a Conservation Programme for the Côa Valley Archaeological Park that set the bases for monitoring and recording natural degradation threats (Fernandes 2007). The weathering and erosion dynamics affecting the conservation of the Côa Valley rock-art have been described and discussed elsewhere (Fernandes 2006, 2007, 2009)[7] and one of the most important actions already implemented by the Conservation Program was the pilot conservation interventions in un-engraved outcrops where weathering and erosion dynamics work in similar ways to those affecting the engraved outcrops. These experiments were designed to test the applicability and ageing of conservation materials and techniques that might be used in future to confer stability to the rock-art outcrops and panels (Fernandes 2008a; Fernandes and Rodrigues 2008)[8].

Considering its relevance, dimension and the complexity of conservation issues, the Côa Valley is an ideal test-bed for research on the natural causes of rockart degradation. For instance, most of the outcrops that carry rock-art motifs are scattered along both banks of the final 17 kilometres of the River Côa positioned at the foot of sharply inclined hills. The topographical location of the outcrops decisively influences the weathering and erosion mechanisms that endanger the survival of the rock-art motifs. Nevertheless, the sites in the Côa are exposed to further diverse degradation dynamics (climate, geological or biological based, for example). It must be stressed, however, that while these are intricate dynamics it makes perfect sense to understand the Park's approach to the conservation of the Côa rock-art as an attempt:

> "(...) to retard the development of all the active dynamics that, directly or indirectly, affect the conservation state of the rock-art. It also aims to reconcile our desire to preserve the engraved surfaces unaltered, belonging to a conceptual and immutable time, with the action of the regular alteration dynamics of a 'natural' world in constant re-equilibrium. Hence, in this context, a philosophy of active conservation does not aspire to arrest time and its consequences, but to be a realistic effort to harmonize the will of human memory with the will of nature." (Fernandes 2007, 72)

In 2006, the author co-ordinated an academic session at an international Congress organised by the PAVC to discuss and evaluate the conservation experiments that had been carried out in the previous years (Fernandes 2008a, 2008c; Fernandes and Rodrigues 2008). The consensus view amongst the attending specialists was that the experiments were relevant and trustworthy conservation proposals adapted to the peculiarities of the Côa rock-art. Nevertheless, it was also

---

7 Fernandes 2006 available at http://www.arte-coa.pt/Ficheiros/Bibliografia/1316/1316.pt.pdf.
8 Fernandes and Rodrigues 2008 available at http://www.artecoa.pt/Ficheiros/Bibliografia/1310/1310.pt.pdf.

recommended that the next stage in developing the PAVC Conservation Program should be to carry out the research proposal that constitutes the core of what is reported in this PhD. That is, to create a suitable method to assess the state of conservation of any given engraved outcrop thus developing our knowledge on natural weathering dynamics affecting rock-art panels.[9]

1.6. Questions, Aims, and Objectives

The twin interconnected questions for this research are: What natural processes can be identified in relation to short-, medium-, and long-term degradation of rock-art outcrops in the Côa Valley? And how can the understanding and monitoring of these processes be structured and used to provide an evidential basis for informed conservation?

From these questions the overarching aim is therefore to identify, document, and understand natural processes that cause the degradation of open-air rock-art panels, and their interrelationships, as a means of informing practical conservation and management measures. Through the development of an 'urgency scale' that can help prioritize the deployment of resources.

In pursuit of this goal, the following objectives have been set:

a) Background research into existing ongoing related studies of rock-art degradation and conservation;

b) Background research on natural causes of rock-art degradation;

c) Creation of a list of relevant natural processes identifying key characteristics and measuring their effects;

d) Examination of a selection of relevant parameters in other rock-art areas in the world;

e) Collection and storage of data on the identified risk parameters active on rock-art panels in the Côa Valley;

[9] It must be noted that present research builds on data gathering concerning all relevant natural constraints that influence the conservation of the Côa Valley rock-art that has been conducted by the author for the last decade. Work already carried out includes the systematic condition recording and monitoring of weathering dynamics active in some key engraved outcrops; collection and analysis of the data provided by the weather station operating in one of the Côa rock-art sites or the collection and analysis the data provided by the seismic station operating in another of the Côa rock-art sites as reported in the already quoted author papers'.

f) Create and test a ranking system to categorise risk intensity in each assessed engraved outcrop on which the draft intervention scale will be based;

g) Consolidation of results of the three strands of research (background; case studies and Côa Valley fieldwork) as a draft intervention scale that will rank conservation work urgency;

h) Creation of a site-specific model "tool-kit" for application of the intervention scale at open-air rock-art sites that will validate and inform future conservation work.

1.7. Methods and approaches

Carrying out this research involved three strands of investigation. First, undertaking a synthesis of the available published material on rock-art and natural processes. This was directed towards objectives a, b, and c. Second, a comparative study of similar sites in other parts of the world, those selected being in Norway, Arizona (USA), Serra da Capivara (Brazil), and Bangudae (South Korea). In all cases attention was directed towards existent and ongoing research and arrangements for monitoring natural processes and change to rock-art panels in order to accomplish objectives c and d.

The third strand involved interpretative studies of data collected in the Côa Valley, namely weather records, the physical characterization of weathering processes and Digital Elevation Modelling (DEM) aimed at identifying and understanding active natural degradation processes. Throughout this work a synthetic approach to multidisciplinary studies relevant to conservation was followed, with a focus on the practical side. Bibliographic reviews of relevant case studies and natural threats parameters were undertaken. Schist samples were collected to determine the petrologic characteristics of rocks in the area. Another important source of data was a 10-meter resolution DEM that made possible to reliably measure aspect, slope, and solar radiation in the whole area of study. In all the hillsides with engraved outcrops the slope gradient was measured (both on the micro and macro local scale) and slope aspect was identified. A sample of Côa Valley rock-art outcrops was selected in order to examine and assess their condition, also measuring how natural weathering has influenced their degradation. These data were collected during episodes of intensive fieldwork carried out in the spring, summer and fall of 2010. Every outcrop present in the sample was visited and assessed regarding its condition. The Park's archaeologist

Mário Reis supplied the indispensable geographic coordinates of every rock-art outcrop known in the Park as of January 2010. Some fieldwork was undertaken together with the biologist Joana Marques, who is carrying out a PhD on lichen colonization and degradation of rock-art in the area of the Park. All gathered data were stored on a purpose-built database (see Annex A – Database of collected information on the condition of analysed outcrops).

Research did not take into account rock-art located in granite and quartzite formations. Hence, the weathering mechanisms affecting the relatively few rock-art surfaces located in granite and quartzite terrains will not be examined. This option was taken in light of the specificities of weathering mechanisms that affect granite and quartzite rock surfaces. To consider different sets of weathering processes would significantly increase the scope of research while making it lengthier and would contribute to further complexify an already quite demanding study.

1.7.1. Sample selection

For practical reasons it has been necessary to sample a proportion of the 1000 or so engraved outcrops rather than examine them all. The structured sample takes into account the disparities among outcrops. Of the total universe of rock-art outcrops known in January 2010 (924), those that are currently submerged due to the influence of the Pocinho dam in the Douro (see Chapters 4 and 5) were not considered to be included in the sample since it would not be possible to assess their condition. Moreover, as detailed above, sites located in granite and quartzite rocks were also not considered for inclusion in the sample. Hence, the sample was chosen from a pool comprising a total of 822 outcrops.

Giving the magnitude in the number of considered outcrops, it would have been impossible (or at least, massively time-consuming) in the scope of present research to carry out a condition assessment of each one. Hence, it was decided to assess only a chosen structured sample of 40 outcrops, roughly corresponding to 5 percent of the total number of considered rock-art outcrops. The list of selected outcrops is available in Annex A (also comprising their condition assessment). Table 2 lists all the outcrops selected per site also summarising and highlighting, considering the factors discussed below, the reasons why those outcrops were chosen for the sample.

The method chosen to select the rock art outcrops was by picking a structured sample taking into account the disparities among outcrops arising from their precise location namely geomorphological attributes or altitude, which is relevant when considering flooding episodes (see Chapters 4 and 5). The aim was to select a sample of outcrops comprising the conservation risk factors that affect the condition of rock-art panels. It is fundamental to correctly choose the rock art outcrops to be present in the sample and to carry out their condition assessment. In turn, this assessment will provide the data from which the intervention urgency scale will be established.

In the selection of the sample two main features were taken in to account: geological formation and precise location. Regarding geology, it should be noted that the schist rock art sites in the Côa Valley considered in the scope of the current research are located in two different formations: Pinhão and Desejosa, each with dissimilar characteristics, as discussed in Chapter 4. In the former, only two rock art sites exist (Quinta da Barca and Penascosa) roughly accounting for less than 10% of the whole outcrops of the Côa Valley rock-art complex. A random sample selection would mean that it would be statistically very likely that these two sites would be under-represented or not represented at all. Therefore, it could occur that weathering dynamics at work in the outcrops located in the Pinhão formation would not be present in the sample and taken into consideration when establishing the urgency scale. Moreover, the largest (in number of engraved outcrops) rock-art site in the valley (Foz do Côa) possesses almost 200 art outcrops in just one slope (see Figure 25). Even though the site's relevance, choosing randomly might probably result in its over representation in the sample.

Another issue with the use of a random sample is that it could result in disparities regarding the aspect of outcrops. Aspect has been categorized following Yalcin and Bulut (2007) (see Table 3). Literature review on the subject (see Chapters 2 and 5) suggests that different aspects may determine different rates of evolution in weathering and erosion processes. Preliminary DEM data revealed that of all rock-art outcrops known in the Côa Valley in January 2010, only 11 percent and 21 percent faced North and West, respectively (see Figure 26 and Figure 27). A similar situation occurs with slope. Slope data has been categorized according to the Slope Steepness Index (Anon. 2012) detailed in Table 4. Preliminary DEM manipulation also revealed that most rock-art outcrops in the Côa Valley are placed in quite steep slopes (see Figure 28 and Figure 29). However, a few are located in less steep hillsides. Again, choosing a random sample could result in the under-representation of outcrops located in North and West oriented slopes and in less precipitous inclines. Solar radiation issues were also a concern since by definition, outcrops located in North oriented slopes receive lesser amounts of sunlight (see Figure 30).

Location of outcrops on areas prone to flooding were yet another factor in choosing the sample. On one hand, the majority of outcrops are located at or near the river bottom at altitudes comprised between 110 and 200 m (see Figure 31 and Figure 32). Hence, in a randomly selected sample, the relatively few outcrops to be found at mid-slope could end up being underrepresented[10]. On the other hand, of the majority of outcrops positioned at or near to the river bottom, only a small portion is placed below maximum flood level (see Chapter 4). Yet again, a randomly selected sample would probably mean the underrepresentation of outcrops subject to periodical flooding.

Figure 33, Figure 34, Figure 35 and Figure 36 summarise sample outcrops data regarding altitude, aspect and slope. A comparison of sample attributes with the same data regarding the 822 outcrops included in the pool considered when choosing the sample (see Figure 37, Figure 38 and Figure 39) displays the extent to which the sample is representative of the considered universe. Regarding altitude, making sure there was a representative number of outcrops subject to periodical flooding (hence, located at the lowest elevation possible) meant that the lowest altitude class (120-150m) has a larger presence in the sample than in the total considered universe[11]. Nevertheless, as average and median values reveal (190 m vs. 217 m and 155 m vs. 190 m, respectively), the difference in altitude between sample and total considered universe, although not negligible, is believed not to be significant enough to render the sample unrepresentative.

Regarding the classification proposed by the Slope Steepness Index, it must be noted that none of the outcrops of the considered universe are located in the first two categories, i.e. Level and Nearly Level. Accordingly, the sample reflects this fact.

---

[10] The quite minute portion of outcrops (11) located in higher terrains (above 400 m) has not been considered for inclusion in the sample.

[11] Altitude of outcrops kept in the Park's records is not an absolute measure but rather an approximate value. Hence, for comparison purposes, the class corresponding to the lowest altitude starts at 120 m since, of the 822 outcrops comprised in the considered universe, there are 5 located at the 120-130 m altitude interval. These 5 outcrops are located in areas where this height positions them quite near to the normal river level being the first to become flooded during the occurrence of such episodes. The lowest altitude of all the outcrops contained in the sample is 130 m.

Moreover, the sample does not contain any outcrop located in the following two categories, Very Gentle Slope and Gentle Slope, since they amount to just 1% and 2%, respectively, in the total considered universe[12]. Even though the correlation between the values of each category in the considered universe and the sample is not totally identical, it is believed that the sample closely relates with the considered universe. The existing discrepancy in the category with a wider divergence (Steep Slope – 23% vs. 13%) will not significantly alter representativity as average and median values of both universes demonstrate.

Given the predominance of East facing outcrops in the total considered universe (see discussion in Chapters 5 and 6), care was taken to avoid an overrepresentation of outcrops with that orientation in the sample. Hence, there is a discrepancy between the values of East facing outcrops between the considered universe and the sample. Moreover, the above-mentioned concern explains the overrepresentation of West and, marginally, North-facing outcrops. The 'higher' average and median aspect values of the sample also reflect, as clarified above, the method, regarding aspect, in which the outcrops to include in the sample have been chosen.

1.8. Conclusion

Research presented here contributes considerably to knowledge in this little researched area within rock-art studies and provides a draft urgency scale to help prioritize future work. The Côa Valley is used here as a 'live' laboratory where pioneering but reliable direct conservation interventions on vertical schist outcrops can be developed and tested alongside methods to characterize and systematically monitor the evolution of weathering processes. The development of a tool-kit to assess and monitor the condition of engraved outcrops is essential before major conservation work at the World Heritage Site in the Côa Valley. Within rock-art studies methods to assess the condition of open-air engraved (or painted, for that matter) outcrops are scarce and have a non-systematic nature and restricted application. The possibility of creating a thorough and adaptable tool-kit for that purpose is therefore a significant step forward. It is, to the best of the author's

[12] However, in the chart that constitutes Figure 36 both non-existing categories have been kept (hence the 0% indication) to facilitate comparison with data presented in Figure 39, namely regarding the colour scheme.

knowledge, the first comprehensive study to be carried out in Europe on the conservation, monitoring, and condition assessment of open-air rock-art located on schist (or other core rock) outcrops. The present research is therefore expected to be of use to rock-art researchers, managers and conservators that endeavour to assure the longest possible survival of open-air rock-art sites. Carefully choosing (by analyzing their applicability) parameters to assess the condition of the outcrops will be essential to establish the urgency scale. However, the sheer number of variables present in the various natural processes that are likely to affect the condition of rock-art outcrops is quite considerable. Some are quite straightforward to measure but others require ingenious or novel methods to assess the effects of their action. This research will hence also draw as appropriate on methodologies established by other fields of investigation.

This transdisciplinary approach means that each of the identified parameters will not be the subject of very exhaustive analysis since it is believed it will be more important to ascertain how each influences the condition of the engraved outcrops as a totality and thereby plays a part in prioritizing conservation interventions. Furthermore, building the intervention urgency scale is not an end in itself. The fieldwork discussed here includes a thorough analysis and recording of the condition of each engraved outcrop in the sample. To achieve this a feasible and practical method for condition-recording of engraved outcrops was created.

Taken together the results of this work will enhance our comprehension of the complex dynamics that affect the conservation of open-air rock-art. If the invaluable Côa Valley rock-art heritage (and that of other sites around the world) is to be entrusted to future generations in the best possible condition it is essential to implement well-planned and well-informed conservation work that makes the most of the limited available resources.

In the following Chapter attention is directed towards expanding the key issues in open-air rock-art conservation touched on above. This provides the basis of developing a series of case studies from around the world (Chapter 3) before focusing on the detail of the Côa Valley case-study (Chapter 4). In Chapters 5 and 6 there is a detailed assessment of the physical condition of the Côa Valley panels and the processes that affect their long-term survival. Extensive use is made of the data collected during fieldwork for this research which leads to an evaluation of the condition of those outcrops in the studied sample (Chapter 6). Using the experience of the Côa Valley sites and the case-studies from other countries an ‘urgency scale’ is developed that helps prioritize future work and the deployment of resources. The urgency scale is evaluated and conclusions drawn for future applicability and refinement (Chapter 7).

Chapter 2: Literature review of open-air rock-art conservation issues

2.1. Introduction

It is extraordinary that so much open-air rock-art has survived despite the harsh environmental conditions many sites face (Bahn 2010c, 170-197; Carrera Ramírez 2002; Dorn *et al.* 2008; Hall *et al.* 2007b; Herráez 1996; Hygen 2006; Lucas Pellicer 1977; Manning 2003; Soleilhavoup 1993; Swantesson 2005; Tratebas *et al.* 2004; Walderhaug and Walderhaug 1998), the impact of human actions (ranging from vandalism to theft) (Anon. 2011; Bahn 2010c, 170-197; Bauman 2005; Harry *et al.* 2001; Keenan 2000; Searight-Martinet 2006; Sims 2006; Soler i Subils and Brooks 2007; Taruvinga and Ndoro 2003) and human led environmental changes affecting areas where sites are located (Aberg *et al.* 1999; Christensen 2005; Fitzner *et al.* 2004; Hansen 1999). Yet it is a field of study that has received relatively little attention, a situation that contrasts with the conservation of motifs located in caves which has benefited from extensive research (see for instance Brunet 1995; Brunet *et al.* 1995; Brunet *et al.* 1987); similarly, methods to monitor the evolution of weathering dynamics in caves with rock-art are also well developed (Brunet and Vidal 1993; Malaurent *et al.* 2007; Vouvé *et al.* 1983). What little is available for open-air rock-art sites tends to warn of the dangers of ill considered and hastily prepared conservation interventions (see for instance Bakkevig 2004; Devlet and Devlet 2002).

This state of affairs is quite understandable since cave sites were the first to be discovered and recognized as prehistoric art, coinciding with the moment archaeology come of age in Europe by the mid 1800s (Bahn 1998, 1-69). Therefore, there has been an early focus on the study of these sites, which eventually led to the realization of their fragility and the need to take conservation measures.

The cave of Lascaux gives a paradigmatic example regarding the conservation of Ice Age cave rock-art. Discovered in 1940, the cave was soon after opened to the public. Uncontrolled public opening of the cave led to the carrying out of intrusive construction work such as the widening of the entrance or the installation of an air-conditioning system. This ‘upgrade’, together with the over-visitation of the cave, with many hundreds of daily visitors, meant the rupture of the fragile ecosystem that existed in the cave prior to its discovery. The first signs of the ‘green sickness’ (rapid growth of algae, fungi and bacteria taken inside by visitors) and of the ‘white sickness' (crystals growing on the walls due to water evaporation and the subsequent appearance of calcite) began to be noticed by the 1950s. By 1963 the situation was so extreme that the French Ministry of Culture decided to close the cave to the public. Meanwhile, a facsimile was commissioned and opened to the public in 1983. At the same time, specialists were called in to research the installation of capable biologic risk monitoring and air circulation systems (Vouvé *et al.* 1983). Apparently, existing threats were avoided by such measures, which prevented the further development of the two sicknesses. However, the cave remains closed to the present day. Nonetheless, in the last decade concerns on the conservation of Lascaux have arisen once again due to the reportedly ill conceived and haphazardly installed new air circulation system (Bahn 2010b)[13]. It should be noted that Altamira, the other emblematic Ice Age rock-art cave, has today similar conservation problems as Lascaux and is also closed to the public (Gonzalez *et al.* 2008; Lasheras and de las Heras 2006) despite political pressure to reopen it (Saiz-Jimenez *et al.* 2011). Both sites display the complexity and difficulties in designing and influencing preservation and conservation measures. In the remainder of this Chapter the available literature is reviewed in order to establish the state of play with such matters as a whole and the conclusions drawn that might be of use in formulating new researches in the Coa Valley and in developing an urgency scale to inform prioritization and resource deployment.

2.2. Open-air rock-art conservation[14]

The case of Lascaux serves as a cautionary tale regarding human intervention in the environments where rock-art exists (either in the open-air or in caves). These have subsisted in delicate equilibrium for millennia. Evidently, albeit being subject to weathering dynamics that originate in the same natural realms (namely geology, geomorphology, or biology), these patterns operate and manifest themselves quite differently in open-air and cave-located rock-art as Fossati (2001) notes. If biodegradation factors tend more to affect motifs situated in caves 'closed' systems, these natural facets of the landscape are not immune to the regular motion of the earth

---

[13] (Studies on the conservation of the cave but also accounts on the tribulations Lascaux has undergone can be found, for instance, in the following papers: Bahn 2010b; Bastian and Alabouvette 2009; Bastian *et al.* 2010; Brunet 1988; Di Piazza 2007; Jurado *et al.* 2009; Malaurent *et al.* 2007; Montelle 2009b; Vouvé *et al.* 1983)

[14] The term *conservation* is used here in the sense of the definition put forward in the Introduction section of the thesis.

and, for instance, there is a cave in France (Cosquer) with prehistoric art that had "four-fifths of the wall surfaces (…) destroyed by the Mediterranean; art survived only in those chambers that remained above sea level" (Clottes 2006). Similarly, if physical weathering dynamics are most threatening to the survival of open-air rock-art (as will be discussed in the course of the present thesis), biodegradation factors such as lichen colonisation do pose conservation threats. If cave rock-art only exists in geological environments that allowed the formation of natural cavities, open-air sites are rather more ubiquitous and vastly outnumber 'underground' sites (Clottes 2008). Therefore, the range of conditions in which rock-art located in the open-air faces varies according to the specific situations where sites exist, from desert to arctic environments.

Considering that the following Chapter will constitute an in-depth review of relevant world case studies regarding the conservation of open-air rock-art that bears some similitude with the case of the Côa Valley, the present Chapter will attempt to characterize the global situation concerning the conservation of such sites. There is no claim to be exhaustive, rather the aim is to provide a general characterization of the worldwide situation in respect to open-air rock-art conservation.

Before proceeding, an important distinction should be made between the conservation of open-air petroglyphs and pictographs. Both categories of images suffer the effects of regular and 'innate' weathering processes acting on the chosen media since rock surfaces are naturally unstable (Avery 1978, 66). However, the later category is also affected by the conservation problems of natural pigments (David 2008) that were used to paint rock-art motifs. Moreover, paint will seal the rock surface obstructing moisture evaporation and the migration of salts from within the parent rock thereby further worsening weathering processes active in the decorated area of the panel (Avery 1978; Hall *et al.* 2007a). Thus, the conservation of rock paintings constitutes a specific area of knowledge, which attempts to tackle different conservation issues than the endurance of the decorated rock itself. In the Côa Valley very few paintings have been recognized and the major conservation issues identified have to do with the stability of engraved rock-art outcrops. Furthermore, in theory, petroglyphs and pictograms are equally affected by the weathering of the rock masses that were chosen for decoration. Therefore, the following review will focus on presenting and analysing weathering dynamics affecting the continued existence of rock-art outcrops and panels.

At this point it should be explained what is understood by the terms 'outcrop' and (rock-art) 'panel'. Drawing on the author's experience in the Côa Valley, an outcrop can be understood as the (more or less) whole block of stone that emerges from the ground (see Figure 40). On the other hand, the panel should be acknowledged as the vertical[15] or horizontal, cohesive and mostly flat stone surface that contains ancient imagery (see Figure 41). Therefore, while an outcrop may contain several rock-art panels, the opposite does not occur.

2.2.1. Transdisciplinary approaches

From the many calls for conservation of rock-art coming from very different parts of the world (see, for instance, Anati 1983; Anati *et al.* 1984; Crotty 1989; Pearson 1978; Seglie 2006; Silver 1989; Steinbring 1994; Tyagi 1991; Vidal 2001), it becomes apparent that there are many threats to the perpetuation of this significant heritage. Nevertheless, while some authors reference physical weathering as the most pressing risk (see for instance Fitzner *et al.* 2004; Lewis 2007; Meiklejohn *et al.* 2009; Pope *et al.* 2002; Walderhaug and Walderhaug 1998), others invoke the negative effects of biodegradation, specially when lichen colonisation is concerned (Chiari and Cossio 2004; Dandridge 2006; Florian 1978; Knight *et al.* 2004; Tratebas 2004) and human factors (for instance, Cittadini 1993; Deacon 2006; Dragovich 1995; Fossati 2003; Haskovec 1991; Hygen 1996) that will not be dealt with in the present thesis. It is suggested that these different attributions of the nature of risk have more to do with the specific area of expertise of each researcher, and, more importantly, with the different environments where rock-art exists. Hence, these different settings will determine which weathering patterns are more active and pose more urgent risks to be dealt with by rock-art managers and conservators.

The worldwide paucity of such professionals signals that open-air rock-art conservation has not received the attention (Silver 1989) that other archaeological features have attracted (as, for instance, the conservation of Roman sites). The panorama is slowly changing as touristic development is contributing to raised awareness and the transformation of some sites into tourism attractions (for instance, Deacon 2006). Hence, other more developed fields of research, within conservation

---

[15] In the case of the Côa, panels are overwhelmingly vertical. In fact, there is only one known case of rock-art inscribed in a horizontal surface (Vale do Forno II 6 – see Annex A).

studies, should be examined at this point. One of those areas is building stone conservation (see for instance Clark 2001; Doehne and Price 2010), from which, in theory, relevant insights can be drawn for open-air rock-art conservation. Unfortunately, the two disciplines deal with the treatment of stone material that exists in very different conditions: fresh unweathered stone recently exposed to decay as against paleo-weathered rock surfaces that have been out in the open for many millennia. As the two types of exposure are in essence quite different, so are the appropriate conservation strategies, materials, and methods that can be successfully applied (Cerveny 2005, 9-12). Moreover, as Cerveny puts it, "very few natural rock art panels rest on the type of fresh rock found in quarries for building stones." (Cerveny 2005, 10).

On the other hand, Doehne and Price (2010) note that the conventional approach in building stone conservation tends to order weathering dynamics in closed areas of research such as geological, biological or chemical. In fact, it is important to recognize the "important interrelationships between environmental, material, and historical variables. As is the case with most natural systems, a few key parameters often dominate each weathering process and the result can be nonlinear and even chaotic, in contrast to previous assumptions about linear rates of erosion. (…) The straightforward concepts of magnitude, frequency, and dose-response (…) are being modified by ideas of thresholds, feedback loops, and nonlinearities" (Doehne and Price 2010, 75). To understand and tackle, in the most complete way possible, these interconnected weathering patterns ideally requires an interdisciplinary approach. But there are dangers. A quote from a French author provided by Doehne and Price intended to portray the general situation regarding built stone conservation also applies here to rock-art conservation studies:

> "I am a bit worried to notice that you are carrying out your research without organized dialogue, each person working in his or her own corner, the exchange of information remaining very limited (…) I also have the feeling that the general tendency among researchers is to remain confined to one's own specialty (…) Don't fail to see the wood for the trees! Before going into detail, an assessment of the whole is necessary" (Chamay, quoted in Doehne and Price 2010, 69)

To see precisely the wood and not only the trees, an interdisciplinary approach is fundamental (see Figure 42). Unfortunately, rock-art conservation experts often work in a 'closed circuit'. As Cerveny notes, "the application of stabilizing agents on rock-art panels is not widely discussed in refereed publications, (although) proponents discuss active intervention on the stage of newsletters and similar forums" (Cerveny 2005, 8). She also "urge(s) treatment advocates to come out of the newsletters and short courses (and to) publish suggested treatments" (2005, 38). Even though her remarks refer only to proponents of the use of stabilizing agents on rock-art panels, it is suggested that her criticism depicts quite accurately the global situation within (open-air) rock-art conservation research. Indeed, studies and contributions are rarely published in peer-reviewed journals but abound in the so-called 'grey literature'. Obviously, this is a state of affairs that does not foster a true transdisciplinary approach to rock-art conservation and the further advancement of this field of study.

2.2.2. The importance of documenting rock-art

Since rock weathering dynamics are complex and not yet fully understood processes (Bland and Rolls 1998; Doehne and Price 2010), many authors point out that compiling competent documentation work is of paramount importance to the endurance of ancient rock-art imagery. As the argument goes, since it is unrealistic to tackle weathering dynamics active on the total corpus of the planet's rock-art (at least, at the same time), some panels and outcrops that host ancient imagery will inevitably breakup and their motifs lost forever. Carrying out documentation work will assure that at least accurate copies of motifs will be available to future generations (see, for instance, Anati *et al.* 1984; Doehne and Price 2010; Letellier 2007, 15; Sharpe *et al.* 2008, 12). Furthermore, documentation work (of both motifs and of the whole rock massif where they are located) can be an essential tool to record, describe and precisely locate weathering patterns active at a given rock-art panel or outcrop (Arango 2000; Brink 2007; Fitzner 2004; Lewis 2007; Loubser *et al.* 2000; Thorn and Brunet 1996; Vogt 2007). In the last few years, quite a few methods have been developed for recording rock-art and associated natural weathering patterns. Most have taken advantage of the possibilities offered by combining new photographic and computer technologies (Clogg *et al.* 2000). Such is the case of digital enhanced photography (Brady 2006; Chandler 2007; Mark and Billo 2006, 2011), photogrammetry (Chandler *et al.* 2005; Simpson *et al.* 2004), laser scanning (Barnett *et al.* 2005), a combination of laser recording with ground-based remote sensing (Diaz-Andreu *et al.* 2006), combining terrestrial laser scanning with a geographic information system (Vogt 2007), Optical Coherence Tomography to measure surface porosity (Bemand *et al.* 2011), and multispectral photography (Pires *et al.* 2011).

The application of these new technologies have made available accurate, relatively simple to use, reasonably cost-effective[16], and essentially non-contact methods to record rock-art and weathering patterns (Sharpe *et al.* 2008, 12-16; Vogt 2007, 32-35). The quite swift introduction and adoption of these new methods has almost entirely replaced the 'old-fashioned' intrusive and sometimes damaging methods of recording rock-art (Sundstrom and Hays-Gilpin 2011, 354). Moreover, documentation is fundamental for dissemination and depiction of rock-art and, therefore, a valuable tool for raising awareness of the public, communities, and, especially, future generations to its value, the need to preserve it, and the proper 'ethical' fashion to visit and experience it (Fossati 2003; Pilles 1989; Seglie 2006; Soleilhavoup 1991-1992).

Complementing the importance of the documentation work detailed above, identifying and understanding natural degradation patterns in open-air panels is another facet of the worldwide effort to save the planet's rock-art. Quite a lot of work has been carried out in several areas of the world possessing rock-art sites such as Italy (Attorrese and Fossatti 2002; Grassi *et al.* 2006), Scandinavia (Bjelland and Helberg 2007; Swantesson 2005; Walderhaug and Walderhaug 1998; Walderhaugg 1998), Spain (Carrera Ramírez 2011; Herráez 1996; Jordá Pardo 1999; Lucas Pellicer 1977; Martín Escorza 1999; Mas Cornellà *et al.* 1994), Russia (Anon. 2002; Bednarik 1996; Devlet and Devlet 2002), South Africa (Avery 1978; Leuta 2009; Meiklejohn 1997; Meiklejohn *et al.* 2009; Venter 2011), Canada (Brink 2007; Conway 1979), Southern and Central North America (Cerveny *et al.* 2007; Grisafe 1996; Hogue 1993; Ralph 1990), Northeastern Brazil (Cavalcante and Rodrigues 2009; Guidon and Lage 2002a), Colombia (Arango 2000), Australia (Lambert 1989; Rosenfeld 1985; Sullivan 1978; Watchman *et al.* 1995; Watchman 2005), New Zealand (Williams and Tupara 2000), and Northern Africa (Kerzabi *et al.* 1986; Searight-Martinet 2006). In fact it can be said that in every country with rock art, some sort of document dedicated to the conservation and preservation of rock-art has been published. Unfortunately, standards vary greatly as these studies are often quite incomplete and

[16] Due to its technical and equipment requirements, laser scanning is considerably less affordable than photogrammetry. The later, for the same reasons, will be less affordable than 'plain' digital photography (Chandler *et al.* 2005; Chandler 2007).

do not try to offer a comprehensive characterization of each site's specific condition. Typically, one or other subset of the range of weathering patterns at work is examined while all others are insufficiently addressed or even not considered at all.

More ambitious works are available aiming at the full characterization of the conservation, management, and documentation issues related to a country's rock-art. Darvill *et al.* (2000) coordinated a detailed study (The Rock Art Pilot Project – RAPP) that describes the situation in England also offering proposals to address some of the problems faced by rock-art in that country. The results of RAPP enabled English Heritage to create a Rock Art Management, Access, Study and Education Strategy aimed at the amelioration of the situation regarding the management and divulgation of England's rock-art (Sharpe *et al.* 2008). Other countries have also developed their own systematic studies on these matters, such as those coordinated by Hygen (2006) and by Bjelland and Helberg (2007) devoted to Norwegian rock-art.

2.2.3. Understanding natural degradation of open-air rock-art

Not surprisingly, the most developed methods to categorize weathering of rock surfaces arise from the building stone conservation literature. Cerveny lists more than a dozen methods that range from GIS data referencing to microscopic fractal analysis (2005, 102). Most of these methods are difficult to apply in the context of open-air rock-art conservation due to ethical (sample collection in areas of the panel where rock-art motifs are located), logistical, financial, or even conceptual constraints (for instance, assuming that rock coatings, such as lichen, are always detrimental to rock-art panels when, in fact, these may provide some protection from other weathering agents (Cerveny 2005, 100-102)).

The research reported here gathered contributions from other relevant fields of research. For instance, while there is a lot of work done on individual natural processes by experts in particular disciplines such as geology, geomorphology or climate studies, the present project attempts to be a *comprehensive* archaeology-based study on the conservation, monitoring, and condition assessment of open-air rock-art sites. Nevertheless, there are many relevant insights available from research carried out in other areas of study. For instance, Bennie *et al*. (2008) examined the role solar radiation plays in rock surface temperature and moisture, while Viles (2005) demonstrated how different solar exposures may determine diverse climate induced weathering rhythms. Other areas of interest include slope (Summerfield 1991, p. 163-189) and aspect studies (Bland and Rolls 1998, p.102-111; Yalcin and Bulut 2007).

Another example of research pertinent to rock-art conservation connected with other fields of knowledge would be the study of pollution-led deterioration of rock-art. Aberg *et al.* (1999) analysed the effects of pollution on a rock-art site located in the Norwegian capital, Oslo. The authors concluded that besides the risk coming from natural weathering patterns, the site is also heavily impacted by road traffic, road-salt deposition (used to melt ice in the winter), and local and long-range atmospheric pollution (Aberg *et al.* 1999, 1488). Another area of the world where the effects of different types of pollution on rock art have been investigated is Western Australia and especially the Burrup Peninsula and Dampier Archipelago which is witnessing a major increase in industrial development. Concerns have been expressed regarding the connection between industrial emissions and the deterioration of rock-art (Bednarik 2007, 226). Hence, the state government of Western Australia commissioned a report to "investigate and report on impacts of proposed industrial developments on the rock art of the Burrup" (Bednarik 2007, 227). The results suggest that the impacts of industrial emissions are low (CSIRO 2006; Lau *et al.* 2007). Nonetheless, Bednarik disagrees with the findings noting that the impact of acid rain on rock coatings has not been addressed by the study even though such depositions are believed to be occurring in the area. It is suggested that the impact of acid rain is quite significant because of the dissolution of surface minerals which in turn contributes to the acceleration of weathering dynamics (Bednarik 2007, 226-30).

2.2.4. Open-air rock-art conservation and climate

Yet another area of interest for rock-art conservation is climate change. Hansen reports on the disappearance of rock-art surfaces in the Central Sahara Desert related by the author to changes of humidity in the area due to a broader area being under the influence of monsoons (Hansen 1999). However, Hansen's observations are perhaps 'over' emphatic and one is left with the sense, after reading his paper, that such a complex subject was inadequately explored. Nonetheless, other fields of study can provide insightful clues on how climate change can affect the conservation of rock-art. It is agreed that future climate change will not be "smooth and progressive" as available evidence strongly suggests that the "variability and clustering of events in time and space will be an important part of the geomorphic future" (Viles and Goudie

2003, 127). These authors in particular also draw attention to the need for measuring "oscillations in climate over interannual to century scales" since "geomorphological impacts of (…) climatic variability vary from place to place and time to time, and are often complexly related to impacts of tectonic and human factors" (2003, 105) to better understand how these variations will behave (see Figure 43 and Figure 44). As the historian Ian Morris phrased it, "climate change is non-linear: everything is connected to everything else, feeding back in ways too bewilderingly complex to model" (2010, 600). Moreover, "the various research avenues (in climate change science) remain tempered by politics, often being commissioned by special interest groups" (Chapman 2002, 242) thus increasing the potential of interpretation bias[17].

Attempts to model impacts of climate change in specific environmental systems have been carried out. Kincey *et al.* (2008) point out that river basins are among one of the natural systems that will be affected by future climate change. Hence, the authors developed GIS-based predictive models to determine how natural and anthropogenic responses to climate change will affect two British river systems. As many open-air rock-art sites throughout the world (notably the Côa) are located in river valleys and quite near to or even on floodplains, it is of paramount importance to understand the potential impact of climate change on fluvial systems. Generally speaking, an increase in rainfall and especially in the intensity of heavy precipitation events (flash flooding), is one of the major effects of climate change (IPCC 2007). These episodes will give (and are already giving) rise to more river flooding incidents, which in turn will further enhance soil erosion (Kincey *et al.* 2008, 116) but also soil re-deposition dynamics[18]. Besides the further instability that flooding will provoke on the slopes with rock-art, there will also be an increase in the frequency that stone massifs experience water-induced expansion and retraction cycles that in turn will considerably decrease the solidity of rock-art panels and outcrops (Bland and Rolls 1998, 101).

A necessarily speculative but plausible exercise on the different ways climate change may affect built stone conservation was undertaken by Viles (2002). This

[17] As Le Treut *et al.* summarise (2007) there still a degree of uncertainty on climate change dynamics and to what extent it is human driven. Moreover, as noted, this is an emotional and politically charged issue. Still, available data is used here in order to try to understand and to some extent foresee the impacts of climate change on open-air rock-art conservation.

[18] Drawing from the author's working experience in the Côa Valley it is clear that river floods erode the soil but can also deposit considerable quantities of soil in the bottom of the valley and around and inside rock-art outcrops (see Figure 45).

author suggests that there will be deteriorating processes hastening or getting worse but that others will slow down. However, Viles also points that the outcome of these often-competing impacts will be difficult to individualize or measure. Moreover, there is a general lack of knowledge on how climate precisely influences deteriorating processes preventing therefore the emission of accurate predictions (Viles 2002, 410). Regarding physical weathering processes, Viles proposes that global warming will signify a decrease in the impact of freeze-thaw induced weathering in several areas of the planet, namely in those located outside cold regions. Likewise, expected "reduced diurnal temperature range" (2002, 410) will imply a decrease in scale and incidence of stress provoked by thermoclasty. However, variability in pluviometric regimes may inversely affect thermal expansion as well as the other two major physical weathering processes, crystallization and hydration. As for chemical weathering processes it is likely that higher temperature and precipitation will hasten the role these processes play in stone deterioration. However, regions that undergo a decrease in rainfall may not suffer such a hastening (Viles 2002, 411), eventually experiencing some degree of deceleration of these processes. The impacts of climate change on biological weathering dynamics remain unclear. Viles hypothesises that "as rainfall increases, biological growth will also increase, but the growth will be more benign and less damaging (in wetter areas) than in drier environments where endolithic growth forms are common" (2002, 411). Nonetheless, "further work needs to be done to establish whether changing climates will alter the balance in any one area between biophysical and biochemical attack and bioprotection." (2002, 411). Lastly, increase in salt weathering in coastal areas, changes in the formation and depth of groundwater, and alterations in social behaviour are proposed to be among the most significant indirect impacts of climate change on build stone weathering (Viles 2002, 411-12). Although the study specifically addresses impacts on built stone conservation, it is suggested that the propositions put forward by Viles can be applied to rock-art conservation since the weathering mechanisms that will be impacted upon are also quite active in 'natural' *in situ* stone decay.

Work being carried out in South Africa by Meiklejohn *et al.* (2009) endeavours to assess the interrelationship between micro-climatic, rock temperature, rock moisture, rock chemistry, and rock properties variables and weathering dynamics at work on rock-art surfaces. The collaborative effort being carried by the team builds on previous work undertaken by Hoerle (2005) and Hall *et al.* (2007a). The authors note that there is a "general lack of understanding concerning specific mechanisms of rock weathering" and that "most literature on the subject is speculative, qualitative, and lacks the scientific rigour required for an adequate evaluation of the role of specific rock weathering processes" (Meiklejohn *et al.* 2009, 973). Hence, there was an attempt to approach the issue systematically by carrying out climatic measurements and surface condition monitoring in two sandstone rock shelters featuring South African San rock-art. This was accomplished by collecting rock surface temperatures and also those at a depth of 5 cm., rock moisture values, and also mesoclimatic variables inside the shelters (air temperature, solar radiation, relative humidity, wind speed and wind-direction). These measurements were complemented by the determination of rock porosity and general chemical and mineralogical properties (Meiklejohn *et al.* 2009, 974-5). Although it is known from the available literature that rock temperatures do have an active role in weathering dynamics (see for instance Hall 1999; Hoerle 2005), Meiklejohn *et al.* reached the conclusion that, in the two rock shelters they examined, "thermal fatigue and other thermally affected weathering processes are not singularly responsible for the breakdown of rock" (2009, 976). On the other hand, it was concluded that the analysed sandstone is quite porous (a find that contradicted previous studies), making "rock moisture regime (…) the most important contributor to the current weathering-related rock art deterioration at the Main Caves and Battle Caves sites" (Meiklejohn *et al.*, 977). Still, the authors close the paper stating that further work is necessary to more thoroughly elucidate the role of these variables in rock weathering processes. Therefore, they argue, it is of paramount importance to implement effective management policies in order to mitigate the decline of San rock-art located in sandstone terrains. The work being carried out in South Africa has been quite inspirational to the present thesis. The methods used to measure the influence of rock surface temperature and porosity have been used by the author in the Côa in an attempt to use these variables in the risk characterization that is the main goal of the present research.[19]

2.3. Conservation interventions on open-air rock-art

---

[19] Research carried out in the different areas of study examined above will be analysed in detail in Chapters 5 and 6 when parameters to characterize the condition of the engraved outcrops of the Côa are to be evaluated.

Devlet and Devlet (2002) provide an illustrative account helpful in promoting informed conservation of rock-art. The authors describe interventions (crack filling, surface impregnation with cement and other materials), carried out in the 1970s that was intended to stop the surface deterioration of south Siberian schist engraved rock-art panels. These actions produced irreversible impacts and became complementary factors in deterioration. For that reason, in the last few decades, crack filling, reattachment, massif consolidation, and the impregnation of rock surfaces, are being approached with great caution, especially given the scale of unintentional damage that resulted from past interventions (Andersson 1986; Finn and Hall 1996; Rosenfeld 1985; Walderhaug and Walderhaug 1998). Against a background where conservation actions are of a complex and delicate nature, there is often little information on the long-term implications of using new materials (Dean 1999), which are often used within largely uncontrollable environments (Price 1996). An extreme example would be the one supplied by Ponti and Persia (2002) regarding the use of the acrylic resin Paraloid B72 to consolidate rock-art paintings in the Tadrart Acacus World Heritage site in Lybia. Original application took place some 30 years before the authors carried out their investigations and led to alterations in the colour of the paintings. Nevertheless, its application was still considered appropriate by the authors, albeit in a low concentration, despite recognizing that, besides changes in colour, high temperatures also cause the resin's chemical bonds to break down thus becoming ineffective (Ponti and Persia 2002, 130-1).

Avery (1978) offers an enlightening account of how laboratory testing might prove helpful avoiding ill-prepared interventions at rock-art outcrops. According to Avery, "a preservative with penetration of over one centimetre was introduced into a rock sample." (1978, 68). If subsequent weathering tests were considered to be satisfactory regarding the strengthening of the sample rock surface, after a short space of time, the 'protected' outer surfaces tidily broke off precisely "at the point of deepest penetration" (1978, 68). Avery closes his account offering a word of warning about prior laboratory testing with the intent of subsequent use of its conclusions in rock-art conservation: "success in simulated laboratory experiments may not necessarily indicate results which might be obtained over long periods of time under natural conditions in the field." (1978, 68).

2.3.1. Experiments in the Côa Valley

As mentioned earlier, pilot tests have been carried out in the Côa precisely to begin establishing records of the behaviour of materials in the specific environment of the Côa Valley. The implementation of these also sought to avoid having the errors described by Devlet and Devlet (2002) occurring in the Côa. A thorough account and discussion of these experiments, carried out in 2004, can be found in Fernandes (2008a) and Fernandes and Rodrigues (2008). Nevertheless, it is worthwhile to examine briefly some of the practical results of the experiments and relevant references available in the specialized literature before engaging in a more detailed discussion of ethical matters related to open-air rock-art conservation.

The three Portuguese companies involved in the experiments followed, generally speaking, similar strategies and used analogous materials. The background all the companies share, which is one of built stone conservation, explains the similarities. It would have been reassuring to hire specialists in the conservation of open-air rock-art located in schist outcrops but unfortunately these are not readily available in Portugal or any other European countries. On a conceptual level, all three companies opted for the consolidation of the tested un-engraved outcrops, which meant filling up of fractures, gaps, and diaclase boxes. The materials used included a range of different supplies (such as elastomeric membranes to help seal diaclase boxes, and epoxy resins to test the reattachment of small loose portions of outcrops). However, the core material consisted of lime-based mortar that was mixed in different gradations and adding (or not) local ground schist. At the testing stage it was decided not to emulate tones and textures of the rock so that the interventions would remain easily discernible (Blanes *et al.* 2008; Machado 2008; Raposo and Proença 2008).

On one of the test outcrops, one of the applied mortars has, with time, become covered with a green layer, which appears to be of biological origin, probably algae. Bednarik (1996, 23-4) reports a similar case in which the cement applied to fill up fractures was colonised by a greenish layer which the Australian author describes as algae. Bednarik's account of the conservation interventions at the Siberian site of Shishkino offers an in-depth evaluation of a conservation intervention on open-air rock-art. Hence, his remarks on the results of this intervention are of considerable use when considering the experiments carried out in the Côa, although the bedrock in Siberia was sandstone. Nevertheless, the existing rock-art (petroglyphs and paintings) had been executed on highly fractured and exfoliated vertical surfaces.

On two of these panels, an experimental stabilisation experiment was undertaken that consisted of sealing fractures and filling gaps with a mixture of tetraethoxysilane – a compound "also used for weatherproofing and hardening of stone" (INTOTA 2011) – and local eroded sand. The sand was used so that the mix would emulate the tones and textures of the parent rock faces. The results of the experiment were disappointing as the "grout in the cracks had failed structurally within a year, some had become dislodged and numerous fractures of up to 1 mm had appeared, not only between the rock and the cement but also within the cement itself" (Bednarik 1996, 23). Moreover, "two of the fillings had fallen off, the third had become dislodged and protruded about 1 mm, while still adhering to the rock" (1996, 23). Although Bednarik does not make clear if the experiments were carried out on panels containing rock-art motifs, these remarks further strengthen the strategy followed in the Côa, that is exhaustive testing on outcrops containing no rock-art before applying these approaches to the real art-covered panels.

2.4. Ethical and aesthetical issues regarding conservation work

Regarding ethical and aesthetical issues, and particularly in the case of the Côa, the author has attempted to demonstrate that it is the whole outcrop that should be considered when planning and carrying out conservation interventions (Fernandes 2008a). It would be fairly pointless to try only to tackle the weathering patterns that are active on individual panels comprising rock-art without endeavouring to stabilise and consolidate the whole outcrop. On the other hand, the *entirety* of the outcrop should be regarded as the 'total' art object because it has been singled out for attention. Hence, our conservation efforts should be aimed at promoting the long-term endurance of the total art object, i.e. outcrop + panel + existing ancient rock-art (and its milieu). However, as discussed in the above-mentioned paper, conservation interventions following similar methods and strategies employed by the companies hired to carry out the Côa experiments can be considered as quite intrusive and even harmful to the authenticity of the total rock-art object.

Moreover, as Dix suggests with reference to an Australian case, the creators of the art would be aware of the fact that surfaces they repeatedly chose to paint were prone to water seepage. Therefore, Dix asks if the painted motifs were not intended to disappear when the rains came and, giving that was the case, whether we have the 'right' today of trying to preserve motifs that were meant to be ephemeral (1978). It is difficult, in the case of the Côa and other sites, to understand whether the original artists had in mind a transient or permanent awareness of their creations. In the Côa, available data seems to suggest a desire for permanence because many panels host superimposed motifs that have been accumulated on the same surface over a period of decades if not centuries or even millennia, as discussed in the Introduction. However, it is also true (in many Upper Palaeolithic European rock-art sites, the Côa included) that natural features of rock faces (namely fractures) were incorporated into motifs or sometimes used to prompt or structure the composition (see Figure 46). Thus, some of the same fractures that conservation interventions propose to fill and seal in order to confer stability to the panels are actually an unequivocal part of the total art object. Nevertheless, the precise intentions and frame of mind of the original creators will always be unknown and so much conservation work involves a degree of double-guessing. Furthermore, as with any other work of art (including pieces of contemporary art), from the moment an engraving was completed it no longer 'belonged' to the artist but to everyone who views it. Today, only contemporary living beings enjoy these prehistoric artistic motifs and in a sense, rock-art now 'belongs' more to present-day admirers than it did to the original communities that produced it. That said, it is nevertheless a token of respect and humility to try to consider, when planning conservation work, what the motivations and idiosyncrasies expressed in the rock-art were for the original creators and viewers. The goal would thus be to intervene only when strictly necessary (and in the least intrusive fashion possible) to ensure the endurance of a rock-art site, if and when it is agreed that the panels should not be allowed to completely decay because of weathering or other natural processes.

2.5. Rock-art removal

On an ethical and especially on a practical level the issue of removing rock-art panels from their original position and placing them in a safer one for conservation purposes should also be discussed. Unfortunately, the removal of rock-art by collectors and/or thieves has a long tradition in several parts of the world (Bednarik 2008; Henry 2007; Keenan 2000; Searight-Martinet 2006). At the same time, removal has been also carried out for preservation purposes since major human interventions on some landscapes (for example during the construction of dams, roads or mining) have put rock-art panels in peril in several parts of the world (see for instance Bednarik 2008).

Indeed, when the debate on the fate of the Côa rock-art was still undecided, the power company that was building the dam proposed to consolidate *in situ* and then cut off the most significant engraved outcrops in order to place them in a Museum or a Thematic Park of some sort (Baptista and Fernandes 2007). The removal of an un-engraved outcrop was even carried out to prove such a plan was technically feasible (Fernandes and Rodrigues 2008). Nevertheless, archaeologists and other rock-art experts rejected the proposal as it would cause the loss of spatial information on the relationships between the engraved outcrops themselves and also with the wider landscape. Furthermore, it would mean the loss of authenticity of the art in 'its' landscape and, if the procedure produced damage during removal, transport and relocation, it could have caused a loss of integrity (Baptista and Fernandes 2007). Hence, when the final decision of the Portuguese government went in favour of the archaeological stance for the rock-art panels to be preserved *in situ* many believed that this would signal a new ethical position for valuing, managing and preserving the world's rock-art (Gonçalves 2001; Sundstrom and Hays-Gilpin 2011, 365). Regrettably, the removal of rock-art for preservational reasons still continues (unfortunately as also does theft[20]). The more recent example comes from Australia, where, as noted above, Dampier rock-art is currently being relocated away from its natural setting because of industrial development (Bednarik 2008).

2.5.1. Removal for conservation purposes

Another issue regarding rock-art displacement that should be discussed is whether the removal of panels purely for conservation purposes makes any sense? That is, when there is no direct or major humanly caused menace to rock-art surfaces, and the most serious threats faced are from natural processes, do we have the 'right' to move rock-art panels (or outcrops) to a 'controlled optimum conservation environment'? This is a question that might be posed most pressingly when rock-art surfaces are in a rather poor condition. Nevertheless, the issue might be put (at least at a theoretical level) to the whole corpus of recorded open-air rock-art imagery[21]. Prehistoric rock-art has already survived for many millennia over the long duree that can be measured in

---

[20] Sometimes in the most 'curious' of contexts, as described by Soler i Subils and Brooks (2007).
[21] Due to its location specificities, cave art is not being considered in the present discussion. However, would it make sense to remove rock-art located in caves to an 'artificial' replica of the original cavity designed to possess a 'controlled optimum conservation environment'?

geological time spans as well as over the course of the more directly appreciable human time-spans. However since all this ancient imagery will eventually disappear it apparently makes sense to try to conserve it *in situ*. Removing and repositioning endangered rock-art panels or outcrops in a 'controlled optimum conservation environment' would arguably be the best solution to achieve that end. There are of course technical feasibility issues and financial questions connected with carrying out such endeavours. As Bednarik notes, "rock art exists generally only because it has managed to survive a series of natural degradation processes over often very long time spans. These taphonomic factors select in favour of those occurrences that are in relative equilibrium with their environment" (2008, 9). Therefore, if removal for conservation purposes is to be carried out, the utmost care should be pursued in order to assure that the originals will be truly placed in the best conditions possible that will allow for their continued endurance. However, Bednarik's admonition can also be applied when *in-situ* non-removal interventions are considered. The gist of the debate focuses on the fact that the reservations mentioned above pose quite serious doubts if removal, even for conservation purposes, is ethically justifiable (Lee 1986, 5). In the medium or long-term, will the new site chosen to protect relocated panels be any better than their original position?

Elsewhere this author has questioned, whether we should "let the art outcrops 'die' in their own due 'natural' time" (Fernandes 2008a, 91) or do we directly intervene with more or less impact on the open-air rock-art outcrops in peril? In the above referenced paper, the author discussed the ethical and aesthetic implications of direct *in-situ* intervention, that is, trying to consolidate and stabilize panels and outcrops in their original setting without considering the need for removing them. At the time it was suggested that, while posing some relevant questions, *in-situ* conservation is more readily and easily accepted by those concerned with rock-art conservation ethics than *ex-situ* measures. However, when the above-cited paper was reviewed in *Rock Art Research*, Montelle noted that "a possible way out of the explicitly stated dilemma is to create a facsimile where reconstructed breakages and filled-in fractures could be presented in their natural texture while a zero intervention policy be enforced on the original" (2009a, 109). Enforcing this suggestion would definitely solve the dilemma so far as ethical issues were concerned, but "a zero intervention policy (to) be enforced on the original" would not address the ongoing impact of weathering dynamics that threaten the medium- and long-term endurance of the original rock-art. Another possible solution that would ‘guarantee’ the survival of the rock-art heritage would be replacing a removed (for conservation purposes) panel or outcrop by an exact replica that was to be located in precisely the same spot where the original stood (António Martinho Baptista, pers. comm.).

These are issues that have hardly been debated by the international rock-art community because of the political, economic and landscape management ramifications. These are quite sensitive issues since, first of all, admitting to the need to displace rock-art (or any other heritage value) because of natural threats would undermine the worldwide efforts to retain, in their meaningful locations, precious prehistoric (and historic) rock-art sites (Long 2011; Sundstrom and Hays-Gilpin 2011, 364-5). At the time of the dam’s construction in Côa, the ‘battle’ for preservation of the art would have been severely impaired if removal would have been promoted by the power company not as a way of having the best of two worlds (the dam and the engravings) but exclusively as the best solution to ‘guarantee’ the long-term conservation of the Côa rock-art[22]. This author believes the issue deserves further debate since complex cases, such as the ones noted above, will continue to crop up and it would be beneficial for the international rock-art and archaeological community to clarify positions and acceptable outcomes. While further discussion of the issue is admittedly out of the scope of the present thesis, it is interesting to conclude this section with a quote from arguably the most widely-followed guidance document regarding good practice in cultural heritage management, protection, and conservation, ‘The Burra Charter’. This states that:

> “contents, fixtures and objects which contribute to the *cultural significance* of a *place* should be retained at that place. Their removal is unacceptable unless it is: the sole means of ensuring their security and *preservation* (...)” (Australia/ICOMOS 1999, 5; emphasys in original).

2.6. Conclusion

From this brief review two important general points can be identified regarding the complex issue of open-air rock-art conservation. First, a transdisciplinary approach will significantly increase the likelihood of attaining the fullest possible comprehension of weathering dynamics and their impacts on the rock-art objects, at

[22] This is yet another reason to justify the present thesis in the context of the Côa, since all that can be accomplished towards the ultimate end of trying to conserve the rock-art *in-situ* will support the decision taken not to build the dam and to create the Archaeological Park in order to protect, manage and present to the public the engravings.

any given site. Second, a case-by-case approach is fundamental to conceptualize, plan, and implement *in situ* interventions since each site is unique and presents different technical, ethical, and aesthetical challenges. What might be justifiable in one case might be entirely indefensible in another.

It has been suggested above that complicated and difficult decisions have to be taken about rock-art conservation. Summing up the discussion, three possible but quite distinct courses of action can be identified when it comes to direct intervention on rock-art panels arise:

- Zero intervention. Considering that over the geological time-frame all rock surfaces possessing rock-art will eventually be lost; notwithstanding all the uncertainties surrounding conservation work in a totally 'natural' environment discussed above its ultimate disappearance should be accepted. Therefore, as a last tribute to the art, and to fully respect its authenticity, these rock surfaces should be allowed to 'pass away' in a dignified manner without any further meddling. If much of the art has survived until modern times, it is reasonable to assume that it will continue to exist for many years more if the basic environment in which it lies remains relatively unaltered.
- *In situ* conservation. Geological time has a much greater scale than human time. Therefore, within human time scales it is worth trying to preserve panels *in situ* in their landscape context where the art can retain its full significance as evidence for the early nature of Humankind's creative spirit. Many sites and panels across the world are in a quite worrying condition in relation to the non-anthropogenic threats they face. Hence, if, as in the case of the Côa Valley, the earliest art is some 20 000 years old, we should aim today at trying to offer it the conditions to last (at least) another 20 000 years.
- *Ex-situ* conservation through the removal of rock-art to an 'optimized' conservation environment. Because of the same moral imperatives enunciated in the previous paragraph it is believed that rock-art should be preserved. However, instead of trying to preserve it in its natural setting it is suggested that the goal of enduring existence justifies relocation from its meaningful but hazardous context to a controlled and stabilized optimum conservation environment.

All these options have a range of negative and positive consequences already touched on above and there is no simple answer as to which path to pursue. In the near future, mainly because of the political ramifications also mentioned above, a general set of rules covering the best ways to proceed (or not) with open-air rock-art conservation is unlikely to surface. Moreover, it is quite obvious that the necessary funds will not be available to intervene (or to do indispensable maintenance work on interventions already taken) at the vast majority of rock-art sites given their large numbers across the world. Therefore, the first mentioned alternative (zero intervention) is the most likely to continue to be preferred, which in itself might not necessarily be a dire option (Allemand and Bahn 2005). Zero intervention will also keep on being favoured not by choice but because it is impossible to consider supporting either of the two remaining options on cost grounds even if there is the political will to try to address the ongoing disappearance of open-air rock-art sites.

Chapter 3: Analysis of relevant international case studies

3.1. Introduction: Fieldtrip visits to rock-art sites of interest

In the course of present research, the author visited a few areas of the world comprising important open-air rock-art sites. The choice of the sites was carried out taking into account two major factors. On the one hand, major concentrations of scientifically and aesthetically significant rock-art from different periods and cultures. On the other, these are sites where existing conservation problems (and already implemented mitigating strategies) bear similarities with the case of the Côa. Hence, the information gathered in the visit to these sites will make a contribution to the identification and discussion of weathering dynamics and condition assessment methods in the case of the Côa.

The visited areas of the world were Norway (from the 1st to the 11th of June 2009), Northeastern Brazil (from 29th of June to the 3rd of July 2009), Southwestern USA (from the 12th to the 25th of October 2009) and Korea (from the 25th to the 30th of October 2010). The present chapter will examine individually the case of each visited area. The review will include a short description of the visit, a general characterization of the sites and existing rock-art, and a discussion of conservation problems faced by these sites and implemented mitigation strategies.

3.2. Norway

Belonging to the wider tradition of Scandinavian rock-art, Norwegian painted and carved imagery is located in over 1100 sites scattered across the country. In this area of Europe, rock-art has been typically divided into two major groups: the Northern Tradition, related with hunter-gatherer communities from the regional Stone Age (from 9,000 to 2,000 BC), and the Southern Tradition, made by farming societies from the Bronze and Early Iron Age (circa 1,800 BC to 400 AD). The difference between the two traditions is thematic: while the Northern Tradition consists mainly of zoomorphic representations (diverse species of deer and large sea mammals), Southern Tradition rock-art features a vast array of motifs, such as anthropomorphic depictions, boats and circular motifs (rings, spirals and cup marks). It has not yet been clarified if these two units are a product of autonomous and dissimilar societies or, whether, they constitute a continuous tradition involving thematic modifications over time. Nevertheless, available evidence seems to suggest that the oldest art in Norway dates back to the Early or Middle Mesolithic and that, from the end of the Neolithic onwards, the Southern Tradition begun replacing the Northern Tradition (Lodoen and Mandt 2010, 1-14).

The rock-art sites visited in Norway were Alta, in the far north of the country, and Vingen and Ausevik, in the south of Norway. Alta was inscribed in the World Heritage List in 1985 with the justification that “it is the largest collection of rock carvings made by hunter-gatherers in Northern Europe” (Tansem and Johansen 2008, 65). It is situated in the inner parts of the Altafjord in Finnmark, and comprises four sites with engraved rock-art (Hjemmeluft, Storsteinen, Kåfjord, and Amtmannsnes), and one area with paintings (Transfarelv). Today, some 6,000 figures inscribed in around 100 panels are known. The art, inscribed mostly on sandstone and shale panels, has been made over an extensive period of time encompassing five different phases dating from 4,200 BC to 200 AD. Apparently, the two more recent periods are linked with the Southern Tradition while the more ancient ones fit the Northern Tradition. Dating of the rock-art was done resorting to a technique commonly used in Scandinavia, the prehistoric and historic retreat of shorelines. A small Museum has been created from where visitors can access the Hjemmeluft rock-art area (see Figure 47, Figure 48, Figure 49 and Figure 50). The Museum and site receive around 60,000 visitors per year paying an entrance fee of roughly 10€. Some 85 percent of visitors are foreigners due to the location of the site on the very touristic route towards the North Cape, the mythical northern end of Europe (Helskog 2000, 2008; Lodoen and Mandt 2010, 15-26; Hans Seborg personal communication; Tansem and Johansen 2008).

Vingen is a quite undisturbed site located in the small Vingepollen fjord, in the municipality of Bremanger. Since its discovery it has been credited with a special aura, attributed to those sites where nature and rock-art come together to offer a near-mystical experience. As its discoverer Kristian Bing referred to it, Vingen is “a barren and untamed place” (quoted in Lodoen and Mandt 2010, 142) that nevertheless constitutes the largest rock-art ensemble known in Southern Norway. More than 300 sandstone panels comprising some 2,100 motifs have been identified. Due to the high number of deer representations, rock-art at Vingen is associated with the Northern Tradition, although the precise chronological attribution remains unclear. Vingen is today understood as having been a sacred place, some sort of sanctuary, where people would meet seasonally to share knowledge, reinforce social and economical bonds while leaving culturally meaningful traces of their presence at the site (Lodoen and Mandt 2010, 139-161; Walderhaug 1998; Walderhaug and Walderhaug 1998). The site can only be visited with a special permit from Bergen University, which manages the site. There are no visitor facilities and, besides the ruins of an abandoned house, the only man made structures at the site is the peer, indispensable to reach the site since there are no access roads, and a small hut to lodge researchers (see Figure 51, Figure 52, Figure 53 and Figure 54).

Ausevik site consists of just one phyllite panel yet comprising circa 350 individual motifs depicting, amongst other, deer, humans and abstract or geometric signs. It is located in Flora municipality and it is one of the most well-known rock-art sites in Southern Norway belonging to the Northern Tradition. The site is also notorious due to the conservation problems it faces (discussed below), documented as early as its discovery in 1934 (Lodoen and Mandt 2010, 309-11; Walderhaug 1998; Walderhaug and Walderhaug 1998) (see Figure 55, Figure 56 and Figure 57).

3.2.1. Management, preservation and conservation issues

In Scandinavia, significant rock-art sites are covered during cold months (from fall to late spring) some being only uncovered and accessible to the public in the summer (see Figure 58 and Figure 59). This is done to reduce the effect of low temperatures on weathering dynamics such as frost shattering (Bjelland and Helberg 2007, 90-100; Tansem and Johansen 2008). However, as the author witnessed as Ausevik was awaken from its winter sleep, if covering panels might prevent freezing from damaging rock art outcrops, it also causes the accumulation of sediments, incipient biological colonization and humidity in the interface between panel and cover (see Figure 60). The same issues have been observed in covered panels at Alta (see Figure 61). This accumulation, together with the creation of an 'artificial' environment in that interface, might led to the surfacing of new or beforehand non-active biodegradation or chemical weathering dynamics.

Scandinavians also pay great attention in dissuading vandalism in their rock-art sites (Hygen and Lasse 2000, 202-9). Therefore, some sites can be visited only with a special permit (as Vingen) while others have pathways, interpretative placards, guided tours to the rock-art and on site Museums (as Alta) or interpretative centres (see Figure 62). At the time of the author's visit, Ausevik was being prepared to be opened to the public and work was being carried out on pathway and interpretative centre construction. These protective measures can be considered successful insofar as they present the rock-art harmoniously and try to protect the sites from human impact and some natural causes of degradation. Documentation work on the rock-art is also well advanced (Bjelland and Helberg 2007, 309-19; Lodoen and Mandt 2010; Tansem and Johansen 2008).

Walderhaug and Walderhaug (1998) performed an instructive review on the conservation of the vast Norwegian corpus of open-air rock-art. Their opinion apparently contradicts Aberg's view (1999) mentioned in the previous Chapter since the authors find pollution not to be a foremost menace to Norwegian open-air rock-art sites. Instead they regarded, at the time their paper was written, more than a decade ago, frost and biodeterioration as the major menaces to the conservation of the country's rock-art. Furthermore, they suggest that weathering rates are not alarming as 70 years ago major Norwegian sites were already in poor condition (Walderhaug and Walderhaug 1998, 119). Bjelland and Helberg offer a more recent assessment of the current condition of Norwegian rock-art comprising a slightly more grim outlook: "The reason that the damage to Norwegian rock art panels appears to have increased in recent years is probably because weathering has reached a critical point" (2007, 21).

Bakkevig has an interesting approach to rock-art conservation in Norway, which can also be of use elsewhere. Besides being extremely critical of direct interventions on rock-art panels that have been carried out in the last decades, he proposes that "ecology-based methods can give weathered sites prolonged life" (2004, 65). Firstly, he suggests that the surrounding environment of rock-art panels "should be treated as an important part of the magic or imaginative value of the site." (2004, 67). Therefore, he questions, on one hand, the systematic vegetation cleaning of sites, suggesting "treat(ing) the environment in agreement with ecological principles, and to develop a sustainable and stable vegetation around the rock art" (2004, 67). On the other hand, Bakkevig harshly criticizes the removal of lichens and moss from rock-art surfaces, regularly carried out in Norwegian sites, challenging what he calls misunderstandings on the detrimental role these organisms play in biodegradation of rock-art (2004, 72-77). The method applied to remove lichens consists of mechanical removal followed by ethanol spraying and finally complete covering of the panel (see Figure 63). The application of ethanol must be repeated each or every other summer in order to prevent lichens from re-colonizing treated surfaces. Several materials have been experimented with until results after some years of testing proved that ethanol was the most suited for the desired purpose (Bjelland and Helberg 2007; Tansem and Johansen 2008, 93-6).

Without anticipating the discussion carried out in Chapter 5 on biodegradation and rock-art conservation, it is believed Bakkevig's approach can prove to be adequate in planning and carrying out conservation or maintenance work in order to avoid an end-result that proves to be intrusive and harmful for the preservation of a site's authenticity. However, as Bakkevig acknowledges, "assessing the effects of lichens on petroglyphs should be specific to each site" (2004, 76). Thus, the Norwegian researcher is indirectly recognizing that lichens (to which other organisms such as plants and mosses can be added) *do* have an effect on petroglyphs. Then, if it is scientifically established that these organisms have a direct and harmful impact upon the conservation of a given rock-art site, actions to prevent the damaging action of such living entities will be ethically justified, insofar as it will prevent or mitigate biological weathering of significant heritage features. Results from a study carried out in Vingen by Bjelland and Thorseth (2002) suggest that different lichen species have distinct but effective weathering repercussions for the host rock (sandstone in the case of Vingen). However, it should also be admitted that besides the damage scrubbing off lichens can motivate to rock-art surfaces, applying ethanol each year or even every two or three years must be noted as being a somewhat aggressive conservation treatment.

Bakkevig's paper is also quite valuable since it provides a list of negative effects originated by conservation interventions on Norwegian rock-art, namely when filling fractures with, sometimes cement-based, mortar. Hence, after a few years problems become visible such as, to name a few, structural fragility in the edges of treated fractures and shrinking or swelling of different cement-based mortars leading to the surfacing of new fractures or the widening of existing ones. Furthermore, he notes that in many attempts to glue detached sections of panels incorrect procedures and materials were followed resulting in further damage, namely in Vingen and Ausevik (2004, 68-72).

3.2.2. Conservation work at Ausevik

In Ausevik, the author had the opportunity to participate in the yearly week in which conservation work is carried out. It was possible to verify that what Walderhaug and

Walderhaug (1998, 134) pointed out a decade ago is still valid: little progress has been made in successfully trying to tackle the effects of natural weathering dynamics. In fact, Ausevik is probably the site in worst condition in Norway. A long history of intrusive direct interventions over more than thirty years has resulted quite poorly for the condition of the engraved outcrop (Bakkevig 2004). It is quite difficult to assess if the interventions were successful in retarding weathering dynamics since it is now impossible to determine what would have been their natural evolution if no conservation work had been carried out. Nevertheless, the fact is that the outcrop is today a patchwork, result of interventions made with several kinds of materials namely Portland cement mixed with stabilizer and rock grind in different proportions, Mowilith DM 123 S binder, mainly used to fill cracks and reattach loose elements, or Paraloid to consolidate weak areas (Eva Ernfridsson, Kjartan Gran personal communication; Bjelland and Helberg 2007, 101-3). Michelsen provides an elucidating account on how there was a lack of adequate methodology when approaching the conservation of the site:

> “When we in 1979 were doing some work at the rock art site at Ausevik, we noticed that a group of figures had loosened in small flakes with a thickness of about 15 mm. Since the figures were already destroyed it was found permissible to do a panicky experiment. The only adhesive we had brought with us in our field equipment was an emulsion meant as an additive to cement mortar to make it more plastic and give better adhesion. It was raining cats and dogs, and the rock was saturated with water. The glue was poured on the rock undiluted, and just left.” Michelsen, quoted in Bakkevig (2004, 68)

According to Bakkevig, lab tests on the suitability of the glue in such conservation work were carried out only after application on the panel. The use of Mowilith DM 123 S as a binder agent in the reattachement of loose rock fragments (also known as the ‘Bergen method’ due to the affiliation of Michelson with Bergen University) was also a methodology employed in Vingen (Bakkevig 2004, 68) (see Figure 64). Moreover, as Bakkevig notes and the author had the opportunity to confirm, mortar filling of fractures in rock art panels (carried out throughtout Norway but of which Ausevik is perhaps the most elucidative example) has been done in an objectionable fashion. As noted above and in the preceding chapter, cement, and notably Portland-based cement, has proven to be a highly inadequate substance to be used in rock art conservation, namely in fracture or gap filling (Bakkevig 2004, 71).

Other materials used in the case of Ausevik also show evidences of loss of coherence and colour changing (see Figure 65, Figure 66, Figure 67, Figure 68 and Figure 69).

If technical and methodological issues are critical in Ausevik, the aesthetic and ethical questions raised by the interventions at the site are tremendous. On one hand, as cement and binders, used in diverse mixes and applied in dissimilar weather conditions, cure differently in color or texture, the outcome of 30 years of intervention is aesthetically very unpleasant. The authenticity of the rock-art site was irreversibly and strongly altered. On the other hand, from an ethical point of view, after just a few years of intervention, these negative results would become easily observable. Instead of pausing interventions in these early years, in order to conduct further testing both in the lab and in un-engraved outcrops, it was preferred to continue these unreliable interventions for several decades now. Furthermore, again as noted by Bakkevig (2004, 72), when these mortars break and begin disintegrating just after a decade or so it will be required to periodically substitute or restore these interventions (see Figure 69 and also discussion in previous Chapter). That would be a somewhat unsustainable strategy regarding the conservation of these rock-art panels. All of the above reflects, in the author's opinion, an inadequate approach to the conservation of open-air rock-art. The first interventions set in motion an irreversible vicious circle that requires continuous re-intervention to maintain earlier applications of ill-fitted materials not previously tested in the laboratory. The fact that present-day managers and conservators face a situation in which they had to 'jump aboard an already moving train' offers some scarce comfort regarding the frail condition in which Ausevik survives today. The history of intervention in the site also serves as a(nother) enlightening cautionary tale on the complex and delicate matter of rock-art conservation.

3.3. Piauí, Brazil

The Brazilian state of Piauí is located in the Northeastern area of the country, known as the 'Sertão' (Wilderness or the Bush). This is a semi-arid vast area comprising several Brazilian states that can be characterized as a 'green desert' since for many stretches of land there is nothing more than bush (see Figure 70 and Figure 71). Not surprisingly, this region is one of the most underdeveloped areas of the country and Piauí is among the poorest Brazilian states.

Piauí, occupying an area roughly equivalent to that of Romania, possesses quite a few rock-art sites of which the Serra da Capivara National Park, in the South of the state, arguably comprises the most important ones (Cavalcante *et al.* 2008; Cavalcante and Rodrigues 2009; Guidon and Lage 2002a; Lage *et al.* 2009; Nash 2009). In 1991, Capivara was inscribed by UNESCO in the WHL. The Park possesses an enormous collection of prehistoric rock-art (some 1000 sites) comprising paintings and a much lower number of engravings[23] located in natural shelters situated along the walls of sandstone canyons created by the geological down-cutting process of now dry river valleys (Nash 2009). Results from research carried out on the context of the rock-art led by Fundação Museu do Homem Americano (The Museum of American Man Foundation – FUMDHAM), have been in the center of a fierce controversy involving no less than the first humans inhabitants of the Americas. Indeed, dating of fallen painted rock pieces and hearths found in archaeological layers and calcite that covered some paintings situates the occupation of the area well before the Clovis period. One of the dates resulting from the calcite cover even pushes the arrival of the first American human settlers to a surprising 48,000 years BP (Pessis and Guidon 2009). However, researchers invited to confirm these results obtained the more modest date of 2,490 years BP by also analyzing calcite samples from the same painting (Steelman *et al.* 2002) that was dated to such an old period by the team working at FUMDHAM.

Be that as it may, dating controversies aside, the fact is that Capivara rock-art possesses enough aesthetical and scientific relevance for the Park to be considered one of the foremost prehistoric rock-art areas of the world. The paintings are mainly red (because of the use of haematite), although a few polychromous compositions are also known. The paintings primarily represent human beings and wild animals such as red deer, armadillos, capybaras (a large rodent), lizards, and giant rheas (a now extinct ostrich). Human beings are quite often represented in a ‘procession’ arrangement (lines of sometimes 30 plus individuals). There are also many compositions in which human beings are depicted in association with animals such as in hunting or sexual intercourse scenes. Additionally, there is also portrayal of supernatural beings (Nash

[23] As stated in a previous chapter, while the conservation of petroglyphs (engravings) and pictograms (paintings) pose distinct problems, the conservation of the rock surfaces where rock-art has been inscribed is common to both categories. Hence, the following analysis of work carried out in Capivara will focus on the conservation of the ‘media’ that today still hosts prehistoric motifs.

2009) (Figure 72, Figure 73, Figure 74, Figure 75, Figure 76, Figure 77 and Figure 78).

As stated above, the chronology of the art remains somewhat unclear. Nevertheless, local researchers propose a prudent division of the art in two major periods comprising not only the Park but also the whole Northeastern region of Brazil: the Northeastern tradition from around 12,000 BP to 6,000 BP and the Agreste tradition from around 10,500 BP to 3,500 BP. Generally speaking, the more ancient period corresponds to the most aesthetically well-achieved art while the Agreste tradition comprises more awkward depictions. Animal depictions are absent from this most recent period. As both traditions co-existed for a long period of time, several panels comprise motifs from the two styles. In fact, in some occasions it appears that there was an intention, on the part of artists from the Agreste tradition, to make disappear motifs from the earlier period since many were painted over. In some panels, painted motifs also appear to depict fighting scenes which can correspond to the representation of conflicts between groups belonging to the two different traditions (FUMDHAM 2007; Guidon and Lage 2002a; Nash 2009).

3.3.1. Management issues at Capivara

Management of the Park and research on the art, its conservation and archaeological context is carried out by the ONG FUMDHAM with the support of the federal government, the state government and major Brazilian private or semi-private companies such as the oil giant Petrobras. FUMDHAM elaborated a management plan for the Park that focuses in using the rock-art as a major factor in the social and economic growth of this underdeveloped area of the country. As a result of this strategy, the American Man Museum and a branch of the Federal University of the São Francisco Valley teaching archaeology and related subjects were set up in S. Raimundo Nonato, the major city in the area with a population of about 30,000. As for visitor management in the Park, FUMDHAM only allows tourists to take the more than existing 20 trails comprising visits to rock-art sites if accompanied by a guide (see Figure 79). The guides, although operating under the supervision of and trained by FUMDHAM, work independently of the said ONG. The trails vary in difficulty and some are adapted to individuals with special demands such as wheelchair users.

Pathways, trash bins, signs and informative panels have been installed at some of the rock-art sites included in the trails on offer (Buco 2011; Oliveira Filho 2007).

In the last decade, Brazilian rock-art managers and conservation experts, especially in this Northeastern area of the country but also elsewhere, have been carrying out interventions at rock-art sites (Cavalcante *et al.* 2008; Cavalcante and Rodrigues 2009, 2010; David and Souza 2002; Lage and Silva 2010; Lage *et al.* 2009). Capivara served as a testing field to develop correct conservation intervention methodologies. After a first moment in which conservation work was carried out under cooperation agreements with foreign institutions, interventions began to be locally prepared beforehand by trying to fully understand the conservation environment and the effects of weathering dynamics. Moreover, there was a concern in building a corpus of knowledge on the subject that could also contribute to train local conservators in the several areas of the country with rock-art. Today, conservation work is carried out by these teams supported by local Universities experts (for instance, Lage *et al.* 2004/2005). Funding as well as global coordination of these interventions is given by IPHAN (Instituto do Património Histórico e Artístico Nacional), a federal government agency similar to English Heritage. In the last few years it was possible to intervene in more than 20 sites, preparing them to receive tourists but also performing direct conservation work on the rocky walls featuring rock-art motifs. This level of commitment signals a growing interest and investment in the preservation and conservation but also in the touristic use of the country's rock-art sites (IPHAN 2009; Oliveira Filho 2007).

3.3.2. Conservation interventions at Capivara

In the specific case of Capivara, specific weathering dynamics pose serious conservation threats in several of the shelters hosting rock-art (Figure 80, Figure 81 and Figure 82). As stated above, the first conservation efforts have been undertaken by international teams (from Germany and Japan) under collaboration and funding agreements established with the Park. Today, Brazilian experts from the State University of Teresina have developed their own conservation methods (Figueiredo and Puccioni 2006; Giordano Macêdo personal communication; Guidon and Lage 2002a). This was due to the realization that the techniques used and materials employed by the international teams were not the most appropriate, namely when considering effectiveness in countering weathering dynamics but also the aesthetic dimension. Therefore, local experts began testing, both in the lab and in the field, innovative approaches that eventually produced a method deemed suitable to fill gaps and reinforce the condition of the rock faces covered with prehistoric paintings (Figueiredo and Puccioni 2006; Guidon and Lage 2002a). Several shelters (Tocas) have been intervened upon at Capivara (Guidon and Lage 2002b). In the following paragraphs, the case of a specific intervention will be examined regarding techniques and materials used as well as results and aesthetic and ethical issues.

3.3.2.1. Conservation of Toca da Entrada do Pajaú

Conservation work in this site followed a thorough transdisciplinary and, most importantly, inter-institutional approach that is deemed to make the case of this Toca (Figure 76) the standard to aim for in the conservation of similar rock-art sites in the regional and national scale. Indeed, further and more recent conservation work in rock-art shelters in the Capivara region have greatly benefited from the methodology that has been developed for this specific case (see Figure 83).

Experts from different areas have been called in to give input in their field of expertise. Therefore, detailed characterization of the shelter regarding Botany, Geomorphology and Geology, Entomology, Microbiology and Archaeometry was achieved. Moreover, from the initial planning stage, it was agreed to use the utmost prudence in the intervention following a principle of minimum intervention. The conservation project for the site developed along the last two decades and had as its main goals the thorough condition assessment of the site, to propose measures for the structural consolidation of the Toca and to carry out conservation interventions. It should be noted that some specific objectives (notably mapping the percolation and drainage system of pluvial water throughout the Toca) were not achieved due to financial or time constraints. Nonetheless, armed with a quite comprehensive corpus of data including micro-climatic, geomorphologic and geologic characterization, description of weathering dynamics in action and the effects of different organisms (micro-organisms, lichens, mosses, plants and insects) on the conservation of the site, Brazilian experts proposed a series of recommendations. Of these, the creation of a drainage system to prevent pluvial water from impregnating the rock massif during the wet season is among the recommendations that have been carried out, together with planting well-adapted and less aggressive native vegetation in the surrounding area of the shelter and conservation interventions on the rock-art panels (Figueiredo and Puccioni 2006; Lage *et al.* 2002).

After noticing that many rock-art motifs have been lost due to the action of weathering dynamics (mostly arising from high rainfall storms, insect colonization and aeolian erosion) that were aiding the further weakening of the shelter's structural fracture system, direct interventions were undertaken. The first one consisted in the complete cleaning of the walls removing insect nests, mineral efflorescences, plant roots, smoke stains and recent graffiti. The second stage included the consolidation and/or reattachment of painted panels. Prior chemical testing of the components of the sandstone that makes up the walls of the Toca and of the soil and rocks found inside the shelter indicated that these have a similar composition. Thus, a very simple mix (consisting of quicklime and grinned rock from the interior of the Toca) was used to that effect. Fractures have been also filled with the same mortar (see Figure 84, Figure 85, Figure 86 and Figure 87). Small drip lines made of latex were fixed to the wall above the areas with paintings to avoid water flow over these zones (see Figure 88). In order to confer further stability to the shelter, some non-painted areas underwent partial reconstruction of the rocky wall features and/or reattachment of loose or fallen blocks using plastic moulds, silicone and the above-mentioned mortar. Weather monitoring inside and around the shelter continues to this day. Gathered data shows great thermal variation (30º C) in parts of the walls in different periods of the day. Hence, Conceição Lage, the chief conservation advisor, alerts to the necessity of continuing to monitor weathering dynamics at work in the Toca, and to intervene when necessary. This recommendation is partially followed since the local team that was set up to carry on conservation work, regularly performs maintenance of past interventions while still preparing and intervening in other rock-art shelters in Capivara. Nevertheless, more in-depth interventions are foreseeable to be crucial in the near future (Lage 2006).

From an effectiveness point of view, the interventions in Toca da Entrada do Pajaú come across, at the time of the author's visit, a decade after the major conservation works were undertaken, as successful. Fillings have maintained coherence and consistency as no gaps and cracks appeared on the applied mix; reattached blocks have kept in place and motifs stand out quite vividly which signals that water flow has not washed them away. Visits to other shelters that have also been intervened with similar conservation methodology and materials suggest that the approach followed has also proven its merits for the whole corpus of Capivara rock-art in need of conservation (IPHAN 2009) (see Figures above).

Although direct intrusive interventions were indeed carried out in Capivara, there is little comparison with the situation in Ausevik, namely when aesthetic and ethical issues are concerned. While in the Scandinavian country, interventions are easily perceivable and even disruptive to the appreciation of the rock-art, in Piauí it is reasonably difficult to tell apart an area that has been intervened from another not dealt with. The methodology followed by Brazilian experts was also quite different: when it was found that one course of action was not the most suitable one, interventions were halted while new and more apt approaches were methodically investigated. Although intervened upon Capivara rock-art evidently also 'suffered' the potentially disruptive results to its authenticity that direct interventions do entail, there has been a consistency in the methods used to fill and structurally reinforce the rock-art panels.

3.4. Arizona, United States of America

The USA state of Arizona is located in the Southwestern region of the country and occupies an area that roughly equals that of Poland. As other less populated North-American states, Arizona keeps a significant corpus of rock-art. Local researchers cannot exactly say how many sites exist (Ronald Dorn personal communication) but estimates range from 6,000 to 8,000 (Malotki 2007, 6). Arizona rock-art belongs to the greater prehistoric and historic tradition of art making in the North-American Southwest, a region comprising the states of Arizona, New Mexico, Utah and Colorado and parts of California and Texas. Following that tradition, Arizona rock-art, which mainly consists of engravings, is divided in two major distinct periods: the Archaic and the Post-Archaic, closely following the general chronology of human occupation in North America (Bostwick 2005). Both periods comprise several different traditions associated with diverse regions or ethnic groups. The most ancient phase – Archaic period – is thematically subdivided in the Geocentric (geometric designs) and Biocentric (depictions of humans) styles and is believed to date approximately from 6,000 to 1,000 BC. Dating of Arizona rock-art is mostly based on stylistic comparison. Nonetheless, four dates for Arizona's painted rock-art have been obtained, all falling in the protohistorical and historical period (Rowe 2005).

Generally speaking, Archaic rock-art has been made by nomadic hunter-gatherer societies that might in fact have carried on with their way of life beyond the contact period. This fact explains the persistence of Archaic rock art styles (such as the Gravepine Style) well in to the historic epoch. The Post-Archaic period, ranging from 1,000 BC virtually until the present, presents a multitude of regional styles that were probably made by groups in different stages of the transition from a hunter-gatherer lifestyle to a less nomadic way of life featuring rudimentary agriculture, an improvement that slowly moved northbound from Mesoamerica. Pottery was also among the innovations that began appearing in the region during this stage. Interpretation of art belonging to both periods generally follows what is proposed for most rock-art in the world. Hence, shamanism, hunting or fertility magic, and marking the landscape are among the interpretations put forward to try to answer, in the case of Arizona, the most asked question in rock-art studies, 'What does it mean?' (Bostwick 2005; Malotki 2007; Rowe 2005).

3.4.1. Visits to rock-art sites

During the stay in Arizona, the author visited several rock-art sites and accompanied Ronald Dorn during a one-day fieldwork outing. Therefore, the following paragraphs will constitute a general account of management and preservation faced by sites in the region, albeit conservation issues will also be considered. Since the only conservation work was carried out with Dorn, namely regarding the use of the RASI, special relevance will be given to the above mentioned fieldwork outing. Since quite a number of sites were visited in Arizona (and two in the neighboring state of Utah), the following account will focus on the ones considered to be the most relevant and insightful.

Chevelon Steps is a site located near the Arizona city of Winslow. It is privately owned and is a part of the 'Rock Art Ranch', a still operating cattle ranch that is also a tourist attraction (see Figure 89). For a fee, the owner takes visitors to the site besides offering some demonstrations of 'early' cowboy life in the Wild West. The owner has installed an aesthetically unpleasant viewing platform over the area of the small canyon possessing rock-art. A staircase has been also installed to facilitate access to the site (see Figure 90). The site features a few hundreds images in just a small stretch of the canyon (see Figure 91). Among these, the most well-known and discussed image is that of a women apparently giving birth (see for instance Hays-Gilpin 2000) (see Figure 92). Other imagery includes several representations of the so-called *flute player*, an ubiquitous theme in Southwestern rock-art (Patterson 1992) and shaman like figures (see Figure 93). In the visit to the site, the author accompanied Robert Mark and Evelyn Billo, of Rupestrian CyberServices, in their documentation work of some of the rock-art panels in the site resorting to the creation of GigaPan panoramas (Mark and Billo 2011)[24].

Utah's Newspaper Rock is located near Canyonlands National Park, an area also rich in rock-art (see Schaafsma 1980). As it name implies it constitutes just one panel, although quite large and possessing numerous images (more than 650 motifs) (see Figure 94). As with other 'Newspaper Rocks' that exist in the Southwest region (for instance, another Newspaper Rock stands in Petrified Forest National Park, Arizona), the engraved panel constitutes a true prehistoric and historical record of events in the area. In the case of this particular Rock, it gives the impression that relevant post-contact events are depicted in the rock (introduction of the horse, and of the wheel, fur trade) together with more ancient indigenous tradition rock-art, such as animals and anthropomorphic figures (see Figure 95). It also interesting to note that individuals from the same family scratched their names (and dates of inscription) on the Rock in two distinct inscription events separated by more than 50 years (see Figure 96). In fact, the first one, Ramon Gonzalez, was one of the first Hispanic settlers to arrive to Utah from New Mexico (Gonzalez and Padilla 1984), which arguably makes these inscriptions also worthy of preservation[25].

Canyon de Chelly National Monument is located within the Navajo Nation, quite close to Chinle, one of the major cities of that "sovereign but dependent" US territory (Anyon *et al.* 2000). It is a vast geological structure housing rock-art from different traditions and ages, including Pueblo, Hopi and Navajo imagery (Grant 1978) (see Figure 97). In fact, rock-art and the archaeological finds made in the Canyon give evidence of one of the longest permanently occupied areas in North America (Dix 1979). The National Park Service in cooperation with the Navajo

---

[24] Links for the many panoramas Robert Mark and Evelyn Billo have been creating in the last few years can be found in the Rupestrian CyberServices website at http://www.rupestrian.com/links-to-gigapans.html

[25] See Fernandes (2010c) for a discussion of issues regarding vandalism, graffiti and rock-art (available at http://www.arte-coa.pt/Ficheiros/Bibliografia/1327/1327.pt.pdf).

Nation manages the Monument. Visits are only possible (with the exception of a trail) with the permission of the Park. For a fee, local Navajo guides take tourists to the Canyon (see Figure 98) and show, from afar, existing rock-art as well as other relevant historical or natural features of the landscape (see Figure 99 and Figure 100).

Deer Valley Rock Art Center, a 47-acre preserve and interpretation center/small on-site museum opened to the public in 1994 (see Figure 101). Its goal is to protect and promote public awareness on the importance of rock-art. It comprises an ensemble of circa 1,500 petroglyphs from the Hohokam and Archaic periods (see Figure 103). The Center is located in the outskirts of Phoenix, the largest city in Arizona, and is run by Arizona State University. The creation of the center and preserve is part of the agreement arising from the construction of a dam to control river flooding (Bostwick 2005). Simple yet clever solutions were implemented to better show and explain the rock-art to visitors (see Figure 103). These solutions prove that it is not necessary to dispend large sums of money to present rock-art (or other heritage features) in enticing and imaginative ways. If at Deer Valley rock-art has been preserved *in situ*, the same cannot be said about rock-art in another tourist attraction in the Phoenix area. In fact, at Taliesin West, Frank Lloyd Wright's winter home now part of the Foundation with his name, rock-art panels that were found in the mountains belonging to the estate have been relocated, in the 1930's, to the central plaza of the building complex (see Figure 104 and Figure 105). One of the motifs has even been incorporated in the logo of the estate.

3.4.2. Management, preservation, and conservation issues

Although the author has not been involved in conservation work on rock-art panels during his stay in Arizona, some relevant points can be made mainly regarding rock-art preservation but also conservation. Firstly, there is the question of scale. The management of the extensive corpus of rock-art of a US state such as Arizona, with an area corresponding to a medium-sized European country, is a colossal task. Hence, it is not surprising to verify that there is no precise idea on how many rock-art sites there are in Arizona. Moreover, the fact that government and/or tribal agencies only administer the small portion of sites not privately owned makes the global management of rock-art sites an unsystematic and greatly complex task, as the case of

Chevelon Steps and the ‘Rock Art Ranch’ exemplifies. The vast size of the territory evidently precludes any comparison between the situation in the Côa Valley (or any other precise rock-art site) and the one in Arizona, besides concluding that the management of a minor area is obviously a more straightforward undertaking. However, if a particular Arizona site is considered, such as Canyon de Chelly, some relevant insights might be inferred. The first is that even in such a reasonably small site covering a total of 33,929 ha (the area of the PAVC is roughly 6 times larger), it is hard to know the exact number of existing rock-art motifs and panels (Grant 1978). On one hand, this is due to the general lack of interest on the part of North-American mainstream archaeology regarding rock-art studies (Bostwick 2005, 51-4; Ronald Dorn personal communication). On the other hand, traditional ownership questions further handicap in-depth study of the Canyon’s rock-art.

As noted above, the researchers that studied Canyon de Chelly found evidence that supported a widespread use of rock faces by different communities throughout diverse periods to engrave or paint imagery. Nevertheless, the Navajo guide that took the author on the tour to the Canyon believed the rock-art had all been made by her Navajo ancestors, thus disbelieving claims by the Hopi Nation of ownership of this territory where researchers also found imagery that fits Hopi rock-art tradition. There is rivalry between these two Indian Nations and land disputes are still a major source of dissent, notably since the much smaller territory of the Hopi Nation is completely engulfed by that of the Navajo. Hence, the evidence suggesting that Hopi rock-art is a continuation of the more ancient Ancestral Pueblo tradition while Navajo art is much more recent (Navajo, as well as Apache, have arrived recently to the Southwest, circa 1,500 AD) (Malotki 2007, 94), will obviously support, even if unintentionally, one side of the dispute[26]. Hence, it is not surprising to note that First Nations try to restrict or lock up the access of non-tribal institutions or individuals to cultural resources. Furthermore, it led some Nations to encourage its members to pursue a ‘White-man’ conventional education in archaeology and heritage management and related disciplines (Anyon *et al.* 2000). This has also contributed to further restrict access since now First Nations are better equipped to manage and research their own

[26] It is interesting to note that recent news point to a new understanding between the two Nations regarding the preservation of an important Hopi rock-art panel located in Navajo territory (Arrillaga 2012).

heritage, or at least what they perceive to be their ‘own heritage’, and to claim back remains unearthed during past archaeological excavations (Fonseca 2011).

First Nations may well have good reasons to try to protect all rock-art they can as, throughout the US Southwest, panels are in a quite vulnerable situation. For instance, Berverly Canyon in Phoenix is a recreational area quite sought by Phoenix residents. Even if so far no damage to rock-art has been reported as a result of recreational activities, Ronald Dorn (personal communication) expressed concerns regarding the preservation of the site, since panels are completely unprotected and it is known from other cases that rock-art is a magnet for vandals and even thieves (see Figure 106 and previous Chapter). The case of the relocated rock-art in Taliesin West further reinforces Native Americans claims of ownership of what they perceive to be their ‘direct’ heritage. Today, obviously, the relocation would have been frowned upon quite harshly and attempts to prevent it would possibly be undertaken by heritage NGOs since it is widely believed that rock-art only retains its full meaning if located in the original landscape context of creation (see for instance Zilhão 1998). Nonetheless, the 1930s relocation made the rock-art part of the present lure of the place. Therefore, it is believed that any suggestion to return these panels to their original standing would not be welcomed at present. On the other hand, the case of Utah’s Newspaper Rock suggests that contemporary public is capable of respecting these ancient sites. Apart from the Hispanic historical inscriptions (and other, meanwhile erased, more recent writings), the most striking fact about the Rock is that it does not present evidence of more grievous forms of graffiti or even of pure vandalism actions[27]. This is quite revealing since the site is not physically protected at all besides, the existence of a ‘non-protective’ circa one-meter tall metal barrier around the panel (see Figure 107 and Figure 108).

3.4.3. Rock coatings

Another issue dear to Dorn was also discussed during the visit to Beverly Canyon. Rock coatings are a phenomenon that affects the conservation of rock-art motifs. Dorn, one of the world’s leading experts on the matter, lists more than a dozen types of coatings that cover rock panels (2007, 247) (see Figure 93). These coatings originate in biotic processes (such as lichens or even human-made paint placed on

---

[27] See footnote 25.

surfaces by individuals) and in geochemical sedimentary dynamics. Some authors suggest that these coatings offer some sort of protection to rock-art insofar as they shield it from different forms of weathering (Cerveny 2005; Dorn 2006; Pope 2000). Moreover, the use of an artificial version of one of these coatings, namely rock varnish – also known as ‘desert varnish’ when existent in arid areas (Dorn 2007, 246) – was presented as “a method for restoring defaced (by graffiti) petroglyph surfaces.” (Elvidge and Carleton 1980, 108). One of the best-understood rock coatings is precisely rock varnish (Dorn 2007, 246). It is has been claimed that rock varnish can be used to date rock-art using a variety of methods such as cation-ratio and lead profile dating, microlamination of varnish layers and AMS dating of organic materials ‘trapped’ in rock varnish (Dorn 2004). However, some researchers (including Dorn) warn that wildfire events may contaminate samples (Tratebas *et al.* 2004). Moreover, Dorn also stresses that rock coatings must be found as a closed system to produce reliable dating (Dorn 1997). Hence, since these coatings go through complex and little-understood deposition/erosion/redeposition processes (Rosenfeld 1985; Zilhão 1995), it is difficult to find rock surfaces that might provide ‘pristine’ undisturbed samples that really date the moment when a given petroglyph was actually made. Lastly, as Dorn admits, “the answer for variability in cation-ratio results rests in deciding what samples to collect” (Dorn 2004, 215). Although it expressly mentions just cation-ratio dating, it can be suggested that the sentence is also applicable to the other above-mentioned methods.

3.4.4. Ronald Dorn and the Rock Art Stability Index (RASI)

In the outskirts of Phoenix, the author had the opportunity of visiting a rock-art site with Ronald Dorn, one of the leading North-American specialists in rock-art dating and conservation and one of the brains behind the creation of RASI. On the visit to Beverly Canyon, Ronald Dorn, besides discussing other physical weathering processes active in the desert environment such as scaling and flaking, exemplified how wedging, a poorly known and understood process, affects rock-art panels. When in already open fractures and fissures the wind makes sediments accumulate, these deposits will further enhance the potential for scaling or flaking (hence, for detachment) of surface material due the exerted pressure (see Figure 109) (Villa *et al.* 1995).

Hence, Dorn highlighted the need to document the condition of rock-art in the North American Southwest (and elsewhere). RASI, as Dorn explained and exemplified at one panel in Beverly Canyon, was developed towards that aim. This Index is an attempt to group and associate several dimensions of rock-art weathering patterns under a single ranking method. Dorn *et al*. have developed a “field-friendly” catalogue that incorporates “elements of existing strategies to characterize the stability of stone” (2008, 35). The Index is presented as being able to be used by individuals without prior knowledge on rock weathering requiring only rudimentary training. The Index can be downloaded from a dedicated webpage where an explanation and interpretation of considered weathering factors and instructions for indexers can be also found (Dorn and Cerveny 2009). Drawing on the author’s short pratical experience with the Index during the fieldtrip but also the available literature published by the Index’s authors, it is suggested that RASI constitutes a valuable and flexible method to be used by rock-art managers and conservators. However, some minor predicaments somewhat deter a wider use of the Index.

It should be noted that since the research group that developed it is based in Southwestern USA, the Index was foremostly designed to address the weathering dynamics affecting open-air rock-art sites located in that area of the world. For instance, it describes and assesses both anthropogenic and natural threats but it does not, such as it is believed to be important in the case of the Côa, consider slope, aspect or solar radiation contributions to rock-art deterioration (see Chapter 5). Furthermore, it was designed to be widely employed in different regional sites possessing diverse characteristics. Hence, subcategories have been designed in a general ‘all-catching’ fashion so that they could easily encompass these diverse characteristics. Therefore, if the Index is to be used in just one area possessing a few rock-art sites (such as the Côa) where characteristics (petrology, for instance) are quite similar or even indiscernible, the end-result may not accurately depict the precise condition of panels since the categories used are to broadly, thus insufficiently, characterized. On the other hand, since it was designed to be used by different volunteers, even in the same site, RASI allows subjective input, although countermeasures were put in place to prevent distortion of results and assure consistency. However, one of those measures entails further subjective input since it fosters site the manager’s discretion in analysing and validating results from field assessment (Dorn *et al*. 2008, 51-55).

3.5. Bangudae, South Korea

The site consists of a large panel containing some 200 motifs featuring animal depictions and hunting scenes dating from the period between the end of the local Neolihtic and the Bronze Age. Some of the most interesting motifs depict whales and whale hunting. The panel is located in a large and tall cliff made up of sedimentary rocks (namely sandstone, siltstone and sandy shale) by the margins of the Daegok River in the South-Korean province of Ulsan. In 1995, the site was designated as National Treasure of South Korea. In the vicinities of this panel, other rock-art sites also exist (Caldwell 2007; Song 2009).

3.5.1. Preservation and conservation issues

In the 1960s, a dam was built in the river causing the seasonal submersion of the rock-art panel from early spring to autumn (Fitzner *et al.* 2004) (see Figure 110 and Figure 111). Therefore, the panel goes through significant impacts each year due to submersion/emersion cycles, especially those caused by repeated and fast wetting/drying episodes, as described by Bland and Rolls (1998). Hence, the precise context in which this site is involved does have some affinities with the Côa Valley. First, the Bangudae case offers instructive insights on how submersion affects rock-art panels. Second, it provides a test case to accurately measure the weathering dynamics motivated and/or accelerated by repeated wetting/drying episodes, namely when considering the few Côa engraved outcrops that suffer the same fate during winters of heavy regional precipitation and consequent flooding of the river.

The author's visit to the site occurred during a period when the rock-art panel is not submersed. Nonetheless, it is impossible to inspect the panel from a close distance since there is no viewing platform near to the panel. Regular visits (such as the one the author integrated) only observe the rock-art from the far-off opposing bank with the help of existent binoculars and of an information panel (see Figure 112). A Museum[28] has been built nearby featuring replicas of the engravings and additional information on local prehistory and the region. The site has been 'only' placed in UNESCO's World Heritage Tentative List (UNESCO 2010a) since the complex preservation and integrity issues it faces with the lowering/rise of the river waters, precludes its inscription in the World Heritage List. Nevertheless, Korean

[28] See http://global.designb.com/disko/read.asp?boardseqnum=8482.

authorities seem to be quite keen in having the site inscribed in the WHL as it is or by considering remedial interventions such as the construction of a small dam that would prevent its seasonal submersion also allowing visits to the panel (Caldwell 2007). In fact, the author had the opportunity of visiting the site during the course of an international Conference organized by the Northeast Asian History Foundation[29] to commemorate the 40th anniversary of the discovery of the Bangudae Petroglyphs. During the Conference, it became apparent that the international experts present at the event had been invited to support the application of the site for WHL status.

One of the avenues pursued by Korean authorities during this process was to completely assess the condition of the monument. Hence, a team of German experts was called in to carry out such a task. As a result, Fitzner *et al.* (2004) have accomplished what is perhaps the most comprehensive monographic study on the characterization, analysis and diagnosis of rock-art weathering dynamics. The objectives of condition assessment were the

> “evaluation and scientific rating of the weathering damage on the Bangudae Petroglyphs, the petrographical characterization of the rocks, a risk prognosis and the deduction of information on need and urgency of preservation measures” (Fitzner *et al.* 2004, 504).

The end-result was an extremely detailed description of the rock itself (for instance mineral composition, porosity, and hygric properties), the mapping and categorization of active weathering dynamics and recommendations regarding the urgency to pursue conservation interventions on different areas of the panel. Nonetheless, as Cerveny notes,

> “the damage diagnosis at Bangudae will be recognized in the future as an ideal to shoot for in future rock art conservation studies, but the costs required to undertake that level of analysis is simply not widely available” (2005, 101-2).

Cerveny is accompanied by Vogt in the critique when he states, regarding the work undertaken by Fitzner et al., that “time consuming, esoteric, and costly approaches will likely not be followed for the assessment of a vast number of rock art panels” (2007, 33). Be as it may, Fitzner *et al.* study remains to this day the most clear demonstration of the possibility of accomplishing depth of analysis and meticulous characterization in rock-art conservation studies, if sufficient resources are available.

---

[29] See http://www.historyfoundation.or.kr/eng/.

The fact that resources for rock-art conservation are not readily available speaks volumes regarding cultural heritage management and conservation priorities, especially in affluent countries, such as the United States where the issue has not deserved much attention in the past century (Silver 1989). Therefore, the 'messenger should not be blamed'; rock-art conservation studies *should always* aim towards the most complete characterization possible. Nevertheless, as Vogt (2007) attempts to demonstrate, cost effective, easy to use but still thorough methods can be preferred to more highly complex and resource-consuming approaches such as it happened at Bangudae[30].

3.6. Conclusion

The current chapter presents and discusses the most relevant finds of the visits carried out by the author to rock-art sites of interest in regard to conservation problems similar to the case of the Côa and implemented strategies to addressed them. It should be noted that other sites might have been visited. That is the case of rock-art areas in Russia, namely in Siberia, and South Africa. Unfortunately, logistical and mostly financial constraints prevented carrying out such fieldtrips. Hence, the above-described panorama only directly pertains to visited sites. However, it can be argued that the visits carried out provide some key general points regarding conservation interventions at open-air rock-art panels and outcrops.

Since each case is dependent on the precise natural context (for instance, the Brazilian sites in Piauí are not subject to the freeze-thaw cycles Norwegian sites face), weathering patterns and their effects vary considerably. Hence, a case-by-case approach is the cornerstone of any conservation work philosophy. Furthermore, it can be argued that conservation practices are also culture-dependent; what can be acceptable as a conservation treatment in a certain country might not be tolerated elsewhere.

There is still a considerable lack of precise knowledge on weathering dynamics and their effects on rock-art, but most of all on the end-result of applying conservation materials and techniques on natural features of the landscape such as

[30] The Bangudae case and especially the Fitzner *et al.* study will be discussed in detail in Chapter 5 and 6.

outcrops. Proper intervention methodologies are also lacking. This is quite evident when analyzing the case of Ausevik in Norway.

The direct interventions discussed eloquently illustrate the ethical and aesthetical issues relating to rock-art conservation. These prove that once a decision is taken and interventions are carried out, there is no coming back. The direct interventions in Norway and Brazil effectively demonstrate that reversibility (at least in rock-art conservation) is a myth: how to revert a natural stone makeup to a previous existing state when the carried out interventions have the aim of structurally reinforcing outcrops and panels? The only possible answer would be to *apply new materials*, since it is highly probable, if not certain, that the outcrops and panels would not withstand, after consolidation work, being reverted not to their original condition but to a weakened condition because of the removal of applied reinforcing materials.

Moreover, if applied materials do prove to be inadequate or even harmful to the condition of a rock-art panel or outcrop or start to lose strength and cohesion, one can wonder how many reinforcement interventions will be needed after the first one. If 'uncomplicated' maintenance work in past interventions has to be performed on a regular basis, are major reinforcement actions to be carried out every decade or so? Finally, would rock-art outcrops and panels endure for a few decades more without major losses of motifs, if no interventions were carried out?

These findings suggest that it is of the upmost importance to abundantly gather the most relevant data on outcrops and panels condition so that well-informed decisions can be made. Moreover, accurately monitoring the condition and weathering rates in open-air rock-art panels is critical to correctly assess the urgency of implementing conservation interventions. For instance, if it is determined that weathering rates are not alarming, conservation work would be less urgent. Hence, the present project includes the condition assessment of a sample of rock-art outcrops in the Côa Valley, which will be discussed and presented in subsequent chapters. Arguably, a condition assessment is the first step of an empiric traditionally based monitoring process since repeated assessments will provide the basis to determine weathering advances in open-air rock-art outcrops. In the last few years, many new monitoring methods in relation to rock-art weathering have been developed. Nonetheless, while not being completely outside the scope of the present project, a detailed discussion of several available monitoring methods in the context of the present PhD is not the among its key objectives. However, the author has elsewhere discussed the use of monitoring methods to periodically evaluate the condition of the Côa Valley rock-art outcrops (Fernandes *et al.* 2006b)[31].

[31] Available only in Portuguese at http://www.arte-coa.pt/Ficheiros/Bibliografia/1334/1334.pt.pdf.

BLANK PAGE

Chapter 4: Characterization of the Lower Côa region with a focus on climate patterns

4.1. Introduction

Weather and geology are the two factors that most decisively influence the 'natural' conservation of the Côa Valley rock-art outcrops. It can be said that geology provides the backdrop where weathering unfolds. In turn, weathering dynamics and rates are most decisively determined by climate variables (for instance Bland and Rolls 1998). Accordingly, the following characterization will present a detailed analysis of regional climate patterns while presenting a concise description of the geological background. It should be noted that a detailed characterization of regional, local, and micro-local weather variables is also determinant in setting the conservation intervention scale since varying microclimate conditions will differently affect the condition of engraved outcrops (Aubry *et al* 2012).

4.2. General background[32]

Geomorphologically speaking, the PAVC area is part of the northern extremity of the Iberian Meseta and of the hydrographical basin of the Douro. This region's climatic, morphological and topographic attributes include schist bedrock, poor agricultural soils, low annual rainfall and a dry warm climate, especially in the low-lying riverside areas where temperatures are high in the summer.

Adapted to these harsh conditions, over the last two millennia, was the establishment of a model of land exploitation based on three major monocultures (olives, almonds, and wine), complemented by sheep-farming. The inaccessibility of some riverside areas, and the hard work needed to cultivate the steep slopes, has meant that human activity in these zones has been largely non-intrusive (see Figure 113 and Figure 114). This is probably the reason for the survival of many of the rock art motifs. Modern economic models of land exploitation, however, have more destructive characteristics, for instance a schist quarry located above the Canada do Inferno rock art site (see Figure 115). Normally schist extraction involves the use of

[32] This section includes parts of text taken from the following papers: Fernandes (2004, 2007). After careful consideration, it was decided to include these excerpts to provide more structure to this Chapter and to provide concise information on the region's overall context. Moreover, to rewrite general introductions to the regional context that were achieved in the above-mentioned occasions was deemed as a time-wasting task.

explosives, which can affect the stability of the engraved outcrops in the area. Another issue is the existing dam system in the Douro river basin which has in recent years made the water level rise in the final section of the Côa, causing great disturbance to the natural flow of the river. The Pocinho dam even submerged some engraved surfaces along the shores of both the Douro and the Côa. The dams, coupled with winters of heavy rain, have also led to some engraved outcrops being temporarily submerged by the rising river level (see Figure 116). Sheep farming can also influence the preservation of the rock art. In summer some shepherds set fire to bush areas, convinced that the vegetation will grow stronger and greener the following year, giving more pasture to the animals. While in the short term this is true, in the medium and long term this practice results in the progressive impoverishment and erosion of soils (Ana Berliner personal communication).

4.3. Regional geomorphological and geological setting[33]

The Côa is a geologically young river (some 2 million years old) and its down-cutting process took advantage of two major regional pre-existent joint families of NE-SW and WNW-ESE orientation (Aubry *et al.* 2012; Ferreira 1978; 1993, 413; Ribeiro 2001) (see Figure 117 and Figure 118). A large portion of the PAVC territory is composed of metamorphic formations (most of them meta-greywaches and schists) belonging to what is known as the Complexo Xisto-Grauváquico (CXG/Schist-Greywachian Complex) resulting from regional metamorphism processes (see Figure 119). The deposition of this geological complex, which occupies a large portion of Portugal, began in pre-Cambrian times, some 540 million years ago. As a result of the variety of original sedimentary environments, this is lithologically very diverse (Ribeiro 2001). Exposure of the rock-art surfaces results from the river down-cutting process. The metamorphic bedrock created ‘ideal’ surfaces for rock art, as the gradual river down-cutting process caused the emergence of smooth vertical panels (Aubry 2009; Aubry *et al.* 2012) (see Figure 120 and Figure 121). Among the tectonic faults in the region the most significant is the Vilariça-Longroiva fault. This feature “is a complex accident, with fractures of kilometric band width (…)[and] judging by the deformation of the relatively recent sediments and contemporary seismic activity

[33] This section includes passages taken from papers indicated, and for the reasons invoked, in footnote 32.

records” (Ribeiro 2001, 6, author’s translation) its activity continues up to the present day (see Figure 118 and Figure 122).

The area of the Park occupied by the CXG is divided into three distinct formations, each with different characteristics: Rio Pinhão, Pinhão and Desejosa (see Figure 119). The majority of the identified rock art sites are located on the Desejosa formation. Just one rock art site has been identified on the Rio Pinhão formation (Ribeira da Volta, possessing only 4 engraved outcrops[34]) and only two, the major sites of Penascosa and Quinta da Barca, have been identified on the Pinhão formation. In addition, other sites are located in hercynian sintectonic granites and quartzite and silica formations from Ordovician times that superimpose on the older metamorphic lithologies (Ribeiro 2001). All considered, these sites account for a quite minute portion of the Valley’s rock-art (a total of 12 engraved and painted outcrops) and, as mentioned in Chapter 1, are not included in the present study. Ribeiro (2001) carried out a general geological characterisation of the Park’s territory. In the Pinhão formation, Ribeiro has identified “phyllites and quartzophyllites chlorites with magnetite and metacalcareous intercalations” (Ribeiro 2001, 13; author’s translation). This goes in line with the finds of one of the stone conservation companies that participated in the pilot conservation tests, working in Penascosa, a site located in the Pinhão formation (Fernandes 2008c). The team, besides confirming Ribeiro analysis, also found the following minerals to be present: quartz, chlorite, muscovite, pyrite, biotite and turmaline (Fernandes *et al.* 2006a). For the Desejosa formation only the Ribeiro characterisation is available. This author found that this lithological unit is mainly composed of ancient argillites that, due to later metamorphic and structural processes, transmuted into the chlorite phyllites and meta-greywaches observable today (Ribeiro, 2001, 14-16). It should be also mentioned that, because of the easily discernable lamination of the different layers that compose it (see Figure 123), the Côa valley schists are quite anisotropic (Rodrigues 1999, 4). This characteristic may have great influence on the condition of engraved outcrops or even of different areas in the same outcrop. These differential conservation issues will become apparent in subsequent Chapters, when the condition assessment of engraved outcrops is discussed and carried out.

[34] This site is not considered in the present PhD project since it was discovered when research was already under way.

4.4. Climate in the Lower Côa Valley region.

To characterize the region’s climate patterns two resources are used: (1) data gathered by the regional network of weather stations belonging to the Instituto de Meteorologia (IM - the Portuguese state weather bureau), compiled in the Iberian Climate Atlas (AEMET and IM 2011), and in the Atlas Climático de Portugal Continental 1971-2000 (Cunha *et al.* 2010), based on a data series taken from 1971 to 2000, and the Portuguese Atlas do Ambiente (APA 2012), based on data series ranging from 1931 to 1960 (depending on the precise weather variable); (2) data gathered by the network of weather stations installed by the Park in four different locations within the Park’s boundaries.

The former provide the basis for a macro and medium-scale analysis of climate in the Lower Côa region while the later allows a micro scale approach for just the Park’s territory.

4.4.1. Macro and medium-scale analysis

The Iberian Climate Atlas, according to the Köppen Climate Classification system, categorizes the area of the Iberian Peninsula where the Park is located as “temperate with dry or hot summer”, known by the abbreviation *Csa* (AEMET and IM 2011, 15-18) (see Figure 124). This type of climate, which spans most of the Peninsula’s territory, with a predominance in its southern half, is characterized by an average temperature of the coldest month situated between 0º and 18ºC and of the hottest month higher than 22ºC.

The network of weather stations that in the region gathered data included in Atlas do Ambiente is composed of four different equipments (Figure 125). On the other hand, the Portuguese part of the Iberian Climate Atlas was based on the Atlas Climático de Portugal Continental (1971-2000) which resorted only to two of those stations, Figueira de Castelo Rodrigo and Pinhão (Cunha *et al.* 2010). As observable in Figure 125 the four stations are located quite far from the Lower Côa region where the Park is located, and more importantly, with the exception of Pinhão, at higher altitudes than most of the PAVC’s territory, especially if considering the low elevation waterways margins where most of the rock-art sites are located. Hence, instead of individually examining the data gathered by each station, an analysis of the summary provided by the Atlas Climático de Portugal Continental 1971-2000 and the

Atlas do Ambiente was preferred. While the former only provides information regarding temperature and precipitation, the later compiles data pertaining these two plus a variety of variables that are of interest to the present PhD (listed below). Additionally, INAG's (Instituto da Água) regional network of weather stations (INAG 2012) will be used regarding precipitation values.

The Iberian Climate Atlas and Atlas Climático de Portugal Continental 1971-2000 resorted to interpolation methods with Geographical Systems Information software to map air temperature and temperature (AEMET and IM 2011, 24 and Cunha et al. 2010). Methods used to map the different weather variables addressed by the Atlas do Ambiente differ and are available in distinct publications. In each subheading below, a footnote will point to the relevant publication. Maps featured in this section were done by the author (except when stated otherwise) using shapefiles supplied by IM (in the case of the 1971 – 2000 data series) and Agência Portuguesa do Ambiente (in the case of the data series ranging from 1931 to 1960) and manipulated employing the ArcView 9.3 software suite.

4.4.1.1. Air temperature[35]

Data collected between 1931 and 1960 presented in the Atlas do Ambiente shows that the PAVC is located in an area with annual average temperatures comprised between 12.5º and 16ºC (Figure 126). It should be mentioned that the northern half of the PAVC's territory closest to the River Douro presents higher values of annual average temperature (between 15º and 16ºC) while the southern half exhibits lower values (between 12.5º and 15ºC).

The more recent data from the Atlas Climático de Portugal Continental shows that average annual temperatures, while slightly cooler (between 12.5 and 15ºC) in almost the totality of the PAVC's area, are higher (between 15º and 17.5ºC) in the low altitude riverbed corridor where most of the rock-art sites are situated[36] (Figure 127). Maps pertaining to average temperature in summer (Figure 128), winter (Figure 129) and average annual lowest temperature (Figure 130) confirm such a suggestion. In the Lower Côa region, average annual lowest temperatures as well as average

---

[35] Atlas do Ambiente publication: INMG (1984a).

[36] This is because the used interpolation methods confer more relevance to low altitude than the methods used in the Atlas do Ambiente 1931-1960 data series, thus better reflecting actual temperature values in the bottom of river valleys.

temperatures in winter are between 7.5º and 10ºC in the bottom of the Côa and Douro river valleys. The annual number of days in the region with temperatures ≥25ºC is shown in Figure 131. Most significantly for the scope of the current project, the annual number of days with temperature ≤0ºC is quite low, ranging, in the area of the park, from between 10 to 20 in its most northern area and 20 to 40 in its most southern zone (Figure 132).

4.4.1.2. Insolation[37]

According to Atlas do Ambiente, based on a data series from 1931 to 1960, almost the entirety of the Park's territory is located in an area receiving 2,700 to 2,800 hours of insolation per year (Figure 133). In Portugal, the regions with higher insolation values reach well over 3000 hours per year. Hence, the Park is located in an area higher than average when considering only Portuguese territory. In turn, Portugal has quite higher insolation values than all other European countries with the exception of a few patches of the Mediterranean shoreline (Azevedo and Marques 1987, 12, 14).

4.4.1.3. Solar radiation[38]

An Atlas do Ambiente slightly longer data series, ranging from 1938 to 1970, is available for Portugal regarding solar radiation. The Park´s territory is located in an area possessing an annual average amount of solar radiation between 145 and 150 Kcal/cm^2 (Figure 134). This is the value that occurs in the majority of the territory of mainland Portugal. This is also an average value considering the highest and lowest amounts calculated for Portugal (lowest solar radiation in the Northern shoreline and highest values in the Southern interior).

4.4.1.4. Precipitation[39]

Data from 1931 to 1960 presents evidence of the region's low rainfall values, as the Park's territory is almost completely included in an area with an average annual total precipitation of 400 to 500 mm. (Figure 135). The same dataset shows that in most of

---

[37] In Portugal, the term insolation is used with reference to the number of hours the sun is uncovered above the horizon, contrary to its current use in the general weather bibliography where it translates in to the solar radiation received by a given surface area over a period of time (Azevedo and Marques 1987, 9).
[38] Atlas do Ambiente publication: GTA (1988).
[39] Atlas do Ambiente publication: INMG (1984b).

the Park's area it rained, on average, between 50 to 75 days per year. In the southern region of the Park, values comprised in the interval are slightly higher: 75 to 100 days per year (Figure 136).

The more recent data from the Atlas Climático de Portugal Continental 1971-2000 does not differ much from Atlas do Ambiente when it comes to average annual total precipitation. In fact, the sole difference is the interval used, which, in this case, is of 400 to 600 mm per year (Figure 137). On the contrary, the figure regarding annual number of days with precipitation is higher in the more recent data pointing to an interval of 95 to 110 days (Figure 138). Rather than assuming that there has been an overall increase of rain days in the area, it is suggested that the different interpolation methods used in mapping yearly days with precipitation (Cunha *et al.* 2010; INMG 1984b) might account for the discrepancy. Partial annual average data pertaining summer (Figure 139) and winter (Figure 140) further confirm the low levels of precipitation in region.

4.4.1.5. Water flow[40]

Average yearly water flow values are low in the Park as shown in Figure 141. However, since in the area of the Park and its close vicinities precipitation is low, water flow in the entire Côa hydrological basin is mostly determined by upstream pluvial regimes. The Côa drains a total surface of 2,520 km2. The Upper Côa area presents higher precipitation values than the Lower Côa region where the Park is located (see Figure 142, Figure 143 and Table 5). Moreover, the predominant rock types in the basin (schist and granites) do not possess high permeability characteristics. Nevertheless, granitic terrains promote faster superficial water flow. Together, these factors contribute for superficial water flow that is highly dependent on precipitation (Alexandre 1995; Jorge 2009).

In the Lower Côa area, flooding episodes happen with moderate frequency. Since the year 2000, when the author began working in the Park, there has been only three winters in which major flooding occurred. One of these instance occurred in the winter of 2002/03 when the river flooded from the beginning of December until the end of January. That occurrence can be observed in Figure 144, which depicts the

[40] Data regarding water flow is also from the Atlas do Ambiente 1931-1960 data series. However, contrary to other variables, no detailed publication is available.

level of the Côa at that location measured by the established hydrometric station. In the beginning of the period mentioned above, water rose to more than 6 m when the average for the measured time interval was of 1.75 m (INAG 2012). These floods affect areas (and engraved outcrops) in most of the rock-art sites located in the Côa banks. For instance, the three sites open to the public need to be closed for the duration of a major flood. The behaviour of occurring floods is quite predictable, at least for the last 25 years. The normal level of the Côa today is not its ‘natural’ level. In 1984, the Pocinho dam was concluded. This dam, since it is located in the Douro River downstream to the mouth of the Côa, led to an increase in the level of the latter by 10 to 12 metres meaning also that some rock-art art sites became submerged (Baptista 1983). Later, during the construction of the now abandoned and unfinished Côa dam, two caissons were built in order to remove water from where the main dam was to be implanted. Even though a tunnel was built to assure the run of water, the structure was not built to allow the flow of the massive quantities of water characteristic of Côa floods. Furthermore, the tunnel has never been cleaned. This means that floods, in the Lower Côa region, always reach the same recurring level; i. e 10 to 12 m higher than the current level of the Côa, which is equivalent to the height of the most upstream still existing caisson (Figure 145).

4.4.1.6. Groundwater flow[41]

As would be expected, considering the precipitation regime, groundwater productivity in the region is low, in fact below 50 m3/day per Km2 (Figure 146). Indeed, low precipitation and permeability characteristics of regional rock types determine that the low water levels, besides the considerable amount that is naturally lost through evapotranspiration (Figure 147) and other but less determinant factors, is mostly drained by the hydrological network as superficial water flow.

4.4.1.7. Relative humidity[42]

Data from Atlas do Ambiente shows that the average relative humidity in the Park’s area is reasonably low, i. e between 65 percent and 75 percent (Figure 148). In fact, the Park is quite near to the zone possessing less than 65 percent of average relative

[41] Atlas do Ambiente publication: Paradela (1984).
[42] Atlas do Ambiente publication: INMG (1985).

humidity (appearing in the map featured in Figure 148 immediately north to the Park's territory), one of the two areas in mainland Portugal with the lowest values regarding this variable. Moreover, in the region, it is reasonable to assume that values drop significantly in the summer (to around 50 percent or less) without increasing in the same proportion in the winter (INMG 1985, 16).

4.4.1.8. Frost[43]

Data from Atlas do Ambiente taken from 1941 until 1960 places the Park quite close to one of the two zones of Portugal where the number of days with frost per year is higher (between 70 and 80). Annual frost averages range from 40 to 50 days in the most northern area of the Park to 60 to 70 days in the most southern zone (Figure 149). Hence, there is a clear decrease in the annual number of days with frost in the Park's territory in the area closest to the Douro River.

4.4.1.9. Wind[44]

In Portugal, wind blows predominantly from the NW (Azevedo 1990, 14-15). Atlas do Ambiente includes only a data series from 1951-1960 referring to readings made on 41 locations at 18:00 UTC (in some cases, at 15:00 or 21:00 UTC). Since the period of observations included in Atlas do Ambiente is relatively minute, data supplied by IM were chosen to give some indication of wind patterns in the region. Hence, the Climate Normal for the Figueira de Castelo Rodrigo (FCR) weather station, the nearest existing IM station to the Park (see Figure 125 and Figure 143), pertaining to the period between 1961-1990 was used. The results somewhat contradict the pattern for mainland Portugal since NE (31,8 percent), followed by SW (28,8 percent) and only then by NW (20,7 percent), are the most predominant wind directions (see Figure 150). Calms correspond only to 3 percent of the measured period. Average wind velocity for the period was 10,7 Km/h (IM 2010a).

4.4.2. Microclimate variables in the Park's territory

Microclimatic monitoring of rock art sites can provide useful data on the connection between climate and occurring weathering phenomena (Hoerle 2006; Viles 2005). In

[43] Atlas do Ambiente publication: Azevedo (1986).
[44] Atlas do Ambiente publication: Azevedo (1990).

accordance with what has been done in rock art sites elsewhere (Hoerle and Salomon 2004), the Park installed, in January 2004, a weather station in the Penascosa rock art site (Fernandes 2005), henceforth referred to as PEN1.

So that climate data could be used as a parameter to distinguish between the condition of different engraved outcrops, it would be needed, ideally, to install specifically equipped weather stations at or near all of them. For instance, it is relevant to continuously measure rock surface temperature, which is not recorded by PEN1, so to have data on the thermal seasonal variations occurring. However, to install this equipment would be financially impossible. Hence, the preferred option was to install three stations in North- (Vale de José Esteves station, henceforth VJE), East- (Canada do Inferno station, henceforth CINF) and South- (Penascosa 2 station, henceforth PEN2) facing slopes in order to try to characterize microclimatic variation that might be induced by aspect (Figure 151). One of the goals of installing these stations in this fashion is, as discussed in the subsequent Chapter, to determine the role of aspect in microclimatic variations between different locations within the same area, namely within the same slope.

4.4.2.1. Data from PEN1

PEN1 is located in the Penascosa rock-art site above the seasonal flooding area, 10 m higher than the closest engraved outcrop (see Figure 151 and Figure 152)[45]. PEN1 measures air temperature, relative humidity, and rainfall values, recording data at intervals of 15 minutes from its launch until September 2006 and of 30 minutes from then on. PEN1 has been in operation from the 13th of January 2004 until April 2009[46]. Regrettably, although maintenance work has been carried out, the station has ever since not been able to gather data in a systematic fashion[47]. Hence, the following data covers 5 years of operation: 2004, 2005, 2006, 2007 and 2008. Data from subsequent

[45] The precise location of PEN1, a WatchDog Model 700, complying to the norms established by the World Meteorological Organization for this kind of equipment (WMO 1996), is: N 41º 00’ 19.9”/W 07º 06’ 17.2” WGS84, at an altitude of 130 meters. Its acquisition was entirely supported by Instituto Português de Arqueologia, the Portuguese state institution under whose authority the Park operated at the time.

[46] With the exception of 18 to 30 of August 2004, 12 of July to 26 of September 2006 and 30 of October to 22 of December 2008, periods during which the station suffered several malfunctions and did not record air temperature data. In the period from 30 of October to 22 of December 2008 it did not also record precipitation and air humidity data.

[47] It may record for two months in a row and then stop for another 2 or 3 months. Due to various reasons it has not been possible to replace it, even when the new stations where acquired.

years were not used due to incomplete recording.

4.4.2.1.1. Air temperature

Table 6, Table 7, Table 8 and Table 9 summarize data gathered by PEN1 regarding average temperatures, which generally confirm the values of both the Atlas do Ambiente and Atlas Climático de Portugal data series (see Figures above). There is only a slight discrepancy regarding values (in either annual averages and total average for the period) in the bottom of the valley (where PEN1 is located), which tend to be marginally lower than the 15º to 17.5º interval suggested by Atlas Climático de Portugal. The older dataset presented by Atlas do Ambiente for the location of PEN1 concurs with the values gathered by the weather station. It is noteworthy to mention that 2006 average values are significantly lower than average due to the station's malfunction during the summer. Likewise, 2008 average values are significantly higher than average due to the station's malfunction in November and December. All considered, it is suggested that the total average (14.77º) for the comprised period constitutes a fairly accurate figure since the two malfunctioning periods (one during the hottest period of the year, the other during the coldest) tend to annul each other, thus averaging the final value.

Other values show more significant discrepancies between the more recent dataset of Atlas Climático de Portugal and the data gathered by PEN1. Average lowest temperatures, for instance, are considerably lower than the intervals suggested by the said publication. Thus, the recorded number of days with temperatures ≤0º C is (from 2004 to 2007) higher than the limits calculated from the Atlas de Climático de Portugal 1971 – 2000 data series. Conversely, Atlas do Ambiente older data series regarding frost (which requires a temperature ≤0º C to form) as shown in Figure 149 does more adequately compares with the data gathered by PEN1 since the average number of days from 2004 to 2007 (50) neatly falls in the interval characterized for the region in the said publication. On the contrary, data gathered by PEN1 shows the number of days with temperature ≥25º C is noticeably higher than the values presented by Atlas Climático de Portugal. The subsequent analysis of data collected by PEN2, VJE and CINF will help to clarify if the above discrepancies only relate to the case of PEN1 and its precise location or, on the contrary, are also present in the other stations.

Annual (and even monthly) temperature variation is quite outstanding, reflecting the wide range of temperature values in each period of the year, exceeding, in some years, more than 50º. As curious as these values might be, arguably, the most significant variable for the scope of this PhD is Diurnal Temperature Variation (DTV) because of its influence on weathering inducing mechanisms such as the expansion and retraction cycles of rock (Bland and Rolls 1998, 68). Table 9 presents absolute values for the coldest and hottest day of each year. Additionally, to provide some sort of validation and comparative parameter, values for the hottest and coldest days in April and October of each year were also calculated. These months have been chosen since they possess the closest monthly average temperature to the total yearly average value (see Table 8). It would have been a mammoth and greatly time-consuming task, even with the help of a spreadsheet, to calculate all daily thermal amplitudes for the period in question. Hence, the values presented in Table 9 are not intended to substitute in any way a full characterization of the complete absolute daily thermal amplitude regime measured by PEN1 in the period in question. Instead, these values are supplied as a general indication of what such a regime would be since, as it is suggested by data shown in Table 9, DTV may significantly fluctuate from day to day as there are quite a few interconnected variables (such as wind or cloud cover) that determine its range (Dai *et al.* 1999). Moreover, for the scope of research reported here, it is more relevant to evaluate thermal fluctuations in air and rock temperature at an hourly (or even a lesser timescale) basis. That task will be carried out in subsequent Chapters, when microclimate variables will be assessed as parameters to characterize the condition of the Côa Valley rock-art outcrops.

4.4.2.1.2. Precipitation

Table 10, Table 11 and Table 12 present the data gathered regarding precipitation in the period 2004-08. It generally confirms the general data discussed from both the Atlas do Ambiente and Atlas Climático de Portugal for the region (see Figures above) albeit a lower average precipitation value. Total annual precipitation values are also lower than those established by both publications and only in 2006 precipitation surpassed 400 mm. Seasonal precipitation data further confirmed this trend since Summer (June, July and August) and Winter (December, January and February), average values are lower than those derived from the data series present in Atlas Climático de Portugal (see Figure 139 and Figure 140), the sole publication, of the two used, that supplies information divided by periods of the year. Regarding average number of rain days, data gathered falls precisely in the middle of the slightly disagreeing intervals described for the area of the Park in both publications.

Because of implications in flash flooding and general weathering dynamics, extreme precipitation events are an issue to consider. The definition of what can be an "extreme precipitation event" is context dependent and involves four key factors: "intensity of precipitation, duration of precipitation, the wetness of the ground and the response of the rainfall catchment" (Hand *et al.* 2004, 16). Considering only the first two, Table 12 presents total and hourly precipitation values recorded by PEN1 in the 5 days in the period 2004/2008 with higher precipitation. Data available for mainland Portugal, sets maximum historical hourly and daily precipitation for the area of the Park at 52-59 mm. and 86-112 mm., respectively (Brandão *et al.* 2001, 16-7). For a 1:100-year return period, values are similar although the daily values interval is slightly higher (Brandão *et al.* 2001, 16-7). Probable maximum precipitation values for the area of the Park were determined to be between 143-175 mm. for one hour and 297-388 mm. for a twenty-four hour period (Brandão *et al.* 2001, 16-7). Analysis of Table 12 suggests that PEN1 did not record any extreme precipitation event. It must be stressed, however, that if these were indeed the 5 wettest days, it cannot be claimed that the rainiest one-hour period did really occur in one of these days[48]. Nevertheless, hourly precipitation figures for these 5 days suggest that, if indeed the wettest hour in the recorded period did not take place in one of those days, values reached in that hypothetical hour would have not been significant. It also should be noted that presenting a shorter time lapse (30 min., for instance) in Table 12 could also have been considered. However, since the maximum historical record for the area of the Park in a 30 min. period is 31-36 mm. (Brandão *et al.* 2001, 16-7), and values presented in Table 12 in double that period are less than half of the mentioned values, such a task was considered not to be worthwhile as it would not produce relevant results.

4.4.2.1.3. Relative humidity

Data presented in Table 13 is not comparable with data from Atlas do Ambiente

[48] The sheer volume of data to treat statistically would have made the determination of the most wet hour in the entire recorded period, again, a mammoth task, even resorting to spreadsheets.

shown in Figure 148, as the later corresponds to the average relative humidity measured daily at 09:00 (GMT) from 1931 to 1960 and the former to monthly average relative humidity. Nevertheless, it should be pointed out that the low average value for the period measured by PEN1 (63 percent) is not at all surprising considering the also low value arising from the analysis of the data series contained in Atlas do Ambiente. Regarding the malfunctioning period of the station, it should be noted that the missing days (the entire month of November and part of December 2008) would not considerably change, if at all besides decimal values, the average total values for the period in question.

4.4.2.2. Data from CINF, PEN2 AND VJE[49]

PEN2, VJE and CINF were launched in March 2010 and measure the same weather variables as PEN1 plus wind direction, speed and gust intensity, solar radiation, and surface moisture (by means of a Leaf Wetness Sensor). One sensor to measure rock surface was also installed per station[50]. Measuring intervals for all variables were set at 15 minutes. Although a wider period of recording is available, the following section presents data regarding the only full year available, 2011. This option was preferred for consistency reasons when comparing with the data made available by PEN1.

Before presenting the gathered data it must be mentioned that, unfortunately, some caveats prevented the 'perfect' positioning of one of the stations, specifically the North-facing one. On the one hand, the stations needed to be installed in properties owned by the Park since no funds were available to buy or rent land for that purpose. On the other, having the stations installed in the rock-art sites owned by the Park, open for public visits and guarded by security personnel, would make it easier to prevent vandalism or even theft of the stations. In the case of the South-

[49] The precise location of the weather stations, three WatchDog Model 2000, complying to the norms established by the World Meteorological Organization for this kind of equipment (WMO 1996) (with the exception of wind speed measurement which is carried out at a height of 1,5 m above the ground instead of the recommended 10 m) is: VJE – N 41º 04' 51"/W 07º 06' 35,5", at an altitude of 300 meters; CINF – N 41º 03' 18"/W 07º 06' 47", at an altitude of 150 meters and PEN2 – N 41º 00' 16"/W 07º 06' 12", at an altitude of 170 meters, all WGS84 (see Figure 151, Figure 152, Figure 153 and Figure 154). Their acquisition was entirely supported by Instituto de Gestão do Património Arquitectónico e Arqueológico, the Portuguese state institution under whose authority the Park operated at the time.

[50] Leaf wetness and rock surface temperature data is displayed and analysed in Chapter 6 when micro-climate variables are used to try to establish, considering the creation of the intervention urgency scale, a relationship between different aspects and weathering rates.

(PEN2) and East- (CINF) facing stations it was unproblematic to find, not only such prerequisites but also low altitude locations, a trait common to the huge majority of rock-art outcrops in the Côa. On the contrary, the choice of site for the North-facing equipment was thornier since no entire slope with that orientation possessing rock-art is located in a property owned by the Park. Hence, the option was to install the North facing station (VJE) near to the new Côa Museum (Fernandes 2010a), in terrains owned by the Park. Regrettably, this location results in having the station installed at a somewhat elevated altitude (in the context of the Côa rock-art) and not at the point (the shaded foot of a North-facing slope) where it would be expectable to gather more 'extreme' climate data.

4.4.2.2.1. Air temperature

Table 14, Table 15 and Table 16 display average temperature values recorded by the three stations during 2011 as well as the number of days in the year with temperature ≤0º C and ≥25º C. Generally, recorded average temperature figures are similar to the values provided by PEN1, albeit these present slightly higher values for highest and year temperature averages, nevertheless in tune with the figures, for the bottom of the valley, of Atlas Climático de Portugal. VJE, standing at a higher elevation than the other three stations, is the exception, presenting lower highest average and average values as well as a higher lowest temperature average value. It should be mentioned that the previous highest temperature record (44.4º C) was surpassed by the value of 45.3º C measured by PEN2 on the 26th of June. For comparison purposes, it is noteworthy to point out that the highest temperature ever recorded in Portugal was of 47.4º C, in Amareleja (South of Portugal) on the 1st of August 2003 (AEMET and IM 2011, 38). Regarding the number of days in the year with temperature ≤0º C, CINF, PEN2 and VJE present lower values than PEN1, although similar to the Atlas Climático de Portugal data series. The number of days in the year with temperature ≥ 25º C recorded by CINF and PEN2 is considerably higher than PEN1 and Atlas do Ambiente values. VJE presents lower values than the other stations (similar to PEN1 values), which, in any case, are significantly higher than those present in Atlas do Ambiente.

DTV values were determined in the same fashion as it was done for PEN1. Values presented in Table 17 generally coincide with the figures for PEN1.

Nevertheless, VJE figures are systematically lower than those recorded by the remaining two stations. For comparison purposes, the data supplied by IM weather stations was browsed regarding measured DTVs in the region. Data are only available for a period covering the past 6 months. Hence, at the time of writing, only data pertaining to October 2011 was available. Stations used were the closest to the Park (Figueira de Castelo Rodrigo - FCR) and the one located at a similar altitude (PINHÃO – PIN). DTV values present in Table 17 for CINF and PEN2 regarding October 2011 are systematically higher by an excess of 2º C than those recorded for the same days in both FCR and PIN. Regarding VJE, the case is somewhat different as DTVs recorded by this station are, according to the precise days and stations, higher, lower or similar than those measured by FCR and PIN. Hence, while measured DTV is lower in VJE on the 5th and 30th when compared with PIN values, it is similar on the 30th and higher on the 5th when compared with FCR (IM 2012). It is suggested that such a divergence, as overall lower DTV values, might be explainable by the same reason VJE presents different average values than the other stations, i. e a higher altitude location.

4.4.2.2.2. Precipitation

Annual precipitation values recorded by the new stations are similar, albeit slightly lower, to the ones measured by PEN1 and well below the 400 mm. per year threshold (Table 18). It should be noted that summer values recorded by all three stations are quite low. Another interesting fact is the reasonably higher precipitation value measured by VJE, the North-facing station. The annual number of rain days is also similar to what was determined by PEN1, in spite of a slightly higher figure when compared to the PEN1 average value (Table 19).

Table 20, Table 21 and Table 22 present values regarding days with the highest amount of precipitation. The quite low values, when compared with PEN1, stand out. In fact, the highest value measured (23,3 mm.) by the three stations is less than half of the highest values recorded by PEN1. Nevertheless, it has to be mentioned that a comparison between absolute values contained in Table 12 and in Table 20, Table 21 and Table 22 is somewhat unbalanced since data regarding PEN1 pertains to five years while value pertaining to the new stations present a one-year dataset. However, a more detailed analysis of Table 12 reveals that values regarding days with the highest amount of precipitation only refer to three years of the measured five being that figures from 2005 and 2006 appear twice. Hence, it is suggested that such a comparison can be made. Lastly, it should be stressed that VJE presents the highest precipitation values. Moreover, VJE also presents a striking disparity with the other stations regarding the precise days in which the highest values were recorded. This seems to suggest that on the microregional scale of such a relatively minute area such as the Park there is clear dissimilarity in climate patterns.

4.4.2.2.3. Relative humidity

Relative humidity values measured by CINF, PEN2 and VJE (Table 23) are similar to those recorded by PEN1, notably for the five-year average presented in Table 13. Again, while CINF and PEN2 present quite identical values, VJE recorded lower values.

4.4.2.2.4. Wind

Since PEN1 does not measure wind velocity and direction, the only possible comparison of CINF, PEN2 and VJE data is with what was established above resorting to the Climate Normal for Figueira de Castelo Rodrigo. The most striking conclusion is that average wind velocity recorded by the Park's station is quite lower than the values measured by FCR in the period 1961-1990[51] (Table 24). In fact, VJE (the Park station at the highest value) recorded a value that is less than a third of the average velocity recorded by FCR. These discrepancies are probably connected with the more elevated position of this equipment regarding the other two stations. In fact, if a correlation is made between altitude of stations and recorded values, it is possible to conclude that CINF (the station located at a lowest altitude, 150 m) presents also the lowest value for wind speed, PEN2 (the following station in terms of altitude, 170 m), the second lowest value and VJE (300 m), the highest value. Moreover, CINF presents the highest percentage of calms again followed by PEN2 and only then by VJE. Nevertheless, it is admitted that other factors related to the precise location of

---

[51] As noted above, the Park's stations measure wind velocity at a height above ground of 1,5 m. This is not what it happens in FCR station, which, as recommended by WMO, measures that variable at a height above ground of 10 m. Hence, a conversion factor was applied to what was recorded by FCR station, which converts values recorded at a height of 10 m to the correspondent value at a height of 2 m (FAO 1998). The conversion formula is as follows: Wind Speed at 2m = Wind Speed at 10m x 0,75. The conversion result for FCR recorded value is thus 10,7 Km/H x 0,75 = 8,025 Km/H. For comparison purposes, it is suggested that the 0,5 m difference between what is assumed by the conversion factor and the actual height of the Park's stations is negligible.

the stations play a part in these discrepancies such as slope steepness, topographical shaping or ‘confluence’ of smaller ‘tributary’ valleys. As wind gust values are not available for FCR, it is not possible to carry out any form of comparison regarding this variable. However, it can be noted that values measured by the Park’s stations are low. Wind direction data are quite disparate to what is presented in Figure 150. Moreover, each station presents dissimilar values (Figure 155, Figure 156 and Figure 157) although PEN2 and VJE data suggests that in the locations of these stations wind predominantly blows from the Southern quadrant.

The quite short measured interval of just one year (2011) might account for these discrepancies and somewhat prevents a comparison between FCR data (relating to an average of three decades) and records from the Park’s stations. If this is indeed true when considering wind direction, a variable more prone to greater standardization when considering larger periods of time, it is also true that when taking into account velocity it can be noted that average values for 2011 measured by the Park’s stations are considerably lower than the average value recorded by FCR during the above-mentioned 30-year period.

4.4.2.2.5. Solar radiation

A comparison with Atlas do Ambiente reveals that the values recorded by the Park’s station generally correspond to the 145-150 Kcal/cm2 per year interval proposed for this area of Portugal[52]. Notably, CINF and PEN2 present slightly lower values while VJE exhibits a marginally higher value. These results are somewhat puzzling since VJE is the station located at the North-facing slope, an orientation that in the Northern Hemisphere receives less amount of sun sunshine that the other three major orientations (see Figure 30 and discussion in subsequent Chapter). Again, the precise location of the stations may account for these results. Although located on a slope, VJE is positioned relatively near to its summit. On the other hand, CINF and PEN2 are located almost at the foot of steep hillsides (see Figure 158). Thus these stations will receive less amount of sunshine due to the steepness of the slope. Moreover, CINF is located in a steeper slope than PEN2.

[52] The Park’s stations measure solar radiation in w/m2. For a better comparison with Atlas do Ambiente data, the recorded values were converted to Kcal/cm2 according to the conversion formulas that can be found in Campbell Scientific Pyranometer Manual (CS 1998, 8).

4.5. Overall conclusions

Data gathered by the four stations installed in the Park generally confirms the already accomplished portrait for the region in terms of climate patterns. It is a dry and hot area with precipitation regimes and temperature values similar to the south of the Peninsula. It should be noted that although the data series resulting from both sets of station recordings correspond to a limited period of time (five years in the case of PEN1 and just one year in the case of CINF, PEN2 and VJE), results are quite consistent with data series furnished by Atlas Climático de Portugal and Atlas do Ambiente. If a general trend can be discerned it has to do with decreasing precipitation and higher temperature values (both on number of days with temperature higher than a certain value and average values) in the measured period and also when comparing with the above mentioned data series. Figure 159, Figure 160, Figure 161, Figure 162 Figure 163, Figure 164, Figure 165, Figure 166, Figure 167 and Figure 168 present comparative graphics of values recorded by all the Park's stations regarding temperature, precipitation and relative humidity.

4.5.1. Air temperature

Data gathered by the four weather stations operating (or that operated) in the Park regarding monthly temperature are shown in Figure 159. Monthly average temperature values for 2011 have been consistently higher (by an excess of 1º C), during the hotter months of the year, in CINF, the station installed in the East-facing slope of Canada do Inferno. The South facing station, PEN2, presents the second highest, during summer months, monthly average temperature values. Moreover, when comparing CINF and PEN2 values with monthly average temperature recorded by the West-facing PEN1 in the period 2004/08, summer temperatures present a similar curve in spite of the fact that the new stations recorded slightly higher values than PEN1. Indeed, this signifies that 2011 was a hotter year than average for the region as recorded by PEN1 in the period 2004/08. A comparison of spring values further confirms this assumption. Figure 161 and Figure 162 summarise data regarding days with temperature ≥25º C and ≤0º C recorded by all four stations. Values for days with temperature ≤ 0º C are higher for PEN2 and CINF. Quite surprisingly, considering the North facing aspect of the slope where it stands, VJE presents the lowest figure. Nevertheless, values for all new stations are reasonably homogenous and approximately represent half of the 2004/07 average value for PEN1. Values for days with temperature ≥ 25º C are again higher for PEN2 and CINF with VJE presenting the lowest value which is also the closest to the average recorded by PEN1 in the period 2004/08. DTV values for the days with the highest temperature and lowest temperature, and days with the highest and lowest temperature recorded in the months of April and October for all the stations are plotted in Figure 160. It is noteworthy to mention VJE recorded the lowest values in all considered days whereas PEN1 scored the highest. DTVs values presented in Table 9 and Table 17 generally follow what would be expected in the geographic context of the Côa Valley. In fact, inland dry areas are more prone to experience higher DTVs in the order of 30º C plus than coastal humid zones that typically experience amplitudes of half that value or even less (Ahrens 2007, 63).

4.5.2. Precipitation and relative humidity

Total precipitation values gathered by new stations (CINF, PEN2 and VJE) show that VJE reached the highest value, which is also the closest to the average recorded by PEN1 for the 2004/08 period (see Figure 164). Average monthly precipitation in 2011 and for the 2004/08 period for PEN1 is shown in Figure 163. Rain days values (equal in CINF, PEN2 and VJE) recorded by the new stations stand as slightly higher than the average value measured by PEN1 in the 2004/08 period (Figure 165). On the other hand, daily and hourly highest recorded precipitation values are again fairly similar in all three new stations and indeed PEN1, considering only hourly values (Figure 166). As for daily records, PEN1 recorded a quite higher value than the other stations. Such a discrepancy is expectable since PEN1 data series comprises a longer period of time thus increasing the probability of recording more extreme values. Moreover, the highest recorded daily value in the above-mentioned 4 regional weather stations (Figure 125) for the period of 1961-90 was of 124,8 mm. in Moimenta da Beira (IM 2010b), well bellow the probable maximum daily precipitation values set for the region of 297-388 mm. (Brandão *et al.* 2001, 16-7). Brandão *et al.* (2001) note that national pluviometric highest values are quite below international ones and that the areas where extreme events are more likely to happen do not coincide with the Park's location. As for relative humidity values, average monthly relative humidity values in 2011 and for the 2004/08 period in PEN1 are shown in Figure 167. Total figures are quite homogenous in both the new stations and PEN1 (Figure 168).

4.6. Final considerations on climate change

The final considerations of the Chapter should address the issue of climate change and how foreseen alterations in weather patterns can impact the Côa Valley rock-art. In spite of the fact that it is quite long, the following passage adequately portrays the difficulties in understanding how climate change might affect heritage values, even when climate data is available:

> "An important issue is the difficulty of linking global-scale changes in climate to the deterioration of individual walls, buildings or structures. One aspect of this is the problems involved in meaningful downscaling of global climatic predictions to smaller regions. A second aspect is the difficulty of relating regional climatic data to the microclimates which control most weathering processes. (…) For example, despite given rainfall amounts recorded for a city at the local meteorological station, the four walls of a building in a city centre street canyon may receive highly variable and contrasting amounts of rainfall. Similarly, average air temperature values from a meteorological station will not reflect the diversity of temperatures experienced on stone surfaces within the complex geometry of buildings, but it is these temperatures which are crucial to the deterioration processes occurring on those surfaces. Some progress has been made in understanding the relationships between regional climate and the microclimates of buildings, but this needs to be consolidated upon if useful predictions are to be made." (Viles 2002, 413)

As Viles notes, it is difficult to derive micro-scale predictions from global forecasts. Hence, data supplied by the Park's stations is helpful in modelling what can be expectable climate change trends will signify for the region and the rock-art. At the same time, it is acknowledged that stone surfaces may experience a variety of temperatures throughout the day, month or year according to their specific location. It was for that reason that, in the scope of research reported here, several temperature sensors were installed in different non-engraved outcrops facing different orientations. Gathered data and implications for the creation of the intervention urgency scale are be analysed in detail in subsequent Chapters.

The necessarily speculative but plausible exercise regarding the different ways climate change may affect build stone conservation undertaken by Viles (2002) may be of further use in understanding how it may affect the Côa Valley open-air rock-art. According to Viles, there will be deterioration processes hastening in pace while others will slow down. However, Viles also points that the outcome of these often-competing impacts will be difficult to individualize or measure. Moreover, there is a general lack of knowledge on how climate precisely influences deterioration processes preventing therefore the production of accurate predictions (2002, 410). Regarding physical weathering processes, Viles proposes that global warming will signify a decrease in the impact of freeze-thaw induced weathering in several areas of the planet, namely in those located outside cold regions. Likewise, expected “reduced diurnal temperature range” (2002, 410) will imply a decrease in scale and incidence of stress provoked by thermoclasty. However, variability in pluviometric regimes may inversely affect thermal expansion as well as two other major physical weathering processes, crystallization and hydration. As for chemical weathering processes it is likely that higher temperature and precipitation will hasten the role these play in stone deterioration. However, regions that undergo a decrease in rainfall may not suffer such a hastening (Viles 2002, 411), eventually experiencing some degree of deceleration of these processes. The impacts of climate change on biological weathering dynamics remain unclear; Viles hypothesises that

> “as rainfall increases, biological growth will also increase, but the growth will be more benign and less damaging (in wetter areas) than in drier environments where endolithic growth forms are common”. (Nonetheless) “further work needs to be done to establish whether changing climates will alter the balance in any one area between biophysical and biochemical attack and bioprotection.” (2002, 411)

Lastly, increase in salt weathering in coastal areas, changes in the making and deepness of groundwater plus social behaviour alterations are proposed to be among the most significant indirect impacts of climate change on build stone weathering (Viles 2002, 411-2). Although the study specifically addresses impacts on building stone conservation, it is suggested that the propositions put forward by Viles can be applied to open-air rock-art conservation since the mentioned weathering mechanisms are also quite active in ‘natural’ *in situ* stone decay.

Hence, it is reasonable to suppose from Viles analysis that the most threatening aspect of climate change, when considering the present region of study, is the unpredictability of future precipitation regimes. Kincey *et al.* point out that river basins are among one of the many natural systems that are affected by climate change (2008). As several open-air rock-art sites throughout the world (notably the Côa) are located in river valleys and quite near to or even on floodplains, it is of paramount importance to understand the impact of climate change on fluvial systems. Generally speaking, an increase in rainfall and specially in the intensity of heavy precipitation events (flash flooding), is one of the expected major effects of climate change (IPCC

2007). These episodes are already originating more river flooding incidents which in turn will further enhance soil erosion (Kincey *et al.* 2008, 116) but also soil re-deposition dynamics[53]. Besides the further instability flooding will provoke in the slopes with rock-art, an increase in the frequency stone massifs experience in water induced expansion and retraction cycles will also contribute to considerably lessen the sturdiness of rock-art panels and outcrops (Bland and Rolls 1998, 101). As analysed above, the Lower Côa region is quite prone to the occurrence of flash floods that often imply the submersion of a significant number of rock-art outcrops for considerable periods of time and, what's worse, the recurrence of several wetting and drying cycles during the seasons when flooding takes place, that is fall and winter.

In spite of the recognized influence climate patterns and extreme climate change-related incidents will have in the conservation of the Côa Valley open-air rock-art, it must be stressed that during the last 25 millennia the existing inscribed outcrops have endured and survived many extreme climatic events. It is of course impossible to identify how many (if any) have been lost because of extreme weather episodes. The number of rock-art outcrops known today (about 1000) and the fact that there are many more outcrops equally suited to be engraved (at least 'technically' if not culturally[54]) but with no inscriptions still standing today, suggests that losses might have been relatively low. In fact, it has been proposed that it was the benign dry and warm weather conditions (coupled with low human interference resulting from the chronic economic underdevelopment of the region) that allowed the survival of the Côa Valley rock-art until the present day (Zilhão 1998). Nevertheless, evidence of incomplete motifs due to fracture of the host rock (see Figure 169) is relatively common and constitutes a clear indication of the relentless nature of weathering processes. Thus, it is necessary to persist in monitoring climate and climate change-related episodes in the area as a way of continuing to inform conservation strategies and decision-making procedures.

---

[53] See footnote 18.
[54] See footnote 5 and discussion in subsequent Chapters.

BLANK PAGE

Chapter 5: Evaluation of parameters to assess and monitor the condition of the Côa Valley rock-art outcrops

5.1. Introduction

In order to create the conservation intervention urgency scale it is necessary to establish parameters to assess the condition of the Côa Valley rock-art outcrops. To this end, it is essential to carefully choose (by analyzing their applicability) the evaluation parameters that most comprehensively assure a correct assessment of the condition of the outcrops. However, the sheer number of variables present in the various natural processes that are likely to affect the condition of the Côa Valley rock-art outcrops (or, for that matter, in any natural or built feature of the landscape) is quite sizeable. Some are quite straightforward to assess, while others probably require ingenious or novel methods to evaluate the effects of their action. This Chapter attempts to systematize a comprehensive list of parameters, reviewing, with the help of available bibliography, how to measure their impact. The creation of the intervention urgency scale requires development of a hierarchic list that ranks the condition of the analyzed outcrops. After carrying out the examination of the outcrops, each is given a different score, the sum of all of the parameters identified. Hence, this Chapter identifies and reviews condition evaluation parameters of the Côa Valley rock-art outcrops. The following Chapter discusses how relevant and usable identified parameters can be used in the condition assessment of the Côa Valley rock-art outcrops while the closing Chapter groups data supplied by each identified parameter in the intervention urgency scale.

5.2. Rock characteristics

The petrologic characteristics of different types of rock significantly determine how and at which rates weathering unfolds (Bland and Rolls 1998, 51-2). Hence, it is relevant to consider the role of the following set of rock characteristics in the ranking scale since dissimilar characteristics have an influence on weathering processes. Towards that end rock samples from the two schist formations that in the area of the

Park comprise rock-art outcrops have been collected[55]. Collection points and other relevant data on the samples are given in Annex B - Rock samples from the Côa.

5.2.1. Mineralogical characteristics

As indicated by Walderhaug and Walderhaug (1998) (see Figure 170), there are important variations in the dissolution rates of different minerals. In the course of the present PhD project, samples from schist outcrops in the Côa have been collected. The objective was to establish if there are disparities in the mineralogical composition of the different schist formations that comprise rock-art outcrops. Results from thin section analysis under the microscope and use of mineral composition as a parameter to distinguish between different outcrops are discussed in the following Chapter.

5.2.2. Chemical characteristics

With the similar aim of discerning between different outcrops, as described in the last subsection, a chemical characterization of the collected samples was also completed.
Towards that aim a Scanning Electron Microscope (SEM) model JEOL JSM – 5300 was used. Results of SEM analysis are presented in Annex C and discussed in the following Chapter.

5.2.3. Porosity properties

Porosity is one of the most important properties of rock when weathering is concerned. Indeed, high porosity increases the likelihood of higher water content inside the rock, enhancing the detrimental effects of water percolation such as mechanical pressure or frost-based weathering. Moreover, it has been noted that the range of porosities within a single rock formation may significantly differ (Bland and Rolls 1998, 41-6; Molina Ballesteros *et al.* 2010).

Meiklejohn *et al.* performed rock porosity analysis when addressing the connection between weather variables and weathering of painted rock-art and its sandstone support in two sites in South Africa (2009, 975-6). Their results suggest

[55] Directly collecting samples from outcrops and panels containing rock-art (even if not from the precise areas of panels containing engravings or paintings) is a very delicate matter, as it can be ethically questionable to do so (Bednarik 1990). In fact, the total art object, that is the whole rock-art outcrop, is the sum of engraved motifs and its rocky support (Fernandes 2008a). Therefore, samples coming from rock-art sites have been collected in un-engraved outcrops, located reasonably near engraved ones.

that the most weathered rock samples analyzed have a smaller range of pore sizes. These samples also presented pores with greater diameters. It was put forward, contrary to what had been proposed before, that the particular investigated sandstone formation is not particularly porous and permeable. However, as acknowledged,

> “the structure of the rock samples is such that the pores affected by humidity changes are close to the rock surface, where rapid changes are possible. This outer zone is the area in contact with the outside atmosphere and where pore sizes are assumed to be the largest and most conducive to moisture absorption and movement, and also where San art is painted.” (Meiklejohn *et al.* 2009, 977)

Hence, porosity properties of the two distinct geological formations that comprise rock-art outcrops have been measured. Its use as an aid in the condition characterization and in setting up the urgency scale will be discussed in the following Chapter.

5.2.4. Rock Strength

Every rock has different strength characteristics, according to the specific nature and circumstances. Among the factors that determine rock mass strength, the first to consider is intact strength, the ‘natural’ strength of the rock without taking into account the effects of fractures and joints. This can be measured using a Schmidt hammer (Summerfield 1991, 165-6). Schist, for instance, is considered a weak rock when referring to its intact strength classification, the second lowest ranking in a total of five categories (Summerfield 1991, 165). On the other hand, rock mass strength can be estimated by taking into consideration weathering, joint spacing, width, continuity, infill, and orientation and ground water flow. This can be done by weighting each variable “in proportion to its estimated importance and its value can be assessed for each variable for any particular rock type” (Summerfield 1991, 166) (see Figure 171). Since Ribeiro (2001), in her geological characterization of the Park’s territory, notes the remarkable resistance of the existing schists it will be relevant to measure their intact strength and also their rock mass strength to ascertain if indeed they are as weak as the general characterization provided by Summerfield (1991) implies. The following Chapter comprises an assessment of each sample outcrop regarding intact and rock mass strength.

5.3. Weathering processes

Graniczny defines weathering as “the decomposition and disintegration of rocks and minerals (…) (involving) little or no movement” (2006, 172). Hence, the following section attempts to identify the parameters arising from this set of processes and to what extent these impact the open-air rock-art outcrops in the Côa Valley.

Physical weathering processes[56]

In 1999, José Delgado Rodrigues, a Portuguese geologist with a vast curriculum in building stone conservation, and belonging to the State’s National Civil Engineering Laboratory (LNEC), was commissioned a report by the Park on the conservation of the Côa Valley rock-art (Rodrigues 1999). After a brief summary regarding the geomorphological processes active in the region, which, on one hand originated the emergence of the (afterwards engraved) outcrops and, on the other, will determine their disappearance in the long run of geological time, he presents a brief overlook of the particular state of conservation of some chosen outcrops and of the motifs they host. Rodrigues emphasizes that information on the very specific topic of open-air rock-art conservation located in schist outcrops (and also on specifically active weathering dynamics) is quite scarce (Rodrigues 1999, 4). He points out that, although his observations were made in only three of the sites, the characterization of weathering phenomena occurring is valid for all the area possessing rock-art, due to “the similarity in lithology, geomorphology and climate” of the existing schist outcrops and their location (Rodrigues 1999, 4). He also notes:

> “The physical alteration of the massifs seems predominant, as abundant vestiges of exfoliation of the surfaces, detachment of fragments, opening of diaclases and fall of blocks are easily discernible.” (Rodrigues, 1999, 5)

He concludes by stating that these phenomena are not in a dormant phase of evolution. The risk is in some situations so pronounced that new damage can occur at

[56] The following list, originally written in Portuguese, presents mechanisms that may be understood as the end result of both weathering and erosion processes. Mechanisms as Toppling or Collapse can be regarded as such cases since there is initial weathering of areas in the rock mass which are more prone to be later displaced by erosion due to weathering induced weakness (Johnson 1980; Pritchard and Savigny 1990). To avoid further complexity and confusion, and since all the mechanisms in the list below constitute or, in some cases, are activated by weathering processes, throughout the text these will be grouped and referred to as ‘Physical Weathering Processes’.

any moment. Therefore, he asserts, interventions to reinforce the more threatened areas must be undertaken (Rodrigues 1999, 6).

Rodrigues produced a list describing the most relevant active Physical weathering processes with the intent of helping the Park categorizing the identified mechanisms when carrying out condition documentation of the engraved outcrops. At the same time, the description of these active weathering processes was also aimed in guiding conservation interventions deemed necessary to be undertaken in the near future. The characterization made by Rodrigues proved very useful when carrying out condition documentation, one of the priorities of the Conservation Program the author has been developing in the Park since 2000 (Fernandes 2007, 83-4; Fernandes *et al.* 2006b). Furthermore, it proved again helpful when it was decided to undertake pilot conservation tests in un-engraved outcrops in the valley. The goals of these tests were to have data on what would be the evolution of conservation materials used and the applicability of typical (building) stone conservation methods in the Côa context (Fernandes 2008c; Fernandes and Rodrigues 2008). The following list[57] is again useful in the present endeavour:

> **Aveolization –** Weathering process manifesting in the form of multiple cavities of variable dimensions. These present a subcentimetric exterior opening. The loss of material occurs in the form of dust or small granules. Save for eventual exceptions (judged to be rare), these are active processes, so they must be looked at as areas of elevated risk. (see Figure 172)
>
> **Collapse –** The fall of massive blocks from the outcrops leaves clear and abundant scars, something that can be only identified after the collapse has occurred. Therefore, usually, it will be a term to use to characterize past phenomena. Nevertheless, it might also be used to describe situations that might in the future lead to this type of situation. In cartographic terms, it can be acknowledged that it can be individual areas that are in risk of collapse. (see Figure 121, Figure 173 and Figure 174)
>
> **Concretion -** Compact deposits at surface level with limited extent in area and with sub-millimetre to millimetre thickness. Usually present in a surface with numerous small cavities localized in areas where the flowing of water split the interior of the massif. In general, such deposits do not cause damage to the engravings, so it is not necessary to remove them. (see Figure 175)

[57] The list originally constituted a section of the Rodrigues report that was translated from Portuguese to English by Jennifer K. K. Huang whilst the present author revised the final version. Jennifer carried out an internship in the Park, sponsored by US-ICOMOS, for three months in the summer of 2000. Accompanying figures, unless stated otherwise are by the author of the present PhD.

Deposits of Other Kinds - A generic term to use when it is not possible to apply the term Concretion. Generally corresponds to dirt deposits similar to the ones present in poor condition stone monuments or the sediments left by floods or rainwater drainage. In general, such deposits do not cause damage to the engravings, so it is not necessary to remove them. (see Figure 175)

Diaclase[58]- A fracture that traverses the massifs, in which there is no visible significant movement between the two sides of the fracture. To use when it is clear that this fracture corresponds to some of the families of fractures that, with great persistence and continuity, generally affect the areas where engravings are present. (see Figure 176, Figure 177 and Figure 178)

Differential Weathering - Damage on the surface level of the massif that is manifest by the contrasting morphology between neighboring zones (zones more or less eroded). This form can be associated either with relatively stable situations, where the degradation can be very slow or, on the contrary, associated with quite rapid evolution. (see Figure 179)

Disconnected Blocks – Term to be used when outcrops possess different blocks. These blocks, which can have different dimensions, exhibit signs of deficient cohesion or of relative dislocations among themselves. This is one of the most worrisome situations since it will (and has already) damage(d) engravings. Not all situations show the same gravity and urgency, so it is possible to foresee with certainty that there will be an escalating need to undertake interventions over time. (Figure 180, Figure 181 and Figure 182)

Disintegration/Pulverization – Loss of cohesion of the stone easily put in evidence through mechanical efforts of weak intensity. In these situations, particles are created in the form of powder or of small granules. The areas where this phenomenon occurs are free of deposits or colonization, have colors close to that of the intact rock, or present a light covering of dirtiness that disguises the area of precarious cohesion on the interface between deposits and stone. These highly sensitive areas demand careful approach. (Figure 183)

Dislocated Elements - Singular elements, or groups of blocks, dislocated in relation to the nearby areas or elements. Similar to loose blocks and areas in risk of collapse.

Efflorescence - Formation of thin-layered crystalline aggregates in the rock surfaces, generally of fragile cohesion and clear colour. These phenomena occur quite rarely. (Figure 184)

---

[58] Although Diaclase is an English language word, the term Joint is more widely referred to in the specialized bibliography. Nevertheless, see Taboada *et al.* (2008) for an example of use of the word Diaclase in an international Geology peer-reviewed Journal. However, since both are synonyms, the term that more closely follows the Portuguese original is preferred and will be used throughout the present PhD.

Exfoliation - Separation of the rock into more or less fine and repetitive splinters, following (and taking advantage of) the same markedly parallel orientation of the original deposition layers. (Figure 185 and Figure 186)

Fissure - A particular case of fracturing in which at least one of the extremities does not reach the contour (or 'border') of the surface where it is located. They constitute a factor of weakness in the rock and, consequently, for the engravings, but its evolution can be sufficiently slow to permit some time of observation before making any decision to intervene. (Figure 187)

Fracture - Surface crack that divides the object into distinct parts, and makes possible the reciprocal removal of these parts. In the engraved outcrops, the fractures can present diverse configurations and fillings that can be used to identify distinct situations. (Figure 181, Figure 182, Figure 188 and Figure 190) Some of the situations are characterized below:

> **Open Fracture** - Fracture in which significant movement is occurring.
> **Eroding Fracture** - Fracture in which occurs a loss of material along its borders.
> **Fracture with Filling** - Open fracture where debris is subsequently accumulating.

Gapping - The absence of material resulting from damage. Can be superficial or profound. Cartographically, this term ought to be used only for referring to surfaces where the phenomenon is or will affect in the near future engraved motifs. (Figure 191)

Scaling – Loss of small, rough and low thickness (0.5 cm) fragments. These are also highly sensitive areas. (Figure 183)

Splintering - Distinct fragments of reduced lateral extension and centimetre thickness, sub-parallel to the surface. The elements about to detach show precarious cohesion. (Figure 191)

Stains - Chromatic alterations in areas surrounded by stark contrast with the adjoining rock surface. These occurrences can be relevant as cartographic elements, but it doesn't seem that they present risks to the engravings. It is not foreseen, therefore, that any type of intervention will be necessary. (Figure 191)

Toppling - Advanced progress of the blocks located in the more elevated part of the slope or outcrop. This progressive un-stabilization phenomenon leads to the collapse of the unstable blocks. These occurrences can have relevant repercussions to the stability of the outcrops. The large vertical fractures that often follow (and take advantage of) the original deposition stratigraphy, isolate portions of the outcrops. The forces necessary to make the blocks advance originate in the rock expansion and retraction cycles caused either by the seasonal variation of temperature, or by the differences in the volume of water drifting through the outcrops in dry and rainy periods. The advancement of upper blocks can, at least in some cases, be aided by the existence of debris

> and small blocks in the diaclases boxes and, similarly, by the presence of plants like shrubs and trees. (Figure 192 and Figure 193) Rodrigues (1999, 20-6)

First of all, it is important to state that the list tries to objectively identify alteration forms. Why and how these alterations come about is an altogether different matter. These may be caused by one or another precise weathering process or set of processes. The point is that trying to explain how these processes precisely weather rock masses is a necessarily interpretative procedure, thus more prone to error. Hence, it is important to correctly identify the precise alteration form without worrying, when categorizing, about recognizing the more likely weathering mechanism at work. Nevertheless, at a different 'more scholarly' level of analysis, it is not only possible but also desirable to try to understand how weathering processes may indeed result in the alteration forms observable in the outcrops (José Delgado Rodrigues personal communication). Thus, the following remarks on Rodrigues' list are such a second level of analysis exercise.

Many of the weathering mechanisms that result in the alteration forms described by Rodrigues overlap; some may be active together while others are the result of previously acting mechanisms. Active *Fractures*, for instance, may lead that some elements in the outcrops become in a *Toppling* position. The toppling slabs can in turn constitute themselves as *Dislocated Elements*/*Disconnected Blocks*. It must be noted that these two last categories, which have not originated from *Diaclases* but rather from fractures occurring on the outcrops, can be regarded as, essentially, the same mechanism. On the other hand, *Gaping* is the general end-result of other mechanisms, notably *Splintering*. Rodrigues, contrary to Dorn (Villa *et al.* 1995; see Chapter 3), apparently does not value weathering promoted by wedging processes. Indeed in the item *Deposits of Other Kinds* of the above list, it is explicitly stated that "in general, such deposits do not cause damage to the engravings, so it is not necessary to remove them". Nevertheless, it can be argued that indeed it is the existence of fissures, gaps and diaclases that provide an opportunity for mechanical weathering processes similar to wedging to occur. In theory, if an outcrop or panel is completely 'whole', with an absence of fractures or fissures, weathering by wedging cannot take place.

Only by carrying out a careful analysis of each outcrop's case is possible to correctly identify existing alteration forms. For instance two outcrops may present fractures on the surface level. However, while one has only a few fractures, the other exhibits a vast fracture network that crosses the panel and outcrops in different directions. Therefore, the systematic identification of alteration forms active in each outcrop plays a major role in differentiating the condition of each one and, hence, in establishing the intervention urgency scale. It should also be pointed out that Rodrigues believes that the physical weathering alteration forms he describes are the most prominent danger to the endurance of the engraved outcrops. As noted above, he suggests that the region schists are quite resistant to chemical weathering suggesting that the most important mechanisms at work are the physical (or mechanical) weathering processes described above (Rodrigues 2003, 429). If chemical weathering is a reasonably well-understood process, “physical weathering encompasses a range of mechanisms, the relative effectiveness of which are not accurately known but clearly vary significantly as a function of environmental conditions” (Summerfield 1991, 144). Therefore, much of the success of the current project will depend on the correct identification of how physical weathering mechanisms manifest in the specific case of the Côa Valley open-air rock-art outcrops.

5.3.2. Chemical weathering processes

Weathering mechanisms usually referred to as of chemical origin such as hydration, solution, hydrolysis or carbonation (Bland and Rolls 1998, 116-148) should be discussed. However, as already pointed out, Rodrigues reached the conclusion that chemical weathering processes are not a major cause of concern in the case of the Côa. This is because of, on the one hand, the relatively ‘benign’ pH value of water present in the Côa environment (Rodrigues 2003, 428-9) and, on the other, the quite mild regional pluvial regime (see Chapter 4). Therefore, a relatively limited supply of water determines that water-based chemical processes have a diminished impact in the weathering of the Côa Valley rock faces. Nonetheless, it should be noted that physical weathering mechanisms result also from chemical alterations in a body of rock. Nevertheless, the resulting weakness will present itself as one of the types of physical weathering dynamic, which have been dealt with in the previous section of this Chapter.

5.3.3. Rock coatings

As mentioned in Chapter 4, rock coatings are also an issue in rock-art conservation. It has been suggested that engraved panels in the Côa are covered by silica skins (Dorn 1997; Watchman 1996), one of the coatings listed by Dorn (2007). Chauvière *et al.* when analysing the composition of the coating from five rock samples collected in the region confirmed such a suggestion also finding core elements such as aluminium, clay, iron and titanium (2009, p. 455). This coating has contributed[59], in differing degrees, to the conservation of the surfaces and the engraved motifs (Chauvière *et al.* 2009, 453-466). In fact, Chauvière *et al*. have divided, from the observation of five engraved panels in the Penascosa site, the condition in which the coating subsists in 4 distinct categories: 1 – Conserved; 2 – Partly altered; 3 – Altered; 4 – Totally altered (2009, 454). The last two categories are characterized, besides the non-existence of engravings, by the presence of more (category 4) or less (category 3) developed lichen colonies. Hence, the authors propose that the existence of lichens generally signals the absence of the protective coating on rock surfaces[60]. Moreover, the higher engraved outcrops are located, the less the protective rock coating is present (Chauvière *et al.* 2009, 454).

This protective layer is subjected to complex and little-understood deposition/erosion/redeposition processes (Rosenfeld 1985; Zilhão 1995). Pope (2000) has suggested that the sulci of the engraved motifs may be harder, softer, or possess the same 'hardness' as the host panels, depending on the skin's re-deposition processes, which vary from site to site but also within areas of the same panel. In some panels, the coating has become completely altered and provides little or no protection for the engravings. One of the reasons are winter floods that cause significant erosion to this protective layer (Chauvière *et al.* 2009, 453-466). Thus, since the same engraved panel may possess differently preserved layers in its diverse sections, this rock coating will not be used as a parameter to distinguish between outcrops. To do so it would be necessary to divide the condition assessment of the outcrops according to the different sections possessing differentially preserved coatings. This would mean an excessive and arguably unnecessary complexity both in condition assessment and ranking. Moreover, there is no possible remediation measure that can be taken to

---

[59] Silica acts as a cementing mineral that occupies the space between rock pores thus lowering porosity (Bland and Rolls 1998, 43-4)

[60] Nevertheless, it was also observed that, at least in one engraved outcrop, different species of lichens do directly colonize the protective rock coating (Chauvière *et al.* 2009, 454).

promote the ‘refilling’ of these protective coatings[61], contrary to what can be done to mitigate the action of the physical weathering mechanisms identified by Rodrigues (see Fernandes and Rodrigues 2008). Only the said complex natural deposition/erosion/re-deposition processes will determine, in the long run, the evolution of the condition of rock coatings present in the Côa Valley rock-art outcrops.

5.4. Setting

This subsection includes parameters that affect the condition of the outcrops connected to their specific location: slope and aspect. Aspect analysis comprises several subsections dealing with specific issues which are aspect related or dependent such as solar radiation weathering or aeolian erosion.

5.4.1. Slope

There is a great deal of work done on slope angle and its connection with landslides, rock falls and even massive rock failure (see, for instance, Brooks 2003; Ercanoglu *et al.* 2004; Evans *et al.* 2006; Hutchinson 2006; Tangestani 2004; Varga 2006; Yalcin and Bulut 2007). General works on geomorphology classify slopes as “the basic element of the landsurface” (Summerfield 1991, 163). This author also points out the distinction that has to be made between the two components of slopes: rock, a tough consistent material that does not appreciably weakens from water saturation and soil, a weak inconsistent deposit that if impregnated by water easily subsides (1991, 163). It has been demonstrated that when slope angle increases, the susceptibility for landslides or rock slope failure also increases (Yalcin and Bulut 2007; Hutchinson 2006: Summerfield 1991, 163-189). Among the factors that might contribute to such occurrences, “lithology, (...) slope angle disturbance (...), glacial or fluvial erosion, hydrogeological and meteorological factors, neotectonics and seismicity, and both surface and hydrothermal weathering” (Hutchinson 2006, 621) are the most prominent ones.

In the Côa Valley, slopes are not very prone to landslides due to the low quantity of soils in slopes. The kind of catastrophic rock failing described in some of the references above (Evans et al. 2006; Hutchinson 2006) must be considered as rare

---

61 With the possible exception of the ethically quite questionable method (or a similar one) proposed by Elvidge and Carleton (1980).

events as evidence for such occurrences are not easily observable in the Côa. In fact, since 2000, when the author began working in the Valley, no landslides or rock falls, of sufficient significance to be detected, have taken place, at least in slopes possessing rock-art outcrops. Nevertheless, as rock-art outcrops are mostly located at the foot of sharply inclined hills, slope dynamics play an important part in the mechanical disturbance of outcrops. On one hand, gravity itself will force different sized elements (from small soil particles to heavier rock blocks) to roll downhill that may result in serious damage to the outcrops located below (Aubry *et al.* 2012, 860). On the other hand, the hill itself applies great pressure to the outcrops located at its foot. As Rodrigues points out, the hillsides are in a continuous process of trying to reach a more stable profile; in fact, to have less pronounced slope angles (1999, 2). Therefore, the progressive dismantlement of the outcrops located at their base is a part of that process. The outcrops will try to respond, in an attempt to release the pressure that is being applied, by taking new forms, which result in mechanical failure and in much of the physical weathering phenomena identified in the Rodrigues Report. A geotechnical study conducted by one of the companies that participated in the pilot experiments mentioned in Chapter 1, on the one of the slopes of the Penascosa rock-art site, ascertained that toppling, one of the physical weathering dynamic considered to be most problematic to the conservation of the Côa Valley rock-art is directly linked to the stability of hillsides (Blanes *et al.* 2008) (see Figure 28, Figure 194 and Figure 195).

5.4.1.1. Tilting of outcrops

Generally speaking, it is expected that the higher slope angle is (and hence, gravitational pressure to outcrops), the more likely it is for an outcrop to present a more pronounced tilting (see Figure 177). Other factors may also contribute to the tilting of outcrops, such as tectonic forces, the precise dynamics of the river downcutting process that exposed outcrops, high precipitation events or, in the case of certain outcrops in the Côa, flooding, and the dimension of diaclases and the quantity and nature of their infill (Graniczny 2006; Kliche 1999; Selby 1982). Hence, it will be interesting to verify if in the analyzed sample the more inclined outcrops are located in the steepest slopes. Moreover, it will also be interesting to correlate slope steepness, tilting of outcrops and physical weathering processes at work in the Côa Valley rock-art outcrops.

5.4.2. Aspect

Aspect has been identified by some authors as one of the factors that can determine the occurrence of landslides or rock falls (Yalcin and Bulut 2007, 212). Nevertheless, other researchers have pointed to a lack of consensus on the subject (Ercanoglu et al. 2004, 8). Authors that have investigated the role of aspect in rock weathering (Egli *et al.* 2006; Grab 2007; Hall *et al.* 2005; Paradise 2002) arrived at different conclusions. While Egli *et al.* found that there is a marked difference in weathering patterns between South and North-facing Alpine rock surfaces (more prominent in North-facing surfaces), Hall *et al.* also concluded that there are noticeable dissimilarities in the biological weathering of differently oriented granite rock boulders located in the Kunlun Mountains in China. On the other hand, Grab, working on the Southern Hemisphere Drakensberg mountain range in South Africa, discovered that there is a marked difference in surface and 10 cms. deep temperature readings between rock faces located in South and North-facing slopes. The author suggests that weathering processes are thus controlled, to a great extent, by rock thermal characteristics. Lastly, Paradise investigated the connection between weathering and aspect in the case of ancient sandstone quarries in Petra, Jordan. The author found out that there is greater weathering of Southern faces, which he ascribed to the fact that superior solar flux increases daily heating and cooling cycles. He also notes that higher weathering rates are better explained by external factors (available humidity and insolation) than by the intrinsic characteristics of the concerned rock, namely its density.

Within the rock-art field of studies there is a interesting reference to a case where, in a fluvial island in the Columbia River (Oregon, USA), the scarcity of rock-art motifs with a given exposure (in the case, North-facing outcrops) is linked to aspect ‘enhanced’ weathering (Loubser *et al.* 2000). In fact, the authors suggest that weathering phenomena, such as lichen colonization and freeze-thaw cycles, are more active on North-facing outcrops. Another interesting find was that West-facing outcrops are the aspect class in which more rock-art motifs still exist. Since the prevailing summer winds blow with East – West orientation, it is suggested that motifs located in West-facing outcrops will be more protected from the deleterious effects of wind (Loubser *et al.* 2000, 13). It is interesting to point out that Yalcin and Bulut (2007, 212-3) suggest that aspect contributes to mass wasting events in connection to meteorological phenomena. These phenomena are exposition to rainfall, wind and solar radiation (Bland and Rolls 1998, 102-111).

5.4.2.1. Aspect, expansion and retraction cycles, and solar exposure

The expansion/retraction behaviour of rock can be induced by hygric dilation resulting from rapid or less rapid wetting and drying episodes (Bland and Rolls 1998, p. 101-102; Weiss *et al.* 2004). It is known that rocks undergo expansion and retraction cycles (Jenkins and Smith 1990; Koch and Siegesmund 2004; Ramana and Sarma 1980; Rodrigues 1999; Wong and Brace 1979). This behaviour is mainly determined by insolation received by any given rock mass and available humidity. In turn, these variables greatly depend on the orientation of the concerned rock mass. Nevertheless, some authors suggest that metamorphic rocks, such as schist, are less prone to hygric dilation and solar exposure weathering, due to their low porosity, than sedimentary rocks (Weiss *et al.* 2004).

As solar exposure is one of the factors that may determine temperature and moisture in any exposed surface (in this case, the engraved outcrops), the expansion and retraction cycles differently faced outcrops undergo may significantly differ. As these cycles play a major role in several of the weathering phenomena that occurs in the engraved outcrops (Díez Herrero *et al.* 2006; Rodrigues 1999; Weiss *et al.* 2004), solar exposition must be regarded also as a feature that might influence the condition of outcrops. Insolation, although not a very well studied phenomenon (Halsey *et al.* 1998), has an effect on rock weathering through three different factors: thermal and photic deterioration and induction of capillary processes. If the later (photic deterioration and capillarity) only comprises surface or subsurface phenomena, such as chromatic alteration or the appearance of efflorescences or crusts on the rock face, the former does have more serious implications. Due to the variation in daily temperature amplitudes, felt at surface level but also in the interior of the rock, insolation may lead to thermal fatigue, which translates in the hastening or appearance of such physical weathering issues such as fissures, aveolization, gaping or exfoliation (Díez Herrero *et al.* 2006, 994-5; Halsey *et al.* 1998; Paradise 2002). Díez Herrero *et al.* (2006) investigated how solar exposure affects the conservation of painted rock-art and, what is of more interest to research reported here, of its rocky support. The authors arrived to the conclusion that sandstones and siltstones that constitute the rocky support rock-art paintings weather at different rates according to solar orientation. It was suggested that rock faces exposed to SE weather at a slower pace than those orientated to W, a fact the authors connect with the different times of the day these surfaces receive insolation (Díez Herrero *et al*. 2006, 1005).

5.4.2.2. Aspect and aeolian erosion

Wind erosion can be an issue in rock-art conservation as well as in built stone conservation. For instance, Alshawabkeh *et al.* list wind-blown sand as a weathering agent in the case of the Al-Deir Monument in Petra, Jordan (2010, 126). Regarding rock massifs in natural environment, Villa *et al*. note that aeolian activity influences weathering rates in deserts via abrasion of rock faces, increase in wedging processes but also rock protecting case hardening processes (1995). Currently, to the best of the author's knowledge, there is only one reference available in the specialized literature specifically analyzing how dust distributed by wind affects rock-art (Watchman 2002). Unfortunately, the negative effects of dust accumulation were primarily studied considering painted rock-art although it was noticed that on one site a 1 mm thick layer covered engraved (as well as painted and repainted) motifs. However, no consequences for the conservation of engraved motifs are referred to the contrary of what is suggested regarding painted rock-art (Watchman 2002, 27). On the other hand, Rodrigues and Saraiva (1985) carried out a study in which they examined how wind affects the stability of heritage, in this case a church tower. Wind has two main eroding effects in rock as noted above, abrasion by airborne particles and direct action. The authors point out that the former, except in very rare favorable conditions, is unlikely to have great effects in erosion. The latter, nonetheless, has a more negative outcome, that is, suction forces acting on the less exposed surfaces of a monument. That is, wind when blowing through a structure, will generate suction of rock particles located in the surfaces that do not directly face wind. (Kapp *et al.* 2011)

5.4.2.3. Aspect and low-temperature weathering mechanisms

Low-temperature weathering mechanisms comprise freeze-thaw weathering, hydration shattering, ice crystal growth and hydraulic pressure (Bland and Rolls 1998, 85-94). It has been established that schist has a very low breakdown rate (compared with other rock types) when hydration shattering is considered (Bland and Rolls 1998, 188). The contribution of these mechanisms to weathering is only fully achieved in cold climates, which is not the case of the Côa. However, it has been observed that even in a mild climate such as the Côa, temperatures fall below freezing point, the essential condition for the action of these mechanisms (Bland and Rolls 1998, 68), in some of winter coldest days (see previous Chapter). Hence, authors have suggested that one of these mechanisms (freeze-thaw weathering) is one of the most important instability factors in the case of the Côa (Blanes *et al.* 2008, 54). Aspect is, arguably, one of the determinant factors regarding the degree in which ice formation affects different rock surfaces.

5.4.2.4. Aspect and vegetation growth

Aspect determines the amount of solar radiation reaching vegetation. In turn, this will determine not only vegetation growth but also existing species in differently facing slopes (Bennie *et al.* 2008). For instance, mosses, in sunny temperate northern hemisphere climates, will grow in the north side of rocks (or trees) since these organisms require a moist and shaded environment to live in (Porley and Hodgetts 2005, 80-1). While some suggest that mosses contribute to weathering of colonized rock surfaces by root wedging in to pores and crevices thus making rocks crumble (Michelson quoted in Bakkevig 2004, 72), others question the extent of the damage caused by the relatively small and non-penetrating rhizoids (Bakkevig 2004) or put forward that mosses only colonize already weakened surfaces (Bech-Andersen 1985, 126). Be as it may, North-facing rock-art panels will be more prone to the detrimental effects of moss colonization, even if these organisms might only further weaken already frail rock surfaces as the ecology of plants always entails biochemical weathering processes (Bland and Rolls 1998, 159-61), namely when mosses are concerned (Altieri and Ricci 1997). Conversely, other species that demand high quantities of sunlight to develop, such as shrubs and trees, will be more profusely present and reaching larger dimensions in South-facing slopes (Bennie *et al.* 2008, 48). Hence, deterioration by higher plants will be more active in these slopes versus North-facing ones.

5.5. Biodeterioration

Generally speaking, living organisms contribute to rock weathering by way of two different mechanisms: physical pressure and the excretion of different substances such as organic acids (Bland and Rolls 1998, 149). Therefore, this category comprises all weathering and erosion dynamics originated by living organisms' behaviour with the exception of those that might arise from human activity that are regulated by the management practices already established by the Park. Hence, the following paragraphs will focus on a discussion of the conservation threats posed by living organisms, usually referred to as Biodeterioration (Warscheid and Braams 2000). These can roughly be divided in four categories: microorganisms, lichens, plants and animals (either smaller, such as insects, or larger ones, such as mammals).

5.5.1. Micro-organisms

It is acknowledged that micro-organisms contribute to rock weathering (Bland and Rolls 1998, 152-6). Hirsch et al. (1995) or Warscheid and Braams (2000) offer useful reviews on the well identified ways in which microbial activity contributes to deterioration of many different types of rock, either in a natural setting or building stone environment, namely monuments such as churches. Nonetheless, they point out that most research on the topic only describes the identified microorganisms and the result of their detrimental impacts to rock surfaces while little is know about the weathering mechanisms at work and subsequent weathering rates. Even so, it is generally believed that these microorganisms prepare the ground for larger organisms such as lichens, insofar as they increase the porosity of the rock substrate leaving it more exposed to the creeping in by macroborers (de los Rios *et al.* 2002).

Therefore, colonization by these types of organisms has been suggested to affect the condition of rock surfaces possessing prehistoric art (MacLeod *et al.* 1995; O´Hara 2006; Sutton 2003; Walderhaug and Walderhaug 1998, p. 125). Gonzalez *et al*. (2008) examined the role of micro-organisms in the deterioration of rock-art. Unfortunately, their case study was Altamira cave famous for its prehistoric paintings but constituting an environment and type of rock-art that has little to do with open-air engraved rock-art. Therefore, to the best of the author's knowledge, the sole studies that have been carried out on the specific case of microbial originated deterioration of open-air rock-art have been pursued in Australia. While MacLeod *et al.* (1995) have determined that the availability of moisture is a major deterrent to microbiological activity in rock-art surfaces in the West Kimberley region of West Australia. O´Hara (2006) and Sutton (2003) have analyzed the matter in the semidesertic Burrup Peninsula region located in the same area of Australia. Despite the fact that microbiological activity was identified, even if in low quantity, Sutton stresses that its contribution to rock-art deterioration is not clearly defined and is inadequately understood since

> "the effect of many variables is unknown (site-specific substrates such as rock type; nature and amount of natural and anthropogenic nutrients; types of microbes naturally present; environmental factors such as temperature, water availability, pH, etc)" (Sutton 2003, 24).

He adds that, while it is possible to monitor their activity, to precisely establish the role of micro-organisms in rock-art weathering would be quite complex. Moreover, he concludes, "control of microbial deterioration of rock-art is unlikely" (Sutton 2003, 37).

In the specific case of the Côa, Watchman (1996) identified fossilized micro-organisms (diatoms, that is, phytoplankton) in the Côa Valley surfaces. However, the purpose of his research was to directly date the engravings[62] and not to determine if these micro-organisms promote rock surface weathering. Rodrigues (1999), in his Report, also refers to microbial colonization in the Côa surfaces, without, however, making a detailed analysis of the subject.

Studying the effects of the micro-organisms that might colonize the Côa Valley rock-art surfaces admittedly falls out of area of expertise of the author[63]. It can nonetheless be suggested that the action of these microorganisms is not the most pressing phenomena contributing to the weathering of the Côa rock-art outcrops. Therefore, it is suggested that, considering current knowledge on the conservation problems of the Côa Valley, it will have to be sufficient to say that the issue has been acknowledged has being a (minor) component of the deterioration processes affecting the rock-art outcrops. Hence, at this stage of knowledge it will be impossible to use

---

[62] Three different researchers tried to directly date the Côa engravings: Watchman (1996), Bednarik (1995) and Dorn (1997). While Dorn arrived to the conclusion that it is not possible, with the presently available experimental methods, to date directly engraved rock-art, Zilhão (1995) categorically rebuffed the results obtained by both Watchman and Bednarik.

[63] Being the topic matter, in its own right, for a different PhD project within another scientific discipline.

micro-organisms in making the distinction between the condition of different rock-art outcrops.

5.5.2. Lichens

The role of lichens in rock biodeterioration is a relatively well-studied field of knowledge. From the first studies (Fry 1927), to recent reviews (Chen *et al.* 2000; Lisci *et al.* 2003; Wilson 2004) and ending in more detailed analysis (Adamo and Violante 2000; Aghamiri and Schwartzman 2002; Ascaso and Wierzchos 1995) there are many references to chose from. Most discuss the weathering effects of lichen behaviour upon rock surfaces, either in building stone environments or in natural settings. It has been demonstrated that lichens, "symbiotic systems consisting of a fungus (…) and a eukaryotic alga and/or a cyanobacterium" (St. Clair and Seaward 2004, 2), actively contribute to rock weathering. This contribution in twofold: physical, as the hyphae (root-like structures) penetrate the rock substrata and the thalli (the 'body' of the lichen) undergoes expansion and contraction cycles and chemical, as a result of the 'corrosive' substances (oxalic acid, for instance) lichens produce and deposit upon rock surfaces (Chen *et al.* 2000; Seaward 1997, 2004). While there is a general consensus on the weathering action of saxiculous lichens, some authors point out that lichens might also constitute, quite paradoxically, an "umbrella-like protective layer" (Carter and Viles 2005, 275) shielding rock surfaces from erosion by atmospheric agents (Mottershead and Lucas 2000).

Some references focus on lichens colonization (and documenting their induced weathering phenomena) occurring in monuments (Saiz-Jimenez 1999) and more specifically in churches (Prieto Lamas *et al.* 1995) or even in archaeological sites (Romão and Rattazzi 1996). Bjelland and Thorseth (2002), working in the already mentioned Vingen rock-art site in Norway (see Chapter 3), tried to establish if different lichen taxa promote different weathering rates in similar sandstone engraved surfaces. Their results suggest that "the variation in weathering effects between taxa is greater than the variation in mineralogy of the sandstone" (Bjelland and Thorseth 2002, 95). The authors offer as an explanation the fact that some of the observed lichen taxa produce more detrimental types of acids than others.

In the more narrow rock-art field of expertise there are several references on the role lichens play in the weathering of rock-art surfaces. Florian (1978) was perhaps the pioneer in such studies while other authors devoted PhD research projects to the issue (Dandridge 2006). Chiari and Cossio (2004), Knight et al. (2004) or Silver and Wolbers (2004) carried out analysis of lichen induced weathering in specific rock-art sites. Walderhaug and Walderhaug (1998) offer a comprehensive overview dedicated to a particular country (Norway) while Tratebas (2004) extensively reviews the subject also offering insightful views on the ethics pertaining to lichen cleaning in rock-art surfaces. Tratebas notes that taking lichen from rock-art surfaces, either by chemical or mechanical methods, may have worse consequences to the given condition of that surface and, subsequently, to the motifs it hosts, than not removing at all. It may also hasten weathering dynamics and even trigger the surfacing of unforeseen ones. On the one hand, since the 'roots' of lichens penetrate the rock surface, even if only a few millimetres[64], when lichens are scrubbed off or 'liquidated' through the use of biocides, any removal act will cause the rock layer where the hyphae are encroached to also fall off. The new freshly exposed layer will be more prone to weathering (and to new lichen colonization) since a) it doesn't have the protective umbrella provided by lichen cover and b) it hasn't yet reached the adaptative (but also evolving) weathering 'compromise' that prevailed before (Bjelland and Thorseth 2002; Pellizzer and Sabatini 1972; Tratebas 2004; Warscheid and Braams 2000). Furthermore, new colonies settle in quite swiftly, as observed in the Côa in the panels where lichens were removed just a few years ago (Fernandes 2007).

The Portuguese biologist Joana Marques is currently carrying out a PhD on lichen biodiversity in the Côa Valley and the detrimental effects of lichen colonization on the rock-art outcrops. Although the conclusion of this PhD is due after the submission of the present PhD, some preliminary conclusions are available. It has been determined that besides the considerable total penetration of hyphea in Côa Valley outcrops (in the most extreme example, more than 4 mm), there is a lichen associated alteration band that affects, in the case of one species, a 33 mm radius of surface area being that other species present values of half that figure (Marques *et al.* 2011). Moreover, new to science lichen species have been identified in the region (Joana Marques, personal communication). Two older studies are also available (Romão 1999; Vanska 2001) on lichen colonization and rock-art weathering in the Côa Valley that point to different conclusions and recommendations. While the

[64] According to St Clair and Seaward, "up to 15-20 mm" (2004, 4).

Portuguese biologist Paula Romão advocates removing lichens from rock-art surfaces because of the weathering action of these organisms as described above, the Finnish botanist Vänskä recommends that they should not be removed because of the motives stated above regarding the role of lichens in rock surface protection[65].

The removal of lichens from Côa Valley rock-art surfaces was done in the middle 1990's, when the current author was not yet working for the Park. It was motivated, on the one hand, by the need to document the engravings and, on the other, to offer the Park's visitors the chance to completely observe the motifs, since some were difficult to spot because of the well developed lichen colonies that covered some, either partial or totally. The present author, as coordinator of the Côa Valley Archaeological Park Conservation Programme, has stated his position regarding the issue elsewhere (Fernandes 2004; Fernandes 2007). Briefly describing the stance, the later 'ecologically-friendly' position was favored, especially if one considers the need to be repeating removal operations every one or two decades, if the rock-art panels are to be free of lichen colonies (see Figure 196). Moreover, it is believed that lichens are part of the whole rock-art landscape, a position that partly subscribes to Bakkevig's ecological approach (2004).

Nevertheless, since the role of lichens in biodeterioration dynamics is not at all negligible, the extent of the presence of lichens in Côa rock-art surfaces will be one of the parameters to be used in the characterization of the condition of the outcrops. It will be possible to use these organisms as a parameter to distinguish between the conservation condition of different outcrops. If lichens have a sizeable part in the biodeterioration of rock (-art), those outcrops that present more extensive colonization will have an extra weathering dynamic at work than those who do not possess lichen colonies or, if having them, they present themselves in an more incipient state. Even if in all of the already documented rock-art panels[66], lichens were removed, these panels form a relatively minute part of the total universe of Côa Valley rock-art outcrops. Furthermore, it will be also interesting to check in what stage is the re-colonization process on those outcrops where lichens were removed.

---

[65] Rodrigues (1999) also briefly analyses the role of lichens in the biodeterioration of the Côa Valley rock-art surfaces. His recommendations are similar to the ones made available by Romão.

[66] By documented rock-art panels it is meant those where the researchers working in the Côa already recorded the existent motifs producing drawings such as the ones featured in Figure 8 and Figure 9.

5.3.5. Plants

Plants – a taxonomical kingdom containing countless different organisms presenting diverse behaviors and ranging from small liverworts or mosses to considerable sized trees – can pose serious conservation threats (Lisci et al. 2003; Mottershead et al. 2003), especially in the case of the Côa outcrops that offer many opportunities for root encroachment. For instance, once diaclase boxes became filled with sediments, plants can start colonizing the area (Figure 176 and Figure 197). Likewise, plants can start growing from within fractures that might separate sections of the same outcrop (Figure 198). In these instances, particularly in cases where higher plants (trees or bushes) are concerned such as the example depicted in Figure 198, vegetation contributes for the weakening of the outcrop where they settle due to the pressure applied unto rock by root growth (Rodrigues 1999). Furthermore, “a plant root is a complex microsystem that both emits and absorbs substances as part of its life processes” (Bland and Rolls 1998, 159). These processes “actively contribute to mineral decay mechanisms” (Bland and Rolls 1998, 159). Another issue to consider is the occurrence of brush fires. Although different types of vegetation have distinct combustible characteristics, outcrops closely surrounded by plants growing out of control will be more susceptible to the hazardous effects of wild or human originated fires (Dandridge 1999).

Therefore, in almost every paper concerned with open-air rock-art conservation there will be a section dealing with the issue of vegetation induced weakening of engraved or painted outcrops (for instance, Carrera Ramírez 2002; Chaloupka 1978; Walderhaug and Walderhaug 1998). However, other authors challenge the predominant view that states that all offending plants should be removed and draw attention to the need of thoroughly evaluate the need to dispose of plants. Dandridge, for example, states that “wholesale removal (…) could have more deleterious effects in the long term than doing nothing in the short term” (1999, 5). Bakkevig notes that vegetation may have also beneficial effects in the preservation of rock-art and its surrounding environment (2004). Carter and Viles speak of the role vegetation may have in slope stabilization and in the formation of protective layers (2005). These notions can also be applied to the Côa where vegetation growth can contribute to stabilize the slope where the rock-art outcrops are located by anchoring sediments that otherwise would roll downhill. Moreover, in a more diminished scale, vegetation can also contribute, if its growth is well managed, to the existence of a protective layer (of small plants plus soil) on top of the rock-art outcrops. If no harmful higher plants and their intruding roots are present, it is proposed that this layer can contribute to shield outcrops from the elements and even from the downhill dislocation of minor rock elements (Figure 199).

Nevertheless, the presence of vegetation will be also used to distinguish between the diverse conservation states of rock-art outcrops. If the case presented in Figure 198 is quite an extreme one as few engraved outcrops in the Côa have trees growing from 'within', it constitutes the perfect example not only of how vegetation can endanger the stability of outcrops, but also the contribution plants can give in establishing the conservation work intervention scale.

5.5.4. Animals

The behaviour of different animals can pose serious threats to the conservation of any given rock-art outcrop. Lambert (1989) and Bednarik (2009) review the subject pointing out the hazardous consequences the activity of insects, birds and mammals can have for rock-art panels and outcrops. Damage to rock-art panels done by insects such as wasps or termites has been reported in several Australian sites (Chaloupka 1978; Sullivan 1978; Wylie *et al.* 1987). In the Côa, fortunately, there are no termites and the existing wasp species do not build their nests (the main cause of harm to rock-art surfaces) on schist outcrops (or at least, such an occurrence was never identified). Nevertheless, other Arthropod species (a phylum that includes insects and arachnids besides other species) might have an active role in the biodeterioration of the Côa Valley outcrops. It has been observed that different spider species have established colonies inside gaping areas of outcrops (Figure 200). It was not, of course, spider activity that provoked deterioration in the first place. However, their activity (movements and substances expelled) contribute, even if just minimally, to further weaken these already fragile areas of the rock surface leading to a swifter fall out of superficial frail layers.

Birds can also damage rock-art panels either by building nests or by their droppings, which can be quite acid, thus contributing to biodeterioration dynamics at work (Bednarik 2009). As with wasps, no bird species nest in the schist Côa Valley outcrops. Nonetheless, their droppings have been detected on Côa rock-art surfaces

(Figure 189). Damage originating from larger mammals such as feral pigs, buffaloes, bears or goats has been described in different circumstances (Bednarik 2009; Chaloupka 1978; Sullivan 1978). These large animals damage rock-art surfaces in two distinct ways. The first is by rubbing themselves against surfaces, thus making paintings disappear, engravings weather or even making portions of engraved or painted panels fall off. The second is by scratching surfaces with their horns or claws. In the Côa, the only large animals that might damage rock-art in such ways are wild boars and domesticated sheep. Wild boars are difficult to manage in their, mostly nocturnal, activities. Nevertheless, hunting associations in the region control their numbers by periodically carrying out hunting events. Be that as it may, the author has never observed any damage inflicted upon rock-art surfaces for which wild boars could be blamed for. As for sheep, controlling their activity falls within the management and surveillance of human economic exploitation of the territory that is institutionally executed by the Park.

Regarding what was discussed above, it is necessary to make a distinction between small and large animals. Similarly, to what has been established for lichens (and plants), if arthropod activity and/or colonies can be observed to be active in an outcrop, this will be another parameter to consider. Conversely, larger animals should not be considered as their activity can randomly affect any outcrop (engraved or not) in the Valley.

5.6. Regional scale processes and phenomena affecting outcrops

This subsection reviews processes and phenomena possessing different origins. However, it is believed that it will be easier to group these processes under the same title, attempting to identify which can be used to differentiate between the engraved outcrops to be examined.

5.6.1. Acidity of ground water

Water is one of the major factors in rock weathering (Summerfield 1991, 129), namely when considering its pH and ionic content. Before the final decision on the preservation of the Côa rock-art, Rodrigues (2003) conducted a study aimed at ascertaining if water acidity would damage the engraved outcrops if these had been submerged by the dam. He found, carrying out laboratory tests, that highly aggressive water (twice-distilled, pH=5,3 and with an electrical conductivity of 2,0mS.cm-1) produced reduced levels of chemical weathering to the tested schist samples (Rodrigues 2003, 428-9). Since the tested samples were freshly cut from the bedrock, thus more vulnerable, he adds that the engraved outcrops should witness even lower levels of chemical weathering since, supposedly, they are less susceptible to dissolution. If that was not the case, rainwater, of more aggressive characteristics than the one that flows in the Côa, would have, long ago, promoted major dissolution of the engraved outcrops. Rodrigues suggests that, considering the proposed age of the most ancient engravings in the Côa, the tests he conducted prove the very high resistance of outcrops to dissolution. Moreover, it is also known that ground water flowing through schist bedrock has very low mineralization levels. He therefore concludes that the most important weathering dynamics to consider in the case of the Côa are of physical nature rather than chemical (Rodrigues 2003, 429).

It would be interesting to confirm the conclusions of Rodrigues regarding the pH of rain and ground water in the Côa. However, since all the engraved outcrops are exposed to both variables, if not always in the same way (see discussion on Aspect), at least in a randomly equal distribution fashion, using water pH values as parameters to distinguish between the engraved outcrops would be thus, in the author's opinion, pointless. The only exceptions are outcrops that locate themselves below the highest flood levels. However, flooding as a variable that might affect the condition of the engraved outcrops (and hence help distinguish between them) will be taken into consideration below as a distinct parameter in the present list.

5.6.2. Flooding

Albeit the quite low precipitation occurring in the area of the Park, flooding must be regarded as a risk factor for the engraved outcrops located below the maximum flood level (see previous Chapter, Figure 45 and Figure 116). Besides the mechanical pressure that outcrops experience during submersion due to water circulation, another stressful phenomenon takes the form of relatively fast-paced wetting and drying episodes (Bland and Rolls 1998, 101; Blanes *et al.* 2008, 54) that might occur when water levels rise and lower significantly several times within the same flooding season. As detailed in Chapter 3, Fitzner *et al*. describe similar damage provoked to rock-art motifs and their supporting bedrock by the lowering and increasing of water levels at a seasonally submerged panel by the banks of an artificial reservoir in Korea (2004). Hence, outcrops location in an area affected by flooding will be one of the risk parameters to use when trying to distinguish between different outcrops.

5.6.1. Seismicity

As it was noted in the previous Chapter, the Park is located in a fairly seismically active region. In 2004, the Park commissioned the installation of a seismic station to the Centro de Geofísica da Universidade de Lisboa (CGUL). The station, which operated for a period of 2 years, was set up in the Canada do Inferno rock-art site. The gathered information confirmed the data supplied by historic records on the area's seismic activity. It is a moderately active area where earthquakes of medium intensity happen two or three times each century. Higher intensity ones will occur once every century (Veludo *et al.* 2008) (see Figure 201).

The occurrence of earthquakes is undoubtedly a factor that can contribute to the further weakening or even disappearance of engraved outcrops either directly (Holmlund and Wallace 1994), or as a result of events that follow in the aftermath of an earthquake, such as landslides or slope failure (Murphy 2006). In the case of the Côa, Blanes *et al.* determined that there is a 95% probability of a maximum displacement of 8 mm per year of the outcrops' constituting blocks (2008, 54). Unfortunately, it is a phenomenon not at all controllable in its origin, albeit the outcrops might be consolidated in such a way they can better resist the effects of an event. Nevertheless, the use of this risk factor as a parameter to make a distinction between outcrops seems impracticable. Earthquakes are random events that can happen at any location and any given depth. So, engraved outcrops in the Côa Valley are all exposed to the same risk, and it is impossible to point out an outcrop that is more susceptible than others. Evidently, outcrops in poorest condition will be more vulnerable to the effects of earthquakes, but it is in itself the condition of the outcrops that is the quantifiable risk, not the occurrence of an earthquake that will affect randomly the area where the engraved outcrops exist. Moreover, as part of a study on evidence of archaeoseismicity in Portugal, Gomes *et al.* (2008) attempted to correlate the fractures existing in Côa Valley engraved outcrops with seismic activity (which may generate the displacement, the partial or complete loss of motifs[67]). One of the analyzed cases during fieldwork is that of Quinta da Barca Rock 3, namely the fracture that traverses the doe motif (see Figure 169). Nonetheless, the authors arrived to the conclusion that existing fractures result from a) graviturbation because of the already mentioned location of outcrops at the foot of generally quite steep slopes; b) bioturbation due to the mechanical action of plants roots and c) natural cleavage of schist. (Gomes *et al.* 2008, 86).

5.7. Conclusion

Most of the above-identified parameters are used in condition assessment of the outcrops included in the analyzed sample and in creating the conservation intervention urgency scale in following Chapters. The current Chapter thus constituted a first level filtering of parameters that can be of use. The following Chapters precise the detailed manner in which the parameters deemed to be relevant to the specific case of the Côa Valley are applied. It is believed that the thorough examination of each one of these parameters, as a base for setting up the conservation urgency scale carried out in subsequent sections, will contribute for the comprehensive characterization of the condition of Côa Valley outcrops. It should also be noted that many of these variables are interdependent and act in an intertwined fashion. Aspect is the most readily example as, for instance, vegetation growth is dependent of insolation and solar exposure is determined by slope orientation. Moreover, most of these parameters are decisively determined in their action by climate variables, namely temperature and precipitation. Hence, the global weather characterization of region carried out in the previous chapter is complemented in the ensuing Chapter by a micro-spatial analysis of climate variables in slopes with four different aspects.

---

[67] The latter cases can only be supposed since if a complete motif has been lost in the course of the millennia, it is difficult to identify and recover it and, more importantly, to 'place' it again in the original rock-art panel from which it has collapsed.

Chapter 6: Condition assessment of sample outcrops

6.1. Introduction

The following Chapter uses each of the evaluation parameters identified in the previous Chapter and applies it towards the condition characterization of outcrops. Each parameter or set of parameters are assigned different weights in the ranking system according to the extent of the impact each have in the current condition of outcrops, as reviewed in the previous and present Chapters. However, the previous Chapter carried out a general analysis of the role these different parameters have in the rock-art outcrops weathering. Hence, the following list analyses in detail the precise fashion in which all these parameters contribute to open-air rock-art degradation in the Côa and thus to the intervention urgency scale.

The method to select the outcrops to be included in the sample to undergo condition assessment has been detailed in Chapter 1. The list of chosen outcrops is available in Table 2 and Annex A, which stores data from fieldwork condition assessment. Condition assessment was carried out using identified parameters in the fashion detailed in the present Chapter. The general location within the Park of the selected outcrops is shown in Figure 202.

6.2. Rock characteristics assessment

6.2.1. Mineralogical characteristics

Results from thin section examination of samples (Figure 203 and Figure 204)[68] confirm the earlier analysis carried by different authors mentioned in Chapter 4. That is, the Desejosa formation is constituted by a low to medium grade metamorphic greywacke with fine grain size. The original materials upon which the metamorphic process occurred comprise sandstones, turbidites and mud. Among the minerals that could be identified are quartz, plagioclase feldspar, biotite, phylite and glauconite. On the other hand, the Pinhão formation is a high-grade metamorphic schist with coarser grain size. Its original materials were clays and mudstones. Among the recognized minerals during thin section analysis are quartz, biotite (in the form of porphyroblasts), muscovite and garnet.

---

[68] Thin sections have been prepared by the author and analysed at the microscope under polarized light.

Even if there are some variation of minerals present in the two formations there are also striking similarities, notably the presence of quartz (as expected) and biotite in both. Hence, it is proposed that variation of minerals found during thin section analysis and in previous research mainly results from the different high or medium to low-grade metamorphism processes that originated both formations. While Pinhão was formed under high-grade metamorphism conditions, Desejosa is the result of a low to medium grade process. Basically, this means that the body of rock that become Pinhão formation was subject to the higher temperatures and amounts of pressure present at more profound depths. Desejosa, as the tectonic dynamics, which made both formations 'travel' towards the interior of Earth, were less pronounced, was exposed to lower temperatures and amounts of pressure thus originating a low to medium grade metamorphism formation (Thompson and Turk 1999, 61).

Figure 205 illustrates the different grades of metamorphism present in the metamorphic formations of the area of the Park. Following what was detailed in the previous paragraph, it can be proposed that high-grade metamorphism produces a more compact and homogenous rock than low-grade processes. In fact, evidence suggest that low grade metamorphism originates a body of rock more prone to weathering and erosion (for instance, Bintliff *et al.* 2008, 50) due to higher variety of minerals in composition and presence of more hydrous minerals (Nelson 2003).

6.2.2. Chemical characteristics

Results of SEM analysis presented in Annex C point to a very similar chemical composition of the examined samples. Samples revealed a high percentage of Si (around three fifths), followed by Al (around one fifth) and relatively small portions of K and Fe making the Côa schists fall in to the Silicate class according to Dana's classification system (Klein *et al.* 1985). It is believed that these results may be safely generalized to the entirety of the two schist formations that comprise Côa valley rock-art outcrops. Hence, since there are no marked differences in chemical composition of the Côa outcrops, this parameter will not be part of the evaluation of the condition of the engraved outcrops.

6.2.3. Porosity characteristics

Porosity, water absorption capacity and saturation coefficient have been measured in 12 samples (half coming from Desejosa and the other half from Pinhão formation). Measurement of these properties was done following Cooke's methodology where:

> "1. Porosity (is) the volume of pore space expressed as percentage of bulk volume of sample (…)
> 2. Water absorption capacity (is) a measure of the amount of water absorbed in a specified time (…)
> 3. Saturation coefficient (is) the amount of water absorbed in 24 hours expressed as a 'fraction' of the volume of available pore space" (Cooke 1979, 354)[69]

Results of the measurement procedures can be observed in Table 26. The most striking conclusion is that both formations present quite low porosity, water absorption capacity and saturation coefficient, as it would be expected in such types of rock (for instance Ganor *et al.* 1989; Weiss *et al.* 2004). Nevertheless, if saturation coefficient figures are similar for both formations, Pinhão presents higher average values regarding porosity and water absorption capacity. In the case of porosity, Pinhão presents a value more than double that of Desejosa. When considering water absorption capacity, Pinhão's result is almost three times higher than the value measured for Desejosa. Hence, it can be put forward that outcrops located in Pinhão, because of porosity and water absorption capacity, are more prone to weathering than those located in Desejosa formation.

6.2.4. Rock strength

Rock strength was determined for all outcrops comprised in the sample according to the methodology detailed in Figure 171 taken from Summerfield (1991, 166). It is interesting to note that the different items that contribute to determine rock mass strength have diverse weights in the final score. For instance, weathering accounts for 30 percent while groundwater flow only accounts for 6 percent of the final score. As Summerfield notes, "each variable is given a weighting in proportion to its *estimated importance*" (1991, 166; author's highlight). Of all the items included in this category

---

[69] In order to not unnecessarily fill the text with mathematical formulas, the precise fashion in which these properties have been measured can be found in Cooke's original paper. Moreover, it must be mentioned that microporosity characteristics have not been measured due to lack of specific technical equipment. Measuring procedures of the other properties were performed three times and final results present in Table Porosity are the average of these three different measurements, which, nonetheless, delivered quite similar values.

and listed in Summerfield's Table, intact rock strength (Schmidt hammer rebound value) is the only one to be individually mentioned. In measuring intact rock strength, a Type N Schmidt hammer was used following the methodology stated by Goudie (2006)[70]. Other items were quite straightforward to determine during fieldwork. However, it must be noted that all outcrops received maximum score (None, r=6) when the last item, groundwater flow, was analysed since, probably due to the drier period of the year in which fieldwork was carried out, no wetness could be observed flowing through the outcrops or in their nearest vicinities.

Results of Intact rock strength and overall Rock mass strength measurements are kept in the sample outcrops database (Annex A) under the Section Rock Characteristics. Results have also been included in Table 27. Values for both categories are fairly homogenous and with the exception of one outcrop (Quinta da Barca 3, ID # 22), when measuring Intact rock strength, never reach the lowest or highest category. The same outcrop also scored the lowest value (50) when Rock mass strength is considered. Outcrops belonging to the Pinhão formation[71] possess somewhat lower values when Intact rock strength is considered presenting an average of 42 against the 48 scored as average by the Desejosa outcrops. However, Rock mass strength average values do not present a significant discrepancy (71 in Pinhão against 72 in Desejosa).

6.2.5. Tilting of outcrops

During fieldwork, the inclination of rock-art panels and outcrops has been determined with the help of a clinometer[72]. It was decided to add to Table 27 the values obtained during fieldwork regarding the tilting of outcrops faces. In the previous Chapter, this feature of rock-art outcrops was discussed in the Slope section. However, as discussed

---

[70] The methodology implied carrying out ten measurements in different part of the outcrop. After not considering the highest and lowest figures, the final value is the average of the remaining eight readings. Following the concerns stated in footnote 55, Schmidt hammer measurements were carried out in un-engraved areas of the rock-art outcrops far from the panels containing rock-art. When impossible to do so, due to reduced size of outcrops (smaller outcrops, in any case, constituted a minute portion of the sample, i. e. just six), measurements were carried out in the nearest available un-engraved outcrop. It should be stressed that the Schmidt hammer procedure left no visible traces in the outcrops.

[71] ID #'s 15 through 22, signalled with a *P* in Table Rock Charact assess in the first column after ID. The outcrops from Desejosa formation are marked with a *D*.

[72] The device used was a Suunto, model PM-5/360 PC displaying values both in degrees and percentage.

in detail below, there is no apparent correlation between slope inclination and rock face tilting. Nevertheless, it is believed that tilting of outcrop faces constitutes a relevant condition assessment parameter. Hence, it was deemed as the most correct to group the tilting of the rock mass face data together with identified and usable Rock characteristics parameters.

In cases where the rock-art panel constitutes the totality of the outcrop (usually, small outcrops), measurement of the inclination of outcrops was quite straightforward as a few readings confirmed that the entirety of the panel/outcrop presented the same inclination. In cases similar to the previous one with the difference that the outcrop/panel is divided, due to fractures, in two or more panels with slightly varying tilting, several readings were performed the final result being the average value arising from all the readings. Likewise, in the case of larger outcrops possessing several different panels, the final score was determined as the average of readings carried out in all those distinct panels. Finally, when the total area of outcrops was quite high above the ground (a relatively small minority in the sample), readings have been only carried out as high as the author's height allowed for, although, in some cases nearby laying blocks of rock were used as support.

6.2.6. Risk characterization

As Mineralogical, Chemical and Porosity characteristics are not considered eligible to be used in this category, only the remaining Rock mass strength and Tilting of rock-art outcrops faces parameters will be used towards the creation of the intervention urgency scale. The reason not to include Chemical characteristics has been given above in subsection *6.2.2*. On the other hand, the reason not to consider Mineralogical and Porosity characteristics towards the creation of the intervention urgency scale is the understanding that these two categories overrun each other. It has been suggested above that the Desejosa formation, due to its low to medium-grade metamorphism, has a weaker internal structure than Pinhão formation. On the other hand, the Pinhão formation revealed higher average values regarding porosity and water absorption capacity making it more susceptible to weathering dynamics, namely those motivated by the presence of water[73]. These results do not allow ordering risk arising from these

[73] Although generally expected, higher-grade metamorphism, such as Pinhão formation presents, does not always imply lower porosity values than low-grade to medium-grade metamorphism, as suggested

natural traits of the two formations in several categories but rather as a ‘bonus’ value to be added to each outcrop according to its formation of origin. This, in itself, does not pose any methodological issues, as it would be feasible to signal and value both perceived risk susceptibilities. However, if one formation qualifies for that bonus score in a higher risk category, the other qualifies in a lower risk category. It is extremely difficult to assert, due to lack of references on the subject in the specialized literature, if one should be scored higher than the other, that is, if for instance porosity characteristics have a more decisive role in degradation of the outcrops than mineralogical composition. Hence, one thing or the other can be assumed. Therefore, it is perhaps wisest, for the time being, not to use these two categories towards the creation of the intervention urgency scale. Moreover, if an equal bonus value was decided to attribute to each category, it would make no difference to the final score. On the other hand, since porosity and water absorption capacity figures are quite low and the gap between values calculated for the two formations are, in absolute terms, minute, it can be argued that these facts do not make these variables ideal to differentiate between the condition of the outcrops. Likewise, as mineral composition in both formations does not widely differ, what has been just stated above can also be suggested to apply to this parameter.

While the information regarding Tilting of rock-art outcrops faces is kept in Table 27 for simplification purposes, it is scored individually as a stand-alone category in the intervention urgency scale. Hence, Rock mass strength will be the sole indicator from the current section to be used since Intact rock strength is in itself part of the Rock mass strength index. For scoring purposes, in the concluding Chapter, Rock mass strength values will be considered grouped in the five categories present in Figure 171: 1 - Very Strong; 2 – Strong; 3 – Moderate; 4 – Weak and 5 – Very Weak.

6.3. Physical weathering processes assessment

Physical weathering processes at work in the outcrops comprised in the sample will be the most preponderant index towards condition assessment and establishment of the urgency intervention scale. Also considering the arguments presented in the

---

by Schmidt and Robinson when studying Minnesota greenschist (1997).

previous Chapter and the discussion of world relevant cases (notably Ausevik) undertaken in Chapter 3, it is believed that these are the most noteworthy parameters to characterize the present condition of outcrops. Table 28 presents a risk scale for each factor identified by Rodrigues (1999) and discussed in Chapter 5. Of all items in Rodrigues list reviewed in the previous Chapter, a few were not taken in to consideration in the risk scale of physical weathering processes. Hence, **Concretion**, **Deposits of Other Kinds**, **Efflorescence** and **Stains** have not been used since these describe rare and lesser troublesome situations. One item (**Gapping/Splintering**) results from the combination of two of Rodrigues' categories since the first is a consequence of the second. In a similar fashion, the **Disconnected Blocks** and **Dislocated Elements** categories have been merged since they both describe the existence of portions that are dislocated/disconnected among themselves due to fracturing of the outcrops. When considering **Fractures**, the different subcategories considered by Rodrigues (**Open Fracture**, **Eroding Fracture** and **Fracture with Filling**) have been grouped together in order to avoid further complexity.

The scale was created drawing on the analysis carried out by Rodrigues but also on the author's experience in the past decade working towards the informed conservation of the Côa Valley rock-art. Hence, it was preferred to divide it in five Risk Characterization categories ranging from Very Incipient to Very Significant. Seven of the Physical weathering mechanisms (**Aveolization**, **Collapse**, **Differential Erosion**, **Disintegration/Pulverization, Exfoliation, Scaling and Toppling**) the lesser risk category has not been assigned. In the relevant cases, this option signals that the concerned Physical weathering mechanisms are not present. Also drawing on the author's experience, all other physical weathering processes are assumed to be present in the outcrops (even if only on a small scale) that constitute the Côa Valley rock-art complex. In the **Differential Erosion** weathering mechanism, the Very Significant category signals the partial loss of engraved motifs since it would be quite difficult or even impossible to determine if in fact any total loss occurred. Concrete values in determining how to measure the threat magnitude (for instance, <5 cms. wide in the case of Diaclases) have been established by observing how each parameter consistently affects the whole corpus of rock-art outcrops. One further note has to do with how the size of areas affected by Physical weathering mechanisms was established. Hence, a *small area affected* corresponds to up a 1/5 of the total outcrop, a *medium affected area* to between one 1/5 and half of the total and a *major affected area* to more than half of the total outcrop.

In relevant situations, an acknowledgement if in each outcrop rock-art motifs are themselves affected by some of the Physical weathering mechanisms was introduced, present in the last characterization of risk category (Very Significant). Evidently, there is no difference to the condition of outcrops themselves in weathering processes affecting engraved or un-engraved areas. Nonetheless, it was considered to be relevant to make this distinction since for the endurance of *the rock-art motifs* (the ultimate goal of research reported here and of all the efforts undertaken by the author in the last decade) it is of paramount importance to ascertain and quantify which factors pose a direct menace.

6.3.1. Physical weathering risk characterization

Table 29 presents results of the Physical weathering condition assessment carried out in all outcrops comprised in the sample in a systematic fashion. These are also available in the database that keeps the results of fieldwork analysis (see Annex A). Outcrops have been scored from 1 to 5 corresponding 1 to Very Incipient and 5 to Very Significant according to each risk category detailed in Table 28. Rock 24 of Ribeira de Piscos (ID # 26) obtained the highest score while Rock 4 of Penascosa (ID # 16) attained the lowest. These results do not come as a surprise as the case of Rock 24 of Ribeira de Piscos has already been signalled by the author on another occasion (Fernandes 2008a) as one of the outcrops in worst condition in the entire Côa Valley rock-art complex (see Figure 206). On the other hand, Rock 4 of Penascosa, despite presenting noteworthy conservation issues, most definitely reached the lowest score due to the fact that the lower half of this quite minute outcrop (when compared to other Côa Valley outcrops) was covered in soil being only exposed by an excavation carried out after its discovery in January 1995 (Baptista and Gomes 1997, 336) (see Figure 9 and Figure 182). As discussed in the previous Chapter, such a high magnitude of values reinforces the significance attributed to Physical weathering mechanisms as the most pressing group of weathering processes affecting the Côa Valley rock-art outcrops. These results further suggest regarding this set of weathering variables as the component to receive the highest weight in the condition assessment of outcrops.

In the intervention urgency scale, the final score of each outcrop will be grouped in five distinct physical weathering damage categories according to the following rating system: 1 - Very Incipient (10 to 19); 2 - Incipient (20 to 29); 3 - Moderate (30 to 39); 4 - Significant (40 to 49) and 5 - Very Significant (50 to 60). The first group (Very Incipient - 10 to 19) corresponds to quite minimal damage and comprises the lowest possible score (19[74]). Hence, it is used as an indicator of what would be the most 'favourable' attainable outcrop condition assessment (regarding Physical weathering damage) in spite of the fact, not at all surprising, that none scored such a low value.

6.4. Setting assessment

6.4.1. Slope

The literature review carried out in the previous Chapter suggests that the outcrops located in more sharply inclined slopes will be more susceptible to rock falls, landslides and subject to more pressure. Figure 28 presents the slope data in the area of study classified according to the Slope Steepness Index detailed in Table 4. Steeper slopes are obviously located encompassing the area's drainage system constituted by the Douro and Côa rivers and the myriad of the more or less sizeable tributaries of these two rivers. The large majority of rock-art outcrops (both in the total rock-art complex, the total universe considered for the sample and, accordingly, the sample itself) is located in these steeper slopes (see Figure 202). In fact, the river's geomorphological down-cutting process favoured the emergence of outcrops precisely in these steeper slopes.

In the first instance, slope inclination values of the precise location where each outcrop comprised in the sample is positioned have been ascertained by manipulating a 10-meter resolution Digital Elevation Model (DEM)[75] with the ArcView's 9.2 Spatial Analyst slope tool (McCoy and Environmental Systems Research 2004). Since this tool presents results in a default scale other than the one supplied by the Slope

---

[74] As there are 7 out of a total of 12 categories in which the lowest possible score is 2 (Incipient), the overall lowest attainable score is thus 7x2=14+5(categories featuring 1 – Very Incipient) x1=19.

[75] A DEM is a sort of table containing multiple x (Latitude), y (Longitude) and z (Altitude) values of the same geographic points for an entire given area of study and, in this case, taken every 10 meters. This table can be manipulated in GIS software packages in such a way the desired information (namely, spatial analysis information such calculation of slope and aspect) can be obtained and displayed (Anon. 2010).

Steepness Index, scale intervals that appear in figures pertaining slope have been modified accordingly. During fieldwork, a clinometer was used to confirm the values obtained by the software suite. It was verified that just over a quarter of those values (11 in 40) were not correct[76]. In fact, in all these eleven cases, values obtained in field readings were always higher than those computed by the Spatial Analyst tool. Incorrect values are something to expect due to data precision and spatial resolution issues (Carter 1992; Zhou and Liu 2004). Hence, in all cases concerned, for the classification of slope value, the highest field readings were preferred over the ones produced by DEM analysis. Field verification of the values determined by the Spatial Analyst tool has confirmed the above-mentioned accuracy issues while assuring that slope steepness values regarding the precise location of the outcrops comprised in the sample were correctly determined and categorized. It was also decided to measure total slope of the precise hillside where outcrops are located by using available maps of the region containing contour lines[77] since DEM derived calculations only provide the slope for the precise location of each outcrop. Moreover, it was deemed as relevant to ascertain the inclination value for the entire slope since it further characterizes the risk for outcrops regarding slope conditions each is subject to. The final slope risk indicator will therefore be constituted by both values.

6.4.1.1. Slope risk characterization

The first conclusion arising from the examination of data present in Table 30 is that tilting of outcrops faces cannot be correlated with steepness of slopes. That is, it cannot be stated (at least in the case of the examined outcrops) that steeper slopes 'produce' more inclined outcrops faces, contrary to what has been suggested in the previous Chapter. It must be assumed therefore that other factors, namely the precise

---

[76] Considering the purpose of research, DEM analysis' values were only considered incorrect if it meant field readings made the outcrop to be positioned in a different category regarding the Slope Steepness Index. To avoid incorrect readings, two tripods were used (one for the clinometer, the other featuring a reading target) so that both clinometer and target were positioned, along the slope, at the same height above ground.

[77] This was done by applying a common estimation methodology where Rise/Run x 100 = %Slope. For the determination of the straight line from which slope was estimated two positions were considered for each outcrop: the precise location of the concerned outcrop and the nearest (also considering aspect of the hillside) highest summit contour line to the same outcrop (NFES 2007, 2.17-8). The maps that were used range from larger scale maps (1/1 000; 1/1 200; 1/1 500; 1/1 750; 1/2 500) made by in the course of scheduling procedures, under the Portuguese Heritage Law, of rock-art sites in the Côa (Fernandes 2008b) to smaller scale Portuguese Army maps (1/25 000), utilized when the former were not available.

nature and result of the tectonically driven river system down-cutting process upon the particular bedrock present in each slope, may be decisive to explain why outcrops faces present different tilting values. In fact, the relation between steepness and inclination of outcrops appears to be quite random and no trends can be observed. Possibly, the only way to establish if a direct connection can be made is by monitoring if the inclination of outcrops increases with time in such a way that it could be established that steepest slopes foster greatest tilting acceleration. This would obviously be a project for the long run. Hence, as noted above, tilting of outcrops is used as a risk indicator in the category Rock characteristics. Nevertheless, Table 30 presents data regarding tilting of outcrops to illustrate why it is suggested that no direct connection between steepness and tilting appears to occur.

Of the outcrops included in the sample, only one (ID # 27 – Tudão Rock 1) is not included in the last four categories. Only in 13 cases the value obtained for the precise location of the outcrops concurs (that is, falls in the same category) with the figure derived from map-based slope estimation. In all other 27 cases, Slope Steepness Index values differ in category between map and DEM based calculations. Furthermore, absolute results from DEM analysis are higher that those resulting from map-based slope estimation in 21 cases. The contrary is valid for 17 instances while there are 2 cases in which results are equal (ID #'s 16 and 17 – Penascosa Rocks 4 and 5). The later situation can be explained by the fact that these two Rocks are located quite near each other (less than 10 metres). Since slopes are not uniform and possess differently inclined areas these discrepancies are not surprising. Moreover, these dissimilarities further validate the methodology followed of having two distinct measures for slope since the end-result from grouping these two sets of variables will deliver a more accurate assessment of slope derived risk for the rock-art outcrops.

For ranking purposes, risk indicators in this category has been grouped in five classes as follows: 1 - Very Incipient (<30%); 2 - Incipient (30% to 45% - Very Strong Slope); 3 - Moderate (46% to 70% - Extreme Slope); 4 - Significant (71% to 100% - Steep Slope) and 5 - Very Significant (> 100% - Very Steep Slope). The total score corresponds to the average considering in equal proportions the map readings and DEM calculation values, as it is believed (see discussion above) that both measures contribute in identical share towards slope risk characterization. Hence,

Table 30 presents after the final value in column ‘Total average’, a number from 1 to 5 indicating to which risk category class the outcrop falls in.

6.4.2. Aspect assessment

Measurement of aspect of the considered Côa Valley rock-art slopes revealed an interesting find. The data displayed in Figure 38 shows an uneven distribution amongst classes. Considered together North and West oriented slopes only account for just over 10 percent, South-facing slopes total almost a third while East-facing slopes constitute more than half of aspects. It is quite significant that the North class represents just 4 percent of slope aspects. Due to the river down-cutting process, that took advantage of two major regional joint families of NE-SW and WNW-ESE orientation to expose the outcrops that were later engraved, there is, roughly, an even distribution of aspect in the region (around 25 percent for each class - Figure 207). Therefore, it would be expected, if each aspect class featured the same number of outcrops viable to be engraved, to find a similar distribution of rock-art outcrops in each aspect. Elsewhere, the author has suggested that the disparity in the North and West aspect class may be explained by differential conservation issues or cultural reasons (Fernandes 2010b). Aubry *et al.* (2012) disregard any culturally-based explanation as their study of regional geological factors suggests that differential conservation issues may totally explain the discrepancy. Based on a partial study of the area with rock-art, the authors conclude that the regional fault and fracture system has a predominant “NNE-SSW direction with four secondary orientations: ESEWNW, NE-SW, N-S and ENE-WSW” (Aubry *et al.* 2012, 858). Hence, they conclude:

> “The hydrographical down-cutting was forced by this tectonic background and generated the progressive exposition of panels on opposite margins of the watercourse, i.e., facing either SE or NW. Such geologically forced orientation explains the absence of unengraved panels (and, logically, of engraved ones as well) facing N, S, NE, SW, E and W in the area, independent of cultural choice.” (Aubry *et al.* 2012, 858)

These results portray an accurate description of the situation in the study area (encompassing only the rock-art sites located around the mouth of the Côa). However, in other areas of the Park, rock-art outcrops do possess other orientations as data presented in Annex A regarding field aspect measurements illustrates. Moreover, if indeed in Aubry *et al*.'s study area there are only SE and NW facing outcrops, another question arises: why does rock-art has been engraved almost exclusively in SE facing outcrops if indeed both NW and SE facing ones were available to be used? According to the authors, the explanation lies in differential conservation issues, namely those motivated by solar radiation, humidity and presence of lichens and bryophytes. Their argument is twofold. On the one hand, NW facing outcrops presented, at the end of the Upper Palaeolithic, more advanced biodeterioration weathering due to the action of the two types of organisms. Accordingly, these have not been elected to be engraved due to bad surface conditions. On the other hand, the authors suggest, these have been indeed engraved during that period but biodeterioration has since promoted the disappearance of motifs. Considering these two hypotheses, the authors propose that, depending on the specific case of each outcrop, ongoing weathering processes have begun after late Upper Palaeolithic engraving episodes peaking during Early to Middle Holocene times (Aubry *et al*. 2012, 862). This proposition is rather odd since it implies that no substantial weathering occurred prior to late Upper Palaeolithic engraving episodes in the available (and presumably in good condition) surfaces that existed in both NW and SE facing outcrops. Since exposition of outcrops in the Côa, due to the river system down-cutting process, has been dated to have begun some 130,000 years ago (Phillips *et al.* 1997)[78], it is problematic to envisage that weathering has only strongly affected the outcrops in the last 10,000 years or so.

Moreover, if indeed bryophytes do prefer shaded areas to colonize (broadly speaking, North facing surfaces albeit these organisms may be present in other aspects depending on the precise micro-topographic and, thus, microclimatic characteristics of a given precise location), lichens do grow in surfaces facing all aspects, since they require sunlight, even if a minimal quantity, to thrive, as the authors acknowledge (Aubry *et al.* 2012, 861)[79]. Hence, an appreciation of the relationship between lichen colonization and aspect requires a careful determination of lichen diversity present in differently oriented panels, since it has been noted that existent species (thus, their detrimental impacts on outcrops) vary according to orientation (Joana Marques,

---

[78] Phillips *et al.* have dated the 'diclosure' of four rock-art outcrops which provided 36Cl exposure ages ranging from 16,000 to 136,000 years (1997).

[79] However, there are authors that concluded from their specific case-studies that the "relatively minor weathering occurring on northern faces can be attributed to decreased weathering from lichens" (Paradise 2002, 1) while others found that no rapport between lichen induced weathering and aspect could be established (Hall *et al.* 2005).

personal communication). Moreover, as it was discussed in the previous Chapter, there are authors that doubt that lichens and specially bryophytes play such a prominent role in rock weathering dynamics. In fact, some suggest that it is an already weathered condition of rock faces that ‘attracts’ colonization by these organisms (for instance, the previous existence of crevices favours their settlement) (Bakkevig 2004; Bech-Andersen 1985). Accordingly, it may not be a case of lichens and bryophytes being decisively responsible for weathering, but rather one of these organisms taking advantage of and colonizing an ‘auspicious’ previously weathered rock face. Therefore, according to Aubry *et al.*’s argument, if a rock surface was already weathered and in bad shape, then it would not have been chosen to be engraved by prehistoric artists. Hence, if indeed Upper Palaeolithic artists did favour both NW and SE facing existing outcrops to engrave, it is suggested that biodeterioration issues cannot solely explain why motifs in NW facing outcrops have weathered away being today so scarce[80].

The following subsection aims to ascertain if differential aspect has a relevant role in weathering of outcrops in the case of the Côa. Even if Biodeterioration factors are not sufficient to make such a case, an analysis of microclimate variations in different aspects may help to determine if, as the literature review carried out in the previous Chapter seems to imply and Aubry *et al.* suggest, North facing outcrops suffer greater decay than those possessing other aspects. An attempt of characterization of the different levels of risk outcrops located in differently facing slopes might incur is vital to measure and analyze major microclimate variations, namely in the major aspect categories. Therefore, data provided by the weather stations installed in Park are used for that purpose.

6.5.1. Microclimatic data

General weather characterization data gathered by all the Park’s stations presented in Chapter 4 are used together with precise information regarding rock face temperature and wetness to attempt to distinguish if diverse aspects imply different weathering rates. In all three new stations, temperature and wetness sensors have been installed.

[80] This suggestion does not consider cultural issues such as the ones mentioned by the present author in the above referenced paper. Rather, it implies that other weathering processes other than biodeterioration have to be accountable for the paucity of motifs in NW facing outcrops.

Unfortunately, since PEN1 is malfunctioning since the end of 2008, data regarding the West-facing slope where this station is situated will not be available for direct comparison with CINF, PEN2 and VJE. Moreover, if PEN1 was fitted with two rock temperature sensors, these have been installed at depth of 60 cms inside two distinct outcrops. Moreover, PEN1 does not have a leaf wetness sensor installed. To partially counter these limitations, temperature sensors installed in some outcrops faces of the Côa Valley in the course of the PhD that is being currently developed by biologist Joana Marques on the lichen colonization in the area of the Park will be used[81].

6.4.2.1.1. Rock face temperature

Temperature sensors[82] installed in rock faces and connected to the Park's stations are located in all major aspect classes (with the noted West exception): CINF-B (East); PEN2-B (South) and VJE-B[83] (North). Unless stated otherwise, measuring intervals in all the Park's stations were the same as mentioned in Chapter 4, that is 15 minutes[84].

Table 31 and Table 32 summarise recorded temperature data for 2011 by CINF-B and PEN2-B. Figure 208 and Figure 209 present partial data regarding rock face average temperature in the months of March, April and May 2010 (when VJE-B data are available) with the same period of 2011 (when VJE-B data are not available). Although a clear indication that 2011 was hotter than the preceding year, amplitude of variation between sensors are the data with the most interest. Although being an hypothetical exercise applied to variables that do not behave in a linear predictable fashion, comparison of evolution of temperature values between the same period of the consecutive years, suggests temperature in VJE-B, in accordance with data supplied by air temperature values (see Chapter 4), would always be lower than in the other two locations and, furthermore, would maintain a steady interval to both PEN2-B and CINF-B values. A comparison of the 2011 available data regarding average monthly temperatures from CINF-B and PEN2-B with air temperature values for CINF, PEN-2, VJE and the 2004/08 data series for PEN1 is displayed in Figure 210.

---

81 The sensors used by Joana Marques also measure relative humidity. However, due to unreliable measuring of Relative Humidity, this variable has not been considered in research reported here.

82 WatchDog External Temperature Sensor 3367 measuring temperature with a resistance-based sensor, possessing a range/resolution of -32º to 100º C and accuracy of ±0.6º C.

83 The letter B is used to differentiate rock face temperatures from air temperature ones.

84 Unfortunately, sensor VJE-B has been vandalized and stolen in June 2010, shortly after the station was installed. It has not been possible to replace it. Hence, data from VJE-B is only available from the 1st of March until the 31st of May 2010.

In accordance with air temperature data, CINF-B attained the highest values. It is noteworthy to mention that both CINF-B and PEN2-B reached, namely during the summer, quite higher values than air temperature ones.

For comparison and verification purposes, data gathered during 2011 by temperature sensors installed by Joana Marques (TMPJM) in outcrops faces located in all major aspect classes is also discussed. The sensors in question are VC1-B and VC5-B (East), VJERTS-B (South), CA1-B (West) and VJE16-B (North)[85]. Figure 211 illustrates the location of these sensors. It is noteworthy to mention that these are located in an area encompassing less territory than those covered by the Park's stations. Moreover, the sensors installed in North and South facing slopes are located on opposing hillsides of the same valley (Vale do José Esteves), at a lower altitude than the Park's North-facing VJE, positioned in the North-facing slope of the same valley. Contrary to what occurs with the Park's sensors, the South-facing sensor, VJERTS-B, recorded the highest monthly average temperature immediately followed by the East-facing one (VC1-B) Figure 212. Moreover, temperatures recorded by TMPJM sensors are significantly lower, during the summer, than those measured by CINF-B and PEN2-B and peak (with the exception of the North-facing VJE16-B) during August instead of July as it happens with the Park's sensors. It is worthy to mention that VJERTS-B, after a summer evolution in line with other sensors, attains quite higher values during fall. Figure 213, comparing values recorded by TMPJM sensors with air temperatures measured by the Park's stations, shows that only the North-facing VJE16-B has reached lower values than the Park's air temperature

---

[85] DS1923 Hygrochron Temperature/Humidity Looger iButton with 8KB Data-Log Memory with an operating range of -20º C to 85º C and 0,5º C or 0,0625º C measuring resolution. The precise location of the sensors is: VC1-B, N 41º 09' 28.7" / W 07º 11' 61.5" at an altitude of circa 230 meters; VC5-B, N 41º 09' 05.6" / W 07º 11' 89,6" at an altitude of circa 300 meters; VJERTS-B, N 41º 08' 41.1" / W 07º 10' 94.9" at an altitude of circa 200 meters; CA1-B, N 41º 05' 52.4" / W 07º 10' 26.9" at an altitude of circa 320 meters; VJE16-B, N 41º 08' 36" / W 07º 10' 96.1" at an altitude of circa 180 meters. VC1-B had a measuring interval set at 30 minutes while CA1-B recorder every hour until 11/03/2011 and, from then on, every 30 minutes. Sensors VJERTS-B and VJE16-B had measuring intervals set at 1 hour. The former was launched only in 02/07/2011 and the later in 15/04/2011 while VC1-B and CA1-B recorded the complete year. VC1-B and CA1-B sensors suffered minor data loss, which occurred in three different periods of the year, having the longest a 13-day span. All considered, these losses account for just over 9% of the whole year. Hence, these failures are not believed to greatly affect final values. Resolution for all measurements was set at 0,5º C with the exception of the 6th of July 2012 in which values were measured at the higher resolution (0,0625º C) and recording intervals were set at 1 minute, as detailed below. It should also be noted that, contrary to what happens with the Park's B sensors, TMPJM ones do not directly measure surface temperature but rather surface near the surface as they are fixed with an adhesive band that does not allow contact with the rock face (see Figure 214).

sensors, although in the summer it has surpassed VJE values. Nevertheless, the difference intervals between temperatures recorded by both sets of sensors are reasonably constant, in the order of 2º C, with the noted exception of VJERTS-B during fall.

If data presented above are important for microclimatic characterization, analysis of daily and hourly temperature variation is arguably more decisive to establish what impact these variables may have in weathering of differently facing outcrops. Hence, a few days and, within these, hours were selected to be analysed in detail. First, the 13th of March 2010 has been chosen since all of the Park's three rock face temperature sensors were working at the time. Moreover, it was a winter day with air temperatures reaching values below 0º C. Figure 215 shows that while air temperatures plunged below 0º C (although barely, namely in the case of VJE), rock face temperatures did not exceed such a threshold. Moreover, while VJE temperature values (both VJE and VJE-B) remained quite steady[86] and similar to air values recorded by the other stations, PEN2-B and specially CINF-B records rocketed during the afternoon to reach, in the case of the later, 31,2º C, which constitutes in fact the remarkable DTV value of precisely 30º C. Finally, it should be noted that in short periods of time there can occur reasonably high variations in rock face temperature. For instance, in the period from 11:00 to 11:30, PEN2-B values plummeted precisely 3º C while from 11:00 to 11:15 the drop was approximately half that value.

The next day to review in detail is the 26th of January 2011, which was chosen because it was the day reaching the lowest temperature of the year (see Table 17). Rock face temperatures (available only for CINF-B and PEN2-B) generally follow the trend detailed above for the 13th of March 2010, with the difference that values well below 0º C were reached, higher, nevertheless, than corresponding air temperatures figures (see Figure 216). In this regard, it is interesting to note that a comparison between CINF and PEN2 air and rock face temperatures concerning the number of days values below 0º C were reached in 2011, shows that rock surface temperatures have lowered below that threshold only about half the number of days recorded by air temperature sensors (see Figure 217). Available data for TMPJM sensors[87] further

[86] Indeed, the rock face sensor even recorded lower values during the afternoon than air temperature ones for VJE, due to the positioning of the sensor in a shaded area.
[87] According to what was mentioned in footnote 85, only VC1-B (East) and CA1-B (West) supplied relevant information to consider since these were the only TMPJM sensors that recorded temperature

confirms this trend as in all of the measured period, no temperature below 0º C has been measured. DTV values are lower than in the preceding analysed case, while rapid rock face temperature changes display comparable amplitudes (Figure 216). The hottest day in 2011 (26th of June) displays some striking dissimilarities and similarities when comparing with colder days (Figure 218). For instance, while DTV values for rock face temperatures are considerably higher (almost 35º C for CINF-B), air and rock temperature displays fewer differences, especially considering the hottest period of the day. Moreover, rapid rock temperature changes possess similar amplitudes to those of cold days.

A full day measured with a 15-minute interval only provides a limited amount of data regarding rock surface temperature variation. Hence, two days were chosen to set the measuring interval at one minute. Figure 219 depicts daily temperature records plotted in connection to relative humidity values for the 8th of February 2012, a winter day in which air temperatures reached values below 0º C. Besides confirming the already noted pattern on rock face temperatures being consistently higher than air temperature ones (just slightly in the coldest periods of the day but vastly, especially in CINF-B, on the hottest hours), the clear relationship between temperature and relative humidity values can be ascertained. Depending on the precise micro-topographical location of the stations, only when the sun starts to directly beam on the rock faces does temperature begin to rise and relative humidity to fall (hence, the different times for morning temperature rise in CINF-B and PEN2-B). Figure 220 displays not only the lag between CINF-B and PEN2-B temperature rise when the first rays of sunlight appear on the horizon immediately after dawn but also the relationship (in the case of CINF-B) between temperature rise and relative humidity fall. It is interesting to note that in half an hour, CINF-B temperature increased by some 7º C and that during that period there was a double 0.7º C increase per minute (at 08:34 – 08:35 and 08:35 – 08:36). On the other hand, it is interesting to mention that, during the same day but in the afternoon, relative humidity values appear to not greatly influence temperature change, especially in the case of CINF-B. While RH values are somewhat invariant, that did not prevent CINF-B undergoing relatively rapid temperature changes, namely in the period from 13:05 to 13:10 GMT (Figure 221). Moreover, a fact that was already hinted by readings set at a 15 minutes interval

---

all year round.

becomes clearer in Figure 221: besides reaching lower temperatures, PEN2-B undergoes less significant temperature changes than CINF-B. In the analysed period, PEN2-B suffered a circa 2º C amplitude variation while CINF-B reached circa 4º C. Rate of temperature change in CINF-B is analysed in greater detail in Figure 222. During this period, half a degree is the maximum value attained in a one-minute period (13:06 – 13:07 GMT) by CINF-B.

A summer's day (6th of July 2012) was also recorded at a one-minute interval by both the two Park's B sensors in operation and TMPJM sensors (see Figure 223). Since it was a cloudless day, sky conditions cannot account for the discrepancies observed[88]. While the Park's B sensors values generally follow the already identified trend, in spite of the fact PEN2-B (the South-facing sensor) presents higher values than CINF-B, contrary to what was noted above, TMPJM's display quite intriguing values. First of all, VC5-B (the East-facing sensor)[89] displayed an increase curve about an hour after sunrise (which occurred on the considered day at 06:03 GMT[90]) similar to those presented by the Park's B sensors, albeit not reaching as elevated temperature values. Nevertheless, the increase began about two hours earlier than in CINF-B, a fact that was due to the higher altitude positioning of VC5-B (and thus, relatively but also absolutely speaking, lower opposing slope). This has meant that the sun started to shine upon the location of the sensor only about an hour after sunrise contrary to the roughly 3 hours it took before reaching the position of CINF-B. The discrepancies between the values recorded by the East-facing VC5-B and the South-Facing VJERTS-B sensors are, however, harder to explain, especially considering PEN2-B (South-Facing) temperature increase curve. It should be also highlighted that with only VJERTS-B did temperature not exceed the highest measured air temperature of the day (32º C, recorded by CINF, closely followed by PEN2 with 31.2º C). If increase curves shown by CA1-B (West) and VJE16-B (North) are within expected values, the lack of significant augment throughout the day in VJERTS-B is

[88] At this point, it should be noted that an analysis of the discrepancies between the values provided by TMPJM and the Park's sensors must take into account that TMPJM's do not directly measure surface temperature, diverse measuring resolutions, altitude dissimilarities but mostly the fact that the Park's used sensors are located in the Côa river valley, more open than the tributary waterline valleys where TMPJM sensors are positioned (compare Figure 151 with Figure 211).

[89] For logistical reasons, VC5-B was used instead of the previously utilized VC1-B. Nevertheless, both are located quite near to each other in East facing slopes, albeit the former stands reasonably higher than the later (see Figure 224).

[90] Sunrise determined resorting to http://www.sunrisesunsetmap.com/.

quite inexplicable without considering the (apparently decisive) role of micro-topographic issues. CA1-B (West) and VJE16-B (North) values also display some interesting data, namely two temperature increase peaks at the end of the day (CA1-B between 17:30 and 20:00 GMT and VJE16-B between 17:30 and 18:30 GMT) (Figure 225). This corresponds to the periods, during the considered day of the year, in which the sun directly shines on the location of the two sensors. Finally, analysis of other specific periods of the day (Figure 226, Figure 227 and Figure 228) revealed slightly higher values of temperature variation in 1 minute, than those recorded in the winter day measured at a one-minute interval. The West-facing CA1-B presents a value of 0.8º C (20:29 – 20:30 GMT) while the North-facing VJE16-B and the South-facing PEN2-B have notably recorded 1º C (VJE16-B: 18:09 – 18:10 GMT; PEN2-B: 14:31 – 14:32 GMT).

6.4.2.1.2. Rock face wetness

Leaf wetness (LW) sensors[91] have been installed in CINF, PEN2[92] and VJE. Figure 229 displays available data for the three stations from March 2010 until December 2011 regarding average monthly leaf wetness values. Again, as with rock face temperatures, CINF-LW attained the highest values being only, marginally, surpassed by VJE-LW in August 2010. Recorded values for PEN2-LW until August 2010, hint that in the remaining analysed period, this sensor would have, more or less consistently, attained the lowest values. As with rock face temperature, individual days will also be reviewed in greater detail. In the days chosen to review in detail, no precipitation occurred. Data from the 14th of March 2010[93] (Figure 230) shows that CINF-LW attained the highest values (being completely humid during a great part of the evening) while the other two have not. Nevertheless, while CINF-LW underwent rapid increase until reaching the upper limit and then witnessed an also swift decline, VJE-LW suffered several relatively abrupt drops and increases, namely in the period

[91] WatchDog Leaf Wetness Sensor 3666, measuring wetness using a 0-15 scale in which 0 corresponds to totally dry and 15 to completely damp.
[92] Unfortunately, the sensor installed in PEN2 stopped functioning on August 2010 and it has been impossible to replace it.
[93] Initially, the intention was to analyse the same days as the ones that were reviewed regarding rock face temperatures. When it become apparent that in some of those days, the sensor recorded no wetness (only zero values), days close to the days in which rock face temperatures were analysed were selected.

01:30 – 03:00 GMT. Another observation that can be made is that the relationship between LW and RH appears not be completely linear or synchronous.

The 26th of January 2011 (the day when the lowest temperature of the year was recorded) provided some interesting data, namely the further confirmation of what was just suggested above on the LW and RH relationship (Figure 231). It should be noted that both stations recorded the highest values not during the night but in the morning well after sunrise. A summer's day record[94] (Figure 232) again presents CINF-LW as the sensor attaining the highest values (on this occasion, just after noon). Moreover, in this day, a less un-linear and asynchronous relationship can be established between LW and RH during the period in which wetness values were recorded. In one of the days in which measuring was set at 1 minute intervals (the 8th of February 2012), no wetness was recorded by VJE-LW, which is in itself relevant information (Figure 233). Nevertheless, detailed examination of a 20-minute period (07:20 – 07:40 GMT) recorded by CINF-B reveals that in just a minute (07:32 – 07:33 GMT) the wetness value dropped by more than half, from 3,6 to 1,6 LW (Figure 234). This drop precisely coincided with sunrise, which during that day occurred at 07:32 GMT[95]. As other variables, namely air temperature and relative humidity values, are constant during the analysed period, the only changing variable (solar radiation) is shown in rapport with LW decrease in Figure 235.

6.4.2.1.3. Solar radiation

Data presented in Chapter 4 shows that VJE, the North-facing station, recorded the highest amount of solar radiation in 2011. Figure 236, Figure 237, Figure 238 and Figure 239 illustrating solar radiation during four different winter and summer days of 2010, 2011 and 2012[96], generally confirms that find. Even considering and discounting expected fluctuations, motivated by changes in cloud cover that at a certain moment may affect the precise location of each station, VJE consistently and throughout the four analysed days, recorded the highest values. Another conclusion that can be drawn is that daily solar radiation values at any given location are subject

---

[94] The 9th of June 2011 and not the day with the hottest temperature of the year since no dampness was recorded on that day.
[95] Sunrise determined resorting to http://www.sunrisesunsetmap.com/.
[96] Due to a punctual malfunction in PEN2-SR, Figure ? regarding the 8th of February 2012 does not contain data from this station.

to variations that are random in origin, that is to say, those connected with shifting sky conditions. Hence, only the total yearly amount received by a given station should be considered when trying to establish differences between distinct aspects.

6.4.2.2.4. *Wind direction and speed*

Data regarding wind direction during 2011 reviewed in Chapter 4, offers even more inconclusive information about variations in these variables connected to different aspects. In fact, wind direction regimes differ widely between the three stations. Moreover, it does not concur with both the data gathered by FCR weather station and the established prevailing wind direction for Portugal (NW). Evidently, one year recording, especially when comparing with data series abridging several decades, does not allow drawing clear-cut conclusions. Nevertheless, it is apparent that in CINF and PEN2, during 2011, wind predominantly blows from directions that are perpendicular to the orientation of slope itself (E and W in CINF and S and N in PEN2). VJE, probably due to the noted altitude issues of its location, presents a more varied wind direction regime, being that Northern directions account only for about 8 percent of recorded wind directions. These dissimilarities may probably find a partial explanation in specific micro-topographical factors, namely, in the case of PEN2 and VJE, the precise configuration of the river system valleys. Hence, it is quite complex to draw insightful data from wind direction regimes regarding different aspects. It is believed that the only noteworthy conclusion is that, during 2011, calms percentages were much lower for VJE (58,2 percent) than for PEN2 (71,8 percent) and especially CINF (82,8 percent). Again, the different altitude where VJE is located may explain the discrepancy.

On the other hand, wind speed regimes apparently offer broader perspectives. Average speed value recorded by VJE in 2011, still quite lower than what was recorded by FCR, is more than six times the one measured by CINF and almost double that of PEN2 while gust values are similar in all three stations. Nevertheless, such a difference in wind speed regimes may be again attributable to the higher elevation at which VJE is positioned and might not repeat itself in subsequent years.

6.4.2.3. *Aspect risk characterization*

Considering all the data reviewed above and in Chapter 4, it is a quite intricate task to quantify and qualify risk level for outcrops regarding their aspect. Nevertheless, for all subsections regarding aspect identified in the previous Chapter, an evaluation of how available data is of use when characterizing aspect-base risk is carried out below.

6.4.2.3.1. Aspect, expansion and retraction cycles, and solar exposure

Available information regarding thermal daily and hourly temperature amplitudes, one of the variables that arguably most decisively determines expansion and retraction behaviour and thus weathering rates, does not allow the drawing of definite conclusions on the matter. If, on one hand, data obtained by the Park's stations suggests that Eastern aspects suffer the highest daily temperature amplitudes, it is also observable that this does not translate in extreme rates of temperature change per minute (in the analysed cases, 1º C was the highest value recorded). In fact, analysed rock face measurements suggest that rates of temperature change per minute are not as extreme as those described by Meiklejohn *et al.* who mention values of more than 2º C per minute, which "may be sufficient to induce cracks along grain boundaries" (2009, 976), occurring at their test site.

All presently analysed days suggest that rates of temperature change per minute are similar in the considered four aspects. DTV values follow a slightly different pattern with the Southern aspect presenting almost all of the highest values closely followed by East. However, available data from TMPJM sensors suggest that Southern aspects (followed by Eastern, Western and Northern) suffer greater DTV values and also rates of temperature change per minute. These finds are somewhat confirmed by the number of days measured by the Park's stations in 2011 with average air temperature ≥ 25º C, with the South-facing station top of the list followed by East and finally by North.

Available wetness (another major factor connected with the expansion/retraction behaviour and weathering rates) readings, on the other hand, suggest that again Eastern faces suffer higher dampness levels. These levels seem to be independent of humidity, which, at least for 2011, is quite homogenous, with the relative exception of VJE during some months, in the three stations. The Eastern located sensor also appears to undergo more extreme changes featuring, in one of the analysed days around a 10 percent drop in wetness levels in one minute, explainable by sunrise, while in the same period the sensor installed in VJE (Northern aspect), the only one available for comparison purposes, albeit experiencing a decrease, did not endured such a sharp fall.

Precipitation data are more in tune to what the literature reviewed in the previous Chapter suggests: slopes and outcrops possessing a Northern exposure (in the Northern Hemisphere, at least) bear a higher risk of weathering and erosion. In fact, VJE recorded the highest precipitation values by a quite considerable margin. The Southern and Eastern facing stations present quite similar values. Nevertheless, this can be an episodic yearly fluctuation as the higher average 2004/08 values for PEN1 imply. Besides variation between different years, it is very likely that fluctuations between the diversely placed stations may occur. Partial precipitation data recorded by the Park’s stations in 2010 confirm such an assertion as VJE did not (barely) reach the highest amount of precipitation (which occurred in PEN2) and precipitation in the month of September has been higher in PEN2 than in the other two locations (Figure 240). On the other hand, sudden high precipitation episodes do not offer any conclusive insight regarding different aspects since 2011 values are fairly homogenous. Moreover, as noted in Chapter 4 even the highest value reached by PEN1 during its 2004/08 recording run was relatively low.

Data for 2011 place the North-facing station (VJE) as the one receiving the highest amount of solar radiation in 2011. As already noted, this is a quite perplexing result since not only the specialized literature but also empirical knowledge markedly indicates that, in the Northern Hemisphere, North-facing slopes receive the least amount of solar radiation. Hence, as reviewed in the previous Chapter, a higher probability of higher wetness levels occurs in slopes possessing such a exposition which, in turn, are decisive in weathering rates. Again as noted previously, the divergent total results delivered by the Park’s stations must be interpreted, however, bearing in mind the different precise locations of the stations. The same criteria must be applied to the interpretation of information delivered by the detailed analysis carried out regarding precise days together with the acknowledgement of how sky conditions (daily but also hourly) may differ significantly between the different locations of the stations.

Moreover, a DEM-based calculation of total solar radiation in the region during 2008 clearly suggests that North-facing slopes receive much lower amounts than slopes with other orientations (see Figure 30). The same calculation also provided total 2008 solar radiation estimates for the precise location of each of the outcrops comprised in the sample (see Annex A). Not surprisingly, North-facing outcrops present the lowest values[97].

6.4.2.3.2. Aspect and aeolian erosion

Again, data supplied by the Park's stations are inconclusive regarding wind direction and speed patterns during 2011. The precise location of stations does not allow drawing relevant inferences on the relationship between wind regimes, different aspects and weathering rates. It can therefore be suggested that aeolian erosion randomly affects differently oriented outcrops, being that those located in more sheltered slopes and at lower altitudes may suffer less erosion. However, to further validate this suggestion, a longer data series would be required.

6.4.2.3.3. Aspect and low-temperature weathering mechanisms

The most noteworthy conclusion that can be inferred from the analysed data is that, at rock surface level, temperature does not drop below 0º (the essential condition for low-temperature weathering mechanisms to unfold) as much as it does when 'standard' air temperature values are considered (see Figure 217). Moreover, TMPJM sensors have not recorded any value below 0º C during 2011. This is a quite relevant find that may help explain (together with the favourable records of other weather patterns, such as precipitation, since prehistoric times), the survival of the Côa Valley rock-art complex to its present magnitude. On the other hand, data pertaining to precise days suggests that PEN2-B (the South facing sensor) suffers slightly longer daily periods in which temperatures remain below 0º C. Nevertheless, these are only marginally longer periods. Moreover, while it is true that PEN2-B experienced an extra day of temperatures below 0º C than CINF-B (14 against 13), it did not record the lowest temperature and presents a higher yearly lowest average value than CINF-B (7.5º C against 7º C).

[97] Although DEM-based estimates refer to 2008 it is proposed that, discounting minor punctual flutuactions, these are also valid for 2011 regading aspect-based distribution of solar radiation since the topographical setting of the region has not changed.

6.4.2.4. *Conclusion on aspect risk characterization*

The last issue discussed in the subsection dedicated to aspect of the previous Chapter was *Aspect and vegetation growth*. However, vegetation growth impact on weathering is examined in the following section. Data arising from the condition assessment of each outcrop in the sample regarding vegetation growth will be put in contrast with aspect data. For reasons that are illustrated and discussed below, this is the only instance in which aspect as risk indicator parameter is considered as a parameter to include in the intervention urgency scale.

It is believed that analysed weather data are inconclusive and insufficient to establish a relationship between aspect and differential outcrop weathering. Weather variables are complex to interpret and a one-year[98] dataset does not allow distinguishing trends clear enough to draw relevant conclusions. When longer weather data series collected by the stations that exist in the area of the Park are available in the future, it may be possible to identify trends that can help in aspect-based risk characterization. The fact that data regarding some variables are incomplete due to technical failure is also a noteworthy constraint. Nevertheless, it is believed, as complete data sets suggest, that even if a full year of records for the variables with incomplete data were available, information would still be inconclusive.

One of the few conclusions arising from data analysis is that microclimate variables are dependent on the precise location being measured. Micro-topographical features, for instance, vary widely and are dependent on the specific 'architecture' of each slope. Hence, slopes may possess slightly concave recesses that will determine the existence of areas remaining in the shade for longer periods than its vicinities. Vegetation cover (namely by mature bushes and trees) will also influence the extent of shaded areas in a slope. Shade, of course, will have an obvious influence in temperature or solar radiation measurements. Besides altitude of a specific location, contour lines may also affect microclimate variations as sunlight will differently affect (thus determining shade regimes) a steeper or a less steeper slope. Sky conditions are yet another factor that might influence the amount of sunlight different slopes will receive during a given period. The only way to completely deal with micro-topographical constraints would be to install weather stations in all outcrops contained in the sample. That would obviously be impossible. Even the halfway

[98] Or nearly two years, in the case of some variables such as wetness.

solution of carefully choosing 8 or even just 4 ideal slopes would be hindered by the same land ownership issues that prevented a more well suited positioning for VJE.

Other variables, such as wind, present such a random regime (at least during the analysed year) that even the most apparently straightforward inference is difficult to support, such as the one that speed is higher in North aspects. As discussed above, the fact that the one station located on a North-facing slope presents higher wind speed values than the other stations, does not allow generalization of this conclusion to all North-facing slopes. Moreover, as VJE is located at a higher altitude than the other two stations, the differences in wind speed may reside in its positioning. Precipitation data are also inconclusive. On a first analysis, the highest value reached by VJE, the North-facing station, during 2011, would be relevant information to be used in aspect-based risk characterization. However, this must be regarded as a one off event, which might not repeat itself in the following years (and may not have occurred in previous ones as Figure 240 suggests).

The specific impact different weather variables have in rock weathering and erosion patterns can also have an ambiguous nature. For instance, solar radiation greatly determines schist (or any other rock type) expansion and retraction cycles. It might be generally suggested that outcrops that receive more solar light (in the Northern Hemisphere, south facing ones) will be more prone to the detrimental impact of solar radiation than the ones located in less exposed aspects. Conversely, it is also true that hillsides located in areas more exposed to solar light, will 'dry up' faster after a rainfall event than others, especially out of the season in which extreme events occur. Since water circulation on the slopes is one of the factors that can enhance the risk of rock fall and increase physical weathering, a faster drying up of the slope might reduce such a risk.

On the other hand, some authors suggest that in North-facing slopes "less sunlight permits less frequent wetting and drying cycles" than those occurring on South-facing ones (Paradise 2002, 1). If, generally speaking, in the Northern Hemisphere North-facing slopes are more exposed to weathering due to the higher amount of moisture lesser quantities of sunshine dictate[99], South-facing ones will be more prone to insolation weathering. East and West facing slopes will therefore be

[99] Nevertheless, a notion somewhat questioned by Leaf Wetness data analised above provided by the Park's sensors.

positioned half way between these two extremes. If the present survival condition of the Côa Valley rock-art complex is considered, it apparently transpires that, since engraved outcrops located in East and South-facing slopes vastly outnumber those located in the other two aspect categories, moisture-based weathering has a greater impact in differential conservation statistics. Nevertheless, this assumption will only be valid if indeed roughly equal percentages of outcrops exist in all aspects. As noted above, this is not the case, since there is a prevalence of SE oriented outcrops. Therefore, Aubry *et al.* suggest that (engraved or not) NW outcrops have suffered more pronouncedly from physical and biological weathering (2012). Another possible explanation is that, for some geological or geomorphological reason, NW exposed outcrops simply were not exposed in as many numbers as SE facing ones. If this is indeed true, to differentiate between the condition of outcrops on the basis of aspect positioning is pointless, since the distribution of engraved outcrops throughout the four categories is much more dependent of the 'real' physical existence of outcrops than of differential conservation issues. However, it is suggested that the presented and discussed weather data does not permit, when physical weathering is considered and for the time being, to validate Aubry *et al.*'s model[100], or to propose an alternative one. In conclusion, it as been demonstrated that, especially considering days measured at one-minute intervals, currently available data are not sufficiently unequivocal to attempt to establish a solid relationship between outcrop condition and aspect.

6.5. Biodeterioration assessment

Previously identified biodeterioration damage parameters have to do with the presence of lichens, plants and some animal species, namely arthropods. Risk arising from the actions of these all organisms is characterized in Table 33. Nevertheless, the use of these indicators of risk as an aid to assess the condition of outcrops in the sample will be individually analysed in its own subsection below.

6.5.1. Lichens

Characterization of risk arising from the presence of lichen colonies on the outcrops (as well as of plants and arthropod colonies) included in the sample generally follows

[100] Biodeterioration weathering issues arising from Aubry *et al.*'s paper have been discussed above.

the categorization done for other parameters, classifying risk in 5 different categories. The distinction that is made between undeveloped and developed lichen colonies has to do with the size, thus age, of individuals. Generally speaking, and despite some uncertainties regarding their overall growth cycle, saxicolous lichens can develop until attaining a several centimetre radius reaching ages of hundreds if not thousand of years. Indeed, microclimate issues as well as the specific taxa of concerned species constitute factors that precisely determine growth rates in particular environments (Broadbent and Bergqvist 1986; Jomelli *et al.* 2007; McCarthy 1999). Nevertheless, it can be stated that the smaller lichens are, the less developed the colonization of a given rock surface is. Another distinction that is made has to do with lichens covering (or not) engraved areas of the engraved panel. As it was argued in the case of physical weathering processes, if colonies present themselves in a well-developed condition but not directly covering engraved motifs, weathering promoted by these organisms may more or less significantly weaken the whole outcrop. However, if these colonies cover engraved areas, risk for the rock-art is higher, since the bedrock that directly hosts imagery is affected by these organisms. Moreover, the detrimental effects of hyphae penetration and chemical weathering promoted by these organisms will contribute to the relentless disappearance of motifs themselves.

Table 34 presents the results of condition assessment of the sample outcrops regarding lichen presence. Since in some panels lichens have been recently removed (see previous Chapter), an indication is made noting if such an operation was made (R = Removed)[101]. However, lichen removal is not considered in condition assessment since what is assessed is the present condition of the outcrops. Moreover, it would be impossible to accurately know, in all outcrops where lichens have been removed, what was their condition regarding lichen colonization. Nevertheless, an indication is given so that it is explicit what where the panels that ‘suffered’ lichen removal making it possible to compare panels where removal has been carried out with those where it has not and also to assess re-colonization rhythm.

6.5.2. Plants

Characterization of risk arising from the presence of plants has been categorized according to the data present in Table 33. The first category does not imply that plants

[101] Lichens were removed from 28 panels belonging to the sample.

may not be growing near to outcrops but that these are present at the relatively far-off distance of more than 3 metres. The further distinction established between plants growing adjacent to outcrops and those rising from inside diaclases and fractures has to do with the damage for outcrops the two situations entail. While plants growing in the immediate vicinities of outcrops can foster instability in the whole area where an outcrop is located (because of the nearly invisible action of roots or by constituting wildfire combustibles), plants directly growing from the inside of outcrops automatically constitute an immediate and factual threat for rock-art outcrops as examined in the previous Chapter.

The distinction that is made between the types of vegetation is not the traditional one that classifies organisms with no vascular system (such as liverworts or mosses) as Lower Plants and those who possess such a system (ferns, flowering plants or gymnosperms) as Higher Plants (for instance, Jepson and Hickman 1993, 1317). Rather, the distinction is in size, albeit, due to the skeletal nature of soil in the area, usually plants dwelling in the margins and slopes of the river system do not reach great proportions, considering either species or individuals. Hence, for the purposes of research reported here, the lower plants group comprises mosses and liverworts but also flowering plants and small-sized young bushes or trees. On the other hand, the higher plants group consists of well-developed large bushes and trees[102]. It can be said that this distinction lends itself to error since young bush and tree individuals have not yet grown to the full size the species may attain in the specific environment of the Côa. Nevertheless, as noted for the case of lichens, the assessment carried out has to do with the *present* condition of outcrops. For instance, if vegetation growing in and immediately around outcrops is removed, existent young individuals will not live to mature. Thus, in this scenario, higher plants (as defined above), will not pose a future threat to rock-art outcrops. Evidently, such an assumption rests on the notion that vegetation cleaning procedures will be periodic and systematically carried out [103].

6.5.3. Animals

[102] The criteria used to distinguish between young and developed bushes and trees have to do with size and trunk and treetop width.
[103] See Fernandes (2007) for an account of the vegetation cleaning strategies currently enforced by the Park in relation to the conservation of the rock-art outcrops.

As established in the previous Chapter, risk arising from animals has been reduced to a single phylum, Arthropods, which includes, among others, insects and arachnids. Again, what was recorded during field assessment of outcrops was the observable present situation in each outcrop. Most of the identified species were arachnids although vestiges of other species' activity have been observed. In a similar fashion to the other biodeterioration risk categories, the most elevated threat level has been attributed to the direct colonization of engraved areas of the outcrops. The other categories lie on the identified presence of just one, two or more species.

6.5.4. Biodeterioration risk characterization

According to the parameters defined in Table 33, data resulting from field assessment contained in Table 34 points to the conclusion that vegetation poses the more serious Biodeterioration threat to the conservation of the outcrops included in the sample. The second highest score category are the Arthropods. However, it is believed, generally speaking but above all in the Côa Valley context, that the risk arising from the presence of these organisms in outcrops is not of the same magnitude as happens in the case of Plants and Lichens. Hence, the score of the Arthropods category constitutes a minute percentage of the final ranking of Biodeterioration risk present in the following Chapter.

Considering that in most of the outcrops included in the sample (28) lichens have been removed during the last decade and a half, it is not surprising the low score (compared with the other two categories) this risk class has attained. If removal had not been accomplished, scores regarding risk motivated by lichens colonization of outcrops would surely have been higher. In half of the intervened outcrops (14) lichen re-colonization is in a Very Incipient or Incipient stage. Nevertheless, it is interesting to note that in the other half, re-colonization is well on the way being that in half of those cases (7) lichen presence scored a Significant or Very Significant ranking, most probably the case of Quinta da Barca Rock 3 (see Figure 196) being the most prominent one. A connection between lichen colonization deterioration and aspect is quite difficult to establish since in 28 sample panels lichens have been removed leaving only 12 to analyse. Table 35 presents the quite inconclusive results of the exercise mostly because of the limited size of the sample. Nevertheless, it is worthy to mention that the panel ranking higher (Significant risk) has a South-facing orientation and the panel ranking lower (Very Incipient risk) has a North-facing orientation.

Regarding vegetation, it must be noted that the first risk category (No plants) did not apply in any of the assessed outcrops. Nevertheless, it was decided to maintain the category since it constitutes the zero risk threat level possible to happen, in spite of the fact it probably does not occur in any of the Côa Valley outcrops. As noted, the plants category seems to be the most problematic one concerning Biodeterioration. Indeed, only 7 cases were not classified as Significant or Very Significant regarding risk level.

Table 36 presents the relationship between vegetation deterioration assessment and aspect. The high scores reached by almost all outcrops regarding vegetation growth imply that only 7 were not ranked in the top two risk categories. On the other hand, the directed fashion in which the outcrops to incorporate in the sample were chosen, means that almost half (18) face East, 12 South, 7 West and only 3 North[104]. The misrepresentation of some classes (namely West and especially North) will considerably affect results and its interpretation. Nevertheless, it is interesting to note that of the 3 Northern facing outcrops, 2 received top scores while the remaining was ranked in the second highest category. This somehow contradicts both traditional views and data reviewed in the literature in the previous Chapter which states that in the Northern Hemisphere North-facing slopes, due to the lesser amount of received sunshine, present less developed vegetation cover. Nevertheless, it is believed that, because of the noted misrepresentation issues, this inference cannot be generalized. Thus, because of insufficient and inconclusive data, the role of aspect in vegetation growth will not be used towards the creation of the intervention urgency scale following what was established for all discussed aspect-related parameters.

Insects and spiders have not been observed in only 6 of the assessed outcrops. In these outcrops, risk was accordingly classified as Very Incipient. The most common observed situation (Significant) corresponds to the presence in the outcrops of more than two species. In only two situations (see for example Figure 241), were species observed directly colonizing engraved areas of outcrops.

[104] As discussed in Chapter 1, the sample was chosen so that it could faithfully reflect the characteristics of the considered total universe, namely aspect of rock-art panels. As shown above in this Chapter, rock-art panels mostly possess an East and South orientation.

Total Biodeterioration risk values presented in the farthest right column in Table 34 have been calculated according to the following formula: 30 percent (Lichen Colonization) + 60 percent (Vegetation) + 10 percent (Arthropods) = Total score. The formula translates the perceived influence each set of organisms has on Biodeterioration dynamics at work at any given rock-art outcrop. Vegetation constitutes the highest percentage as it is suggested that these organisms have the greatest short to medium-term impact on the condition of the outcrops. Due to their morphology, structure and ecology, it is suggested that lichens foster lesser magnitude mechanical and chemical weathering dynamics than vegetation constituting thus a medium to long-term problem. Arthropods are perceived as posing much lower degree Biodeterioration issues hence the attribution of just 10 percent in the formula mentioned above.

6.6. Flooding

Risk resulting from the precise location of outcrops with relation with flood levels was categorized according to the criteria put forward in Table 37. The distinction that is made between Moderate and Significant risk has to do with flooding dynamics observed in the area. If, as noted in Chapters 5 and 4, upstream of the caisson built for the construction of the dam, water level may rise by 12 meters when flooding occurs, it has been observed that such an increase does not occur during all inundation episodes. Hence, within this 12 meters limit, higher standing outcrops do not always become submerged when flooding takes place. Moreover, it has also been observed that during some flooding episodes, after an elongated period that may last for a couple of months during which outcrops located within the 12 meters limit remain submerged, water may begin to lower only to rise again with a sudden increase in precipitation. In the second (and sometimes third) rise occurrence, higher-standing outcrops tend not to become submerged again, only those located nearer to the normal river level. Hence, these low-standing outcrops may experience, during the same flood season, repeated wetting and drying cycles. As discussed in the previous Chapter, such episodes may significantly contribute to further weaken outcrops, together with the exerted mechanical pressure. Hence, a six-meter limit, which is half of the upper flood limit, constitutes the distinction between Moderate and Significant risk categories.

6.6.1. *Flooding risk characterization*

Thirteen of the outcrops comprised in the sample are subject to periodical flooding (see Table 38). Of these, only 3 present Moderate risk. Considering the Côa Valley rock-art context, the sample comprises a quite disproportional presence of low altitude outcrops since the number of affected outcrops in the total universe is not around a third, as in the sample, but appreciably lower. Nonetheless, this was a conscious decision aiming to assure that the outcrops presumably in worst condition, due to the damage motivated by flooding, had a significant representation in the sample. Cross-tabulation of data regarding the condition of outcrops dictated by Physical weathering mechanisms and flood risk susceptibility will allow us to verify if low altitude outcrops are indeed in worst shape than those not subject to periodical inundations and, moreover, if there are noteworthy differences in the condition of outcrops classified as Moderate and Significant flood risk. Scoring of this category will only have three risk indicators as displayed in Table 37: Inexistent, Moderate and Very Significant.

6.7. Conclusion

This Chapter dealt with the application of the identified and usable parameters in risk characterization of the Côa Valley rock-art outcrops included in the sample. As discussed, risk characterization arising from the different set of parameters identified will weigh differently in the creation of the intervention urgency scale. For instance, Physical weathering processes will receive the highest proportional score because there constitute the most threatening risk for the endurance of the Côa Valley open-air rock-art outcrops. In the subsequent concluding Chapter, the rationale for different pondering of each risk category will be discussed along with the creation of the intervention urgency scale.

Chapter 7: Creation and concluding remarks on merits, weaknesses and applicability of the urgency scale

7.1. Introduction

This concluding Chapter deals with the creation of the intervention urgency scale presenting a discussion on pondering issues, cross tabulation of data between different categories of risk indicators as well as the scale itself. Furthermore, it offers an analysis of the merits, weaknesses and wider applicability of the scale.

7.2. Creation of the intervention urgency scale

For that purpose, it is important to draw relevant inferences from other attempts to establish similar rankings. Rodrigues and Grossi (2007) endeavoured to develop a compatibility scale to use in masonry conservation. Their scale looks at several items regarding past interventions and present intervention proposals (chemical or mineralogical composition, thermal or mechanical properties of the applied or to apply conservation materials and of the structure to which they will be applied), ranks their 'inter'-compatibly ending up with a classification from the more to the least compatible interventions. After decomposing the several items into different homogenous groupings, the final rating results from the adding up of the values each of these subgroups scored. On the other hand, Darvill *et al.* (1987) aimed for the evaluation of ancient monuments with the intent of prioritising the protection of the vast heritage of Britain. Three different levels of criteria or evaluation stages were used: characterization (including period and rarity), discrimination (including potential and amenity value) and assessment (including condition and vulnerability). A simple scoring system was then used and the results kept in a database. The work carried out by the previous authors was a sort of continuation and improvement of the study carried out by Groube (1978). This author dealt with the ranking of research priorities mainly based on threats to the endurance of archaeological sites and structures located in the English region of Dorset.

Methodologies specifically developed to deal with rock-art sites are also available. Fitzner *et al.* (2004), in a previously referred study (see Chapter 3) carried out condition evaluation of just one rock-art outcrop (the Bangudae site in South Korea). After analysing the petrological qualities of the studied outcrop, the authors correlated different weathering groups with six damage categories: "0 – no visible damage, 1 – very slight damage, 2 – slight damage, 3 – moderate damage, 4 – severe damage, 5 – very severe damage" (Fitzner *et al.* 2004, 516). The combination of all these variables results then in a Damage Index that ranks the percentual distribution of each group of weathering forms throughout the considered panel. Not surprisingly, it was possible to establish that not only the lowest area of the panel (closest to the water) is the most severely weathered and threatened one, but also that weathering proportionally decreases from the bottom to the most elevated section of the said panel.

Another potentially interesting ranking method is the RASI, which has been partly reviewed in Chapter 3. RASI is divided in six main categories: "Site Setting (geological factors); Weakness of the Rock Art Panel; Evidence of Large Erosion Events On and Below the Panel; Evidence of Small Erosion Events on the Panel; Rock Coatings on the Panel; and Highlighting Vandalism." (Dorn *et al.* 2008, 35). Each main category is subdivided in to several subcategories. Each scorer ranks every existing weathering dynamic from 0 to 3, being "0 = not present (the default); 1= barely noticeable; 2= obvious; 3= very serious concern" (Cerveny 2005, 108). The scores are added up being 100 the maximum value allowed. The highest possible score would thus correspond to an extremely weathered rock-art panel. A colour code is attributed to the different condition categories: "≤50 (Blue): No urgent issues; 60-69 (Green): Good shape; 70-79 (Yellow): Problem(s); 80-89 (Orange): Urgent dangers; 90+ (Red): In great danger of loss" (Cerveny 2005, 106-7).

Drawing on the above-mentioned methodologies, the urgency scale which is the main objective of research reported here also separately groups and scores each existing set of parameters (for instance Physical weathering, Biodeterioration). The final value regarding the urgency of intervention in each outcrop is reached by adding up each final group scores in a proportional fashion according to impact every one has in overall weathering of outcrops. Regarding the more specific methods developed to create rock-art condition indexes, both the Southwest American and South Korean experiences present some issues in their strict appliance to the case of the Côa Valley rock-art. Besides all the applicability issues previously mentioned[105], it must be said

---

[105] Namely, as mentioned in Chapter 3, financial or time-consuming issues.

that the high level[106] of analysis attained by Fitzner's team is only achievable if the considered universe of analysis is constituted by a single outcrop located in just one rock-art site. Considering a sample of 40 rock-art outcrops (reflecting a total considered universe of 822 outcrops scattered along both margins of a section of river valleys spreading for some 20 kms.), it would just be impossible to attain such a high level of detail of analysis in the case of the Côa.

On the other hand, the adaptation of the more user-friendly and affordable RASI to contexts other than the one it was originally designed for by just incorporating other weathering dimensions can prove to be quite complex. In fact, if some of the weathering dynamics considered in RASI are the same or similar to those that also have been identified in the case of the Côa, even if the employed terminology differs, others are not present in the Côa. Adding missing dynamics or subtracting non-existent ones would imply a profound redesigning of the RASI scoring system. Hence, it is believed that it is simpler to just create an original scoring system specifically designed for the Côa based on the weathering dynamics identified and discussed in Chapter 4 and 5. Hence, while drawing on the methodologies used by the above-mentioned authors, the ranking method to be used in the case of the Côa is specifically developed for the case at hands.

7.2.1. Pondering issues

As stated in previous Chapters, the different identified risk indicators do not affect in exactly the same fashion the condition of the Côa Valley open-air rock-art outcrops. For instance, in the preceding Chapter, the end value for Biodeterioration risk characterization in every outcrop resulted from the disproportional contribution of each of the three identified groups of organisms to weathering processes. Accordingly, the identified individual or set of risk indicators have different weights in the final intervention urgency scale. These have been divided into six major groups (some are composed of just one indicator such as Rock mass strength, Tilting of outcrops, Slope and Flooding) each receiving the following shares towards the creation of the intervention urgency scale: **A** – Rock mass strength (10 percent); **B** –

[106] A level of analysis that can be said to have been almost absurd, or as others authors put it, quite esoteric (see Chapter 3). For instance, "more than 400 partial areas (…) were distinguished as a result of different types, intensities or combinations of weathering forms" (Fitzner *et al.* 2004, 511-2) in a considered rock-art panel measuring circa 10 m x 3 m!

Tilting of outcrops (10 percent); **C** – Physical weathering (30 percent); **D** – Slope (10 percent); **E** – Biodeterioration (20 percent) and **F** – Flooding (20 percent).

Table 39 summarises not only the share of each individual or group of risk indicators but also presents the fashion each is scored towards the creation of the intervention urgency scale. These values have been attributed considering research reviewed in previous Chapters but also the author's work experience in the past decade and condition assessment carried out in the scope of the present PhD as shown in Annex A. Physical weathering is the category that received the highest percentage (30 percent) because of the major impact these mechanisms have in the condition of outcrops. As discussed in Sections *5.3.2.* (page 133) and 6.3 (162), it is believed, following Rodrigues (1999), that Physical weathering mechanisms are the leading threat to the condition of the outcrops. Although these act on a very long timescale, it is clear that these mechanisms relentlessly create the very concrete threats to which these outcrops are subjected. It can be noted that these mechanisms result, to a large extent, from the effect or constraints of the other risk categories. Hence, given their ancient Pre-Cambrian origins, it is no surprise that the outcrops suffer from the natural old-age maladies (fractures, gapping, fissuring, etc.) that ultimately give evidence of their course towards complete decay (see, for instance, Figure 195, Figure 206 or Figure 242), if no remedial action is taken.

The following highest-ranking categories (Biodeterioration and Flooding) receive the same share (20 percent), proportional to the impact these are perceived to have. The living organisms concerned[107] are widely present in the Côa Valley outcrops and their promotion of mostly mechanical but also chemical weathering is quite well established in the specialized literature (see Section *5.5.1.*, page 146). Fieldwork carried out towards the completion of research supplied ample examples of how living organisms are in fact affecting the condition of the rock-art outcrops (see Section 6.5, page 184, and Photo section in Annex A). Despite the fact these organisms act on a much smaller (and potentially much more manageable) timescale than the highest-ranking category, their combined weathering and erosion mechanisms do pose a serious threat, both in the short-, medium- and long-term, to the survival of

[107] And within this group, plants, as acknowledged in the previous Chapter and reflected in the specific biodeterioration risk scoring, pose the highest risk.

the rock-art outcrops.

Flooding is also deemed to be a major issue affecting the overall stability of those outcrops that periodically become partially or totally submerged besides contributing to the further progression of Physical weathering mechanisms. The issue has been discussed in Sections *5.6.2.* (page 154) and 6.6 (page 189) where it was established that the occurrence of repeated (sometimes in the same flooding season) wetting and drying episodes is a major factor in the weathering and erosion of Côa Valley rock-art outcrops. Nevertheless, despite its obvious impacts on the condition of outcrops, the fact that only a minority of rock-art surfaces in the Côa is subject to the current flood regime made attributing a higher percentage unjustifiable. Hence, it is suggested that 20 percent is an appropriate share for this category.

The remaining categories (Rock mass strength, Tilting and Slope) all have a 10 percent share since these are believed to have lesser influence. The fact that Rock mass strength presents reasonably homogenous scores recommends attributing this lower share. As examined in Sections 5.2.4. (page 132) and 6.2.4 (page 159), Rock mass strength is a variable that can be said to reflect the innate cohesive rock characteristics. The fact that rock-art included in the present PhD exists in outcrops located in just two schist formations explains the fairly identical scores present in Table 27. Therefore it was deemed that ten percent was a suitable share for this risk category.

On the other hand, Tilting and Slope both are categories that are also believed to also represent lower, but not negligible, risks to the survival of outcrops. Because of the nature of slope dynamics and the degree of tilting some outcrop faces present (see discussion in Sections *5.4.1.*, page 140, *5.4.1.1.*, page 141, 6.2.5, page 160, and 6.4, page 165, and data in Table 30), a greater impact magnitude would mean that most engraved outcrops would already have completely disappeared. It is obviously impossible to have any degree of certainty about the number that have been totally destroyed by natural forces. However, fieldwork carried out in the Côa Valley by the author in the past decade evaluating the condition of outcrops, as well as the proposed age for the most ancient rock-art motifs, suggests a low intensity of rock-art outcrop loss due to the action of slope dynamics and tilting. Hence, 10 percent is considered to be a reasonable share for these two categories.

While creating and developing the above ranking system, other shares were considered, namely decreasing the value attributed to Physical weathering and increasing the share for Slope dynamics. However, the lower scores attained by Slope dynamics (see Table 30) vs. the relatively higher values reached by Physical weathering (see Table 29) recommended that the above shares regarding both categories should be maintained. Further changes, particularly attributing a higher share to biodeterioration at the expense of other categories, were also likely to distort the final intervention urgency scale, which attempts to faithfully portray the current condition of the examined outcrops. It should be noted that in the creation of the scheme developed above, the author's subjectivity must also be acknowledged. Nonetheless, this subjectivity arises from more than a decade of study, monitoring, and assessment of the factors that could be recognized to play a part in the degradation of outcrops and is supported by the results of this research, particularly in Chapters 5 and 6. The cross-tabulation of the final results obtained for each category carried out in Section 7.3. below attempts to demonstrate that the used formula strikes a quite adequate balance when considering all risk categories thus contributing to accurately describe the present conservation state of the considered Côa Valley rock-art outcrops.

7.2.2. Individual categories ranking system

Regarding the precise grading system comprised in Table 39 it must be noted that it has been adapted from the Table presented by Summerfield to evaluate rock mass strength (1991, 166) (see Figure 171). After careful consideration and testing of other formulas, it was decided, in the interest of simplicity and applicability, to use this reasonably straightforward but reliable grading system. Hence, the rating proportion (r=) is the same (for each risk group) as the one employed in the original table. However, some modifications were introduced to better suit the objectives of outcrop condition evaluation in the Côa Valley. To begin with, the grading categories labels, instead of offering a qualitative title (Incipient or Significant, and so on) have been numbered from 1 to 5 (being 1 the lowest raking and 5 the highest). Then, all risk indicators A to F have been ordered accordingly so that the outcrops in worst assessed condition received the highest score.

7.2.2.1. Rock strength

Qualitative terms for Rock mass strength have been kept from Summerfield's original Table. However, a reverse ordering was put in place. This was done so that better ranked outcrops received the highest score and vice-versa.

7.2.2.2. Tilting of outcrops

Tilting of outcrops faces has been scored in five grading categories, as follows: 1º to 4º of inclination= 1; 5º to 9º= 2; 10º to 19º= 3; 20º to 29º= 4 and ≥ 30º= 5. For the creation of this ranking system, the highest value measured during fieldwork (30º) was taken in consideration. It is believed that it is not likely to measure much higher values in future condition assessment since more than 30º of inclination constitutes a threshold beyond which the stability of the outcrops may be expected to be in serious peril. Nevertheless, the number of outcrops receiving the uppermost score (2 in 40, thus 5 percent) suggests the existence of more such cases, albeit not many, in the total Côa Valley rock-art outcrops universe. Backwards tilting (that is, when outcrops faces are in a situation in which they present themselves 'more parallel' to slope angle) is less straightforward to score. In any case, it is considered that backwards tilting is as problematic to the stability of the outcrops as forward inclination. This suggestion is based on the assumption that outcrops leaning, either backwards or forward, are more exposed to the detrimental effects of gravity and slope dynamics on their stability. Many (if not all) outcrops present, quite large in some cases, diaclase 'boxes' (see discussion in Chapters 5 and 6 and also Annex A). Consequently, since outcrops may not be supported in their rear section, it is also suggested that backwards tilting has the potential to pose an equal threat to stability as forward inclination. Hence, it has been considered relevant to signal and thus score these cases in the same fashion as those with forward tilting. It should be also noted the considerable number of outcrops (7 in 40, thus 17,5%) that present backwards tilting.

7.2.2.3. Physical weathering and Slope

The Physical weathering and Slope categories present a ranking system in accordance with the relative weight each have towards the creation of the intervention urgency scale, 30% and 10%, respectively. These also have kept a qualitative risk indicator of in each grading unit ranging from Very Incipient to Very Significant.

7.2.2.4. Biodeterioration

The biodeterioration category has suffered some adjustments regarding rating. Table 34 presents a total final score resulting from the adding up of three subcategories (Lichen colonization, Plants and Arthropods) in different percentages according to the relative weight each contribute to biotic weathering. Considering that total final scores range between 2,5 and 4,9 it was decided to reflect that fact in the ranking formula for this category. Hence, the five grading units instead of possessing a qualitative label present quantitative values ranging from 2,5 – 2,9 (the lowest score) to 4,5 - 4,9 (the highest). It is believed that this range of total biodeterioration values accurately corresponds to the overall situation of the Côa Valley rock-art complex. These values have been obtained from condition assessment of the outcrops comprised in a sample that is deemed to be well representative of the whole concerned universe. Indeed, the lowest interval value considered (2,5 – 2,9) has been reached by a reasonable low number of outcrops (5 in 40, thus 12,5 percent) and the lowest value (2,5) by even less (2 in 40, thus 5 percent). Nevertheless, if future field condition assessment presents lower values, it is possible to adjust this ranking scale.

7.2.2.5. Flooding

Flooding risk indicators presented a different challenge as there are only two scores possible to be attributed (Moderate – outcrops located more than 6 meters above normal river level and Very Significant - outcrops located up to 6 meters above normal river level)[108]. Therefore, the preferred option was to place these two possible scores according to their qualitative labels, creating thus a grading gap between the two that is believed to reflect the different risk levels the two situations constitute regarding flooding susceptibility. Consequently, only two grading units are used to score this risk indicator.

[108] Location above flood maximum level, hence no risk, is obviously not considered.

7.3. Intervention urgency scale, cross tabulation of results and relevant insights

Although each outcrop is a specific case featuring different ways in which the active weathering and erosion dynamics affect their condition, it was expected the final ranking resulting in reasonably even scores (see Table 40). All outcrops suffer from the action of the identified mechanisms and the disturbance extent and magnitude is in each case precisely established by the intervention urgency scale. Nevertheless, values range from the minimum value of 43 (35 in the case of Penascosa 4 if flooding risk would not have been considered, see discussion below) up to maximum of 83, thus constituting a relatively broad distribution of scores. The fact that the outcrop attaining the lowest ranking scored roughly half of the lowest possible value (22) also suggests, on the one hand, the reasonably similar condition of the outcrops and, on the other, the extent of existing damage and deterioration risk level. The final scale does not rank outcrops in qualitative risk level groups such as Moderate or Very Significant. This is a deliberate choice as it is the final score that in itself establishes the ranking of the intervention urgency scale.

Not surprisingly, outcrops that had previously been identified as being in poor condition occupy the top ten positions of the intervention urgency scale[109]. Indeed, the list is led by Ribeira de Piscos 24, a quite troublesome and delicate case as noted in another occasion (Fernandes 2008a, 90-1), and to which the author usually refers to as "an open-air rock-art conservator worst nightmare" (see Figure 206). The only exception is probably Quinta da Barca 3 which, although placed in the second tier with a score of 62, has not reached the high value the presence of a tree growing from 'within' the outcrop anticipated (see Figure 198). Nevertheless, if flooding risk had been not considered, Quinta da Barca 3 would have ranked in the top-ten group, namely in sixth position.

Hence, also as expected, nine out the top-ten outcrops are subject to periodical flooding and, among these, only one is not located up to six meters above present-day normal river level. The reasonably low score obtained by Penascosa Rock 4, despite flooding risk being scored as Very Significant, as to do with the half-buried condition in which it was discovered, as noted in the previous Chapter. Also to be

[109] For visualization purposes, outcrops in Table 40 have been divided in groups of ten signalled in red in the case of the top ten, yellow and orange in the following two groups and finally green in the bottom ten.

expected is the low lichen colonization of outcrops in periodical risk of submersion: 8 out of 13 present Very Incipient and Incipient scores (see Table 34). Periodical flooding will prevent lichen colonization to significantly develop in affected outcrops. The cases of those that have ranked higher than Incipient are mainly explained by the fact that most are outcrops located 6 meters above the normal river level (but below 12 meters) and hence partially not disturbed by water rise[110]. In addition, flooding, as noted previously, will affect these outcrops less frequently. It is interesting to note that a variable, such as flooding, that has severe implications in the conservation of the outcrops may, on the other hand, prevent the further advancement of another, nevertheless deemed to be less significant as previously discussed, such as lichen colonization.

If flooding risk had not been considered, results would not have changed dramatically. The first place of the list would be occupied by Vale do Forno II 5 with a score of 67, followed Vale do Forno II 5 with 64 and then by Ribeira de Piscos 24 in a group of closely ranked or even tied outcrops with scores ranging from 63 to 61. Hence, flooding risk value acted as an influential risk ranking factor that helped to further distinguish between outcrops. If it had not been valued (and attributed a considerable percentage), the intervention scale results would have been more even.

When comparing C and F categories scores, it becomes apparent that outcrops subjected to periodical submersion present more significant damage from Physical weathering mechanisms. The only two highest punctuations possible to attain in this category (Very Significant r=30), have been reached by the 1st and 3rd highest ranked outcrops. These two outcrops have also been rated with a Very Significant score regarding flooding risk. Additionally, an examination of the remaining top-ten scores further confirms this relationship between high Flooding risk and Physical weathering condition, with the exception of the last outcrop in the top-ten, Vale do Forno II 5. Rankings of the remaining outcrops in C category, although still presenting reasonably high values in the second and, in less extent, third tiers[111], obviously tend to gradually decrease the further down they are positioned in the list.

[110] The precise extent of affected area depends on the dimensions and precise altitude of each concerned outcrop.
[111] With the exception of Penascosa 6 (ranked 12th), which presents only Incipient Physical weathering damage, since it is only partially affected by periodical flooding, as noted above.

Another category that establishes a strong relationship with the Physical weathering condition of outcrops and, as a result, moderately contributes to the final score, is Tilting of outcrops. Almost all of the top-ten outcrops present reasonably high inclinations being in fact ranking led by the outcrop yielding the highest value, together with Penascosa 6 (ranked 12th in the final score).

Biodeterioration is perhaps the risk indicator presenting a more ambiguous connection with the final total score. The top-ten outcrops present relatively average scores and the first highest ranked outcrop in this category (Vale do Forno II 6) appears only at position 14th in the final list. As noted above, outcrops subject to periodical flooding present less developed lichen colonization. Moreover, in most of the outcrops in the sample (28 in 40, thus 70 percent) lichens have been removed. Both these facts help to explain why Lichen colonization scored such relatively low values. However, since Lichen colonization only accounts for 30 percent of the final Biodeterioration risk level indicator, these details only partially account for the lack of clear rapport between Biodeterioration and total score. Hence, the bulk of the answer must lie in the risk indicator that contributes with the highest import (Plants with 60 percent) to the final total score of this category. The conclusion that can be thus drawn is that high Biodeterioration scores (and, correspondingly, especially Plant risk) were not attributed to outcrops in worst Physical weathering condition. Therefore, as already noted in the case of Quinta da Barca 3, there seems that Biodeterioration mechanisms do not establish a clear link with the unfolding of Physical weathering processes.

It can be suggested that the above-enunciated trends are quite self-evident since it was expected to find in the top positions outcrops ranking high values in each category. However, as already hinted by the less obvious relationship between Biodterioration (counting 20% in the final ranking) and total score, an examination of Rock mass strength and Slope values suggests otherwise. Despite the quite even Rock mass strength values, the top-ten outcrops feature a reasonably constant distribution between Strong and Moderate values (6 against 4). Moreover, the only outcrop classified as Weak (Quinta da Barca 3) is ranked only at 18th. Slope values show an even more unapparent relationship with total score. The top-ten features two outcrops classified as presenting Significant risk, exactly the same figure for Incipient grading. Furthermore, Canada do Amendoal 2, the sole outcrop receiving the highest possible score (Very Significant) appears only at position 27. The results of both these categories offer some validation of pondering options towards obtaining the final total score followed for each risk category, as each only contribute 10 percent to the creation of the intervention urgency scale.

The final score resulted in a relative ranking of outcrops. Some of these cases deserve further detailed consideration. Both Canada do Inferno 2 (CI 2 – ranked 8th) and Vale do José Esteves 17 (VJE 17 – ranked 33rd), present incomplete rock-art motifs due to fracture of the rocky support (see Annex A). These are two distinct cases of outcrops in very diverse condition. Albeit both display motif loss, CI 2 is in much worst shape (and also located in the most severe risk level regarding flooding contrary to VJE 17 which is not at all affected) also presenting immediate danger of losing the goat motif because of the action of an open eroding fracture (see Figure 242). VJE 17, despite motif loss, presents itself in much more stable condition as the remainder of the panel is still quite compact and whole without fractures as severe as those present in CI 2 affecting it (see Annex A). Hence, this situation is reflected in the high and low score each attained.

Another case is Vale do José Esteves 16 (VJE 16 – ranked 24th). This outcrop is partially covered by a large slab that shelters part of the engraved panel (see Annex A). Although impossible to determine when the outcrop become partially covered[112], it is suggested that, if the outcrop was not sheltered it may have been ranked at a higher position in the intervention urgency scale. On the other hand, it should be also noted that even the fact that the outcrop is partially covered did not prevent it being ranked at a high position in the second half of the list.

Finally, an attempt to establish a connection between aspect and outcrop condition was carried out. Even if aspect has not been used as a risk indicator category due to the reasons previously enunciated, it is nevertheless possible to try to distinguish trends in the examined sample regarding the existence of any links. Hence, Table 40 presents an 'extra' light-shaded column indicating the aspect of outcrops. Since East-facing outcrops in the considered sample total 18 (thus, 45

[112] But also, if this resulted from natural forces or human action. In any case, it suggested, since the outcrop is located at the foot of valley that has been intervened upon by farmers to create terraces suitable to plant olive and almond trees but also because evidences of human endeavours (namely old farming tools or shelters partially build with loose stone taking advantage of natural crevices and holes in outcrops that can be found very near to VJE 16) that the later explanation, or a combination of the two, may account for the current situation of VJE 16.

percent), final results will also present an overrepresentation of this aspect. Therefore, East-facing outcrops are not the more suitable ones in trying to identify any trend. The least represented orientations (North with 3, thus 7 percent, and West with 7, thus 18 percent) are perhaps more well suited for this purpose. The three North-facing outcrops reached relatively high scores: Fariseu 2 at 9th, Canada do Amendoal 3 at 11th and Vale do José Esteves 16 at 24th. However, the first two have their score increased by 14 due to their positioning below maximum flood level but 6 meters above normal river level. If such an 'extra' score had not been given, these would be positioned in the bottom twenty of the list. Conversely, as noted above, VJE 16 may have had its final score decreased due to the large protecting rock slab that partially covers it. The 7 West-facing outcrops, on the other hand, are reasonably well distributed throughout the list with two in the first, third and fourth tiers while only one appears in the second. Hence, consideration of North and West-facing outcrops does not allow drawing relevant inferences. The 12 (thus 30 percent) South-facing outcrops, however, do present a clear trend as the huge majority is positioned in the bottom half of the list. Moreover, the only two that appear above that threshold are positioned quite modestly at 17th and 19th. Hence, at least in the case of the sample considered, it can be said that South–facing outcrops are in a less worrisome overall condition than those possessing other orientations.

A final note in this Section must mention that such a scale must also consider aesthetic and scientific relevance criteria. It was indeed mentioned in Chapter 1 why present research did not consider these. However, further refinement of the present scale must take in consideration these set of criteria. Aesthetic and scientific significance form a major part of the value contemporary society attribute to rock-art imagery. Precise value attribution may differ reflecting individuals, groups or societies different agendas, interests, context and sensibilities but most will agree that the conservation of Lascaux or Chauvet caves, on grounds of both aesthetic and scientific relevance, is more important than the conservation of 'humble' cupmarks, as interesting as these may be. However, not all cases are so clear cut, as the aesthetic and even scientific relevance of rock art imagery are defined by rather subjective criteria. Hence, integration of these two realms of rock-art appreciation in a fair and balanced way is one of the great challenges in future improvement of any such scale, insofar, but not exclusively, because this is a subject that also calls for a case by case approach.

7.4. Concluding remarks: Merits, weaknesses and applicability of the intervention urgency scale

The intervention urgency scale is proposed as a method to prioritize future conservation work to be done in the sizeable Côa Valley open-air rock-art complex. To that regard, it is believed it does deliver a consistent and clear ranking of outcrops condition. Nevertheless, the scale results from research and methodology priorities as defined by the author. It should be noted that the transdisciplinary, hence holistic, approach on which the overall philosophical but also practical foundation of the PhD is based, is believed to be one of its greatest merits but may also constitute one of its greatest weaknesses. On one hand, to the best of the author’s knowledge, this has been the first time an attempt to apply all the discussed variables in the condition categorization of open-air rock-art outcrops. Indeed a tall order, as the fact that some variables (notably aspect) ended up not being used suggests. As noted at certain junctures in previous passages, the effect each of the identified variables has in open-air rock-art conservation constitutes, on their own merit, subject for several PhDs in different fields of science. Hence, there is an admitted lack of extremely detailed analysis and discussion on the contribution of each variable in open-air rock-art conservation. Nevertheless, this was acknowledged from the outset since the main objective was to have as an end-result a reasonably straightforward and easy method to use *from an archaeological heritage management and conservation point of view*. As noted above, it is believed that the end-result does correspond to that expectation as the combination of variables results in a accurate portrayal of the present condition of the outcrops thus establishing intervention priorities.

Nevertheless, it is not claimed that all major or minor natural weathering and erosion variables that may have an impact on the conservation of the outcrops have been aptly considered. Notably, from the start, aspect appeared to be a promising variable to be used in characterizing the condition of outcrops and establishing the intervention scale. Unfortunately, due to the methodological but also logistical failures discussed in the previous Chapter, acquired data ended up to be insufficient. However, it is believed that in the future, longer data series will make possible to further clarify the issue. Other variables that impact upon the conservation of the outcrops may also not have been identified at all. As a reading of the reasonably scarce specialized literature reveals, weathering and erosion of open-air (schist) outcrops is a matter that so far has not received much attention from the scientific community. Moreover, (rock-art) outcrops exist within a natural world composed of a myriad of interdependent mechanisms, some not yet fully understood, especially in the fashion in which they mutually (wholly or partially, and to what precise extent) influence each other. Hence, it is expected that more or less important variables have not been identified and considered. However, it is believed that the identified and used ones are amongst, if not constituting all of them, the most important variables that determine the 'natural' conservation of outcrops in the Côa Valley.

One inference that can be drawn from the visits carried out towards the completion of research reported here (see Chapter 2), but also from the presented intervention urgency scale, is that each case is a separate case. Each site has its own specificities; each engraved outcrop or panel subsists in its precise condition and even different areas of the same panel may present different weathering degrees. Hence, each level requires different approaches containing several layers of analysis. As already discussed above, methodologies that attempt to assess and rank damage in different sites will necessarily also need to be also different. Consequently, applicability issues can be a major issue when trying to replicate methodological approaches developed elsewhere as, while there are variables that are common to many cases, others can be exclusive to a site or group of sites located in the same region. Moreover, these types of studies are carried out by investigators who have specific backgrounds and research interests. That became apparent when carrying out the literature review on assessment models: while some authors with an Earth Sciences background tend to have a weathering-based approach, researchers with a background in Visual and Computer Sciences revealed a more cost-effective attitude.

It is worthwhile to mention two important notes to be found in Groube's study mentioned in the opening section of this Chapter. On the one hand, weighing of different factors, that is, "the order of information used in establishing the scale" (Groube 1978, 30), will always be subject to a decision process. On the other, and closely linked with the preceding observation, there is an "inevitable subjectivity (…) (involved in) scaling decisions" (Groube 1978, 47). This constitutes a significant weak point of any such process. To counter this issue, Groube suggests that ranking procedures should be led by wide reaching commissions composed of researchers possessing different backgrounds, training and interests. Considering Groube's concern on preventing subjectivity hindering ranking procedures, a fact also noted when reviewing RASI, it is a fact that the present research is an individual project. Nonetheless, the end result will be submitted to an evaluation jury and it is the intention of the author to also present it to the appreciation of the academic community in the form of one or several publications.

Nevertheless, it is suggested that research presented here contains relevant data for open-air rock-art managers and conservators facing analogous situations. First, it carries out a discussion of the most important weathering and erosion variables that, in a specific part of the 'natural' world, play a role in (rock-art schist) outcrops deterioration and instability fostering and enhancing processes. Second, it provides a set of methodological insights that might be helpful in setting up condition assessment models and/or to develop new site-specific approaches. It can be suggested that the toolkit that arises from present research is in itself the methodological but also practical preferred options towards the creation of the intervention urgency scale. Last, the end-result is de facto an intervention urgency scale that will inform future conservation work in the Côa Valley. However, the scale must be seen as a work basis that will need continued improvement. Moreover, the author is quite happy to persist in carrying out such groundwork in his working lifetime while continuing, paraphrasing Allemand and Bahn (2005), to 'leave the outcrops alone', if no unforeseen crisis occurs and remedial intervention is needed. That is, the more is known not only about the weathering and erosion dynamics affecting the Côa Valley open-air rock-art (or any other ensemble) but also about the natural setting where it is located and the intertwined links all different variables establish amongst themselves, the more properly can conservation interventions be prepared. As discussed in detail in the case of aspect, the nature of some of the concerned variables (notably, weather) makes it necessary to gather long data series in order to arrive at consistent conclusions. Moreover, the outcrops exist in a natural environment that, by definition, is extremely dynamic. Accordingly, the fashion in which all variables establish mutually dependent connections will also readapt itself to changing conditions happening within a more or less stable framework (for instance, weather variables recorded over the last century or so against geological ‘movements’ of the last hundreds of thousands of years). Hence, it is proposed that continuing to pursue research on weathering processes is as important as keep on accomplishing regular monitoring of the rock-art condition, as it was done in the course of research presented here. The goal is thus to carry on building a corpus of data that will further inform conservation work. The great scientific but mostly cultural and aesthetic significance of the Côa Valley rock-art recommends prudence but above all respect for what is not stored at any library and survives in a fragile condition. And what survives kept in the Côa schists (Figure 243) is precisely human passion and curiosity for all facets of life.

REFERENCES:

Aberg, G., Stray, H., and Dahlin, E., 1999. Impact of pollution at a stone age rock art site in Oslo, Norway, studied using lead and strontium isotopes. *Journal of Archaeological Science*, 26, 1483-88.

Adamo, P., and Violante, P., 2000. Weathering of rocks and neogenesis of minerals associated with lichen activity. *Applied Clay Science,* 16 (5-6), 229-56.

AEMET, and IM. 2011. *Iberian Climate Atlas.* Madrid/Lisboa: Agencia Estatal de Meteorología/Instituto de Meteorologia de Portugal.

Aghamiri, R., and Schwartzman, D. W., 2002. Weathering rates of bedrock by lichens: A mini watershed study. *Chemical Geology,* 188 (3-4), 249-59.

Ahrens, C. D., 2007. *Meteorology today. An introduction to weather, climate and the environment.* Belmont, CA: Thomson/Brooks/Cole.

Alcolea González, J., and Balbín Behrmann, R. d., 2007. Le gisement rupestre de Siega Verde, Salamanque. Une vision de synthèse. *L'Anthropologie,* 111, 501-48.

Alexandre, J. A. A., 1995. A bacia hidrográfica do Rio Côa. Available from: http://br.monografias.com/trabalhos2/ria-coa-portugal2.shtml [Accessed: 15 of March 2012].

Allemand, L., and Bahn, P. G., 2005. Best way to protect rock art is to leave it alone. *Nature,* 433 (7028), 800-00.

Alshawabkeh, Y., Bal'awi, F., and Haala, N., 2010. 3D digital documentation, assessment, and damage quantification of the Al-Deir Monument in the ancient city of Petra, Jordan. *Conservation and Management of Archaeological Sites,* 12 (2), 124-45.

Altieri, A., and Ricci, S., 1997. Calcium uptake in mosses and its role in stone biodeterioration. *International Biodeterioration & Biodegradation,* 40 (2-4), 201-04.

Anati, E., 1983. Saving the worlds rock art. *Archaeology,* 36 (2), 24-30.

Anati, E., 2000. Orígenes de la escritura. *Boletín de Arte Rupestre de Aragón,* 3, 23-43.

Anati, E., 2004. Introducing the World Archives of Rock Art (WARA): 50,000 years of visual arts. *In: New discoveries, new interpretations, new research methods, XXI Valcamonica Symposium.* Capo di Ponte: Edizioni del Centro, 51-69.

Anati, E., Wainwright, I., and Lundy, D., 1984. Rock art recording and conservation: a call for international effort. *Current Anthropology,* 25 (2), 216-17.

Andersson, T., 1986. Preservation and restoration of rock carvings and rune-stones. *In:* Brommelle, N. S., and Smith, P. eds. *Case studies in the conservation of stone and wall paintings*. London: International Institute for Conservation of Historic and Artistic Works, 133-7.

Anon., 2002. Conservation project by SAPAR in Siberia. *AURA Newsletter,* 19 (2), 19-20.

Anon., 2010. Surface Analysis Usisng DEM Data - ArcGIS 9.3. Available from: http://www.lib.uoguelph.ca/resources/data_resource_centre/help_&_learning_resources/geospatial_help/components/documents/surface_analysis_using_dem_data.pdf [Accessed: 30 of May 2012].

Anon., 2011. $10,000 fine for rock art vandal. *Arizona Daily Sun,* 6 of April 2011.

Anon., 2012. Slope Steepness Index. Available from: http://geographyfieldwork.com/SlopeSteepnessIndex.htm [Accessed: 14 of May 2012].

Anyon, R., Ferguson, T. J., and Welch, J. R., 2000. Heritage management by American Indian Tribes in the Southwestern United States. *In:* Mcmanamon, F. P., and Hatton, A. eds. *Cultural resources management in contemporary society. Perspectives on managing and presenting the past*. London: Routledge, 120-41.

APA. 2012. Atlas do Ambiente. Available from: http://sniamb.apambiente.pt/webatlasIindex.html [Accessed: 17 of February 2012].

Arango, J., 2000. Sistema de registro y documentacion de factores de alteraction y deterioro. *Rupestre: arte rupestre en Colombia.,* 3.

Arrillaga, P., 2012. Indian tribes join forces to save petroglyph site. *Associated Press*. Available from: http://hosted.ap.org/dynamic/stories/U/US_POSTCARD_SAVING_TUTUVENI?SITE=MAHYC&SECTION=HOME&TEMPLATE=DEFAULT [Accessed: 30 of January 2012].

Ascaso, C., and Wierzchos, J., 1995. Study of the biodeterioration zone between the lichen thallus and the substrate. *Cryptogamic Botany*, 5, 270-81.

Attorrese, E., and Fossatti, A., 2002. Rock 53 of Vite-Deria: New elements for the study of degradation of Valcamonica petroglyphs *In:* Woody, A. ed. *American Indian Rock Art Volume 28: Tucson*. Tucson: American Rock Art Research Association, 103-10.

Aubry, T., 2009. Enquadramento geográfico. *In:* Aubry, T. ed. *200 séculos da história do Vale do Côa: Incursões na vida quotidiana dos caçadores artistas do Paleolítico*. Lisboa: IGESPAR, 21-27.

Aubry, T., Luís, L., and Dimuccio, L. A., 2012. Nature vs. Culture: present-day spatial distribution and preservation of open-air rock art in the Côa and Douro River Valleys (Portugal). *Journal of Archaeological Science*, 39 (4), 848-66.

Aubry, T., Mangado Llach, X., Sampaio, J. D., and Sellami, F., 2002. Open air rock art and modes of exploitation during the Upper Paleolithic in the Côa Valley (Portugal). *Antiquity*, 76 (291), 62-76.

Aubry, T., and Sampaio, J., 2008. Fariseu: new chronological evidence for open-air Palaeolithic art in the Côa Valley (Portugal). *Antiquity*, 82 (316).

Australia/ICOMOS. 1999. *The Burra Charter: The Australia ICOMOS Charter for Places of Cultural Significance*. Sidney: Australia/ICOMOS.

Avery, G., 1978. Rock art conservation in South Africa. *In:* Pearson, C. ed. *Conservation of Rock Art. Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977*. Sidney: Institute for the Conservation of Cultural Material, 66-8.

Azéma, M., 2005. Breaking down movement in Palaeolithic Art. *International Newsletter on Rock Art,* 43. Available from: http://www.bradshawfoundation.com/inora/divers_43_1.html [Accessed: 28 of November 2008].

Azevedo, A. J., 1986. *Atlas do Ambiente. Notícia Explicativa I.5.1 e I.5.2. Geada. Duração da época no ano agrícola. Número de dias no ano (Outubro a Setembro).* Lisboa: Secretaria de Estado do Ambiente e Recursos Naturais.

Azevedo, A. J., 1990. *Atlas do Ambiente. Notícia Explicativa I.7. Vento.* Lisboa: Ministério do Ambiente e Recursos Naturais.

Azevedo, A. J., and Marques, C. V., 1987. *Atlas do Ambiente. Notícia Explicativa I.1. Insolação.* Lisboa: Secretaria de Estado do Ambiente e Recursos Naturais.

Bahn, P., 1992. Open air rock art in the Paleolithic. *In:* Lorblanchet, M. ed. *Rock art in the Old World*. New Delhi: Indira Ghandi National Centre for the Arts, 395-400.

Bahn, P., 1995. Rock art without the caves. *Antiquity,* 69 (263), 231-37.

Bahn, P., 1997. Membrane an numb brain: A close look at a recent claim for shamanism in Palaeolithic art *Rock Art Research,* 14 (1), 63-68.

Bahn, P., 1998. *The Cambridge illustrated history of prehistoric art.* Cambridge: Cambridge University Press.

Bahn, P., 2001. Save the last trance for me: An assessment of the misuse of shamanism in rock art studies. *In:* Francfort, H. P., and Hamayon, R. eds. *The Concept of Shamanism: Uses and Abuses*. Budapest: Akademiai Kiadó, 51-93.

Bahn, P., 2002. Ways of Looking at Prehistoric Rock Art. *Diogenes,* 49 (193), 88-93.

Bahn, P., 2010a. Animals in rock art as environmental indicators. *In:* Mainwaring, A. B., Giegengack , R., and Vita-Finzi, C. eds. *Climate crises in Human History. Special Transactions No. 1, in association with the Transactions series of the American Philosophical Society* Vol. 6. Philadelphia: Lightning Rod Press, 61-71.

Bahn, P., 2010b. Lascaux in crisis. The clock is ticking. *World Archaeology,* 40, 28-36.

Bahn, P., 2010c. *Prehistoric rock art. Polemics and progress.* New York: Cambridge University Press.

Bakkevig, S., 2004. Rock art preservation: Improved and ecology-based methods can give weathered sites prolonged life. *Norwegian Archaeological Review,* 37 (2), 65-81.

Baptista, A. M., 1983. O complexo de gravuras rupestres do Vale da Casa (Vila Nova de Foz Côa). *Arqueologia,* 8, 57-69.

Baptista, A. M., 1983-1984. Arte rupestre do Norte de Portugal: Uma perspectiva. *Portugália,* Nova Série 4-5, 71-82.

Baptista, A. M., 1999. *No tempo sem tempo: A arte dos caçadores paleolíticos do Vale do Côa. Com uma perspectiva dos ciclos rupestres pós-glaciares.* Vila Nova de Foz Côa: Parque Arqueológico do Vale do Côa; Centro Nacional de Arte Rupestre.

Baptista, A. M., 2009. *O paradigma perdido. O Vale do Côa e a Arte Paleolítica de ar livre em Portugal.* Vila Nova de Foz Côa: Edições Afrontamento/Parque Arqueológico do Vale do Côa.

Baptista, A. M., and Fernandes, A. P. B., 2007. Rock art and the Côa Valley Archaeological Park: A case study in the preservation of Portugal's Prehistoric parietal heritage. *In:* Pettitt, P., Bahn, P., and Ripoll, S. eds. *Palaeolithic cave art at Creswell Crags in European context*. Oxford: Oxford University Press, 263-79.

Baptista, A. M., and García Díez, M., 2002. L'art paléolithique dans la vallée du Côa (Portugal): La symbolique dans l'organisation d'un sanctuaire de plein air. *In:* Sacchi, D. ed. *L'art paléolithique à l'air libre: Le paysage modifié par l'image*. Saint-Estève, France: GAEP; GÉOPRE, 187-205.

Baptista, A. M., and Gomes, M. V., 1997. Arte Rupestre. *In:* Zilhão, J. ed. *Arte rupestre e pré-história do Vale do Côa. Trabalhos de 1995-1996. Relatório Científico ao Governo da República Portuguesa Elaborado nos Termos da Resolução do Conselho de Ministros nº 4/96, de 17 de Janeiro.* Lisbon: Ministério da Cultura, 213-406.

Baptista, A. M., and Reis, M., 2008. Prospecção da arte rupestre no Vale do Côa e Alto Douro português: Ponto da situação em Julho de 2006. *In:* Balbín Behrmann, R. ed. *Arte al aire libre en el Sur de Europa.* Salamanca: Junta de Castilla y Léon., 145-92.

Barnett, T., Chalmers, A., Díaz-Andreu, M., Longhurst, P., Ellis, G., Sharpe, K., and Trinks, I., 2005. 3D laser scanning for recording and monitoring rock art erosion. *International Newsletter on Rock Art,* 41, 25-28.

Barr, A., 1946. *Picasso: Fifty years of his art.* New York: The Museum of Modern Art.

Bastian, F., and Alabouvette, C., 2009. Lights and shadows on the conservation of a rock art cave: The case of Lascaux Cave. *International Journal of Speleology,* 38 (1), 55-60.

Bastian, F., Jurado, V., Nováková, A., Alabouvette, C., and Saiz-Jimenez, C., 2010. The microbiology of Lascaux Cave. *Microbiology,* 156 (3), 644-52.

Bauman, J., 2005. Man charged with rock art vandalism. *AURA Newsletter,* 22 (1), 3.

Bech-Andersen, J., 1985. Biodeterioration of natural and artificial stone caused by algae, lichens, mosses and higher plants. *In:* Barry, S., Houghton, D. R., Llewellyn, G. C., and O'rear, C. E. eds. *Biodeterioration, Vol. 6. CAB International Mycological Institute and the Biodeterioration Society.* Slough, UK: CAB International Mycological Institute and the Biodeterioration Society., 126-31.

Bednarik, R. G., 1990. About professional rock art vandals. *Survey - Bollettino del Centro Studi e Museo d'Arte Preistorica di Pienrolo, Italia,* 6, 9-12.

Bednarik, R. G., 1995. The Côa petroglyphs: An obituaryto the stylistic dating of Paleolithic rock art. *Antiquity,* 69 (266), 877-83.

Bednarik, R. G., 1996. Rock art preservation in Siberia. *In:* Thorn, A., and Brunet, J. eds. *Preservation of rock art*. Melbourne: Australian Rock Art Research Association, 21-27.

Bednarik, R. G., 2007. The science of Dampier rock art - Part 1. *Rock Art Research,* 24 (2), 209-46.

Bednarik, R. G., 2008. Removing rock art. *International Newsletter on Rock Art,* 50, 8-12.

Bednarik, R. G., 2009. Biological weathering factors. *Auranet* Available from: http://mc2.vicnet.net.au/home/conserv/web/biolog.html [Accessed: 27 of September 2009].

Bemand, E., Bencsik, M., and Liang, H., 2011. *OCT and NMR for non-invasive in-situ monitoring of the vulnerability of rock art monuments.* Paper presented at the O3A: Optics for Arts, Architecture, and Archaeology III, Munich.

Bennie, J., Huntley, B., Wiltshire, A., Hill, M., and Baxter, R., 2008. Slope, aspect and climate: Spatially and implicit models of topographic microclimate in chalk grassland. *Ecological Modelling,* 216, 47-59.

Bintliff, J., Slapsak, B., Noordervliet, B., van Zwienen, J., Wilkinson, K., and Shiel, R., 2008. The Leiden-Ljubliana Ancient Cities of Boeotia Project 2008 Season. *Pharos: Jounal of the Netherlands Institute in Athens,* XVI, 31-60.

Bjelland, T., and Helberg, B. H. (Eds.). 2007. *ROCK ART. A guide to the documentation, management, presentation and monitoring of Norwegian rock art.* Oslo: Directorate for Cultural Heritage.

Bjelland, T., and Thorseth, I. H., 2002. Comparative studies of the lichen-rock interface of four lichens in Vingen, western Norway. *Chemical Geology,* 192 (1-2), 81-98.

Bland, W., and Rolls, D., 1998. *Weathering: An Introduction to the Scientific Principles.* London: Arnold.

Blanes, F. L., Marques, M. L., Rodrigues, M., and Catita, C., 2008. Estudo prévio de conservação das rochas gravadas no núcleo de arte rupestre da Penascosa - Parque Arqueológico do Vale do Côa (PAVC). *In:* Fernandes, A. P. B. ed. *A arte da conservação: Técnicas e métodos de conservação em arte rupestre. Actas das Sessões do 3º Congresso de Arqueologia de Trás-os-Montes, Alto Douro e Beira Interior. Volume 2*. Porto: ACDR de Freixo de Numão, 54-92.

Bostwick, T. W., 2005. Rock art research in the American Southwest. *In:* Loendorf, L., Chippendale, C., and Whitley, D. eds. *Discovering North American rock art*. Tucson: The University of Arizona Press, 51-92.

Brady, L. M., 2006. Documenting and analyzing rock paintings from Torres Strait, NE Australia, with digital photography and computer image enhancement. *Journal of Field Archaeology,* 31 (4), 363-79.

Brandão, C., Rodrigues, R., and Costa, J. P., 2001. *Análise de fenómenos extremos. Precipitações intensas em Portugal Continental.* Lisbon: Direcção dos Serviços de Recursos Hídricos.

Brink, J., 2007. Rock art conservation research at Writing-on-Stone Provincial Park, Alberta. *Revista de Arqueologia Americana,* 25, 55-99.

Brink, J., Campbell, I., and Peterson, A., 2003. Experiments in rock art preservation at Writing-on-Stone Provincial Park, Alberta, Canada. *International Newsletter on Rock Art*, 36, 17-22.

Broadbent, N. D., and Bergqvist, K. I., 1986. Lichenometric chronology and archaeological feature on raised beaches - Preliminary results from the Swedish North Bothnian coastal region. *Arctic and Alpine Research,* 18 (3), 297-306.

Brooks, S. M., 2003. Slopes and slope processes: research over the past decade. *Progress in Physical Geography,* 27 (1), 130-41.

Brunet, J., 1988. Conservation of prehistoric rock art in France: Some examples. *ICCM Bulletin,* 14 (1&2), 25-48.

Brunet, J., 1995. Theories and practice of the conservation of our heritage of rock art. Concrete examples of interventions in natural climatic environment. *In:* Thorn, A., and Brunet, J. eds. *Preservation of rock art*. Melbourne: Australian Rock Art Research Association, 1-11.

Brunet, J., Dangas, I., and Vidal, P., 1995. Consolidating prehistoric rock art: The future today *International Newsletter on Rock Art,* 10, 17-20.

Brunet, J., and Vidal, P., 1993. Appréciation de la vulnérabilité du site et de la grotte préhistorique du Cro de Granville à Rouffignac (France). *In: ICOM Committee for Conservation Triennial Meeting*. Paris: ICOM Committee for Conservation, 831-36.

Brunet, J., Vidal, P., and Vouvé, J., 1987. *The conservation of rock art. Two studies. Illustrated glossary.* Paris: UNESCO.

Buco, E., 2011. *Archaeological tourism. Serra da Capivara National Park region.* S. Raimundo Nonato: FUMDHAM.

Caldwell, D., 2007 2007. Save the Prehistoric whales! Available from: http://web.me.com/ducancaldwell/Site/Saving_Korean-petroglyphs.html [Accessed: 14 of December 2011].

Carrera Ramírez, F., 2002. La protección del arte Prehistórico Ibérico, ¿Misión Imposible? . *ArqueoWeb,* 4 (3). Available from: http://www.ucm.es/info/arqueoweb/numero4_3/conjunto4_3.htm [Accessed: 4 of March 2008].

Carrera Ramírez, F., 2011. *El arte parietal en monumentos megalíticos del Noroeste Peninsular. Dimensión del fenómeno y propuestas de conservación.* Oxford: Archaeopress.

Carter, J. R., 1992. The Effect Of Data Precision On The Calculation Of Slope And Aspect Using Gridded DEMs. *Cartographica: The International Journal for Geographic Information and Geovisualization,* 29 (1), 22-34.

Carter, N. E. A., and Viles, H. A., 2005. Bioprotection explored: the story of a little known earth surface process. *Geomorphology,* 67 (3-4), 273-81.

Carvalho, M., 1994. Barragem de Foz Côa ameaça achado arqueológico. *O Público,* 21 of November 1994.

Cavalcante, L. C. D., Lage, M. C. S. M., Pereira, M. C., and Fabris, J. D., 2008. Estudo químico e espectroscópico dos pigmentos pré-históricos do sítio de arte rupestre Arco do Covão, Piauí, Brasil. *International Journal of South Americam Archaeology,* 3, 59-66.

Cavalcante, L. C. D., and Rodrigues, A., 2009. Análise dos Registros Rupestres e Levantamento dos Problemas de Conservação dos Sítio Pedra do Atlas, Piripiri, Piauí. *Clio Arqueológica,* 24 (2), 154-73.

Cavalcante, L. C. D., and Rodrigues, A., 2010. Arte rupestre e problemas de conservação da Pedra do Cantagalo I. *International Journal of South American Archaeology,* 7, 15-21.

Cerveny, N. V., 2005. *A weathering-based perspective on rock art conservation.* Thesis (PhD). Arizona State University, Tempe.

Cerveny, N. V., Dorn, R. I., Gordon, S. J., and Whitley, D. S., 2007. Atlas of petroglyph weathering forms used in the Rock Art Stability Index (RASI). Available from: http://alliance.la.asu.edu/rockart/stabilityindex/RASIAtlas.html [Accessed: 10 March 2007].

Chaloupka, G., 1978. Rock art deterioration and conservation in the "Top End" of the Northern Territory. *In:* Pearson, C. ed. *Conservation of Rock Art. Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977.* Sidney: Institute for the Conservation of Cultural Material, 75-80.

Chandler, J. H., Fryer, J. G., and Kniest, H. T., 2005. Non-invasive three-dimensional recording of aboriginal rock art using cost-effective digital photogrammetry. *Rock Art Research,* 22 (2), 119-30.

Chandler, J. M., 2007. The developement and application of a simple methodology for recording rock art using consumer-grade digital cameras. *The Photogrammetric Record,* 22 (117), 10-21.

Chapman, H., 2002. Global warming: The implications for sustainable archaeological resource management. *Conservation and Management of Archaeological Sites,* 5, 241-45.

Chauvière, F.-X., Tymula, S., Calame, A., and Dechanez, I., 2009. Conservation et évolution des surfaces rocheuses gravées et piquetées de la Vallée du Côa: les données du projet «Quinta da Barca Sul». *In:* Aubry, T. ed. *200 séculos da história do Vale do Côa: Incursões na vida quotidiana dos caçadores-artistas do Paleolítico*. Lisboa: IGESPAR, 443-77.

Chen, J., Blume, H. P., and Beyer, L., 2000. Weathering of rocks induced by lichen colonization - a review. *Catena,* 39 (2), 121-46.

Chiari, G., and Cossio, R., 2004. Lichens on Wyoming sandstone. Do they cause damage? *In:* St Clair, L. L., and Seaward, M. eds. *Biodeterioration of stone surfaces: Lichens and biofilms as weathering agents of rocks and cultural heritage*. Dordrecht: Kluwer Academic Publishers, 99-113.

Chippendale, C., Taçon, P., Montelle, Y.-P., and Bednarik, R., 2006. What's in a word, what's in a hyphen? A modest proposal that we abandon the words 'petroglyph' and 'pictograph', and hyphenate 'rockpainting', 'rock-engraving', 'rock-art' among the words we use. *Rock Art Research*, 23 (2), 254-60.

Christensen, D., 2005. Wildland fires impact east Mojave rock art. *La Pintura*, 32 (2), 9-10.

Cittadini, T., 1993. Rock art and territory: Approach to the formulation of a policy of protective intervention and of cultural use for prehistoric rock art areas. *International Newsletter on Rock Art*, 93, 3-7.

Clark, K., 2001. *Informed conservation: Understanding historic buildings and their landscapes for conservation.* London: English Heritage.

Clegg, J., and Heyd, T. (Eds.). 2005. *Aesthetics and rock art*. Burlington, VT: Ashgate.

Clogg, P., Diaz-Andreu, M., and Larkman, B., 2000. Digital image processing and the recording of rock art. *Journal of Archaeological Science*, 27 (9), 837-43.

Clottes, J., 1998. The 'Three Cs': Fresh avenues towards European Palaeolithic art. *In:* Chippindale, C., and Taçon, P. eds. *The archaeology of rock art*. Cambridge: Cambridge University Press, 112-29.

Clottes, J., 2002. *World rock art.* Los Angeles: Getty Publications.

Clottes, J., 2006. Rock Art Today. *Getty Institute Newsletter*, 21.3 (Fall). Available from: http://www.getty.edu/conservation/publications/newsletters/21_3/feature.html [Accessed: 4 of July 2011].

Clottes, J., 2008. Unesco’s World Heritage List and Rock Art. *Adoranten*, 2008, 5-12.

Conway, T., 1979. Rock art and conservation in Northeastern Ontario. *British Columbia Provincial Museum Heritage Record*, 8, 127-45.

Cooke, R. U., 1979. Laboratory simulation of salt weathering processes in arid environments. *Earth Surface Processes and Landforms*, 4, 347-59.

Coulson, D., and Campbell, A., 2010. Rock Art of the Tassili n Ajjer, Algeria. *Adoranten*, 2010, 24-38.

Crotty, H. (Ed.). 1989. *Preserving our rock art heritage. ARARA Occasional Paper 1*. San Miguel, California: American Rock Art Research Association.

CS. 1998. *SP-Lite Silicon Pyranometer.* Shepshed, Leicestershire: Campbell Scientific.

CSIRO. 2006. Burrup Peninsula air pollution: final report. Available from: http://www.dampierrockart.net/Media/2006-10-16%20Burrup%20final%20report.pdf [Accessed: 14 October 2007)].

Cunha, S., Silva , A., Santo Coelho, F. E., Nunes, L. F., Pires, V., Mendes, L., Cota, T., Belo, M., Neto, J., and Mendes, N., 2010. Atlas climático de Portugal Continental, 1971-2000: Modelação SIG da precipitação e temperatura do ar. *In: 11º Encontro Ibérico de Utilizadores de Informação Geográfica - ESIG 2010,* Oeiras, Portugal.

Dai, A., Trenberth, K. E., and Karl, T. R., 1999. Effects of Clouds, Soil Moisture, Precipitation, and Water Vapor on Diurnal Temperature Range. *Journal of Climate*, 12 (8), 2451-73.

Dandridge, D., 1999. Rock art, vegetation and fire. *La Pintura*, 25 (4), 4-5.

Dandridge, D. E., 2006. *Lichens: The challenge for rock art conservation.* Thesis (PhD). Texas A&M University, Galveston.

Darvill, T., Saunders, A., and Startin, B., 1987. A question of national importance: Approaches to the evaluation of ancient monuments for the Monuments Protection Programme in England. *Antiquity*, 61, 393-408.

Darvill, T., Ucko, P., and Gibson, A. 2000. Rock Art Pilot Project Main Report. Bournemouth and London: Bournemouth University, Institute of Archaeology, English Heritage.

David, H., 2008. *Contribución a la conservación del arte rupestre prehistórico.* Thesis (PhD). Universidad Politécnica de Valencia, Valencia.

David, H., and Souza, L., 2002. Prehistoric rock art conservation in Peruaçu Valley, Mina Gerais, Brazil. *In:* Chalmin, E. ed. *L'art avant l'histoire. La conservation de l'art préhistorique.* Paris: SFIIC, 172-78.

de los Rios, A., Wierzchos, J., and Ascaso, C., 2002. Microhabitats and chemical microenvironments under saxicolous lichens growing on granite. *Microbial Ecology*, 43 (1), 181-88.

Deacon, J., 2006. Rock art conservation and tourism. *Journal of Archaeological Method and Theory,* 13 (4), 379-99.

Dean, C., 1999. Hardware store conservation: Why this week "best buy" may not be such a bargain. *In:* Dean, C. ed. *Images past, images present: the conservation and preservation of rock art*. Tucson: American Rock Art Research Association, 21-6.

Devlet, E., and Devlet, M., 2002. Heritage protection and rock art regions in Russia. *In:* Chalmin, E. ed. *L'art avant l'histoire. La conservation de l'art préhistorique*. Paris: SFIIC, 87-94.

Di Piazza, M., 2007. The crisis in Lascaux: update March 2007. *Rock Art Research*, 24 (1), 136-37.

Diaz-Andreu, M., Brooke, C., Rainsbury, M., and Rosser, N., 2006. The spiral that vanished: the application of non-contact recording techniques to an elusive rock art motif at Castlerigg stone circle in Cumbria. *Journal of Archaeological Science,* 33 (11), 1580-87.

Díez Herrero, A., Lario Gómez, J., Gutiérrez Pérez, I., Alonso Azcárate, J., Sánchez Moral, S., and Cañaveras Jiménez, J. C., 2006. Análisis de la insolación directa potencial como factor de degradación de los conjuntos pictóricos rupestres de Villar del Humo (Cuenca). *In:* Pérez Alberti, A., and López Bedoya, J. eds. *Geomorfología y territorio. Actas de la IX Reunión Nacional de Geomorfología*. Santiago de Compostela: Universidade de Santiago de Compostela, 993-1008.

Dissanayake, E., 1992. *Homo aestheticus: where art comes from and why*. New York: Free Press.

Dix, A., 1979. *An archaeological interpretation of rock art in Canyon de Chelly.* Thesis (Master). Colorado State University, Fort Collins.

Dix, W., 1978. The role of the Australian Institute of Aboriginal Studies. *In:* Pearson, C. ed. *Conservation of Rock Art. Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977.* Sidney: Institute for the Conservation of Cultural Material, 3-5.

Doehne, E., and Price, C., 2010. *Stone conservation. An overview of current research. Second edition.* Los Angeles: Getty Conservation Institute.

Dorn, R., 1997. Constraining the age of the Côa Valley (Portugal) engravings with radiocarbon dating. *Antiquity*, 71 (271), 105-15.

Dorn, R., 2004. Experimental approaches to dating petroglyphs and geoglyphs with rock varnish in the California deserts: Current status and future directions. *In:* Allen, M. W., and Reed, J. eds. *The human journey & ancient life in California's deserts*. Ridgecrest, CA: Maturango Museum, 211-24.

Dorn, R., 2006. Petroglyphs in Petrified Forest National Park: Role of rock coating in as agents of sustainability and as indicators of antiquity. *Museum of Northern Arizona*, 63, 53-64.

Dorn, R., 2007. Rock varnish. *In:* Nash, D. J., and Mclaren, S. J. eds. *Geochemical sediments and landscapes*. London: Blackwell, 246-97.

Dorn, R., and Cerveny, N. V., 2009 2009. Atlas of petroglyph weathering forms used in Rock Art Stability Index (RASI). Available from: http://alliance.la.asu.edu/rockart/stabilityindex/RASIAtlas.html [Accessed: 10 of October 2011].

Dorn, R., Whitley, D. S., Cerveny, N. V., Gordon, S. J., Allen, C., and Gutbrod, E., 2008. The Rock Art Stability Index. A New Strategy for Maximizing the Sustainability of Rock Art. *Heritage Management*, 1 (1), 35-70.

Dowson, T. A., 2009. Re-animating hunter-gatherer rock-art research. *Cambridge Archaeological Journal*, 19 (3), 378-87.

Dragovich, D., 1995. Site management and the visitor book, Mootwingee. *In:* Ward, G., and Ward, L. eds. *Management of rock imagery*. Melbourne: Australian Rock Art Research Association, 103-06.

Egli, M., Mirabella, A., Sartori, G., Zanelli, R., and Bischof, S., 2006. Effect of north and south exposure on weathering rates and clay mineral formation in Alpine soils. *Catena*, 67 (3), 155-74.

Elvidge, C. D., and Carleton, B. M., 1980. Restoration of Petroglyphs with Artificial Desert Varnish. *Studies in Conservation*, 25 (3), 108-17.

Ercanoglu, M., Gokceoglu, C., and Van Asch, T. W. J., 2004. Landslide susceptibility zoning north of Yenice (NW Turkey) by multivariate statistical techniques. *Natural Hazards,* 32 (1), 1-23.

Evans, S. G., Mugnozza, G., Strom, A. L., Hermanns, R. L., Ischuk, A., and Vinnichenko, S., 2006. Landslides from massive rock slope failure and associated phenomena. *In: Landslides from Massive Rock Slope Failure*, 03-52.

Fabião, C., 1996. Archaeology and nationalism. The Portuguese case. *In:* Diaz-Andreu, M., and Champion, J. eds. *Nationalism and archaeology in Europe*. London: UCL Press, 90-107.

FAO. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. Available from: http://www.fao.org/docrep/X0490E/x0490e07.htm [Accessed: 18 of March 2012].

Fernandes, A. P. B., 2004. Visitor management and the preservation of rock art: Two case studies of open air rock art sites in Northeastern Portugal: Côa Valley and Mazouco. *Conservation and Management of Archaeological Sites,* 6 (2), 95-111.

Fernandes, A. P. B., 2005. Programa de conservação do Parque Arqueológico do Vale do Côa: Primeiros resultados da estação sismológica e da estação metereológica em funcionamento no PAVC. *Côavisão,* 7, 159-66.

Fernandes, A. P. B., 2006. Understanding an unique conservation work environment: The case of the Côa Valley rock art outcrops. *In:* Rodrigues, J. D., and Mimoso, J. M. eds. *Theory and Practice in Conservation: A Tribute do Cesare Brandi (Proceedings of the International Seminar).* Lisboa: Laboratório Nacional de Engenharia Civil, 323-32.

Fernandes, A. P. B., 2007. The Conservation Programme of the Côa Valley Archaeological Park: Philosophy, objectives and action. *Conservation and Management of Archaeological Sites,* 9 (2), 71-96.

Fernandes, A. P. B., 2008a. Aesthetics, ethics, and rock art conservation: How far can we go? The case of recent conservation tests carried out in un-engraved outcrops in the Côa Valley, Portugal. *In:* Heyd, T., and Clegg, J. eds. *Aesthetics and Rock Art III Symposium. Proceedings of the XV UISPP World Congress (Lisbonne, 4-9 Septembre 2006) Vol. 10, Session C73*. Oxford: Archaeopress, 85-92.

Fernandes, A. P. B., 2008b. O papel da classificação na inventariação e salvaguarda da arte rupestre e demais sítios arqueológicos do Vale do Côa. *In:* Lima, A. C. P., Baptista, A. M., Coixão, A., Luís, L., and Rodrigues, M. eds. *Investigar e Valorizar o Património. Estudos Judaicos, Sítios Arqueológicos e Visitantes. Fórum Valorização e Promoção do Património Regional. Vol. II*. Porto: ACDR de Freixo de Numão, 64-69.

Fernandes, A. P. B. (Ed.). 2008c. *A arte da conservação: Técnicas e métodos de conservação em arte rupestre. Actas das Sessões do 3º Congresso de Arqueologia de Trás-os-Montes, Alto Douro e Beira Interior. Volume 2*. Porto: ACDR de Freixo de Numão.

Fernandes, A. P. B., 2009. Conservation of the Côa Valley rock art outcrops: A question of urgency and priorities. *Antiquity,* 83 (319). Available from: http://antiquity.ac.uk/projgall/batarda/ [Accessed: 03 of March 2009].

Fernandes, A. P. B., 2010a. The new Côa Museum. *International Newsletter on Rock Art,* 58, 26-28.

Fernandes, A. P. B., 2010b. *Slope orientation of rock art sites in the Côa Valley, Portugal: A case study in the spatial distribution of open-air Upper Palaeolithic rock art.* Paper presented at the IFRAO Congress, September 2010 – Symposium: Pleistocene art in Europe (Pre-Acts), Tarascon-sur-Ariège.

Fernandes, A. P. B., 2010c. Vandalism, graffiti or 'just' rock art? The case of a recent engraving in the Côa Valley rock art complex in Portugal. *FUMDHAmentos,* 9 (III), 729-43.

Fernandes, A. P. B., Marques, M. A., Rodrigues, M., Blanes, F., and Costa, C., 2006a. Estudo das formas de degradação de filitos com gravuras rupestres no Vale do Côa. *In:* Baldino, A., and Mirão, J. a. P. eds. *Actas do VII Congresso Nacional de Geologia*. Évora: Universidade de Évora.

Fernandes, A. P. B., Rico, M. T., and Huang, J. K. K., 2006b. Metódos de mapeamento das dinâmicas erosivas em acção nos painéis do Vale do Côa. *Côavisão,* 8, 50-9.

Fernandes, A. P. B., Mendes, M., Aubry, T., Sampaio, J., Jardim, R., Correia, D., Junqueiro, A., Bazaréu, D., Dias, F., and Pinto, P., 2008. The evolving relationship between the Côa Valley Archaeological Park and the local community: An account of the first decade. *Conservation and Management of Archaeological Sites,* 10 (4), 330-43.

Fernandes, A. P. B., and Rodrigues, J., 2008. Stone consolidation experiments in rock art outcrops at the Côa Valley Archaeological Park, Portugal. *In:* Rodrigues, J., and Mimoso, J. M. eds. *Stone consolidation in cultural heritage: Research and practice (Proceedings of the International Symposium)*. Lisbon: Laboratório Nacional de Engenharia Civil, 111-20.

Ferreira, A. B., 1978. *Planaltos e montanhas do Norte da Beira. Estudo de geomorfologia*. Lisboa: Centro de Estudos Geográficos.

Ferreira, A. B., 1993. As rãnas em Portugal. Significado geomorfológico e estratigráfico. *In:* Carvalho, G. S., Ferreira, A. B., and Senna-Martinez, J. C. eds. *O Quaternário em Portugal. Balanço e perspectivas*. Lisboa: Colibri, 7-15.

Figueiredo, D., and Puccioni, S. (Eds.). 2006. *Consolidação estrutural da Toca da Entrada do Pajaú: diagnóstico e proposta de intervenção*. Teresina, Brazil: IPHAN.

Finn, P., and Hall, N., 1996. Removal of iron fastenings and iron stains from sites in the Grampians. *In:* Thorn, A., and Brunet, J. eds. *Preservation of Rock Art.* Melbourne: Australian Rock Art Research Association, 65-71.

Fitzner, B., 2004. Documentation and evaluation of stone damage on monuments. *In:* Kwiatkowski, D., and Lofvendahl, R. eds. *Proocedings of the 10th International Congress on Deterioration and Conservation of Stone*. Stockholm: Elanders Gotab, 667-90.

Fitzner, B., Heinrichs, K., and La Bouchardiere, D., 2004. The Bangudae Petroglyph in Ulsan, Korea: studies on weathering damage and risk prognosis. *Environmental Geology,* 46, 504-26.

Florian, M. L. E., 1978. A review: The lichen role in rock art - Dating, deterioration and control. *In:* Pearson, C. ed. *Conservation of Rock Art. Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977.* Sidney: Institute for the Conservation of Cultural Material, 95-8.

Fonseca, F., 2011 2011. Navajo Nation wants return of remains. Available from: http://archaeologynewsnetwork.blogspot.com/2011/12/navajo-nation-wants-return-of-remains.html [Accessed: 14 of December 2011].

Fossati, A., 2001. Balanços de cinco anos de um Parque Arqueológico polémico. *O Expresso*, 11 of August 2001 p. 6.

Fossati, A., 2003. 'But they are only puppets...': Problems of management and educational programs in Rock Engravings National Parks, Valcamonica and Valtellina, Lombardy, Italy. *Rock Art Research*, 20 (1), 23-52.

Fry, E. J., 1927. The mechanical action of crustaceous lichens on substrata of shale, schist, gneiss, limestone, and obsidian *Annals of Botany* 41, 437-60.

FUMDHAM. 2007. *Parque Nacional da Serra da Capivara da Pré-história à História*. S. Raimundo Nonato: Ministério da Cultura - Fundo Nacional de Cultura/Fundação Museu do Homem Americano.

Gabora, L., and Kaufman, S. B., 2010. Evolutionary approaches to creativity. *In:* Sternberg, R. J., and Kaufman, S. B. eds. *The Cambridge Handbook of Creativity*. Cambridge: Cambridge University Press, 279-300.

Ganor, J., Matthews, A., and Paldor, N., 1989. Constraints on effective diffusivity during oxygen isotope exchange at a marble-schist contact, Sifnos (Cyclades), Greece. *Earth and Planetary Science Letters*, 94 (3,Äì4), 208-16.

Gombrich, E. H., 1995. *The story of art*. London: Phaidon Press.

Gomes, J. A., Angelucci, D., and Cabral, J., 2008. Arqueossismologia: Estado actual do conhecimento em Portugal. *Comunicações Geológicas*, 95, 73-92.

Gonçalves, M., 2001. Da "pré-história" à história do caso de Foz Cóa. *In:* Gonçalves, M. ed. *O caso de Foz Côa: Um laboratório de análise sociopolítica*. Lisboa: Edições 70, 27-64.

Gonzalez, J. M., Portillo, M. C., and Saiz-Jimenez, C., 2008. Bacterial diversity in the cave of Altamira. *Coalition*, 15, 2-6. Available from: http://www.rtphc.csic.es/PDF/NL15.pdf [Accessed: 13 of April 208].

Gonzalez, W. H., and Padilla, G. M., 1984. Monticello, the hispanic cultural gateway to Utah. *Utah Historical Quarterly*, 52 (1), 3-8.

Goudie, A. S., 2006. The Schmidt Hammer in geomorphological research. *Progress in Physical Geography,* 30 (6), 703-18.

Grab, S. W., 2007. Near-surface rockwall temperatures in high Drakensberg basalt: spatio-temporal differences and possible implications for weathering. *Zeitschrift fur Geomorphologie, Supplementary Issues*, 51 (1), 103-13.

Graniczny, M., 2006. Exogenic geological processes as a landform shaping factor. *In:* Zektser, I. S. ed. *Geology and ecosystems*. New York, NY: Springer, 171-82.

Grant, C., 1978. *Canyon de Chelly, its people and rock art.* Phoenix: University of Arizona Press.

Grassi, D., Grimaldi, S., and Simeone, V., 2006. Localizzazione e problemi di stabilità dei siti rupestri dell'area pugliese. *Giornale di Geologia Applicata,* 4, 65-72.

Grisafe, D. A., 1996. Preserving Native American petroglyphs on porous sandstone. *Plains Anthropologist,* 41 (158), 373-82.

Groube, L., 1978. Priorities and problems in Dorset archaeology. *In:* Darvill, T., Parker Pearson, M., Smith, R., and Thomas, R. eds. *New approaches to our past, an archaeological forum: Conference proceedings*. Southampton: University of Southampton Archaeological Society, 29-52.

Grunthal, G. (Ed.). 1998. *European Macroseismic Scale 1998*. Luxembourg: Centre Européen de Géodynamique et de Séismologie.

GTA. 1988. *Atlas do Ambiente. Notícia Explicativa I.3. Radiação solar*. Lisboa: Secretaria de Estado do Ambiente e Recursos Naturais.

Guidon, N., and Lage, M., 2002a. Saving the prehistoric paintings of the northeastern tradition at the site of Toca do Veado (Piauí, Brasil). *International Newsletter on Rock Art,* 33, 29-31.

Guidon, N., and Lage, M. C. S. M., 2002b. Examples de conservation active dans dex sites de peintures préhistoriques du Piaui: La Toca do Veado & Arco do Covão. *In:* Chalmin, E. ed. *L'art avant l'histoire. La conservation de l'art préhistorique*. Paris: SFIIC, 156-58.

Gutiérrez Martinez, M. d. l. L., 2010. The Great Murals of the Sierra de San Francisco. Stone Memory of a Missing People. *Adoranten,* 2010, 52-69.

Hall, C. M., and McArthur, S., 1996. The human dimension of heritage management. Different values, different interests, different issues. *In:* Hall, C. M., and Mcarthur, S. eds. *Heritage management in Australia and New Zealand*. Melbourne: Oxford University Press, 2-21.

Hall, C. M., and McArthur, S., 1998. *Integrated site management: Principies and praclice*. London: The Stationery Office.

Hall, K., 1999. The role of thermal stress fatigue in the breakdown of rock in cold regions. *Geomorphology,* 31 (1), 47-63.

Hall, K., Arocena, J. M., Boelhouwers, J., and Liping, Z., 2005. The influence of aspect on the biological weathering of granites: observations from the Kunlun Mountains, China. *Geomorphology,* 67 (1-2), 171-88.

Hall, K., Meiklejohn, I., and Arocena, J., 2007a. The thermal responses of rock art pigments: Implications for rock art weathering in southern Africa. *Geomorphology*, 91 (1-2), 132-45.

Hall, K., Meiklejohn, I., Arocena, J., Prinsloo, L., Sumner, P., and Hall, L., 2007b. Deterioration of San rock art: new findings, new challenges. *South African Journal of Science,* 103, 361-62.

Halsey, D. P., Mitchell, D. J., and Dews, S. J., 1998. Influence of climatically induced cycles in physical weathering. *Quaterly Journal of Engineering Geology,* 31, 359-67.

Hand, W. H., Fox, N. I., and Collier, C. G., 2004. A study of twentieth-century extreme rainfall events in the United Kingdom with implications for forecasting. *Meteorological Applications,* 11 (1), 15-31.

Hansen, J., 1999. The state of rock art preservation and climate change: An example from the central Sahara Desert. *In:* Dean, C. ed. *Images past, images present: the conservation and preservation of rock art*. Tucson: American Rock Art Research Association, 57-9.

Harry, K. G., Billo, E., and Mark, R., 2001. The challenge of long-term preservation: Managing impacts to rock art at Hueco Tanks State Historical Park. *In:* Freers, S. M., and Woody, A. eds. *American Indian Rock Art Volume 27: Phoenix*. Phoenix: American Rock Art Research Association, 151-59.

Haskovec, I., 1991. On some non-technical issues of conservation. *In:* Pearson, C., and Swartz Jr, B. K. eds. *Rock art and posterity: Conserving, managing and recording rock art*. Melbourne: Australian Rock Art Research Association, 97-99.

Hays-Gilpin, K., 2000. Beyond Mother Earth and Father Sky: Sex and gender in Ancient Southwestern Visual Arts. *In:* Rautman, A. ed. *Reading the body: Representations and remains in the archaeological record*. Philadelphia: University of Pennsylvania Press, 165-86.

Helskog, K., 2000. The Alta rock carvings. *International Newsletter on Rock Art,* 27, 24-28.

Helskog, K., 2008. *Guide. The rock carvings at Hjemmeluft/Jiepmaluokta.* Alta: World Heritage Rock Art Centre - Alta Museum.

Henry, L., 2007. A history of removing rock art in South Africa. *South African Archaeological Bulletin,* 62 (185), 44-48.

Herráez, J. A., 1996. La conservación preventiva del arte rupestre. *In:* Iglesias Gil, J. M. ed. *Cursos sobre el Patrimonio Histórico*. Reinosa: Universidad de Cantabria.

Heyd, T., 2007. Cross-cultural contact, etiquette and rock art. *Rock Art Research,* 24 (2), 191-97.

Heyd, T., and Clegg, J. (Eds.). 2008. *Aesthetics and Rock Art III Symposium. Proceedings of the XV UISPP World Congress (Lisbonne, 4-9 Septembre 2006) Vol. 10, Session C73*. Oxford: Archaeopress.

Hirsch, P., Eckhardt, F. E. W., and Palmer Jr, R. J., 1995. Methods for the study of rock-inhabiting microorganisms - A mini review. *Journal of Microbiological Methods,* 23 (2), 143-67.

Hoerle, S., 2005. A preliminary study of the weathering activity at the rock art site of Game Pass Shelter (KwaZulu-Natal, South Africa) in relation to its conservation. *South African Journal of Geology,* 108 (2), 297-308.

Hoerle, S., 2006. Rock temperatures as an indicator of weathering processes affecting rock art. *Earth Surface Processes and Landforms,* 31 (3), 383-89.

Hoerle, S., and Salomon, A., 2004. Microclimatic data and rock art conservation at Game Pass Shelter in the Kamberg Nature Reserve, KwaZulu-Natal. *South African Journal of Science,* 100 (7-8), 340-41.

Hogue, K., 1993. Conservation measures for the rock art of Kachina Panel, Southeast Utah. *In:* Bock, F. G. ed. *American Indian Rock Art Volume 19: Price*. Price: American Rock Art Research Association, 17-21.

Holmlund, J., and Wallace, H., 1994. Paleoseismicity and rock art in Southern Arizona. *In:* Sanger, K. K. ed. *American Indian Rock Art Volume 13 and 14: Flagstaff and St. George*. Flagstaff: American Rock Art Research Association, 1-8.

Honour, H., and Fleming, J., 1999. *A world history of art.* London: Laurence King.

Howell, S., 1991. Art and meaning. *In:* Hiller, S. ed. *The myth of primitivism: Perspectives on art*. London: Routledge, 215-37.

Hutchinson, J. N., 2006. Masive rock slope failure: Perspectives and retrospectives on state-of-the-art. *In: Landslides from Massive Rock Slope Failure,* 619-62.

Hygen, A.-S., 1996. Conservation, intervention or destruction of rock art? Some Scandinavian experiences. *Rock Art Research*, 13 (1), 49-52.

Hygen, A.-S., 2006. *Protection of Rock Art: The Rock Art Project 1996–2005; Final Report from the Directorate for Cultural Heritage.* Oslo: Directorate for Cultural Heritage Archive.

Hygen, A.-S., and Lasse, B., 2000. *Rock carvings in the borderlands. Bohuslan and Ostfold.* Gothenburg: Swedish National Heritage Board.

IFRAO. 2008. International Federation of Rock Art Organizations rock art glossary. Available from: http://mc2.vicnet.net.au/home/glossar/web/glossary.html [Accessed: 11 April 2011].

IM. 2010a. *Climate Normal for Figueira de Castelo Rodrigo for the period 1961-1990.* Lisboa: IM.

IM. 2010b. *Climate Normal for Moimenta da Beira for the period 1961-1990.* Lisboa: IM.

IM. 2012. Gráficos de observação. Available from: https://www.meteo.pt/pt/otempo/graficosobservação/obsDiariosHistorico.jsp [Accessed: 1st of March 2012].

INAG. 2012. Sistema Nacional de Informação de Recursos Hídricos (SNIRH). Available from: http://snirh.inag.pt/index.php?idMain= [Accessed: 12 of March 2012].

Ingold, T., 2000. Totemism, animism and the depiction of animals. *In:* Ingold, T. ed. *The perception of the environment: Essays in livelihood, dwelling and skill*. London and New York: Routledge, 111-31.

INMG. 1984a. *Atlas do Ambiente. Notícia Explicativa I.2. Temperatura. Temperatura média do ar.* Lisboa: Comissão Nacional do Ambiente.

INMG. 1984b. *Atlas do Ambiente. Notícia explicativa I.4.1 e I.4.2. Precipitação. Quantidade total e Número de dias no ano (Precipitação igual ou superior a 1,0 mm).* Lisboa: Comissão Nacional do Ambiente.

INMG. 1985. *Atlas do Ambiente. Notícia Explicativa I.6. Humidade do ar. Humidade relativa às 09 TMG.* Lisboa: Comissão Nacional do Ambiente.

INTOTA. 2011. Tetraethoxysilane Experts. Available from: http://www2.intota.com/experts.asp?strSearchType=all&strQuery=tetraethoxysilane [Accessed: 18 October 2011].

IPCC. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva, Switzerland: IPPC.

IPHAN. 2009. *Conservação e socialização de sítios arqueológicos.* Teresina, Brazil: IPHAN.

Jacobs, J., and Gale, F., 1994. *Tourism and the protection of aboriginal cultural sites.* Canberra: Australian Governrnent Publishing Services.

Janson, H. W., and Janson, A. F., 1997. *History of art.* London: Thames and Hudson.

Jenkins, K. A., and Smith, B. J., 1990. Daytime rock surface temperature variability and its implications for mechanical rock weathering: Tenerife, Canary Islands. *Catena*, 17 (4-5), 449-59.

Jepson, W. L., and Hickman, J. C., 1993. *The Jepson manual: higher plants of California.* Berkeley: University of California Press.

Johnson, R. H., 1980. Hillslope stability and landslide hazard.A case study from Longdendale, north Derbyshire, England. *Proceedings of the Geologists Association,* 91 (4), 315-25.

Jomelli, V., Grancher, D., Naveau, P., Cooley, D., and Brunstein, D., 2007. Assessment study of lichenometric methods for dating surfaces. *Geomorphology,* 86, 131-43.

Jordá Pardo, J. F., 1999. Geomorfología de la Comarca de Santa María de Real de Nieva y el conjunto de Domingo García. *In:* Ripoll López, S., and Municio González, L. J. eds. *Domingo García: Arte Paleolítica al aire libre en la Meseta Castellana*. Salamanca: Junta de Castilla y Léon; Universidad Nacional de Educación a Distancia, 25-30.

Jorge, M. A. G., 2009. *Geomorfometria da Bacia Hidrográfica do Rio Côa.* Lisbon: Instituto de Geografia e Ordenamento do Território.

Jorge, V. O. (Ed.). 1995. *Dossier Côa*. Porto: Sociedade Portuguesa de Antropologia e Etnologia.

Jurado, V., Fernandez-Cortes, A., Cuezva, S., Laiz, L., Cañaveras, J., Sanchez-Moral, S., and Saiz-Jimenez, C., 2009. The fungal colonisation of rock-art caves: experimental evidence. *Naturwissenschaften,* 96 (9), 1027-34.

Kapp, P., Pelletier, J. D., Rohrmann, A., Heermance, R., Russell, J., and Ding, L., 2011. Wind erosion in the Qaidam basin, central Asia: Implications for tectonics, paleoclimate, and the source of the Loess Plateau. *GSA Today,* 21 (4/5), 4-7.

Keenan, J., 2000. The theft of saharan rock art *Antiquity,* 74 (284), 287-88.

Kerzabi, S., Hachid, M., and Garcia, M., 1986. *Rock art in the Sahara: Conservation methodology and management.* Paris: UNESCO.

Kincey, M., Challis, K., and Howard, A., 2008. Modelling selected implications of potential future climate change on the archaeological resource of river catchments: an application of geographical information systems. *Conservation and Management of Archaeological Sites,* 10 (2), 113-31.

Klein, C., Hurlbut, C. S., and Dana, J. D., 1985. *Manual of mineralogy : (after James D. Dana)*. New York: Wiley.

Kliche, C. A., 1999. *Rock slope stability*. Littleton, CO: Society for Mining, Metallurgy, and Exploration.

Knight, K. B., St Clair, L. L., and Gardner, J. S., 2004. Lichen biodeterioration at Inscription Rock, El Morro National Monument, Ramah, New Mexico, USA. *Biodeterioration of Stone Surfaces: Lichens and Biofilms as Weathering Agents of Rocks and Cultural Heritage*, 129-63.

Koch, A., and Siegesmund, S., 2004. The combined effect of moisture and temperature on the anomalous expansion behaviour of marble. *Environmental Geology*, 46 (3), 350-63.

Kubarev, G., Rozwadowski, A., and Kubarev, V., 2004. Recent rock art research in the Altai Mountains (Russia). *International Newsletter on Rock Art* 39, 6-12.

Lage, M. C. S. M., 2006. Arqueometria. *In:* Figueiredo, D., and Puccioni, S. eds. *Consolidação estrutural da Toca da Entrada do Pajaú: diagnóstico e proposta de intervenção*. Teresina, Brazil: IPHAN, 83-94.

Lage, M. C. S. M., Borges, J. F., and Júnior, S. R., 2004/2005. Sítios de registros rupestres: Monitoramento e conservação. *Mneme*, 6 (13), 1-24.

Lage, M. C. S. M., Puccioni, S., Figueiredo, D., Arraes, M., Ferreira, M. A., Pádua, L. E., Carvalho, E. S., and Medeiros, E., 2002. Intervention de conservation sur un site: La Toca da Entrada do Pajaú, Parc National de la Serra da Capivara (Piauí, Brésil). *In:* Chalmin, E. ed. *L'art avant l'histoire. La conservation de l'art préhistorique*. Paris: SFIIC, 159-63.

Lage, M. C. S. M., and Silva, J. C., 2010. Problemas de conservação dos sítios arqueológicos do Parque Nacional Sete Cidades. *Clio Arqueológica,* 25 (1).

Lage, M. C. S. M., Silva, J. C., Magalhães, S. M. C., Cavalcante, L. C. D., Martins, L., and Ferraro, L., 2009. A restauração so sítio arqueológico da Pedra do Castelo. *Clio Arqueológica,* 24 (2), 67-82.

Lamarque, P., 2005. Palaeolithic cave painting: A test case for trancultural aesthetics. *In:* Clegg, J., and Heyd, T. eds. *Aesthetics and rock art*. Burlington, VT: Ashgate.

Lambert, D., 1989. *Conserving Australian rock art: A manual for site managers.* Canberra: Aboriginal Studies Press.

Lasheras, J., and de las Heras, C., 2006. Cueva de Altamira and the preservation of its Palaeolithic art. *Coalition,* 12, 7-13. Available from: http://www.rtphc.csic.es/PDF/NL12.pdf [Accessed: 13 of April 2008].

Lau, D., Ramanaidou, E., Furman, S., Cole, I., Hughes, T., and Hoobin, P., 2007. *Field studies of rock art appearence.* CSIRO.

Le Treut, H., R., S., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., Peterson, T., and Prather, M., 2007. Historical overview of cliamte change. *In:* Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L. eds. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge and New York: Cambridge University Press, 93-127.

Lee, G., 1986. Problems in the Conservation and Preservation of Rock Art. *WAAC Newsletter,* 8 (1), 5-7.

Letellier, R., 2007. *Recording, documentation, and information management for the conservation of heritage places: Guiding principles.* Los Angeles: The Getty Conservation Institute.

Leuta, T., 2009. *Evaluating the rate of rock art deterioration in the Ukhahlamba-Drakensberg Park, Kwazulu-Natal.* Thesis (MA). University of Pretoria, Pretoria.

Lewis, B., 2007. Towards gathering data: A suggested pro forma for the monitoring of damage to rock art sites in the Sydney and Blue Mountains regions. *Rock Art Research,* 24 (2), 253-55.

Lewis-Williams, J. D., 2003. *Images of mystery: Rock art of the Drakensberg.* Cape Town: Double Storey.

Lewis-Williams, J. D., and Dowson, T. A., 1999. *Images of power: Understading San rock art.* Johannesburg: Southern.

Lisci, M., Monte, M., and Pacini, E., 2003. Lichens and higher plants on stone: a review. *International Biodeterioration and Biodegradation,* 51 (1), 1-17.

Lodoen, T., and Mandt, G., 2010. *The rock art of Norway.* Oxford: Windgather Press.

Long, L. E., 2011. Dams, destruction, and archaeology. Available from: http://globalheritagenetwork.ning.com/forum/topics/dams-destruction-and [Accessed: 30 October 2011].

Lorblanchet, M., 2007. The origin of art. *Diogenes,* 54 (2), 98-109.

Loubser, J., Keyser, J. D., and Yazzolino, B., 2000. The establishment of a rock art monitoring program at two sites on Miller Island (Columbia River, Oregon, USA). *International Newsletter on Rock Art,* 25, 11-14.

Lucas Pellicer, M. R., 1977. Conservación del arte rupestre al aire libre. *CuPAUAM: Cuadernos de Prehistoria y Arqueología,* 4, 1-14.

Luís, L., 2008. Em busca dos cavaleiros com cabeça de pássaro: Perspectivas de investigação da Proto-história no Vale do Côa. *In:* Balbín Behrmann, R. ed. *Arte al aire libre en el Sur de Europa.* Salamanca: Junta de Castilla y Léon, 415-38.

Luís, L., 2009. Rock art as land art. A diachronic view of the Côa Valley (NE Portugal) Post-Palaeolithic rock art. *In:* Balbín Behrmann, R., Bueno Ramirez, P., González Antón, R., and Arco Aguilar, C. eds. *Rock carvings of the European and African Atlantic façade.* Oxford: Archeopress, 129-47.

Luís, L., and Fernandes, A. P. B., 2010. "On endless motion": Depiction of movement in the Upper Palaeolithic Côa Valley rock art (Portugal). *FUMDHAmentos,* 9 (IV), 1304-18.

Luís, L., and García Díez, M., 2008. Same tradition, different views: The Côa Valley Rock Art and social identity *In:* Domingo Sanz, I., Fiore, D., and May, S. K. eds. *Archaeologies of art: Time, place and identity*. Wallnut Creek, CA: Left Coast Press Inc., 151-70.

Machado, L., 2008. Conservação das rochas com gravuras do Vale do Côa: Intervenção piloto, núcleo da Canada do Inferno. *In:* Fernandes, A. P. B. ed. *A arte da conservação: Técnicas e métodos de conservação em arte rupestre. Actas das Sessões do 3º Congresso de Arqueologia de Trás-os-Montes, Alto Douro e Beira Interior. Volume 2*. Porto: ACDR de Freixo de Numão, 29-42.

MacLeod, I., Haydock, P., Tulloch, D., and Ford, B., 1995. Effects of Microbiological Activity on the Conservation of Aboriginal Rock Art. *AICCM Bulletin*, 21 (1), 3-9.

Malaurent, P., Brunet, J., Lacanette, D., and Caltagirone, J., 2007. Contribution of numerical modelling of environmental parameters to the conservation of prehistoric cave paintings: The example of Lascaux cave *Conservation and Management of Archaeological Sites*, 8, 59-76.

Malotki, E., 2007. *The rock art of Arizona. Art for life's sake.* Walnut, California: Kiva Publishing.

Manning, S., 2003. Fires damage rock art. *Vestiges*, 23 (9), 14. Available from: http://www.utahrockart.org/vestiges/archives/2003-09.pdf [Accessed: 4 of March 2008].

Mark, R., and Billo, E., 2006. Computer-assisted photographic documentation of rock art. *Coalition,* 11, 10-14. Available from: http://www.rtphc.csic.es/PDF/NL11.pdf [Accessed: 13 of April 2008].

Mark, R., and Billo, E., 2011. GigaPan panoramas for rock art panel documentation: A practical guide. *Rock Art Research,* 28 (2), 265-67.

Marques, J., Gonçalves, J., and Paz-Bermudez, G., 2011. Lichen induced Mechanical Weathering of Schist in the Côa Valley Archaeological Park (Vila Nova de Foz Côa), Portugal. (Poster presentation). *In: XVIII Simposio de Botánica Criptogámica*, Barcelona: Sociedad Española de Liquenología.

Martín Escorza, C., 1999. Factores geológicos en los grabados rupestres de Domingo García. *In:* Ripoll López, S., and Municio González, L. J. eds. *Domingo García: Arte Paleolítica al aire libre en la Meseta Castellana*. Salamanca: Junta de Castilla y Léon; Universidad Nacional de Educación a Distancia, 31-40.

Martín, J. d. F., 1989. *Conquista y romanización de Lusitania.* Salamanca: Ediciones Universidad de Salamanca.

Mas Cornellà, M., Jordá Pardo, J. F., Cambra Sánchez, J., Mas Riera, J., and Lombarte Carreira, A., 1994. La conservación del arte rupestre en las sierras del Cannpo de Gibraltar. Un primer diagnóstico. *Espacio, Tiempo Y Forma,* 7, 93-128.

McCarthy, D. P., 1999. A biological basis for lichenometry? *Journal of Biogeography*, 26 (2), 379-86.

McCoy, J., and Environmental Systems Research, I., 2004. *ArcGIS 9. Using ArcGIS spatial analyst.* Redlands, CA: ESRI.

McManamon, F. P., and Hatton, A., 2000. Introduction: Considering cultural resource management in modern society. *In:* Mcmanamon, F. P., and Hatton, A. eds. *Cultural resources management in contemporary society: Perspectives on managing and presenting the past*. London: Routledge, 1-5.

Meiklejohn, I., 1997. The role of moisture in the weathering of the Clarens formation of the Kwazulu-Natal Drakensberg: Implications for the preservation of indigenous rock art. *Soulh African Geographical Journal,* 79, 199-206.

Meiklejohn, K. I., Hall, K., and David, J. K., 2009. Weathering of rock art at two sites in the KwaZulu-Natal Drakensberg, southern Africa. *Journal of Archaeological Science,* 36, 973-79.

Molina Ballesteros, E., Cantano Martín, M., and García Talegón, J., 2010. Role of porosity in rock weathering processes: a theoretical approach *Cadernos Lab. Xeolóxico de Laxe,* 35, 147-62.

Montelle, Y.-P., 2009a. Aesthetics and Rock Art III Symposium, edited by Thomas Heyd and Jonh Clegg. BAR International Series 1818. 2008. Archaeopress, Oxford, 102 pages. *Rock Art Research,* 26 (1), 108-10.

Montelle, Y.-P., 2009b. Lascaux: adapting vs eradicating. *Rock Art Research,* 26 (1), 118-20.

Moro-Abadía, O., and González Morales, M., 2007. L'art Paléolithique est-il un « art » ? Réflexions autour d'une question d'actualité. *L'anthropologie,* 111 (4), 687-704.

Morphy, H., 2005. Aesthetics across time and place: an anthropological pesrpective on archaeology. *In:* Clegg, J., and Heyd, T. eds. *Aesthetics and rock art*. Burlington, VT: Ashgate, 51-60.

Morris, I., 2010. *Why the West rules - For now*. New York: Farrar, Straus and Giroux.

Mottershead, D., and Lucas, G., 2000. The role of lichens in inhibiting erosion of a soluble rock. *Lichenologist,* 32, 601-09.

Mottershead, D. N., Baily, B., Collier, P., and Inkpen, R. J., 2003. Identification and quantification of weathering by plant roots. *Building and Environment*, 38 (9-10), 1235-41.

Mountford, C. P., 1965. *Ayers rock; its people, their beliefs and their art.* Sydney: Angus and Robertson.

Murphy, W., 2006. The role of topographic amplification on the initaitaion of rock slopes failures during earthquakes. *In:* Evans, S. G., Mugnozza, G., Strom, A. L., Hermanns, R. L., Ischuk, A., and Vinnichenko, S. eds. *Landslides from Massive Rock Slope Failure*. Dordrecth: Springer, 139-54.

Nash, G., 2009. Serra da Capivara. America‘s oldest art? *Current World Archaeology*, 37, 41-46.

Nelson, S. E., 2003. Types of Metamorphism. Available from: http://www.tulane.edu/~sanelson/geol212/typesmetamorph.htm [Accessed: 24 of May 2012].

NFES, 2007. *Basic Land Navigation.* National Wildfire Coordination Group. Available from: www.nwcg.gov/pms/pubs/475/PMS475.pdf [Accessed.24 of May 2012].

O´Hara, G., 2006. *Monitoring of Microbial Diversity on Rock Surfaces on the Burrup Peninsula.* Perth: Murdoch University.

Oliveira Filho, R., 2007. *Valoração econômica da atividade ecoturística no Parque Nacional Serra da Capivara - Piauí.* Thesis (Master). Universidade Federal do Piauí, Teresina, Brazil.

Paradela, P. L., 1984. *Atlas do Ambiente. Notícia Explicativa I.11. Recursos aquíferos subterrâneos. Produtividade.* Lisboa: Comissão Nacional do Ambiente.

Paradise, T. R., 2002. Sandstone weathering and aspect in Petra, Jordan. *Zeitschrift fur Geomorphologie, Supplementary Issues*, 46 (1), 1-17.

Patterson, A., 1992. *Rock art symbols of the greater Southwest.* Boulder: Johnson Books.

Pau-Preto, F., and Luís, L., 2003. Plano de ordenamento de parque arqueológico: uma nova figura de planeamento. *Planeamento: Revista de Urbanismo e Ordenamento do Território,* 1, 73-79.

Pearson, C. (Ed.). 1978. *Conservation of Rock Art. Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977.* Sidney: Institute for the Conservation of Cultural Material.

Pellizzer, R., and Sabatini, G., 1972. Rocks alteration in natural environment in understanding monument's degradation. *In:* Rossi-Manaresi, R., and Torrace, G. eds. *The treatment of stone: Proceedinmgs of the meeting of the Joint Committee for the Conservation of Stone*. Bologna: Centro per la Conservazione delle Sculture All'aperto, 3-22.

Pessis, A.-M., and Guidon, N., 2009. Dating rock art paintings in Serra de Capivara National Park. Combined archaeometric techniques. *Adoranten,* 2009, 49-59.

Phillips, F. M., Flinsch, M., Elmore, D., and Sharma, P., 1997. Maximum ages of the Côa Valley (Portugal) engravings measured with Chlorine-36. *Antiquity,* 71 (271), 100-04.

Pilles, P. J., 1989. Public education and the management of rock art sites on the Coconino National Forest. *In:* Crotty, H. ed. *Preserving our rock art heritage. ARARA Occasional Paper 1*. San Miguel, California: American Rock Art Research Association, 23-34.

Pinker, S., 2002. *The blank state: The modern denial of human nature.* New York: Penguin.

Pires, H., Lima, P., and Bravo Pereira, L., 2011. Novos métodos de registo digital de arte rupestre: Digitalização tridimensional e fotografia multiespectral. . *In:* Vilaça, R. ed. *Estelas e estátuas-menires: Da Pré à Proto-história. Actas das IV Jornadas Raianas.* Sabugal: Câmara Municipal do Sabugal/Sabugal+, EM/Centro de Estudos Arqueológicos das Universidades de Coimbra e Porto (CEAUCP)/Instituto de Arqueologia do DHAA da FLUC., 175-86.

Ponti, R., and Persia, F., 2002. The preservation of rock-art in Lybia. *In:* Chalmin, E. ed. *L'art avant l'histoire. La conservation de l'art préhistorique*. Paris: SFIIC, 127-33.

Pope, G. A., 2000. Weathering of petroglyphs: Direct assessment and implications for dating methods. *Antiquity,* 74 (286), 833-43.

Pope, G. A., Meierding, T. C., and Paradise, T. R., 2002. Geomorphology's role in the study of weathering of cultural stone. *Geomorphology,* 47 (2-4), 211-25.

Porley, R., and Hodgetts, N., 2005. *Mosses and liverworts.* Collins.

Price, C., 1996. *Stone conservation: An overview of current research.* Los Angeles: Getty Conservation Institute.

Prieto Lamas, B., Rivas Brea, M. T., and Silva Hermo, B. M., 1995. Colonization by lichens of granite churches in Galicia (Northwest Spain. *The Science of the Total Environment* 167, 343-51.

Pritchard, M. A., and Savigny, K. W., 1990. Numerical modelling of toppling. *Canadian Geotechnical Journal,* 27 (6), 823-34.

Ralph, R. W., 1990. Seminole Canyon State Historic Park: An inventory of rock art conservation. *In:* Turpin, S. A. ed. *American Indian Rock Art Volume 16: San Antonio*. San Antonio: American Rock Art Research Association, 93-97.

Ramana, Y. V., and Sarma, L. P., 1980. Thermal expansion of a few Indian granitic rocks. *Physics of the Earth and Planetary Interiors,* 22 (1), 36-41.

Raposo, M., and Proença, N., 2008. Projecto de experimentação prévia para a conservação de uma rocha gravada e de uma rocha-tipo, no núcleo da Ribeira de Piscos, no Parque Arqueológico do Vale do Côa. . *In:* Fernandes, A. P. B. ed. *A arte da conservação: Técnicas e métodos de conservação em arte rupestre. Actas das Sessões do 3º Congresso de Arqueologia de Trás-os-Montes, Alto Douro e Beira Interior. Volume 2*. Porto: ACDR de Freixo de Numão, 93-113.

Ribeiro, M. L., 2001. *Carta geológica simplificada do Parque Arqueológico do Vale do Côa. Esc. 1: 80 000. Notícia explicativa.* Vila Nova de Foz Côa: Parque Arqueológico do Vale do Côa.

Ripoll López, S., and Municio González, L. J. (Eds.). 1999. *Domingo García: Arte Paleolítica al aire libre en la Meseta Castellana*. Salamanaca: Junta de Castilla y Léon; Universidad Nacional de Educación a Distancia.

Rodrigues, J. D., 1999. *Conservação da arte rupestre do Parque Arqueológico do Vale do Côa.* Lisboa: LNEC.

Rodrigues, J. D., 2003. Histórias com água e pedras. Nem sempre mole, nem sempre duras. *In:* Ferreira, M. P. V. ed. *A geologia de engenharia e os recursos geológicos.* Vol. II. Coimbra: Imprensa da Universidade, 419-36.

Rodrigues, J. D., and Grossi, A., 2007. Indicators and ratings for the compatibility assessment of conservation actions. *Journal of Cultural Heritage*, 8, 32-43.

Rodrigues, J. D., and Saraiva, J. A. G., 1985. *Experimental and theoretical approach to the study of the mechanism of wind erosion of stone in monuments.* Lisboa: LNEC Memória nº 654.

Romão, P. M. S., 1999. *Colonização liquénica nas rochas xistosas do Parque Arqueológico do Vale do Côa.*: Report done under a consultancy agreement with the Côa Valley Archaeoogical Park.

Romão, P. M. S., and Rattazzi, A., 1996. Biodeterioration on megalithic monuments. Study of lichens' colonization on Tapadao and Zambujeiro dolmens (Southern Portugal). *International Biodeterioration & Biodegradation*, 37 (1-2), 23-35.

Rosenfeld, A., 1985. *Rock art conservation in Australia.* Canberra: Australian Government Publishing Service.

Rowe, M., 2005. Dating studies of Prehistoric pictographs in North America. *In:* Loendorf, L., Chippendale, C., and Whitley, D. eds. *Discovering North American rock art.* Tucson: The University of Arizona Press, 240-64.

Rusinowski, F., 1990. *Étude de la représentation du mouvement dans les figures animales peintes et gravées de la grotte de Lascaux.* Liège: Préhistoire Liégeoise.

Ruspoli, M., 1987. *The cave of Lascaux: The final photographs.* New York: Abrams.

Sacchi, D., 1995. Brèves remarques à propos su site d"art rupestre de Foz Côa (Portugal), de son importance et de son devenir. *Trabalhos de Antropologia e Etnologia*, 35 (4), 519-22.

Saiz-Jimenez, C., 1999. Biogeochemistry of weathering processes in monuments. *Geomicrobiology Journal*, 16 (1), 27-37.

Saiz-Jimenez, C., Cuezva, S., Jurado, V., Fernandez-Cortes, A., Porca, E., Benavente, D., Ca√±averas, J. C., and Sanchez-Moral, S., 2011. Paleolithic Art in Peril: Policy and Science Collide at Altamira Cave. *Science,* 334 (6052), 42-43.

Sanchidrián, J. L., 2005. *Manual de arte prehistórico.* Barcelona: Ariel.

Sanz, N., 2008. Rock art and World Heritage: Towards a serial transnational nomination to the UNESCO World Heritage List. *In:* Sanz, N. ed. *Rock art in the Caribbean: Towards a serial transnational nomination to the UNESCO World Heritage List*. Paris: UNESCO, 48-79.

Scarre, C., 1998. The Côa Valley. *In:* Scarre, C. ed. *Exploring Prehistoric Europe*. Oxford: Oxford University Press, 45-56.

Schaafsma, P., 1980. *Indian rock art of the Southwest.* Santa Fe, New Mexico: School of America Research, University of New Mexico Press.

Schmidt, S. T., and Robinson, D., 1997. Metamorphic grade and porosity and permeability controls on mafic phyllosilicate distributions in a regional zeolite to greenschist facies transition of the North Shore Volcanic Group, Minnesota. *Geological Society of America Bulletin,* 109 (6), 683-97.

Searight-Martinet, S., 2006. Destruction of rock art sites - the case of Morocco. *Almogaren,* 37, 231-46.

Seaward, M. R. D., 1997. Major impacts made by lichens in biodeterioration processes. *International Biodeterioration & Biodegradation,* 40 (2-4), 269-73.

Seaward, M. R. D., 2004. Lichens as subversive agents of biodeterioration. *In:* St. Clair, L., and Seaward, M. eds. *Biodeterioration of Stone Surfaces: Lichens and Biofilms as Weathering Agents of Rocks and Cultural Heritage*. Dordrecht: Kluwer Academic Publishers, 9-18.

Seglie, D., 2006. Rock art conservation, education and ethics. *Coalition,* 12, 2-7. Available from: http://www.rtphc.csic.es/PDF/NL12.pdf [Accessed: 13 of April 2008].

Selby, M. J., 1982. Controls on the stability and inclinations of hillslopes formed on hard rock. *Earth Surface Processes and Landforms,* 7 (5), 449-67.

Sharpe, K., Barnett, T., Rushton, S., Bryan, P., Lee, G., and Mazel, A., 2008. *The Prehistoric rock art of England: Recording, managing and enjoying our carved heritage*. English Heritage and Northumberland County Council. Available from: http://archaeologydataservice.ac.uk/catalogue/adsdata/arch-836-1/dissemination/pdf/ERA_Brochure.pdf [Accessed.3 of August 2011].

Silver, C., 1989. Rock art conservation in the United States: Wish or reality. *In:* Crotty, H. ed. *Preserving our rock art heritage. ARARA Occasional Paper 1*. San Miguel, California: American Rock Art Research Association, 3-15.

Silver, C. S., and Wolbers, R., 2004. Lichen encroachment onto rock art in Eastern Wyoming: Conservation problems and prospects for treatment. *In:* St. Clair, L., and Seaward, M. eds. *Biodeterioration of Stone Surfaces: Lichens and Biofilms as Weathering Agents of Rocks and Cultural Heritage*. Dordrecht: Springer, 115-28.

Simpson, A., Clogg, P., Diaz-Andreu, M., and Larkman, B., 2004. Towards three-dimensional non-invasive recording of incised rock art. *Antiquity*, 78 (301), 692-98.

Sims, P., 2006. Rock art vandalism in Tasmania. *Rock Art Research*, 23 (1), 119-22.

Soleilhavoup, F., 1991-1992. Scientifiques et touristes dans les sites d'art rupestre de plein air: Des règles à appliquer; une déontologie à fixer. *Survey - Bollettino del Centro Studi e Museo d'Arte Preistorica di Pienrolo, Italia*, 7-8, 81-97.

Soleilhavoup, F., 1993. Art rupestre et aménagement du territoire: Contradiction entre mise en valeur et conservation. *In: ICOM Committee for Conservation Triennial Meeting*. Paris: ICOM Committee for Conservation, 853-56.

Soleilhavoup, F., 1998. An endangered art. *The Unesco Journal*, April 1998, 29-32.

Soler i Subils, J., and Brooks, N., 2007. Damage to rock art sites attributed to MINURSO in Western Sahara between 1995 and 2007. Available from: http://www.google.com/url?q=http://www.udg.edu/Portals/92/Grup%2520del%2520Sahara/minurso/MINURSO_Damage_Inventory.pdf&sa=U&ei=KHyRTtmoCsSztwe0lc2MDA&ved=0CA4QFjAA&usg=AFQjCNGN35qxynaiip8B1qu6MCoz_PdoPQ [Accessed: 09 October 2011].

Song, H., 2009. *Inferring myths from Bangudae Petroglyph.* Paper presented at the International Association for Semiotic Studies Congress, La Coruna (Spain), September 22-26.

St. Clair, L. L., and Seaward, M., 2004. Biodeterioration of rock substrata by lichens: Progress and problems. *In:* St Clair, L. L., and Seaward, M. eds. *Biodeterioration of stone surfaces: Lichens and biofilms as weathering agents of rocks and cultural heritage*. Dordrecht: Kluwer Academic Publishers, 1-8.

Steelman, K. L., Rickman, R., Rowe, M., Boutton, T., Russ, J., and Guidon, N., 2002. Accelerator Mass Spectrometry radiocarbon ages of an oxalate accretion and rock paintings at Toca do Serrote da Bastiana, Brazil. *In:* Jakes, K. A. ed. *Archaeological chemistry. Materials, methods and meaning.* Washington, DC: American Chemical Society, 22-35.

Steinbring, J., 1994. The need for a method and theory in rock art conservation. *In:* Sanger, K. K. ed. *American Indian Rock Art Volume 13 and 14: Flagstaff and St. George*. Flagstaff: American Rock Art Research Association, 23-26.

Sullivan, H., 1991. Site management in Kakadu and Uluru National Parks. *In:* Pearson, C., and Swartz Jr, B. K. eds. *Rock art and posterity. Conserving, managing and recording rock art*. Melbourne: Australian Rock Art Research Association, 3-6.

Sullivan, S., 1978. Conservation of Aboriginal art in New South Wales. *In:* Pearson, C. ed. *Conservation of Rock Art. Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977.* Sidney: Institute for the Conservation of Cultural Material, 71-4.

Summerfield, M., 1991. *Global geomorphology: An introduction to the study of landforms.* Harlow: Longman.

Sundstrom, L., and Hays-Gilpin, K., 2011. Rock Art as Cultural Resource. *In:* King, T. ed. *A Companion to Cultural Resource Management*: Wiley-Blackwell, 351-70.

Sutton, D. 2003. Microbiological Aspects of Rock Art Deterioration, *Burrup Rock Art Monitoring Workshop*. Karratha, Australia.

Swantesson, J., 2005. Weathering and decay. Breakdown rates of rock carvings in the southern part of Sweden. *Adoranten*, 2005, 59-72.

Taboada, J., Rivas, T., Saavedra, A., Ordonez, C., Bastante, F., and Giraldez, E., 2008. Evaluation of the reserve of a granite deposit by fuzzy kriging. *Engineering Geology*, 99 (1,Äì2), 23-30.

Tangestani, M. H., 2004. Landslide susceptibility mapping using the fuzzy gamma approach in a GIS, Kakan catchment area, southwest Iran. *Australian Journal of Earth Sciences,* 51 (3), 439-50.

Tansem, K., and Johansen, H., 2008. The World Heritage rock art in Alta. *Adoranten,* 2008, 65-84.

Taruvinga, P., and Ndoro, W., 2003. The vandalism of the Domboshava rock painting site: Some reflections on approaches to heritage management. *Conservation and Management of Archaeological Sites,* 6, 3-10.

Thompson, G. R., and Turk, J., 1999. *Earth science and the environment.* Fort Worth: Saunders College Pub.

Thorn, A., and Brunet, J. (Eds.). 1996. *Preservation of rock art.* Melbourne: Australian Rock Art Research Association.

Tratebas, A. M., 2004. Biodeterioration of prehistoric rock art and issues in site preservation. *In:* St. Clair, L., and Seaward, M. eds. *Biodeterioration of Stone Surfaces: Lichens and Biofilms as Weathering Agents of Rocks and Cultural Heritage*. Dordrecht: Kluwer Academic Publishers, 195-228.

Tratebas, A. M., Cerveny, N. V., and Dorn, R. I., 2004. The effects of fire on rock art: Microscopic evidence reveals the importance of weathering rinds. *Physical Geography,* 25 (4), 313-33.

Tyagi, G., 1991. Conservation of Indian rock art. *In:* Pearson, C., and Swartz Jr, B. K. eds. *Rock art and posterity. Conserving, managing and recording rock art*. Melbourne: Australian Rock Art Research Association, 28-9.

UNESCO. 1999. Report on the twenty-second session of the World Heritage Commission. Kyoto, Japan. 30 November – 5 December 1998. Available from: http://whc.unesco.org/en/list/866 [Accessed: 26 of November 2008].

UNESCO. 2010a 2010. Daegokcheon Stream Petroglyphs. Available from: http://whc.unesco.org/en/tentativelists/5486/ [Accessed: 14 of December 2010].

UNESCO. 2010b. Report of the decisions adopted by the World Heritage Committee at its 34th Session (Brasilia, 2010). Available from: http://whc.unesco.org/archive/2010/whc10-34com-20e.pdf [Accessed: 14 of December 2011].

Vanska, H., 2001. *An evaluation of the role of lichens in the biodeterioration of rock surfaces with ancient petroglyphs (engravings) in the Côa Valley Archaeological Park in Portugal. Preliminary Report No. 1 from the visit to the Côa Valley Archaeological Park during the Field Seminar of the RockCare Project in Foz Côa (Portugal).* Goteburg, Sweden: RockCare.

Varga, A. A., 2006. Gravitational creep of rock slopes as pre-collapse deformation and some problems in its modelling. *In: Landslides from Massive Rock Slope Failure*, 103-10.

Veludo, I., Matias, L., and Costa, P. T., 2008. Monitorização sísmica do território do Parque Arqueológico do Vale do Côa. *In:* Fernandes, A. P. B. ed. *A arte da conservação: Técnicas e métodos de conservação em arte rupestre. Actas das Sessões do 3º Congresso de Arqueologia de Trás-os-Montes, Alto Douro e Beira Interior. Volume 2*. Porto: ACDR de Freixo de Numão, 12-28.

Venter, G., 2011. *Surface preparation and the effects on rock art deterioration.* Thesis (MA). University of Pretoria, Pretoria.

Vidal, P., 2001. *L'art rupestre en péril: Un patrimoine mondial a sauver*. Périgueux: Pilote.

Viles, H. A., 2002. Implications of future climate change for stone conservation *In:* Siegesmund, S., Weiss, T., and Vollbrecht, A. eds. *Natural stone, weathering phenomena, conservation strategies and case studies*. London: Geological Society, 407-18.

Viles, H. A., 2005. Microclimate and weathering in the central Namib Desert, Namibia. *Geomorphology,* 67 (1-2), 189-209.

Viles, H. A., and Goudie, A. S., 2003. Interannual, decadal and multidecadal scale climatic variability and geomorphology. *Earth-Science Reviews,* 61 (1-2), 105-31.

Villa, N., Dorn, R., and Clark, J., 1995. Fine material in rock fractures: Aeolian dust or weathering? *In:* Tchakerian, V. P. ed. *Desert aeolian processes*. London: Chapman & Hall, 219-31.

Vogt, B. J., 2007. *A visual analytical approach to rock art panel condition assessment.* Thesis (PhD). Arizona State University, Tempe.

Vouvé, J., Brunet, J., Vidal, P., and Marsal, J., 1983. Les ouevres rupestres de Lascaux (Montignac, France): Maintien des conditions de conservation. *Studies in Conservation,* 28 (3), 107-16.

Walderhaug, E. M., 1998. Changing art in a changing society: The hunters' rock-art of western Norway. *In:* Chippindale, C., and Taçon, P. eds. *The archaeology of rock art*. Cambridge: Cambridge University Press, 285-301.

Walderhaug, O., and Walderhaug, E. M., 1998. Weathering of Norwegian rock art – a critical review. *Norwegian Archaeological Review,* 31, 119-39.

Walderhaugg, O., 1998. Chemical weathering at rock art sites in western Norway: Which mechanisms are active and how can they be retarded? *Journal of Archaeological Science,* 25 (8), 789-800.

Ward, G., and Ward, L. (Eds.). 1995. *Management of rock imagery*. Melbourne: Australian Rock Art Research Association.

Warscheid, T., and Braams, J., 2000. Biodeterioration of stone: a review. *International Biodeterioration & Biodegradation,* 46 (4), 343-68.

Watchman, A., 1996. A review of the theory and assumptions in the AMS dating of the Foz Côa petroglyphs, Portugal. *Rock Art Research,* 13 (1), 21-30.

Watchman, A., 2002. The impact of dust in the conservation and management of Aboriginal rock paintings in Northern Australia. *In:* Chalmin, E. ed. *L'art avant l'histoire. La conservation de l'art préhistorique*. Paris: SFIIC, 25-34.

Watchman, A., Sale, K., and Hogue, K., 1995. Conservation of the Rendezvous Creek and Nursery Swamp 2 Aboriginal painting sites, Namadgi National Park, ACT. *Conservation and Management of Archaeological Sites*, 1, 25-34.

Watchman, A. L., 2005. Conservation of Australian rock art. *Coalition*, 10, 14-18. Available from: http://www.rtphc.csic.es/PDF/NL%2010.pdf [Accessed: 13 of April 2008].

Weiss, T., Siegesmund, S., Kirchner, D., and Sippel, J., 2004. Insolation weathering and hygric dilatation: two competitive factors in stone degradation. *Environmental Geology*, 46, 402-13.

Welsh, L., and Welsh, P., 2007. *Rock-Art of the Southwest. A visitor's companion.* Berkeley: Wilderness Press.

Whitley, D. S., and Dorn, R. I., 1987. Rock art chronology in eastern California. *World Archaeology*, 19 (2), 150 - 64.

Williams, A., and Tupara, N., 2000. *Rock art conservation survey, Tongariro/Taupo Conservancy*. Wellington, New Zealand: Department of Conservation,.

Wilson, M. J., 2004. Weathering of rocks by lichens with special reference to stonework: A review. *In:* Mitchell, D. J., and Searle, D. E. eds. *Stone Deterioration in Polluted Urban Environments*. Enfield: Science Publishers, 51-60.

WMO. 1996. *Guide to meteorological instruments and methods of observation. Sixth Edition. WMO-No. 8.* Geneva: World Meteorological Organization.

Wong, T.-f., and Brace, W. F., 1979. Thermal expansion of rocks: some measurements at high pressure. *Tectonophysics*, 57 (2-4), 95-117.

Wylie, F. R., Walsh, G. L., and Yule, R. A., 1987. Insect damage to aboriginal relics at burial and rock-art sites near Carnarvon in central Queensland. *Journal of the Australian Entomological Society*, 26, 335-45.

Yalcin, A., and Bulut, F., 2007. Landslide susceptibility mapping using GIS and digital photogrammetric techniques: a case study from Ardesen (NE-Turkey). *Natural Hazards*, 41 (1), 201-26.

Zhou, Q., and Liu, X., 2004. Analysis of errors of derived slope and aspect related to DEM data properties. *Computers & Geosciences*, 30 (4), 369-78.

Zilhão, J., 1995. The age of the Côa Valley (Portugal) rock art: Validation of archaeological dating to the Paleolithic and refutation of 'scientific' dating to Historic or Proto-Historic times. *Antiquity*, 69 (226), 883-901.

Zilhão, J., 1998. The rock art of the Côa Valley, Portugal: Significance, conservation and management. *Conservation and Management of Archaeological Sites,* 2 (4), 193-206.

Zilhão, J. (Ed.). 1997. *Arte rupestre e pré-história do Vale do Côa. Trabalhos de 1995-1996. Relatório Científico ao Governo da República Portuguesa Elaborado nos Termos da Resolução do Conselho de Ministros nº 4/96, de 17 de Janeiro.* Lisbon: Ministério da Cultura.

Zilhão, J., Aubry, T., Carvalho, A. F., Baptista, A. M., Gomes, M. V., and Meireles, J., 1997. The rock art of the Côa Valley (Portugal) and its archaeological context: First results of current research. *Journal of European Archaeology,* 5 (1), 7-49.

FIGURES

Figure 1. Location of the Côa Valley in Europe.

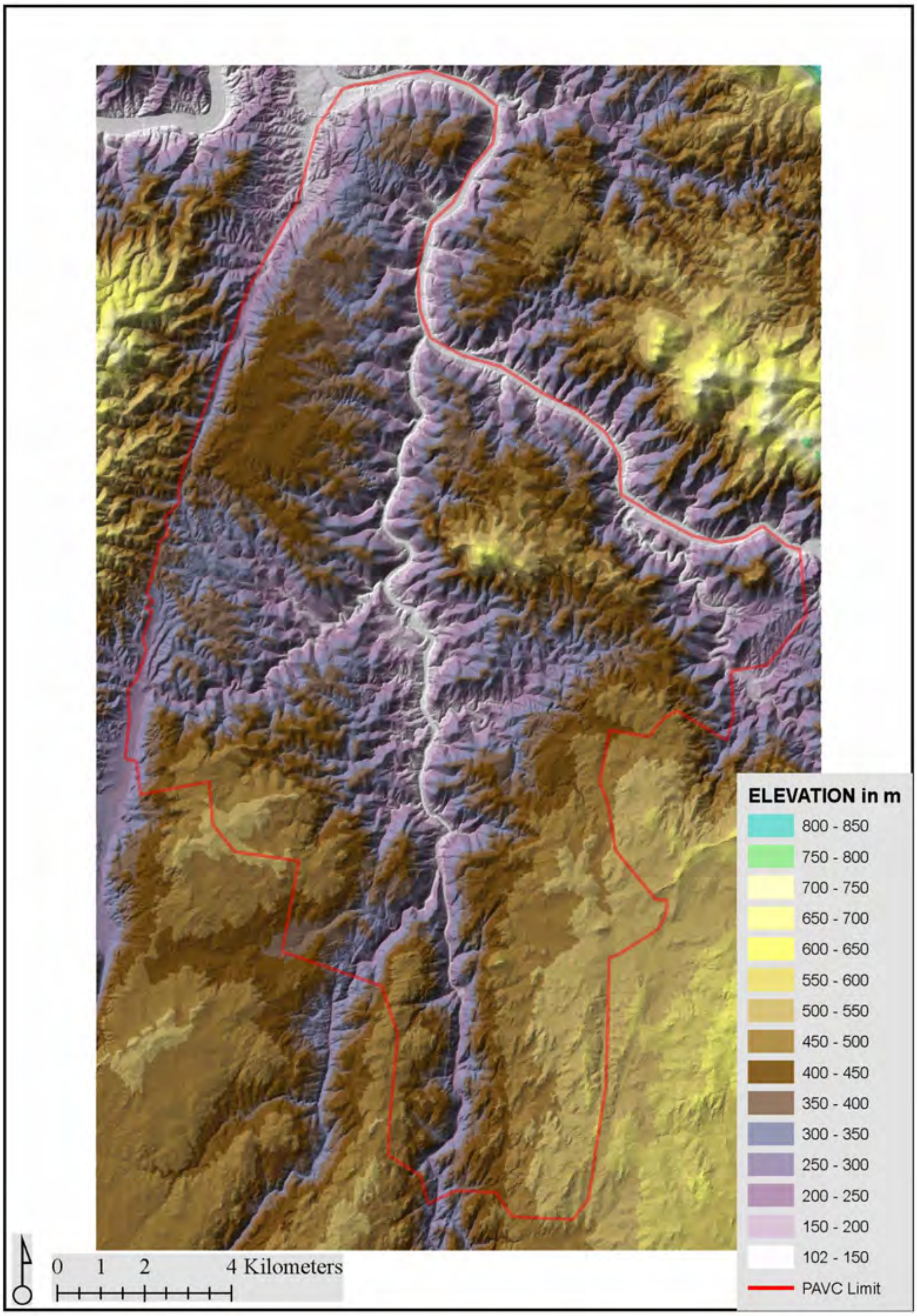


Figure 2. The area of study.

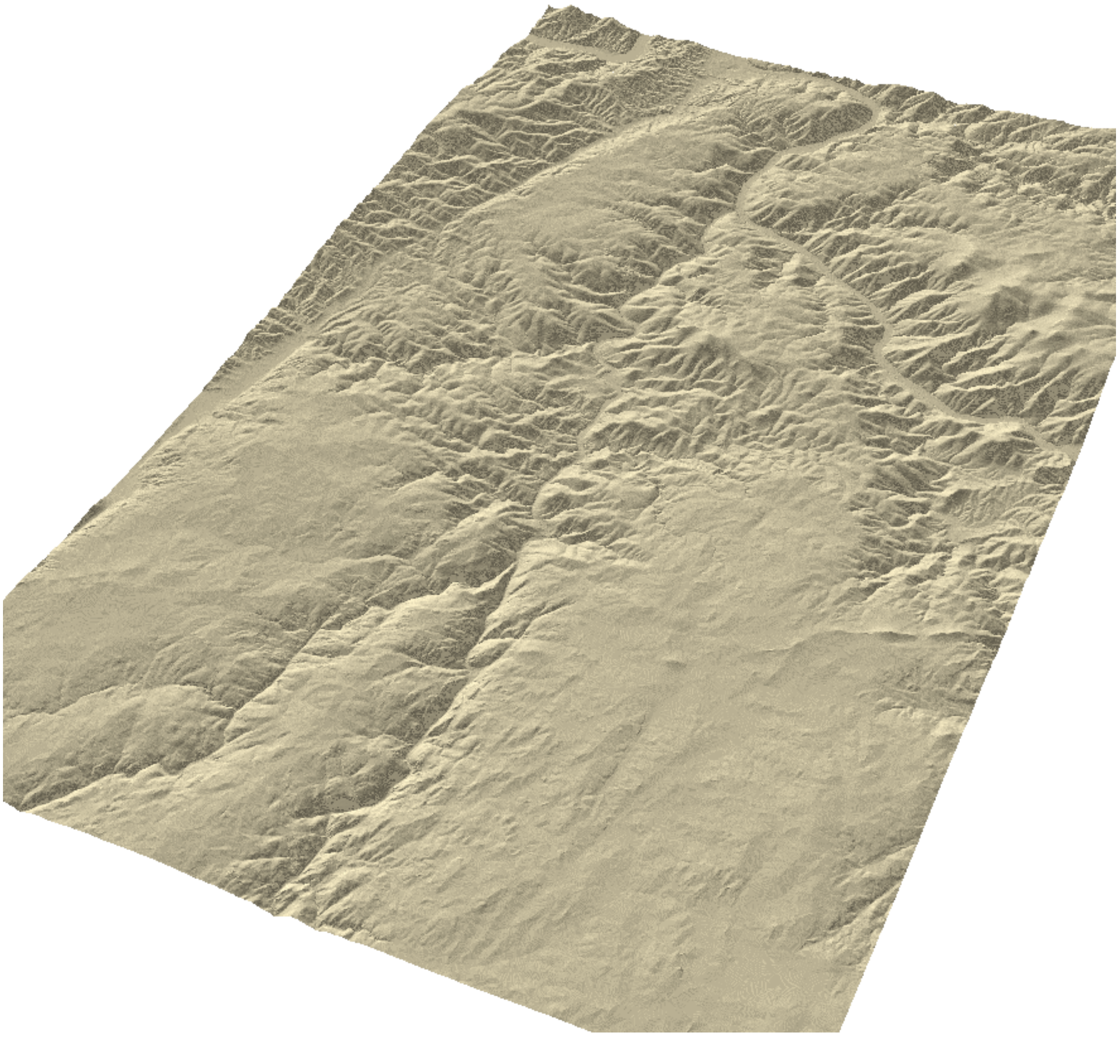


Figure 3. Another perspective of the area of study. Figure with no scale.

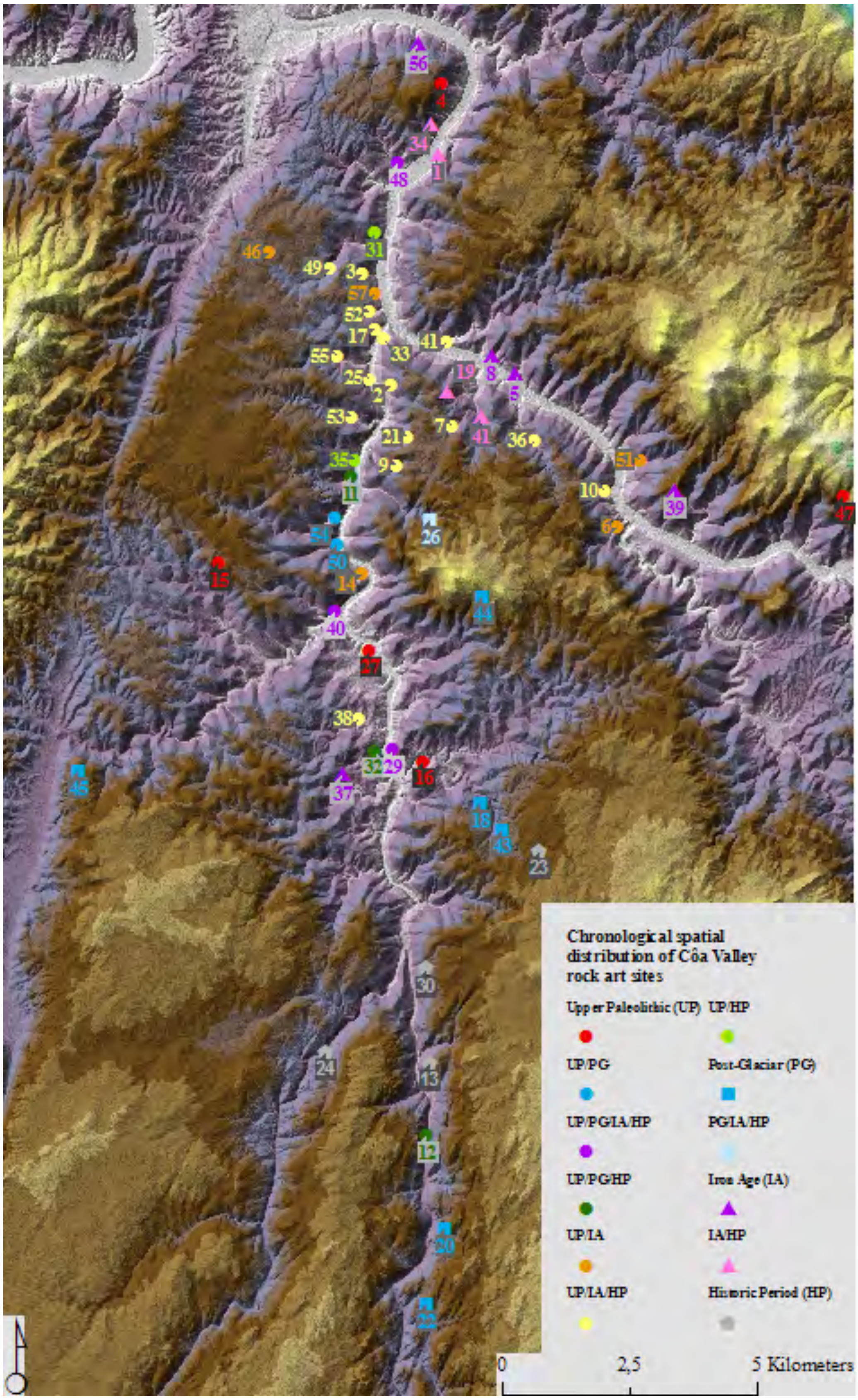


Figure 4. Chronological spatial distribution of the Côa Valley rock-art sites. The site ID number refer to Table 1. Chronologically undetermined rock-art is not signalled.

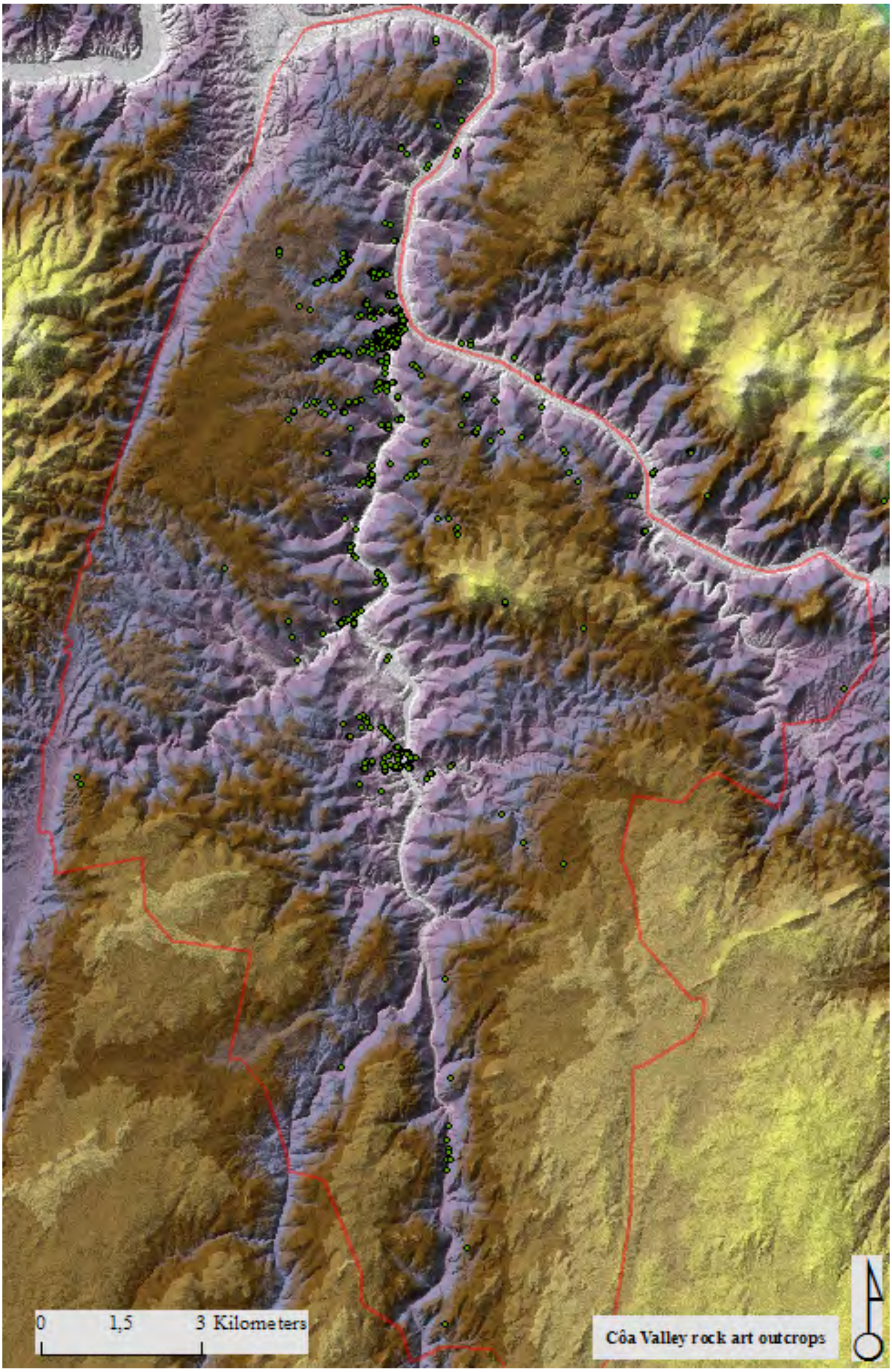


Figure 5. Location of known (as of January 2010) rock-art outcrops in the Côa Valley.

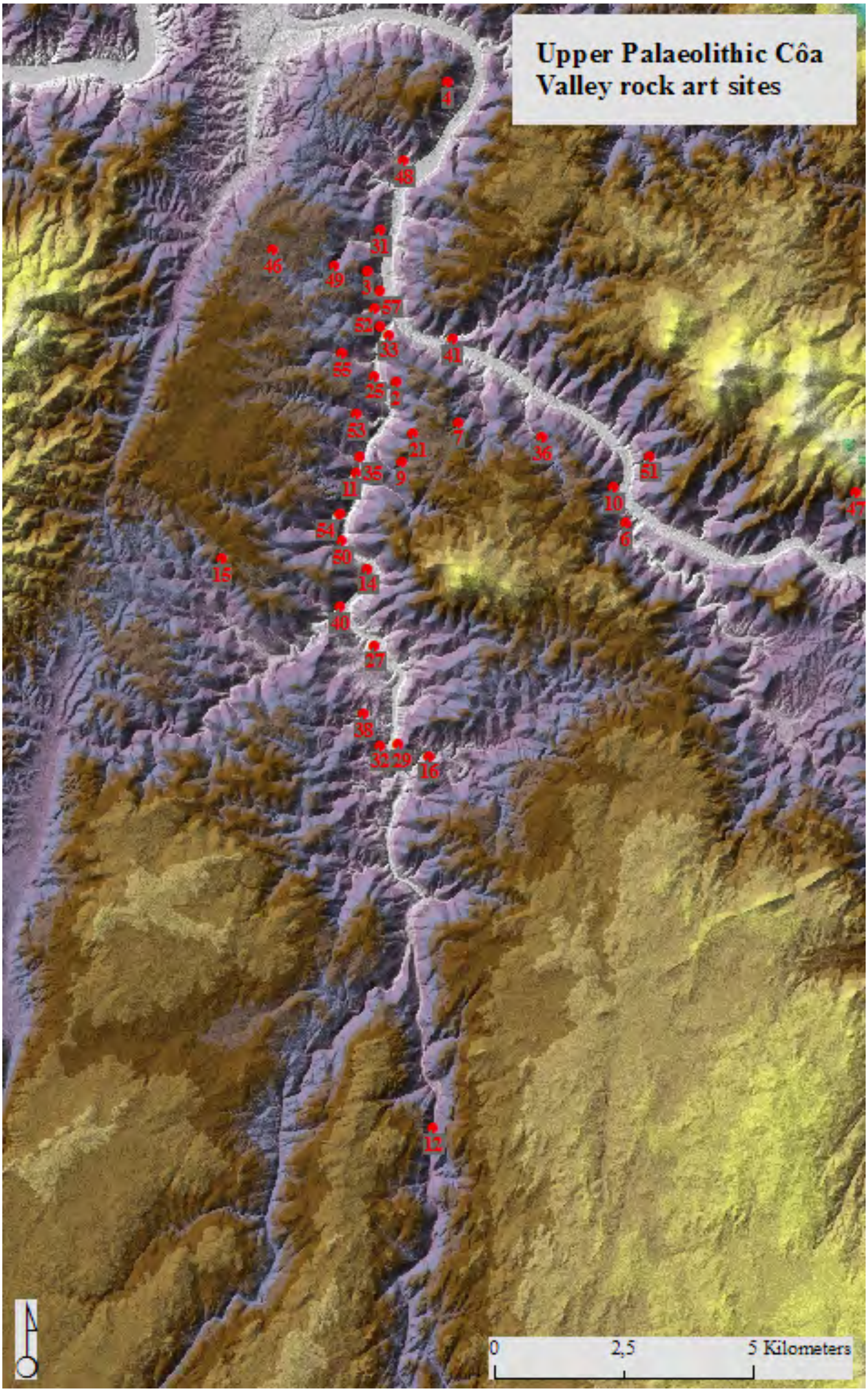


Figure 6. Upper Palaeolithic rock-art sites in the Côa Valley.

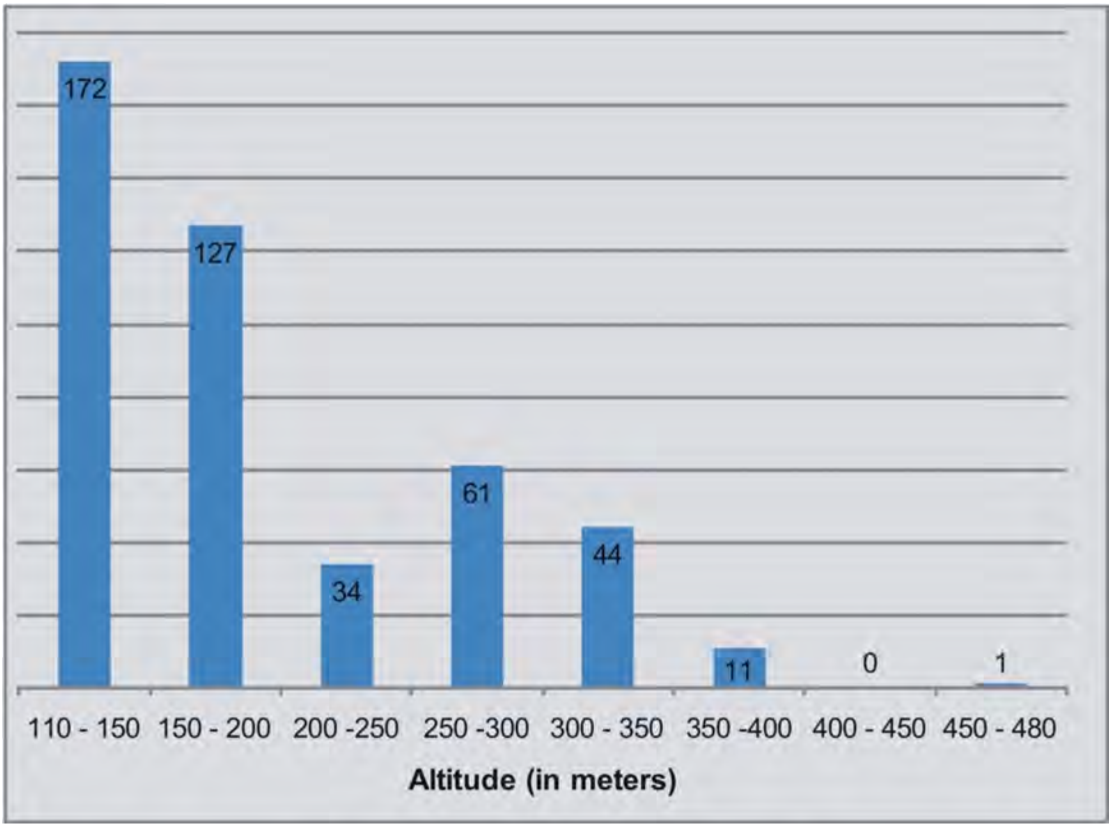


Figure 7. Altitude of Upper Palaeolithic outcrops.

Figure 8. Penascosa Rock 3 featuring numerous superimposed motifs of goats, horses and aurochs. Drawing in Baptista (1999, 99) by Fernando Barbosa.

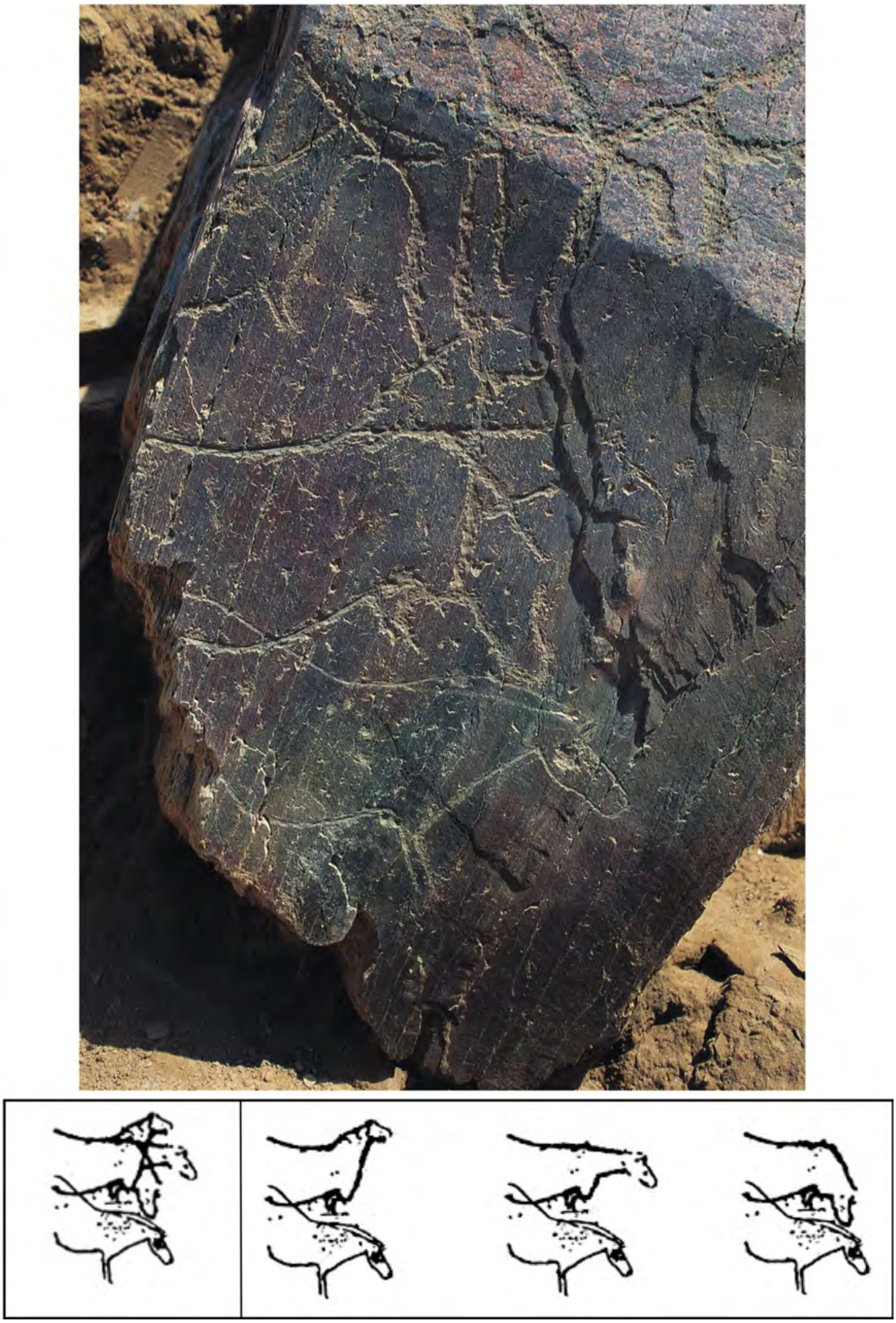


Figure 9. Penascosa Rock 4 featuring a ‘three-headed’ horse. Photo in Baptista (1999, 108). Drawing by Fernando Barbosa.

Figure 10. Two-headed horse motif in Fariseu Rock 1.

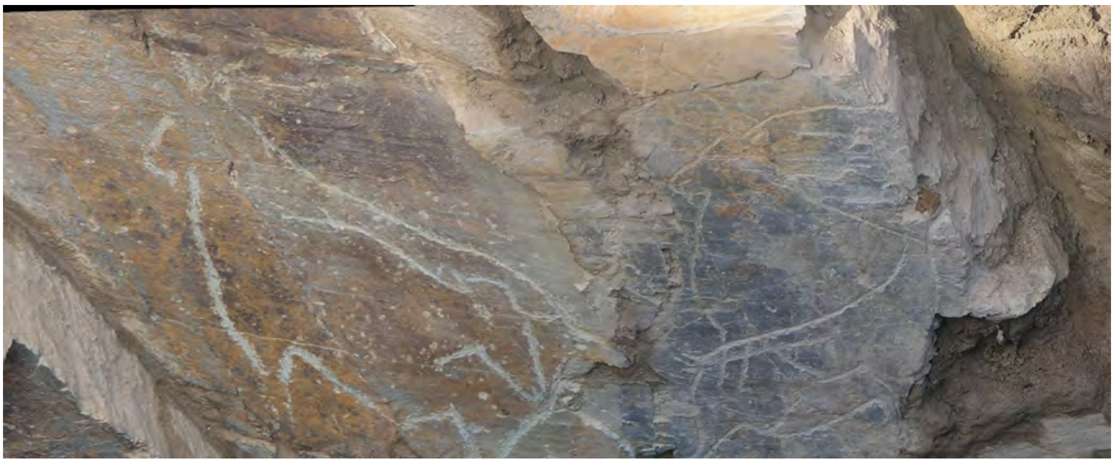


Figure 11. A composition in Fariseu Rock 1 that may portray two different goats or the same individual in motion.

Figure 12. Iron Age warrior engraved on top of a Upper Palaeolithic doe in Vermelhosa Rock 1. Photo in Baptista (1999, 146).

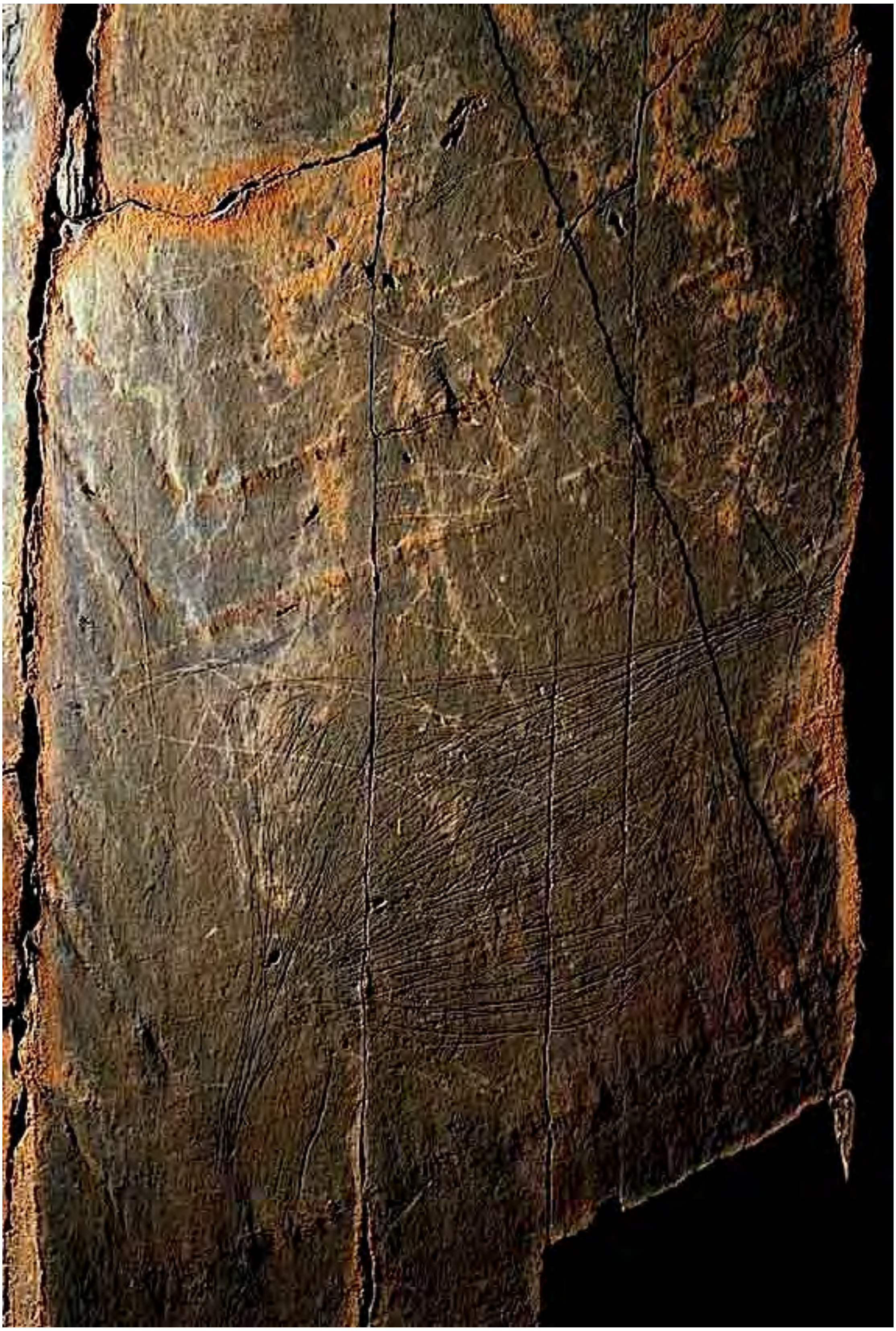


Figure 13. Fine line incised motif (an open mouth goat) in Tudão Rock 1.

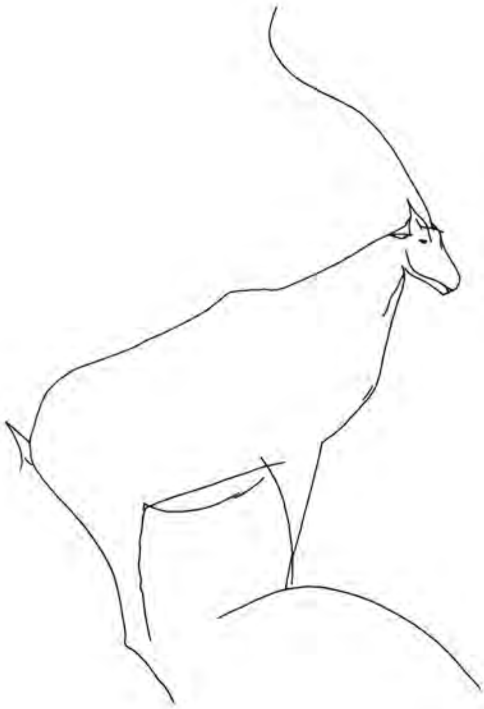


Figure 14. Pirenaic goat motif in Vale de Cabrões Rock 5 (Width: 21 cms; Heigth: 26 cms.). Drawing in Baptista (1999, 131) by Fernando Barbosa.

Figure 15. A rare fish motif in Penascosa Rock 5. Photo in Baptista (1999, 104).

Figure 16. Cave (square symbol) and open-air (sphere symbol) Upper Palaeolithic rock-art sites in the Iberian Peninsula. Map in Alcolea González and Balbín Behrmann (2007, 503).

Figure 17. Neolithic paintings in Faia Rock 1 representing bovines. Photo in Baptista (1999, 159).

Figure 18. Painted anthropomorphic motif in Faia Rock 1. Drawing in Baptista (1999, 160) by Fernando Barbosa.

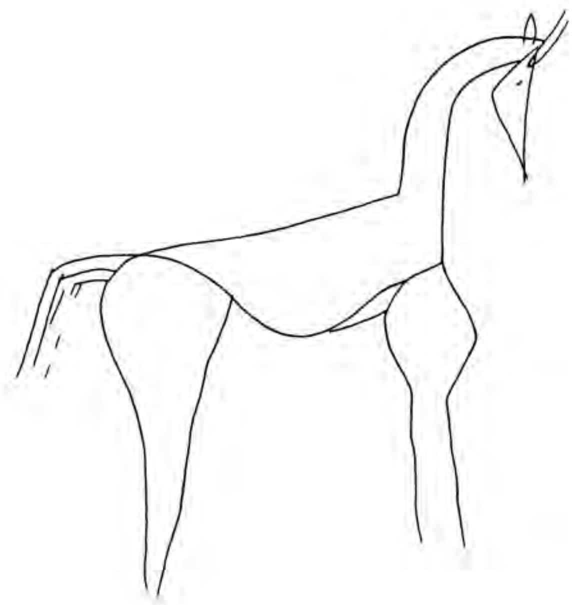


Figure 19. Drawing of the Iron Age horse in Vale de Cabrões Rock 6 (Width: 9,5 cms.; Height: 10 cms.). Drawing in Baptista (1999, 171) by Fernando Barbosa.

Figure 20. Detail of one of the Iron Age warriors in Vermelhosa Rock 3. Photo in Baptista (1999, 167).

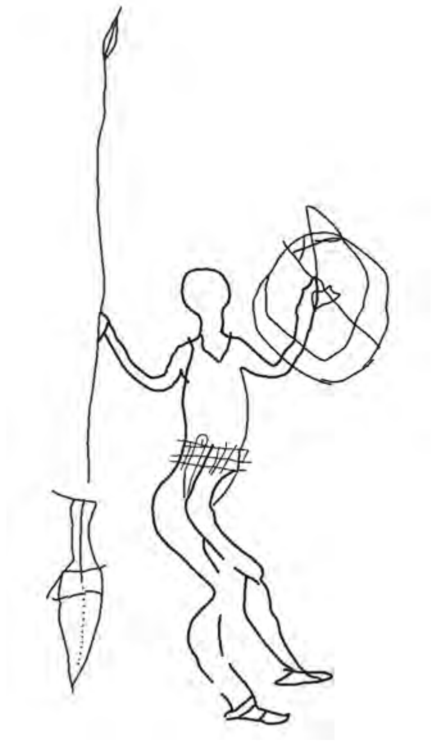


Figure 21. Iron Age warrior in Vale do Forno Rock 6. Scale 1/1. Drawing by Fernando Barbosa.

Figure 22. Modern rock art. Warrior like figure from the XVII-XVIII centuries. Photo in Baptista (1999, 182).

Figure 22. Modern rock art. Warrior like figure from the XVII-XVIII centuries. Photo in Baptista (1999, 182).

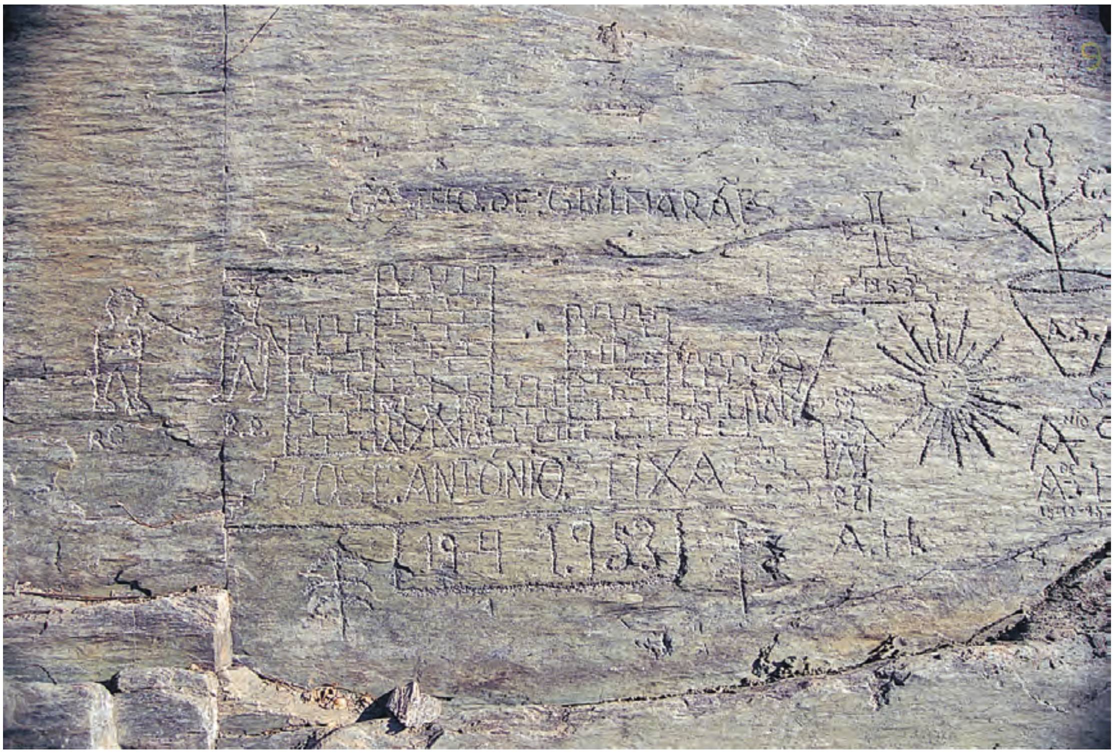


Figure 23. António Seixas engraved the Guimarães Castle in 1953, near to panels with Upper Palaeolithic rock-art. Photo in Baptista (1999, 186).

Figure 24. Canada do Inferno Rock 1.

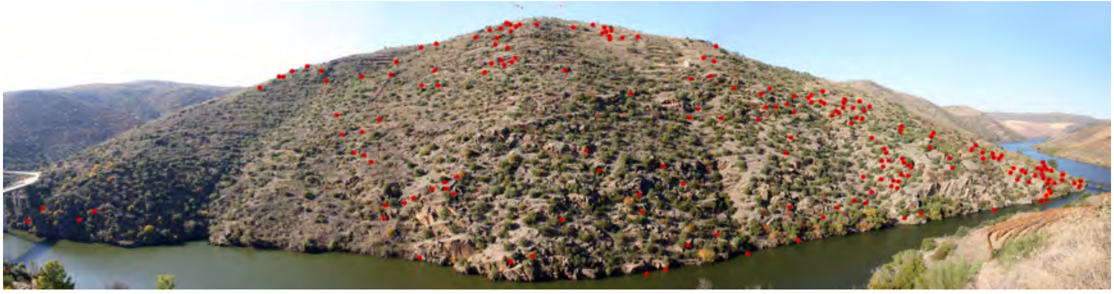


Figure 25. Panoramic view of the Foz do Côa (Mouth of the Côa in English) site featuring the nearly 200 rock-art surfaces found by Mário Reis, the staff archaeologist that carries out the systematic survey of PAVC area. (Photo: Mário Reis).

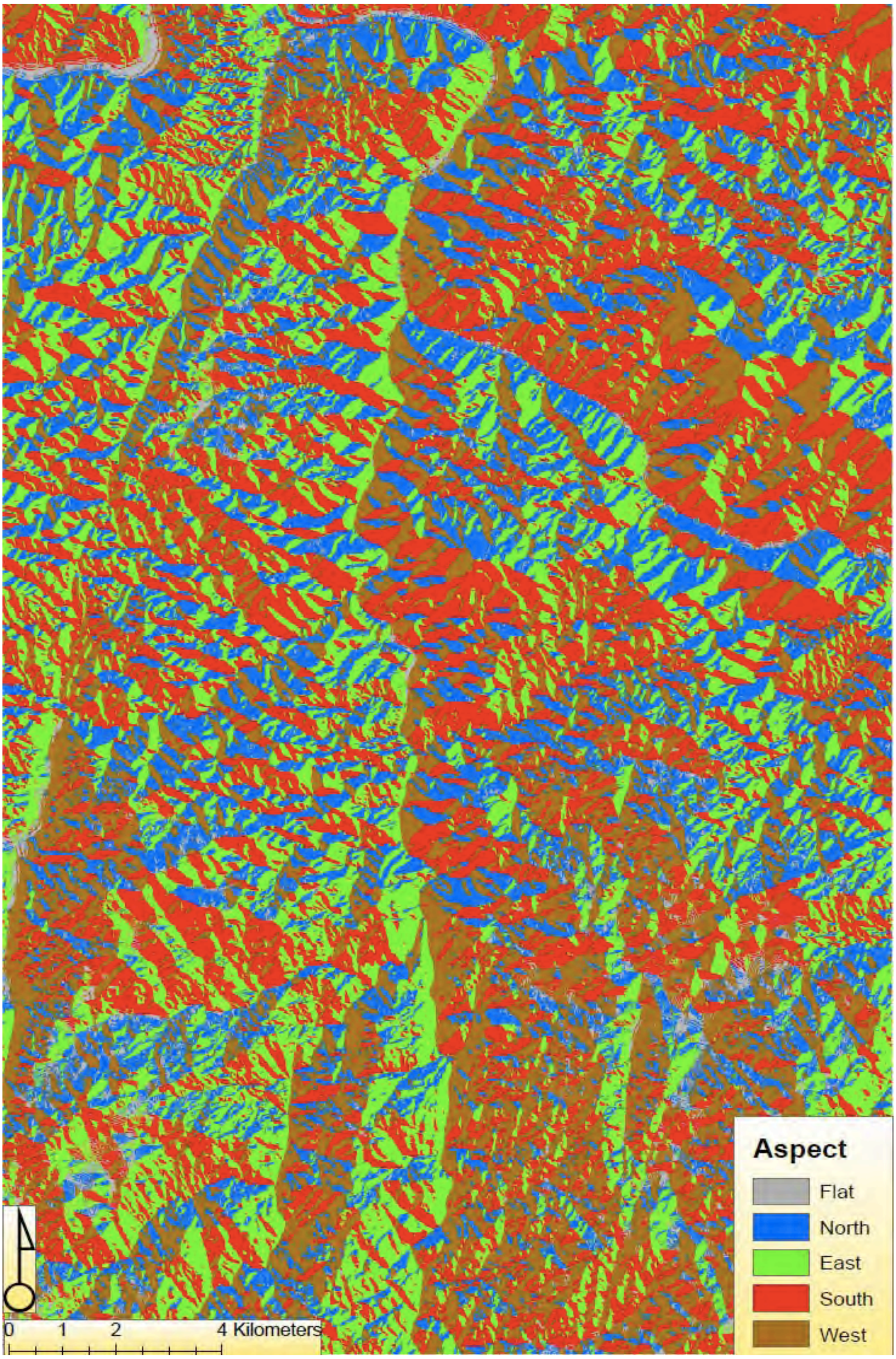


Figure 26. Aspect in the area of study. Map produced in the ArcView 9 suite using a 10 meter resolution DEM supplied by Instituto Geográfico Português (IGEO - www.igeo.pt).

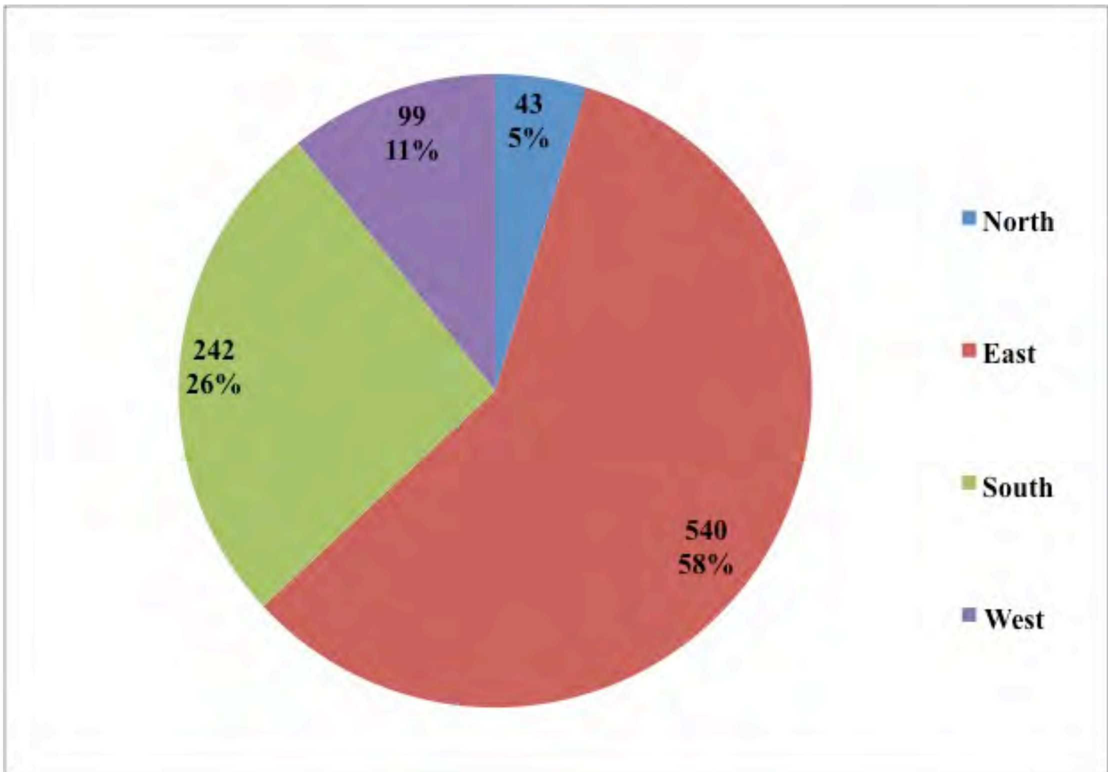


Figure 27. Aspect of the 924 rock-art outcrops known in January 2010.

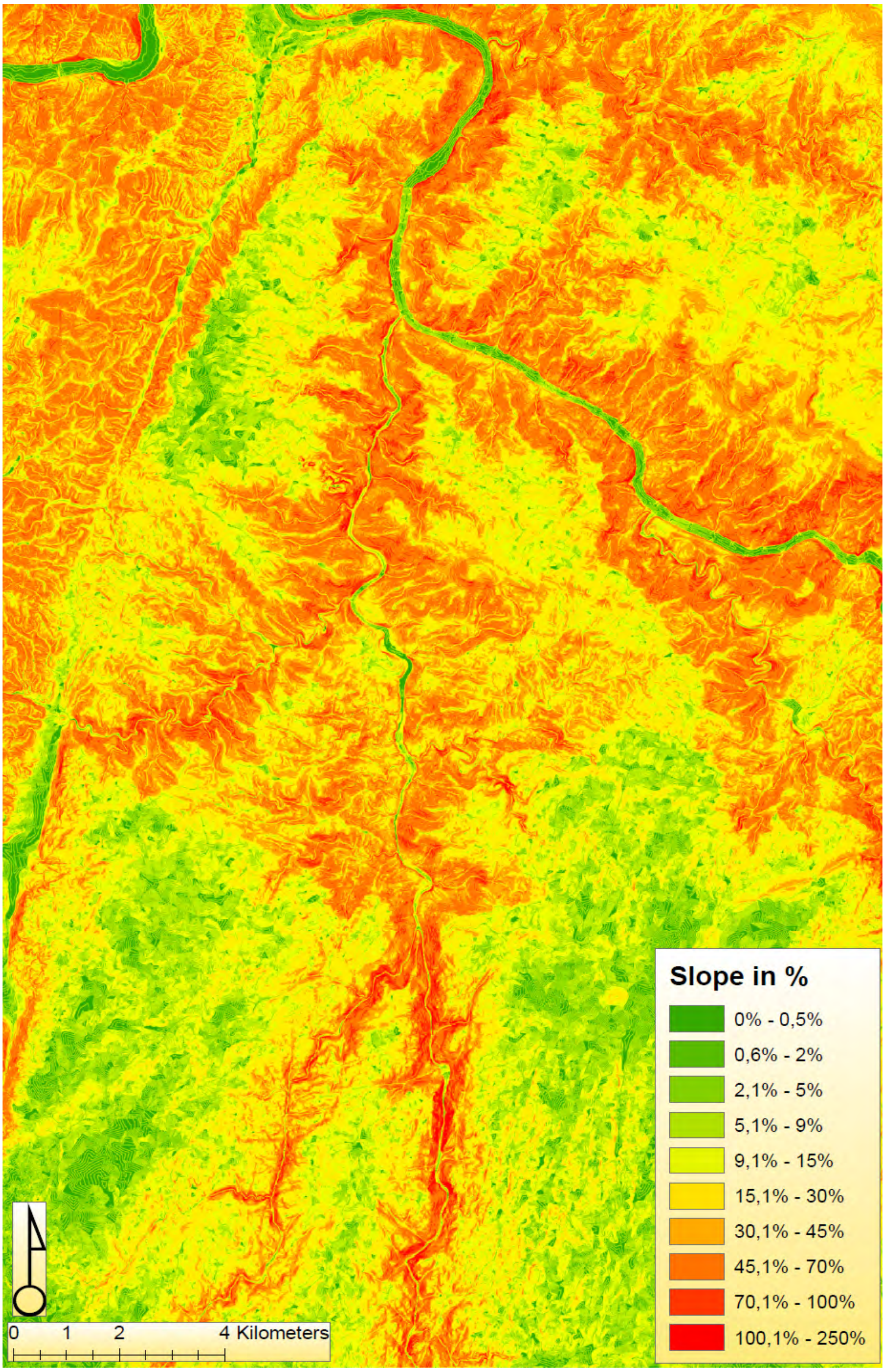


Figure 28. Slope in the area of study. Map produced in the ArcView 9 suite using a 10 meter resolution DEM supplied by Instituto Geográfico Português (IGEO - www.igeo.pt).

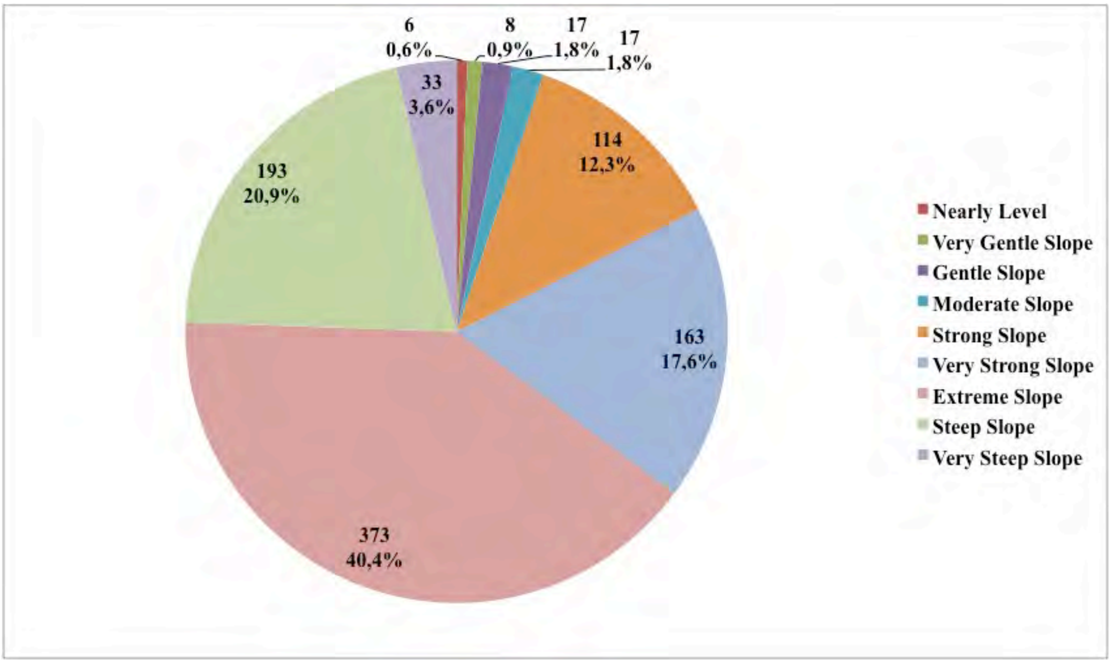


Figure 29. Slope incline regarding the positioning of the 924 rock-art outcrops known in January 2010.

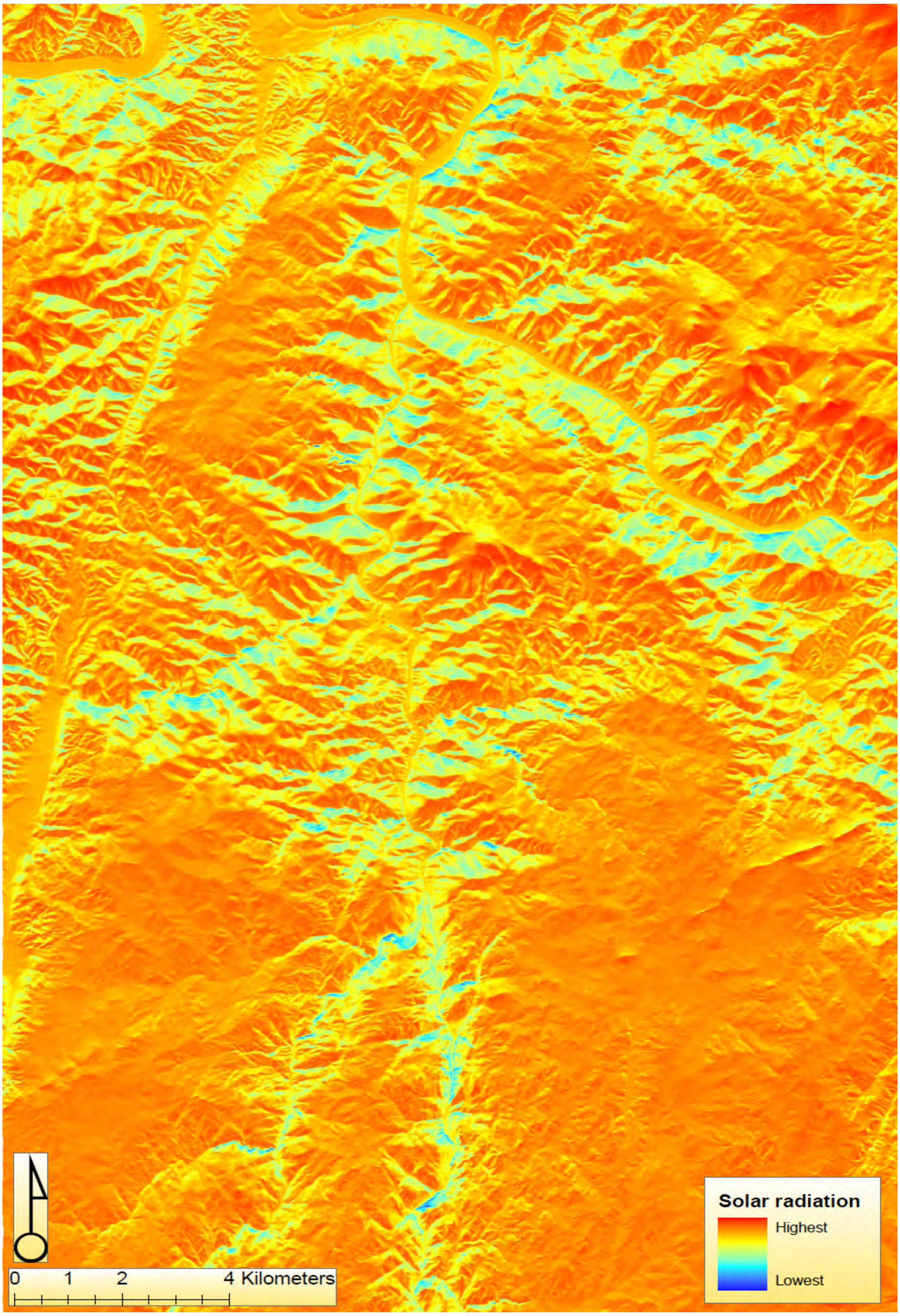


Figure 30. Solar radiation in the area of study. Map produced in the ArcView 9 suite using a 10 meter resolution DEM supplied by Instituto Geográfico Português (IGEO - www.igeo.pt). It depicts average solar radiation in 2008. Not surprisingly, the areas with the least amount of solar radiation are the foot of North facing slopes.

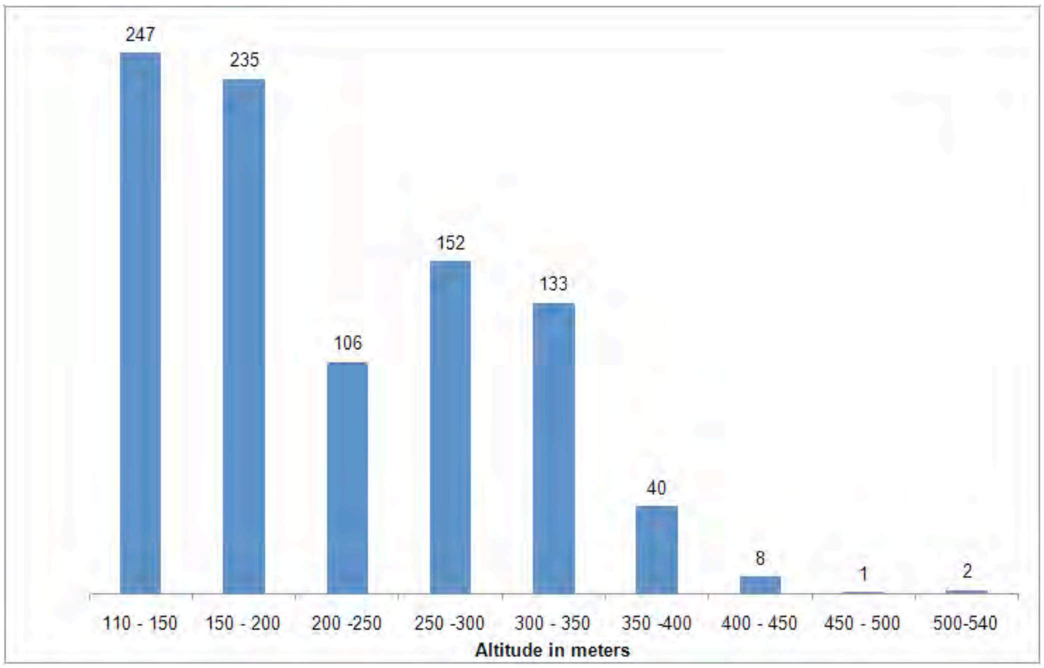


Figure 31. Altitude distribution of the 924 outcrops known in the Côa Valley in January 2010.

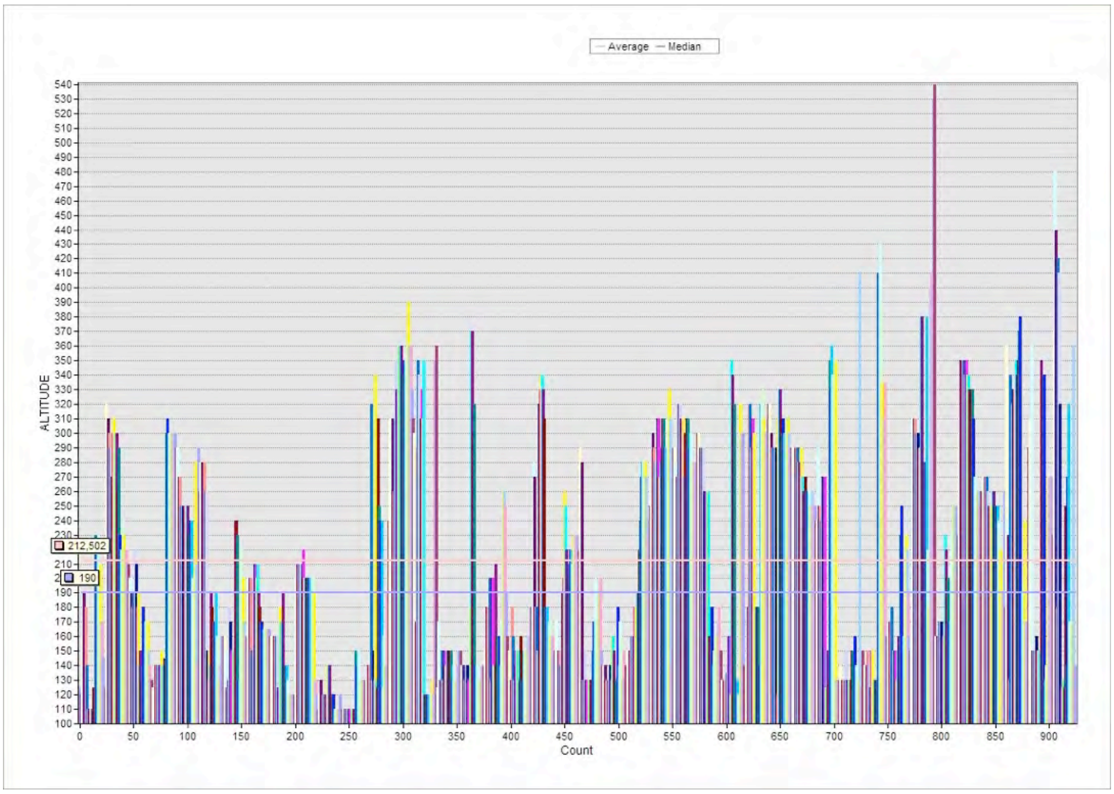


Figure 32. Altitude of the 924 outcrops known in the Côa Valley in January 2010 with indication of average (212,5) and median (190) values.

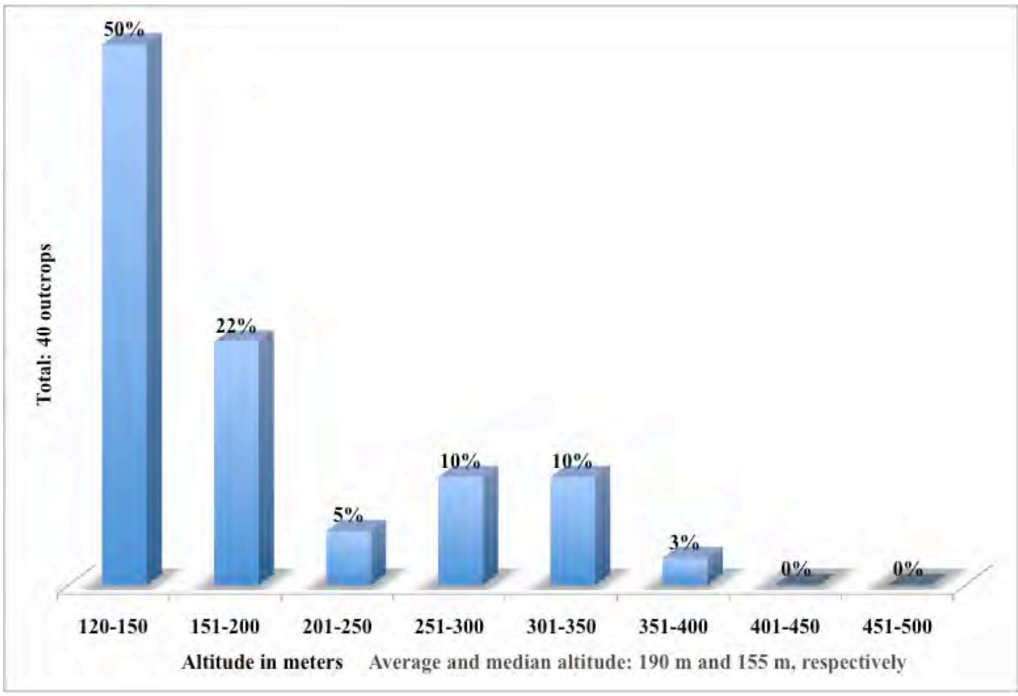


Figure 33. Altitude distribution of sample outcrops.

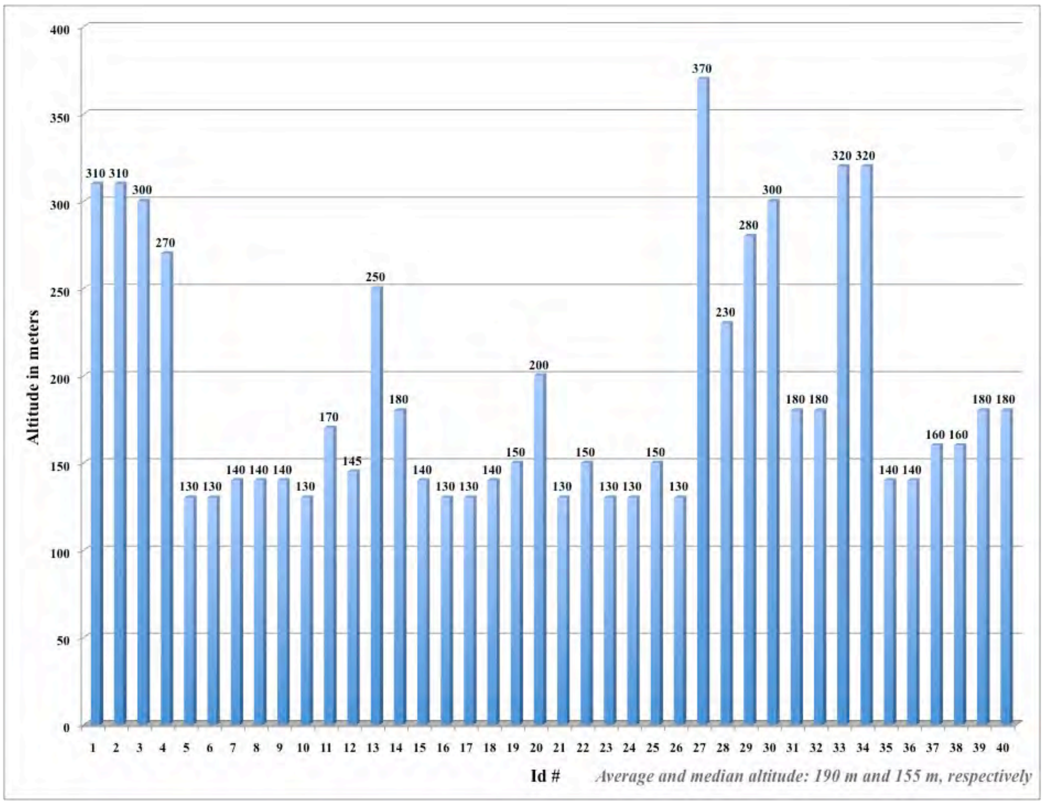


Figure 34. Altitude of each sample outcrop with indication of average and median values.

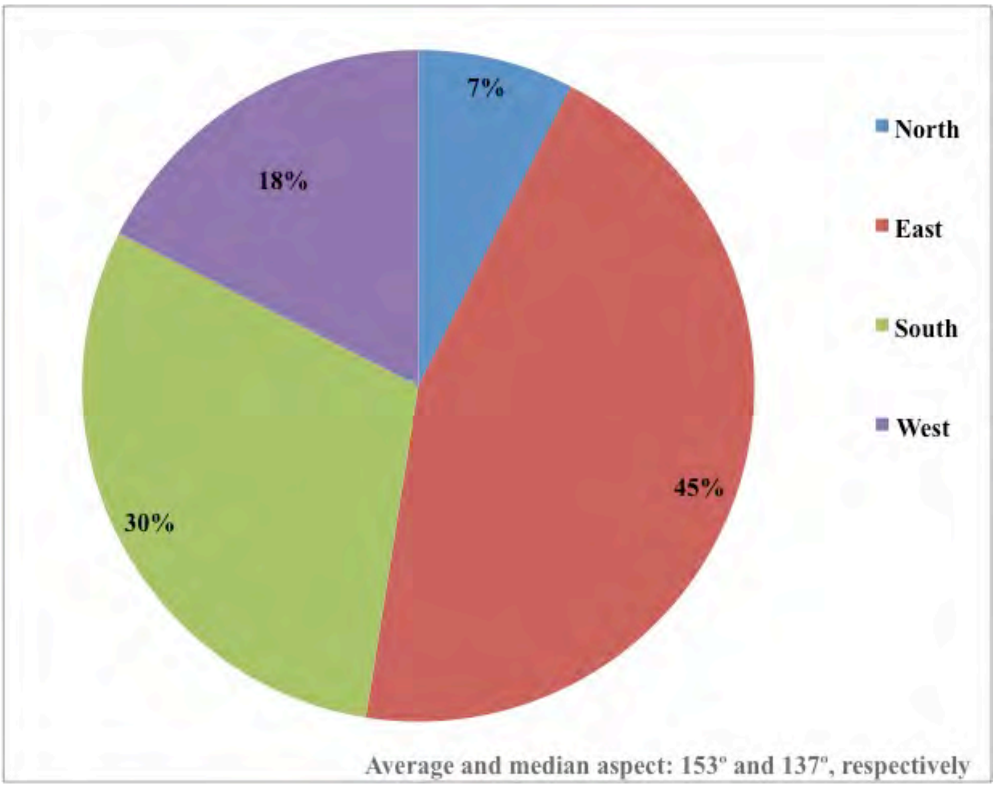


Figure 35. Aspect distribution of sample outcrops.

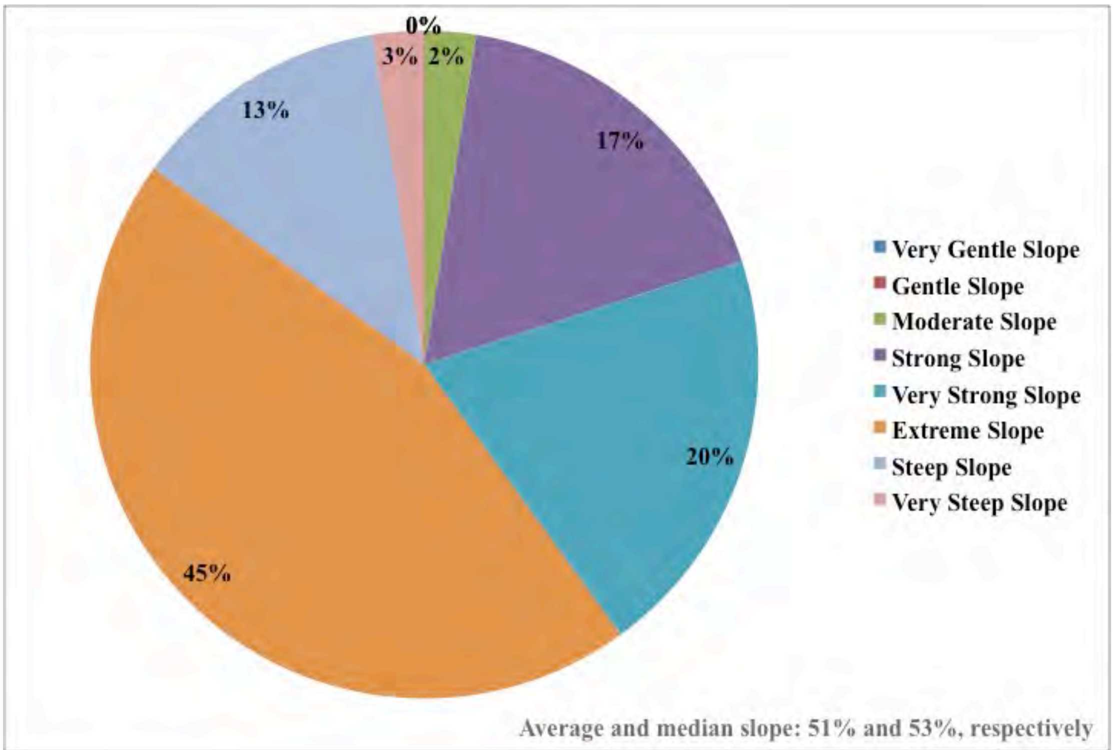


Figure 36. Slope gradient distribution of sample outcrops.

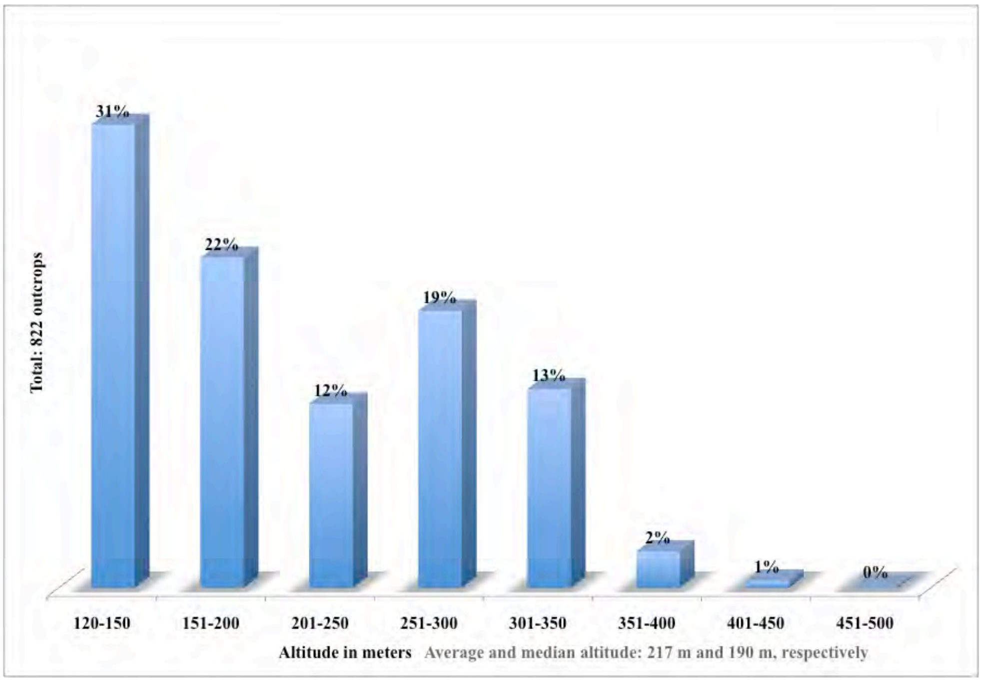


Figure 37. Altitude distribution of outcrops considered for the sample.

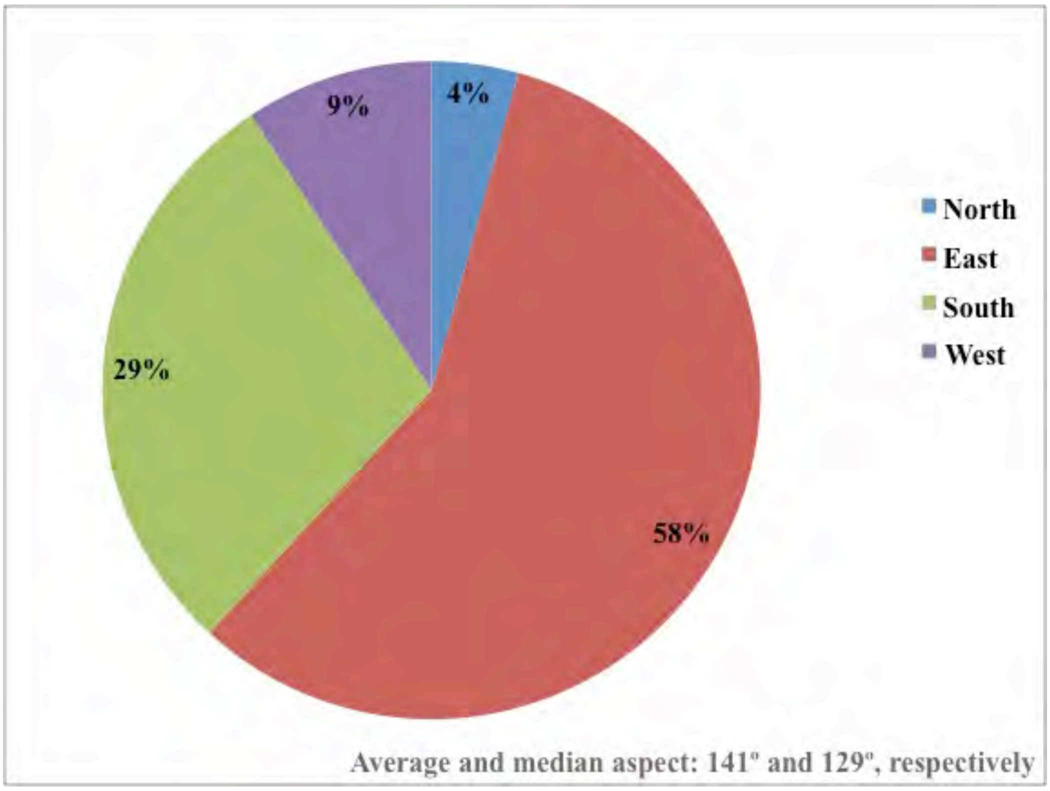


Figure 38. Aspect distribution of outcrops considered for the sample.

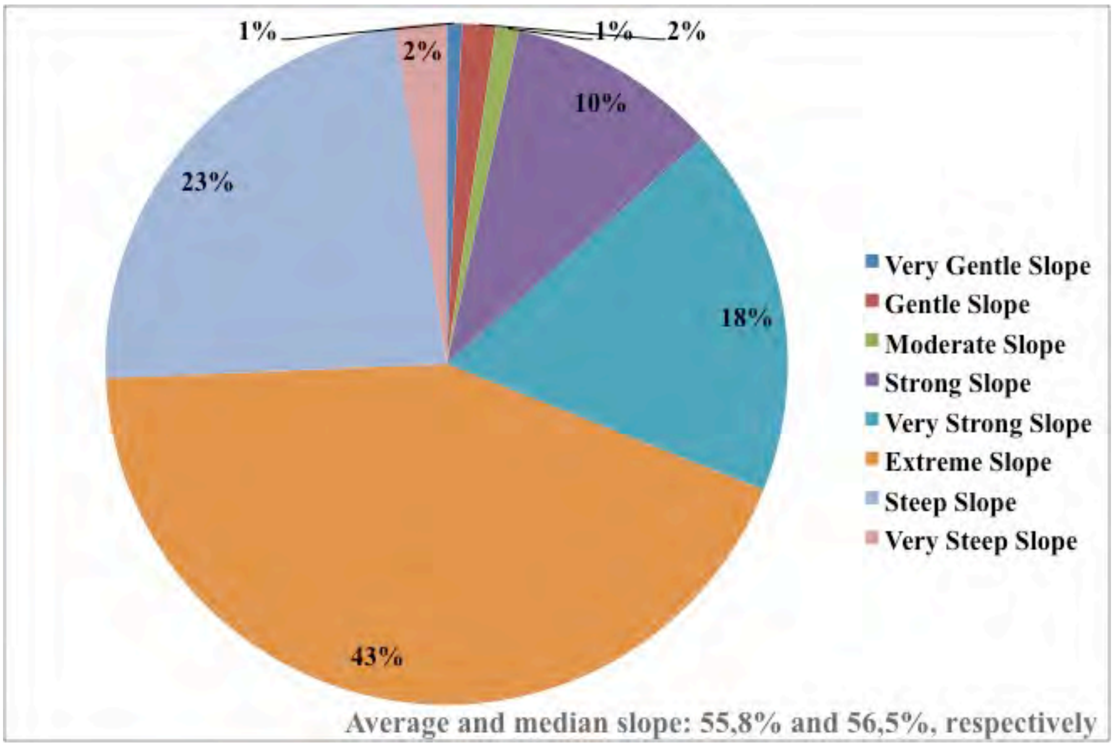


Figure 39. Slope gradient distribution of outcrops considered for the sample.

Figure 40. Ribeira de Piscos 1 whole outcrop.

Figure 41. Panel containing the ‘tangled horses of Piscos’, the only engraved motifs present at this outcrop.

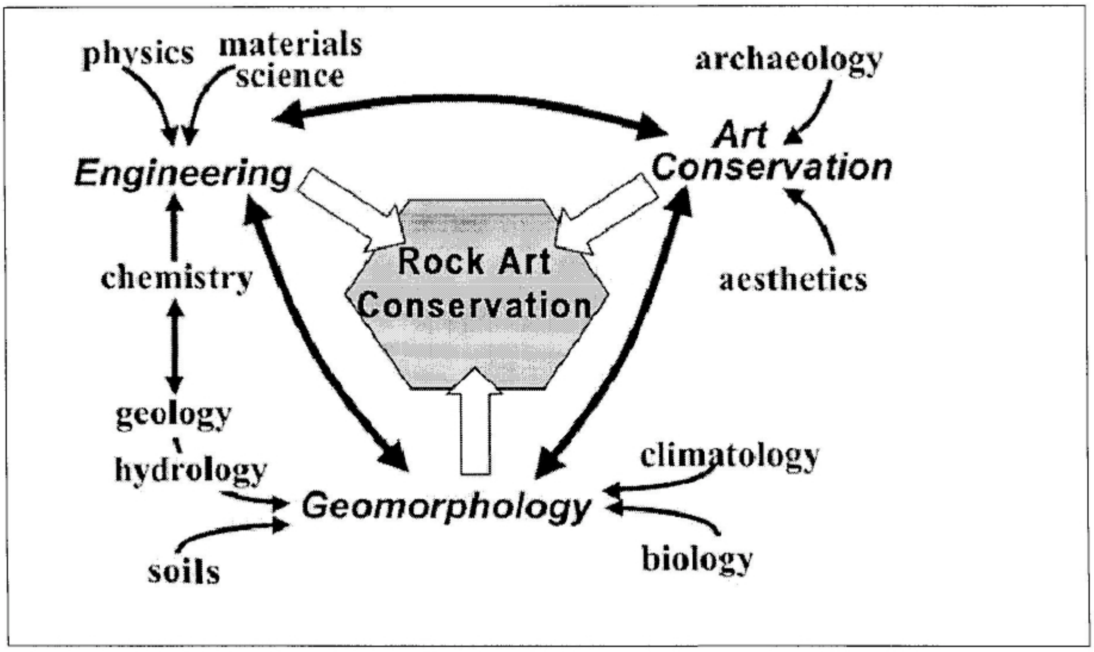


Figure 42. Example of a transdisciplinary approach to open-air rock-art conservation. Figure in Cerveny (2005, 96).

Table 3
Examples of geomorphological effects of decadal to century-scale oscillations

Environment affected	Impacts upon
Terrestrial hydrology	Glacier mass balance
	Lake levels
	River flows
	Snow cover
	Permafrost
Terrestrial geomorphology	Soil erosion
	Floodplain sedimentation and erosion
	Slope instability/ mass movements
	Dune movements
	Geochemical sediment growth
	Effects on fire frequency with knock-on effects on weathering, runoff and slope instability
Coastal/marine ecology and geomorphology	Coastal erosion
	Mangrove defoliation/land loss
	Coral bleaching
	Coastal dune activation

Figure 43. "Examples of geomorphological effects of decadal to century-scale oscillations" (Viles and Goudie 2003, 113).

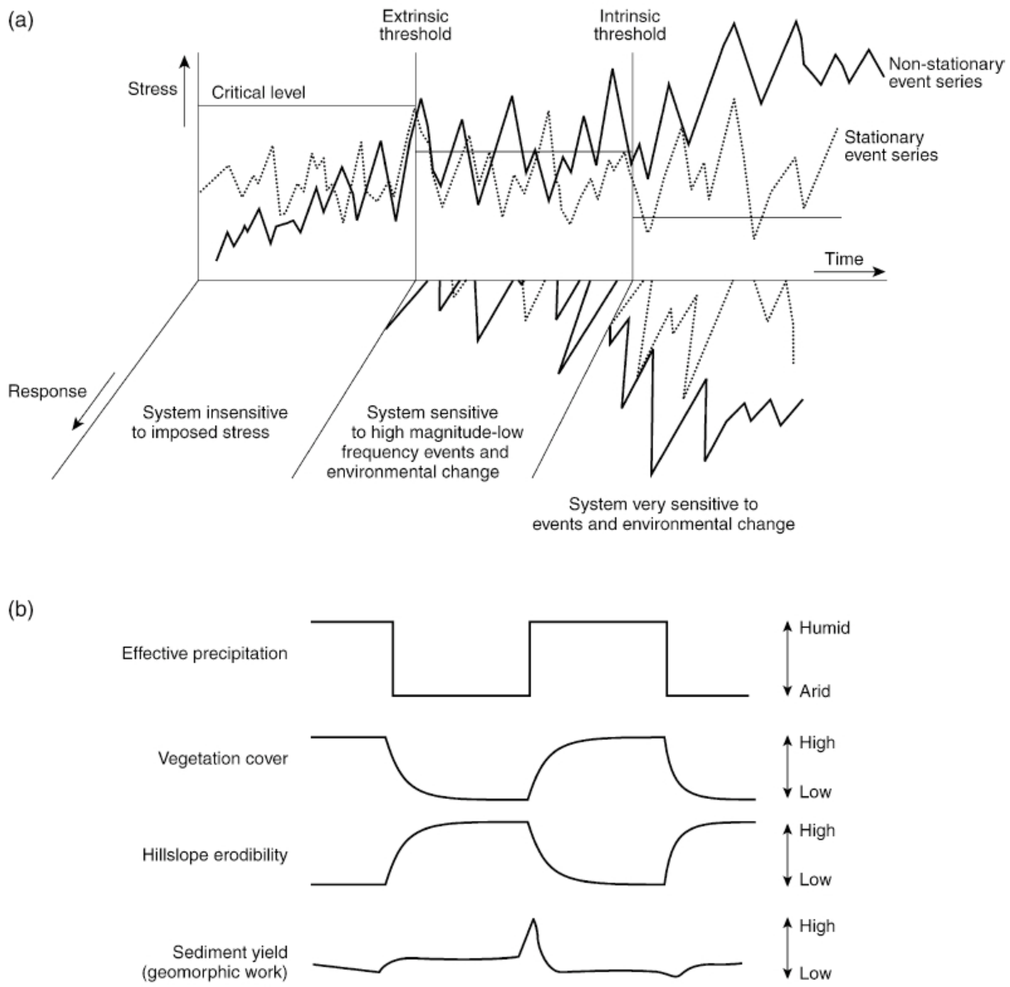


Figure 44. “Representations of the impacts of climatic variability on geomorphic systems. (a) Stress-response sequences including thresholds under stable and changing climate conditions. (b) A simplified view of the biogeomorphic response model” (Viles and Goudie 2003, 124).

Figure 45. Ribeira de Piscos Rock 1 after flooding. Note that the soil platform area in front of the panel with the tangling horses results from deposition by a flooding episode.

Figure 46. Goat in Penascosa Rock 5. The posterior line that makes part of the animal's front leg is not engraved but is rather a natural fracture of the rock. Photo in Baptista (1999, 106-7).

Figure 47. The Hjemmeluft fjord in Alta. The Museum is the white building on the upper left of the photo. Rock-art panels are scattered along the margins but not too near to present day water level.

Figure 48. A rock-art panel in Hjemmeluft, Alta featuring different deer species depictions. The engravings are painted in red to render them more visible to visitors.

Figure 49. Hunting scene in a rock-art panel in Hjemmeluft, Alta. Some of the carvings, especially those of more recent discovery, are not painted thus being preserved as found.

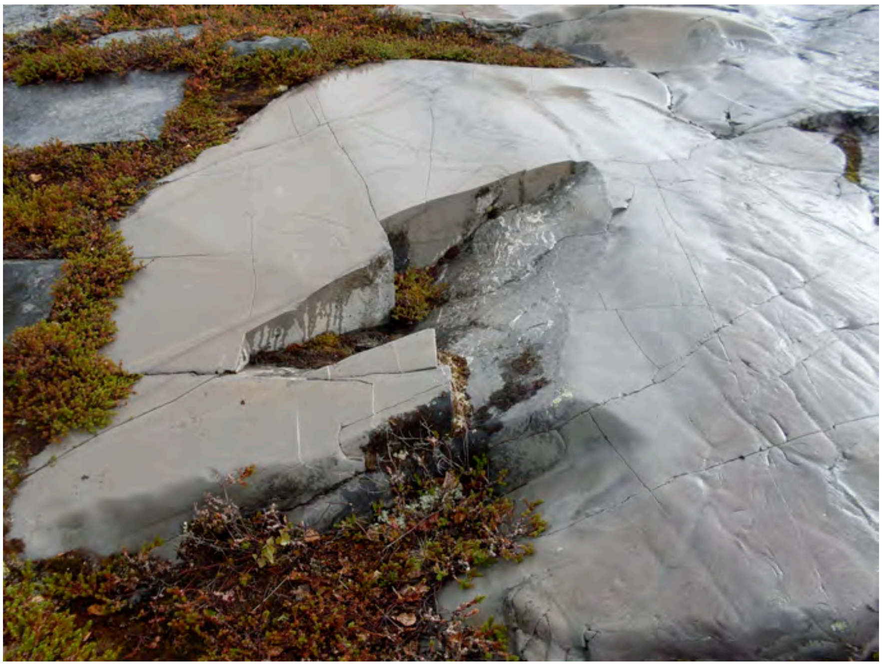


Figure 50. Rock-art panel in Hjemmeluft, Alta. Note the polished surface because of winter ice since the panel is not seasonally protected, contrary to what happens with other panels which are seasonally or permanently covered with isolating materials (see Figures below). Note also that the carvings in this panel have not also been painted.

Figure 51. The Vingen rock-art site is located on the small stretch of land at the base of the slope on the right of the photo.

Figure 52. Rock-art at Vingen is scattered along many outcrops, some visible in the image.

,

Figure 53. Another view of the terrace where rock-art is found in the scattered outcrops.

,

Figure 54. A rock-art panel at Vingen featuring engraved deer motifs. Note the fading red pigments: as motifs are no longer painted, traces of former painting actions are slowly vanishing.

Figure 55. Partial view of the Ausevik outcrop and visitor walkway.

Figure 56. A deer motif at Ausevik.

Figure 57. Heavily weathered area of the Ausevik outcrop. Note surface detachment affecting engraved areas and past remedial interventions in the form of cement-based filling of gaps.

Figure 58. Covered panels at Alta. These panels remain covered all year round and, thus, are not accessible to the public.

Figure 59. Panels at Ausevik just before being uncovered.

Figure 60. Engraved area of the Ausevik site just after being uncovered. Note wetness and organic matter.

Figure 61. Condition in which the panels in Alta remain when covered: humid and affected by organic matter.

Figure 62. Pathway and sign near a panel at Alta.

Figure 63. Ethanol spraying at Ausevik before recovering the panels.

Figure 64. Filling of fractures and gaps of a panel in Vingen.

Figure 65. ‘Patchwork’ condition of areas of the Ausevik outcrop. Note how cement-based mortars applied in different interventions cure differently.

Figure 66. Another perspective of the ‘patchwork’ condition at Ausevik featuring more recent and older cement-based mortar interventions.

Figure 67. Fractures filled and sealed with cement-based mortar and Mowilith DM 123 S binder (white material) in previous interventions in Ausevik.

Figure 68. Small fracture sealed with cement-based mortar in a past interventions at Ausevik.

Figure 69. Area at the Ausevik outcrop in which previous cement-based mortar filling and sealing of less cohesive areas had to undergo maintenance work with the resealing of the cement/parent rock interface.

Figure 70. Location of Piauí and Serra da Capivara National Park. Map in Nash (2009, 43).

Figure 71. Serra da Capivara National Park. The painted shelters are located in canyons below the point where the photo was taken.

Figure 72. Animal motifs at Toca da Entrada do Pajaú shelter.

Figure 73. Anthropomorphic motifs at Toca da Entrada do Pajaú shelter.

Figure 74. Polychromous motifs at Toca do Boqueirão da Pedra Furada shelter.

Figure 75. Polychromous compositions featuring animal and human motifs at Toca do Boqueirão da Pedra Furada shelter. The two thematic groups probably belong to the different artistic traditions described in the body of the text. Most human figures are in the so-called processional arrangement.

Figure 76. Toca da Entrada do Pajaú shelter.

Figure 77. Toca da Entrada do Baixão da Vaca shelter.

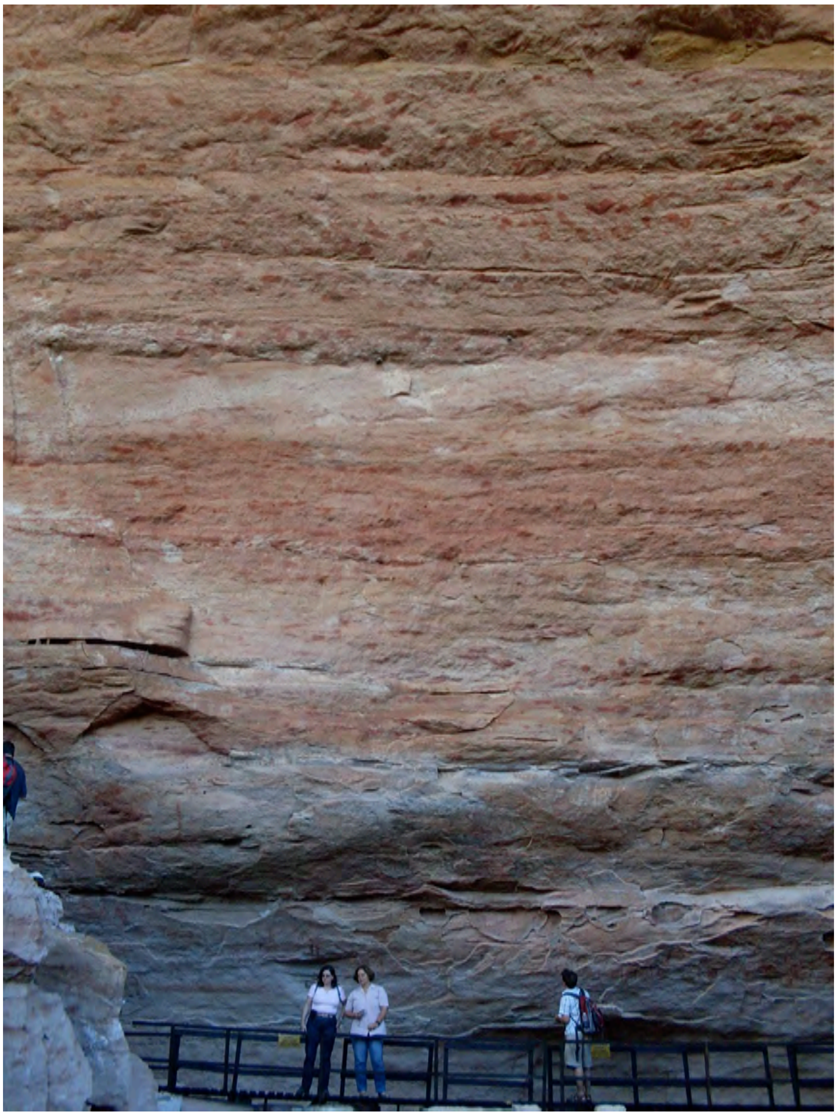


Figure 78. Toca do Boqueirão da Pedra Furada shelter. The paintings are located at the human scale level striking a remarkable contrast with geological time scale present in the rock layers.

Figure 79. Guide entering the Park with his group of visitors.

Figure 80. Surface detachment.

Figure 81. Surface detachment. It is visible though that the paintings are located on different superficial planes. Hence, the panel was probably in the present-day condition (or in a quite similar condition) when these paintings were produced.

Figure 82. Biodeterioration threat in the form of a wasp nest.

Figure 83. Consolidation of a panel in risk of detachment at Toca da Ema do Sítio do Brás I following the same methodology developed for Toca da Entrada do Pajaú.

Figure 84. Sealed part of a panel that was in risk of detachment.

Figure 85. Filling of gaps and fractures.

Figure 86. Sealed panel that was in risk of detachment.

Figure 87. Sealed gaps that are affecting painted motifs.

Figure 88. Drip line made of latex.

Figure 89. “A” Thing of The Past…

Figure 90. Viewing platform and staircase.

Figure 91. Canyon walls where the rock-art motifs have been inscribed.

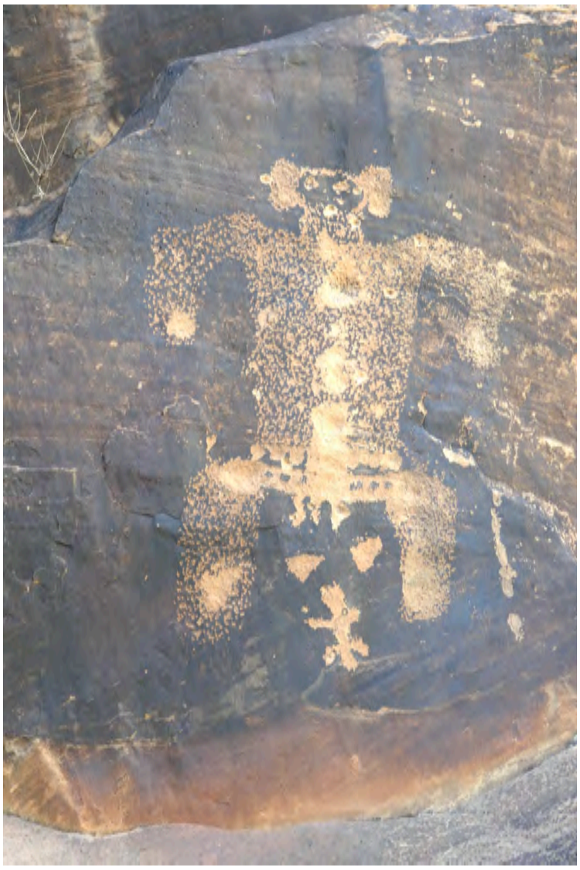


Figure 92. Woman giving birth, according to the interpretation referenced in the body of the text. Note large holes probably result of shotgun blasts.

Figure 93. Shaman figure (?) positioned between what appears to be a male deer and females. Note black rock coating.

Figure 94. Newspaper Rock, Utah.

Figure 95. Hunting scene: a small mounted hunter is chasing a remarkably large quadruped (bison?).

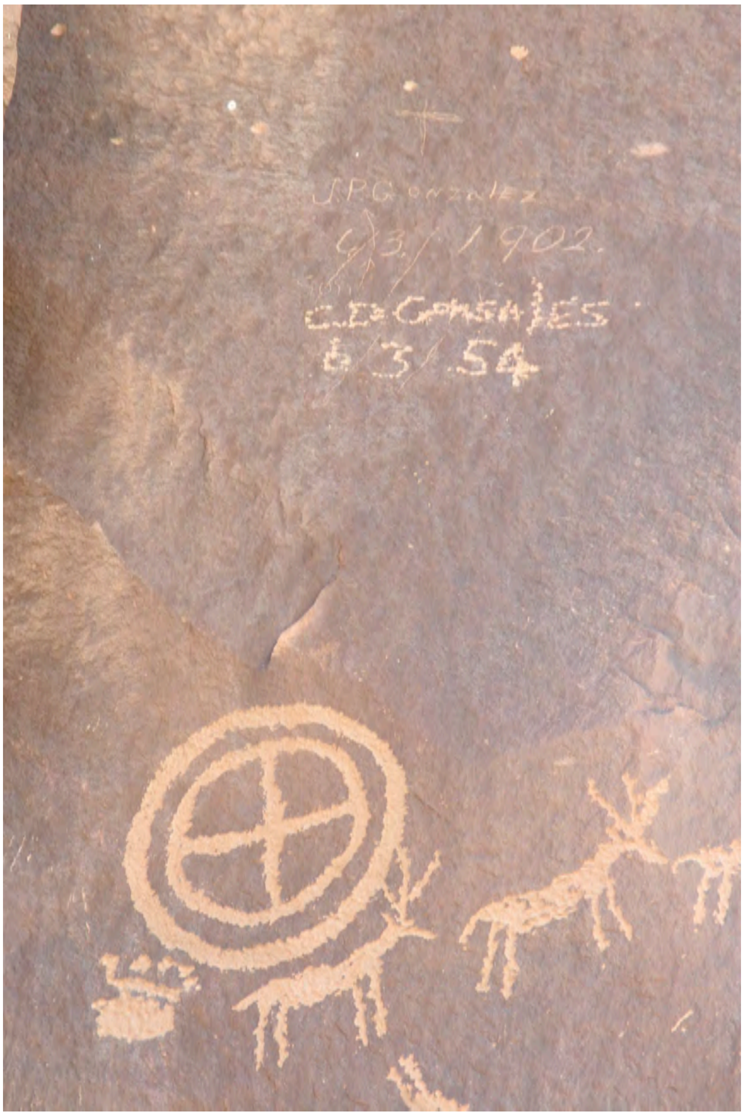


Figure 96. J. P. Gonzalez in 1902 and C.D. Gonzalez in 1954 also left their marks for posterity in a previously empty area of the panel.

Figure 97. Navajo travelling through Canyon de Chelly in 1904. Photo by Edward S. Curtis.

Figure 98. Navajo tour guide showing the Canyon to tourists.

Figure 99. Imagery in a panel at Canyon de Chelly.

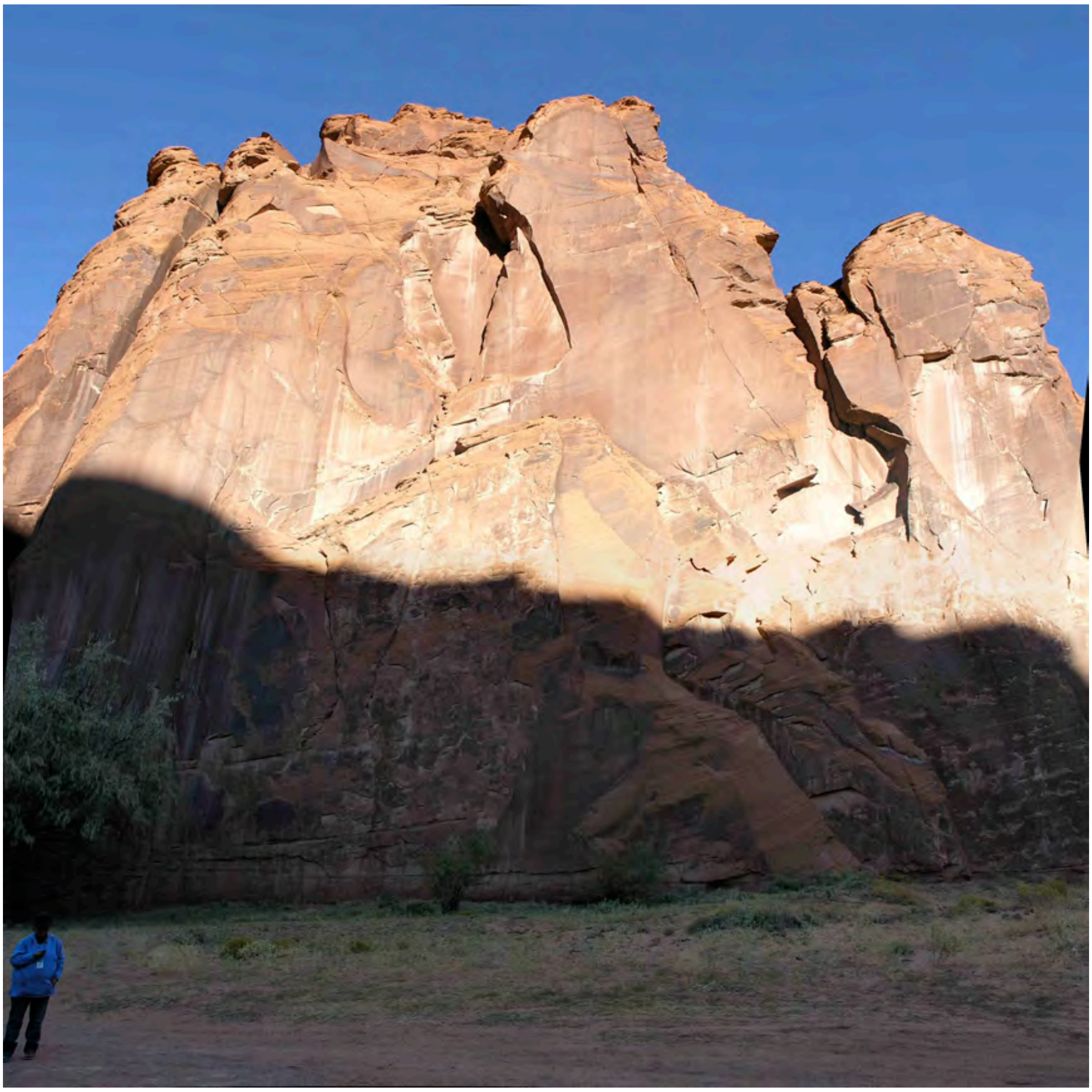


Figure 100. The panel shown in the previous Figure is located halfway up this massive rock face.

Figure 101 Deer Valley Rock Art Center building, harmoniously integrated in the landscape. The area with rock-art is located to the left of the point where the photo was taken.

Figure 102. The engravings are located in this mound of boulders.

Figure 103. A simple yet clever solution in the form of a metal tube to better show the rock-art to visitors.

Figure 104. Taliesin West central plaza. Note the boulder at the center of the image.

Figure 105. Boulder with rock-art dislocated from its original position.

Figure 106. Recreational activities occurring at Beverly Canyon, Phoenix right next to boulders featuring rock-art.

Figure 107. Part of the fence protecting Newspaper Rock, Utah.

Figure 108. A well-behaved enthusiast observing imagery at Newspaper Rock, Utah. These are the kind of visitors rock-art managers are grateful for.

Figure 109. Ronald Dorn indicating the area of an un-engraved outcrop affected by wedging.

Figure 110. The Bangudae petroglyph panel is located at the center of the image.

Figure 111. Partial view of the Bangudae panel. Some of the motifs were still submersed at the time of the visit.

Figure 112. Interpretative panel located on the opposite margin of the river, from where the previous two photos were taken.

Figure 113. The River Côa near to its mouth. Note that in this area, apart from roads and the remains of the abandoned dam, human intervention in the landscape has been relatively minimal. Note also that the river level is not ‘natural’ since the downstream Pocinho dam in the Douro made waters rise by 10 meters. This area also possesses rock-art outcrops on both margins (some submerged) being that the open for public visit Canada do Inferno site is located after the meander. Photo taken with a North to South orientation.

Figure 114. Ervamoira wine farm in the Fall. Wine producing may have impacts for rock-art preservation in the Côa. However, this is the sole 'industrial' farm in the core area of the Park (both margins of the last 17 kms of the Côa) where the great majority of rock-art sites are located. (Photo by António Martinho Baptista.)

Figure 115. The Poio quarries. The red arrow indicates the location of the Canada do Inferno rock-art site.

Figure 116. Normal (left) and maximum flood level in the Côa.

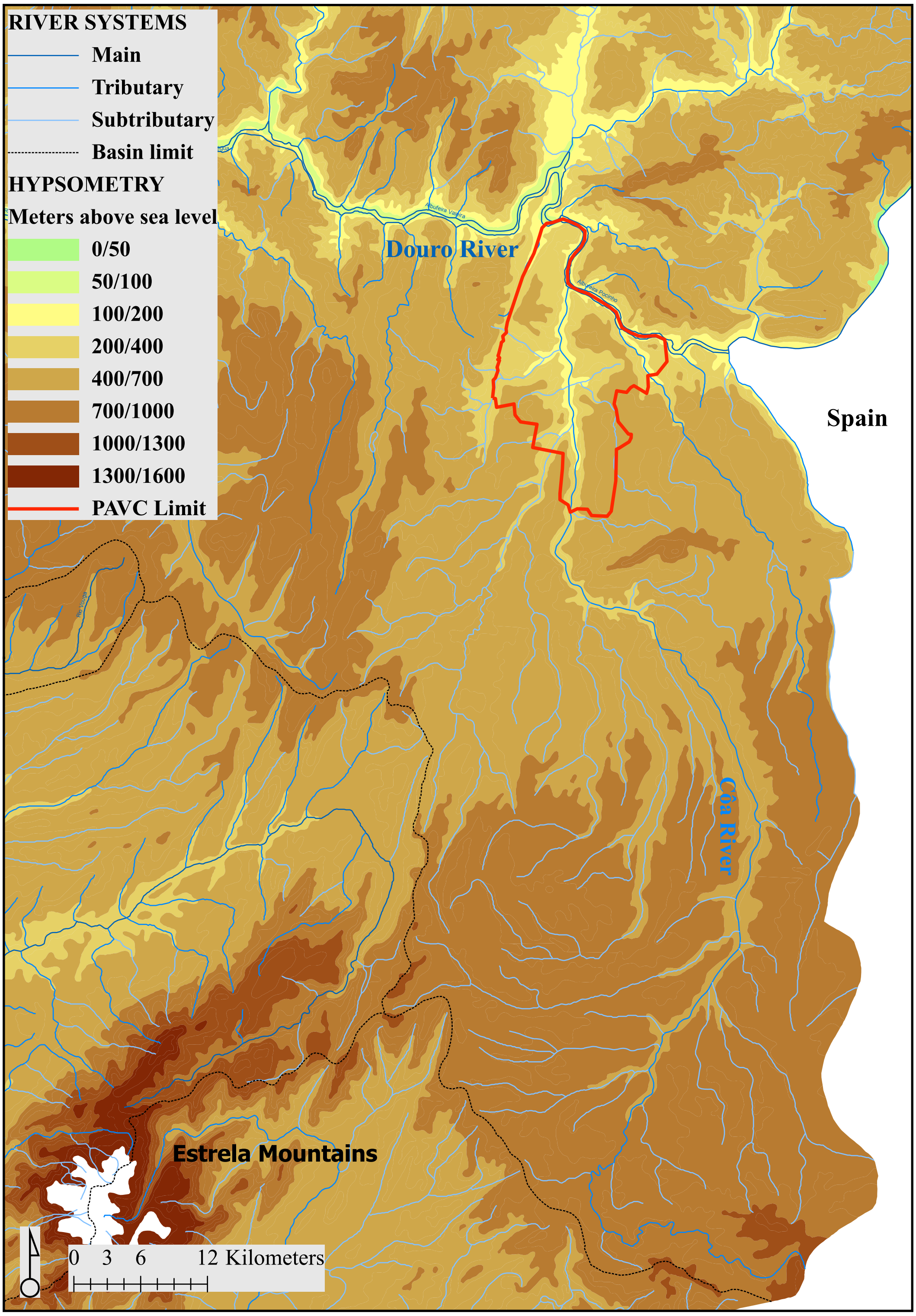


Figure 117. The Côa River and the PAVC.

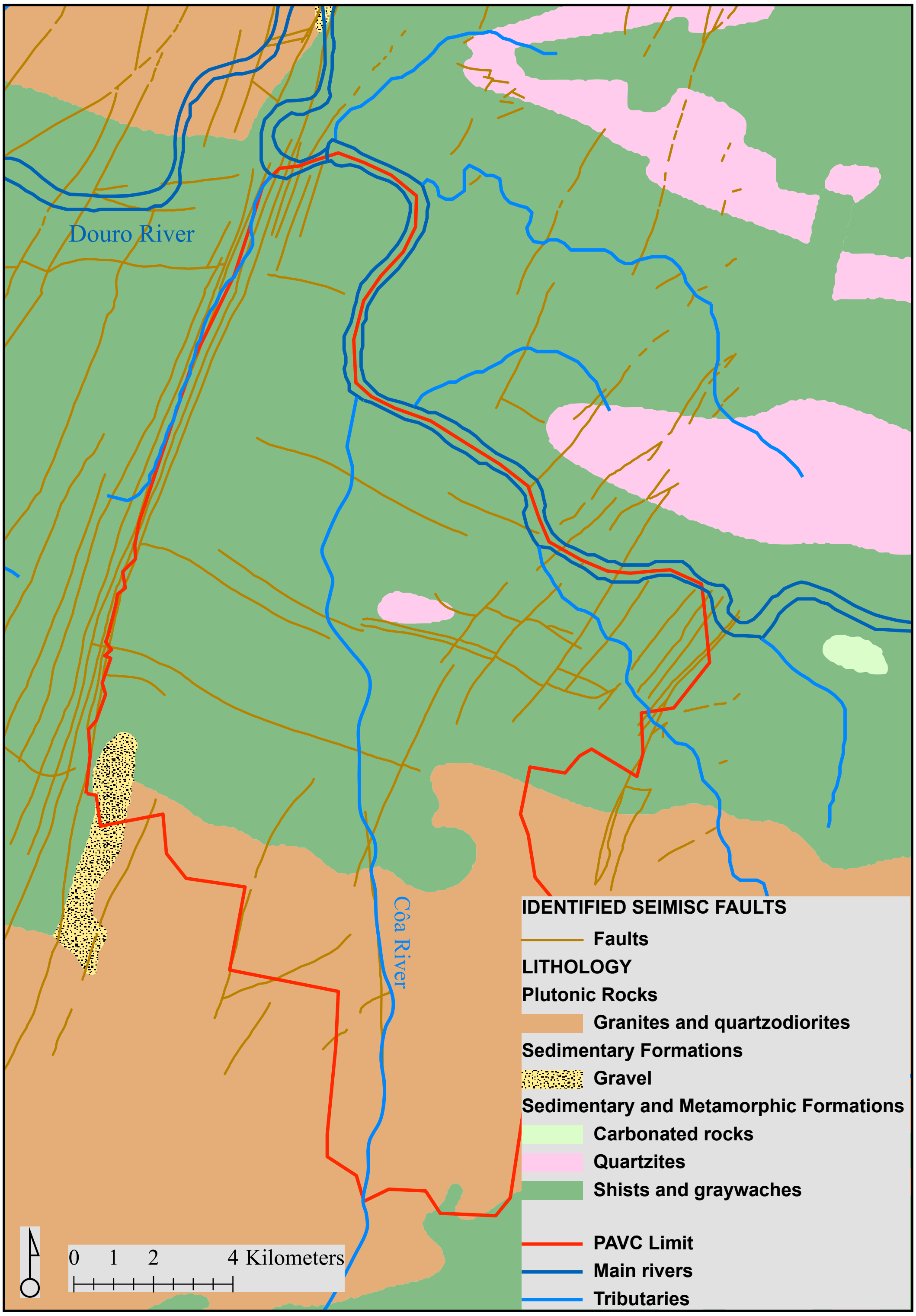


Figure 118. Lithology and identified seismic faults in the region. The Bragança-Vilariça –Manteigas fault crosses the area of the Park in the Western area coincident with the PAVC's limit where several faults are signalled.

Figure 119. Geological formations in the study area. Geological information is provided only within the limits that correspond to the area of the Côa Valley Archaeological Park. Location of major rock-art sites is also indicated together the number of engraved outcrops each possesses. Geological data adapted from Ribeiro (2001).

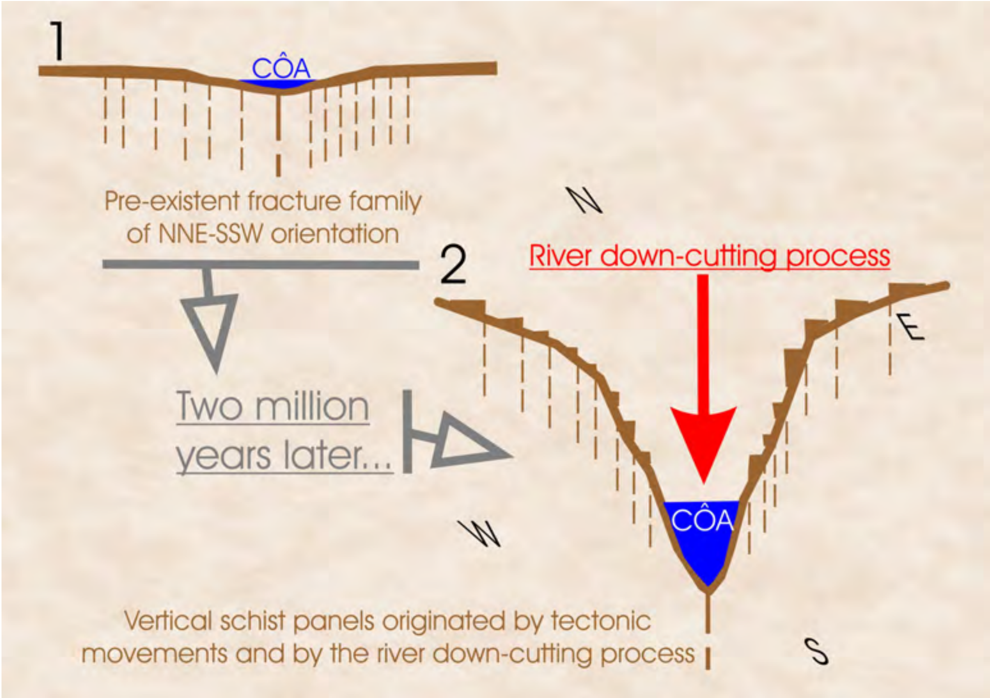


Figure 120. Schematic illustration of the Côa down-cutting process.


Figure 121. Outcrops in the Foz do Côa rock-art site. Note the 'steps' that each outcrops constitutes, a result of the river down-cutting process exposing the bedrock following the orientation of previously existing regional fracture families.

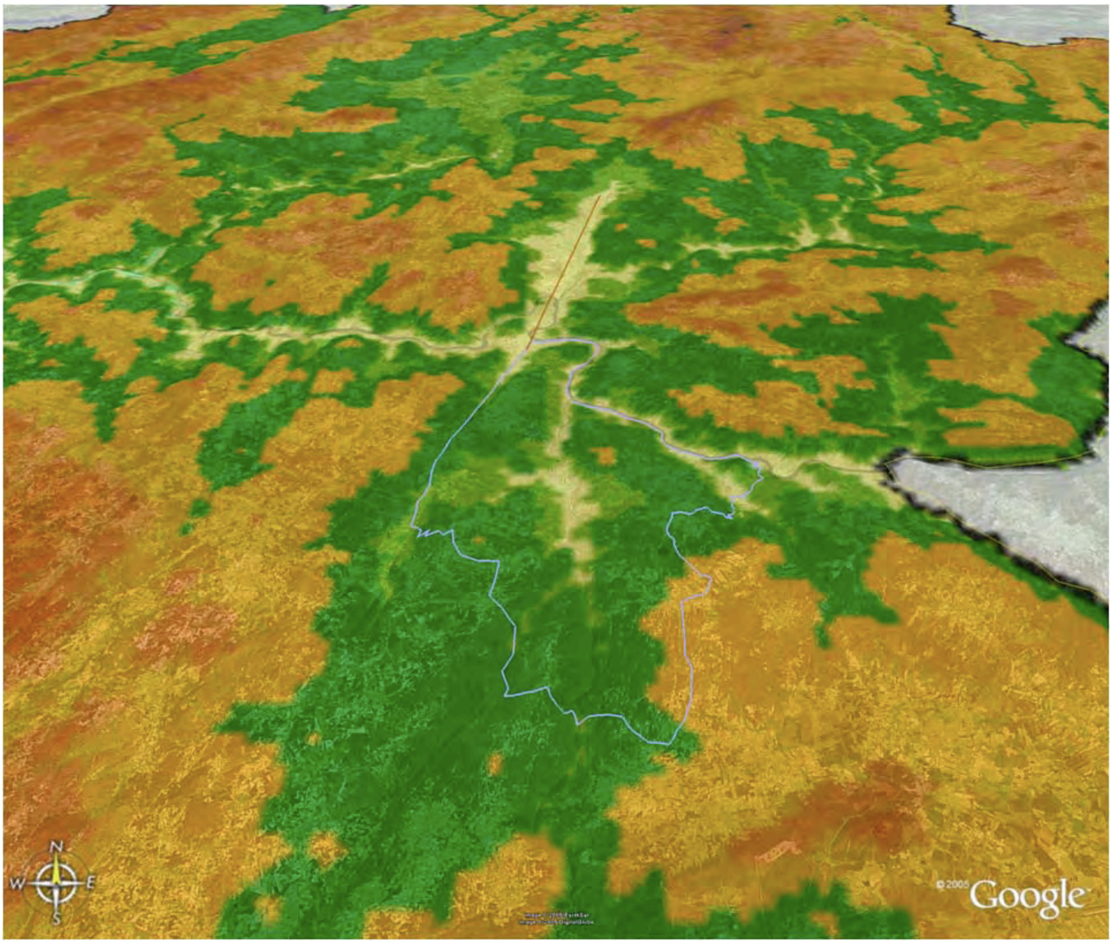


Figure 122. The Bragança-Vilariça-Manteigas fault in its most noticeable feature, the SSW - NNE oriented Vilariça valley (signalled in brown). The Park's limit is shown in purple.

Figure 123. Ribeira de Piscos Rock 1 panel featuring the entangled horses. Note the original schist deposition layers.

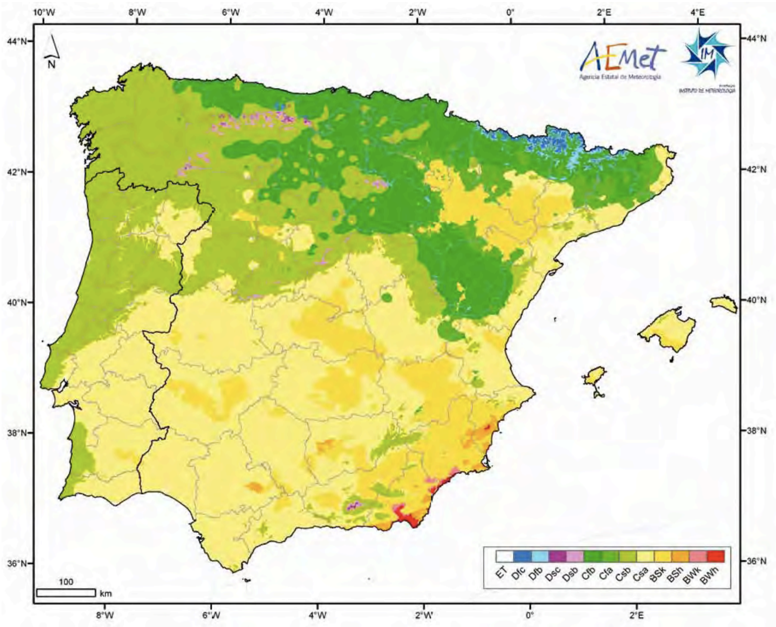


Figure 124. Köppen Climate Classification map of the Iberian Peninsula. Map in AEMET and IM (2011, 18).

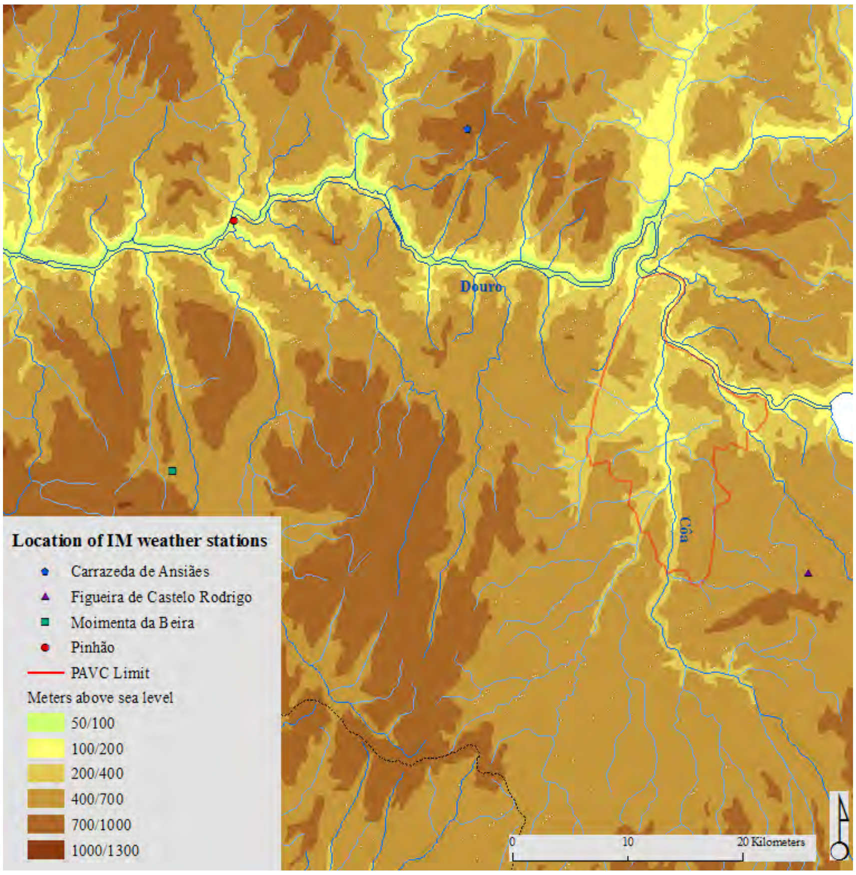


Figure 125. Weather stations that in the region gathered data included in Atlas do Ambiente.

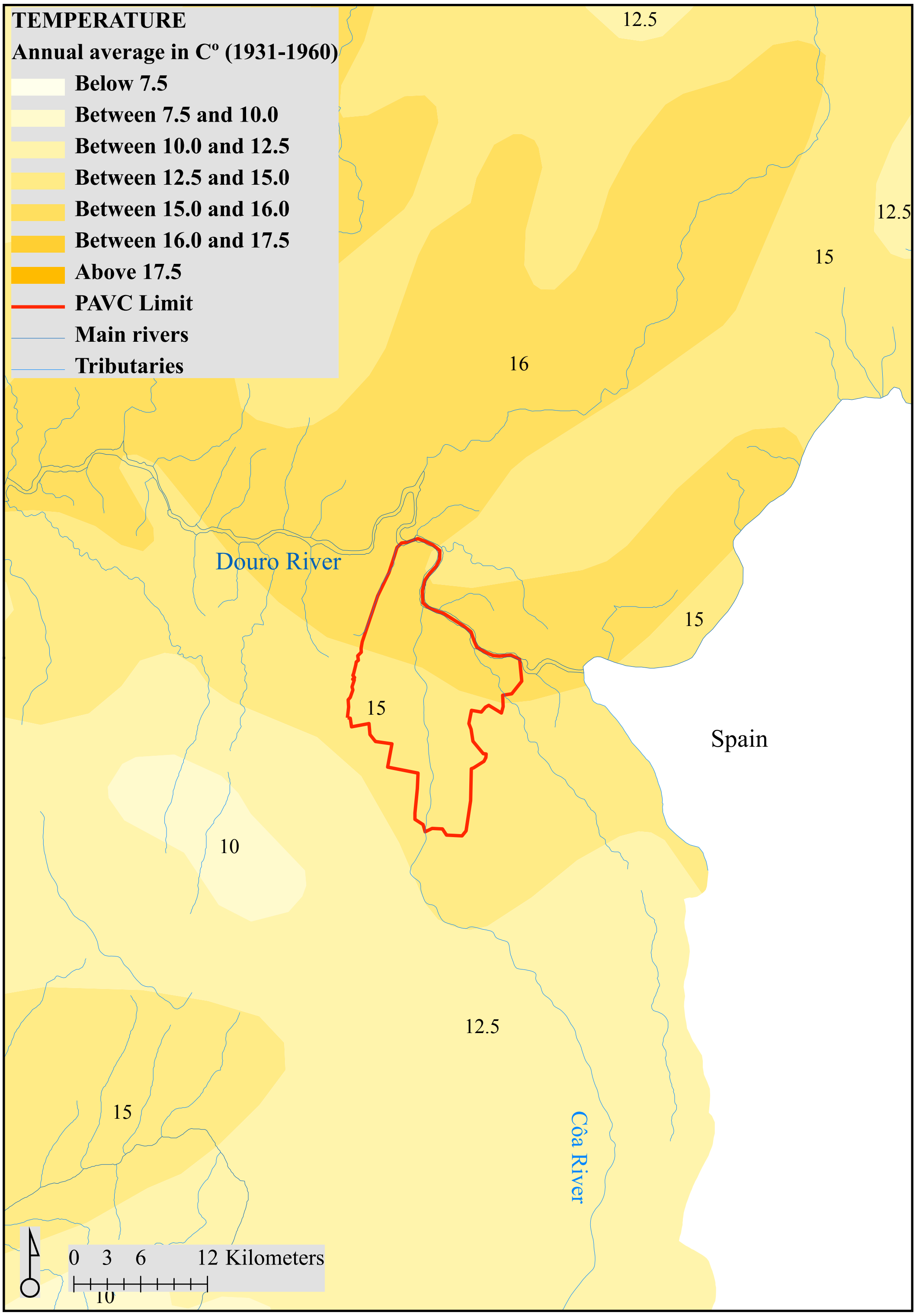


Figure 126. Average annual temperature in the area of the Park from Atlas do Ambiente 1931-1960 data series.

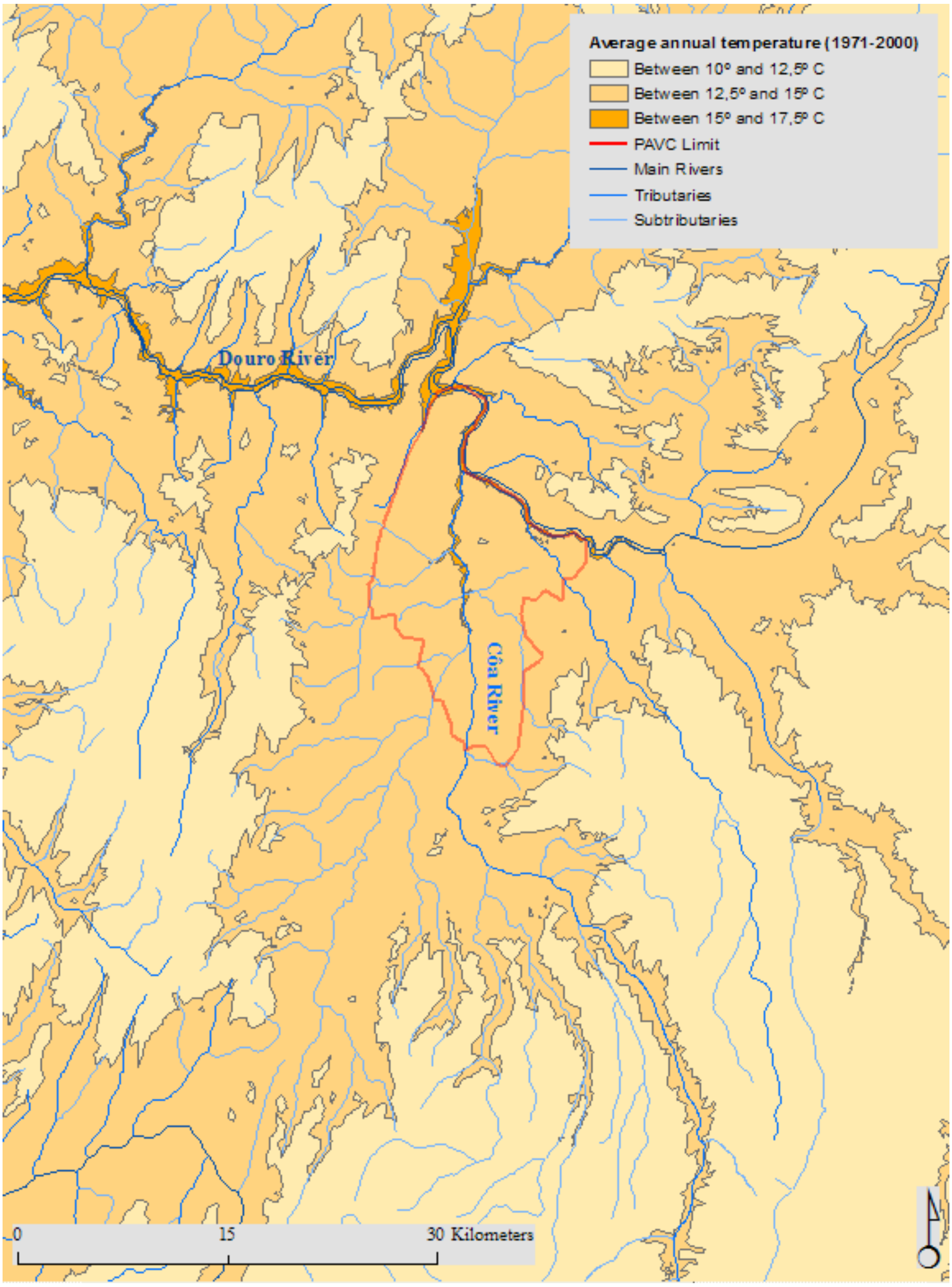


Figure 127. Average annual temperature in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

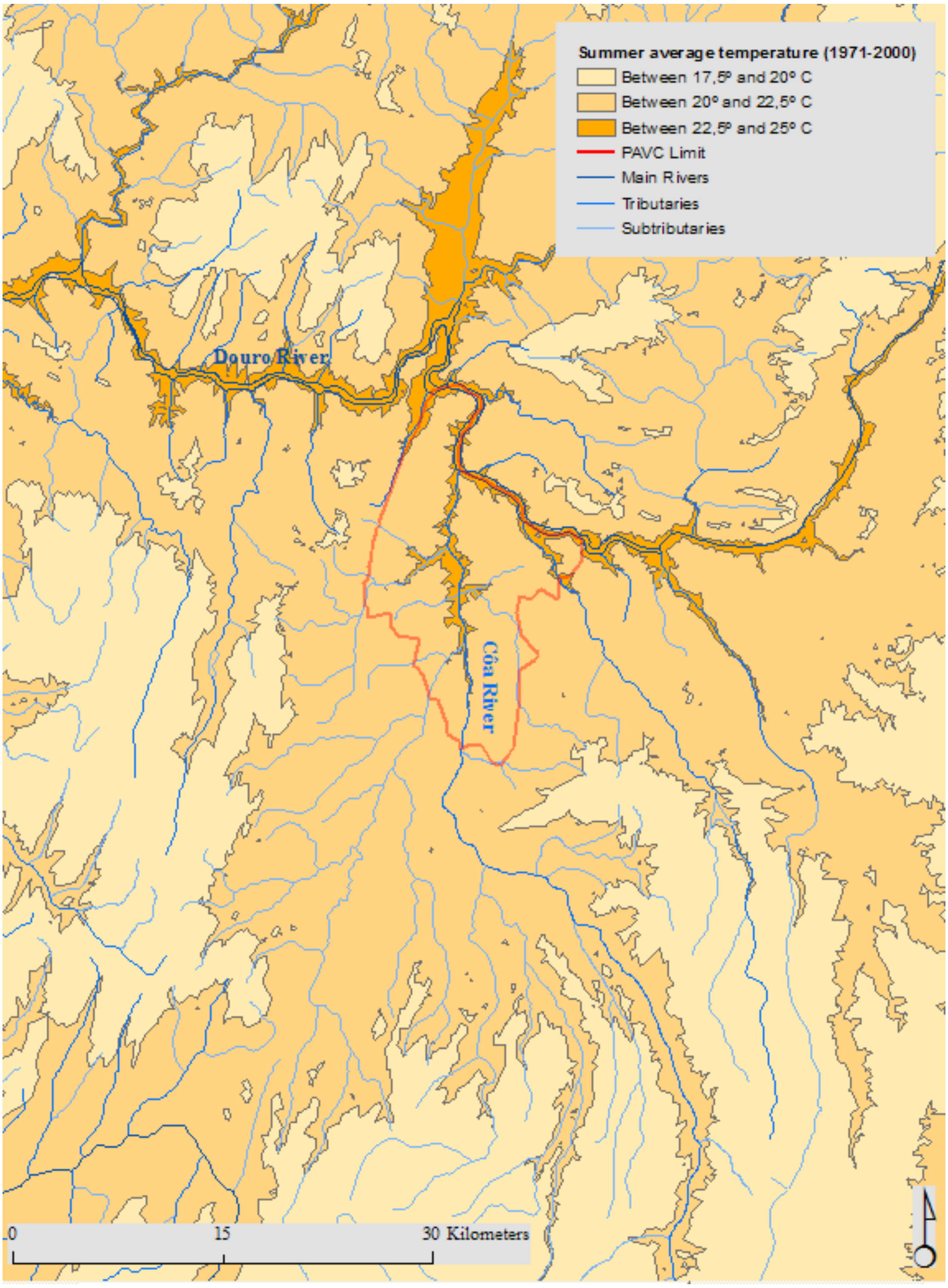


Figure 128. Summer average temperatures in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

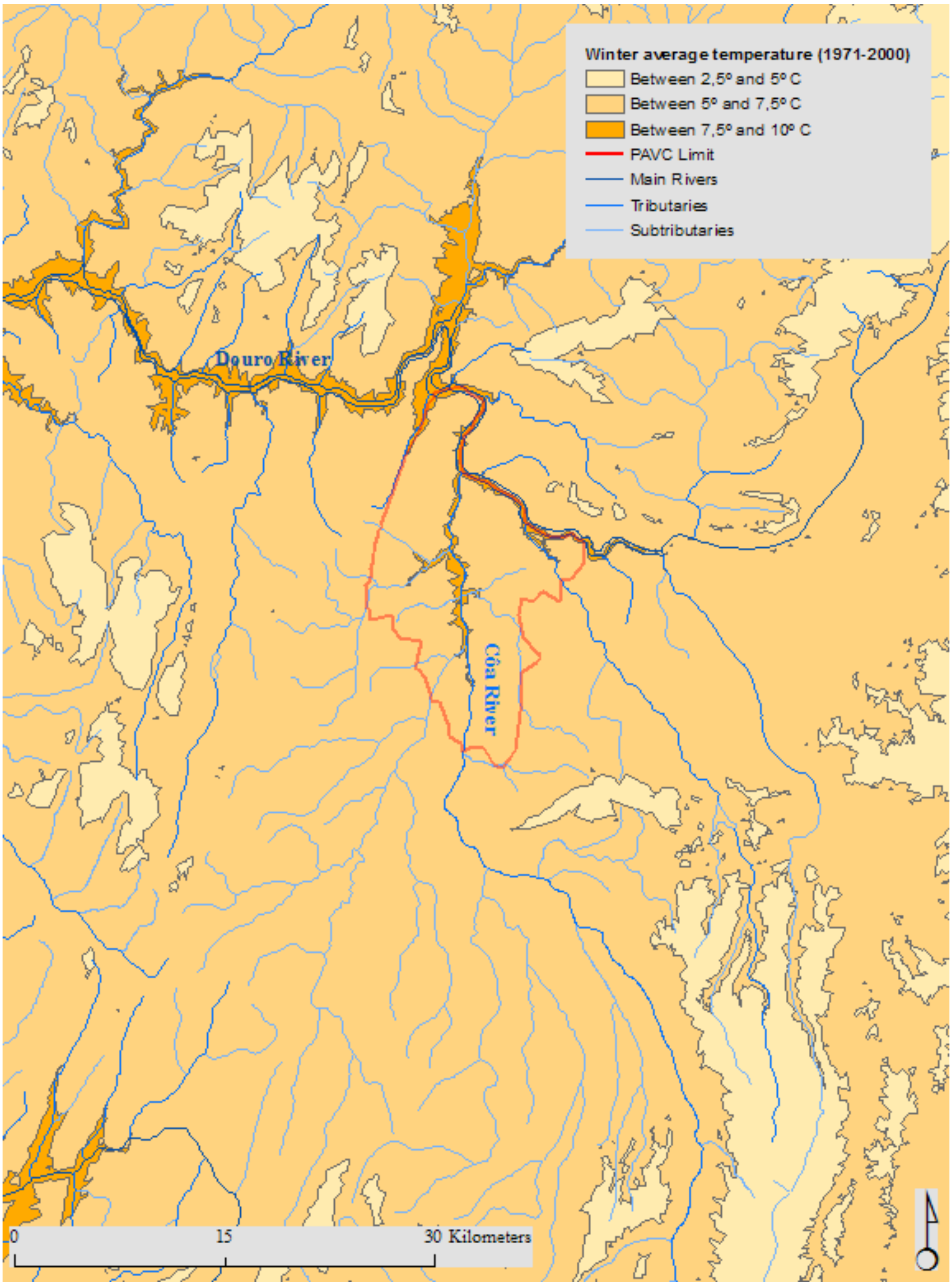


Figure 129. Winter average temperatures in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

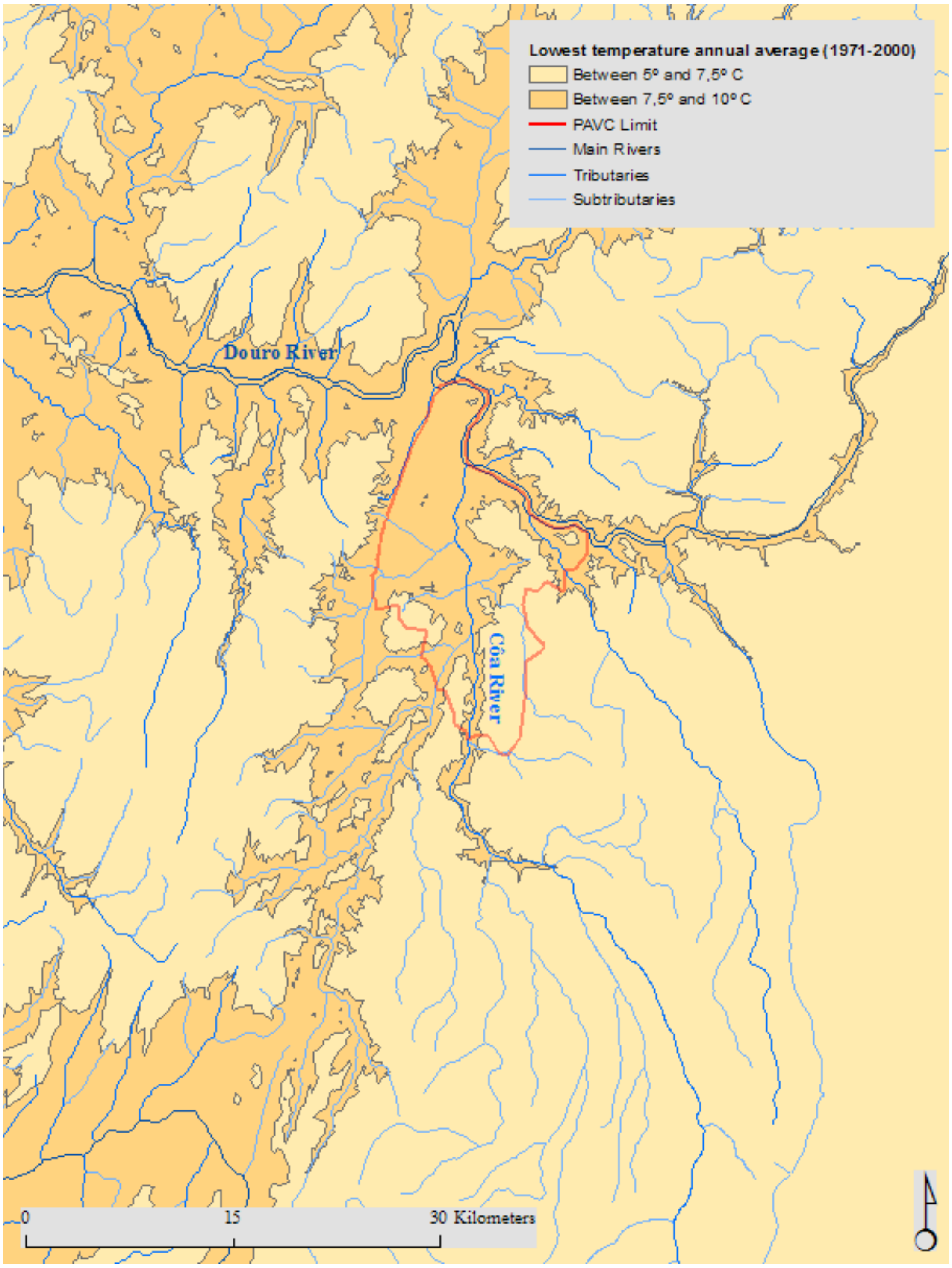


Figure 130. Lowest annual average temperatures in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

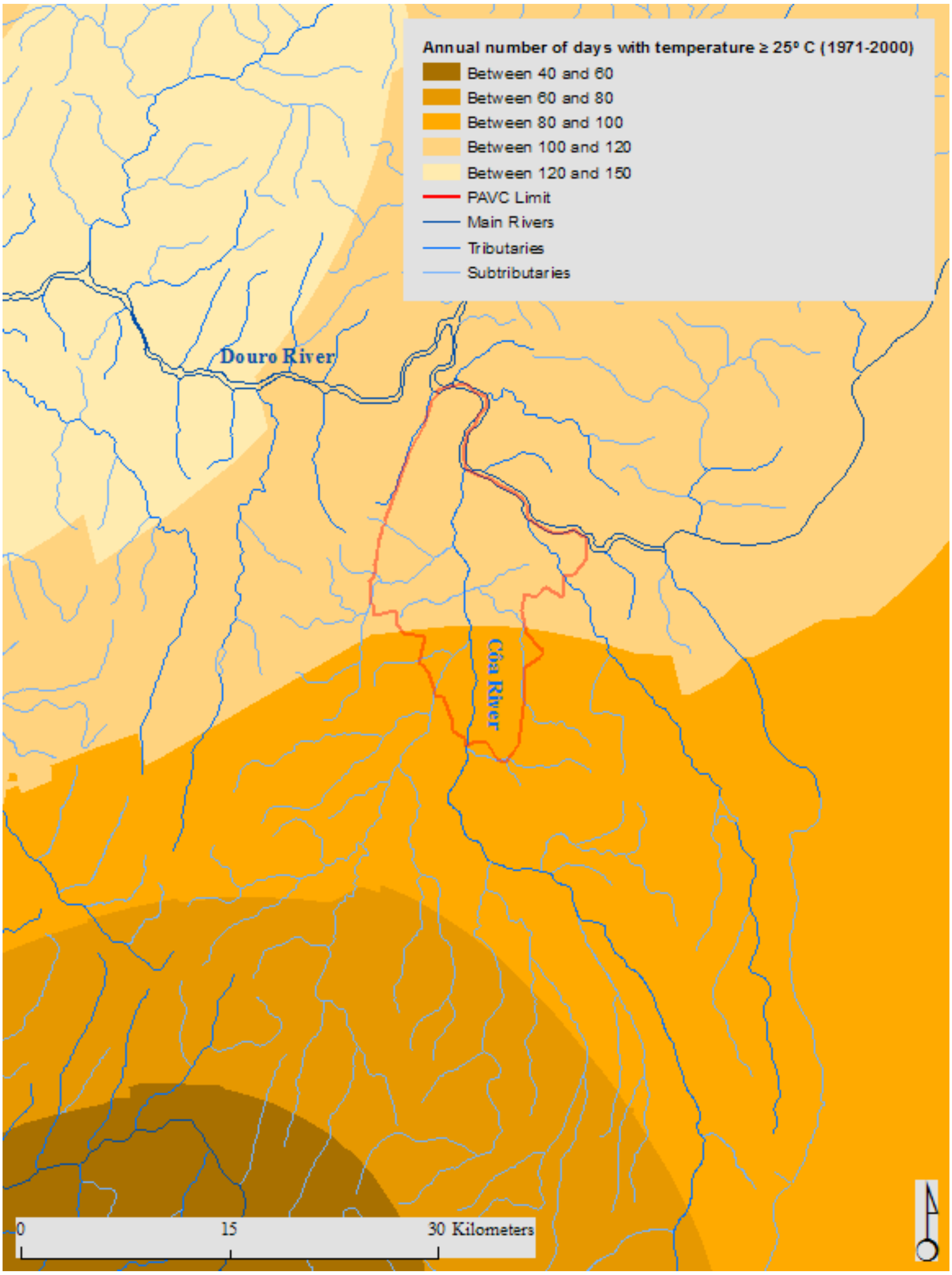


Figure 131. Annual number of days with temperatures ≥25ºC in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

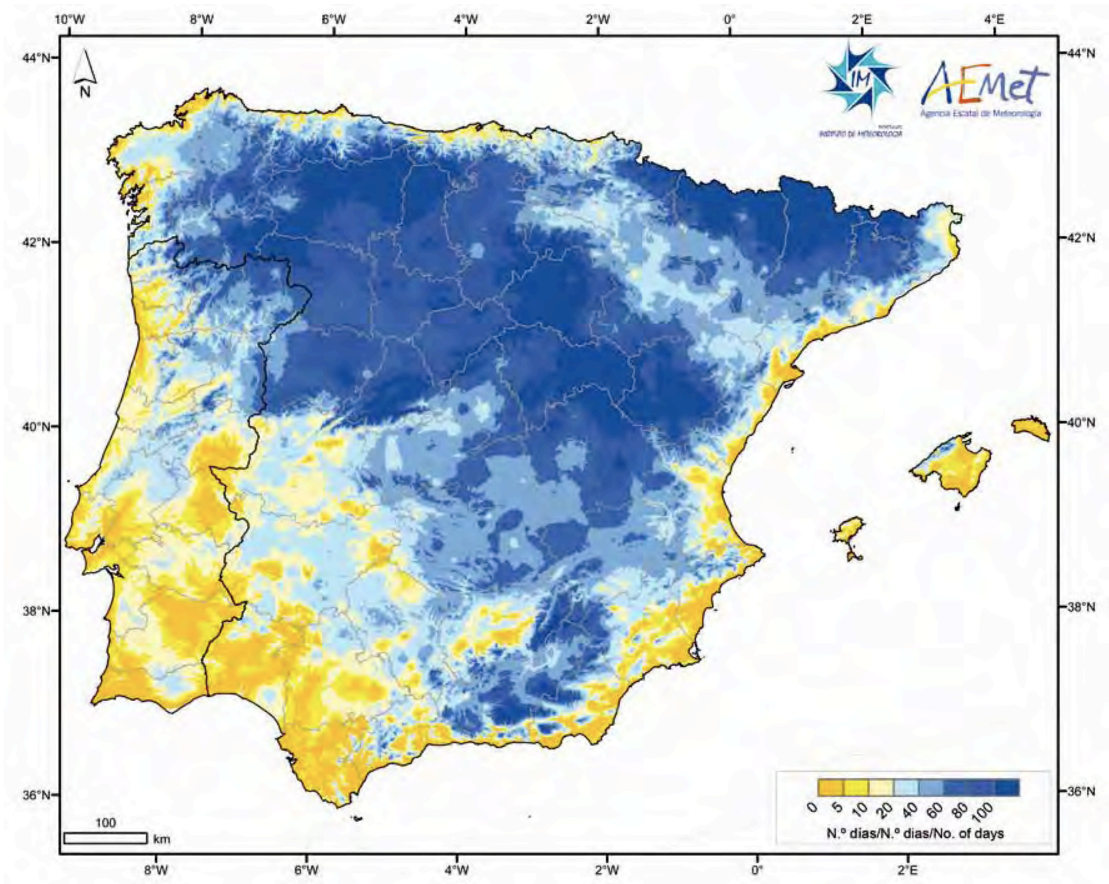


Figure 132. Annual number of days with temperature ≤0ºC in the area of the Park from the Iberian Climate Atlas 1971-2000 data series.[113]

[113] Unfortunately, the author only realized IM had not sent the solicited shapefile pertaining annual number of days with temperature ≤0ºC until a quite advanced phase of the writing up. Hence, the presented figure is a plan B solution for the graphical presentation of weather information. Nevertheless, albeit the low resolution, it is still possible to discern useful information.

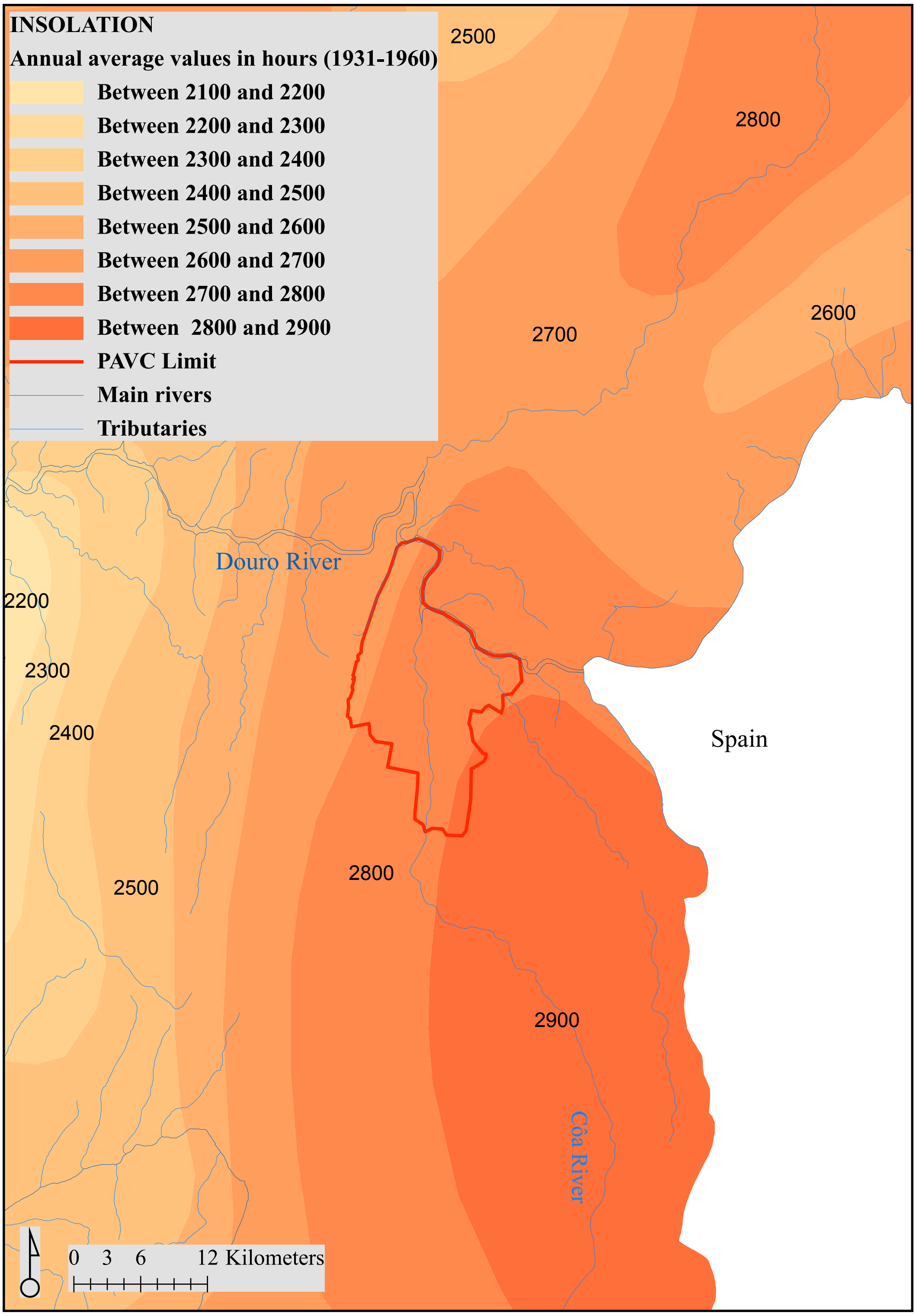


Figure 133. Insolation in the area of the Park from Atlas do Ambiente 1931-1960 data series.

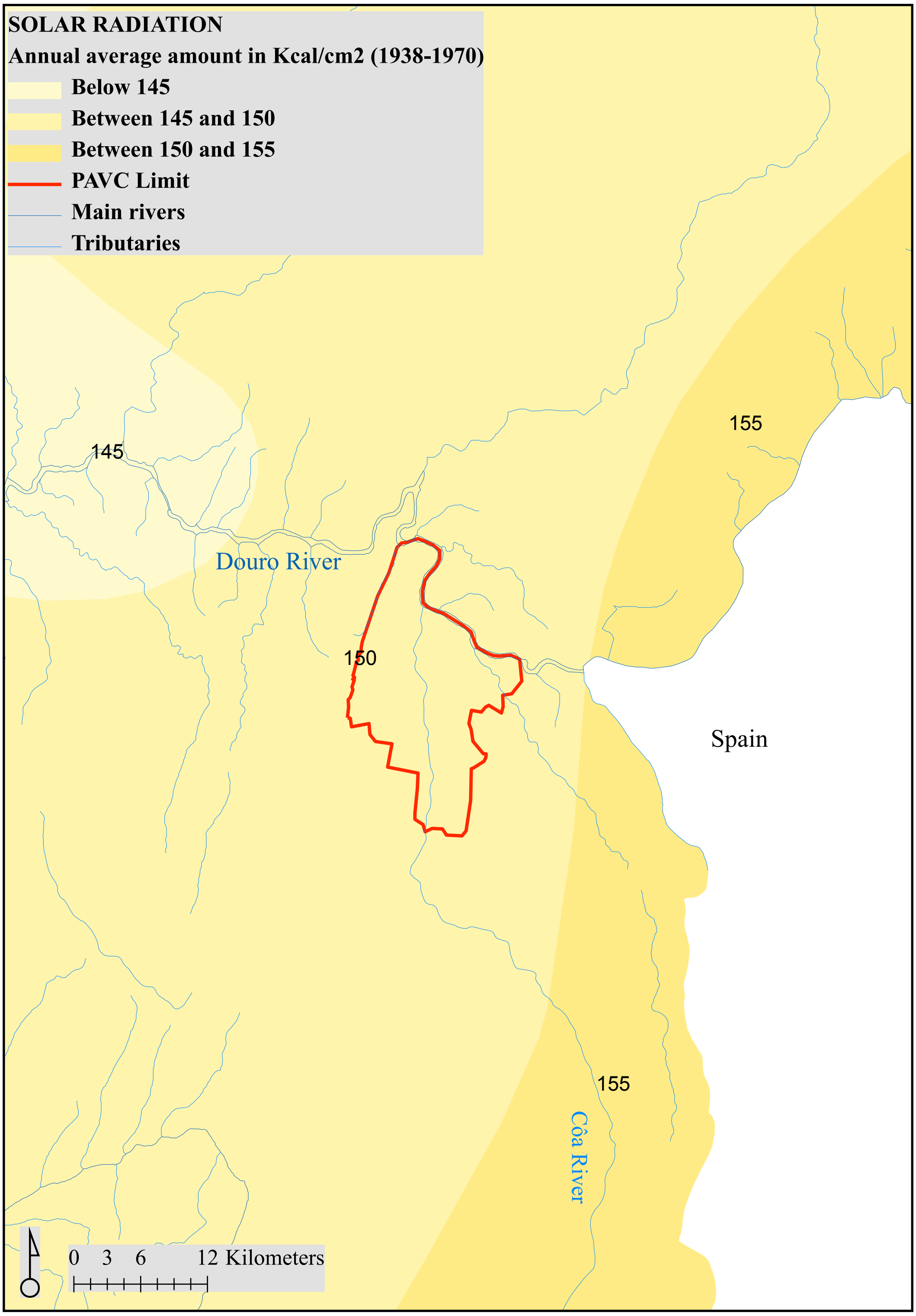


Figure 134. Solar radiation in the area of the Park from Atlas do Ambiente 1938-1970 data series.

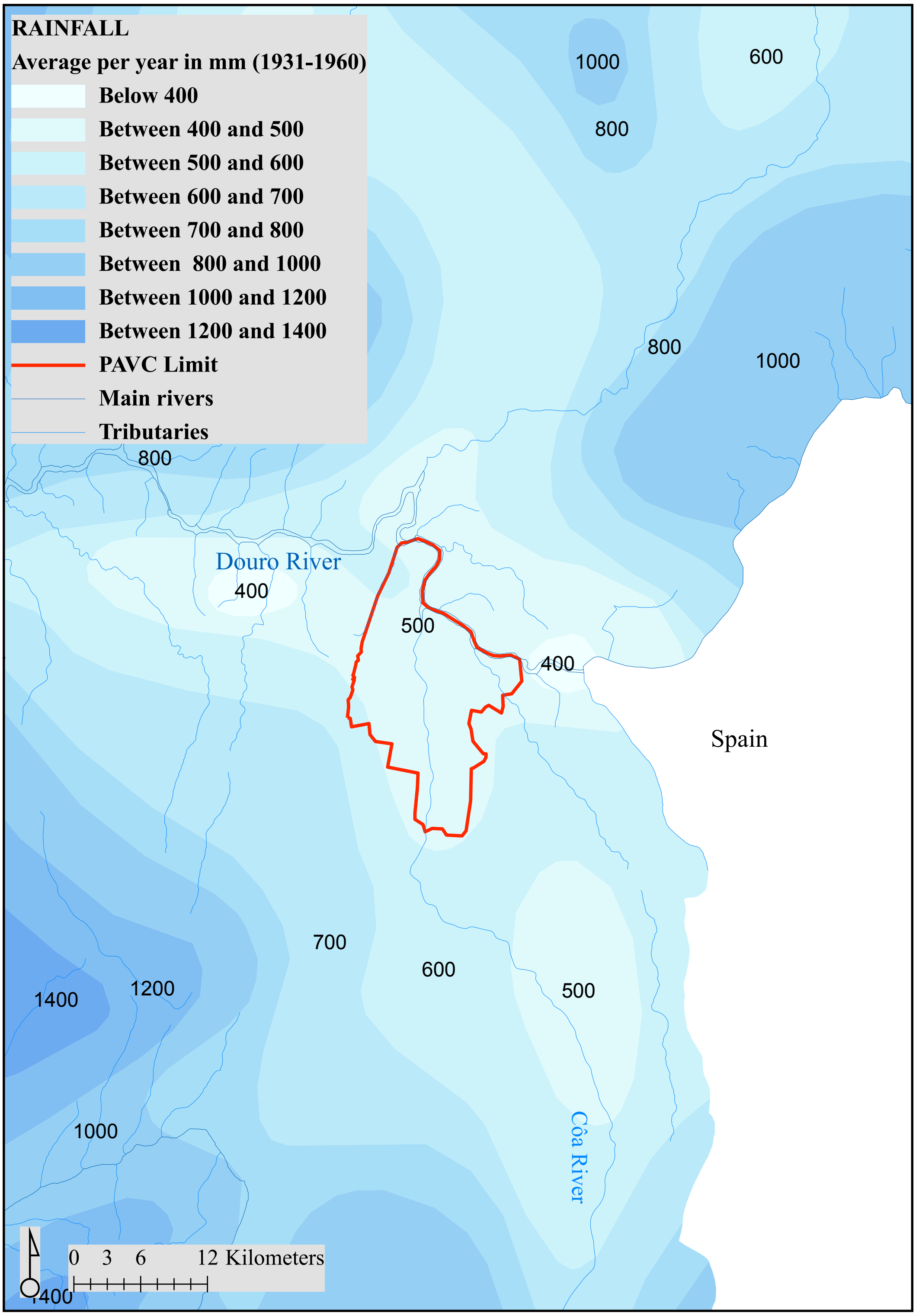


Figure 135. Annual average precipitation in the area of the Park from Atlas do Ambiente 1931-1960 data series.

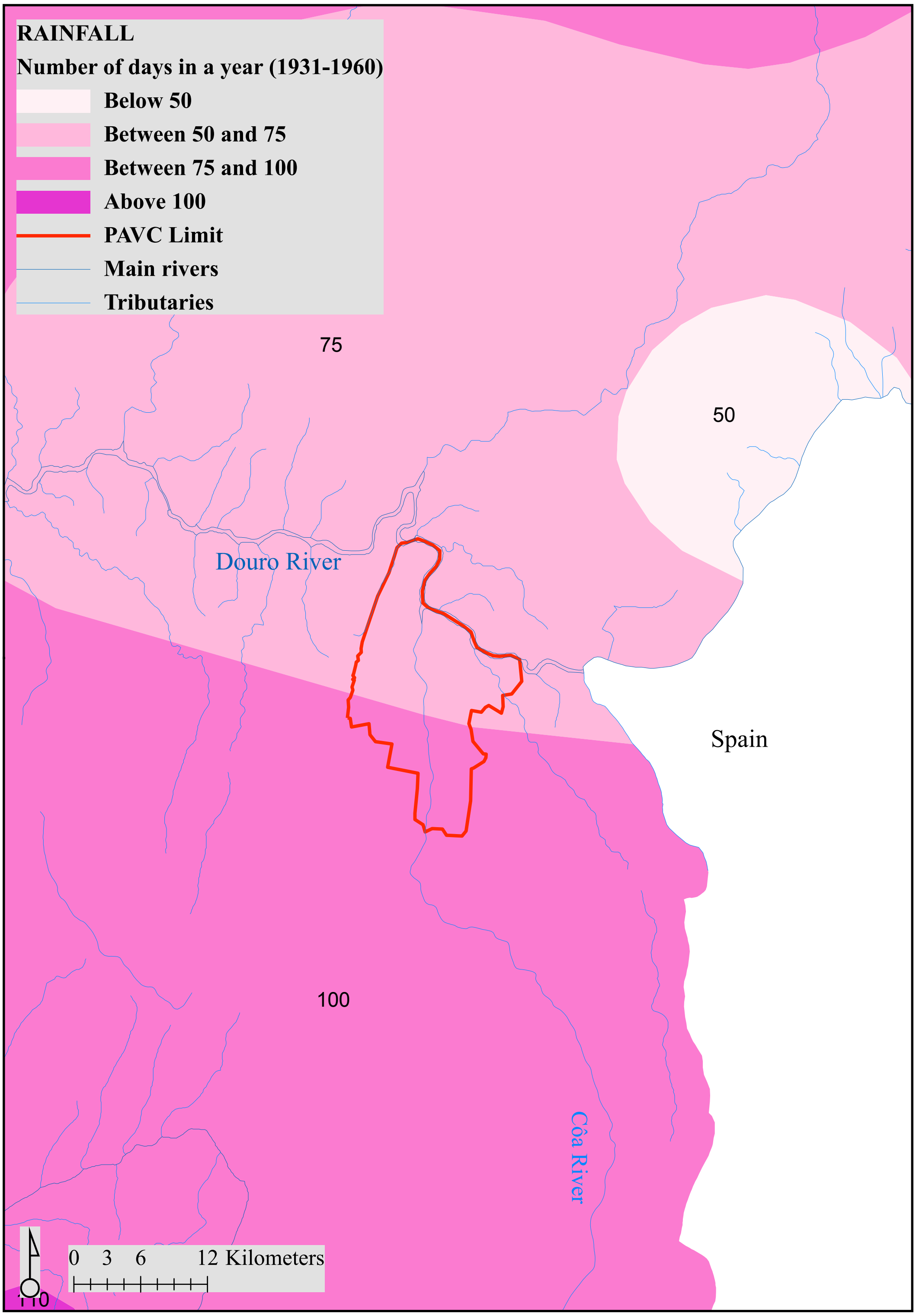


Figure 136. Number of days with precipitation in the area of the Park from Atlas do Ambiente 1931-1960 data series.

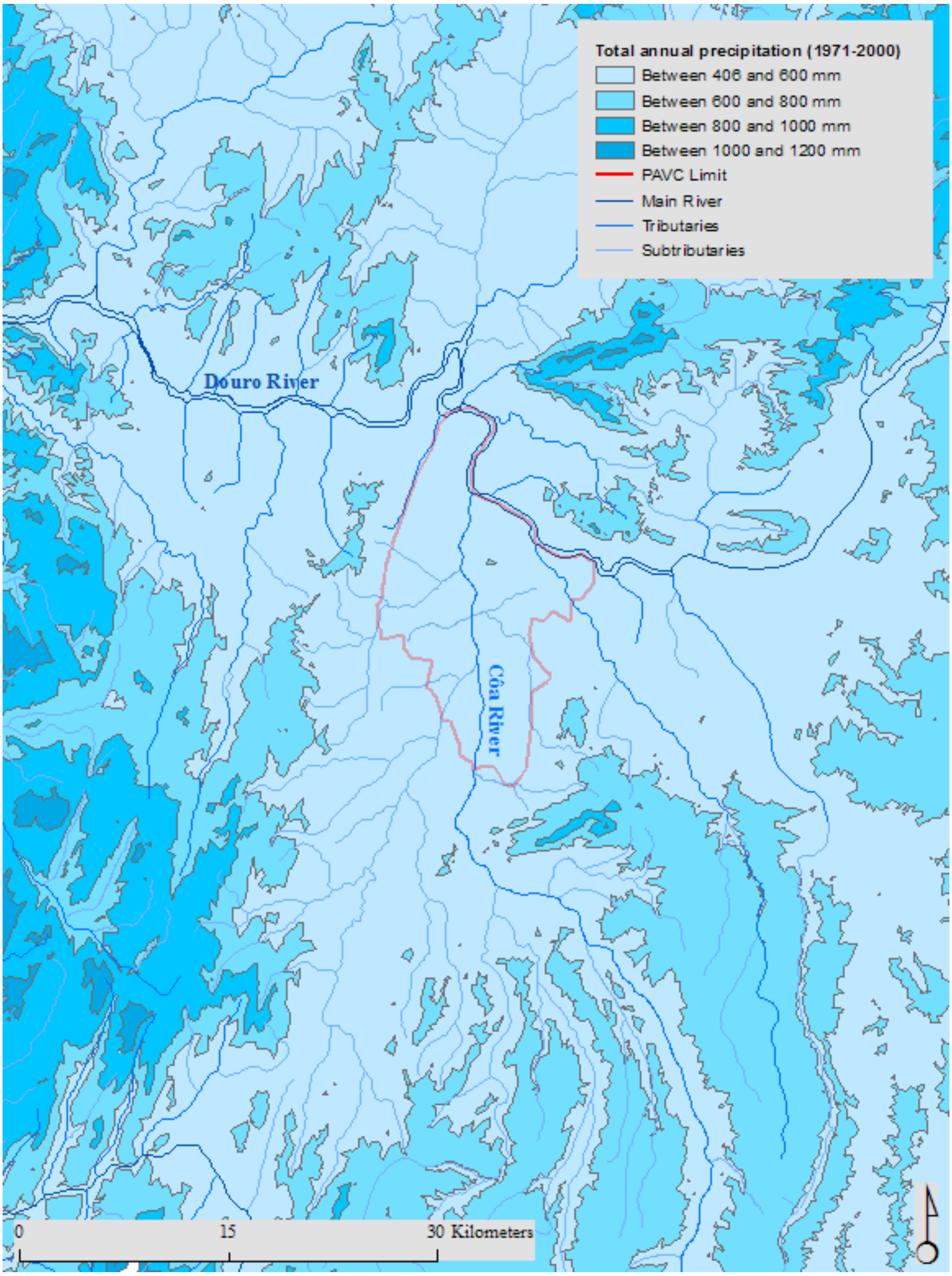


Figure 137. Annual average precipitation in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

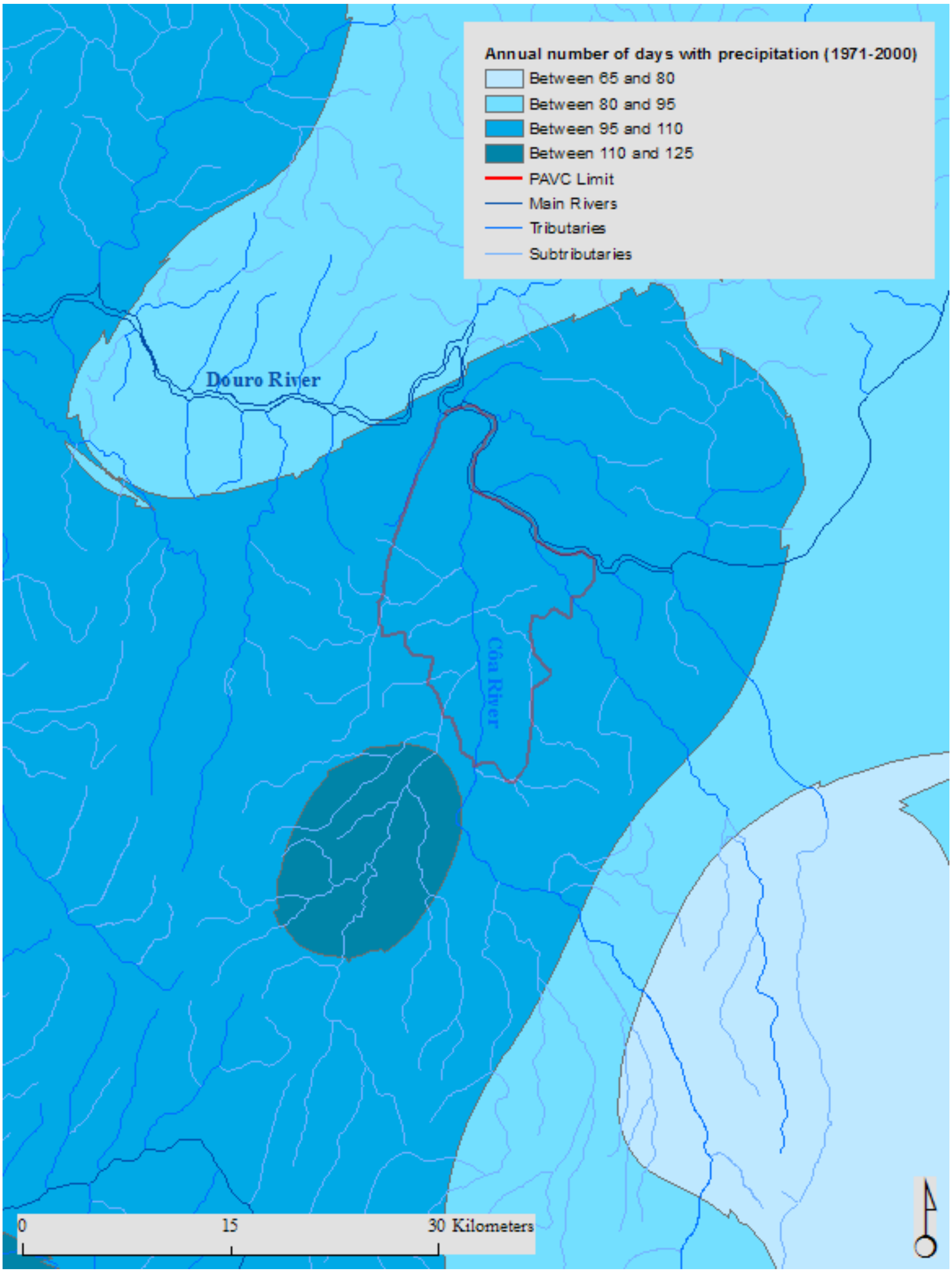


Figure 138. Annual number of days with precipitation in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

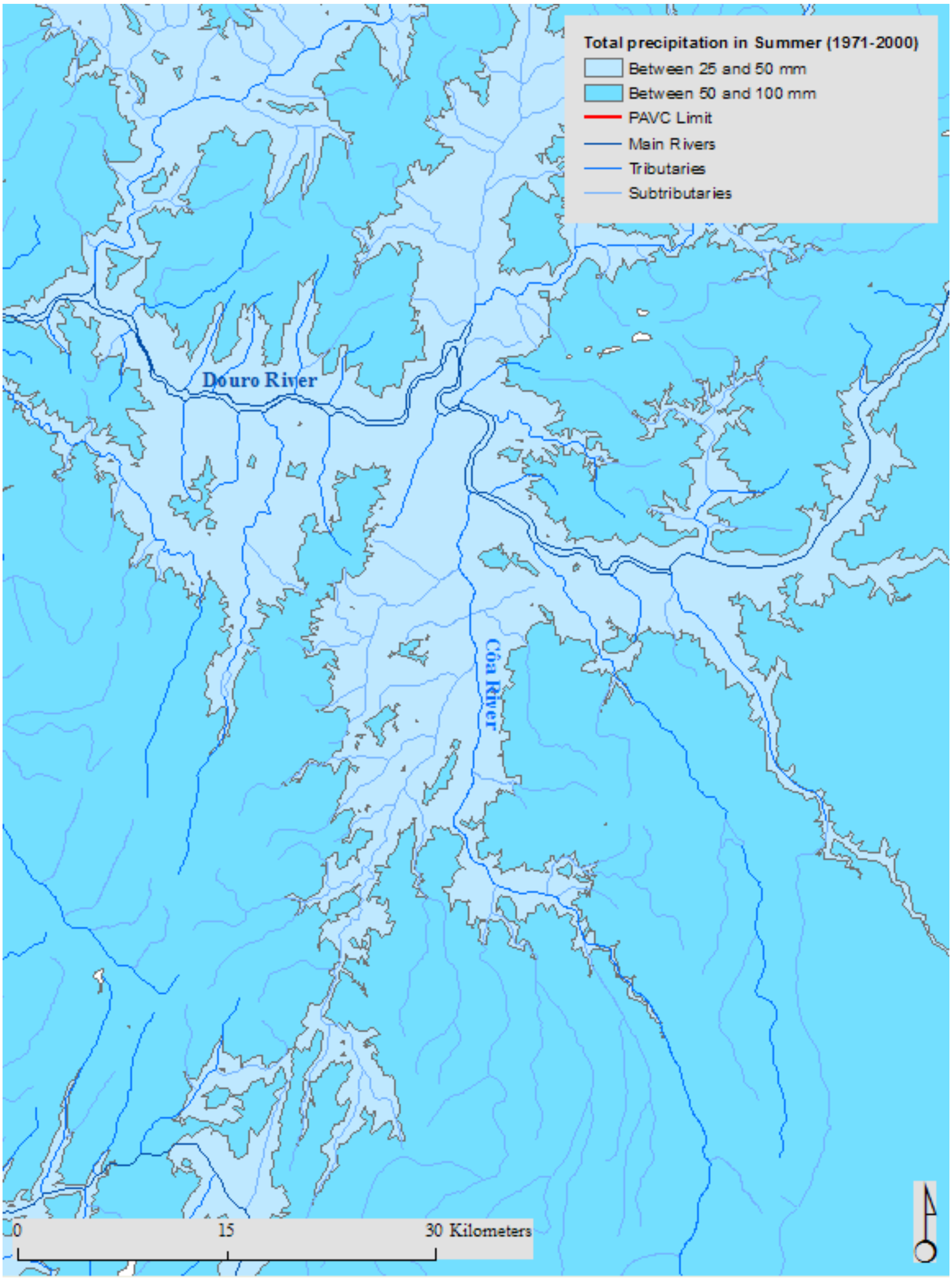


Figure 139. Average summer precipitation in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

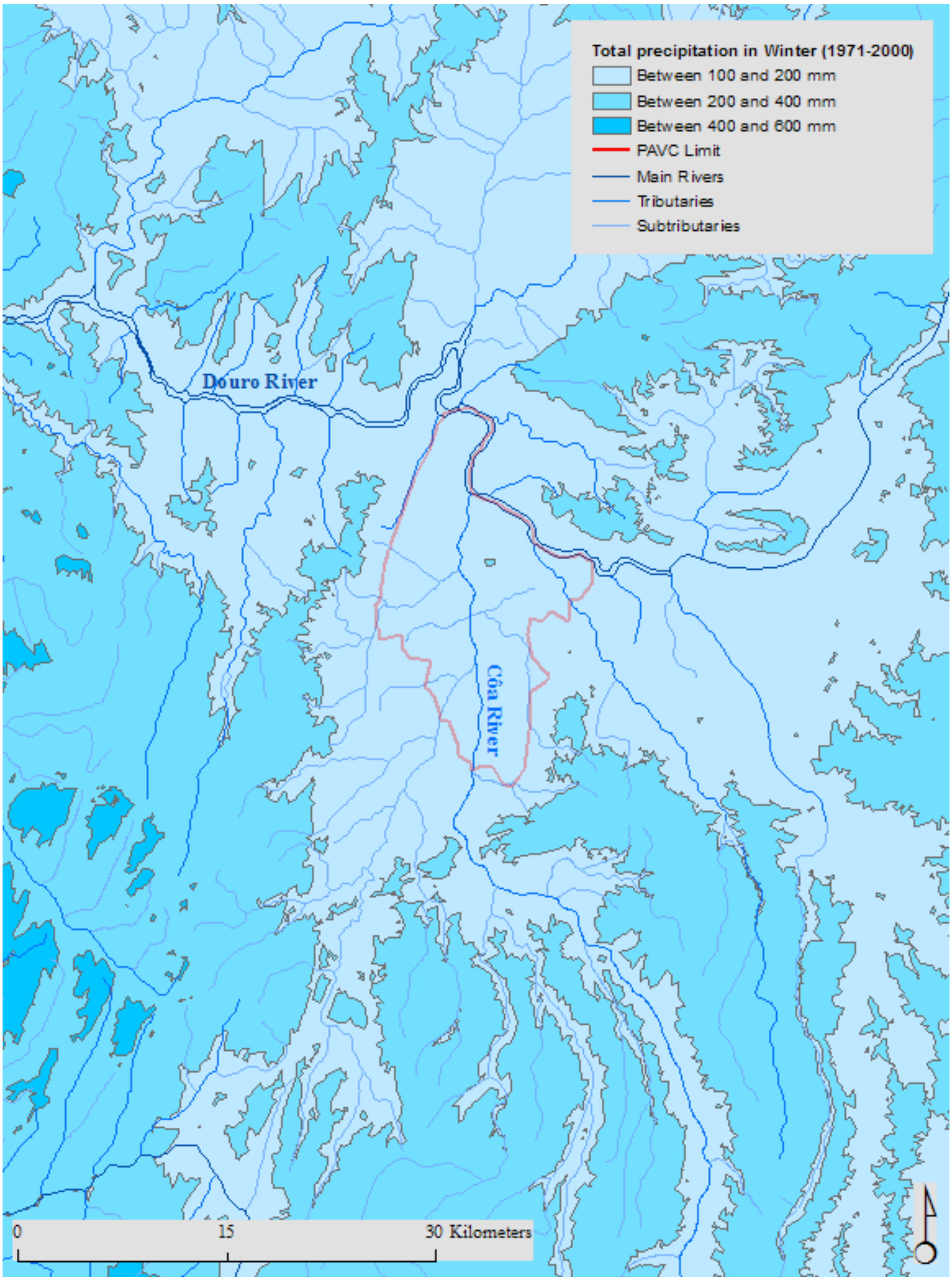


Figure 140. Average winter precipitation in the area of the Park from the Atlas Climático de Portugal Continental 1971-2000 data series.

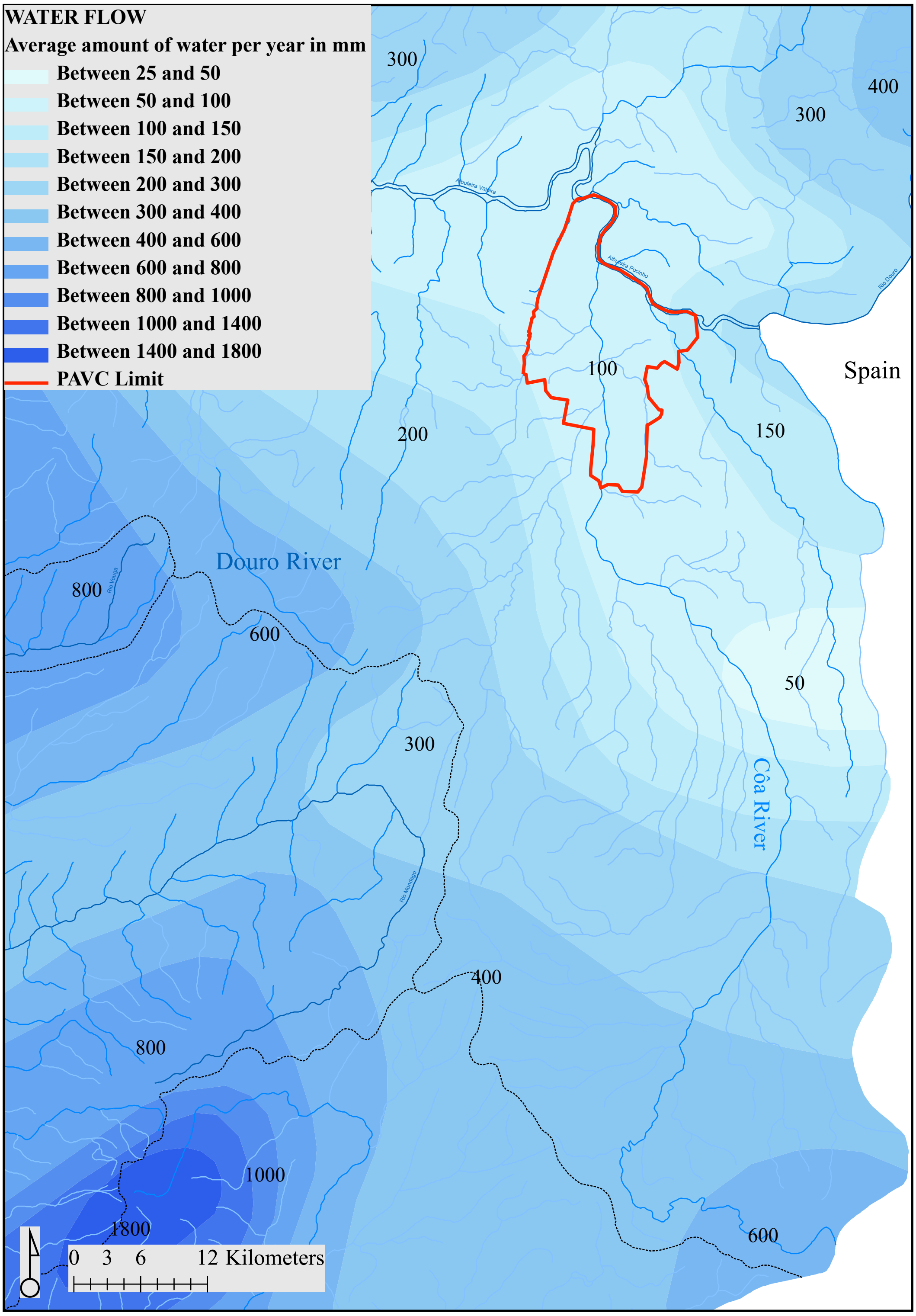


Figure 141. Water flow in the area of the Côa hydrological basin from Atlas do Ambiente 1931-1960 data series.

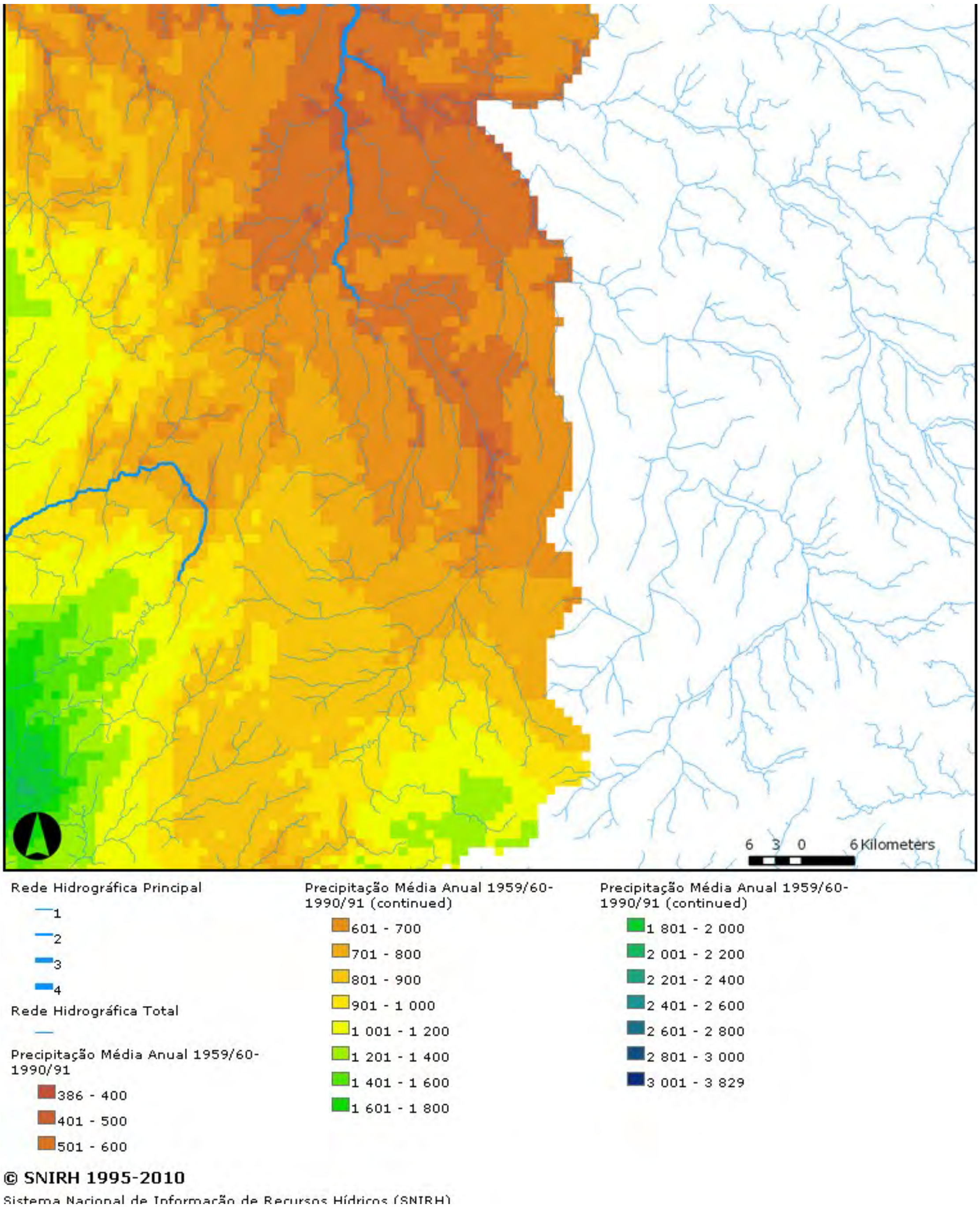


Figure 142. Average annual precipitation in in the area of the Côa hydrological basin from the Sistema Nacional de Informação de Recursos Hídricos data series 1959/60-1990/91. Note that values range from more than 1,000 mm in the Upper Côa to around 400 mm in the Lower Côa where the Park is located. Source: http://snirh.pt.

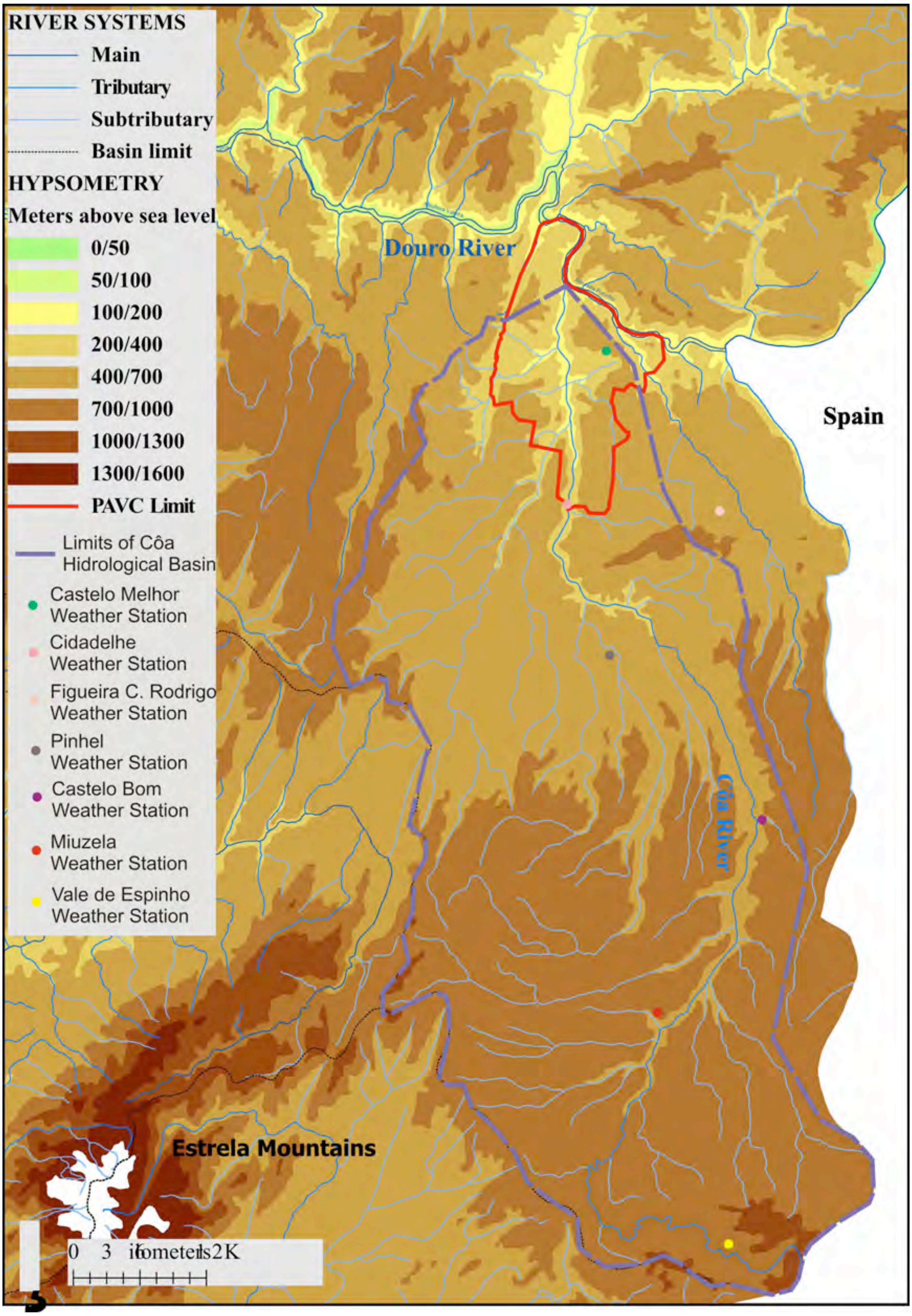


Figure 143. Hydrological basin of the Côa with indication of the INAG and IM (Figueirra de Castelo Rodrigo) weather stations whose data is used in the Water flow subsection.

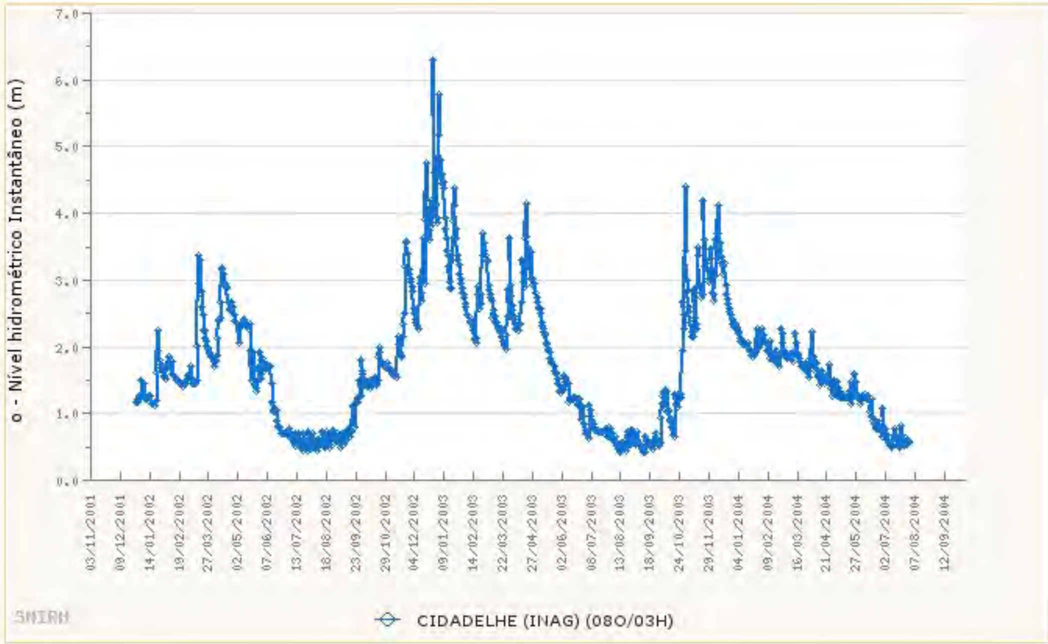


Figure 144. Côa water levels from 03/11/2011 to 12/09/2004 measured by Cidadelhe station. Source: http://snirh.pt.

Figure 145. Area where the meanwhile abandoned dam was to be constructed. Note the caisson and the 'cut' in one of the riverbanks where the dam would fit.

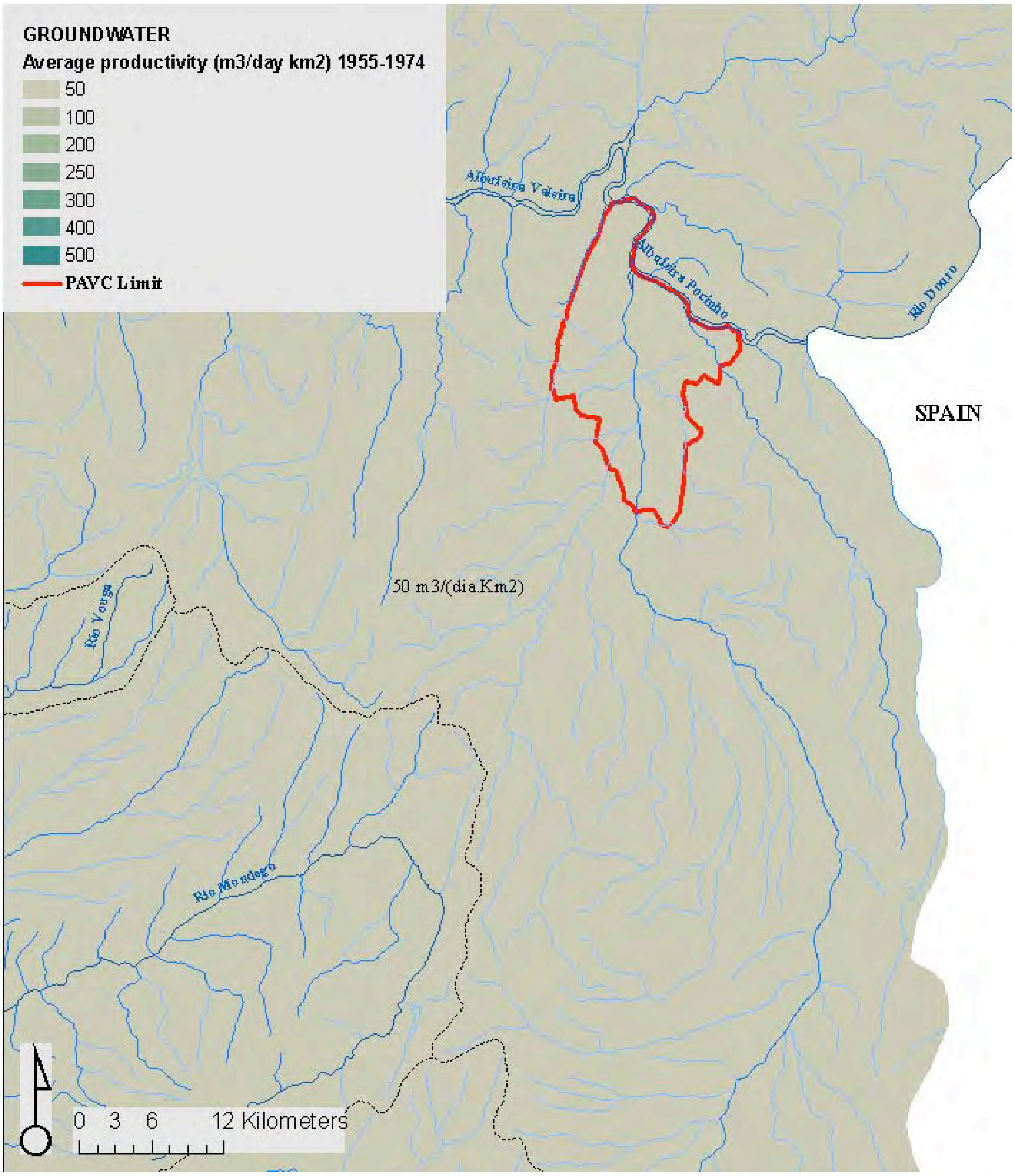


Figure 146. Groundwater in the area of the Park from Atlas do Ambiente 1955-1971 data series.

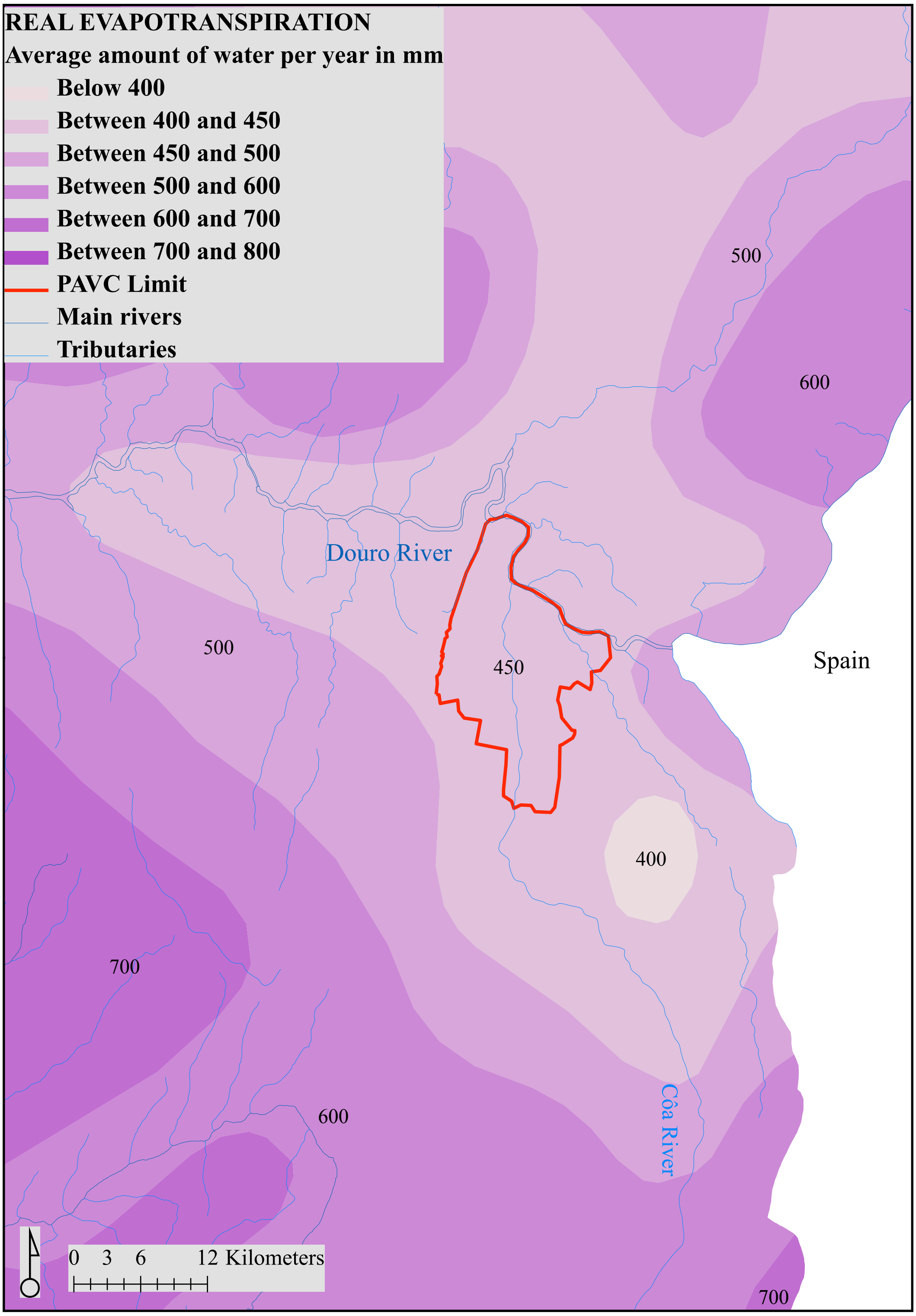


Figure 147. Evapotranspiration in the area of the Park from Atlas do Ambiente 1931-1960 data series.

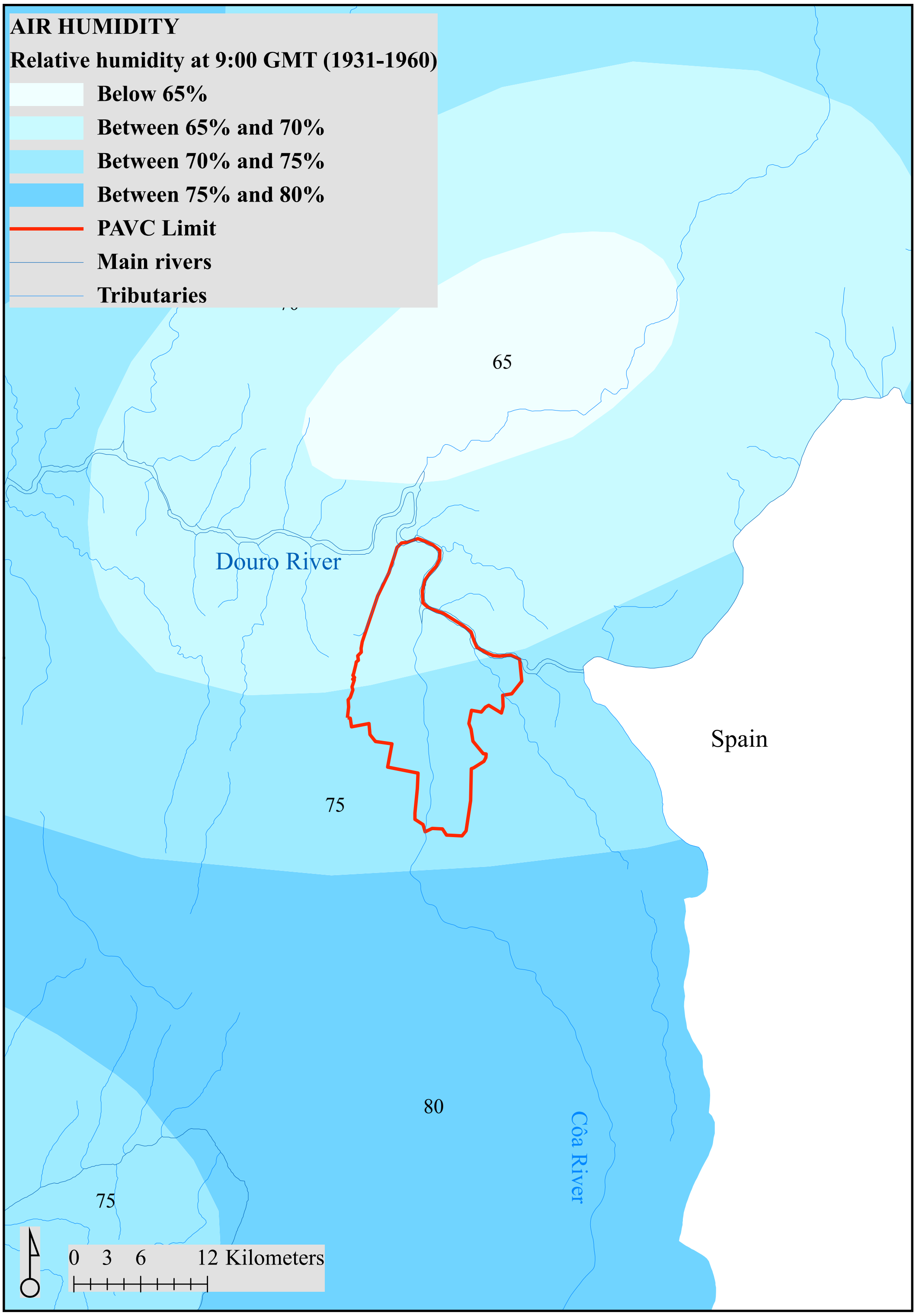


Figure 148. Relative humidity in the area of the Park from Atlas do Ambiente 1931-1960 data series.

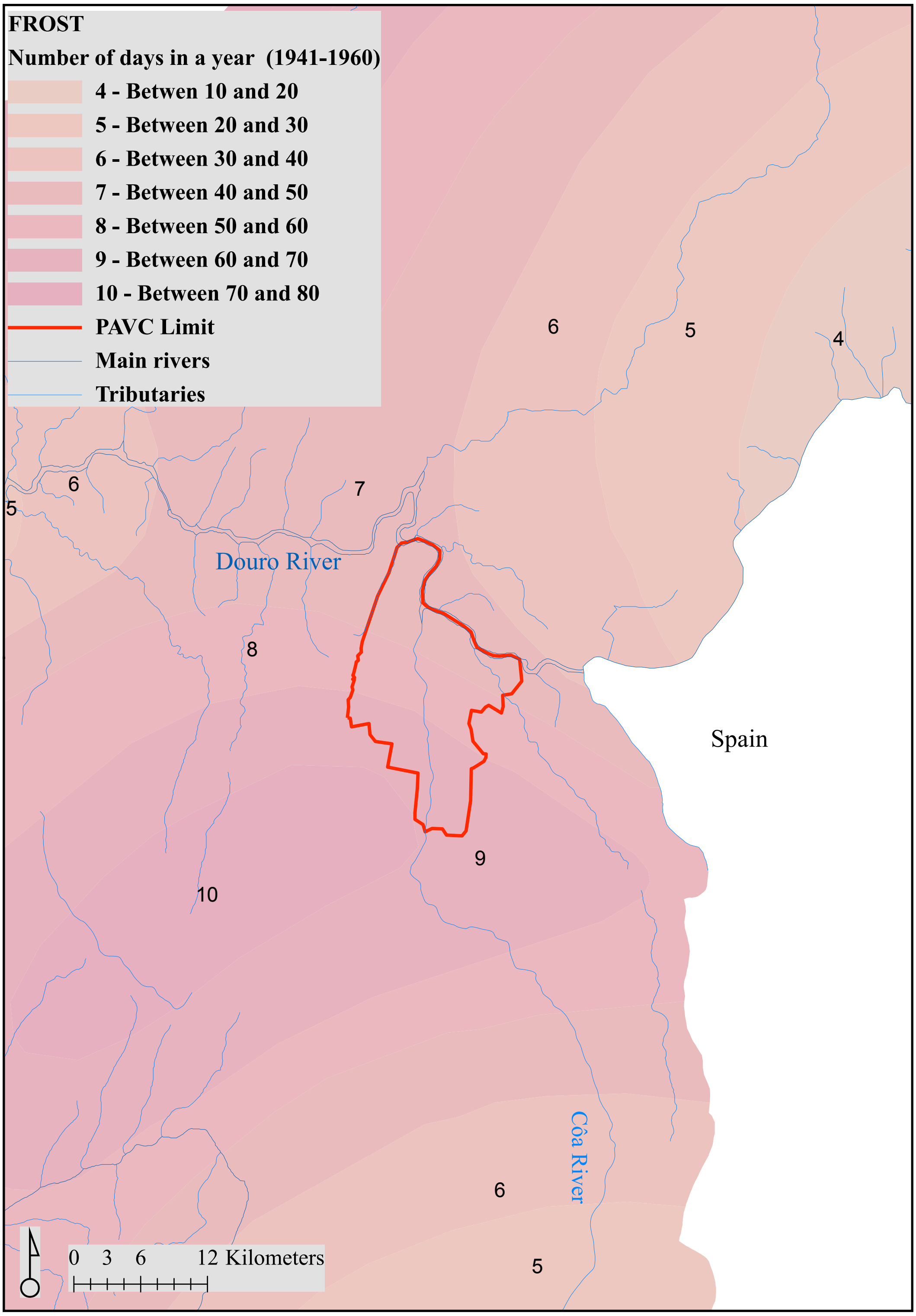


Figure 149. Frost in the area of the Park from Atlas do Ambiente 1941-1960 data series.

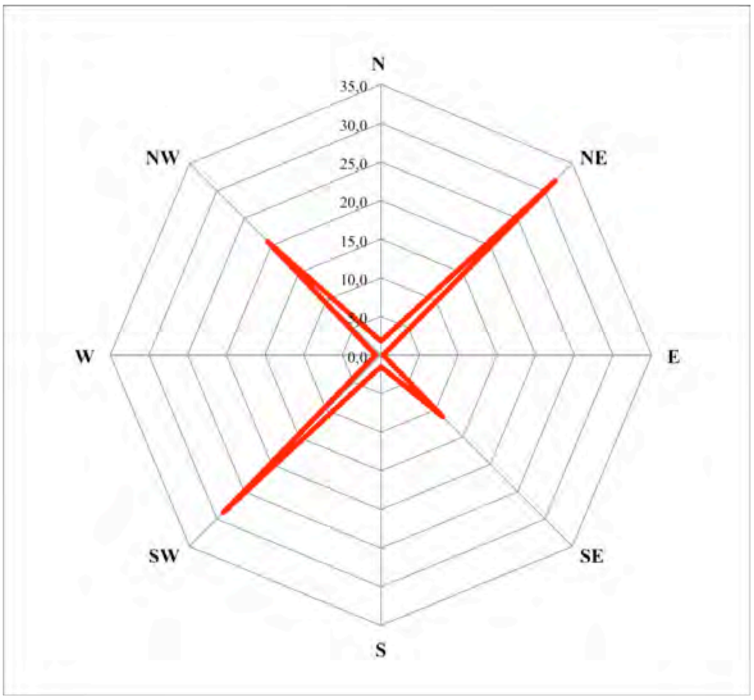


Figure 150. Wind orientation and speed (in Kms/hour) at Figueira de Castelo Rodrigo in the period 1961-1990. Source: Figueira de Castelo Rodrigo Climate Normal.

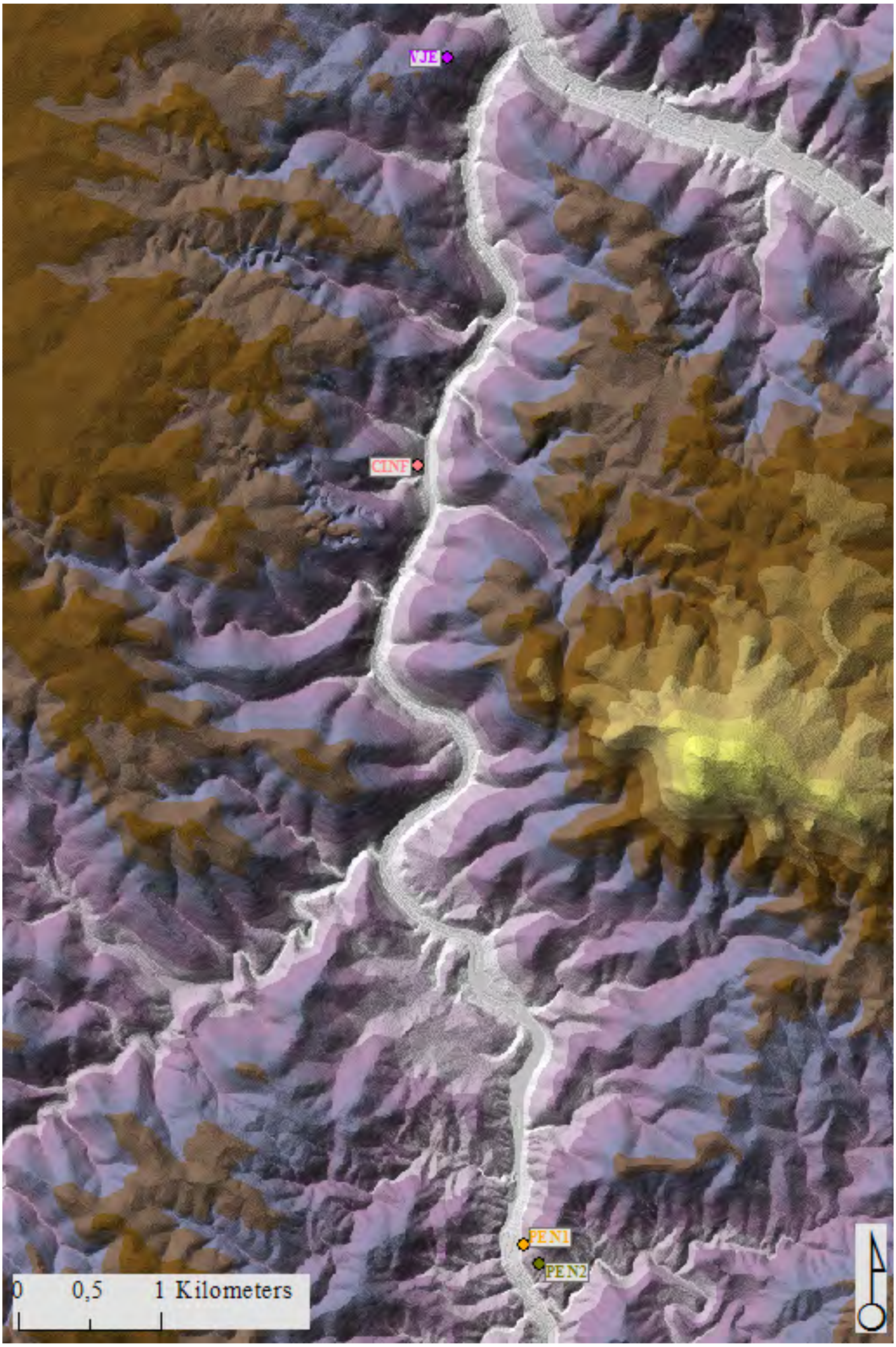


Figure 151. Location of the weather stations installed in the Park’s territory.

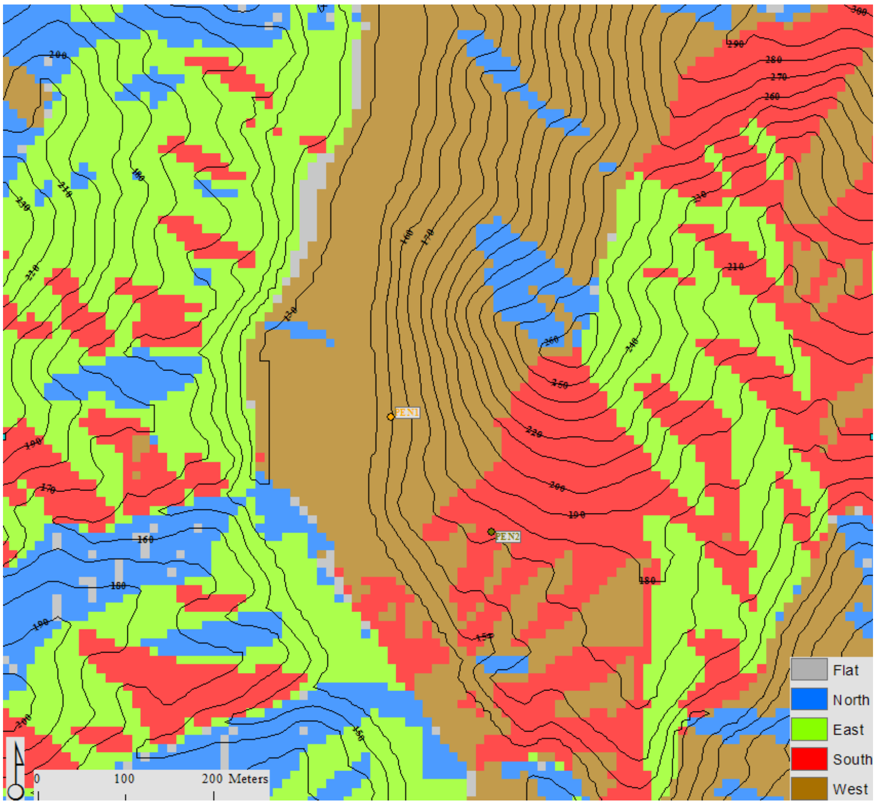


Figure 152. Precise location of PEN1 (orange) and PEN2 (green) at the Penascosa rock-art site.

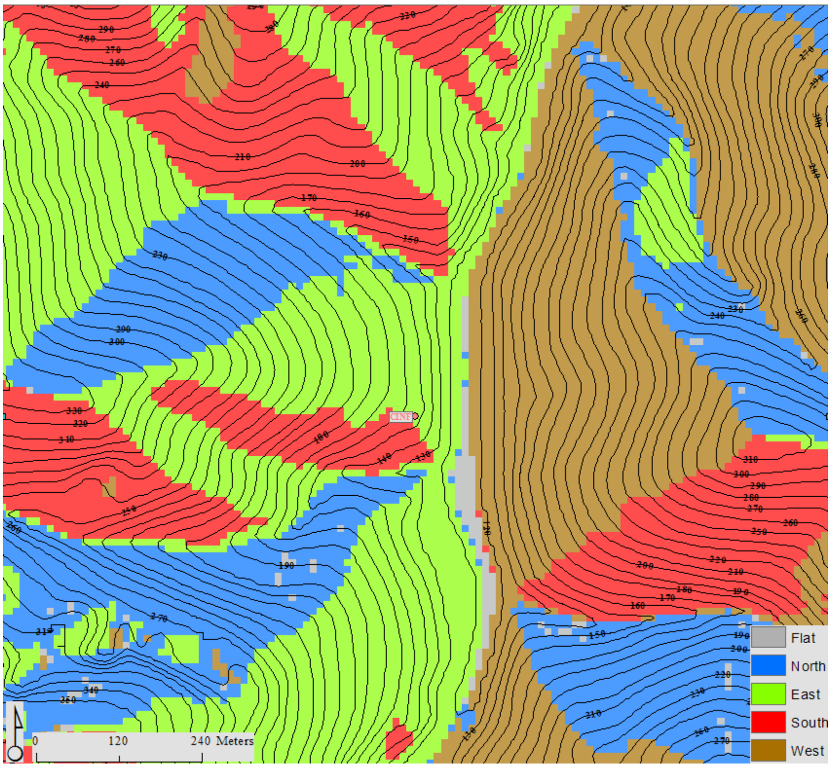


Figure 153. Precise location of CINF at the Canada do Inferno rock-art site.

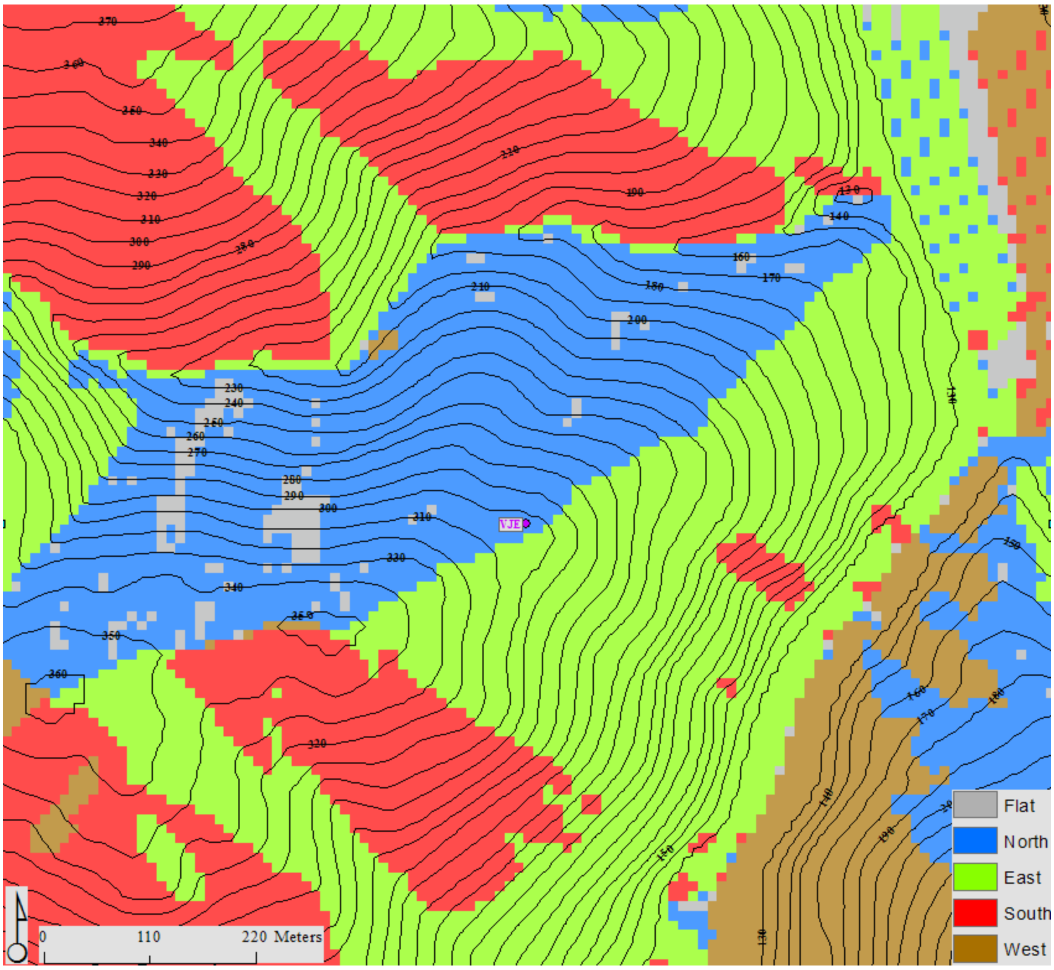


Figure 154. Precise location of VJE near to the newly inaugurated Côa Museum.

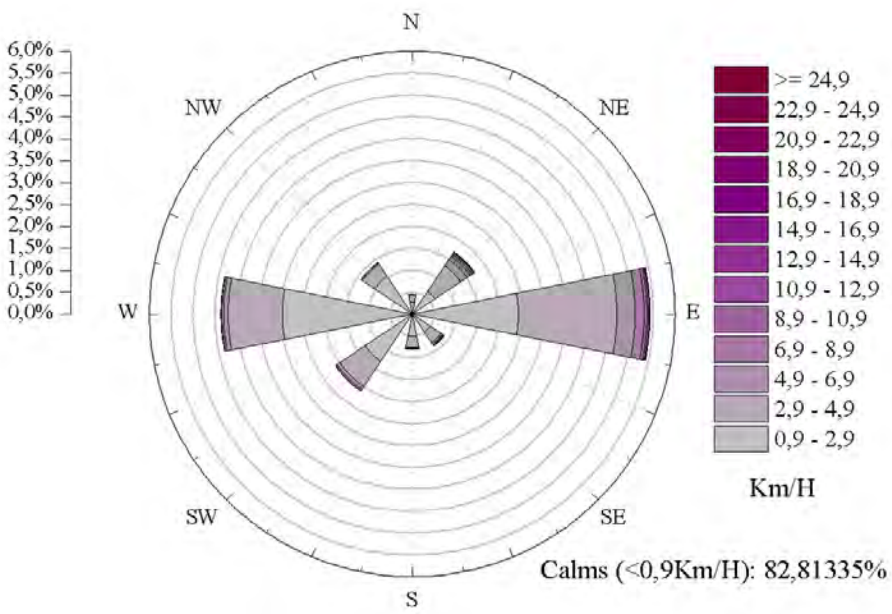


Figure 155. Wind direction and speed patterns measured by CINF during the period in question.

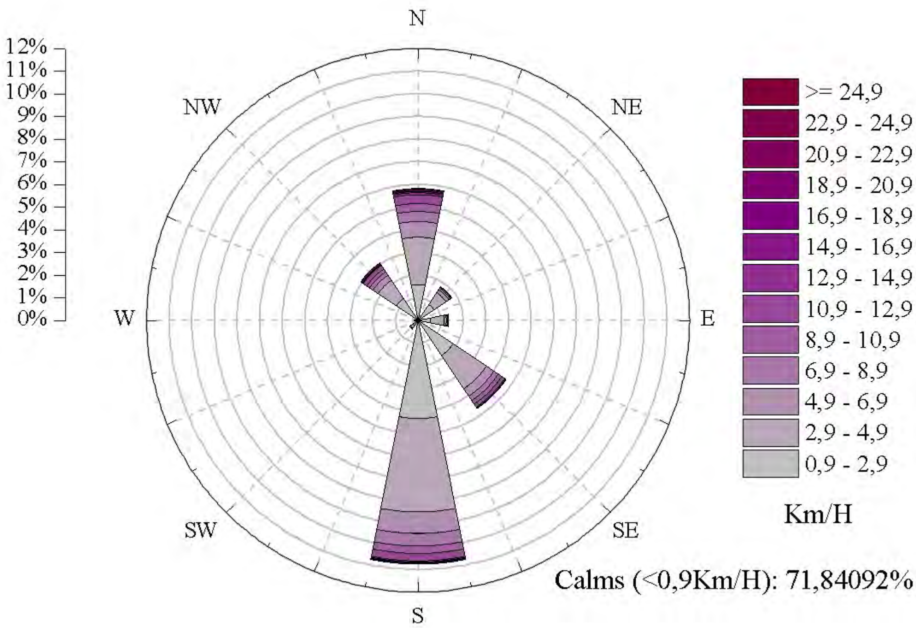


Figure 156. Wind direction and speed patterns measured by PEN2 during the period in question.

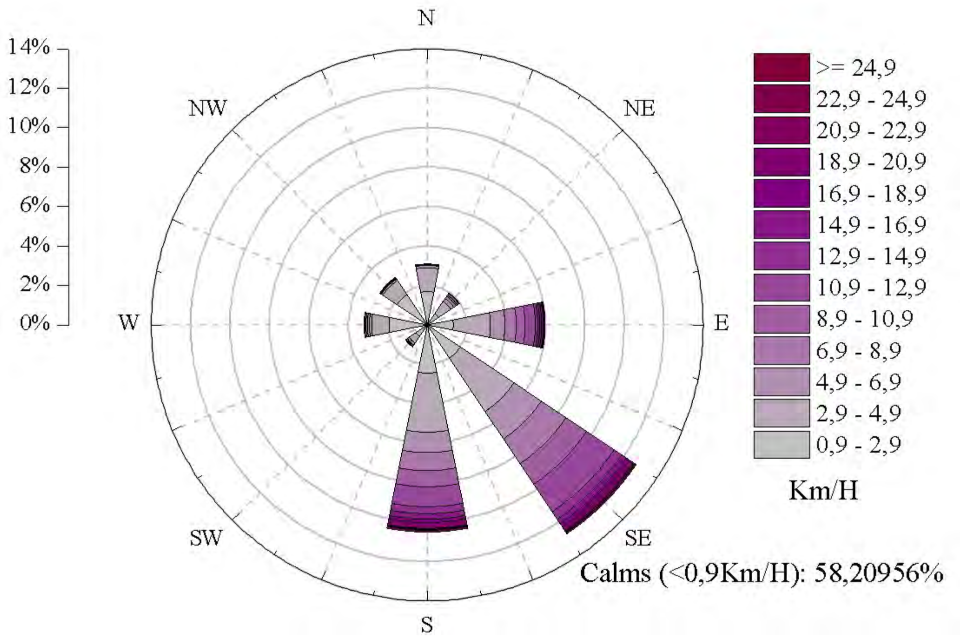


Figure 157. Wind direction and speed patterns measured by VJE during the period in question.

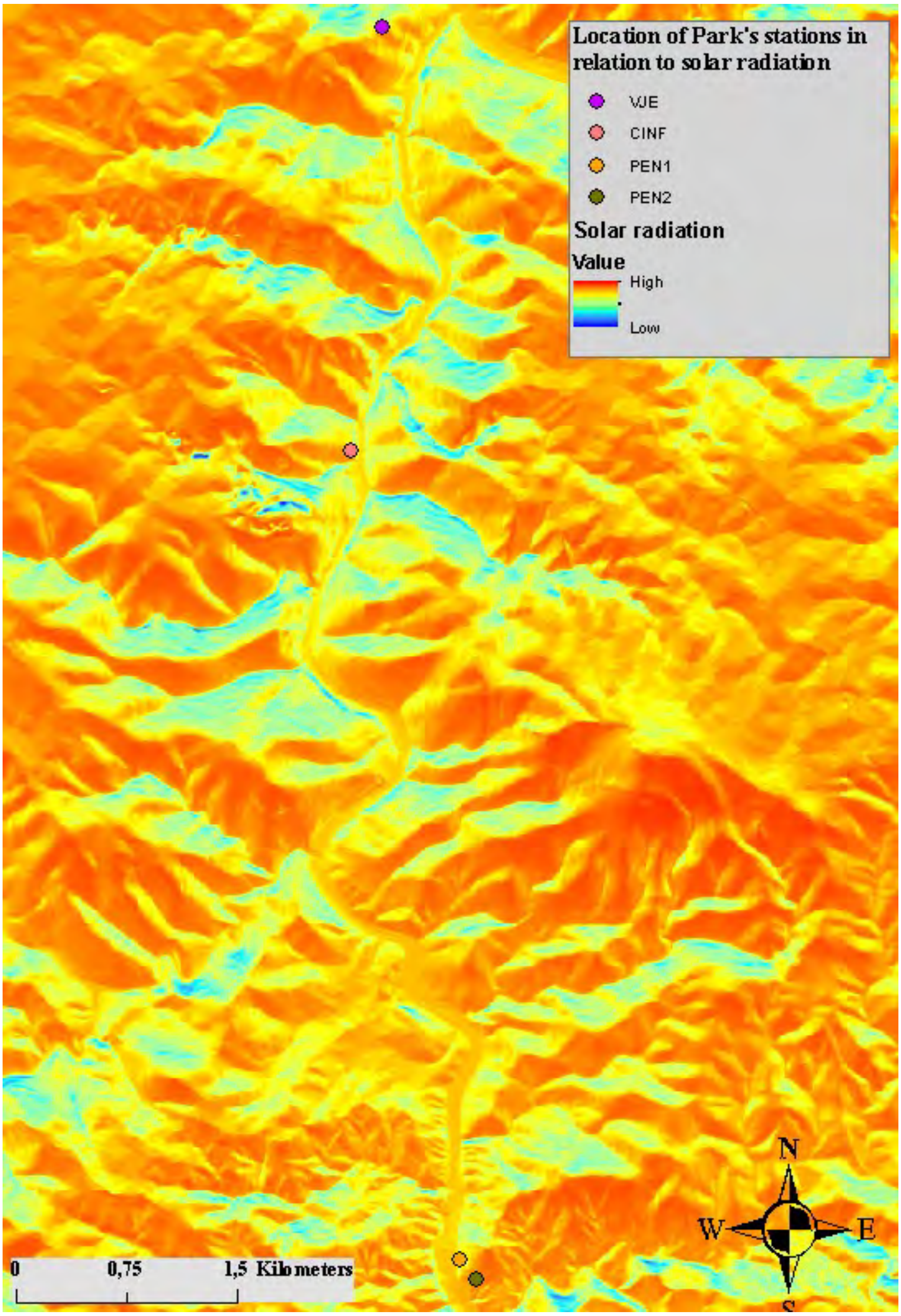


Figure 158. Location of Park's stations in relation to solar radiation as displayed in Figure 30.

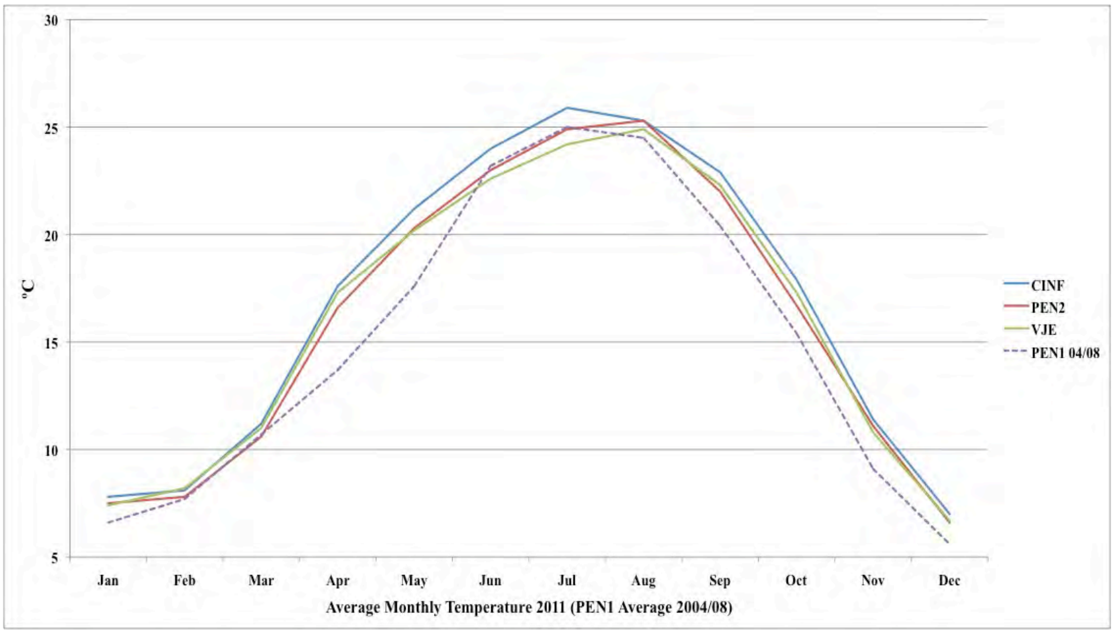


Figure 159. Average monthly temperature values in 2011 for CINF, PEN2 and VJE and in the period 2004/08 for PEN1.

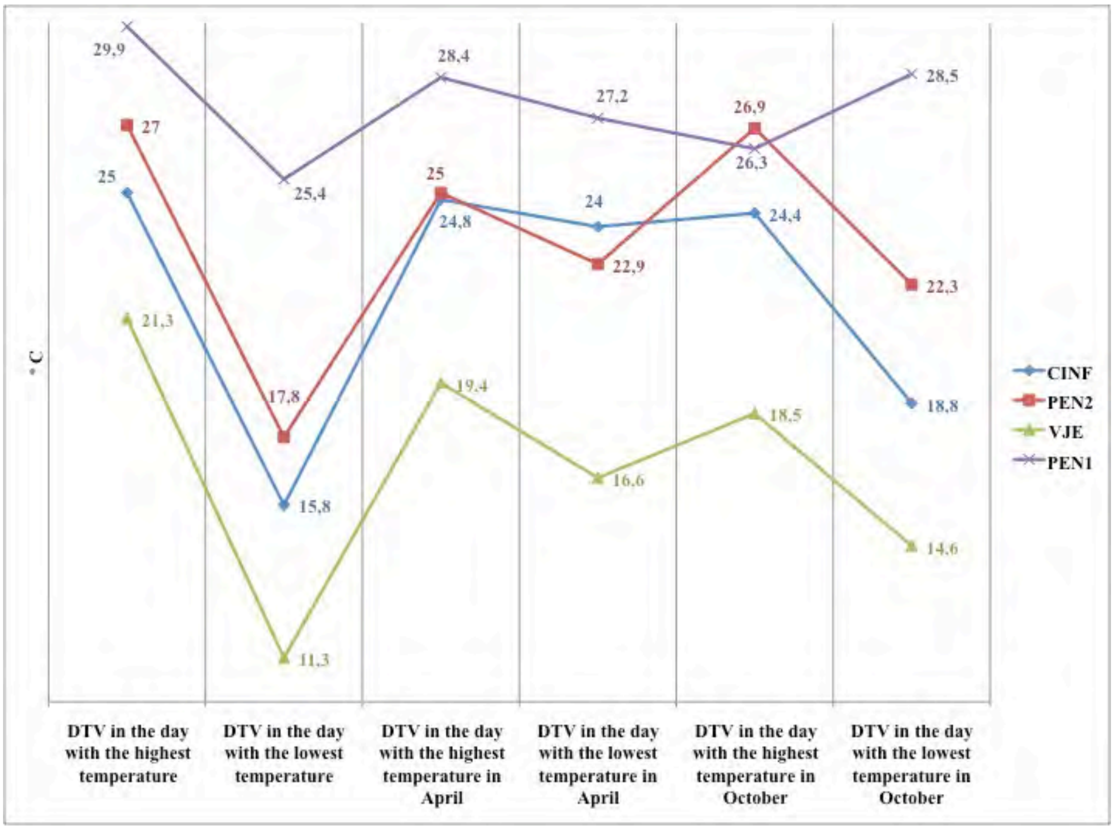


Figure 160. Diurnal Temperature Variation values in selected days (Table 9 and Table 17) for CINF, PEN2, VJE and PEN1.

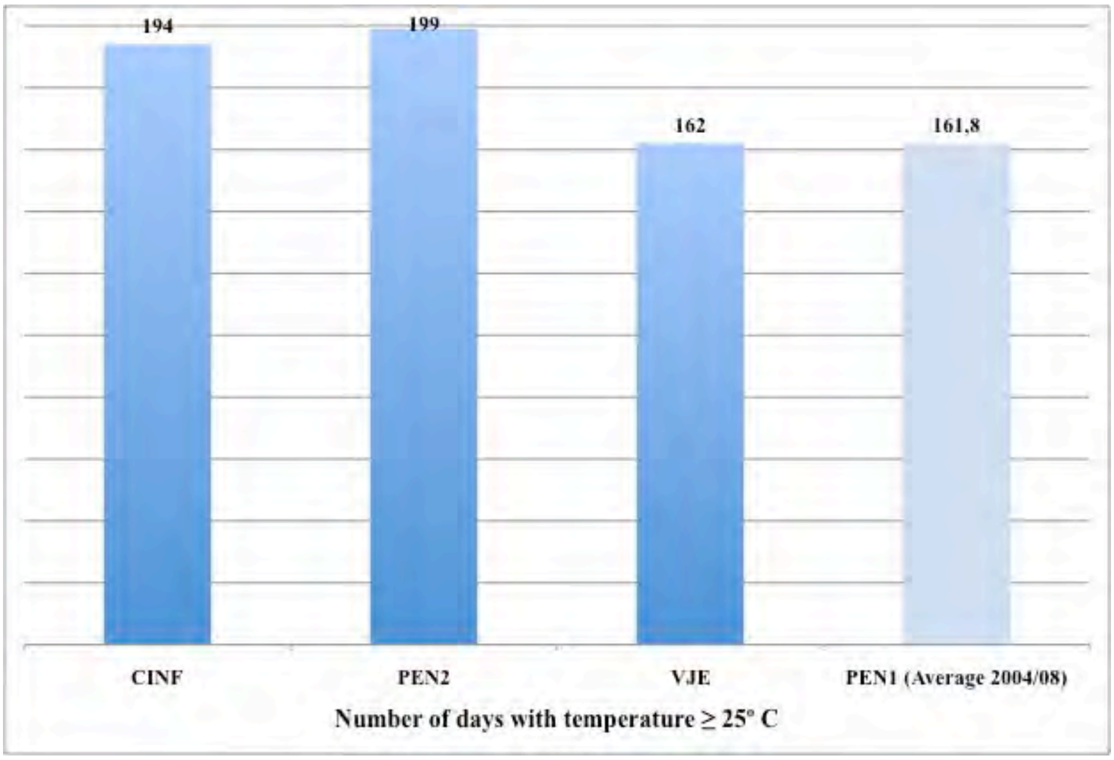


Figure 161. Total number of days with temperature ≥25º C in 2011 for CINF, PEN2 and VJE and average in the period 2004/08 for PEN1.

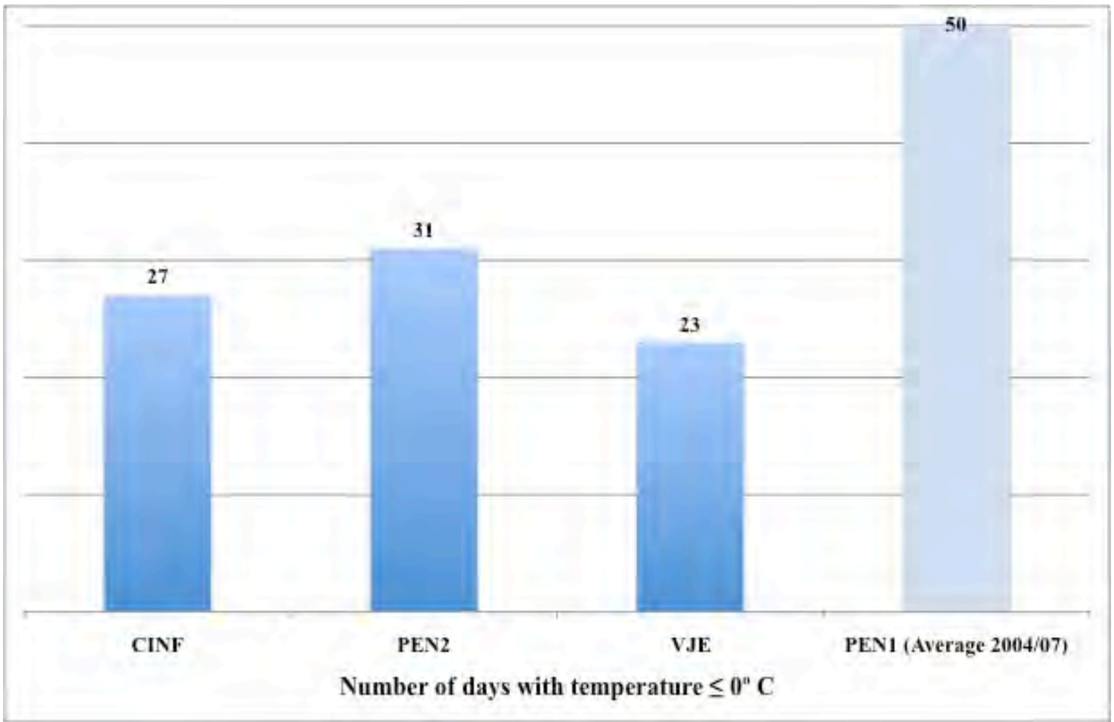


Figure 162. Total number of days with temperature ≤0º C in 2011 for CINF, PEN2 and VJE and average in the period 2004/07 for PEN1.

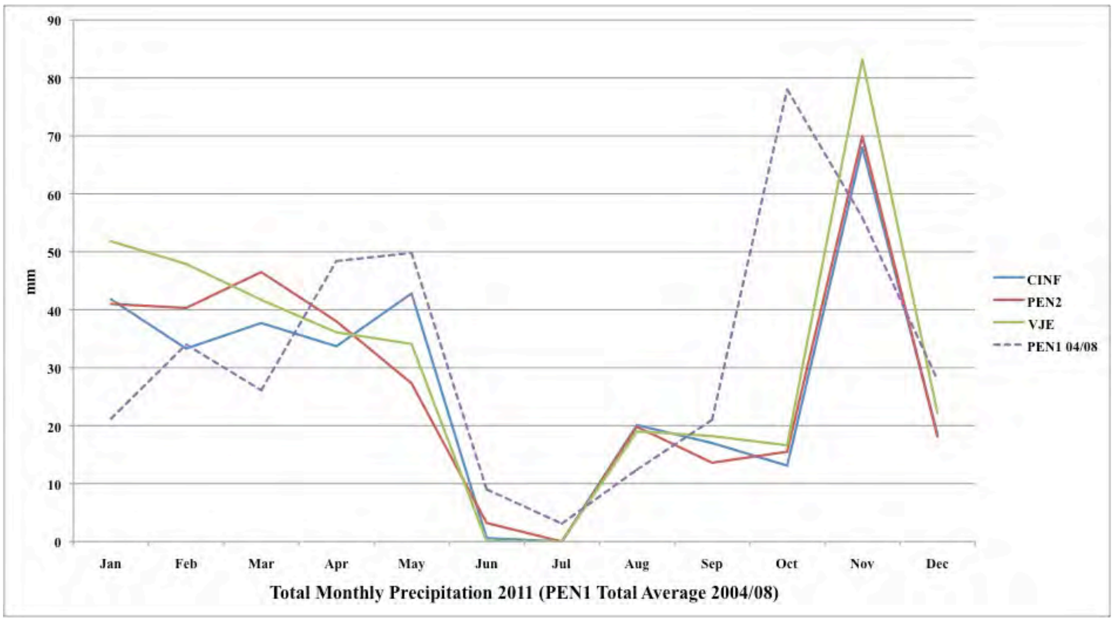


Figure 163. Total monthly precipitation values in 2011 for CINF, PEN2 and VJE and in the period 2004/08 for PEN1.

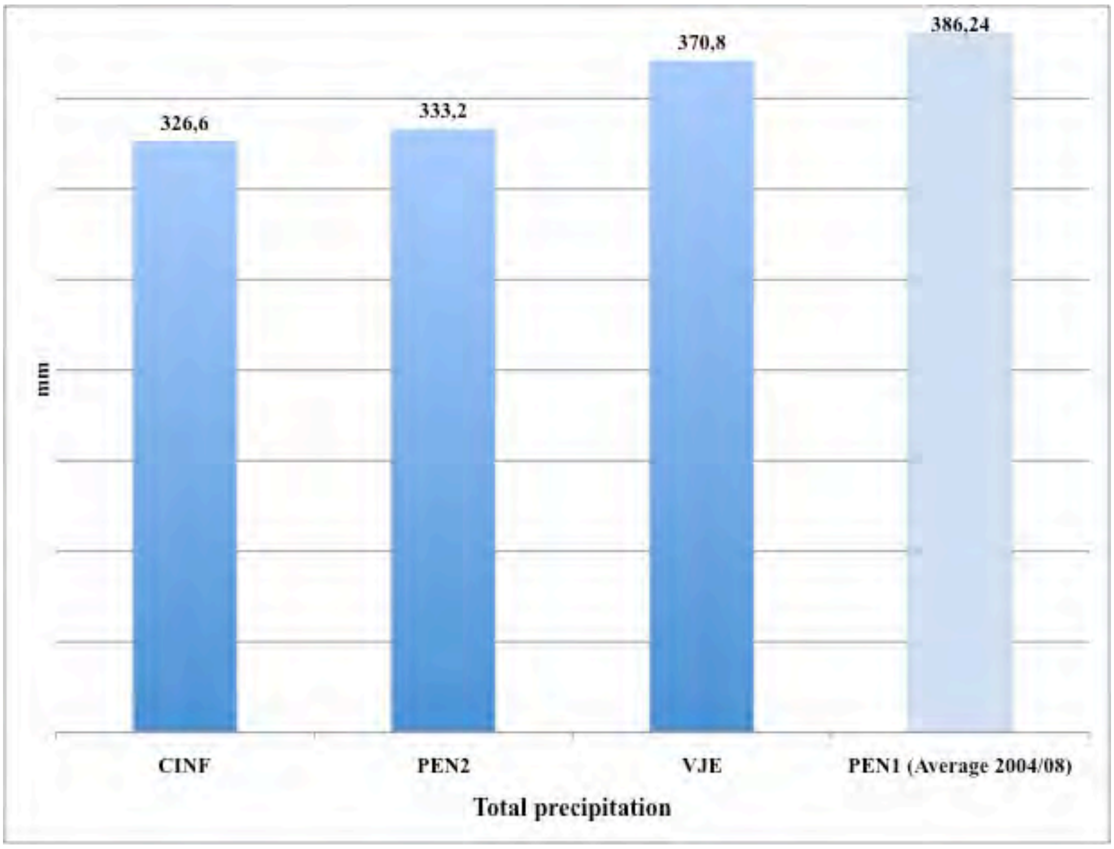


Figure 164. Total precipitation values in 2011 for CINF, PEN2 and VJE and average precipitation values in the period 2004/08 for PEN1.

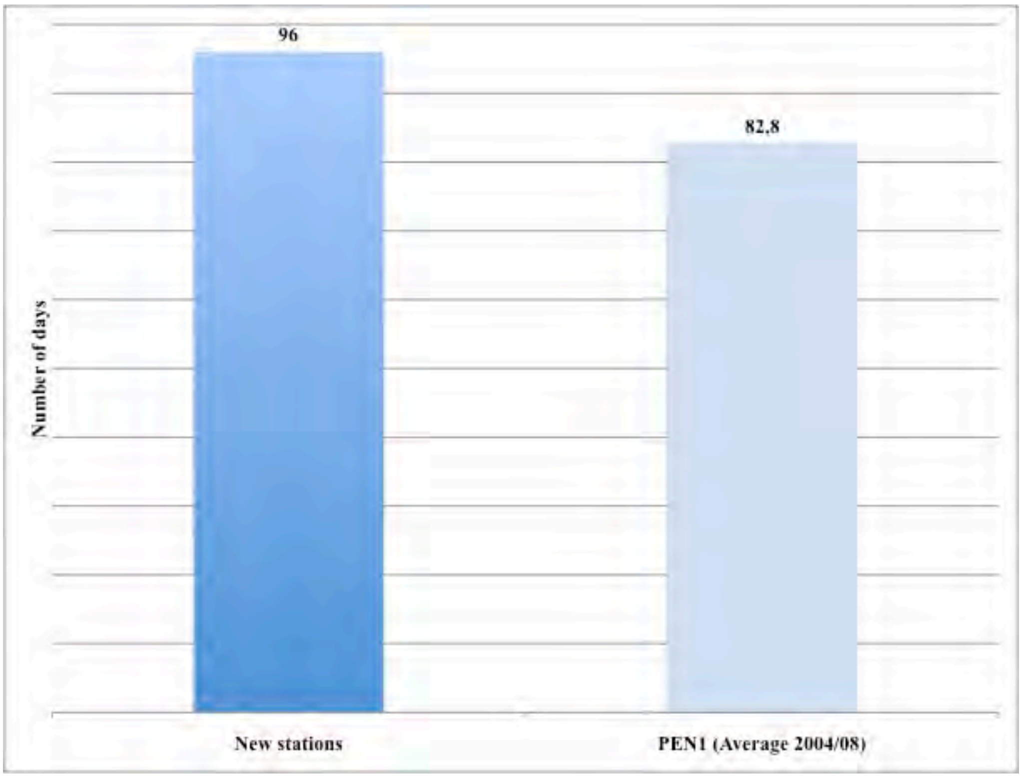


Figure 165. Number of rain days in 2011 for CINF, PEN2 and VJE and average days in the period 2004/08 for PEN1.

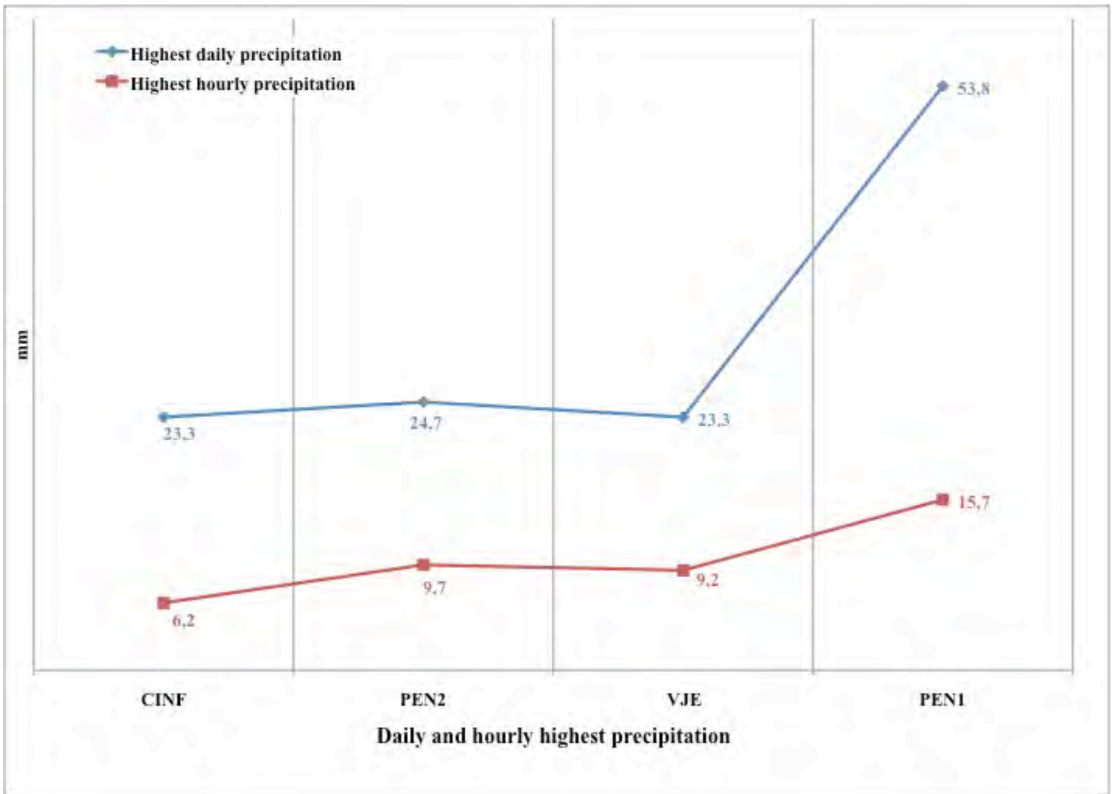


Figure 166. Highest daily and hourly precipitation values recorded by all stations.

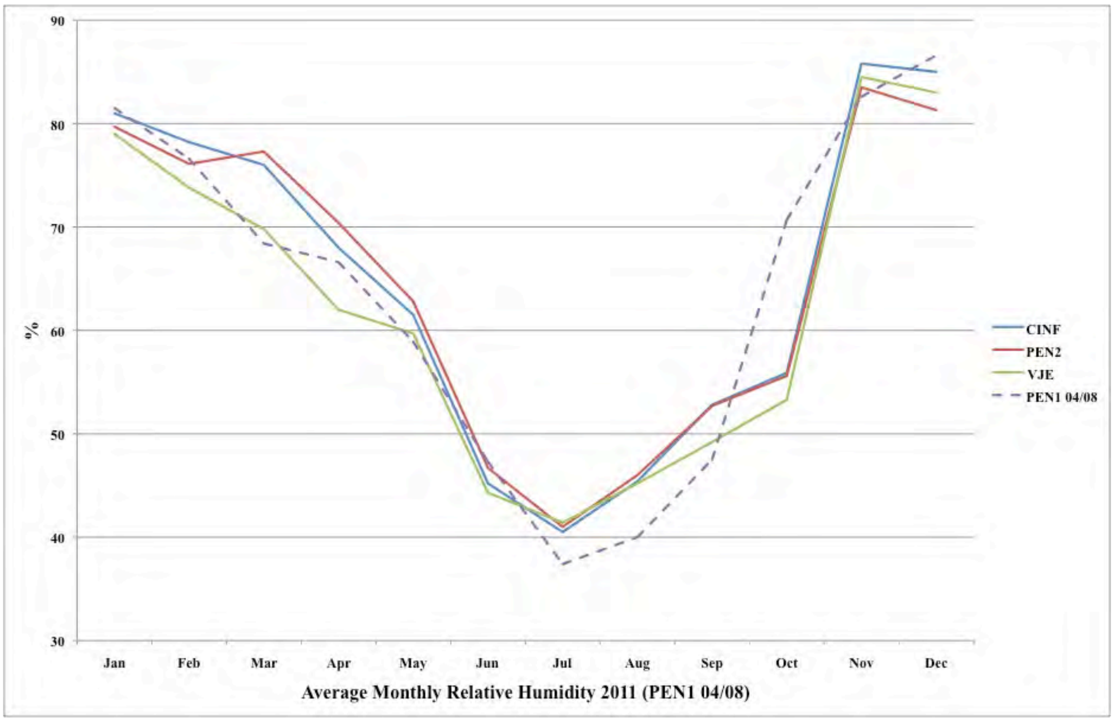


Figure 167. Average monthly relative humidity values in 2011 for CINF, PEN2 and VJE and in the period 2004/08 for PEN1.

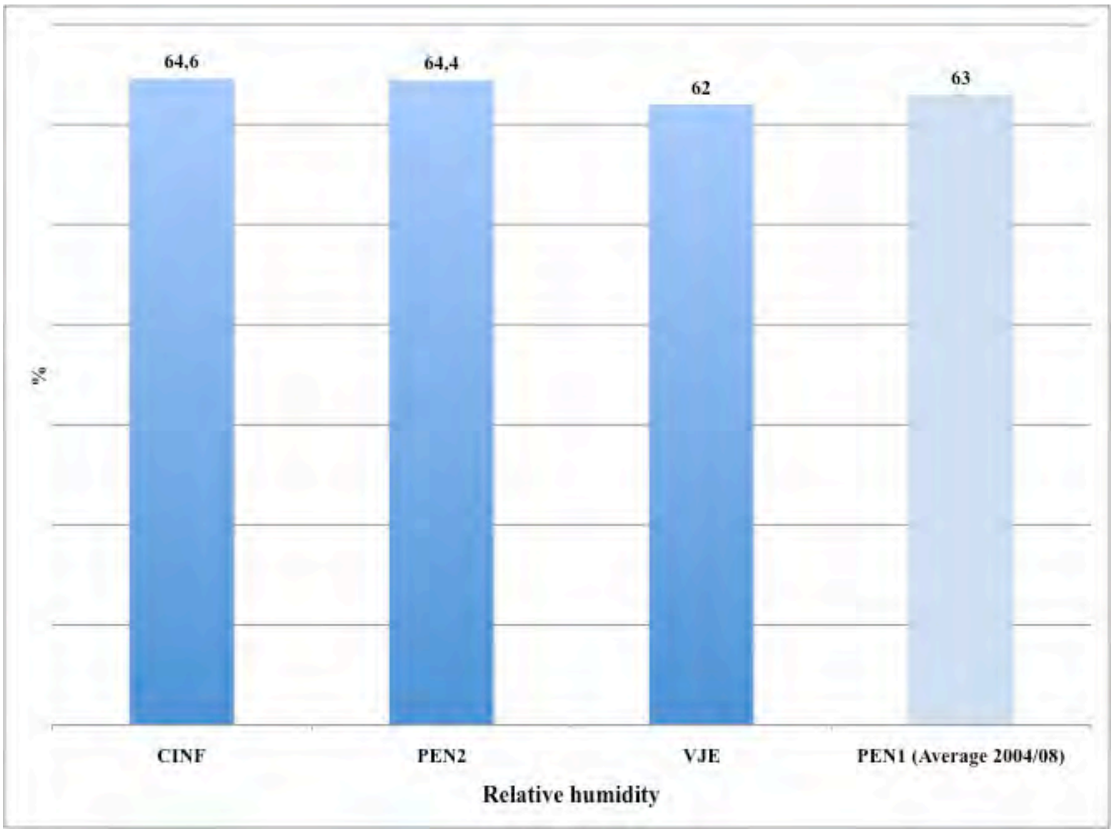


Figure 168. Total relative humidity values in 2011 for CINF, PEN2 and VJE and average in the period 2004/08 for PEN1.

Figure 169. The two headed 'animated' goat of Quinta da Barca 3. Besides eloquently illustrating the outstanding aesthetic and scientific significance of the Côa Valley rock-art this panel demonstrates the relentless impact of natural degradation processes as a third motif and minor parts of the remaining two are now incomplete due to fracture of the panel. Note also that the doe motif is ‘split in two’. Photo in Baptista (1999, 116).

Mineral:	Time:
Quartz	34 million years
Muscovite	2.6 million years
Epidote	630.000 years
Potassium feldspar	520.000 years
Plagioclase (oligoclase)	370.000 years
Albite	190.000 years
Ilmenite	29.000 years
Biotite	11.000 years
Magnetite	5.700 years
Pyrite	3.700 years
Dolomite	57 days
Calcite	31 days

Figure 170. Time required to dissolve 1 mm of various minerals. Adapted from Walderhaug and Walderhaug (1998, 20).

Variable	Weighting %	Very Strong	Strong	Moderate	Weak	Very Weak
Intact rock strength (Schmidt hammer rebound value)	20	100-60 r = 20	60-50 r=18	50-40 r=14	40-35 r=10	35-10 r=5
Weathering	10	Unweathered r=10	Slightly weathered r=9	Moderately weathered r=7	Highly weathered r=5	Completely weathered r=3
Joint spacing	30	>3 m r=30	3-1 m r=28	1-0.3 m r=21	300-500 mm r=15	<50 mm r=8
Joint orientation	20	Very favourable. Step dips into slope, cross joints interlock r=20	Favourable. Moderate dips into slope r=18	Fair. Horizontal dips or nearly vertical dips (hard rocks only) r=14	Unfavourabl e. Moderate dips out of slope r=9	Very unfavourabl e. Step dips out of slope r=5
Joint width	7	<0.1 mm r=7	0.1-1 mm r=6	1-5 mm r=5	5-20 mm r=4	>20 mm r=2
Joint continuity and infill	7	None, continuous r=7	Few, continuous r=6	Continuous, no infill r=5	Continuous, thin infill r=4	Continuous, thick infill r=1
Ground-water flow	6	None r=6	Trace r=5	Slight <40 ml s^{-1} m^{-2} r=4	Moderate 40-200 ml s^{-1} m^{-2} r=3	Great >200 ml s^{-1} m^{-2} r=1
Total rating		**100-91**	**90-71**	**70-51**	**50-26**	**<26**

Figure 171. Classification of rock mass strength. Adapted from Summerfield (1991, 166).

Figure 172. Area of an un-engraved outcrop at Ribeira de Piscos rock-art site weakened by aveolization.

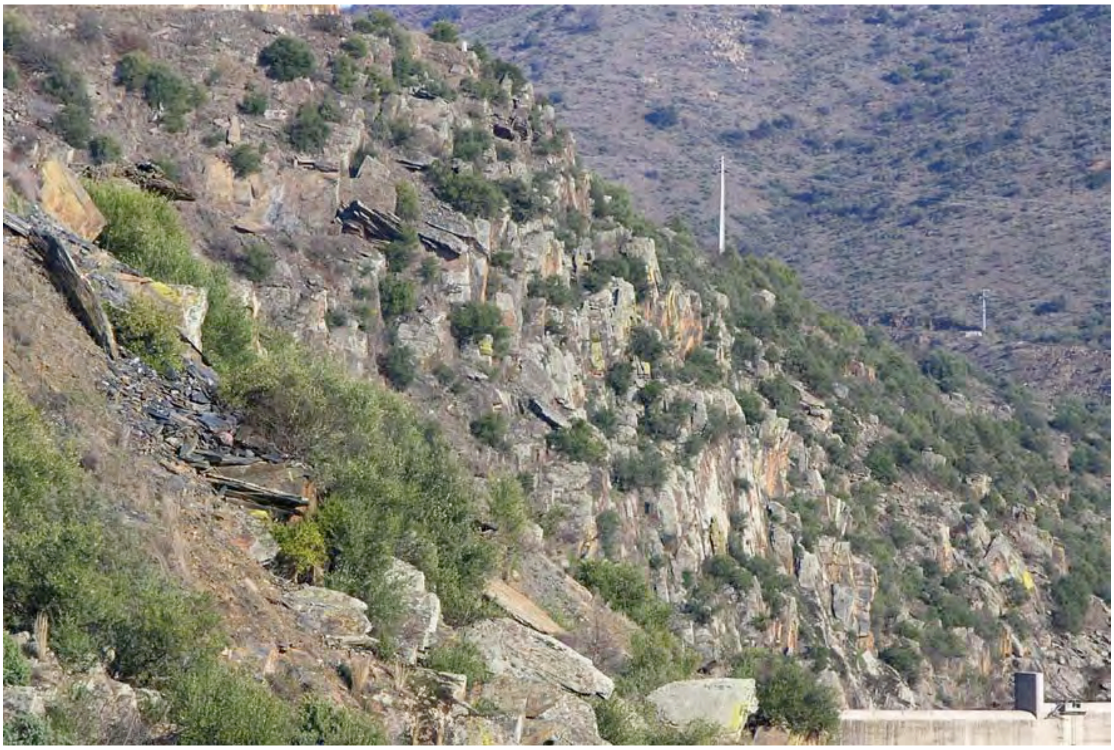


Figure 173. Unstable slope near the dam's abandoned construction site featuring several collapsed blocks. Fortunately, no engraved outcrops have been identified in that precise area.

Figure 174. This engraved block at Penascosa has broken and fallen from an engraved block (probably Penascosa Rock 7 located directly above) and was used to construct a dry stonewall.

Figure 175. Concretions and deposits of other type at an un-engraved outcrop in Ribeira de Piscos rock-art site

Figure 176. Diaclase behind the Canada do Inferno 13 outcrop. Notice infilling with soil, vegetation and loose blocks fallen from above.

Figure 177. Ribeira de Piscos Rock 1. Note the diaclase and forward tilting of the block that contains the tangled horses motif.

Figure 178. Small diaclase behind Penascosa 3 outcrop.

Figure 179. Ribeira de Piscos Rock 2. Note the weaker cohesion areas that follow the orientation of the schist strata and result in the progressive weakening of those less consistent bands.

Figure 180. Canada do Inferno Rock 1. Note the disconnected central block where, in the upper area, the existing engravings concentrate.

Figure 181. Fractures and loose blocks in Ribeira de Piscos Rock 1 outcrop.

Figure 182. Fractures and loose blocks in Penascosa 4 outcrop.

Figure 183. Weak area of an un-engraved outcrops at the Penascosa rock-art site

Figure 184. Penascosa Rock 3. Note the white efflorescence at the lower left area of the panel. Photo in Baptista (1999, 98).

Figure 185. Example of exfoliation in an engraved Côa Valley outcrop. Photo in Rodrigues (1999, 34).

Figure 186. Fragile area of Ribeira de Piscos Rock 1. The small slab in the foreground is in risk of complete breakdown because of exfoliation.

Figure 187. Engraved area of Ribeira de Piscos Rock 2. Note both vertical and horizontally orientated fissures.

Figure 188. Different types of fractures.

Figure 189. Engraved area of Canada do Inferno Rock 1. Note to the right the fracture that delimitates a minor dimension loose block. This fracture also interrupts the engraved lines that compose a two-headed horse. Bird's droppings can also be seen.

Figure 190. Open fractures.

Figure 191. Gaping in Ribeira de Piscos Rock 2 fortunately in an un-engraved area of the outcrop. Note also superficial chromatic alterations. Note also splintering.

Figure 192. Block containing the tangled horses of Ribeira de Piscos (Rock 1). Note toppling in the upper part of the piece.

Figure 193. Toppling in action at Canada do Inferno Rock 14. Note the detachment and progressive creeping of blocks in the upper area of the outcrop.

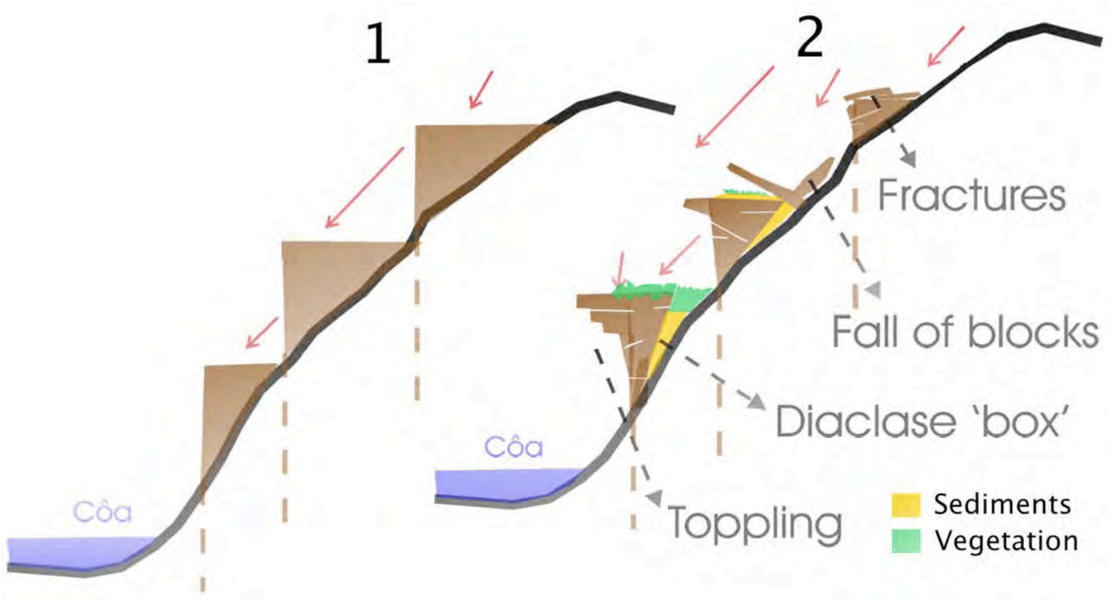


Figure 194. Schematic illustration of physical instability in the slopes caused by gravitational pressure aided by seismic forces and rock expansion and retraction cycles.

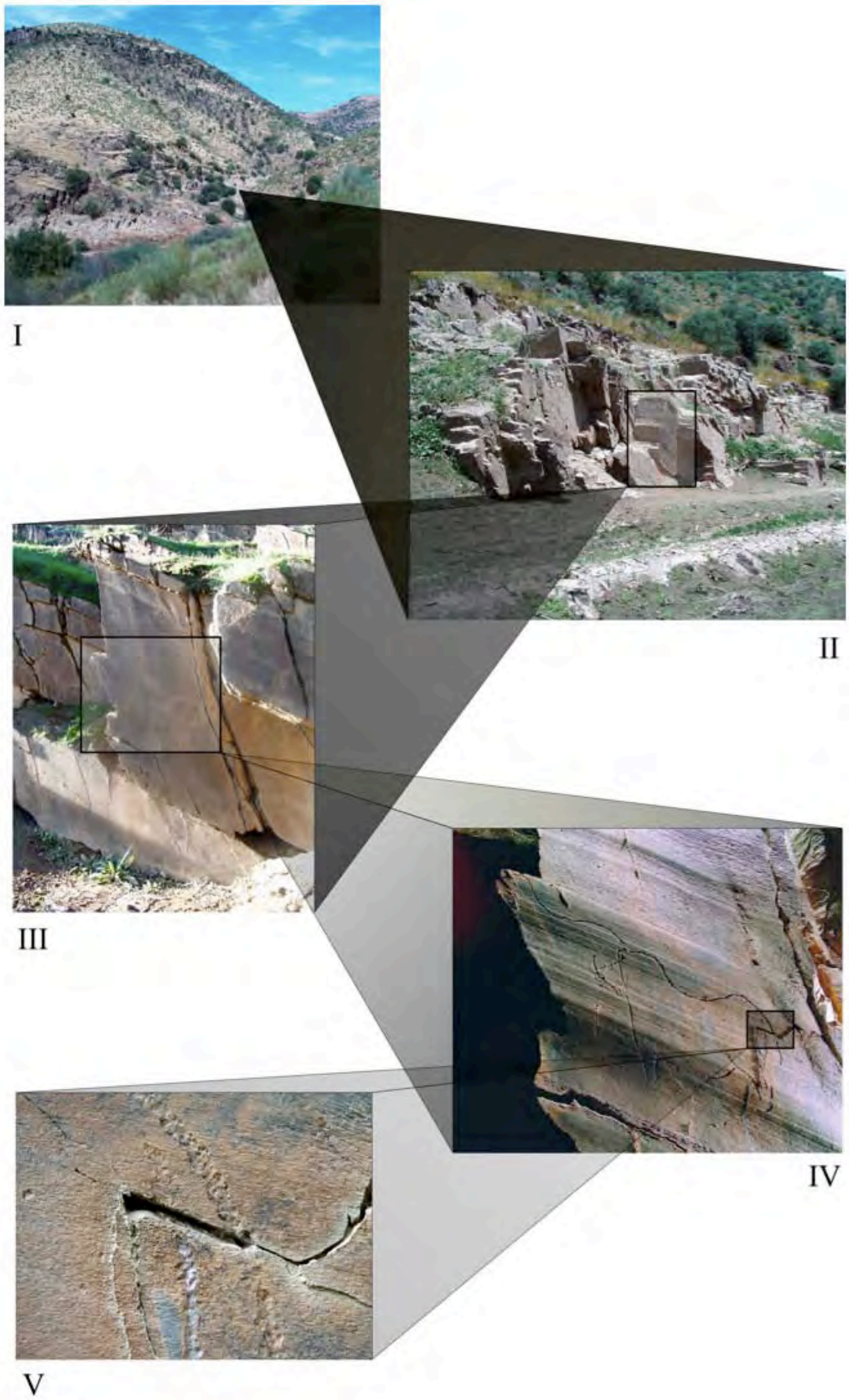


Figure 195. Location of Ribeira de Piscos rock 1. I – Macro local scale. II, III & IV – Different medium local scales. Several weathering processes can be seen in action at this level: disconnected blocks, toppling, fractures, vegetation, etc. V – Micro local scale: several weathering dynamics are seen, e.g. micro fractures, exfoliation, aveolization near the hind leg of one of the horses. Photo IV in Baptista (1999, 120).

Figure 196. Lichen colonization at Quinta da Barca Rock 3. Note that these colonies settle preferentially in more 'cosy' areas, namely the ones provided by holes, fractures and concave portions of the rock surface (and also the engraved grooves). This has been one of the panels in which lichens have been removed for documentation purposes. In less than 20 years, re-colonization of the lines that make the rear part of the incomplete motif seems to be well on the way (compare with Figure 169).

Figure 197. Canada do Inferno Rock 1 from above. Diaclase is located just below the area where vegetation grows more abundantly.

Figure 198. Image featuring the whole Quinta Barca Rock 3 outcrop.

Figure 199. Ribeira de Piscos Rock 1 from above. Note the superficial and incipient cover of sediments and plants.

Figure 200. Spider colonization (contributing to further weakening of this un-engraved outcrop) of pre-existing sub-surface spaces due to gaping and exfoliation.

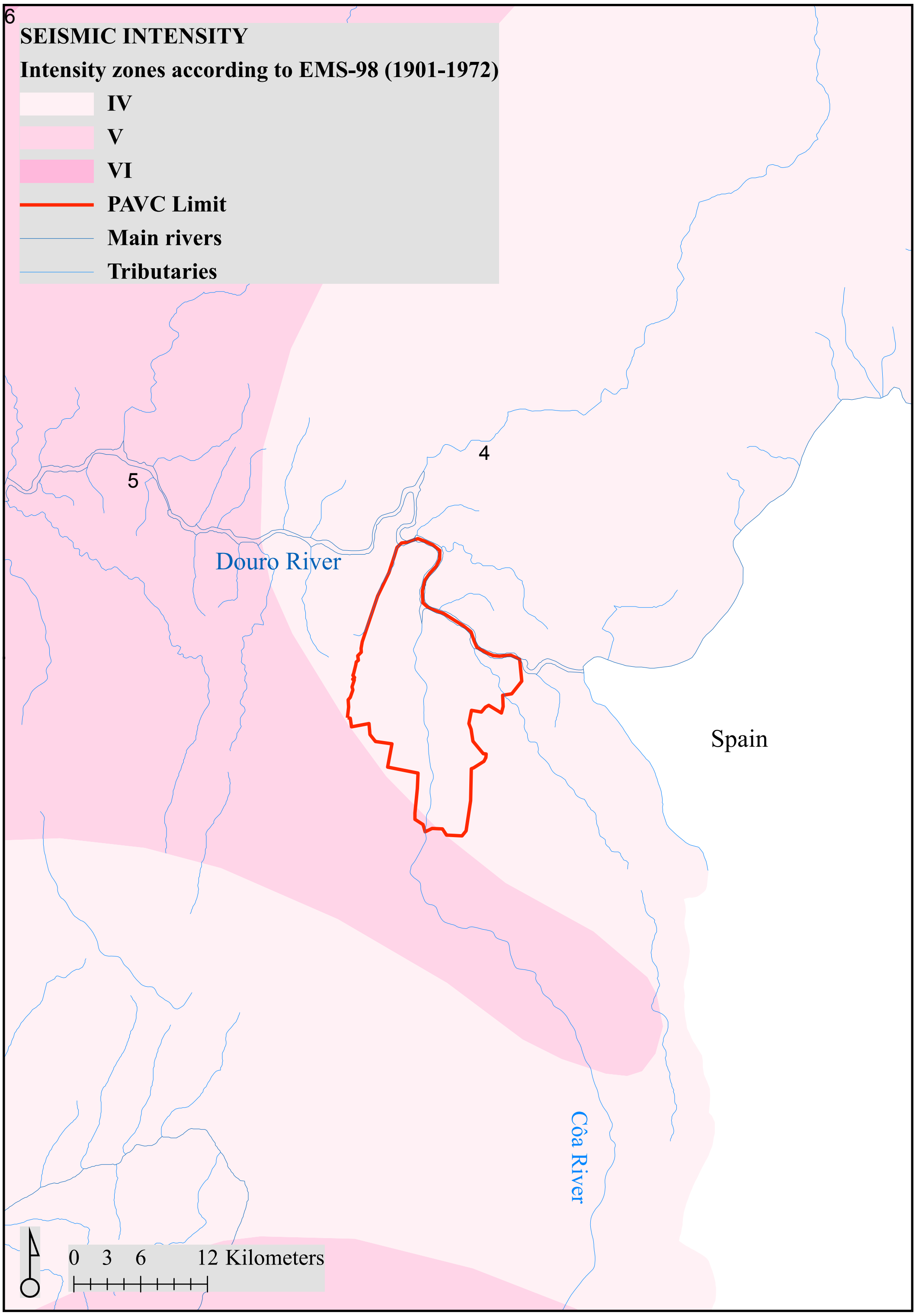


Figure 201. Seismic intensity in the area of the Park. The territory of the Park is located in an area positioned low in a scale possessing 12 intensity categories (being 12 the maximum) (Grunthal 1998).

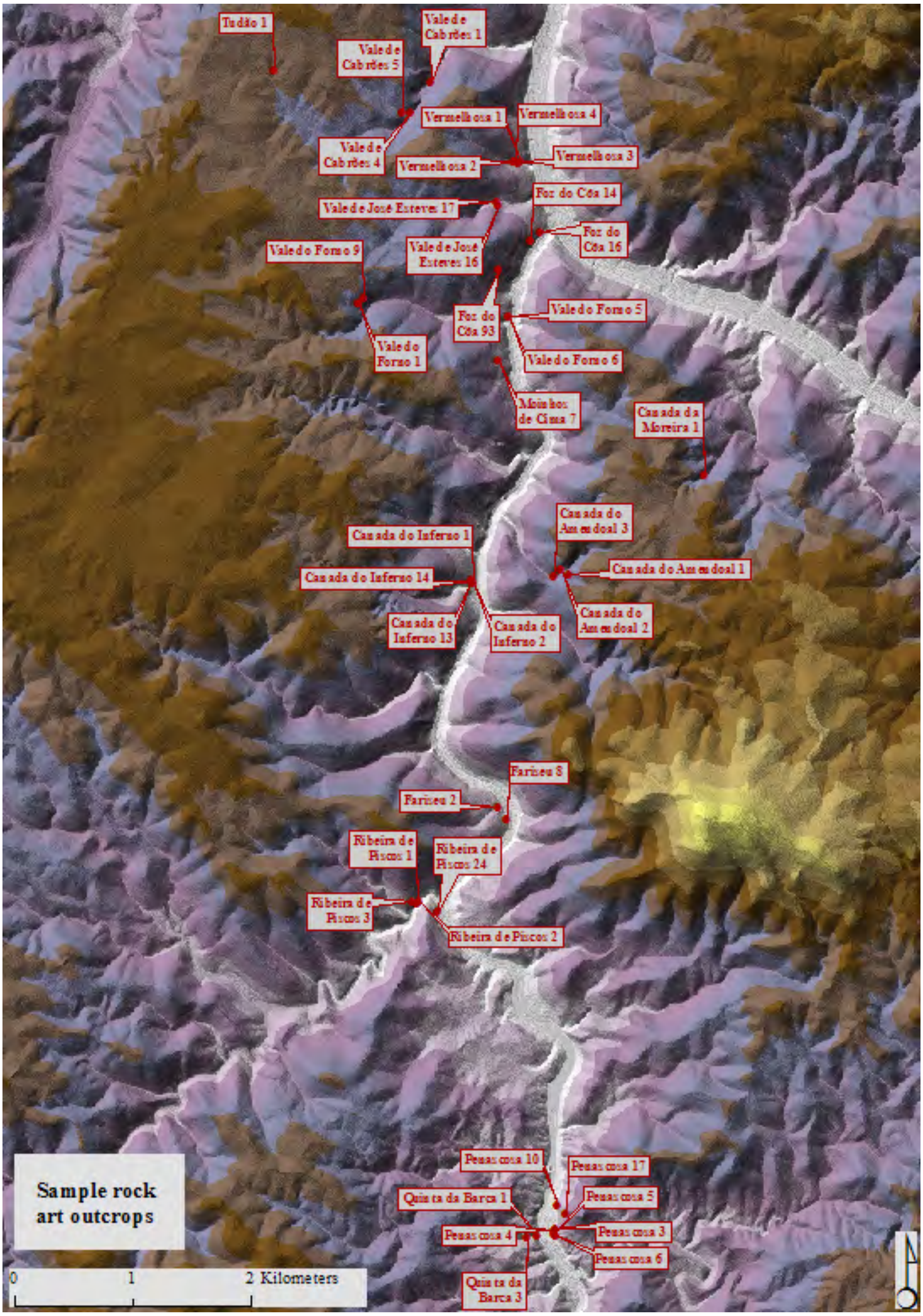


Figure 202. Location of outcrops comprised in the sample.

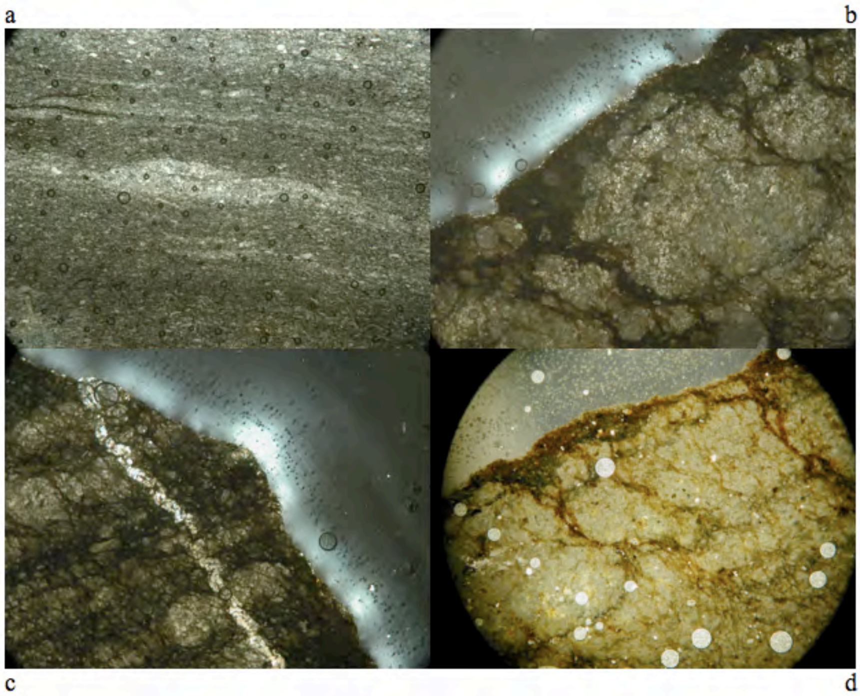


Figure 203. a – Sample 7, 5x magnification: deposition layers; b – Sample 19, 5x magnification: superficial micro-weathering; c – Sample 19, 5x magnification: quartz vein; d – Sample 19, 5x magnification: surface micro-weathering

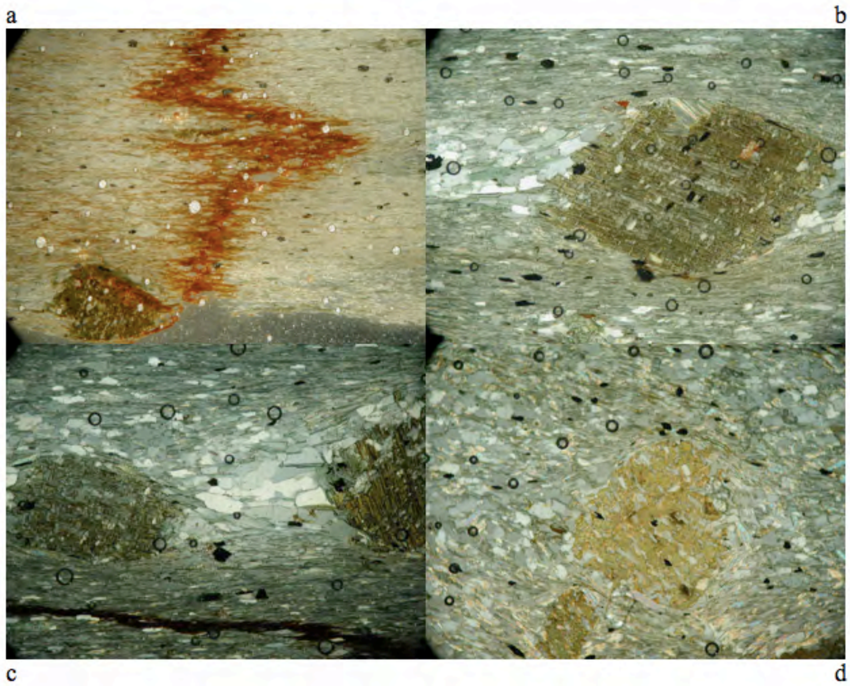


Figure 204. a – Sample 15, 5x magnification: muscovite minerals become ‘rusty’ due to water going in through a micro-fracture; b - Sample 15, 10x magnification: quartz and, possibly, biotite; c - Sample 15, 10x magnification: quartz, biotite and micro-fracture; d – Sample 18, 10x magnification: quartz and biotite.

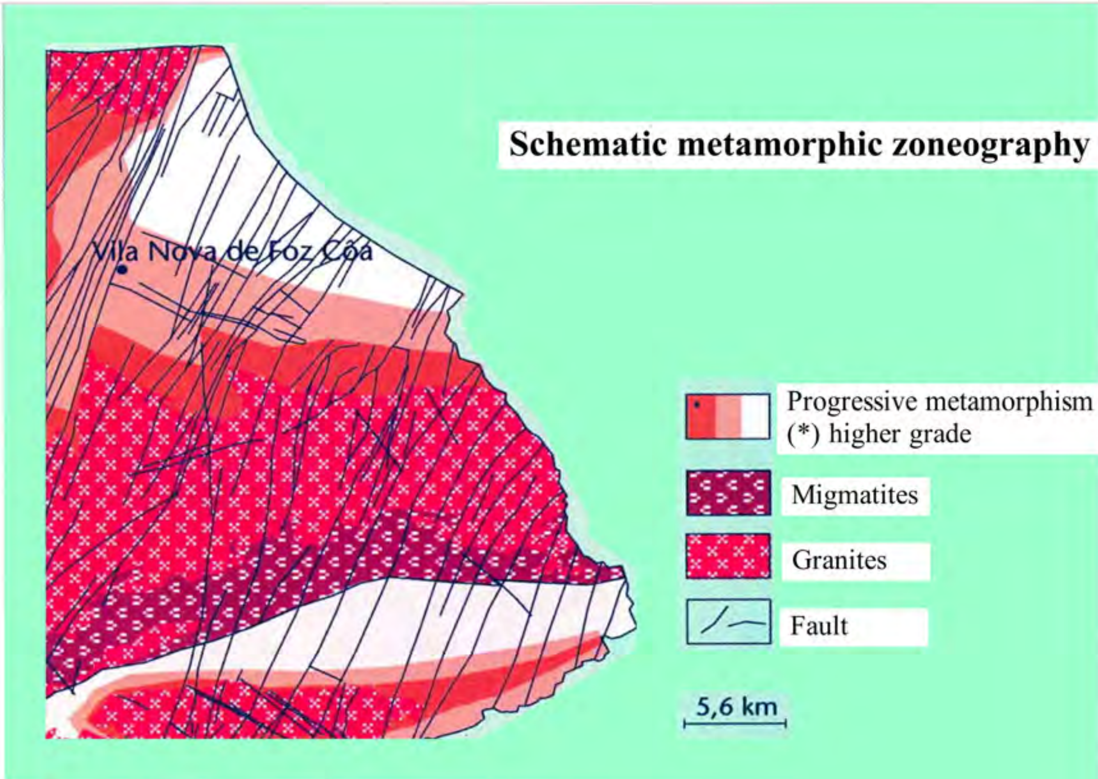


Figure 205. Schematic metamorphic zoneography. Adpated from Ribeiro (2001, 44).

Figure 206. An open-air rock-art conservator's worst nightmare: Ribeira de Piscos Rock 24. Notice the many small panels, many featuring Upper Palaeolithic motifs.

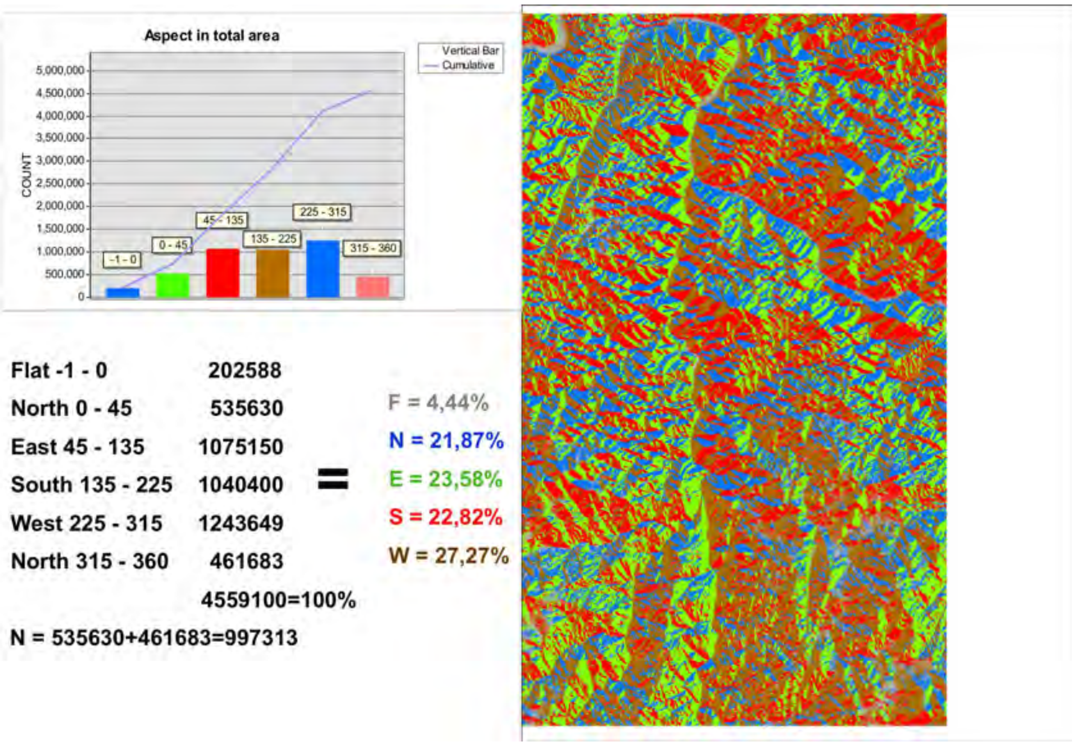


Figure 207. Aspect classes in the area of the Park classified according to Table 3. ArcView Spatial Analyst tool divides North in two groupings (0º - 45º and 315º - 360º). Hence, North appears twice in the calculation of percentage of each class.

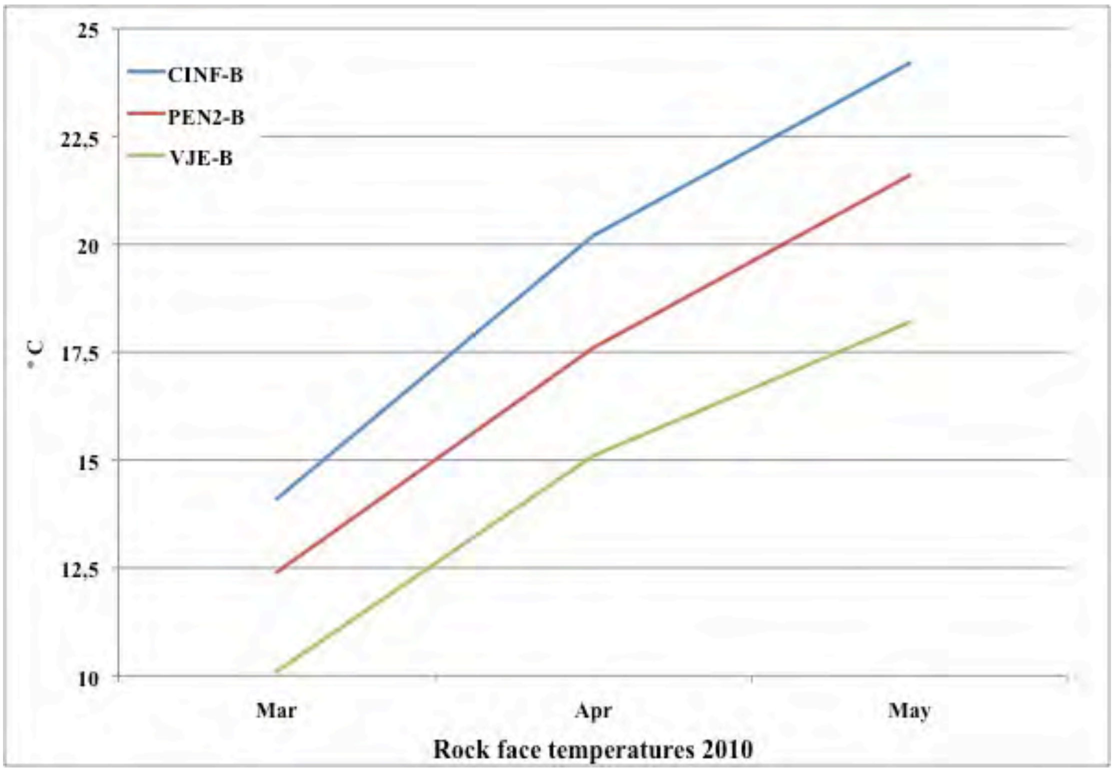


Figure 208. Average rock face temperatures in CINF-B, PEN2-B and VJE-B for March, April and May 2010.

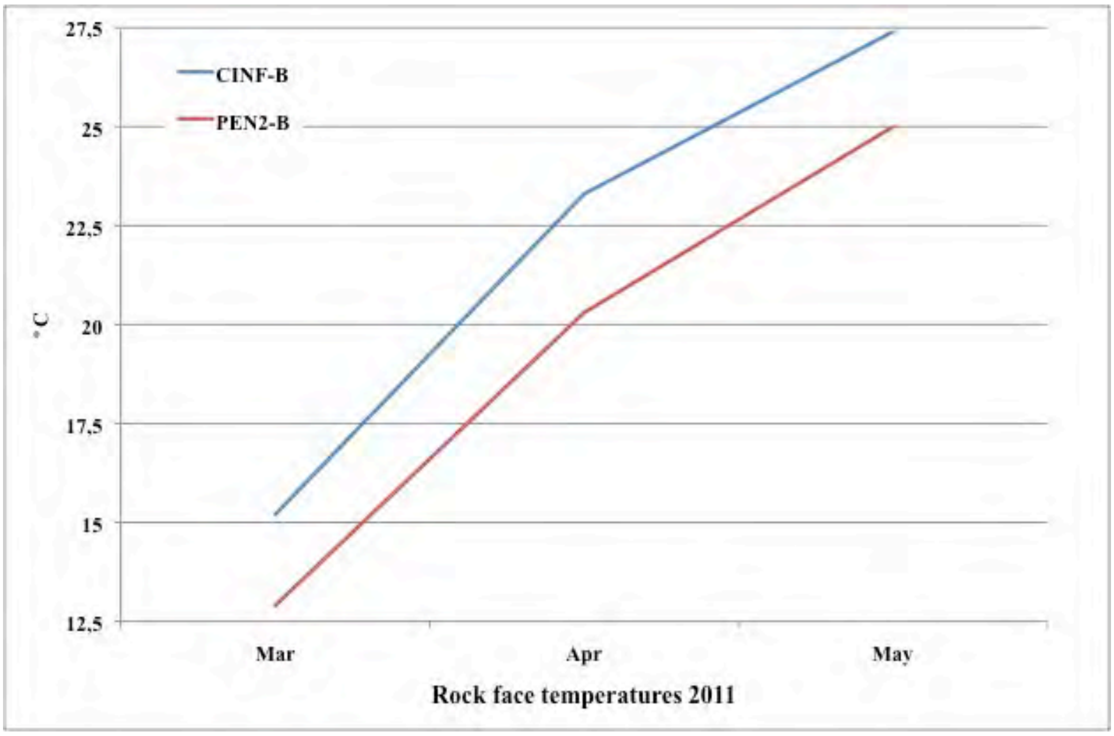


Figure 209. Average rock face temperatures in CINF-B and PEN2-B for March, April and May 2011.

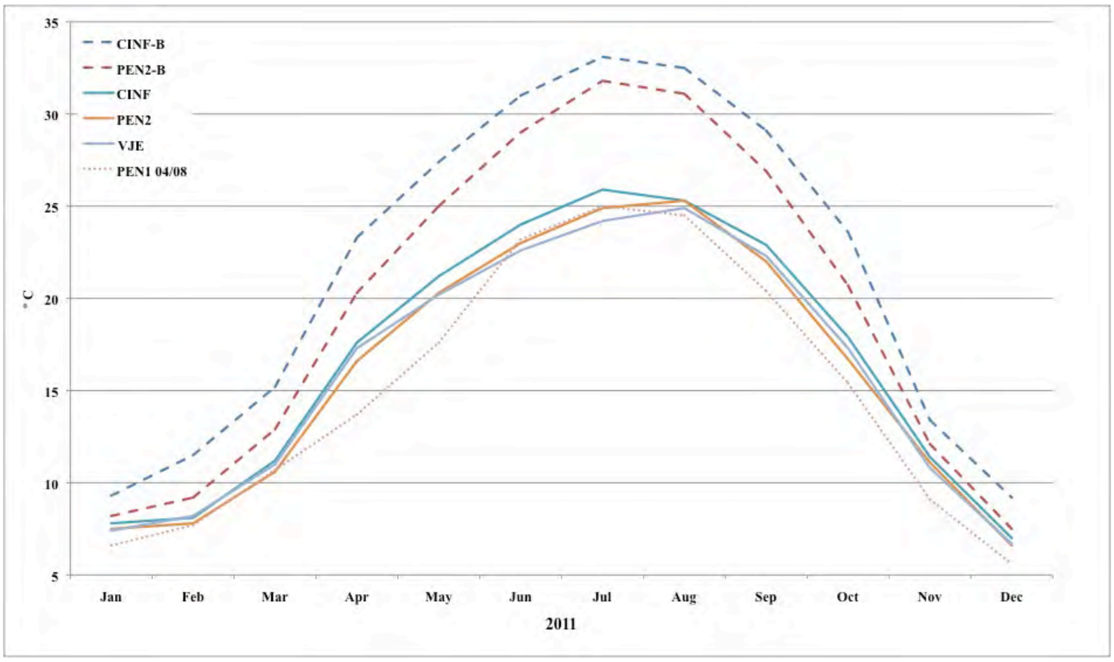


Figure 210. Average monthly temperatures in CINF-B, PEN2-B, CINF, PEN2 and VJE for 2011. PEN1 presents data with reference to the 2004/08 period.

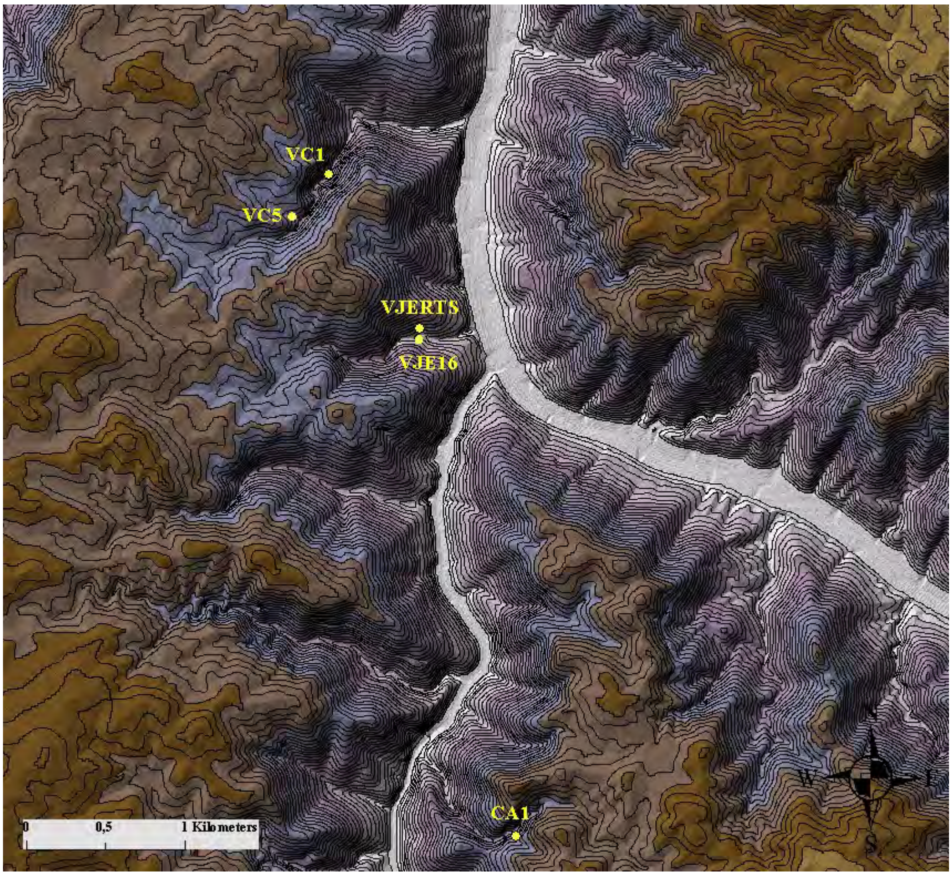


Figure 211. Location of TMPJM sensors.

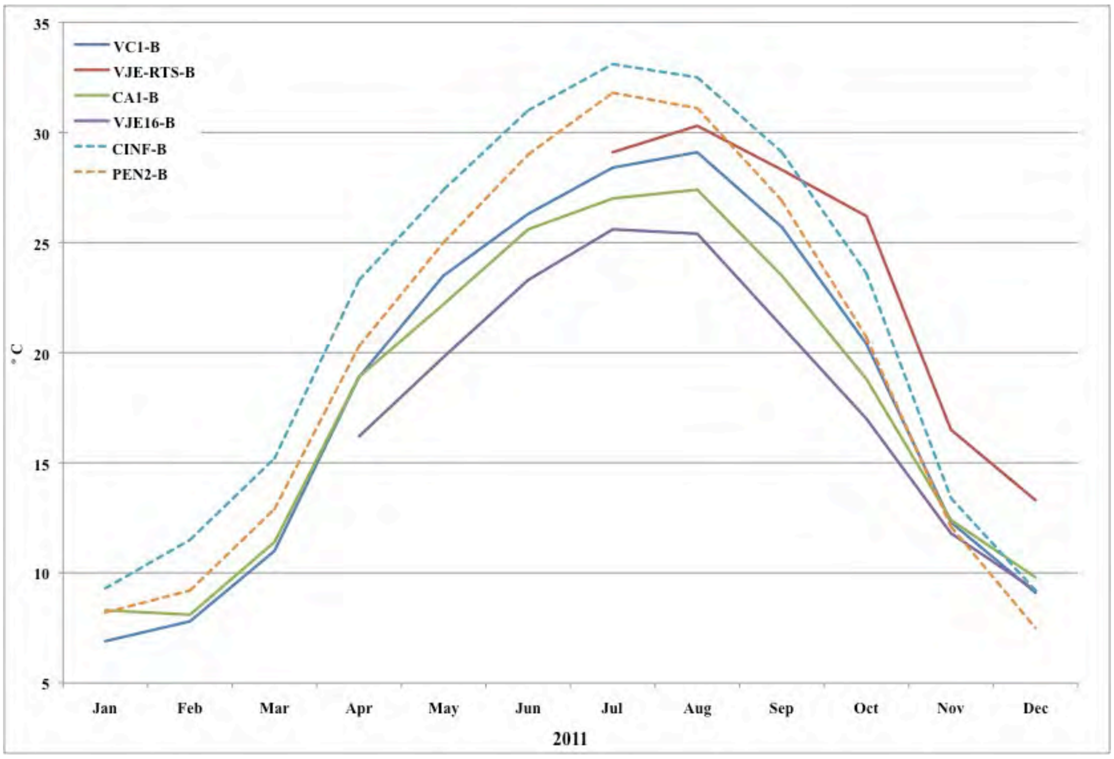


Figure 212. Average monthly temperatures recorded by TMPJM sensors. CINF-B and PEN2-B values are shown for comparison purposes.

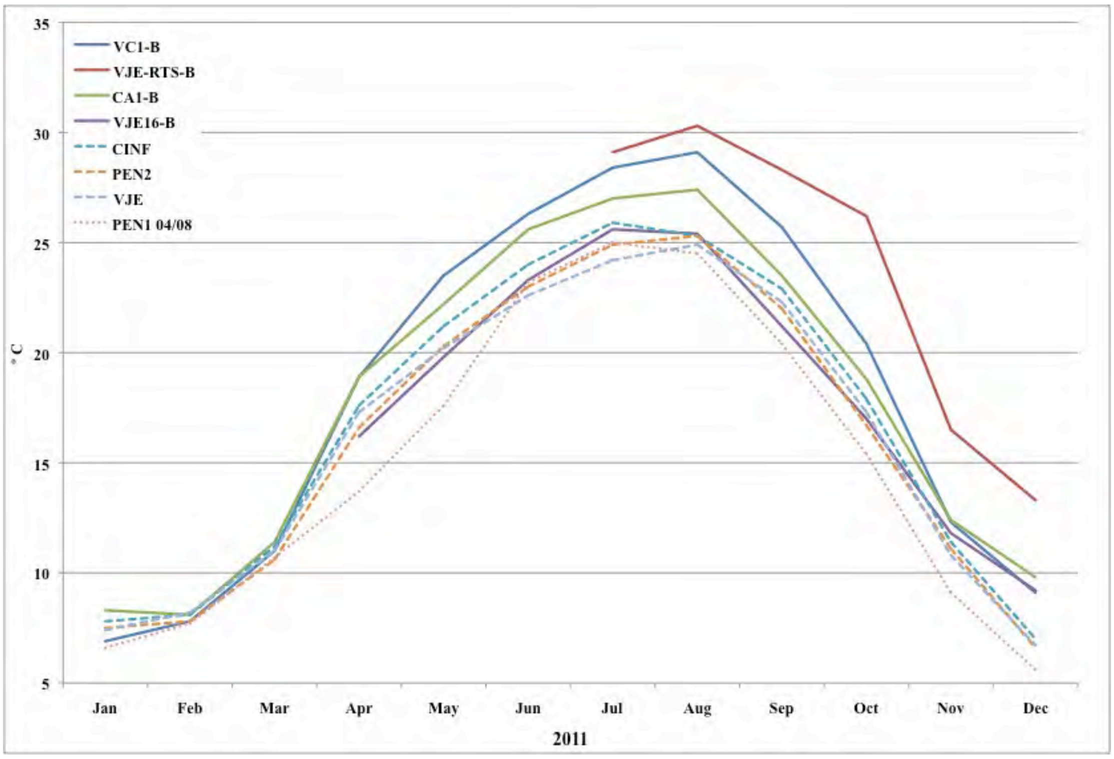


Figure 213. Comparison of values recorded by TMPJM sensors with air temperatures figures measured by the Park’s stations in 2011 and in the period 2004/08 (in the case of PEN1).

Figure 214. TMPJM sensor.

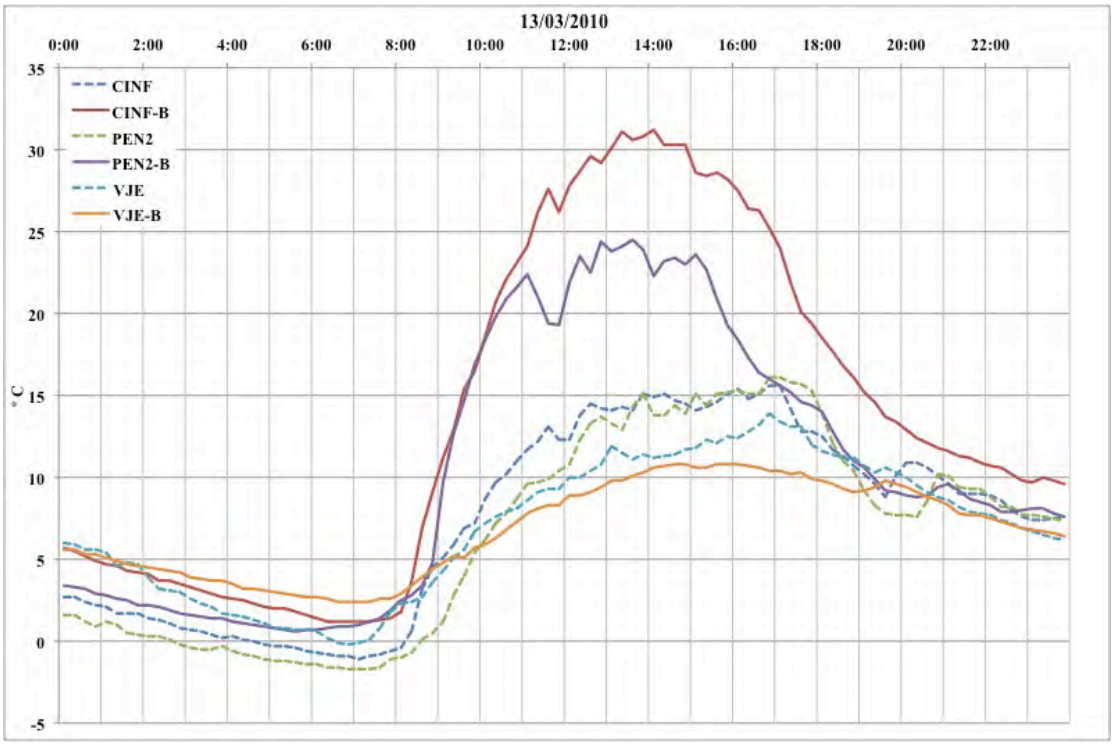


Figure 215. Temperatures recorded in the 13th of March 2010 by Park's temperature sensors in operation at the mentioned day.

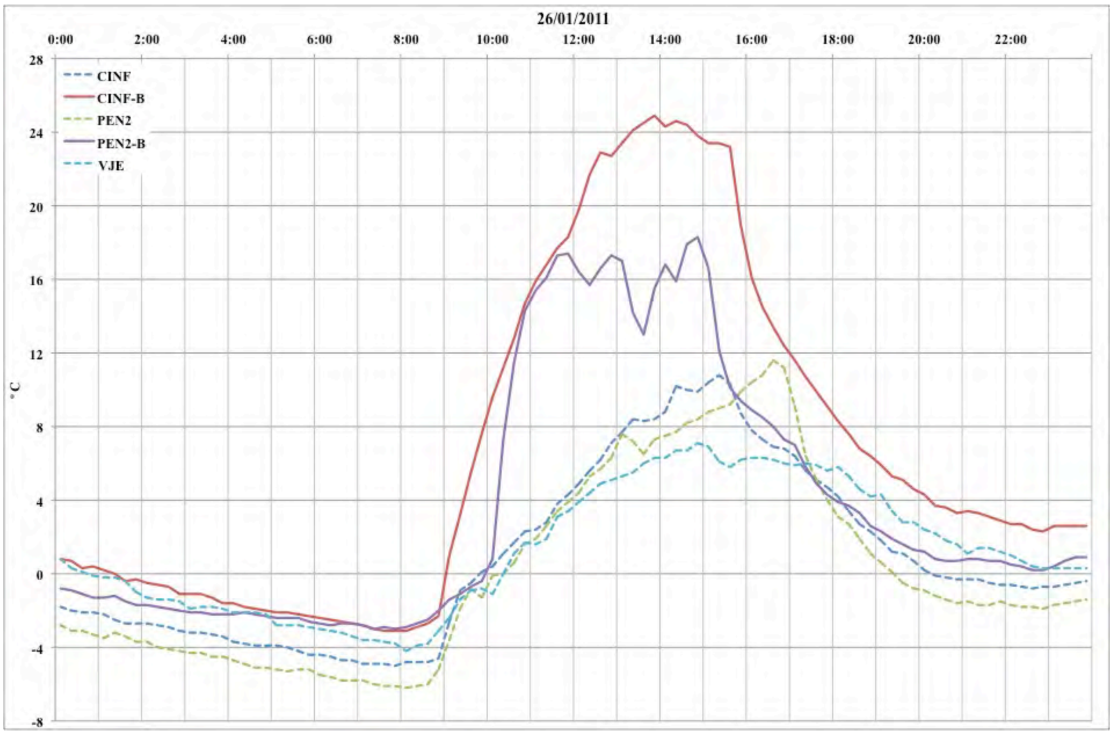


Figure 216. Temperatures recorded in the 26th of January 2011 by Park's temperature sensors in operation at the mentioned day.

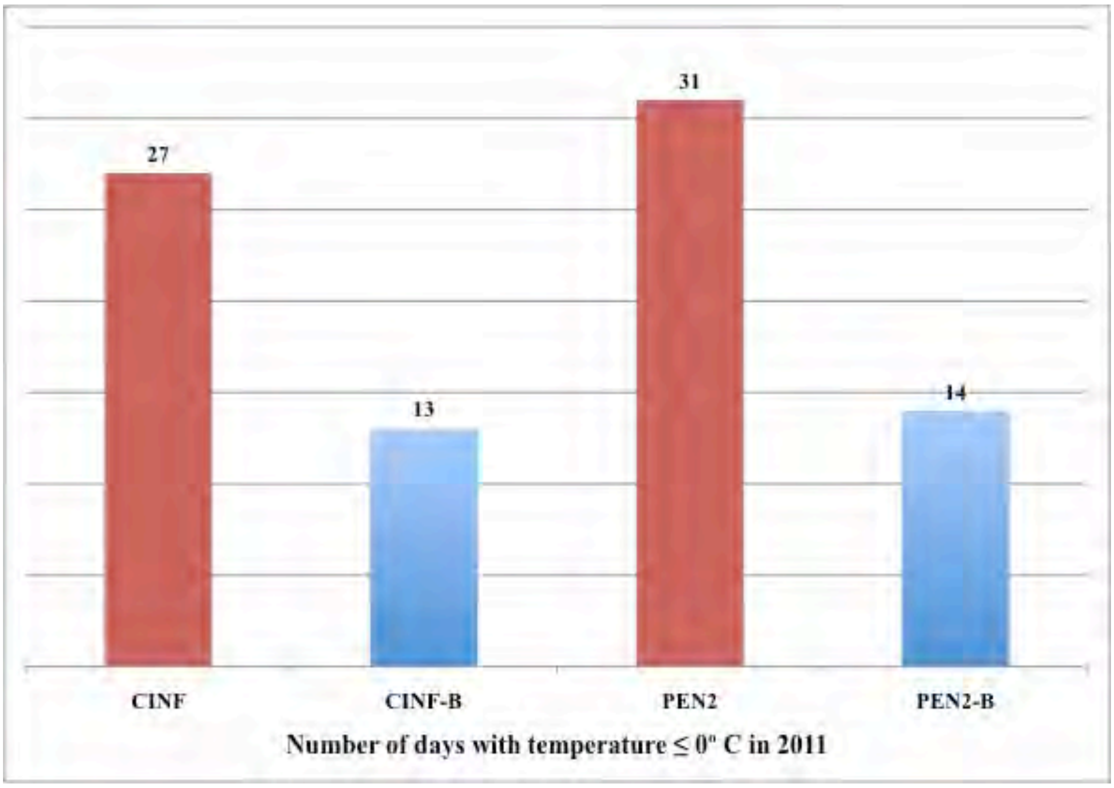


Figure 217. Number of days with temperature ≤ 0º C in CINF, CINF-B, PEN2 and PEN2-B during 2011.

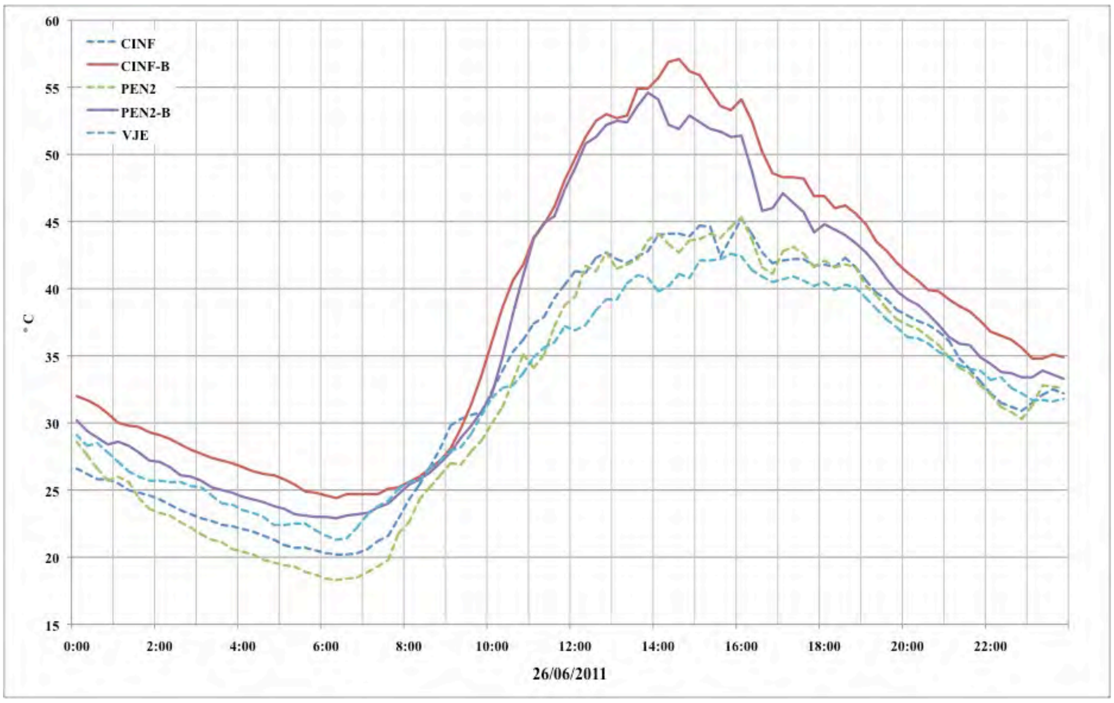


Figure 218. Temperatures recorded in the 26th of June 2011 by Park's temperature sensors in operation at the mentioned day.

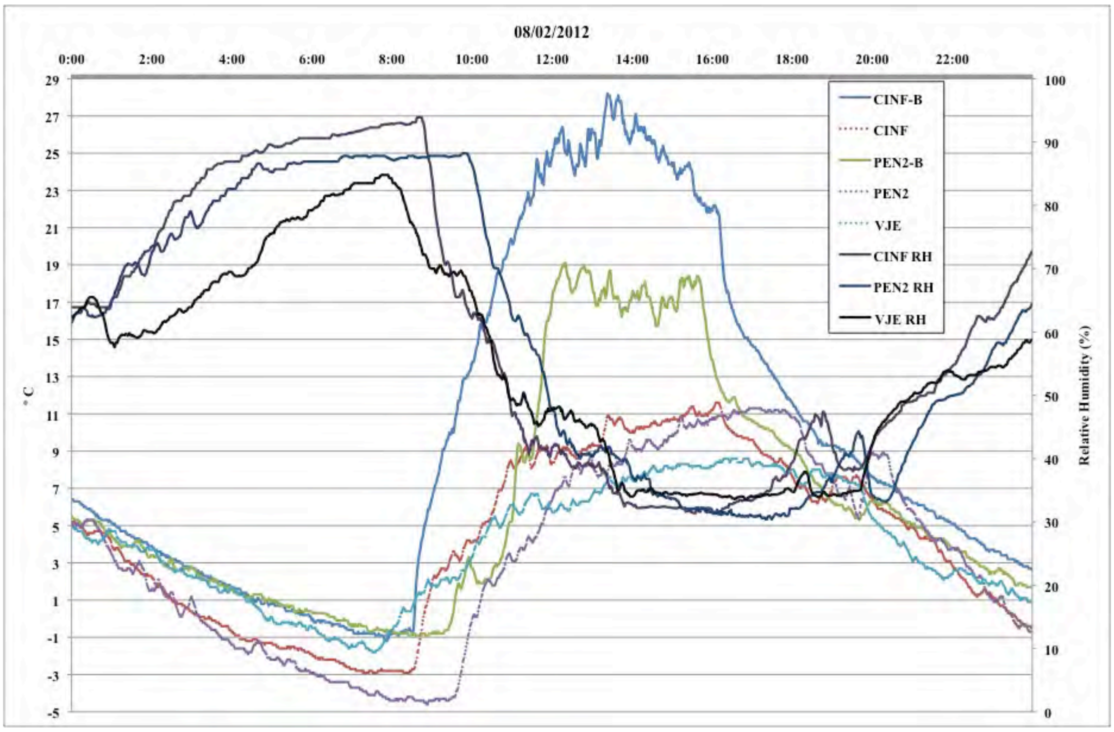


Figure 219. Daily temperature values (recorded every minute) plotted in connection to relative humidity values for the 8th of February 2012.

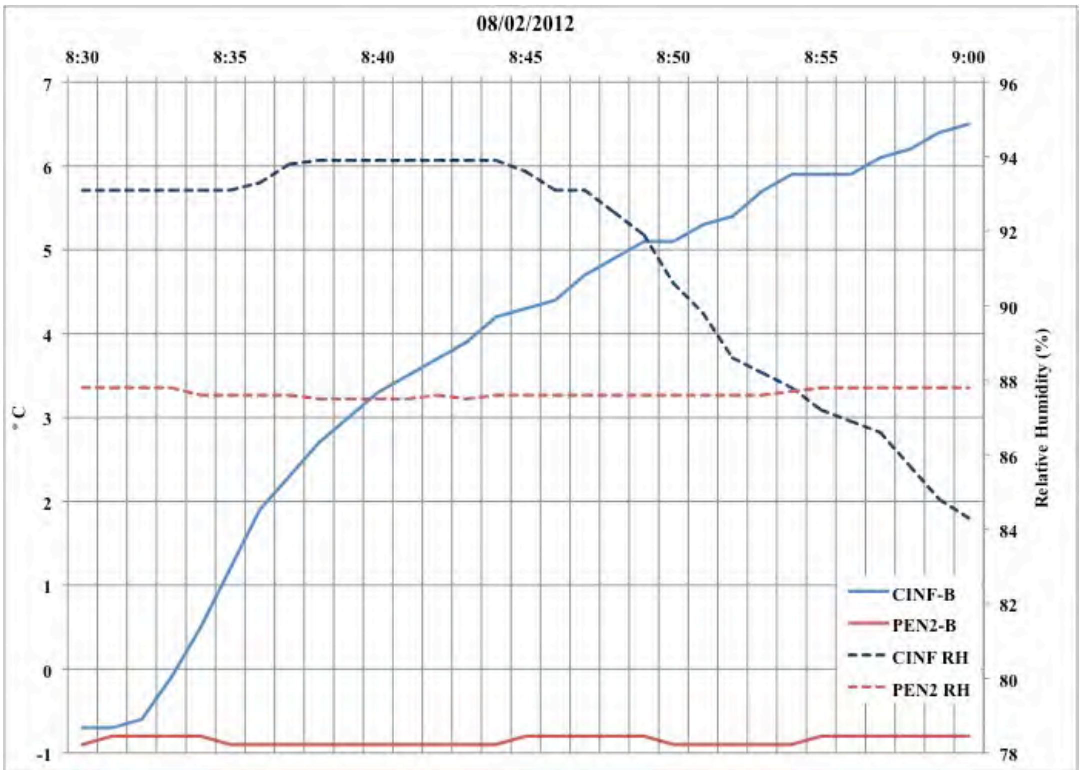


Figure 220. Minute temperature variation between 08:30 and 09:00 GMT on the 8th of February 2012 for CINF-B and PEN2-B plotted in connection to relative humidity values.

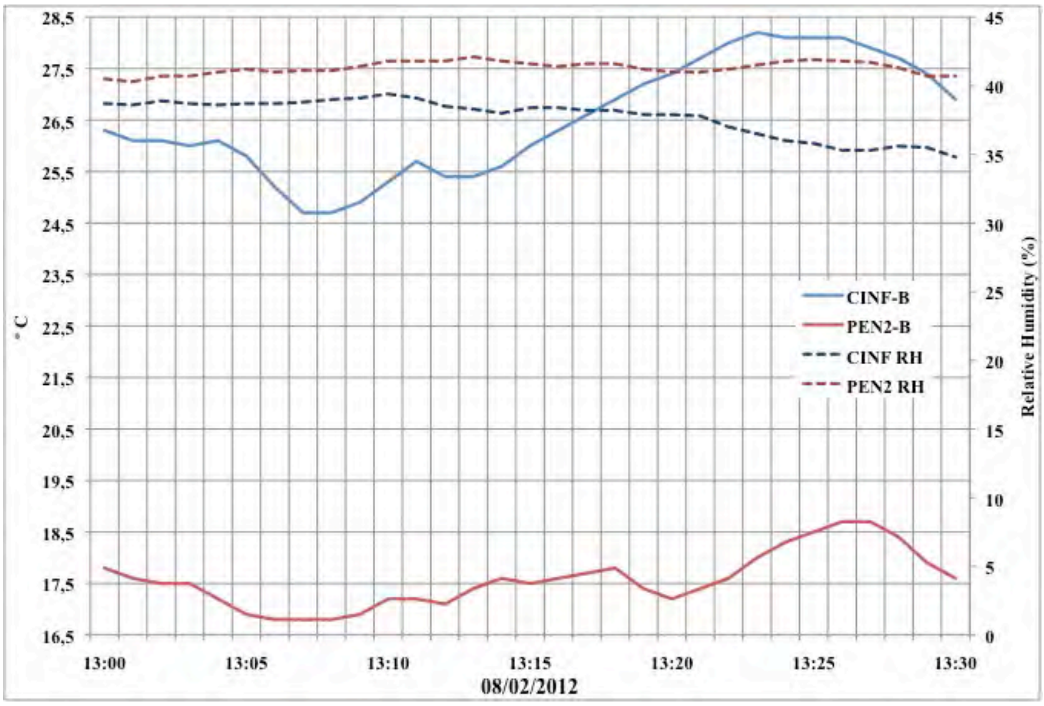


Figure 221. Minute temperature variation between 13:00 and 13:30 GMT on the 8th of February 2012 for CINF-B and PEN2-B plotted in connection to relative humidity values.

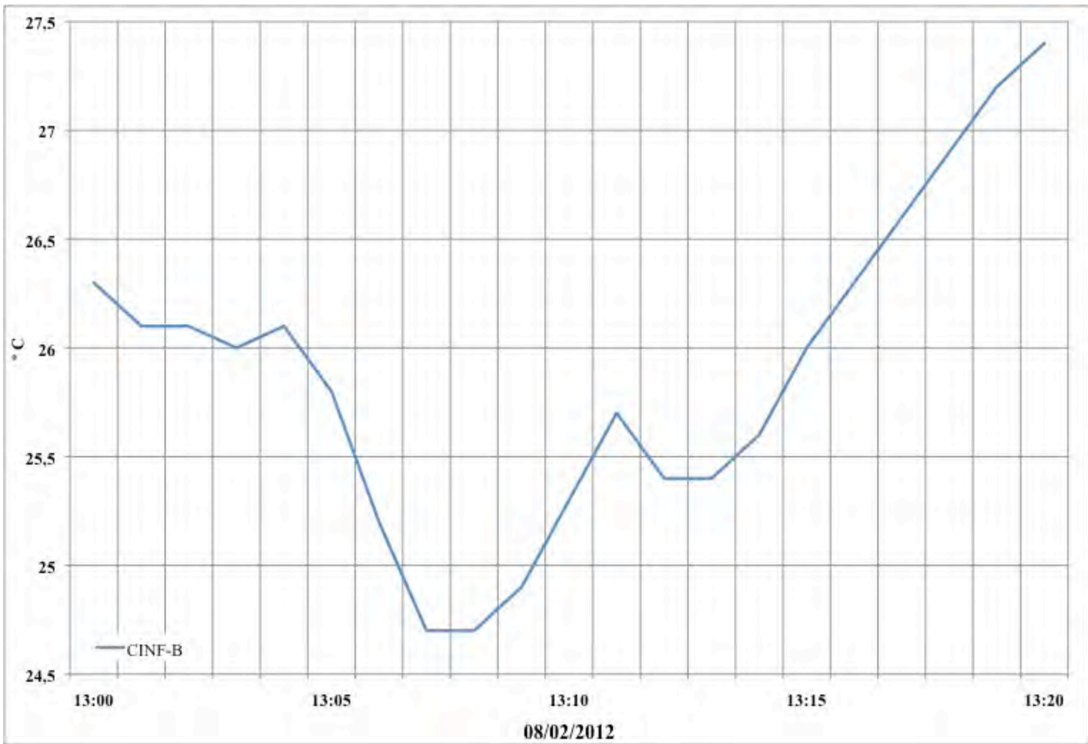


Figure 222. Temperature change measured by CINF-B between 13:00 and 13:20 GMT on the 8th of February 2012.

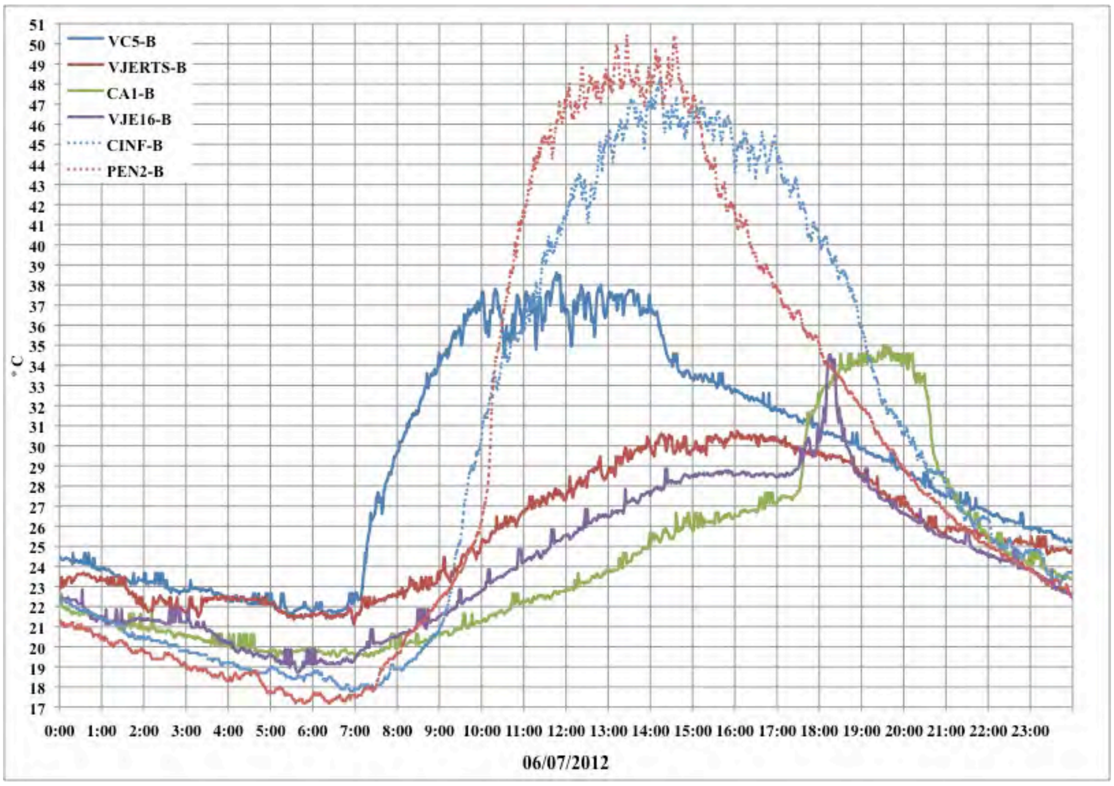


Figure 223. Temperatures recorded by the Park's and TPMJM B sensors on the 6th of July 2012.

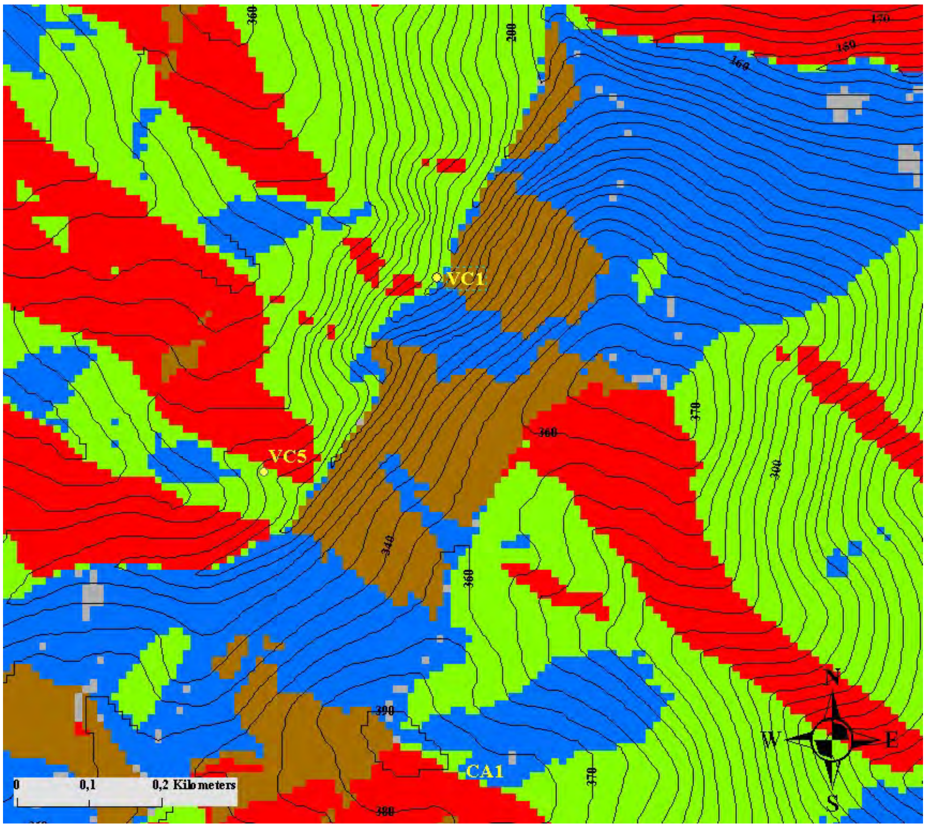


Figure 224. Location of VC1 and VC5 at Vale de Cabrões rock-art site.

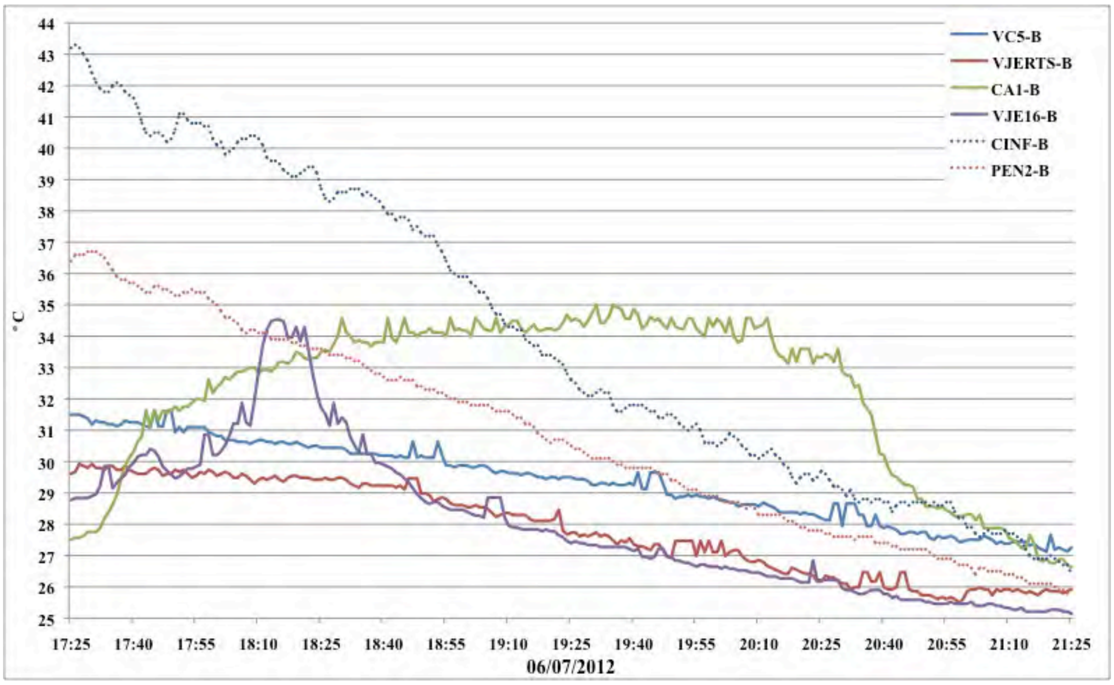


Figure 225. Temperatures recorded during late afternoon/beginning of the night by the Park's and TPMJM B sensors on the 6th of July 2012.

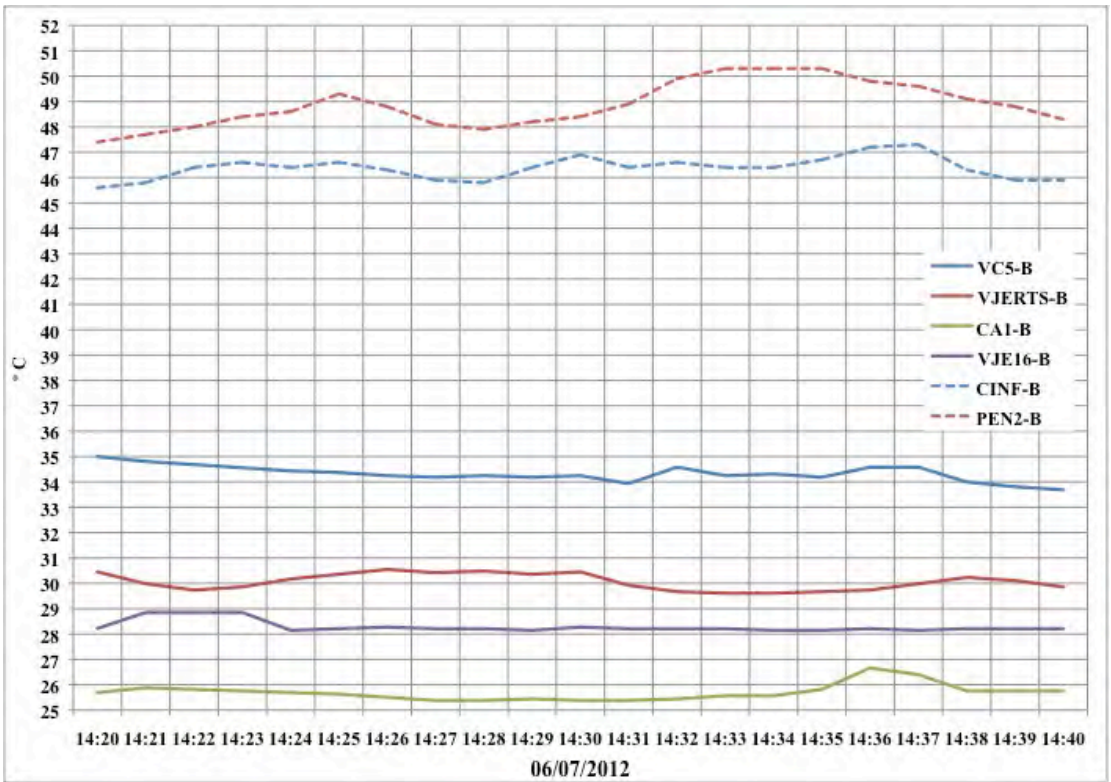


Figure 226. Temperatures recorded between 14:20 and 14:40 GMT by the Park's and TPMJM B sensors on the 6th of July 2012.

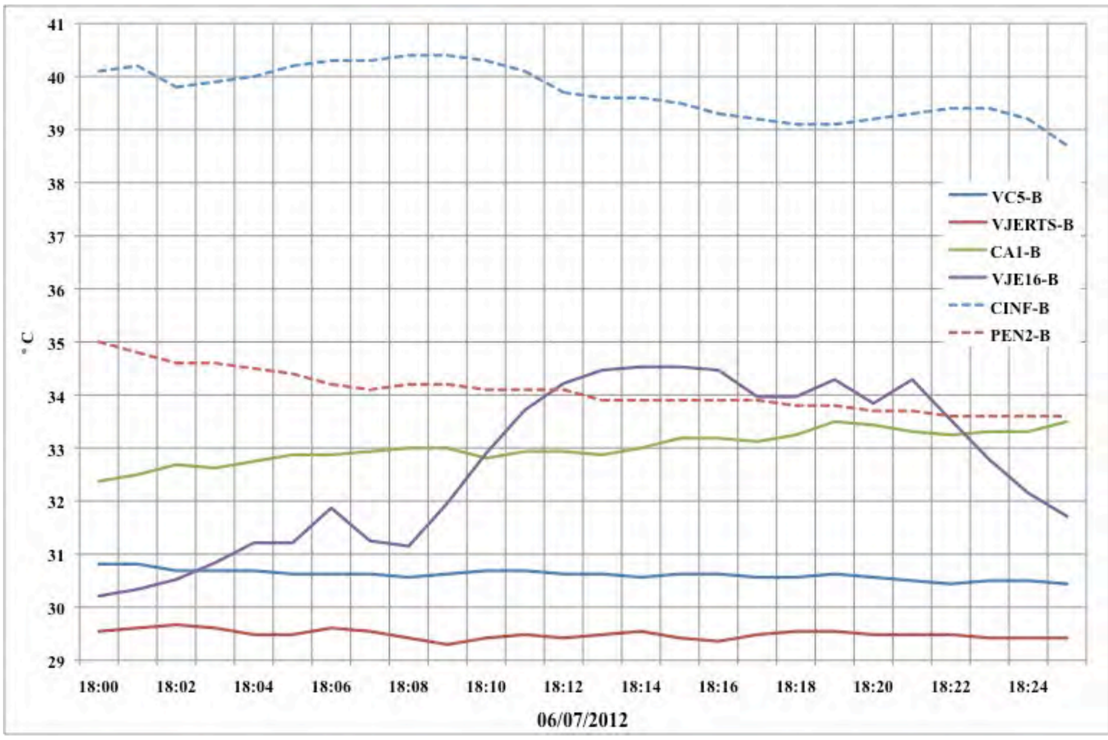


Figure 227. Temperatures recorded between 18:00 and 18:25 GMT by the Park's and TPMJM B sensors on the 6th of July 2012.

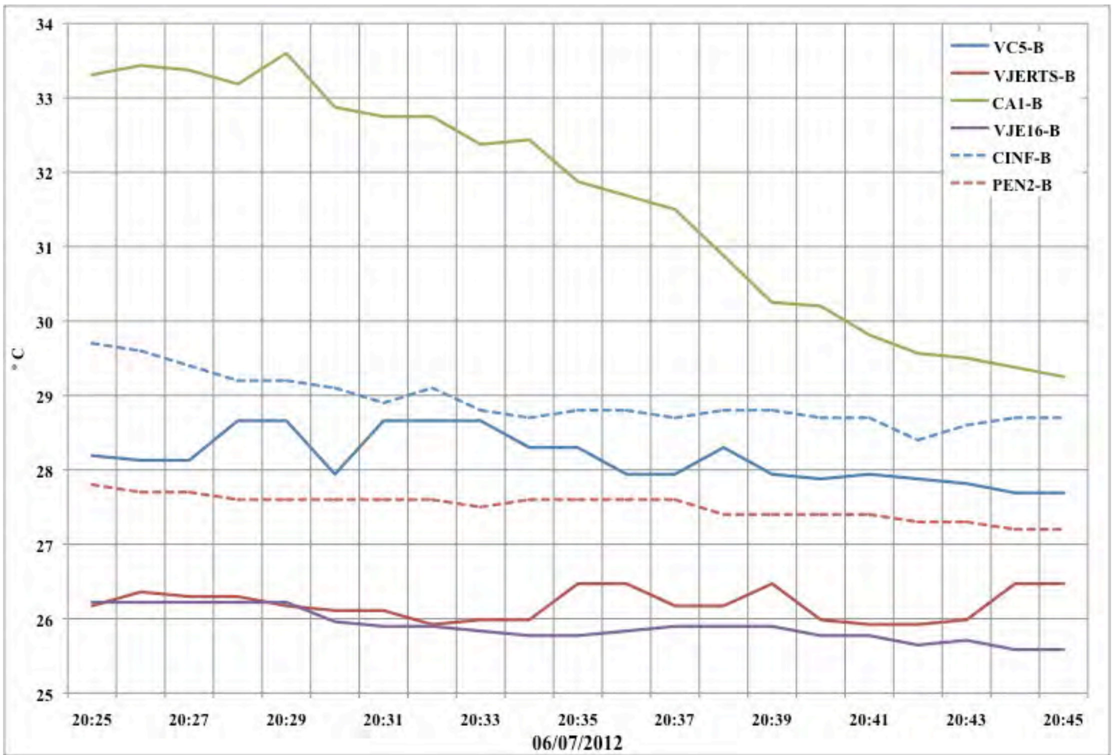


Figure 228. Temperatures recorded between 20:25 and 20:45 GMT by the Park's and TPMJM B sensors on the 6th of July 2012.

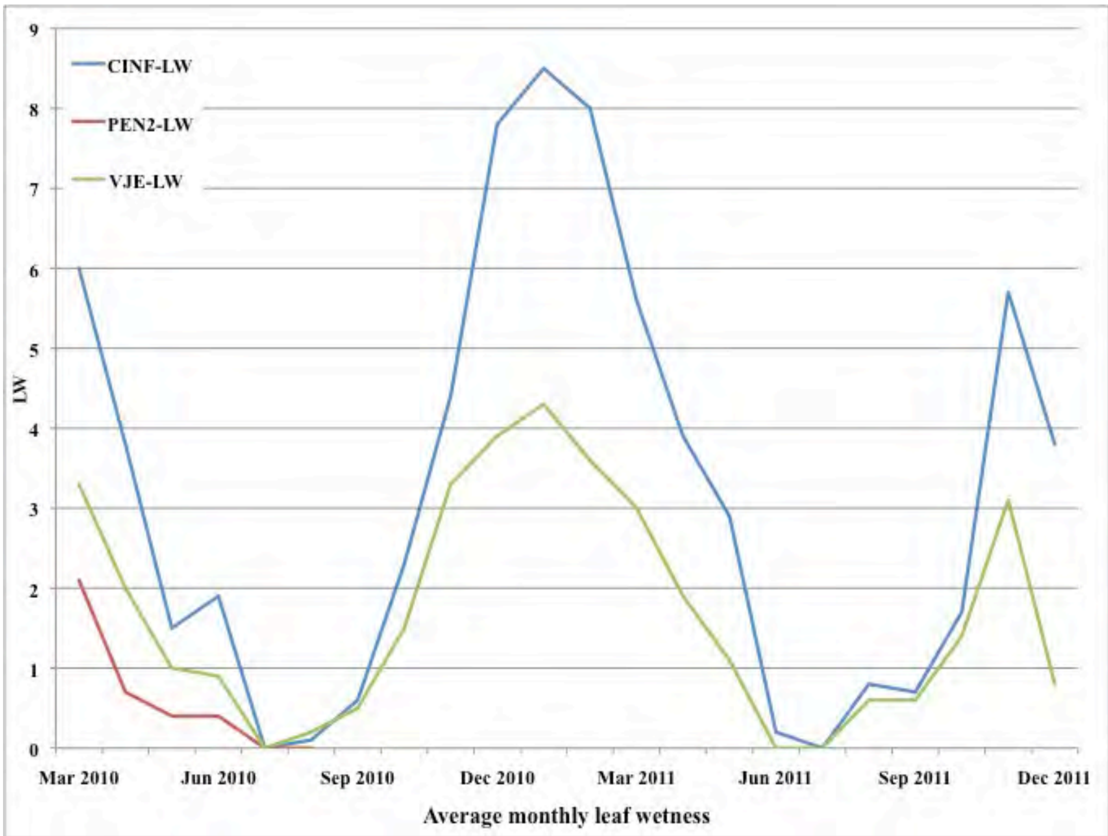


Figure 229. Available data regarding average monthly leaf wetness values from March 2010 until December 2011.

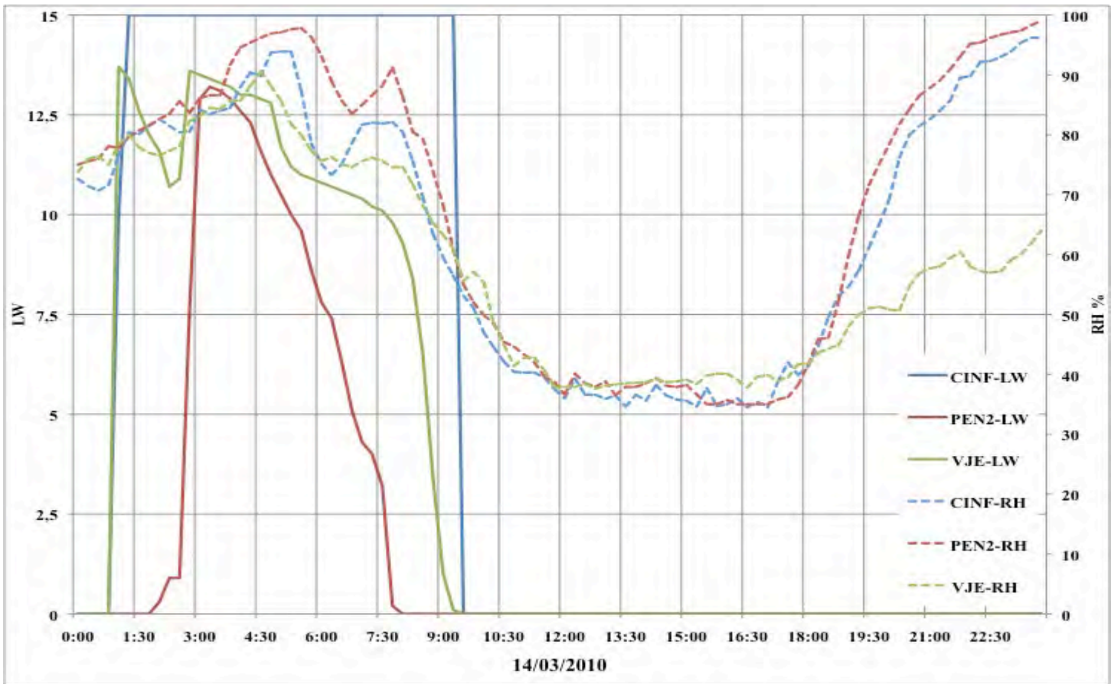


Figure 230. Leaf wetness and relative humidity values for the 14th of March 2010.

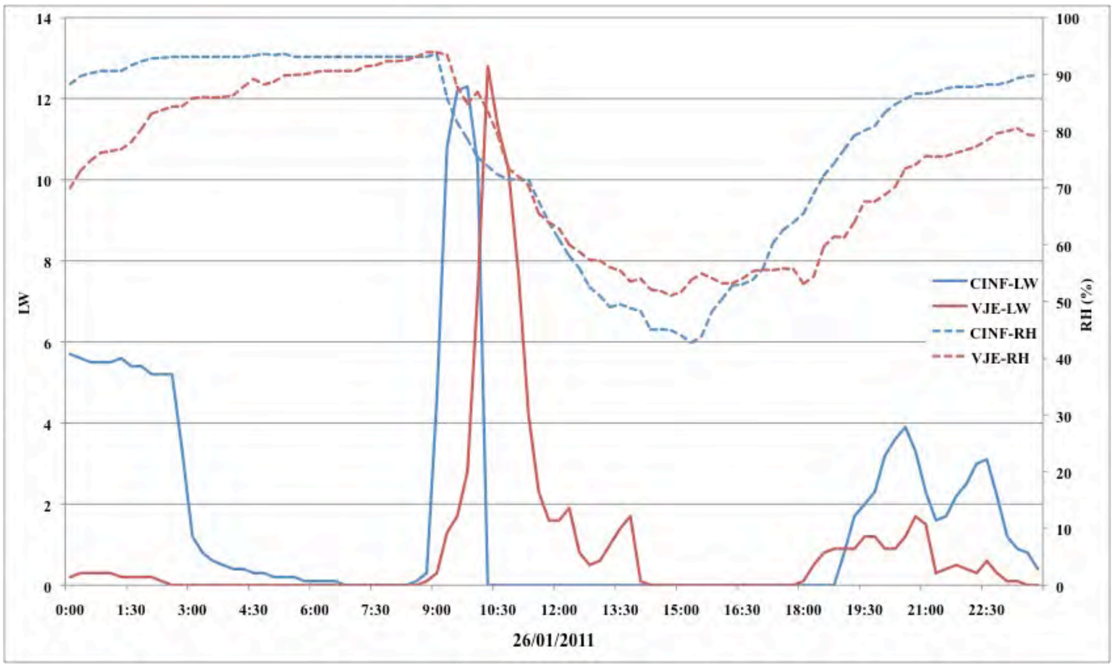


Figure 231. Leaf wetness and relative humidity values for the 26 of January 2011.

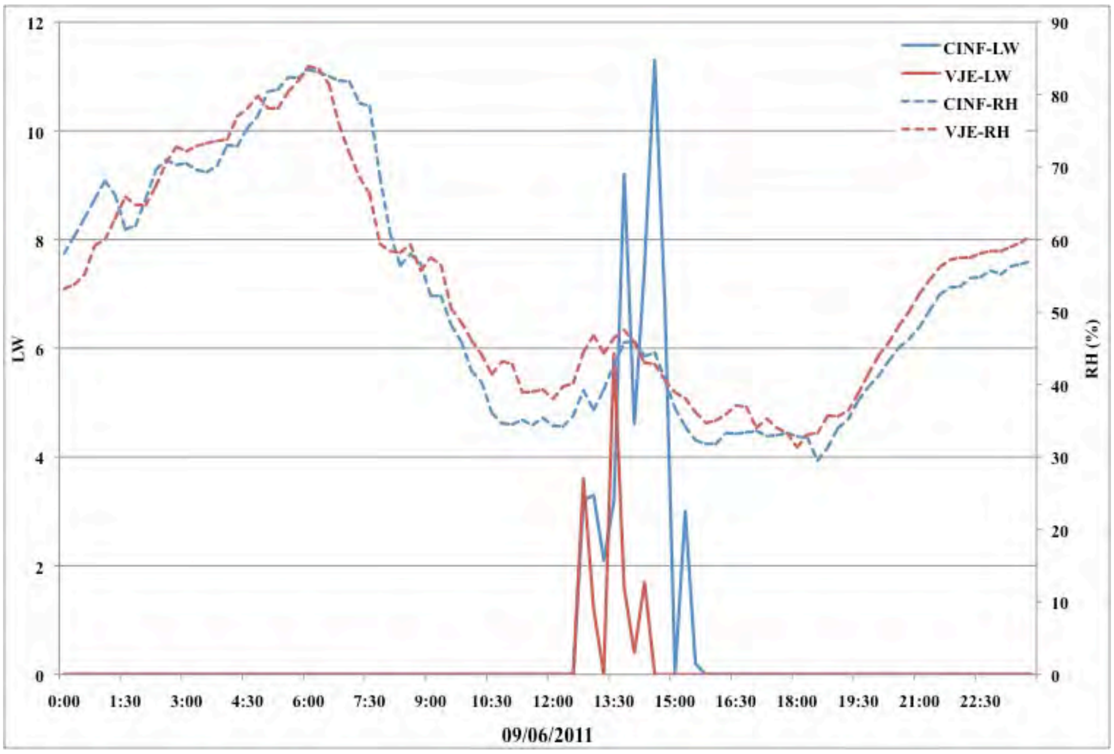


Figure 232. Leaf wetness and relative humidity values for the 9th of June 2011.

Figure 233. Leaf wetness and relative humidity values for the 8th of February 2012.

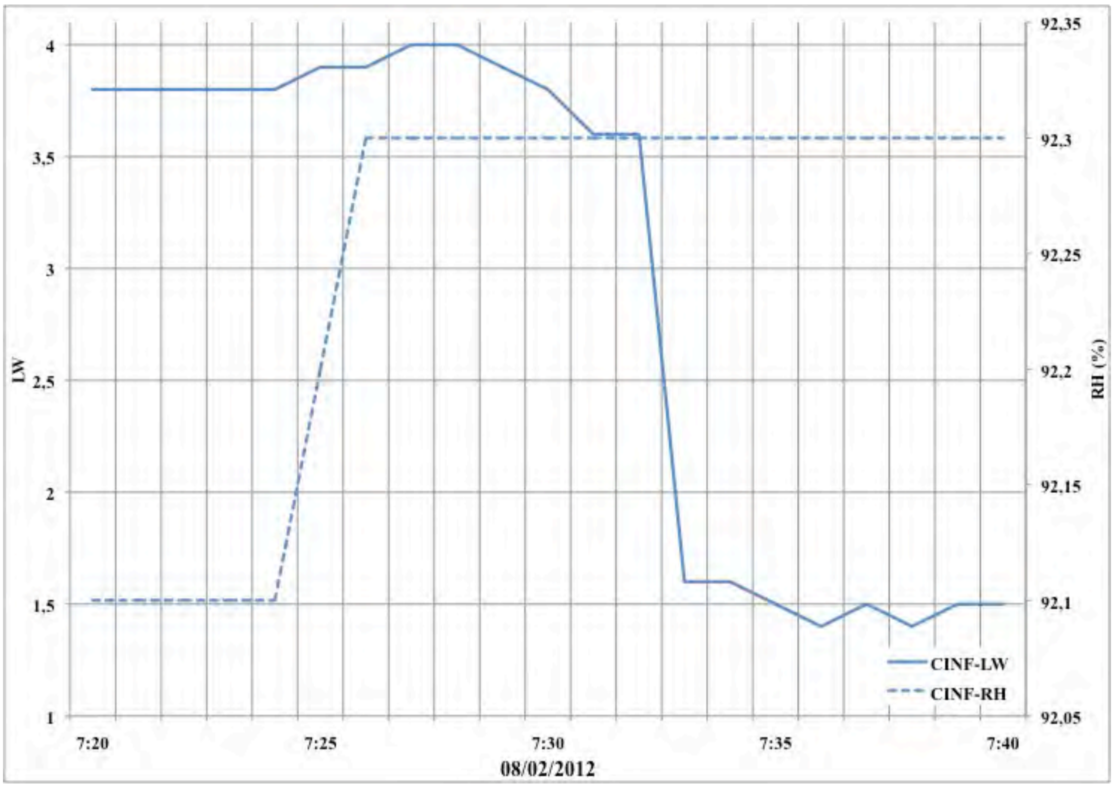


Figure 234. Leaf wetness and relative humidity values during the period between 07:20 – 07:40 GMT on the 8th of February 2012.

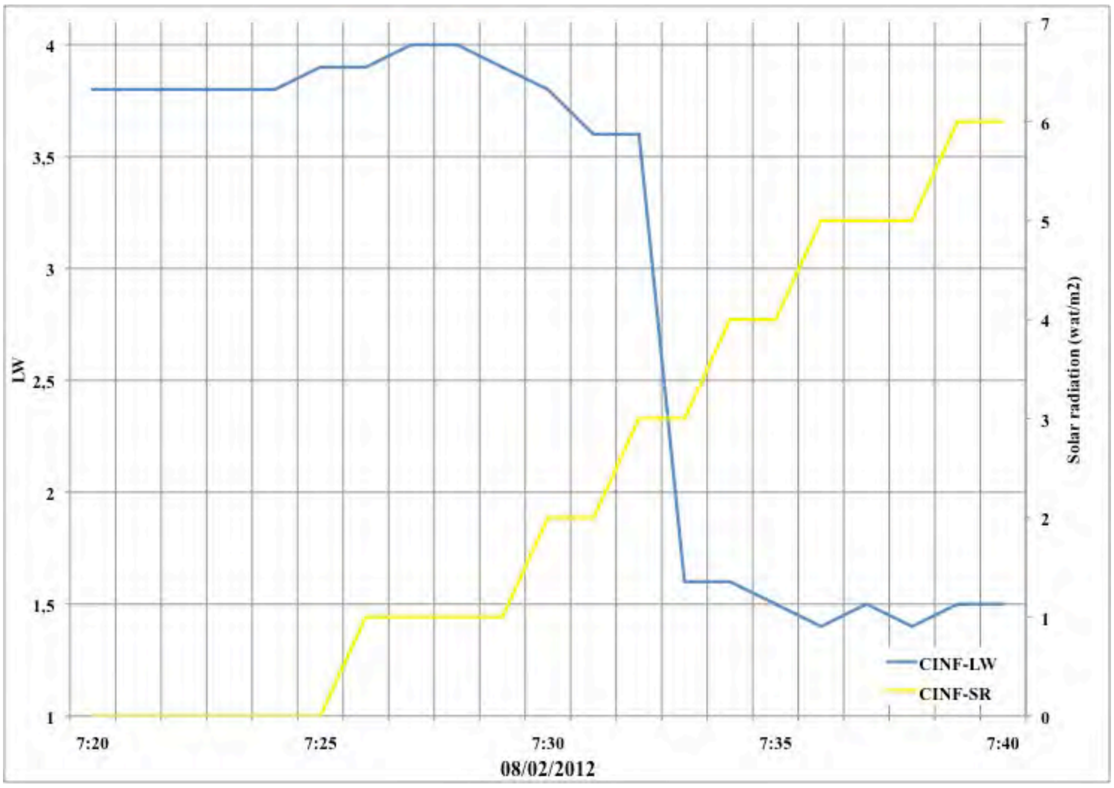


Figure 235. Leaf wetness and solar radiation values during the period between 07:20 – 07:40 GMT on the 8th of February 2012.

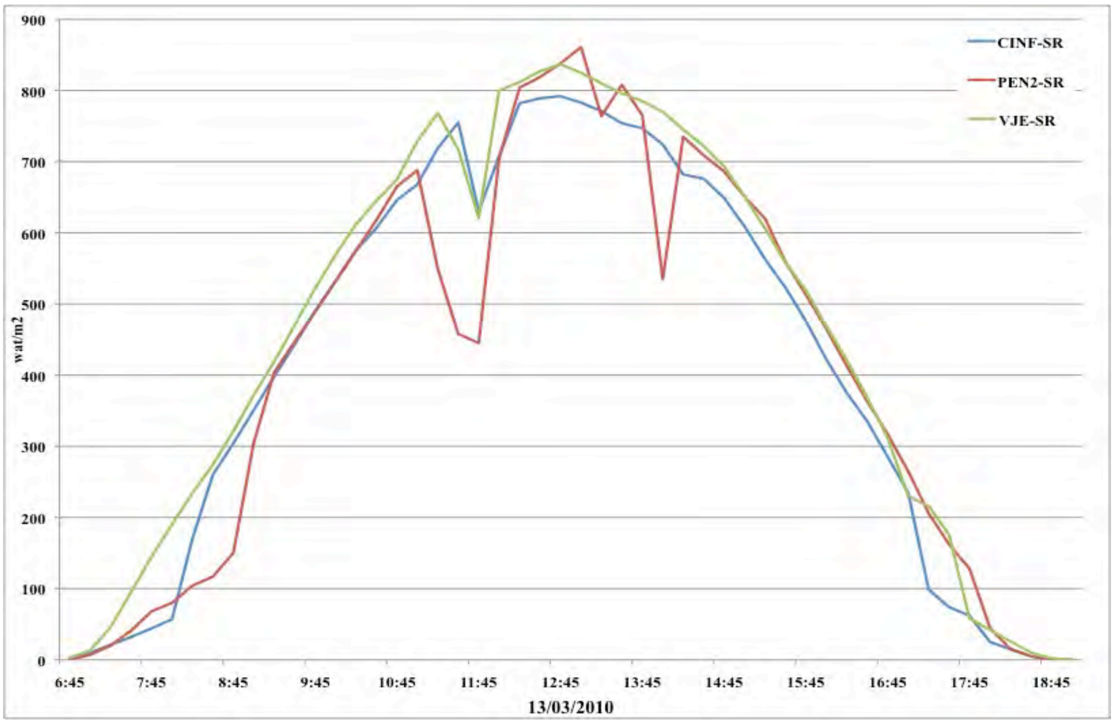


Figure 236. Solar radiation measured by the Park's stations on the 13th of March 2010.

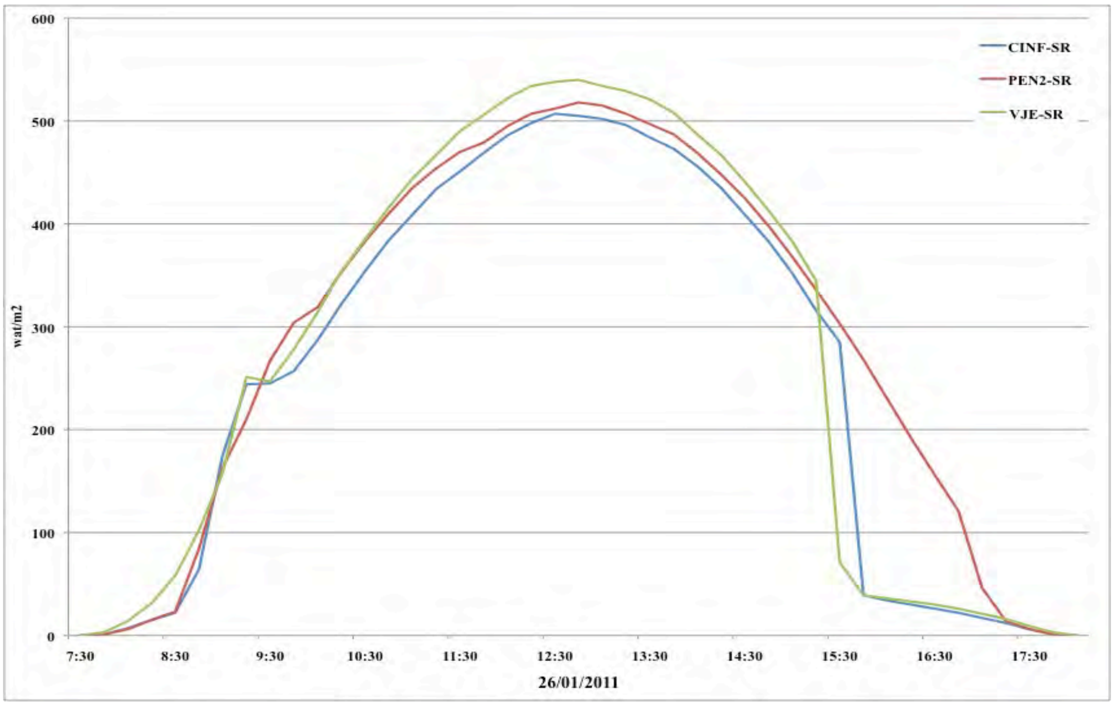


Figure 237. Solar radiation measured by the Park's stations on the 26th of January 2011.

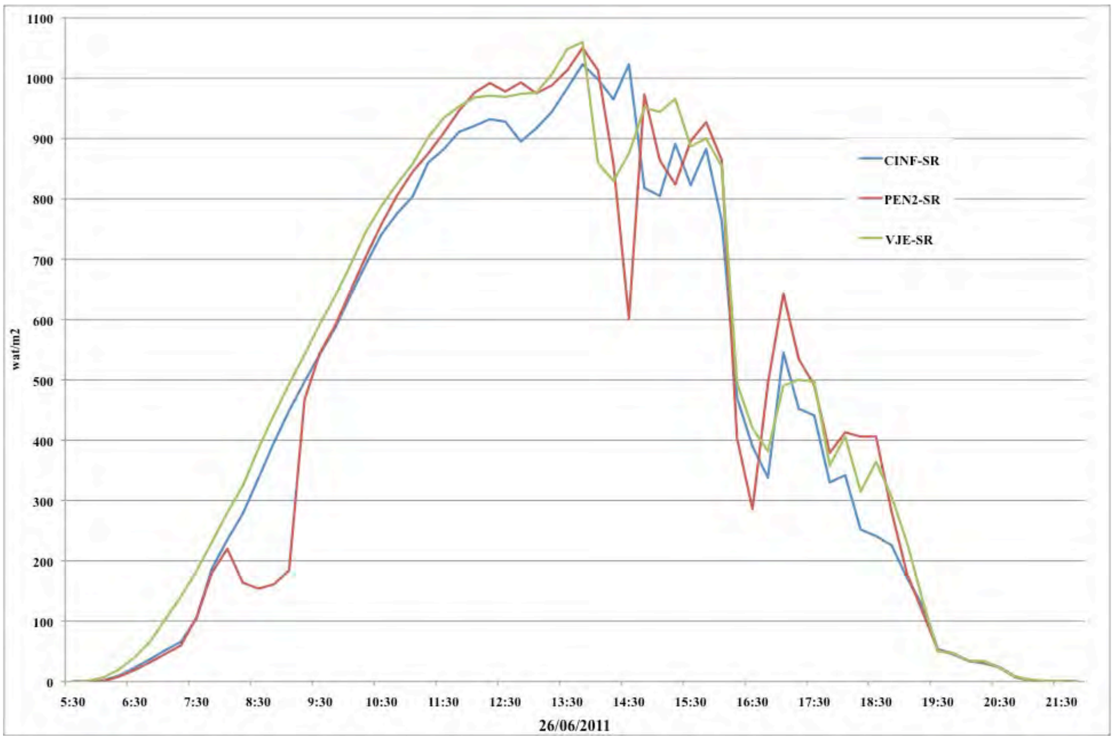


Figure 238. Solar radiation measured by the Park's stations on the 26th of June 2011.

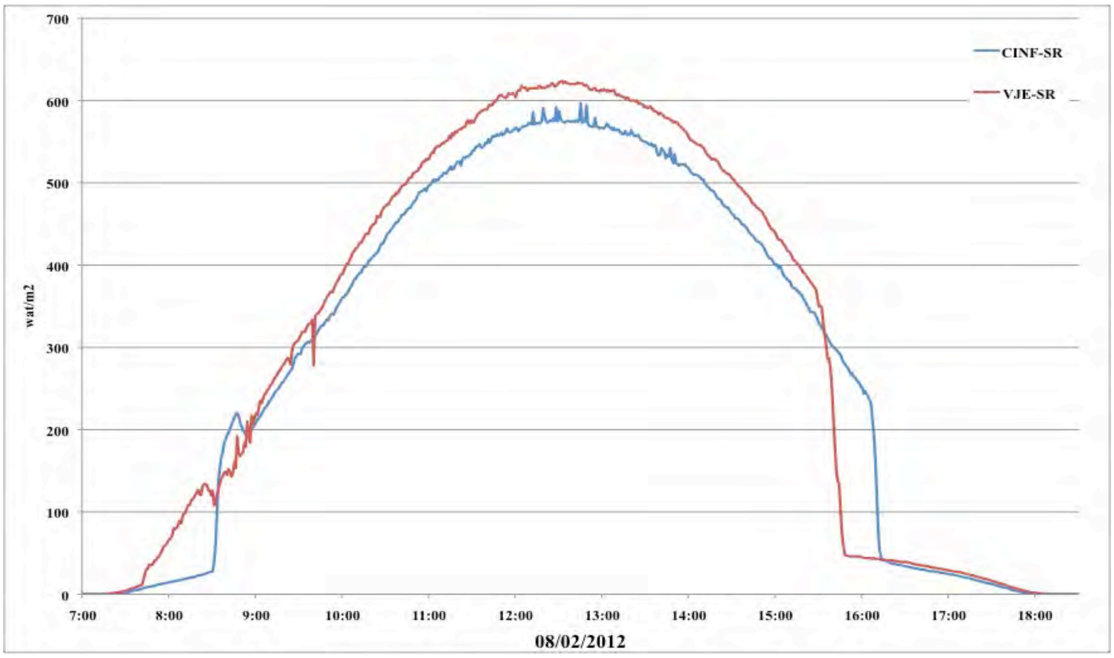


Figure 239. Solar radiation measured by the Park's stations on the 8th of February 2012.

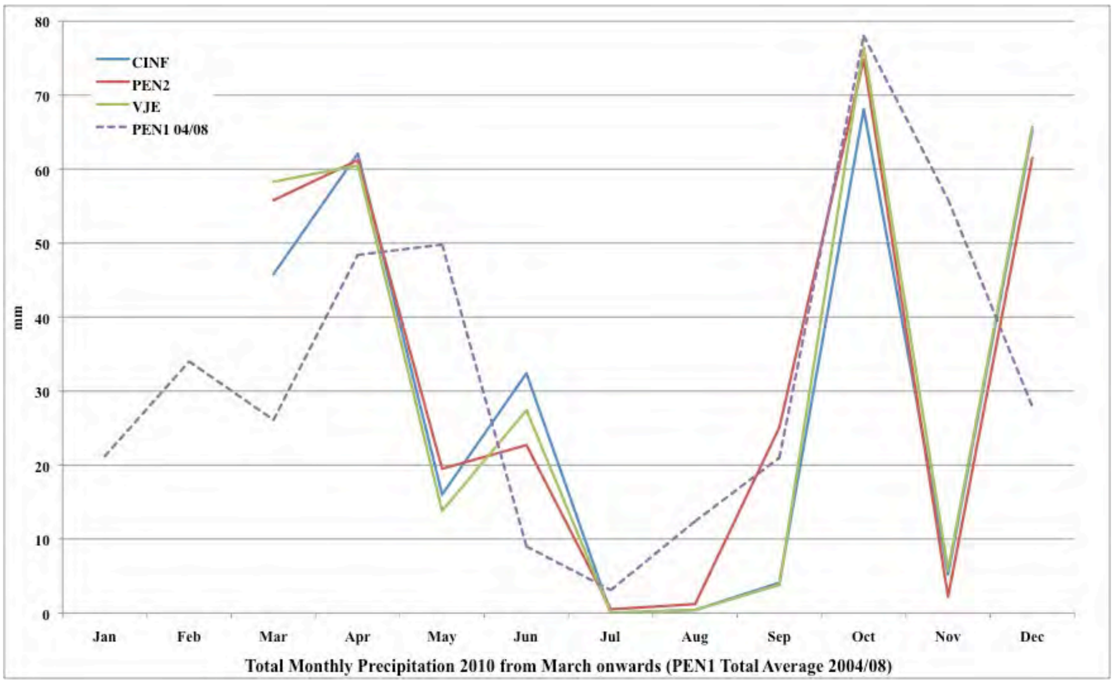


Figure 240. Total monthly precipitation in 2010 from March to December. PEN1 – average 2004/08.

Figure 241. Organic ‘remains’ in Ribeira de Piscos Rock 5.

Figure 242. Canada do Inferno Rock 2. Note the open eroding fracture is affecting the integrity of the goat motif. Photo in Baptista (1999, 80).

Figure 243. The final illustration as been chosen from the many jewels kept by the Côa: one of the staring aurochs in Ribeira de Piscos Rock 24. Another example of mastery by the Côa Valley Upper Paleolithic artists: who stares at who? Photo in Baptista (2009, 156).

TABLES

ROCK-ART SITE		NUMBER OF ENGRAVED OUTCROPS	NUMBER OF OUTCROPS BY PERIOD				
			UPPER PALEOLITHIC (UP)	POST-GLACIAR (PG)	IRON AGE (IA)	HISTORIC PERIOD (HP)	UNDETERM.
1	Azenha	3	-	-	2	1	-
2	Broeira	13	5	-	2	5	2
3	Bulha	42	15	-	24	6	4
4	Cachão	1	1	-	-	-	-
5	Canada da Alvia	2	-	-	2	-	-
6	Canada da Meca	3	2	-	1	-	-
7	Canada da Moreira	14	4	-	13	3	1
8	Canada das Corraliças	1	-	-	1	-	-
9	Canada do Amendoal	7	5	-	4	1	-
10	Canada do Arrobão	3	2	-	1	2	1
11	Canada do Inferno	43	37	4	-	7	1
12	Faia	18	2	7	-	10	-
13	Faia do Coto	3	-	-	-	3	-
14	Fariseu	19	16	-	4	-	-
15	Fonte d’Água Alta	1	1	-	-	-	-
16	Foz da Ribeirinha	8	8	-	-	-	-
17	Foz do Côa	194	95	-	66	47	28
18	Fumo	1	-	1	-	-	-
19	Garrido	6	-	-	5	2	-
20	Lapas Cabreiras	1	-	1	-	-	-
21	Meijapão	4	3	-	3	1	-
22	Mioteira	1	-	1	-	-	-
23	Moinho da Barbuda	1	-	-	-	1	-
24	Moinho do Chocho	1	-	-	-	1	-
25	Moinhos de Cima	25	6	-	12	3	7
26	Namorados	7	-	3	1	1	2
27	Olgas da Ervamoira	4	4	-	-	-	-
28	Paço	1	-	-	-	-	1
29	Penascosa	36	26	2	4	2	6
30	Picão da Lapa	1	-	-	-	1	-
31	Porto Velho	2	1	-	-	1	-
32	Quinta da Barca	60	45	2	-	3	11
33	Quinta das Tulhas	16	3	-	9	5	3
34	Raposeira	2	-	-	1	1	-
35	Rêgo da Vide	12	4	-	-	8	-
36	Ribeira da Cabreira	6	1	-	3	3	1

37	Ribeira da Volta	4	-	-	4	-	-
38	Ribeira das Cortes	24	14	-	8	5	2
39	Ribeira das Fornas	1	-	-	1	-	-
40	Ribeira de Piscos	33	25	3	8	5	-
41	Ribeira de Urros	8	2	-	4	3	-
42	Ribeira do Picão	5	-	-	4	1	-
43	Ribeirinha	1	-	1	-	-	-
44	São Gabriel	2	-	2	-	-	-
45	Tambores	2	-	2	-	-	-
46	Tudão	2	2	-	1	-	-
47	Vale d'Arcos	1	1	-	-	-	-
48	Vale da Casa	6*	2	2	1	2	-
49	Vale de Cabrões	57	27	-	28	14	4
50	Vale de Figueira	7	6	2	-	-	-
51	Vale de João Esquerdo	9	5	-	4	-	-
52	Vale de José Esteves	64	31	-	32	4	6
53	Vale de Moinhos	40	17	-	10	10	8
54	Vale de Videiro	2	1	1	-	-	-
55	Vale do Forno	79	25	-	39	20	11
56	Vale Escuro	3	-	-	2	-	1
57	Vermelhosa	12	6	-	2	-	6
OUTCROPS TOTAL		924	450	34	306	182	106
SITE TOTAL		57	36	15	34	33	20

Table 1. Côa Valley open-air rock-art sites identified as of January 2010.

ID # in Annex A	SITE	ROCK #	REASONS FOR INCLUSION IN THE SAMPLE
1	Canada da Moreira	2	East-facing; Medium altitude
2	Canada do Amendoal	1	West-facing; Medium altitude
3	Canada do Amendoal	2	South-facing; Medium altitude
4	Canada do Amendoal	3	North-facing; Medium altitude
5	Canada do Inferno	1	East-facing; Located in area subject to flooding
6	Canada do Inferno	2	
7	Canada do Inferno	13	East-facing; Located in area subject to minor flooding
8	Canada do Inferno	14	
9	Fariseu	2	North-facing
10	Fariseu	8	East-facing
11	Foz do Côa	14	
12	Foz do Côa	16	
13	Foz do Côa	93	South-facing; Medium altitude
14	Moinhos de Cima	7	East-facing
15	Penascosa	3	West-facing; Located in area subject to flooding
16	Penascosa	4	
17	Penascosa	5	
18	Penascosa	6	West-facing
19	Penascosa	10	
20	Penascosa	17	
21	Quinta da Barca	1	East-facing; Located in area subject to flooding

22	**Quinta da Barca**	**3**	**South-facing**
23	**Ribeira de Piscos**	**1**	**East-facing; Located in area subject to flooding**
24	**Ribeira de Piscos**	**2**	
25	**Ribeira de Piscos**	**3**	**East-facing**
26	**Ribeira de Piscos**	**24**	**East-facing; Located in area subject to flooding**
27	**Tudão**	**1**	**South-facing; Moderate slope; Medium altitude**
28	**Vale de Cabrões**	**1**	**East-facing**
29	**Vale de Cabrões**	**4**	**East-facing; Medium altitude**
30	**Vale de Cabrões**	**5**	**South-facing; Medium altitude**
31	**Vale do Forno I**	**1**	
32	**Vale do Forno I**	**9**	
33	**Vale do Forno II**	**5**	**East-facing**
34	**Vale do Forno II**	**6**	
35	**Vale do José Esteves**	**16**	**North-facing**
36	**Vale do José Esteves**	**17**	**South-facing**
37	**Vermelhosa**	**1**	
38	**Vermelhosa**	**2**	
39	**Vermelhosa**	**3**	
40	**Vermelhosa**	**4**	

Table 2. Outcrops chosen for the sample featuring the main reasons for selection.

TERMINOLOGY	BEARINGS
Flat	-1º
North	315º–360º; 0º–45
East	45º–135
South	135º–225º
West	225º–315º

Table 3. Considered aspect categories.

TERMINOLOGY	APPROXIMATE DEGREES	SLOPE (%)
Level	0	0 - 0.5
Nearly Level	0.3 - 1.1	0.5 - 2
Very Gentle Slope	1.1 - 3	2 - 5
Gentle Slope	3 - 5	5 - 9
Moderate Slope	5 - 8.5	9 - 15
Strong Slope	8.5 - 16.5	15 - 30
Very Strong Slop	16.5 - 24	30 - 45
Extreme Slope	24 - 35	45 - 70
Steep Slope	35 - 45	70 - 100
Very Steep Slope	> 45	> 100

Table 4. Slope Steepness Index.

WEATHER STATION	AVERAGE (mm)	ANNUAL HIGHEST (mm)	ANNUAL LOWEST (mm)	DAILY HIGHEST (mm)
Castelo Melhor (1982/1997)	489,7	687,7	291,3	-
Pinhel	646,1	1032,5	357,1	83
Miuzela	820	1131	445,4	98,5
Vale do Espinho	1373,6	2075	722,5	-

Table 5. Historical precipitation values in the Côa basin in the period 1952/82, except Castelo Melhor (1982/1997) Adapted from Alexandre (1995). Castelo Melhor and Vale do Espinho data supplied by SNIRH (INAG). Values correspond to a hydrological year (beginning on 01/10 and ending on 30/09).

	Year				
VARIABLE	2004	2005	2006	2007	2008
Highest Temperature	43,5º C	44,4º C	42,5º C	44º C	42,5º C
Lowest Temperature	- 5,1º C	- 7,6º C	- 5.1º C	- 9,8º C	- 2,7º C
Average Temperature	14,6º C	15,1º C	13,6º C	14,4º C	16,2º C
Average Highest Temperature	31,08º C	31,9º C	29,08º C	30,14º C	30,86º C
Average Lowest Temperature	2,09º C	1,84º C	2,85º C	0,66º C	2,86º C
Number of days with Temperature ≤0ºC	39	73	44	44	9[114]

Table 6. Temperature values for PEN1 from 2004 until 2008.

[114] Value not comprising the period from 30 of October to 22 of December 2008 (see footnote 46).

[115] In spite of the malfunction of PEN1 during August 2004 (see footnote 46), it was assumed, based on data collected in subsequent years, that all August days had temperatures ≥25ºC.

[116] During the period in which PEN1 malfunctioned in 2006 (see footnote 46), it was assumed that all the missing days in July and August had temperatures ≥25ºC. As for September's missing days it was an altogether different case. Since in the two previous years (2004/05) daily temperatures in September were always ≥25º C and in the subsequent years (2007/08) only about half of the days had temperatures above that mark, it was assumed that September 2006 had 22 days with temperature ≥25ºC.

	2004/2008* PEN1
Average Annual Highest Temperature	**30,63º C**
Average Annual Lowest Temperature	**2,03º C**
Average Annual Temperature	**14,77º C**
Average Number of days with Temperature ≤ 0ºC (2004-07*)	**50**
Average Number of days with Temperature ≥25ºC	**161,8**

Table 7. Average temperature values for PEN1 in the period in question

	MONTHLY AVERAGE TEMPERATURES 2004-08		
	Highest	**Average**	**Lowest**
Jan.	**18,8º C**	**6,6º C**	**-4,8º C**
Feb.	**22º C**	**7,7º C**	**-3,4º C**
Mar.	**26,5º C**	**10,7º C**	**-4,4º C**
Apr.	**32,7º C**	**13,7º C**	**0,8º C**
May	**35,1º C**	**17,6º C**	**3,7º C**
Jun.	**39,8º C**	**23,2º C**	**9,6º C**
Jul.	**42,4º C**	**25º C**	**9,8º C**
Aug.	**42,9º C**	**24,5º C**	**10,8º C**
Set.	**35,7º C**	**20,4º C**	**7,3º C**
Oct.	**31,1º C**	**15,4º C**	**2,7º C**
Nov.	**22,3º C**	**9,1º C**	**-2,3º C**
Dec.	**19,3º C**	**5,6º C**	**-4,4º C**

Table 8. Monthly average temperatures for PEN1in the period in question.

DIURNAL TEMPERATURE VARIATION (DTV)	Year				
	2004	**2005**	**2006**	**2007**	**2008**
DTV in the Day with the Highest	**27,1^{o} C (25th of July)**	**26,9^{o} C (7th of August)**	**26,9^{o} C (9th of July)**	**29,9^{o} C (4th of August)**	**25,7^{o} C (4th of August)**
DTV in the Day with the Lowest	**17,9^{o} C (20th of January)**	**20,9^{o} C (2nd of March)**	**20,6^{o} C (7th of February)**	**25,4^{o} C (18th of November**	**22,4^{o} C (7th of March)**
DTV in the Day with the Highest	**28,4^{o} C (26th)**	**28^{o} C (29th)**	**20,7^{o} C (25th)**	**25,2^{o} C (23rd)**	**21,5^{o} C (26th)**
DTV in the Day with the Lowest	**20,2^{o} C (10th)**	**19,6^{o} C (10th)**	**16,6^{o} C (11th)**	**19,6^{o} C (1st)**	**27,2^{o} C (5th)**
DTV in the Day with the Highest	**26,3^{o} C (2nd)**	**24,6^{o} C (1st)**	**18,1^{o} C (28th)**	**18,9^{o} C (6th)**	**23,9^{o} C (10th)**
DTV in the	**18,4^{o}**		**22,3^{o}**	**21,9^{o}**	**14,6^{o}**

Table 9. Diurnal Temperature Variation in selected days for PEN1 in the period in question.

	TOTAL PRECIPITATION (in mm.)					AVERAGE	
	2004	2005	2006	2007	2008	Precipitation (in mm.)	# of rain days
Jan	35,8	2,9	17,3	10,3	39,9	21,24	7,8
Feb	21,2	16,8	28,6	64	39,7	34,06	10
Mar	41,7	26	53,7	6	3,4	26,16	7,6
Apr	14,9	32,2	61,7	39,4	94,2	48,48	9
May	17,2	32,8	2,1	117,5	79,7	49,86	10,2
Jun	0,3	0,3	32,6	3,5	8,4	9,02	2,8
Jul	0,3	6,7	8,4	0,3	0	3,14	1,4
Aug	35,8	0,3	11,1	9,4	5,6	12,44	2,2
Sep	3,8	25,6	43,1	15,3	17,3	21,02	4.6
Oct	5,6	152,6	176,4	32,6	24,4	78,32	9,6
Nov	5,5	45,4	117,7	55	-	55,9	9,75
Dec	34,2	51,4	29,5	18	6,8 [117]	27,98	9,8

Table 10. Monthly precipitation values for PEN1 in the period in question.

	2004	2005	2006	2007	2008 [118]	Average
Precipitation (in mm.)	265,3	393	582,2	371,3	319,4	386,24
Rain days	60	81	102	92	79	82,8

Table 11. Total and average precipitation values for PEN1 in the period in question.

	DAYS WITH THE HIGHEST AMOUNT OF PRECIPTATION (2004/2008)				
	27/10/2005	30/10/2005	22/10/2006	24/11/2006	20/05/2007
Highest Daily Precipitation (in mm.)	53,8	57	43,2	48,1	38,8
Highest Hourly Precipitation (in mm.)	11,9 (14:00/15:00)	15,7 (10:00/11:00)	9,9 (10:00/11:00)	4,8 (10:00/11:00)	14 (20:00/21:00)

Table 12. Days with the highest amount of precipitation in the period in question.

[117] See footnote 46 (valid also for November 2008).
[118] See footnote 46.

	2004	2005	2006	2007	2008
Jan. Average	**85,30%**	**77,10%**	**81%**	**79,40%**	**85%**
Feb. Average	**83,40%**	**69,90%**	**74,80%**	**73,20%**	**81,80%**
Mar. Average	**73,50%**	**63,50%**	**71,80%**	**66,70%**	**66,80%**
Apr. Average	**65,03%**	**61,80%**	**68,50%**	**67,70%**	**70,40%**
May Average	**59,40%**	**51,70%**	**45,90%**	**64,30%**	**73,20%**
Jun. Average	**42,60%**	**36,50%**	**44,40%**	**58,40%**	**54,80%**
Jul. Average	**35,70%**	**34,80%**	**29,80%**	**44,30%**	**42,40%**
Aug. Average	**53,50%**	**30,50%**	**26,80%**	**44,30%**	**45%**
Sep. Average	**51,50%**	**44,80%**	**33,80%**	**50%**	**57,80%**
Oct. Average	**69,80%**	**65,50%**	**76,90%**	**75,10%**	**66,60%**
Nov. Average	**83,50%**	**83,70%**	**85,60%**	**77,90%**	**-**
Dec. Average	**83,60%**	**82,30%**	**85%**	**88,30%**	**93,80%**[119]
Average	**65,50%**	**58,50%**	**60%**	**65,80%**	**67%**
Total Average	**63%**				

Table 13. Relative humidity values for PEN1 in the period in question.

	CINF		
	Highest (ºC)	**Average (ºC)**	**Lowest (ºC)**
January	**19,8º**	**7,8º**	**-5º**
February	**22,3º**	**8,1º**	**-3,3º**
March	**25,3º**	**11,2º**	**-1,2º**
April	**34,1º**	**17,6º**	**6,9º**
May	**38,4º**	**21,2º**	**8,2º**
June	**45,2º**	**24º**	**9,5º**
July	**41,4º**	**25,9º**	**12,3º**
August	**43,3º**	**25,3º**	**11,3º**
September	**39,1º**	**22,9º**	**9,8º**
October	**36,3º**	**17,9º**	**4,3º**
November	**24,4º**	**11,4º**	**3,2º**
December	**20,3º**	**7º**	**-3,4º**
Highest/Lowest	**45,2º**	**-**	**-5º**
Year Average	**32,4º**	**16,6º**	**4,3º**
Nr. of days with temperature ≤ 0º	**27**		
Nr. of days with temperature ≥ 25º	**194**		

Table 14. Temperature values for CINF in 2011.

[119] See footnote 46 (valid also for November 2008).

	PEN2		
	Highest	**Average**	**Lowest**
January	**20,7°**	**7,5°**	**-6,2°**
February	**21,9°**	**7,8°**	**-4,7°**
March	**25,5°**	**10,6°**	**-2,7°**
April	**33,3°**	**16,6°**	**5,2°**
May	**38,8°**	**20,3°**	**7°**
June	**45,3°**	**23°**	**7,9°**
July	**41,4°**	**24,9°**	**9,8°**
August	**44°**	**25,3°**	**9,1°**
September	**39,4°**	**22°**	**6,9°**
October	**36,5°**	**16,7°**	**1,8°**
November	**23,3°**	**11,1°**	**1,7°**
December	**19,9°**	**6,6°**	**-5,2°**
Highest/Lowest	**45,3°**	**-**	**-6,2°**
Year Average	**32,5°**	**16°**	**2,5°**
Nr. of days with temperature ≤ 0°	**31**		
Nr. of days with temperature ≥ 25°	**199**		

Table 15. Temperature values for PEN2 in 2011.

	VJE		
	Highest	**Average**	**Lowest**
January	**17,9°**	**7,4°**	**-4,2°**
February	**18,9°**	**8,2°**	**-2,7°**
March	**22°**	**11°**	**-0,1°**
April	**31°**	**17,3°**	**8,8°**
May	**34,4°**	**20,2°**	**8,3°**
June	**42,6°**	**22,6°**	**10,1°**
July	**38,4°**	**24,2°**	**12,2°**
August	**40,3°**	**24,9°**	**11,7°**
September	**36,8°**	**22,3°**	**10,9°**
October	**32,7°**	**17,3°**	**4,7°**
November	**22,4°**	**10,8°**	**3,9°**
December	**17,3°**	**6,7°**	**-2,2°**
Highest/Lowest	**42,6°**	**-**	**-4,2°**
Year Average	**29,5°**	**16°**	**5,1°**
Nr. of days with temperature ≤ 0°	**23**		
Nr. of days with temperature ≥ 25°	**162**		

Table 16. Temperature values for VJE in 2011.

DIURNAL TEMPERATURE VARIATION (DTV)	CINF (ºC)	PEN2 (ºC)	VJE (ºC)
DTV in the Day with the Highest Temperature of the Year	25º (26/06)	27º (26/06)	21,3º (26/06)
DTV in the Day with the Lowest Temperature of the Year	15,8º (26/01)	17,8º (26/01)	11,3º 26/01)
DTV in the Day with the Highest Temperature of April	24,8º (8th)	25º (8th)	19,4º (8th)
DTV in the Day with the Lowest Temperature of April	22,9º (1st)	24º (16th)	16,6º (16th)
DTV in the Day with the Highest Temperature of October	24,4º (5th)	26,9º (5th)	18,5º (5th)
DTV in the Day with the Lowest Temperature of October	18,8º (30th)	22,3º (21st)	14,6º (30th)

Table 17. Diurnal Temperature Variation values in selected days for CINF, PEN2 and VJE in 2011.

	PRECIPITATION (in mm.)		
	CINF	PEN2	VJE
January	41,8	41	51,8
February	33,3	40,3	47,9
March	37,7	46,5	41,7
April	33,7	38	36,1
May	42,8	27,3	34,1
June	0,6	3,2	0
July	0	0	0
August	20,1	19,8	19
September	17	13,6	18,2
October	13,1	15,5	16,6
November	68	69,9	83,2
December	18,5	18,1	22,2
Total	326,6	333,2	370,8

Table 18. Monthly precipitation values for CINF, PEN2 and VJE in 2011.

	NUMBER OF RAIN DAYS		
	CINF	PEN2	VJE
January	14	13	16
February	11	10	9
March	14	14	13
April	8	9	8
May	8	11	9
June	3	2	0
July	0	0	0
August	5	4	5
September	2	1	2
October	6	6	5
November	15	16	19
December	10	10	10
Total	96	96	96

Table 19. Monthly number of rain days for CINF, PEN2 and VJE in 2011.

	PRECIPTATION IN THE DAYS WITH HIGHEST AMOUNT (CINF)				
	16/02/11	19/04/11	21/08/11	01/09/11	19/11/11
Daily Precipitation (in mm.)	13,1	15,3	17,3	15,1	23,3
Highest Hourly Precipitation (in mm.)	6,2 (05:00/06:00)	4,4 (22:00/23:00)	9 (20:00/21:00)	3,9 (09:00/10:00)	3,6 (01:00/02:00)

Table 20. Precipitation values in the days with the highest amount of precipitation for CINF in 2011.

	PRECIPTATION IN THE DAYS WITH HIGHEST AMOUNT (PEN2)				
	16/02/11	19/04/11	21/08/11	02/11/11	19/11/11
Daily Precipitation (in mm.)	22,7	14,1	18,6	13,7	22,7
Highest Hourly Precipitation (in mm.)	9,7 (05:00/06:00)	5,2 (22:00/23:00)	9,2 (20:00/21:00)	6,7 (12:00/13:00)	4,1 (01:00/02:00)

Table 21. Days with the highest amount of precipitation for PEN2 in 2011.

	PRECIPITATION IN THE DAYS WITH HIGHEST AMOUNT (VJE)				
	16/02/11	21/08/11	01/09/11	15/11/11	19/11/11
Daily Precipitation (in mm.)	**19,4**	**16,5**	**17,8**	**16,7**	**23,3**
Highest Hourly Precipitation (in mm.)	**6,4 (05:00/06:00)**	**9,2 (20:00/21:00)**	**4,4 (09:00/10:00)**	**4,6 (14:00/15:00)**	**4,4 (01:00/02:00)**

Table 22. Days with the highest amount of precipitation for VJE in 2011.

	CINF	PEN2	VJE
Jan. Average	**81,02%**	**79,77%**	**79%**
Feb. Average	**78,26%**	**76,18%**	**73,89%**
Mar. Average	**76,08%**	**77,37%**	**69,81%**
Apr. Average	**68,02%**	**70,46%**	**62,06%**
May Average	**61,50%**	**62,85%**	**59,73%**
Jun. Average	**45,27%**	**46,73%**	**44,37%**
Jul. Average	**40,50%**	**41,06%**	**41,42%**
Aug. Average	**45,43%**	**46,06%**	**45,23%**
Sep. Average	**52,85%**	**52,75%**	**49,24%**
Oct. Average	**55,97%**	**55,66%**	**53,39%**
Nov. Average	**85,83%**	**83,59%**	**84,51%**
Dec. Average	**85,08%**	**81,30%**	**83%**
Average	**64,65%**	**64,48%**	**62%**

Table 23. Relative humidity values for CINF, PEN2 and VJE in 2011.

	CINF	PEN2	VJE
Average (km/h)	**0,35**	**1,25**	**2,19**
Gust (km/h)	**56 (26/10)**	**54 (21/08)**	**51 (16/02)**

Table 24. Wind speed values for CINF, PEN2 and VJE in 2011.

Total (in Kcal/cm2)	CINF	PEN2	VJE
January	**3,74828958**	**4,10688279**	**4,01135688**
February	**6,44897763**	**6,78567366**	**6,89401953**
March	**9,32514426**	**9,55304271**	**10,01008719**
April	**14,43888864**	**14,4635391**	**15,99191064**
May	**18,23170392**	**18,41109732**	**19,79836326**
June	**19,58627466**	**20,75596695**	**22,13961921**
July	**20,00576268**	**21,89556675**	**22,86155934**
August	**16,86424869**	**16,74942831**	**18,63994221**
September	**13,34678292**	**13,09524498**	**14,37003513**
October	**9,71970219**	**10,17620892**	**7,50006378**
November	**3,89358963**	**4,32572553**	**4,27205808**
December	**3,56511042**	**4,15340892**	**3,68629776**
Year	**139,1744752**	**144,4717859**	**150,175313**

Table 25. Solar radiation values for CINF, PEN2 and VJE in the period in question.

SAMPLE	POROSITY PER CENT	WATER ABSORPTION CAPACITY PER CENT	SATURATION COEFFICIENT
S7 - D	0.36	0,24	0,68
S9 - D	0.06	**<u>0,03</u>**	0,47
S10 - P	0.45	0,25	**<u>0,45</u>**
S14 - P	**<u>0.05</u>**	**<u>0,03</u>**	0,52
S15 - P	**<u>0.64</u>**	0,5	0,77
S16 - P	0.13	0,09	0,69
S17 - P	0.09	0,05	0,60
S18 - P	0.46	**<u>0,44</u>**	0,52
S19 - D	0.05	0,04	**<u>0,83</u>**
S20 - D	0.07	0,04	0,62
S21 - D	0.18	0,12	0,67
S24 - D	0.08	0,05	0,67
AVERAGE	**0,21**	**0,15**	**0,62**
AVERAGE D	**0,13**	**0,08**	**0,65**
AVERAGE P	**0,30**	**0,22**	**0,59**

Table 26. Porosity analysis results. Highest and lowest results are underlined in bold.

ID # in Annex A	SITE	INTACT ROCK STRENGTH	ROCK MASS STRENGTH	TILTING OF OUTCROP FACE
1 - D	**Canada da Moreira**	37 - Weak	65 - Moderate	3º Forward
2 - D	**Canada do Amendoal**	45 - Moderate	78 -Strong	0º
3 - D	**Canada do Amendoal**	52 - Strong	**86 - Strong**	5º Forward
4 - D	**Canada do Amendoal**	45 - Moderate	75 - Strong	0º
5 - D	**Canada do Inferno**	47 - Strong	73 - Strong	5º Back
6 - D	**Canada do Inferno**	46 - Moderate	73 - Strong	2º Forward
7 - D	**Canada do Inferno**	**57 - Strong**	65 - Moderate	9º Forward
8 - D	**Canada do Inferno**	53 - Strong	75 - Strong	5º Forward
9 - D	**Fariseu**	43 - Moderate	65 - Moderate	10º Forward
10 - D	**Fariseu**	56 - Strong	72 - Strong	5ª Forward
11 - D	**Foz do Côa**	54 - Strong	71 - Strong	5º Forward
12 - D	**Foz do Côa**	51 - Strong	75 - Strong	9º Forward
13 - D	**Foz do Côa**	51 - Strong	75 - Strong	0º
14 - D	**Moinhos de Cima**	50 - Strong	80 - Strong	10º Forward
15 - P	**Penascosa**	39 - Weak	71 - Strong	5º Forward
16 - P	**Penascosa**	36 - Weak	78 - Strong	9º Back
17 - P	**Penascosa**	44 - Moderate	73 - Strong	20º Forward
18 - P	**Penascosa**	48 - Moderate	75 - Strong	30º Forward
19 - P	**Penascosa**	48 - Moderate	78 - Strong	0º
20 - P	**Penascosa**	52 - Strong	80 - Strong	5º Forward
21 - P	**Quinta da Barca**	40 - Weak	66 - Moderate	10º Back

22 - P	**Quinta da Barca**	**32 - Very weak**	**50 - Weak**	0º
23 - D	**Ribeira de Piscos**	**57 - Strong**	70 - Moderate	17º Forward
24 - D	**Ribeira de Piscos**	54 - Strong	69 - Moderate	2º Back
25 - D	**Ribeira de Piscos**	42 - Moderate	66 – Moderate	2º Forward
26 - D	**Ribeira de Piscos**	47 - Moderate	55 - Moderate	30º Forward
27 - D	**Tudão**	37 - Weak	77 - Strong	3º Forward
28 - D	**Vale de Cabrões**	49 - Moderate	68 - Moderate	5º Forward
29 - D	**Vale de Cabrões**	45 - moderate	80 - Strong	2º Back
30 - D	**Vale de Cabrões**	44 - Moderate	76 - Strong	0º
31 - D	**Vale do Forno I**	51 - Strong	72 - Strong	2º Back
32 - D	**Vale do Forno I**	44 - Moderate	72 - Strong	0º
33 - D	**Vale do Forno II**	53 - Strong	71 - Strong	10º Forward
34 - D	**Vale do Forno II**	48 - Moderate	68 - Moderate	10º Forward
35 - D	**Vale do José Esteves**	47 - Moderate	74 - Strong	8º Back
36 - D	**Vale do José Esteves**	44 - Moderate	75 - Strong	10º Forward
37 - D	**Vermelhosa**	52 - Strong	74 - Strong	0º
38 - D	**Vermelhosa**	48 - Moderate	61 - Moderate	0º
39 - D	**Vermelhosa**	41 - Moderate	65 - Moderate	1º Forward
40 - D	**Vermelhosa**	50 - Moderate	69 - Moderate	2º Forward
Average	**-**	**47**	**72**	**-**

Table 27. Intact rock strength, rock mass strength and tilting of outcrops faces measurements results. Highest and lowest results are underlined in bold.

	CHARACTERIZATION OF RISK				
PHYSICAL WEATHERING MECHANISMS	**V. INC. - 1**	**INC. - 2**	**MOD. - 3**	**SIG. - 4**	**V. SIG. - 5**
A - AVEOLIZATION	-	Holes affecting small and medium sized areas	Holes affecting major areas	Holes directly affecting small engraved areas	Holes directly affecting medium sized and major engraved areas
B - COLLAPSE	-	Small sized blocks	Medium sized blocks	Sizeable blocks	Engraved blocks
C - DIACLASE	Undeveloped (<5 cms. wide).	Developed (≥5 to ≤20 cms. wide). Small sediment deposits and few plants.	Well developed (≥20 cms). Small sediment deposits and few plants.	Well developed. Moderate presence of sediment and plants.	Well developed. Abundant presence of sediment and plants.
D - DIFFERENTIAL EROSION	-	Small sized affected areas	Medium affected areas	Sizable affected areas	Traces of partial loss of engraved motifs
E - DISCONNECTED BLOCKS/ELEMENTS	Small and medium sized disconnected blocks/elements	Sizeable disconnected blocks/elements	Small sized disconnected blocks/elements containing engravings	Medium sized disconnected blocks/elements containing engravings	Sizeable disconnected blocks/elements containing engravings
F - DISINTEGRATION/PULVERIZATION	-	Small sized affected areas	Medium sized affected areas	Sizeable affected areas	Directly affecting engraved areas
G - EXFOLIATION	-	Small sized affected areas	Medium sized affected areas	Sizeable affected areas	Directly affecting engraved areas
H - FISSURES	Undeveloped network (<10 fissures) of single orientation	Undeveloped network of multiple orientation	Developed network (≥10) with single orientation	Developed network with multiple orientation	Fissures directly affecting engraved areas
I - FRACTURES	Undeveloped network (<5 fractures) of single orientation	Undeveloped network of multiple orientation	Developed network (≥5 fractures) with single orientation	Developed network with multiple orientation	At least one fracture cuts engraved motifs
J - GAPPING/SPLINTERING	Small sized gaps not directly	Medium sized gaps not directly	Sizeable gaps not	Small gaps directly affecting	Medium and sizeable gaps directly

J - GAPPING/SPLINTERING	Small sized gaps not directly affecting engravings	Medium sized gaps not directly affecting engravings	Sizeable gaps not directly affecting engravings	Small gaps directly affecting engravings	Medium and sizeable gaps directly affecting engravings
K - SCALING	**-**	Imminence of individual fragment loss	Imminence of multiple fragment loss	Imminence of individual engraved fragment loss	Imminence of multiple engraved fragment loss
L - TOPPLING	-	Elements with minute dislocation amongst themselves	Elements with significant dislocation amongst	Elements with engravings and minute dislocation amongst	Elements with engravings and significant dislocation

Table 28. Table Physical Weathering risk scale.

ID # in Annex A	A	B	C	D	E	F	G	H	I	J	K	L	Σ
1	3	3	4	2	2	2	2	3	3	4	3	2	**33**
2	2	2	2	4	4	5	5	3	4	5	3	3	**42**
3	2	2	2	3	3	5	5	4	4	3	3	3	**39**
4	2	2	3	3	3	2	2	4	4	3	2	2	**32**
5	4	2	2	5	5	5	3	4	5	2	5	4	**46**
6	2	3	4	5	5	4	4	2	5	5	4	5	**49**
7	3	2	5	4	4	3	4	5	4	4	3	3	**44**
8	4	3	4	4	4	4	4	4	4	4	3	3	**45**
9	2	3	3	5	5	3	2	3	5	4	3	5	**43**
10	4	2	2	4	4	3	2	4	5	2	4	4	**40**
11	4	4	5	4	4	3	2	4	5	4	3	3	**45**
12	3	4	4	4	4	3	4	3	4	4	2	3	**41**
13	3	3	5	3	3	3	2	4	4	3	3	3	**39**
14	3	2	4	4	4	4	2	5	4	3	3	2	**40**
15	5	3	2	5	5	4	2	4	2	4	5	5	**46**
16	4	2	1	4	4	2	2	1	1	1	1	4	**27**
17	4	3	4	5	5	5	5	4	5	5	5	3	**53**
18	2	2	4	4	4	2	2	2	1	3	2	1	**29**
19	4	2	4	4	4	3	2	1	4	3	2	2	**35**
20	1	2	3	3	3	2	2	3	4	3	2	3	**31**
21	5	5	4	5	5	5	2	3	5	2	4	3	**48**
22	4	5	5	5	5	3	2	4	5	3	5	3	**49**
23	2	3	5	5	5	5	3	4	5	2	4	5	**48**
24	4	2	2	3	3	2	5	5	4	3	2	2	**37**
25	1	2	2	2	2	3	2	5	5	4	2	2	**32**
26	5	5	3	5	5	4	3	5	5	5	5	4	**54**
27	4	2	2	3	3	3	3	2	3	5	3	5	**38**
28	3	3	4	3	3	3	3	3	4	4	2	3	**38**
29	4	2	3	2	2	2	2	3	5	3	2	3	**33**
30	4	2	4	2	2	5	3	4	5	4	2	5	**42**
31	2	3	3	3	3	4	5	4	4	4	4	3	**42**
32	3	3	4	3	3	3	5	4	5	3	4	3	**43**
33	3	3	5	4	4	4	4	4	4	4	4	3	**46**
34	2	4	4	3	3	3	2	4	4	4	3	3	**39**
35	3	2	2	5	5	4	5	5	5	5	4	3	**48**
36	4	2	1	4	4	3	2	4	3	4	4	1	**36**
37	4	2	4	4	4	3	2	4	5	4	5	3	**44**
38	4	2	3	3	3	2	2	5	5	4	2	2	**37**
39	2	2	3	3	3	2	3	5	5	4	2	2	**36**
40	3	4	4	4	4	3	3	5	5	3	3	2	**83**

Table 29. Physical weathering risk characterization. Highest and lowest results are underlined.

ID #	SLOPE (FROM MAP)	SLOPE AT OUTCROP'S LOCATION (FROM DEM)	Σ AVERAGE	TILTING
1	41% - Very Strong Slope	47% - Extreme Slope	**44% - 2**	3º Forward
2	50% - Extreme Slope	100% - Very Steep Slope	**75% - 4**	0º
3	104% - Very Steep Slope	99% - Steep Slope	**101,5% - 5**	5º Forward
4	50% - Extreme Slope	65% - Extreme Slope	**57,5% - 3**	0º
5	41% - Very Strong Slope	54 % - Extreme Slope	**47,5% - 3**	5º Back
6	44% - Very Strong Slope	55 % - Extreme Slope	**49,5% - 3**	2º Forward
7	40% - Very Strong Slope	85% - Steep Slope	**62,5% - 3**	9º Forward
8	41% - Very Strong Slope	90% - Steep Slope	**65,5% - 3**	5º Forward
9	40% - Very Strong Slope	50% - Extreme Slope	**45% - 2**	10º Forward
10	42% - Very Strong Slope	53% - Extreme Slope	**47,5% - 3**	5ª Forward
11	57% - Extreme Slope	69% - Extreme Slope	**63% - 3**	5º Forward
12	60% - Extreme Slope	70% - Steep Slope	**65% - 3**	9º Forward
13	52% - Extreme Slope	60% - Extreme Slope	**56% - 3**	0º
14	40% - Very Strong Slope	33% - Very Strong Slope	**36,5% - 2**	10º Forward
15	39% - Very Strong Slope	60% - Extreme Slope	**49,5% - 3**	5º Forward
16	40% - Very Strong Slope	40% - Very Strong Slope	**40% - 2**	9º Back
17	40% - Very Strong Slope	40% - Very Strong Slope	**49% - 3**	20º Forward
18	43% - Very Strong Slope	67% - Extreme Slope	**55% - 3**	30º Forward
19	58% - Extreme Slope	95% - Steep Slope	**76,5% - 4**	0º
20	56% - Extreme Slope	90% - Steep Slope	**73% - 4**	5º Forward
21	42% - Very Strong Slope	29% - Strong Slope	**35,5% - 2**	10º Back
22	40% - Very Strong Slope	35% - Very Strong Slope	**37,5% - 2**	0º
23	83% - Steep Slope	60% - Extreme Slope	**71,5 - 4**	17º Forward
24	85% - Steep Slope	65% - Extreme Slope	**75% - 4**	2º Back
25	80% - Steep Slope	56% - Extreme Slope	**68% - 3**	2º Forward
26	71% - Steep Slope	54% - Extreme Slope	**62,5% -3**	30º Forward
27	9% - Moderate Slope	13% - Moderate Slope	**11% - 1**	3º Forward
28	75% - Steep Slope	65% - Extreme Slope	**70% - 3**	5º Forward
29	58% - Extreme Slope	76% - Steep Slope	**67% - 3**	2º Back
30	50% - Extreme Slope	38% - Very Strong Slope	**44% - 2**	0º

31	60% - Extreme Slope	52% - Extreme Slope	**56% - 3**	2º Back
32	63% - Extreme Slope	57% - Extreme Slope	**55% - 3**	0º
33	71% - Steep Slope	75% - Steep Slope	**73% - 4**	10º Forward
34	74% - Steep Slope	121% - Very Steep Slope	**85,5% - 4**	10º Forward
35	40% - Very Strong Slope	44% - Very Strong Slope	**42% - 2**	8º Back
36	43% - Very Strong Slope	32% - Very Strong Slope	**57,5% - 3**	10º Forward
37	83% - Steep Slope	64% - Extreme Slope	**73,5% - 4**	0º
38	83% - Steep Slope	62% - Extreme Slope	**72,5% - 4**	0º
39	76% - Steep Slope	45% - Extreme Slope	**60,5% - 3**	1º Forward
40	77% - Steep Slope	45% - Extreme Slope	**61% - 3**	2º Forward

Table 30. Slope risk characterization. The Table also features data regarding Tilting of outcrops faces for comparison purposes.

	CINF-B (º C)		
	Highest	**Average**	**Lowest**
January	**26.6º**	**9.3º**	**-3.1º**
February	**34.7º**	**11.5º**	**-1.8º**
March	**40.1º**	**15.2º**	**1.8º**
April	**46.5º**	**23.3º**	**9.4º**
May	**52.3º**	**27.4º**	**12.3º**
June	**57.1º**	**31º**	**13.2º**
July	**55.9º**	**33.1º**	**15.8º**
August	**58.3º**	**32.5º**	**14.7º**
September	**54.3º**	**29.1º**	**13.3º**
October	**50.4º**	**23.6º**	**6.4º**
November	**35.4º**	**13.4º**	**4.8º**
December	**33º**	**9.2º**	**-1.8º**
Highest/Lowest	**58.3º**	**-**	**-3.1º**
Year Average	**45.3º**	**21.5º**	**7º**
Nr. of days with temperature ≤ 0º	**13**		
Nr. of days with temperature ≥ 25º	**295**		

Table 31. Temperature values recorded by CINF-B in 2011.

	PEN2-B (º C)		
	Highest	Average	Lowest
January	22.2º	8.2º	-3º
February	29.3º	9.2º	-1.9º
March	34.2º	12.9º	0.9º
April	45.2º	20.3º	9.2º
May	50.1º	25º	10.9º
June	54.6º	36º	22.9º
July	55.3º	31.8º	15.8º
August	57.1º	31.1º	14.2º
September	50.9º	26.9º	12.1º
October	46.8º	20.7º	6.1º
November	27.2º	12.1º	5º
December	18.3º	7.5º	-1.5º
Highest/Lowest	57.1º	-	-3º
Year Average	40.9º	20.1º	7.5º
Nr. of days with temperature ≤ 0º	14		
Nr. of days with temperature ≥ 25º	235		

Table 32. Temperature values recorded by PEN2-B in 2011.

	CHARACTERIZATION OF BIODETERIORATION RISK				
Variable	**Very Incipient - 1**	**Incipient - 2**	**Moderate - 3**	**Significant - 4**	**Very Significant - 5**
Lichens	Rare undeveloped colonies	Developed colonies that cover relatively minute areas of panels	Well developed colonies that cover major non-engraved areas of panels	Colonies covering engraved areas	Totally (or almost totally) covered panels
Plants	No plants	Lower plants growing adjacent to outcrops	Lower and higher plants growing adjacent to outcrops	Lower plants growing on top of outcrops and/or from inside diaclases or fractures	Lower and higher plants growing on top of outcrops and/or from inside diaclases or fractures
Arthropods	Not observed	One species	Two species	More than two species	Colonies established in engraved areas

Table 33. Characterization of Biodeterioration risk.

ID #	LICHEN COLONIZATION	PLANTS	ARTHROPODS	TOTAL
1	Moderate - 3	Significant – 4 (E)	Significant - 4	**3,7**
2	Moderate - 3	Significant – 4 (W)	Moderate - 3	**3,9**
3	Incipient - 2	Very Significant – 5 (S)	Moderate - 3	**3,9**
4	Moderate - 3	Very Significant – 5 (N)	Significant - 4	**4,4**
5	Incipient – 2 (R)	Significant – 4 (E)	Very Incipient - 1	**3,1**
6	Incipient – 2 (R)	Significant – 4 (E)	Very Incipient - 1	**3,1**
7	Very Incipient – 1 (R)	Very Significant – 5 (E)	Significant - 4	**3,7**
8	Significant – 4 (R)	Significant – 4 (E)	Significant - 4	**4**
9	Very Incipient – 1	Significant – 4 (N)	Very Significant - 5	**3,2**
10	Moderate – 3 (R)	Significant – 4 (E)	Significant - 4	**3,7**
11	Incipient - 2	Very Significant – 5 (E)	Significant - 4	**4**
12	Incipient - 2	Very Significant – 5 (E)	Significant - 4	**4**
13	Moderate - 3	Very Significant – 5 (S)	Significant - 4	**4,3**
14	Incipient – 2 (R)	Significant – 4 (E)	Moderate - 3	**3,3**
15	Moderate – 3 (R)	Significant – 4 (W)	Very Incipient - 1	**3,4**
16	Very Incipient – 1 (R)	Significant – 4 (W)	Very Incipient - 1	**2,8**
17	Incipient – 2 (R)	Significant – 4 (W)	Incipient - 2	**3,2**
18	Significant – 4 (R)	Significant – 4 (W)	Very Incipient - 1	**3,7**
19	Very Incipient – 1 (R)	Significant – 4 (W)	Significant - 4	**3,1**
20	Incipient – 2 (R)	Moderate – 3 (W)	Incipient - 2	**2,6**
21	Moderate – 3 (R)	Significant – 4 (E)	Significant - 4	**3,7**
22	Very Significant –5 (R)	Very Significant – 5 (S)	Significant - 4	**4,9**
23	Very Incipient – 1 (R)	Significant – 4 (E)	Significant - 4	**3,1**
24	Very Incipient – 1 (R)	Moderate – 3 (E)	Significant - 4	**2,5**
25	Very Incipient – 1 (R)	Moderate – 3 (E)	Very Significant - 5	**2,6**
26	Incipient – 2 (R)	Significant – 4 (E)	Significant - 4	**3,4**
27	Significant – 4 (R)	Very Significant – 5 (S)	Moderate - 3	**4,5**
28	Moderate – 3 (R)	Very Significant – 5 (E)	Significant - 4	**4,3**
29	Moderate – 3 (R)	Significant – 4 (E)	Significant - 4	**3,7**
30	Significant – 4 (R)	Significant – 4 (S)	Significant - 4	**4**

31	Moderate – 3 (R)	Very Significant – 5 (S)	Significant - 4	**4,3**
32	Moderate - 3	Moderate – 3 (S)	Significant - 4	**3,1**
33	Moderate – 3	Very Significant – 5 (E)	Significant - 4	**4,3**
34	Significant – 4 (R)	Very Significant – 5 (E)	Significant - 4	**4,6**
35	Very Incipient – 1 (R)	Very Significant – 5 (N)	Significant - 4	**3,7**
36	Moderate – 3	Significant – 4 (S)	Very Incipient - 1	**3,4**
37	Moderate – 3 (R)	Moderate – 3 (S)	Significant - 4	**3,1**
38	Significant – 4	Moderate – 3 (S)	Significant - 4	**3,4**
39	Very Incipient – 1 (R)	Moderate – 3 (S)	Significant - 4	**2,5**
40	Moderate – 3 (R)	Significant – 4 (S)	Significant - 4	**3,7**
TOTAL	**102**	**164**	**136**	

Table 34. Biodeterioration risk assessment.

	RELATIONSHIP BETWEEN LICHEN COLONIZATION CONDITION ASSESSMENT AND ASPECT				
Aspect	**Very Incipient - 1**	**Incipient - 2**	**Moderate - 3**	**Significant - 4**	**Very Significant - 5**
East	-	2	2	-	-
South	-	1	3	1	-
West	-	-	1	-	-
North	1	-	1	-	-

Table 35. Relationship between Lichen colonization condition assessment and Aspect.

Just the 12 panels in which lichens were not removed are considered

	RELATIONSHIP BETWEEN VEGETATION CONDITION ASSESSMENT AND ASPECT				
Aspect	**Very Incipient - 1**	**Incipient - 2**	**Moderate - 3**	**Significant - 4**	**Very Significant - 5**
East	-	2	-	10	6
South	-	-	4	3	5
West	-	-	1	6	-
North	-	-	-	1	2

Table 36. Relationship between Vegetation condition assessment and Aspect.

LOCATION OF OUTCROPS	CHARACTERIZATION OF RISK
Above flood level	Inexistent
More than 6 m above normal river level	Moderate
Up to 6 m above normal river level	Very Significant

Table 37. Characterization of flooding risk.

ID #	RISK	ID #	RISK
4	Moderate	17	Very Significant
5	Very Significant	18	Moderate
6	Very Significant	21	Very Significant
9	Moderate	23	Very Significant
10	Moderate	24	Very Significant
15	Very Significant	26	Very Significant
16	Very Significant		

Table 38. Flooding risk assessment.

		RISK INDICATORS				
RISK CAT.	**%**	**1**	**2**	**3**	**4**	**5**
A	**10**	V. Strong r= 3	Strong r=5	Moderate r=7	Weak r=9	V. Weak r=10
B	**10**	1º - 4º r=3	5º - 9º r=5	10º - 19º r=7	20º - 29º r=9	≥ 30º r=10
C	**30**	V. Incip. r=8	Incip. r=15	Moderate r=21	Signif. r=28	V. Signif. r=30
D	**10**	V. Incip. r=3	Incip. r=5	Moderate r=7	Signif. r=9	V. Signif. r=10
E	**20**	2,5 – 2,9 r=5	3 – 3,4 r=9	3,5 – 3,9 r=14	4 – 4,4 r=18	4,5 – 4,9 r=20
F	**20**	-	-	Moderate r=14	-	V. Signif. r=20

Table 39. Intervention urgency scale risk indicators ranking.

Outcrop ID	A	B	C	D	E	F	Σ	ASP.
26 – R. Piscos 24	Moderate r=7	≥ 30º r=10	V. Signif. r=30	Moderate r=7	3 – 3,4 r=9	V. Signif. r=20	**83**	**E**
21 – Q. Barca 1	Moderate r=7	10º - 19º r=7	Signif. r=28	Incip. r=5	3,5 – 3,9 r=14	V. Signif. r=20	**81**	**E**
17 – Penascosa 5	Strong r=5	20º - 29º r=9	V. Signif. r=30	Moderate r=7	3 – 3,4 r=9	V. Signif. r=20	**80**	**W**
23 – R. Piscos 1	Moderate r=7	10º - 19º r=7	Signif. r=28	Signif. r=9	3 – 3,4 r=9	V. Signif. r=20	**80**	**E**
15 – Penascosa 3	Strong r=5	5º - 9º r=5	Signif. r=28	Moderate r=7	3 – 3,4 r=9	V. Signif. r=20	**74**	**W**
5 – C. Inferno 1	Strong r=5	5º - 9º r=5	Signif. r=28	Moderate r=7	3 – 3,4 r=9	V. Signif. r=20	**74**	**E**
10 – Fariseu 8	Strong r=5	5º - 9º r=5	Signif. r=28	Moderate r=7	3,5 – 3,9 r=14	Moderate r=14	**73**	**E**
6 – C. Inferno 2	Strong r=5	1º - 4º r = 3	Signif. r=28	Moderate r=7	3 – 3,4 r=9	V. Signif. r=20	**72**	**E**
9 – Fariseu 2	Moderate r=7	10º - 19º r=7	Signif. r=28	Incip. r=5	3 – 3,4 r=9	Moderate r=14	**70**	**N**
33 – V. Forno II 5	Strong r=5	10º - 19º r=7	Signif. r=28	Signif. r=9	4 – 4,4 r=18	-	**67**	**E**
4 – C. Amendoal 3	Strong r=5	-	Moderate r=21	Moderate r=7	4 – 4,4 r=18	Moderate r=14	**65**	**N**
18 – Penascosa 6	Strong r=5	≥ 30º r=10	Incip. r=15	Moderate r=7	3,5 – 3,9 r=14	Moderate r=14	**65**	**W**
24 – R. Piscos 2	Moderate r=7	1º - 4º r=3	Moderate r=21	Signif. r=9	2,5 – 2,9 r=5	V. Signif. r=20	**65**	**E**
34 – V. Forno II 6	Moderate r=7	10º - 19º r=7	Moderate r=21	Signif. r=9	4,5 – 4,9 r=20	-	**64**	**E**
8 – C. Inferno 14	Strong r=5	5º - 9º r=5	Signif. r=28	Moderate r=7	4 – 4,4 r=18	-	**63**	**E**
11 – Foz do Côa 14	Strong r=5	5º - 9º r=5	Signif. r=28	Moderate r=7	4 – 4,4 r=18	-	**63**	**E**
12 – Foz do Côa 16	Strong r=5	5º - 9º r=5	Signif. r=28	Moderate r=7	4 – 4,4 r=18	-	**63**	**E**
22 – Q. Barca 3	Weak r=9	-	Signif. r=28	Incip. r=5	4,5 – 4,9 r=20	-	**62**	**S**
7 – C. Inferno 13	Moderate r=7	5º - 9º r=5	Signif. r=28	Moderate r=7	3,5 – 3,9 r=14	-	**61**	**E**
31 – V. Forno I 1	Strong r=5	1º - 4º r=3	Signif. r=28	Moderate r=7	4 – 4,4 r=18	-	**61**	**S**
40 – Vermelhosa 4	Moderate r=7	1º - 4º r = 3	Signif. r=28	Moderate r=7	3,5 – 3,9 r=14	-	**59**	**S**
27 – Tudão 1	Strong r=5	1º - 4º r = 3	Moderate r=21	V. Incip. r = 3	4,5 – 4,9 r=20	-	**58**	**S**
28 – V. Cabrões 1	Moderate r=7	5º - 9º r=5	Moderate r=21	Moderate r=7	4 – 4,4 r=18	-	**58**	**E**

35 – V. J. Esteves 16	Strong r=5	5º - 9º r=5	Signif. r=28	Incip. r=5	3,5 – 3,9 r=14	-	57	**N**
2 – C. Amendoal 1	Strong r=5	-	Signif. r=28	Signif. r=9	3,5 – 3,9 r=14	-	56	**W**
30 – V. Cabrões 5	Strong r=5	-	Signif. r=28	Incip. r=5	4 – 4,4 r=18	-	56	**S**
3 – C. Amendoal 2	Strong r=5	5º - 9º r=5	Moderate r=21	V. Signif. r=10	3,5 – 3,9 r=14	-	55	**S**
16 – Penascosa 4	Strong r=5	5º - 9º r=5	Incip. r=15	Incip. r=5	2,5 – 2,9 r=5	V. Signif. r=20	55	**W**
14 – Moinhos de Cima 7	Strong r=5	10º - 19º r=7	Signif. r=28	Incip. r=5	3 – 3,4 r=9	-	54	**E**
13 – Foz do Côa 93	Strong r=5	-	Moderate r=21	Moderate r=7	4 – 4,4 r=18	-	51	**S**
37 – Vermelhosa 1	Strong r=5	-	Signif. r=28	Signif. r=9	3 – 3,4 r=9	-	51	**S**
1 – C. Moreira 2	Moderate r=7	1º - 4º r = 3	Moderate r=21	Incip. r=5	3,5 – 3,9 r=14	-	50	**E**
29 – V. Cabrões 4	Strong r=5	1º - 4º r=3	Moderate r=21	Moderate r=7	3,5 – 3,9 r=14	-	50	**E**
32 – V. Forno I 9	Strong r=5	-	Signif. r=28	Moderate r=7	3 – 3,4 r=9	-	49	**S**
36 – V. J. Esteves 17	Strong r=5	10º - 19º r=7	Moderate r=21	Moderate r=7	3 – 3,4 r=9	-	49	**S**
38 – Vermelhosa 2	Moderate r=7	-	Moderate r=21	Signif. r=9	3 – 3,4 r=9	-	46	**S**
20 – Penascosa 17	Strong r=5	5º - 9º r=5	Moderate r=21	Signif. r=9	2,5 – 2,9 r=5	-	45	**W**
19 – Penascosa 10	Strong r=5	-	Moderate r=21	Signif. r=9	3 – 3,4 r=9	-	44	**W**
25 – R. Piscos 3	Moderate r=7	1º - 4º r = 3	Moderate r=21	Moderate r=7	2,5 – 2,9 r=5	-	43	**E**
39 – Vermelhosa 3	Moderate r=7	1º - 4º r = 3	Moderate r=21	Moderate r=7	2,5 – 2,9 r=5	-	43	**S**

Table 40. Intervention urgency scale.

ANNEXES

ANNEX A – DATABASE OF COLLECTED INFORMATION REGARDING THE CONDITION OF ANALYSED OUTCROPS[120]

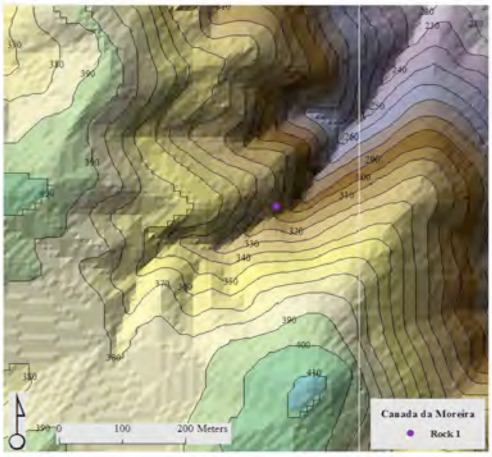
Rock: Canada da Moreira 2 — Nr: 1

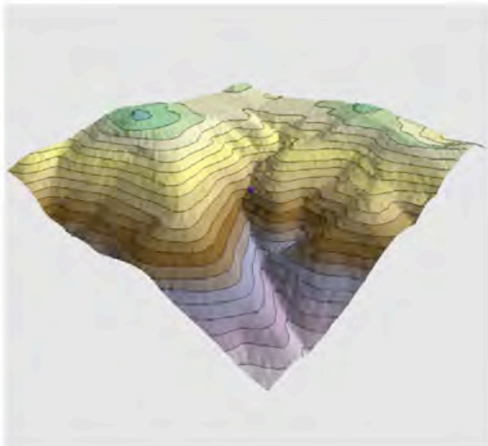
DESCRIPTION:

Medium sized outcrop measuring (6x0,50 m) with several small panels onto which Iron Age motifs (hunting scenes and horsemen) have been engraved. Rock 2 also features Historical Period motifs.

Canada da Moreira is a rock art site with 17 engraved panels located in a narrow waterline valley of SW-NE orientation starting at an altitude of 420 m and ending at 220 m with it's confluence with Ribeira (="Creek") do Picão, which is a left bank tributary of the Douro. The site possesses some of the most appealing aurochsen representations in the region. Nevertheless, Iron Age representations should be highlighted, namely the hunting scenes present in Rocks 1 and 2 .

Location: -7,08905/41,06268





Altitude: 310 m

Risk from flooding episodes: None

Date Created: 2010/03/30

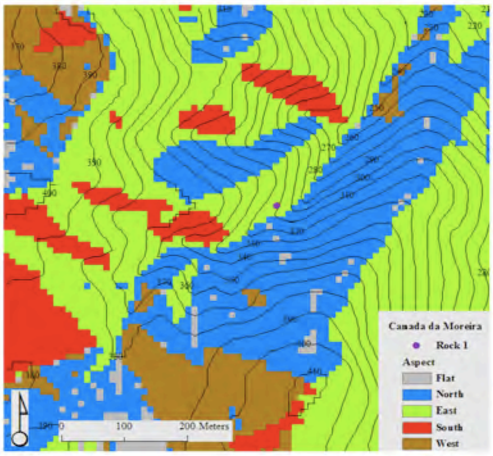
Last Modified: 2012/05/29

[120] Graphics and photos are by the author unless stated otherwise. Other author abbreviations correspond to: AMB – António Martinho Baptista; FB – Fernando Barbosa; MA – Manuel Almeida; MR – Mário Reis and PG – Pedro Guimarães.

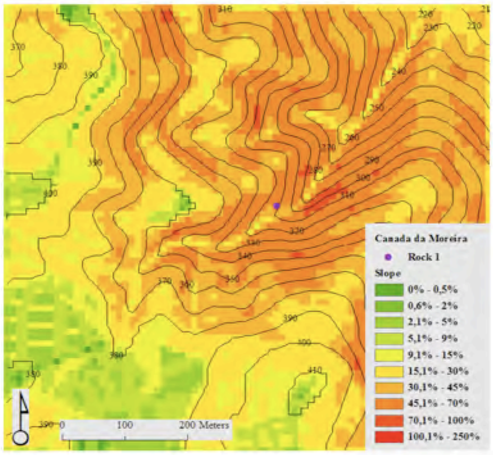
Rock: Canada da Moreira 2

Nr: 1

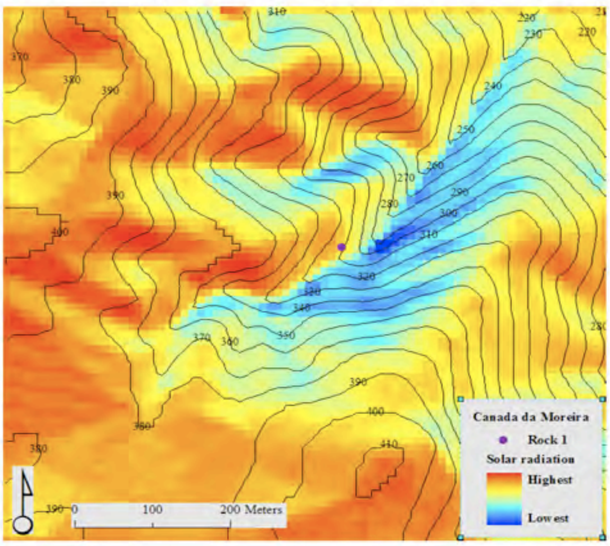
Aspect from DEM: 115º - E Field: Same Value



Slope from DEM: 47% Field: Same Value



Solar radiation: 1193797 KW/M^2



Rock: Canada da Moreira 2

Nr: 1

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 37 - WEAK

Rock mass strength : 65 - MODERATE

Porosity: DESEJOSA

Tilting of panel/outcrop: 3º FORWARD

- Physical weathering

Aveolization: MODERATE

Exfoliation: INCIPIENT

Collapse: MODERATE

Fissures: MODERATE

Diaclase: SIGNIFICANT

Fractures: MODERATE

Differential Erosion: INCIPIENT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: INCIPIENT

Scaling: MODERATE

Disintegration - Pulverization: INCIPIENT

Toppling: INCIPIENT

Rock: Canada da Moreira 2

Nr: 1

- Biodeterioration

Lichens: MODERATE

Plants: SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Iron Age horseman measuring 10x15 cm. (Photo: MR).

Another Iron Age horseman measuring 10x15cm. Note a fissure cutting the motif in to two distinct planes.

Biological colonization: unknown blue organism (fungus?) and spider webs in fracture.

Historical Period anthropomorphic motif.

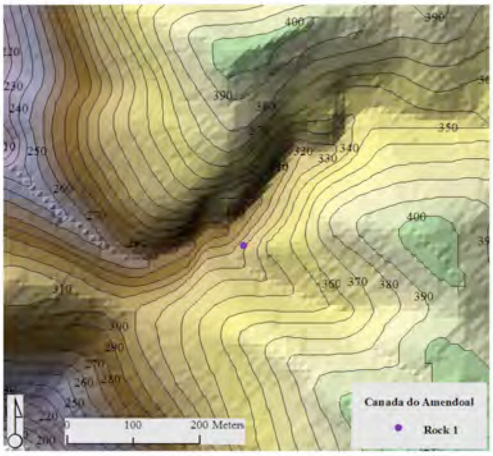
Rock: Canada do Amendoal 1 Nr: 2

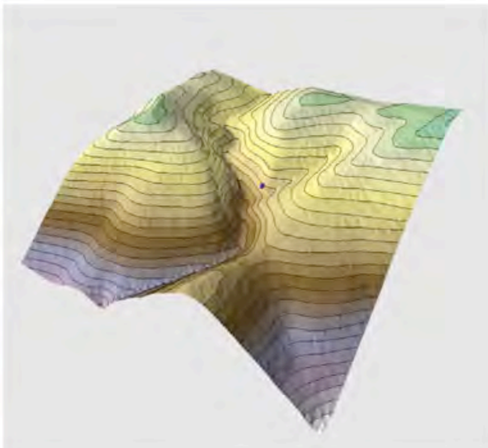
DESCRIPTION:

Very large outcrop (60x25 m) that constitutes a major part of the slope where it is located. Iron Age motifs (2 horses and loose lines) are located in a very small panel (15x40 cm). The outcrop surrounding the reasonably well preserved engraved panel presents heavy exfoliation and a black cover - probably hibernating bacteria (Joana Marques personal communication) that indicates the presence of seasonal superficial water runoff.

Canada do Amendoal is a rock art site with 7 engraved panels located in a narrow, sinuous and rocky waterline valley of preferential SE-NW orientation. The river down cutting process originated a very abrupt profile and a waterline's short length. In fact, it starts at an altitude of circa 350 m and converges with the right margin of the Côa, at an elevation of circa 130 m, in less than 100 m. Amongst the identified panels, 6 possess Upper Paleolithic motifs - mainly striped figures -, 3 have Iron Age figures and one has the representation of a Historical Period warrior.

Location: -7,10269/41,05524





Altitude: 310 m

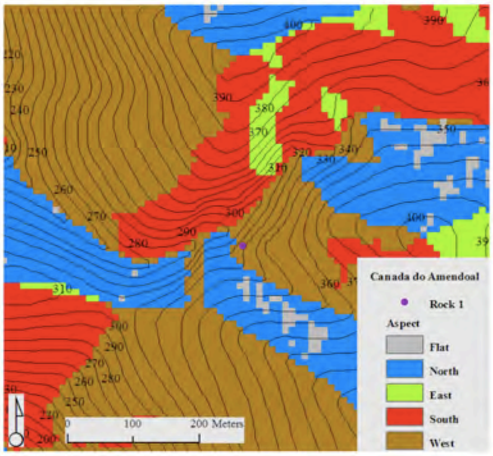
Risk from flooding episodes: None

Date Created: 2010/04/26

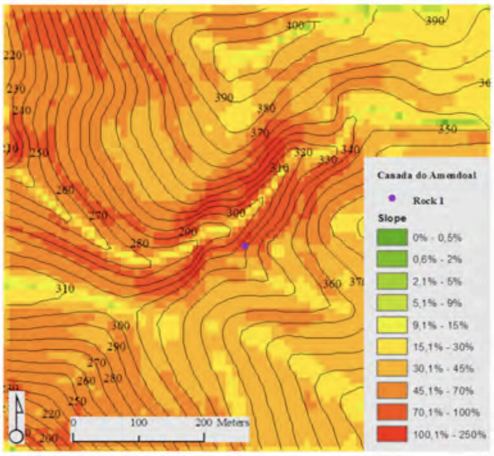
Last Modified: 2012/05/29

Rock: Canada do Amendoal 1 Nr: 2

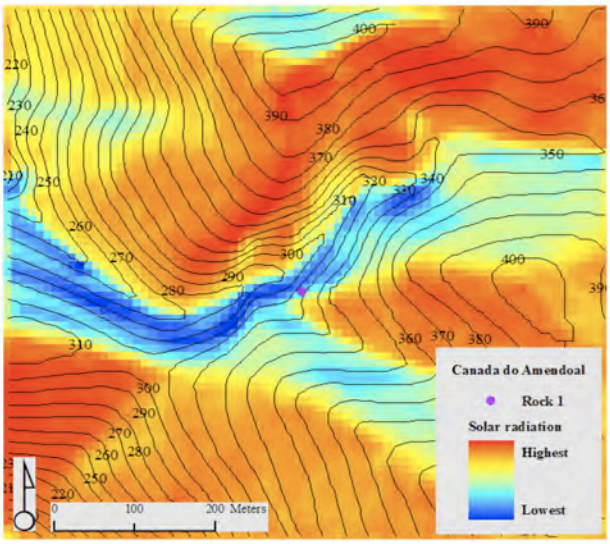
Aspect from DEM: 293º - W Field: Same Value



Slope from DEM: 59% Field: 100%



Solar radiation: 994649 KW/M^2



Rock: Canada do Amendoal 1

Nr: 2

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 45 - MODERATE

Rock mass strength : 78 -STRONG

Porosity:

Tilting of panel/outcrop: 0°

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: VERY SIGNIFICANT

Collapse: INCIPIENT

Fissures: MODERATE

Diaclase: INCIPIENT

Fractures: SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: VERY SIGNIFICANT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: VERY SIGNIFICANT

Toppling: MODERATE

Rock: Canada do Amendoal 1

Nr: 2

- Biodeterioration

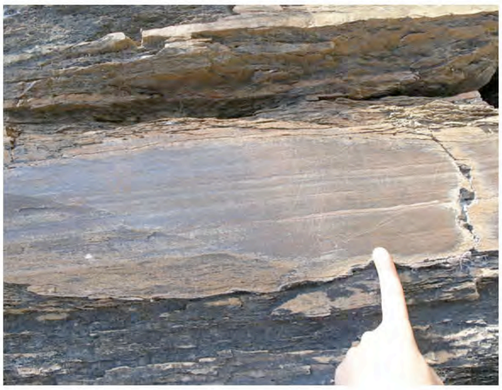
Lichens: MODERATE

Plants: SIGNIFICANT

Insects: MODERATE

- Further photos

Iron Age Schematic horse motif measuring 10x15 cm.



Engraved panel. Note the black bacteria cover around the panel.

Section of the outcrop containing the engraved panel.

Whole slope where the outcrop that contains the engraved panel is located.

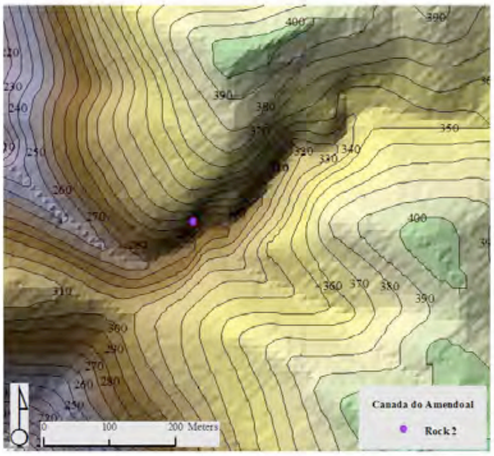
Rock: Canada do Amendoal 2 Nr: 3

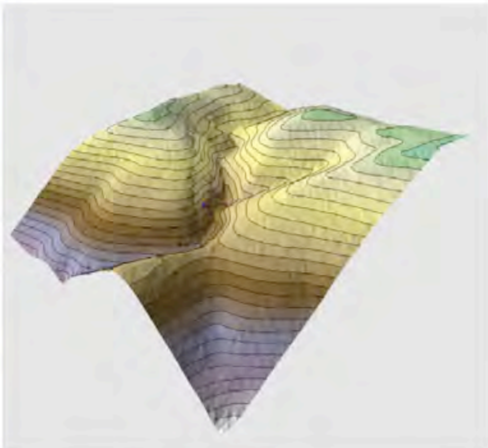
DESCRIPTION:

Very large outcrop (40x30 m) that constitutes a substantial part of the slope where it is located, although to a lesser extent than the previous outcrop. It features few and very small and scattered Upper Paleolithic and Iron Age motifs.

Canada do Amendoal is a rock art site with 7 engraved panels located in a narrow, sinuous and rocky waterline valley of preferential SE-NW orientation. The river down cutting process originated a very abrupt profile and a waterline's short length. In fact, it starts at an altitude of circa 350 m and converges with the right margin of the Côa, at an elevation of circa 130 m, in less than 100 m. Amongst the identified panels, 6 possess Upper Paleolithic motifs - mainly striped figures -, 3 have Iron Age figures and one has the representation of a Historical Period warrior.

Location: -7,10359/41,05559





Altitude: 300 m

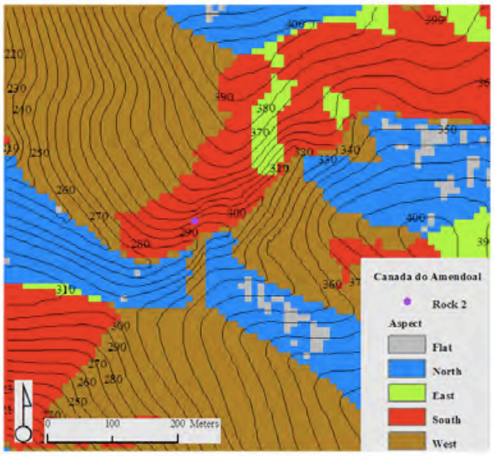
Risk from flooding episodes: None

Date Created: 2010/04/26

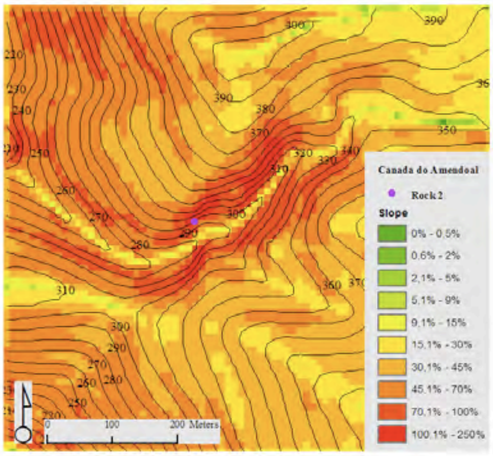
Last Modified: 2012/05/29

Rock: Canada do Amendoal 2 Nr: 3

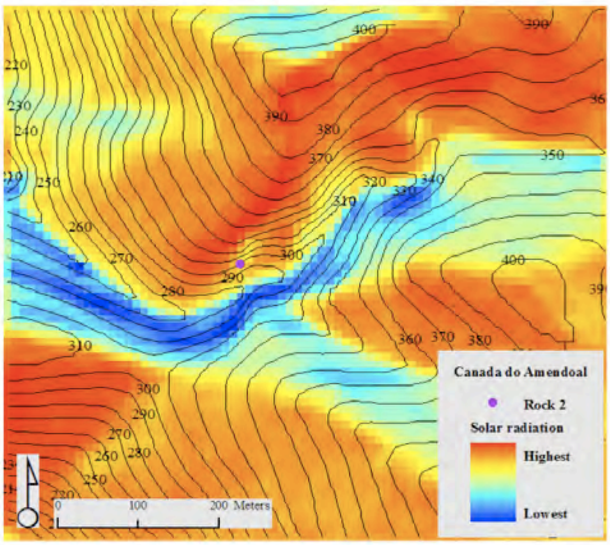
Aspect from DEM: 144º - S Field: Same Value



Slope from DEM: 99% Field: Same Value



Solar radiation: 1183005 KW/M^2



Rock: Canada do Amendoal 2

Nr: 3

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 52 - STRONG

Rock mass strength : 86 - STRONG

Porosity:

Tilting of panel/outcrop: 5º FORWARD

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: VERY SIGNIFICANT

Collapse: INCIPIENT

Fissures: SIGNIFICANT

Diaclase: INCIPIENT

Fractures: SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: MODERATE

Scaling: MODERATE

Disintegration - Pulverization: VERY SIGNIFICANT

Toppling: MODERATE

Rock: Canada do Amendoal 2

Nr: 3

- Biodeterioration

Lichens: INCIPIENT

Plants: VERY SIGNIFICANT

Insects: MODERATE

- Further photos

Outcrop corresponding to Rock 2 in its slope.

Facing slopes that contain Rock 2 (left) and Rock 1 (right).

Small Upper Paleolithic stripped representation of a doe (dimensions: 15x10 cm.). (Photo: MR).

Very small Upper Paleolithic quadruped motif (dimensions: 7x4 cm.). (Photo: MR).

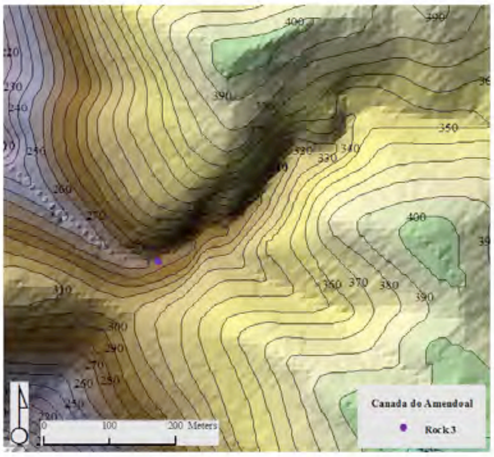
Rock: Canada do Amendoal 3 Nr: 4

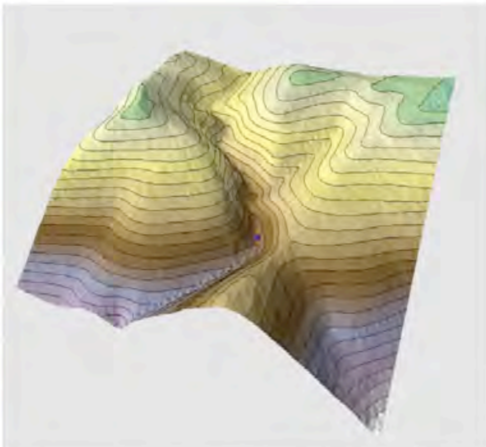
DESCRIPTION:

Medium sized outcrop measuring 10x2 m located very close (less than 1,5 m) to the waterline that names the Valley. In spite of this proximity, traces of seasonal flooding are not observable on the outcrop since, for instance, lichens grow almost from top to bottom. Nevertheless, it is very likely that high precipitation episodes flood the lowest part of the outcrop where few and less developed lichen colonies are present. It features Upper Paleolithic, Iron Age and Historical Period motifs.

Canada do Amendoal is a rock art site with 7 engraved panels located in a narrow, sinuous and rocky waterline valley of preferential SE-NW orientation. The river down cutting process originated a very abrupt profile and a waterline's short length. In fact, it starts at an altitude of circa 350 m and converges with the right margin of the Côa, at an elevation of circa 130 m, in less than 100 m. Amongst the identified panels, 6 possess Upper Paleolithic motifs - mainly striped figures -, 3 have Iron Age figures and one has the representation of a Historical Period warrior.

Location: -7,10423/41,05502





Altitude: 270 m

Risk from flooding episodes: Moderate

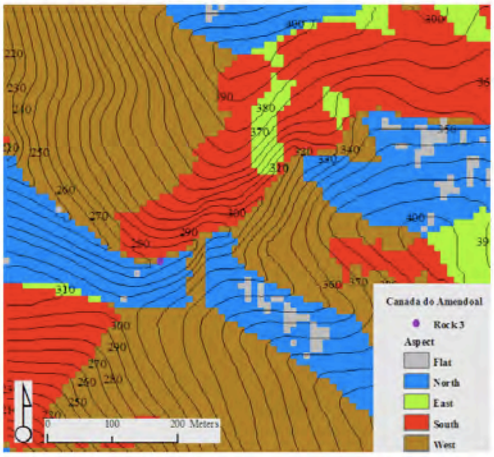
Date Created: 2010/04/26

Last Modified: 2012/05/29

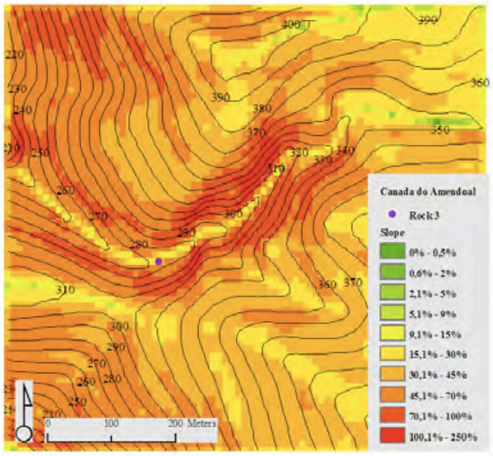
Rock: Canada do Amendoal 3

Nr: 4

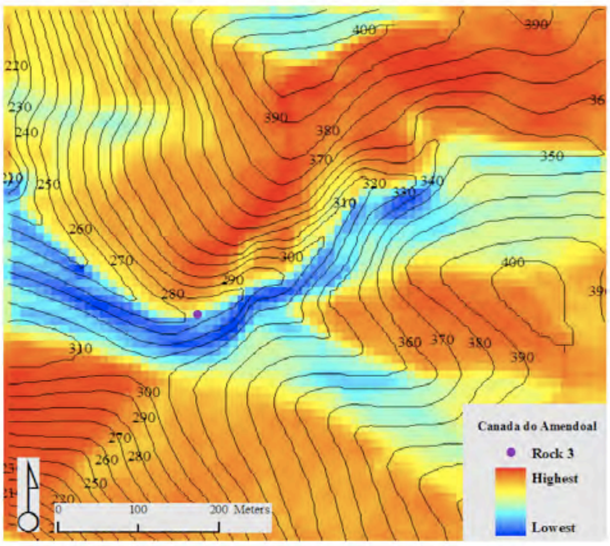
Aspect from DEM: 323º - N Field: Same Value



Slope from DEM: 38% Field: 65%



Solar radiation: 919760 KW/M^2



Rock: Canada do Amendoal 3

Nr: 4

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 45 - MODERATE

Rock mass strength : 75 - STRONG

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: SIGNIFICANT

Diaclase: MODERATE

Fractures: SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: MODERATE

Scaling: INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: INCIPIENT

Rock: Canada do Amendoal 3

Nr: 4

- Biodeterioration

Lichens: MODERATE

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Historical Period anthropomorphic figure in Rock 3 measuring 10x20 cm. (Photo: MR).

Anthropomorphic motif's head. (Photo: MR).

Lichen colonization. (Photo: MR).

Rock 3 seen from above in a photo taken during spring. (Photo: MR).

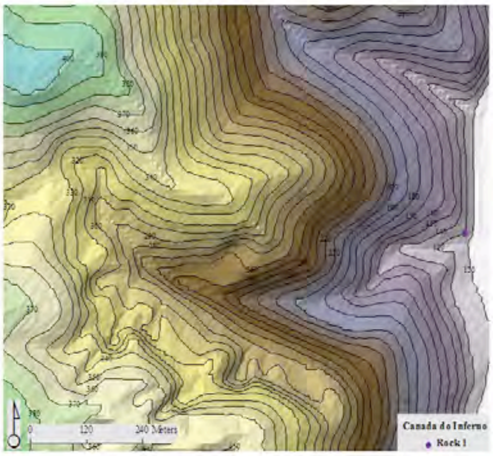
Rock: Canada do Inferno 01 Nr: 5

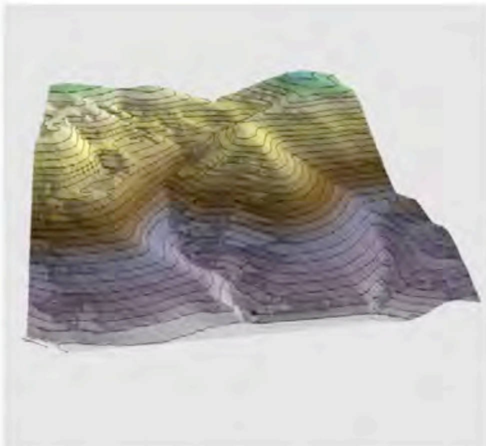
DESCRIPTION:

First rock art outcrop found in the Côa Valley, back in 1991 (although public disclosure of the find only occurred in 1994). Medium sized outcrop measuring 6x2 m. It features only Archaic Period Upper Paleolithic representations, all located in the Upper part of the panel, with the exception of an incomplete quadruped motif.

Canada do Inferno was the first identified Upper Paleolithic rock art site in the Côa Valley. It is located in an ancient fluvial beach on the left margin of the river, being the 43 engraved panels distributed along the overhanging slope. The quantity and quality of Upper Paleolithic figures should be highlighted, albeit the fact most became submerged since construction of the Pocinho dam. Several motifs of modern and contemporary chronology are also present in the site.

Location: -7,11240/41,05458





Altitude: 130 m

Risk from flooding episodes: Significant

Date Created: 2010/04/26

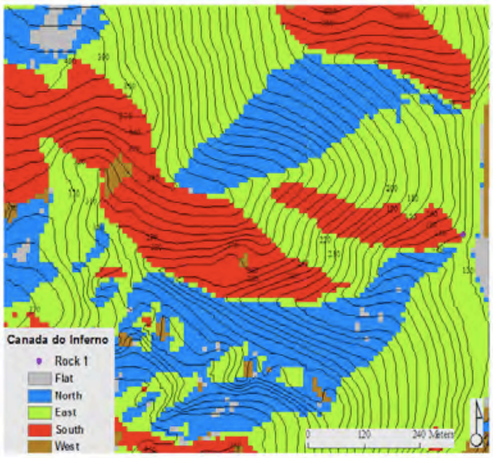
Last Modified: 2012/06/14

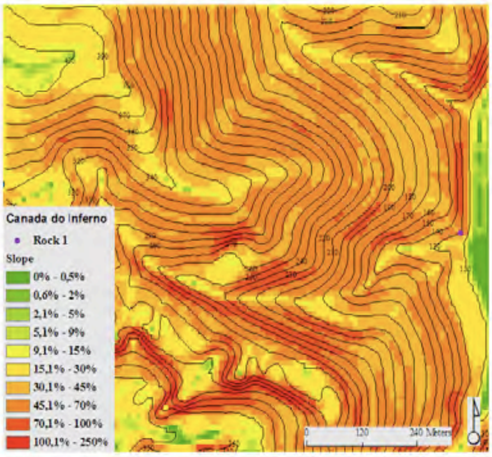
Rock: Canada do Inferno 01

Nr: 5

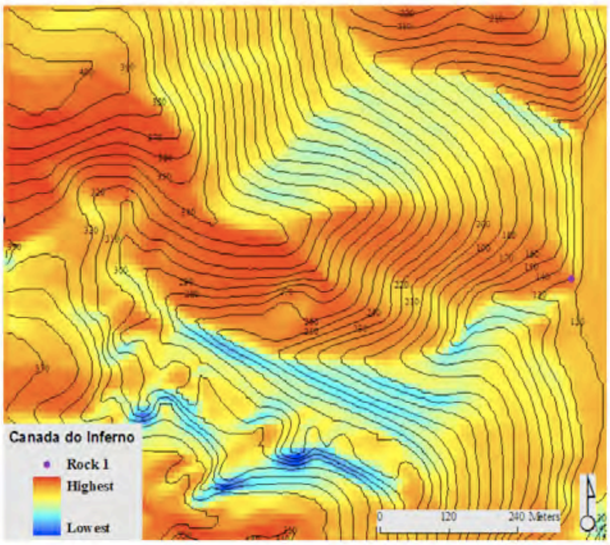
Aspect from DEM: 127° - E Field: Same Value

Slope from DEM: 54% Field: Same Value





Solar radiation: 1195328 KW/M^2



Rock: Canada do Inferno 01

Nr: 5

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 47 - STRONG

Rock mass strength : 73 - STRONG

Porosity:

Tilting of panel/outcrop: 5º BACK

- Physical weathering

Aveolization:	SIGNIFICANT	Exfoliation:	MODERATE
Collapse:	INCIPIENT	Fissures:	SIGNIFICANT
Diaclase:	INCIPIENT	Fractures:	VERY SIGNIFICANT
Differential Erosion:	VERY SIGNIFICANT	Gapping - Splintering:	INCIPIENT
Dislocated Blocks/Elements:	VERY SIGNIFICANT	Scaling:	VERY SIGNIFICANT
Disintegration - Pulverization:	VERY SIGNIFICANT	Toppling:	SIGNIFICANT

Rock: Canada do Inferno 01

Nr: 5

- Biodeterioration

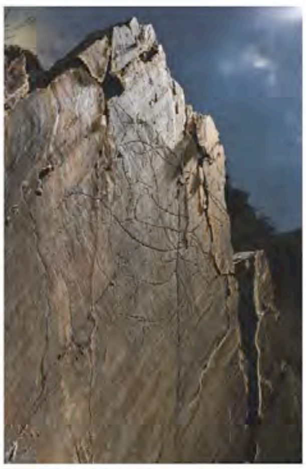
Lichens:	INCIPIENT - CLEANED
Plants:	SIGNIFICANT
Insects:	VERY INCIPIENT

- Further photos

Total slope where Rocks 1 and 2 are located, only fully visible when the Côa River lowers to its natural level. (Photo: AMB)

Rock 1 featuring only Upper Paleolithic rock art. (Photo: PG).

Rock 1 different engraving phases. 1 - No highlight. 2 - All motifs highlighted. (Drawing: FB).



Another view of Rock 1. Note disconnected and slightly detached blocks containing engravings. (Photo: PG).

Rock: Canada do Inferno 02

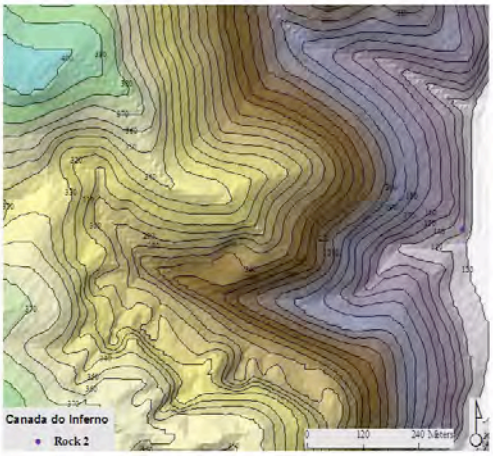
Nr: 6

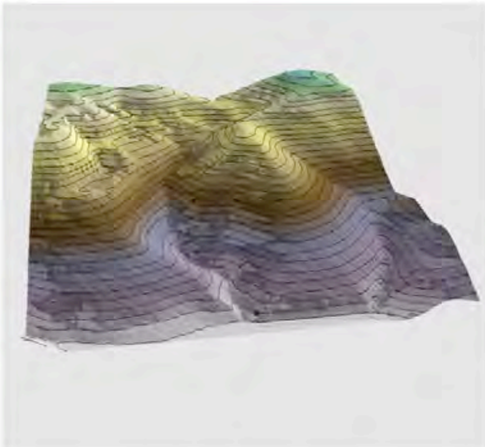
DESCRIPTION:

Located very near to Rock 1, this medium sized outcrop measures 4x2 m. It is situated very close to the Côa River normal level which makes photographing it in its entirety impossible without the use of a boat. It only possesses Upper Paleolithic imagery.

Canada do Inferno was the first identified Upper Paleolithic rock art site in the Côa Valley. It is located in an ancient fluvial beach on the left margin of the river, being the 43 engraved panels distributed along the overhanging slope. The quantity and quality of Upper Paleolithic figures should be highlighted, albeit the fact most became submerged since construction of the Pocinho dam. Several motifs of modern and contemporary chronology are also present in the site.

Location: -7,11239/41,05465





Altitude: 130 m

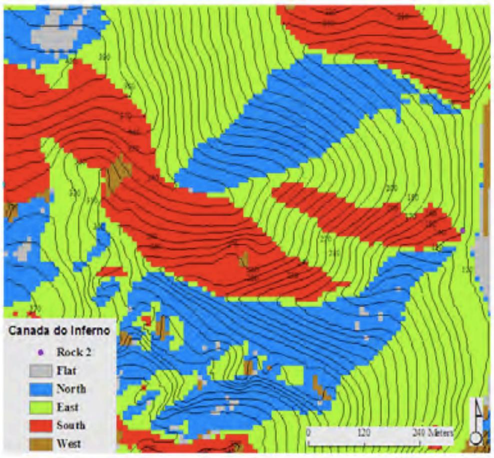
Risk from flooding episodes: Significant

Date Created: 2010/04/26

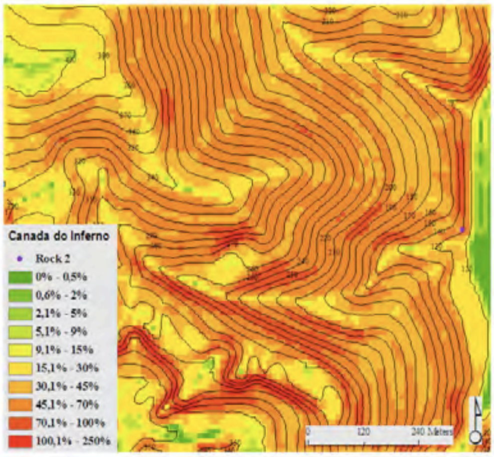
Last Modified: 2012/06/14

Rock: Canada do Inferno 02 Nr: 6

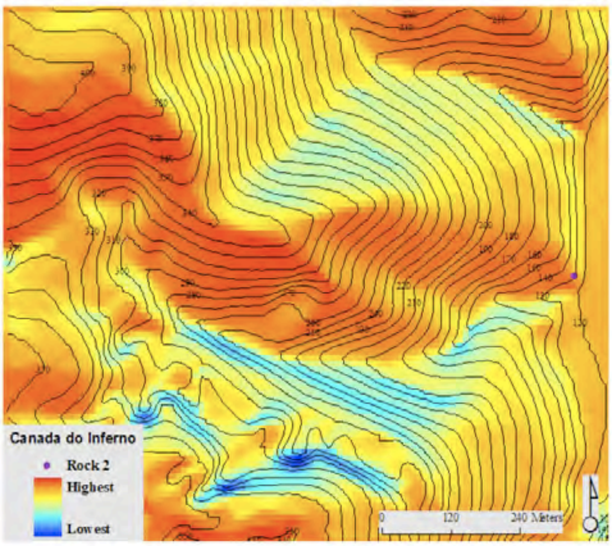
Aspect from DEM: 114º - E Field: Same Value



Slope from DEM: 55% Field: Same Value



Solar radiation: 1145919 KW/M^2



Rock: Canada do Inferno 02

Nr: 6

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 46 - MODERATE

Rock mass strength : 73 - STRONG

Porosity:

Tilting of panel/outcrop: 2º FORWARD

- Physical weathering

Aveolization: MODERATE

Exfoliation: SIGNIFICANT

Collapse: MODERATE

Fissures: INCIPIENT

Diaclase: SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: VERY SIGNIFICANT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: SIGNIFICANT

Disintegration - Pulverization: SIGNIFICANT

Toppling: VERY SIGNIFICANT

Rock: Canada do Inferno 02

Nr: 6

- Biodeterioration

Lichens: INCIPIENT - CLEANED

Plants: SIGNIFICANT

Insects: VERY INCIPIENT

- Further photos

Côa water level in relation to Rock 2.

Incomplete (due to fracture) Upper Paleolithic goat motif measuring 60x30 cm. (Photo: AMB).

Rock: Canada do Inferno 13

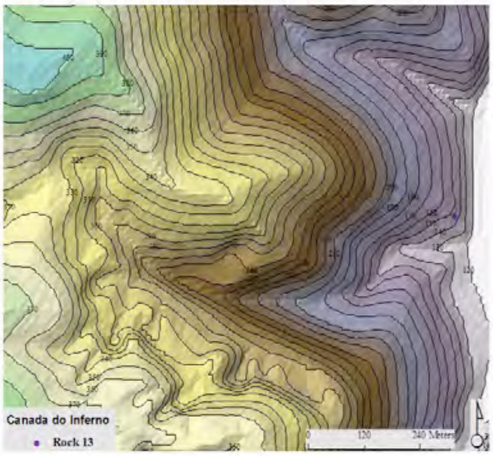
Nr: 7

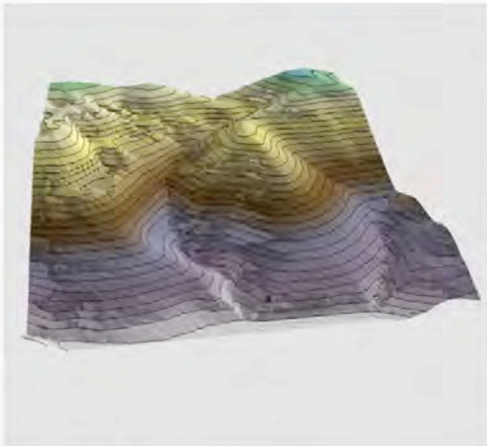
DESCRIPTION:

Large outcrop measuring 15x3 m. Some areas present black bacteria covering which indicates the presence of seasonal superficial water runoff. It bears only Upper Paleolithic motifs.

Canada do Inferno was the first identified Upper Paleolithic rock art site in the Côa Valley. It is located in an ancient fluvial beach on the left margin of the river, being the 43 engraved panels distributed along the overhanging slope. The quantity and quality of Upper Paleolithic figures should be highlighted, albeit the fact most became submerged since construction of the Pocinho dam. Several motifs of modern and contemporary chronology are also present in the site.

Location: -7,11263/41,05489





Altitude: 140 m

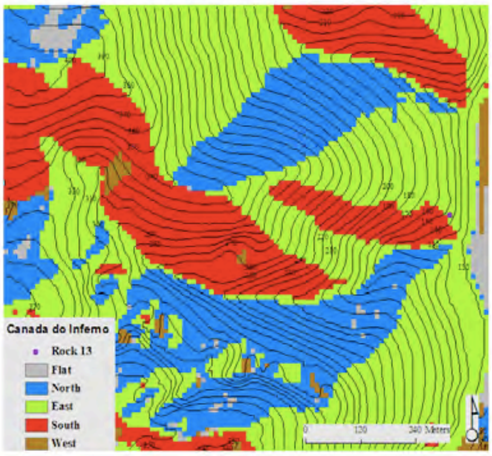
Risk from flooding episodes: None

Date Created: 2010/04/26

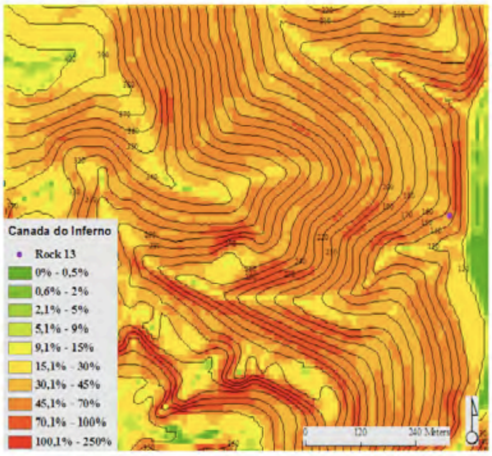
Last Modified: 2012/05/29

Rock: Canada do Inferno 13 Nr: 7

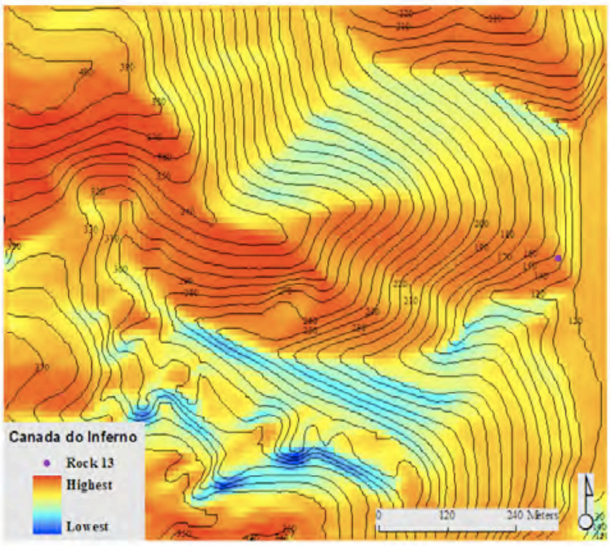
Aspect from DEM: 116º - E Field: Same Value



Slope from DEM: 54% Field: 85%



Solar radiation: 1169229 KW/M^2



Rock: Canada do Inferno 13

Nr: 7

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 57 - STRONG

Rock mass strength : 65 - MODERATE

Porosity:

Tilting of panel/outcrop: 9º FORWARD

- Physical weathering

Aveolization: MODERATE

Exfoliation: SIGNIFICANT

Collapse: INCIPIENT

Fissures: VERY SIGNIFICANT

Diaclase: VERY SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Canada do Inferno 13

Nr: 7

- Biodeterioration

Lichens: VERY INCIPIENT - CLEANED

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Area with superficial and ground water runoff (dark cover zones and large gaps) located just above the engraved panel.

Fractures, disconnected blocks and exfoliation near the engraved panel.

Rock: Canada do Inferno 14

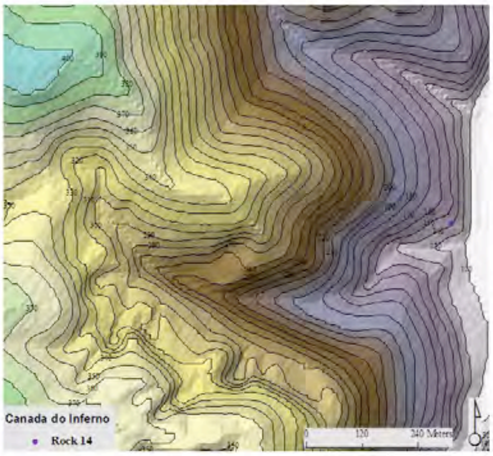
Nr: 8

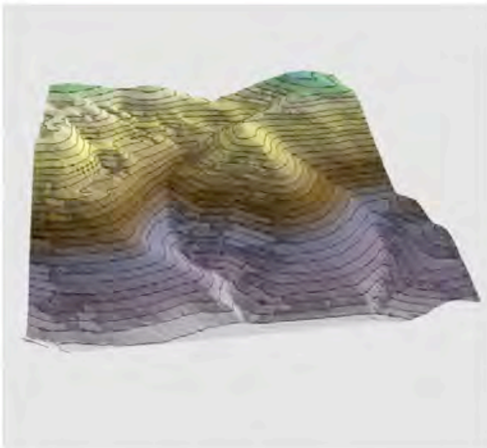
DESCRIPTION:

Medium sized outcrop measuring 3x3 m located very near to Rock 13. The steepness of the particular area of the slope where it is located and the subsequent absence of a sizable viewing platform makes it impossible to photograph it in its entirety. It only possesses Upper Paleolithic imagery.

Canada do Inferno was the first identified Upper Paleolithic rock art site in the Côa Valley. It is located in an ancient fluvial beach on the left margin of the river, being the 43 engraved panels distributed along the overhanging slope. The quantity and quality of Upper Paleolithic figures should be highlighted, albeit the fact most became submerged since construction of the Pocinho dam. Several motifs of modern and contemporary chronology are also present in the site.

Location: -7,11266/41,05476





Altitude: 140 m

Risk from flooding episodes: None

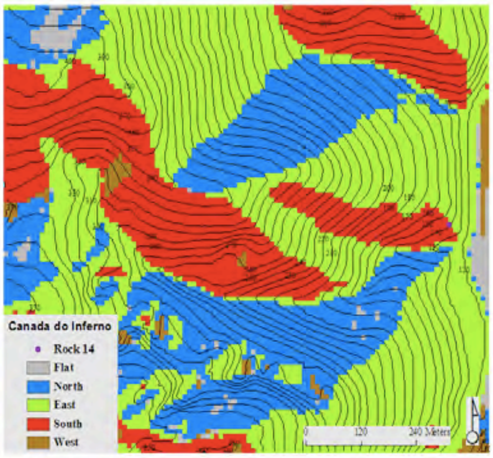
Date Created: 2010/04/26

Last Modified: 2012/05/29

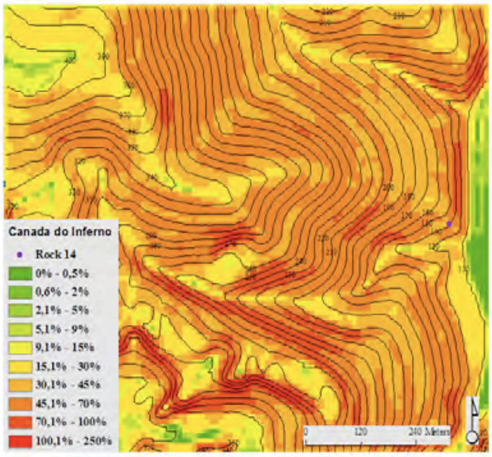
Rock: Canada do Inferno 14

Nr: 8

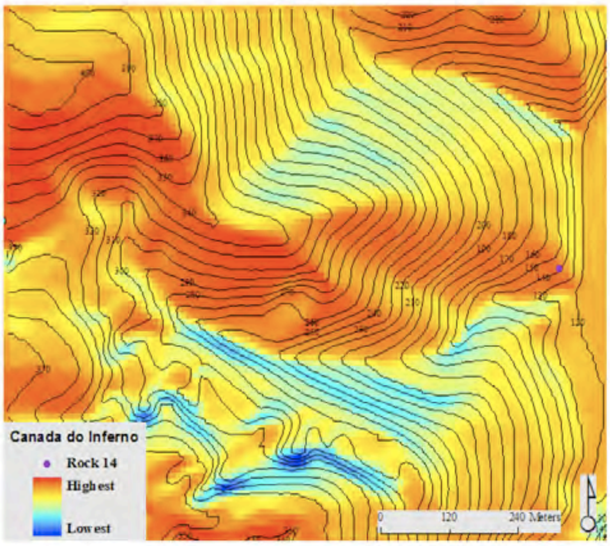
Aspect from DEM: 130º - E Field: Same Value



Slope from DEM: 44% Field: 90%



Solar radiation: 1233525 KW/M^2



Rock: Canada do Inferno 14

Nr: 8

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 53 - STRONG

Rock mass strength : 75 - STRONG

Porosity:

Tilting of panel/outcrop: 5º FORWARD

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: SIGNIFICANT

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: SIGNIFICANT

Toppling: MODERATE

Rock: Canada do Inferno 14

Nr: 8

- Biodeterioration

Lichens: SIGNIFICANT - CLEANED

Plants: SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Fine line incision Upper Paleolithic representation of male ibex measuring 10x15 cm. (Photo: MA).

Incomplete pecked and abraded Upper Paleolithic horse representation measuring 40x20 cm. (Photo: MA).

Note the sub-horizontal schist layers that determine the orientation of one of the fractures family complex.

Large gap located just above the engraved horse motif shown in the penultimate photo.

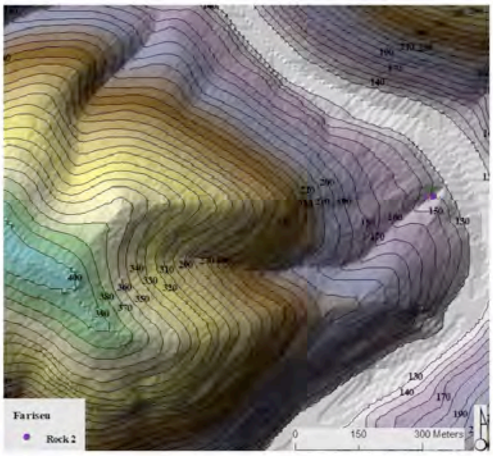
Rock: Fariseu 2 Nr: 9

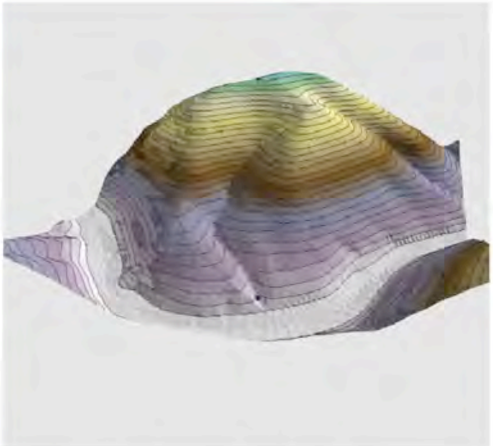
DESCRIPTION:

Relatively small outcrop (1,5x2 m) located near to the mouth of a waterline in to the Côa River. It becomes occasionally flooded specially in its bottom area and during flash flooding episodes. It possesses a sole motif, an Upper Paleolithic deer.

Fariseu is one of the central sites to understand the chronology of the Côa Valley rock art. 19 engraved panels are distributed along this ancient fluvial beach located on the left margin of the Côa. Of these, 16 have Upper Paleolithic engravings and just 1 possesses Iron Age motifs. Excavation of Rock 1 completely proved an Upper Paleolithic chronology for the most ancient art in the Côa, since some motifs were totally covered by layers dated to that period. Excavation also unearthed several tens of mobile art slabs, making Fariseu one of the most important places in the Iberian Peninsula where such finds were made.

Location: -7,11021/41,03751





Altitude: 140 m

Risk from flooding episodes: Moderate

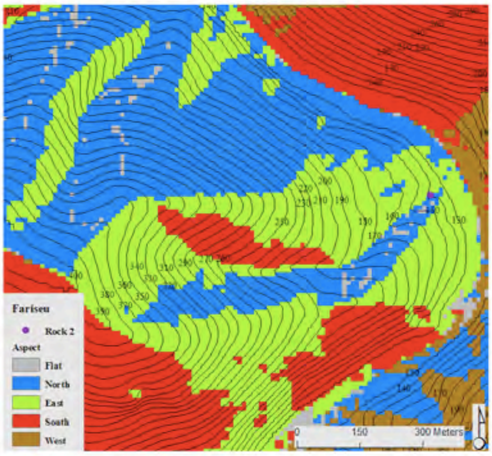
Date Created: 2010/04/26

Last Modified: 2012/05/29

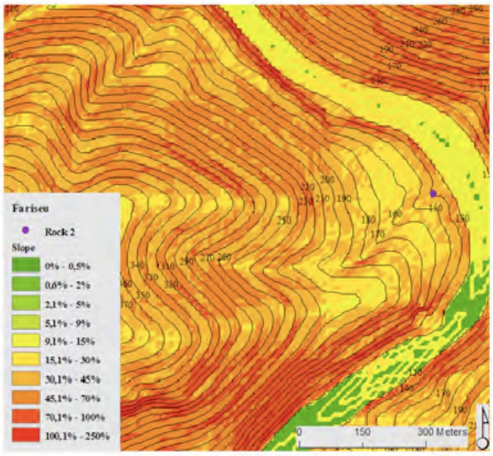
Rock: Fariseu 2

Nr: 9

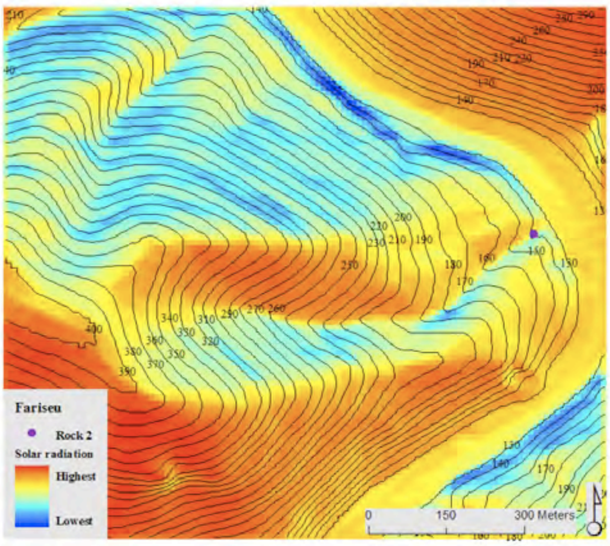
Aspect from DEM: 25º - N   Field: Same Value



Slope from DEM: 26%   Field: 50%



Solar radiation: 1006771 KW/M^2



Rock: Fariseu 2

Nr: 9

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 43 - MODERATE

Rock mass strength : 65 - MODERATE

Porosity:

Tilting of panel/outcrop: 10º FORWARD

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: INCIPIENT

Collapse: MODERATE

Fissures: MODERATE

Diaclase: MODERATE

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: VERY SIGNIFICANT

Rock: Fariseu 2

Nr: 9

- Biodeterioration

Lichens:	VERY INCIPIENT
Plants:	SIGNIFICANT
Insects:	VERY SIGNIFICANT

- Further photos

Upper Paleolithic dear motif (1x0,6 m.) in Rock 2. Note toppling affecting the upper part of the motif. (Photo: MR).

Toppling block possessing the upper part of the deer representation.

Gap in the outcrop.

Biological colonization: spiders using the fracture that divides the outcrop in two distinct blocks as shelter.

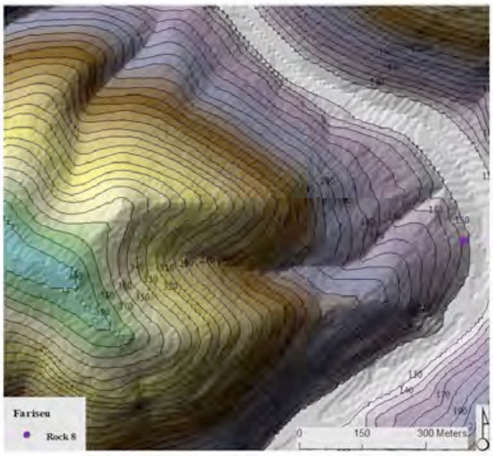
Rock: Fariseu 8 Nr: 10

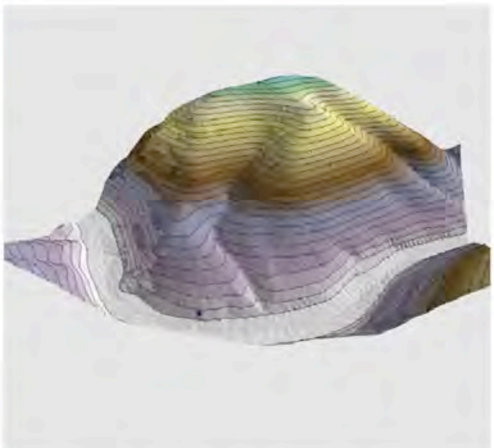
DESCRIPTION:

Large outcrops measuring (20x1,20 m) containing several engraved panels featuring Upper Paleolithic goats and horse motifs.

Fariseu is one of the central sites to understand the chronology of the Côa Valley rock art. 19 engraved panels are distributed along this ancient fluvial beach located on the left margin of the Côa. Of these, 16 have Upper Paleolithic engravings and just 1 possesses Iron Age motifs. Excavation of Rock 1 completely proved an Upper Paleolithic chronology for the most ancient art in the Côa, since some motifs were totally covered by layers dated to that period. Excavation also unearthed several tens of mobile art slabs, making Fariseu one of the most important places in the Iberian Peninsula where such finds were made.

Location: -7,10938/41,03653





Altitude: 140 m

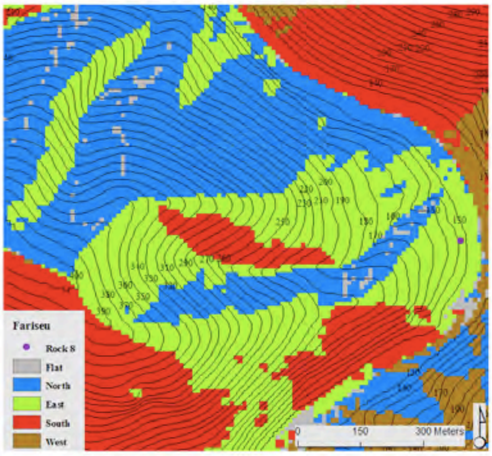
Risk from flooding episodes: Moderate

Date Created: 2010/04/26

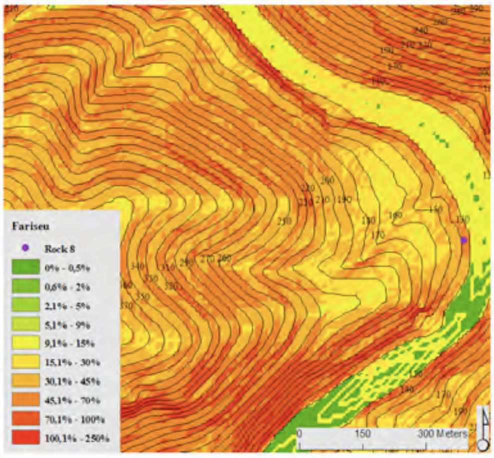
Last Modified: 2012/07/08

Rock: Fariseu 8 Nr: 10

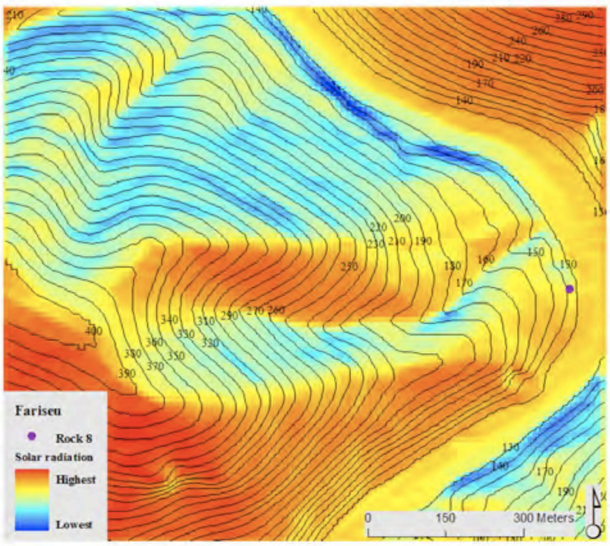
Aspect from DEM: 85° - E Field: Same Value



Slope from DEM: 53% Field: Same Value



Solar radiation: 1021754 KW/M^2



Rock: Fariseu 8

Nr: 10

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 56 - STRONG

Rock mass strength : 72 - STRONG

Porosity:

Tilting of panel/outcrop: 5º FORWARD

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: SIGNIFICANT

Diaclase: INCIPIENT

Fractures: VERY SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: INCIPIENT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Fariseu 8

Nr: 10

- Biodeterioration

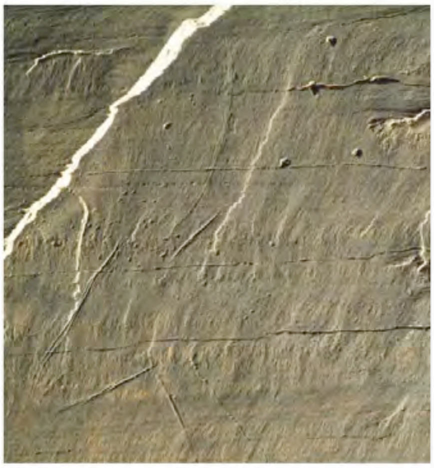
Lichens: MODERATE - CLEANED

Plants: SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Upper Paleolithic goat motif (20x15cm.) located in two distinct planes severed by a fracture. (Photo: MA).



Detail of another Upper Paleolithic goat (40x20cm) in Fariseu Rock 8. (Photo: MA).

Detail of Upper Paleolithic horse motif. As motifs above, it was done by fine line incision. (Photo: MA).

Biological colonization remains.

Rock: Foz do Côa 14

Nr: 11

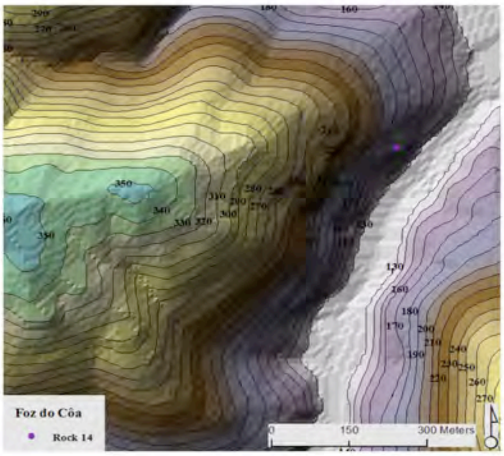
DESCRIPTION:

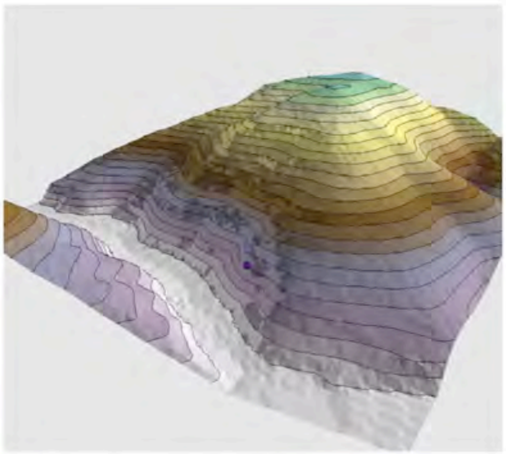
Large outcrop measuring 12x5 m containing Upper Paleolithic and Historical Period imagery. The area around it show evident traces of major collapse, either natural or human motivated since this area has been historically used for agriculture. Although farming has now been abandoned, many terraces have been built in this site, the only way of having groves in the steep slope.

The left bank slope that dominates the mouth of the Côa ('Foz do Côa') keeps the highest concentration of identified rock art outcrops in the whole region - a total of 195 panels. Due to the quality and quantity of motifs from the final stage of the Upper Paleolithic and from the Iron Age, this site must regarded as central in the fashion humans from both periods understood their territories. The finding of two stones with Upper Paleolithic engravings in a recently built wall suggests the destruction of engraved outcrops throughout the ages.

Photo: MR

Location: -7,11263/41,08064





Altitude: 170 m

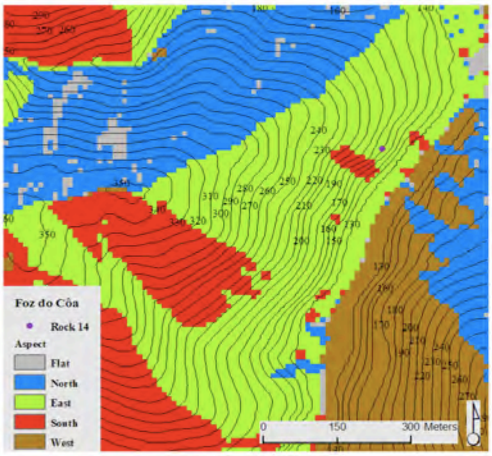
Risk from flooding episodes: None

Date Created: 2010/04/26

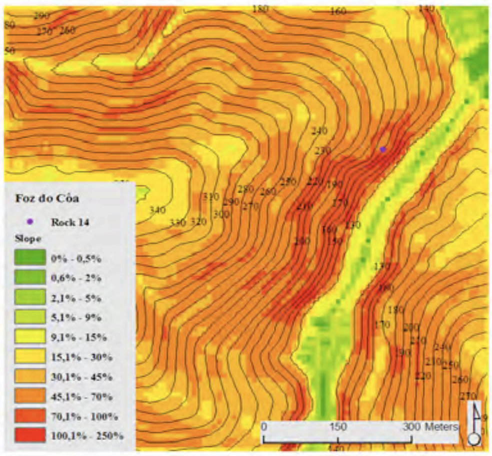
Last Modified: 2012/07/09

Rock: Foz do Côa 14 Nr: 11

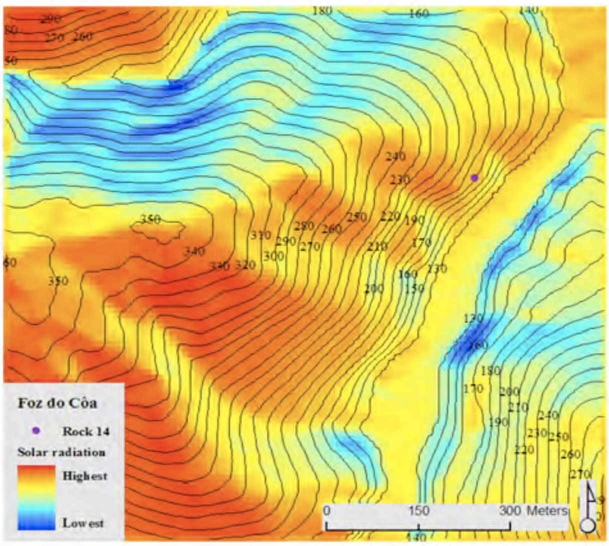
Aspect from DEM: 120º - E Field: Same Value



Slope from DEM: 69% Field: Same Value



Solar radiation: 1191874 KW/M²



Rock: Foz do Côa 14

Nr: 11

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 54 - STRONG

Rock mass strength : 71 - STRONG

Porosity:

Tilting of panel/outcrop: 5º FORWARD

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: SIGNIFICANT

Fissures: SIGNIFICANT

Diaclase: VERY SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Foz do Côa 14

Nr: 11

- Biodeterioration

Lichens: INCIPIENT

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Note the chaos of collapsed blocks. (Photo: MR).

Note toppling and the advancement of portions of the outcrop. (Photo: MR).

Fractures and fissures in Rock 14. (Photo: MR).

Loose lines finely incised. Note aveoliation and parallel orientation of fissures. (Photo: MR).

Rock: Foz do Côa 16

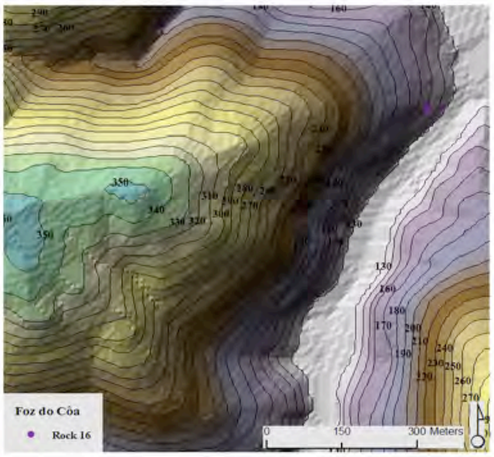
Nr: 12

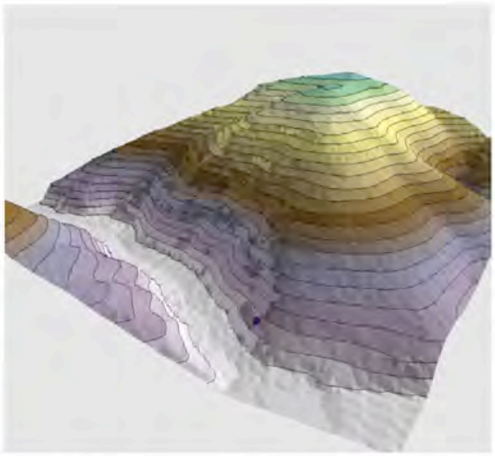
DESCRIPTION:

Large outcrop measuring 10x2,50 m located in a very steep area of the slope. The fact that it does not have a large platform in front of it makes it difficult to photograph it. It possesses Upper Paleolithic, Iron Age and Historical Period imagery.

The left bank slope that dominates the mouth of the Côa ('Foz do Côa') keeps the highest concentration of identified rock art outcrops in the whole region - a total of 195 panels. Due to the quality and quantity of motifs from the final stage of the Upper Paleolithic and from the Iron Age, this site must regarded as central in the fashion humans from both periods understood their territories. The finding of two stones with Upper Paleolithic engravings in a recently built wall suggests the destruction of engraved outcrops throughout the ages.

Location: -7,10522/41,08135





Altitude: 145 m

Risk from flooding episodes: None

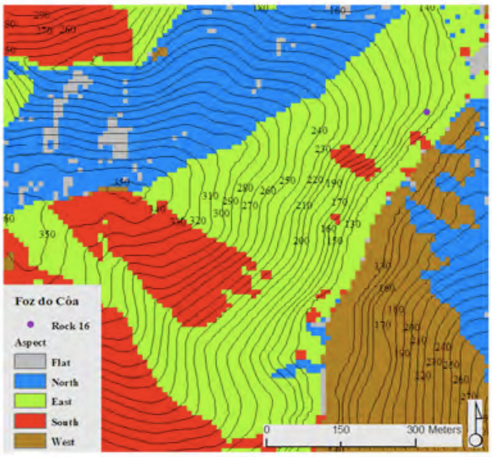
Date Created: 2010/04/26

Last Modified: 2012/05/29

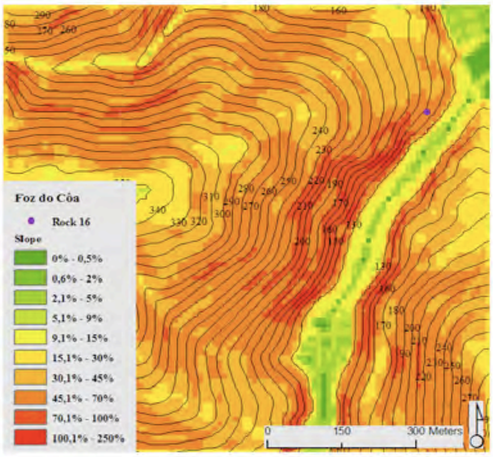
Rock: Foz do Côa 16

Nr: 12

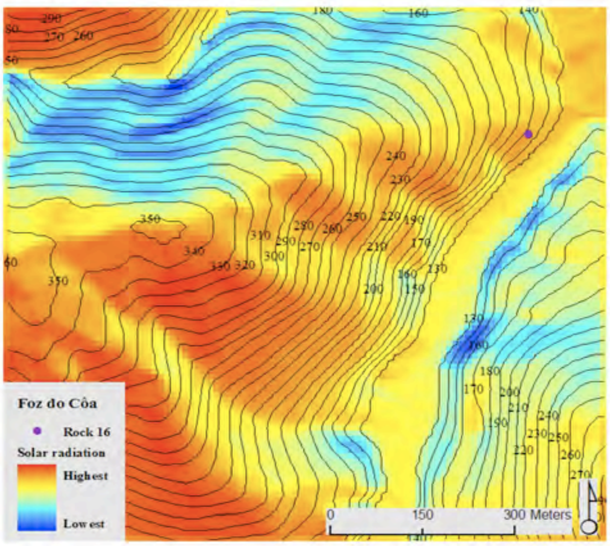
Aspect from DEM: 130º - E   Field: Same Value



Slope from DEM: 59%   Field: 70%



Solar radiation: 1239311 KW/M²



Rock: Foz do Côa 16

Nr: 12

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 51 - STRONG

Rock mass strength : 75 - STRONG

Porosity:

Tilting of panel/outcrop: 9º FORWARD

- Physical weathering

Aveolization: MODERATE

Exfoliation: SIGNIFICANT

Collapse: SIGNIFICANT

Fissures: MODERATE

Diaclase: SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: INCIPIENT

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Foz do Côa 16

Nr: 12

- Biodeterioration

Lichens: INCIPIENT

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Gaping, fortunately in an unengraved area of the outcrop.

Surface runoff (areas with black bacterial cover) from a fracture located at the base of the outcrop.

Weaker area at the top of the outcrop due to surface runoff.

Higher plant growing out of a fracture in the outcrop.

Rock: Foz do Côa 93

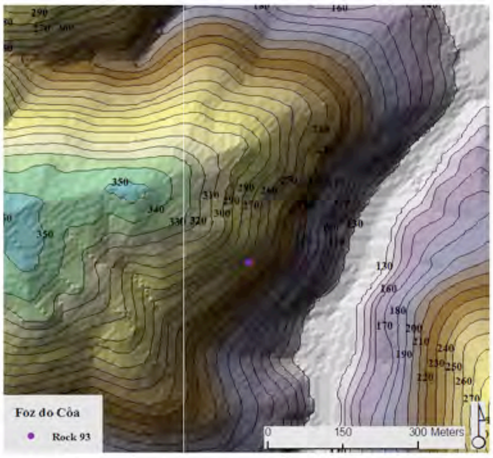
Nr: 13

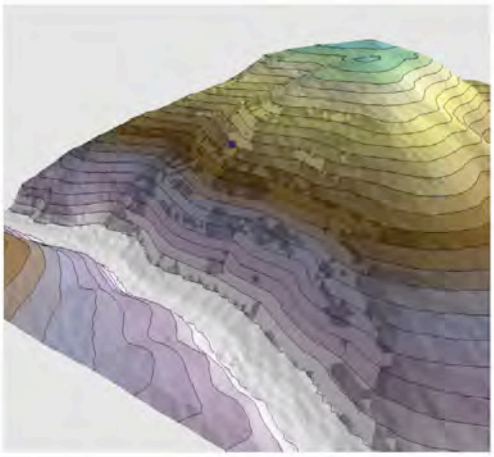
DESCRIPTION:

Large outcrop (27x2,5 m) with several different engraved panels containing Upper Paleolithic, Iron Age and Historical Period fine line incised animals, loose lines and anthropomorphic figures

The left bank slope that dominates the mouth of the Côa ('Foz do Côa') keeps the highest concentration of identified rock art outcrops in the whole region - a total of 195 panels. Due to the quality and quantity of motifs from the final stage of the Upper Paleolithic and from the Iron Age, this site must regarded as central in the fashion humans from both periods understood their territories. The finding of two stones with Upper Paleolithic engravings in a recently built wall suggests the destruction of engraved outcrops throughout the ages.

Location: -7,10956/41,07854





Altitude: 250 m

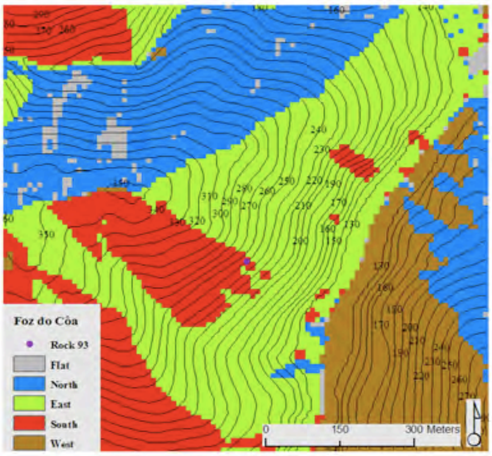
Risk from flooding episodes: None

Date Created: 2010/04/26

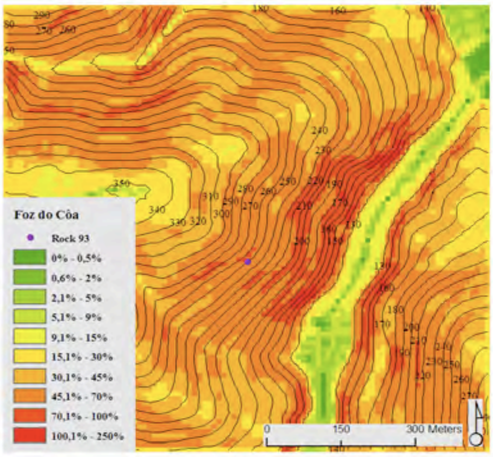
Last Modified: 2012/05/29

Rock: Foz do Côa 93 Nr: 13

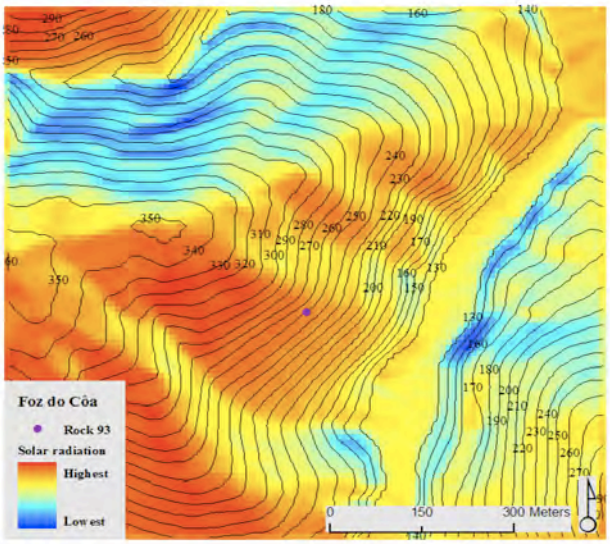
Aspect from DEM: 140º - S Field: Same Value



Slope from DEM: 60% Field: Same Value



Solar radiation: 1302795 KW/M²



Rock: Foz do Côa 93

Nr: 13

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 51 - STRONG

Rock mass strength : 75 - STRONG

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: MODERATE

Exfoliation: INCIPIENT

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: VERY SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: MODERATE

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Foz do Côa 93

Nr: 13

- Biodeterioration

Lichens: MODERATE

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Deer motif (25x15 cm.) from the Upper Paleolithic. (Photo: MR).

Iron Age warrior motif (10x10 cm.). (Photo: MR).

Area with gaping, black organic cover and advanced panels in different planes (a sort of 'horizontal toppling').

Rock 93 (center of the photo) in its slope, located below the recently inaugurated Côa Museum.

Rock: Moinhos de Cima 7

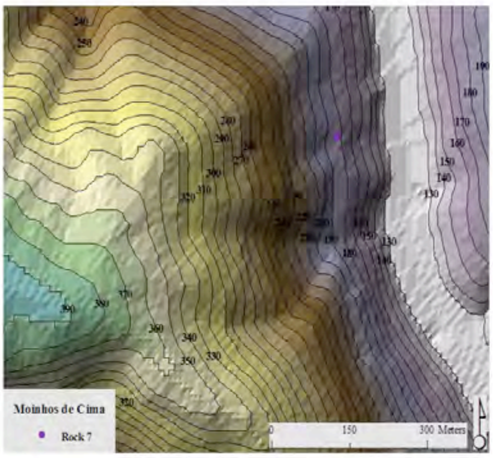
Nr: 14

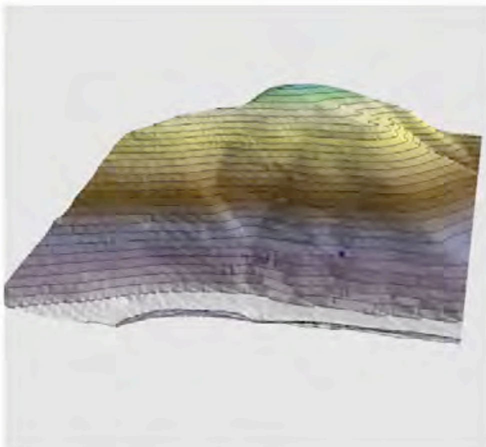
DESCRIPTION:

Medium sized outcrop measuring 6x2 located on the edge of a national road, hence the presence of traffic protections. It presents Iron Age and Historical Period imagery.

Moinhos de Cima is a rock art site located in a slope on the left margin of the Côa, between the upstream Vale de Moinhos site and the downstream Vale do Forno site. 25 panels were identified, mostly grouped in the central area of the slope. Most motifs are from the Iron Age, of which stand out the large ensemble in Rock 5, with some of the most peculiar animal representations in Protohistoric art in the region and the deer in Rock 7. The most striking Upper Paleolithic figure is a male ibex in Rock 10.

Location: -7,10963/41,07162





Altitude: 180 m

Risk from flooding episodes: None

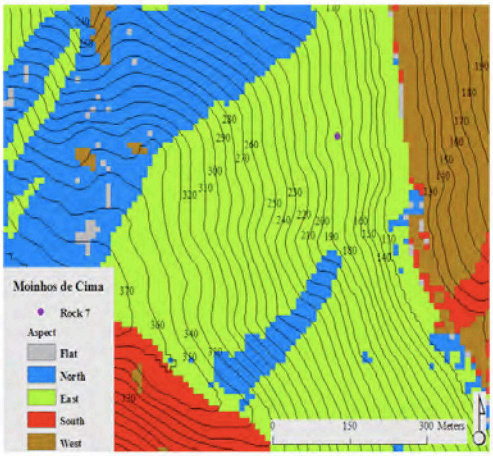
Date Created: 2010/04/26

Last Modified: 2012/05/29

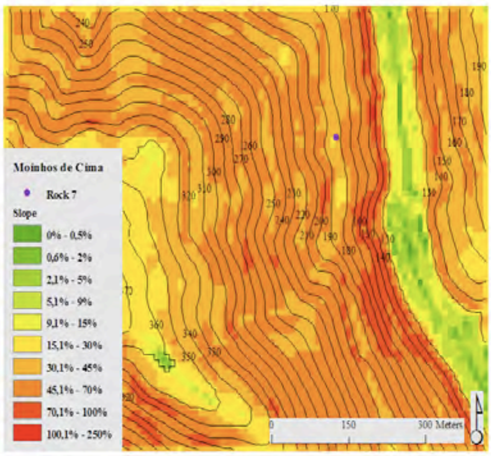
Rock: Moinhos de Cima 7

Nr: 14

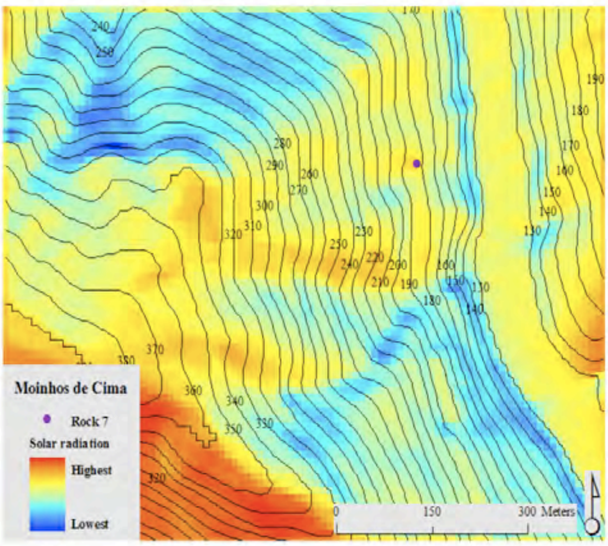
Aspect from DEM: 90° - E Field: 130°



Slope from DEM: 33% Field: Same Value



Solar radiation: 1148054 KW/M^2



Rock: Moinhos de Cima 7

Nr: 14

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 50 - STRONG

Rock mass strength : 80 - STRONG

Porosity:

Tilting of panel/outcrop: 10° FORWARD

- Physical weathering

Aveolization: MODERATE

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: VERY SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: SIGNIFICANT

Toppling: INCIPIENT

Rock: Moinhos de Cima 7

Nr: 14

- Biodeterioration

Lichens: INCIPIENT - CLEANED

Plants: SIGNIFICANT

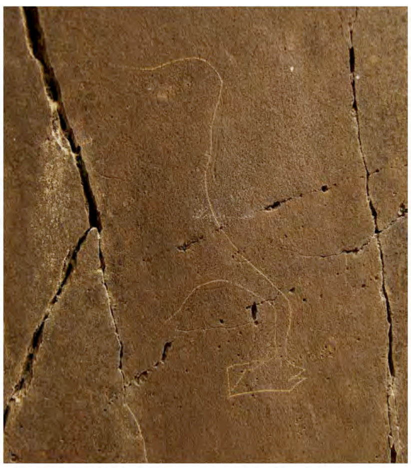
Insects: MODERATE

- Further photos

Engraved area in Rock 1.

Iron Age deer motif measuring 15x20 cm.

Detail (antlers) of the dear motif.



Incomplete Iron Age horse motif facing downwards measuring 7x12 cm.

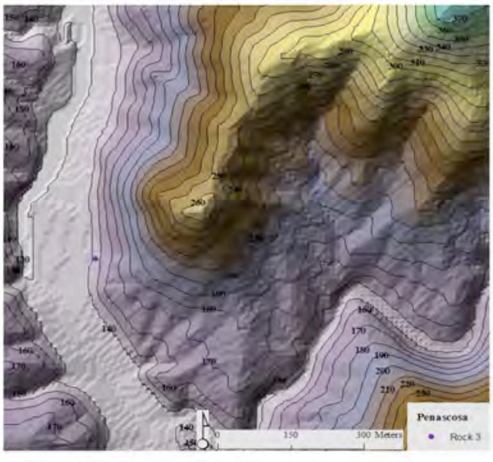
Rock: Penascosa 03 Nr: 15

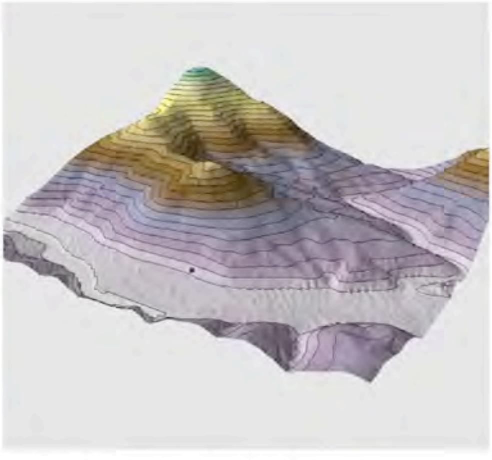
DESCRIPTION:

Rock 3 possesses more than 10 Upper Paleolithic representations of aurochsen, goats, deer and horses. It is a relatively large outcrop 5 m width and 2,5 m tall. Only the right portion of the outcrop has engravings. The engraved panel has a rectangular shape and measures 2 x 1 m. Engraved motifs are also present in a toppling position block adjacent to the above mentioned panel.

Penascosa is a site on the right margin of the Côa. Erosion and sedimentary deposits formed and ample fluvial beach. The 36 identified engraved outcrops, mostly of Upper Paleolithic chronology, are scattered along the steep slope located above this beach. Some of the largest panels found in the Côa are located in this site, such as Rock 5 and 10. Together with Quinta da Barca rock art site - located in the opposite bank - Penascosa constitutes the heart of the symbolic territory of the most ancient period of Upper Paleolithic art.

Location: -7,10486/41,00530





Altitude: 140 m

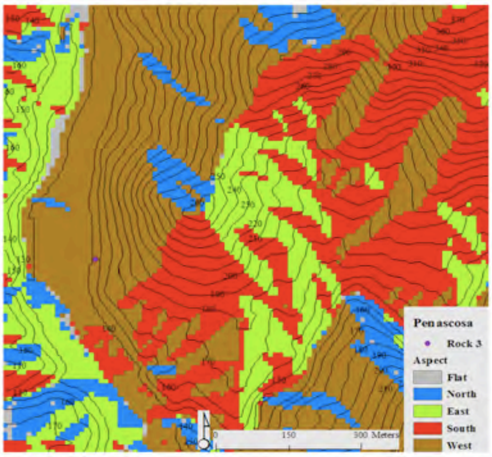
Risk from flooding episodes: Significant

Date Created: 2010/04/26

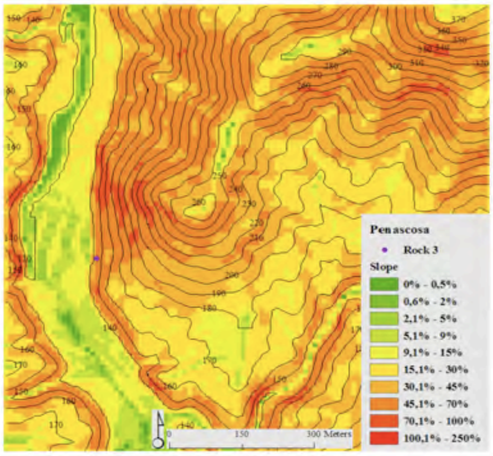
Last Modified: 2012/07/08

Rock: Penascosa 03 Nr: 15

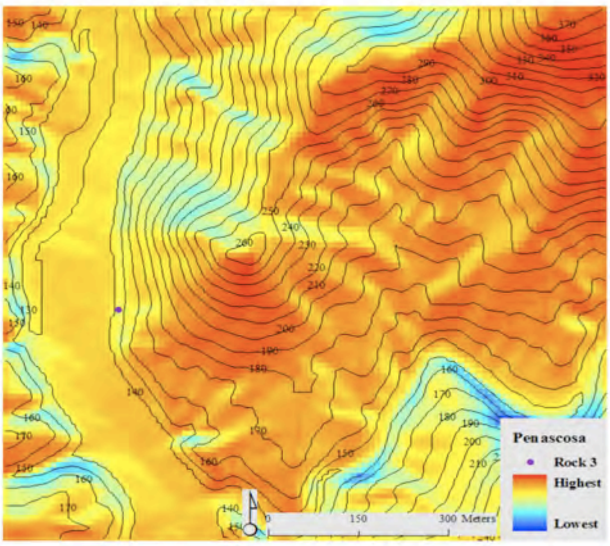
Aspect from DEM: 277º - W Field: Same value



Slope from DEM: 60% Field: Same value



Solar radiation: 1024149 KW/M²



Rock: Penascosa 03

Nr: 15

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 39 - WEAK

Rock mass strength : 71 - STRONG

Porosity:

Tilting of panel/outcrop: 5º FORWARD

- Physical weathering

Aveolization: VERY SIGNIFICANT

Exfoliation: MODERATE

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: INCIPIENT

Fractures: MODERATE

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: VERY SIGNIFICANT

Disintegration - Pulverization: SIGNIFICANT

Toppling: VERY SIGNIFICANT

Rock: Penascosa 03

Nr: 15

- Biodeterioration

Lichens: MODERATE

Plants: SIGNIFICANT

Insects: VERY INCIPIENT

- Further photos

Motifs in Rock 3, all of Upper Paleolithic chronology. (Drawing: FB).

Central portion of the engraved panel. (Photo: AMB).

Detail of Rock 3 showing horse and aurochs heads. Note aveolization. (Photo: AMB).

Different perspective of Rock 3. (Photo: Post-Glaciar).

Rock: Penascosa 04

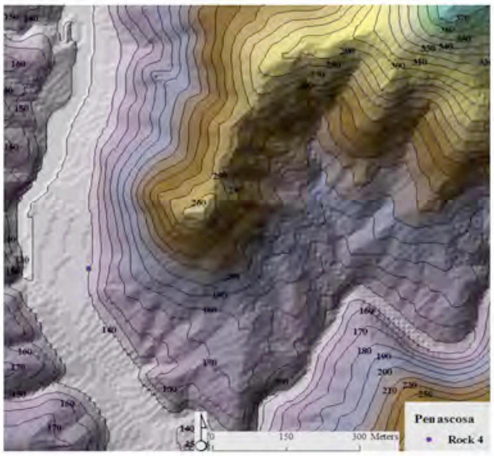
Nr: 16

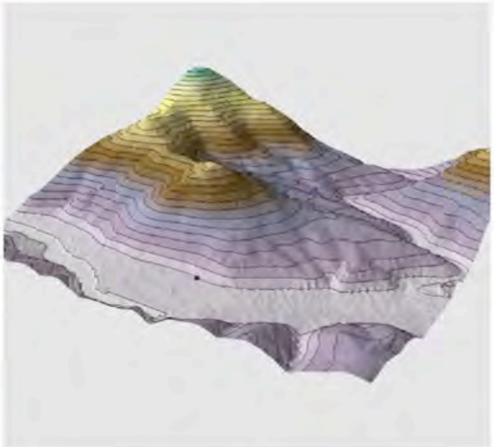
DESCRIPTION:

Rock 4 possesses Upper Paleolithic representations of horses and goats. Among these, a scene in which a horse represented with 3 heads (an attempt to portray motion) is mating with a mare stands out. Rock 4 is a small detached that belongs to an already dismantling outcrop. It has rectangular shape measuring 1 x 0,5 m. The bottom part of the panel (where the mating scene is located) was covered by sediments that were removed in the course of an archaeological excavation.

Penascosa is a site on the right margin of the Côa. Erosion and sedimentary deposits formed and ample fluvial beach. The 36 identified engraved outcrops, mostly of Upper Paleolithic chronology, are scattered along the steep slope located above this beach. Some of the largest panels found in the Côa are located in this site, such as Rock 5 and 10. Together with Quinta da Barca rock art site - located in the opposite bank - Penascosa constitutes the heart of the symbolic territory of the most ancient period of Upper Paleolithic art.

Location: -7,10503/41,00511





Altitude: 130 m

Risk from flooding episodes: Significant

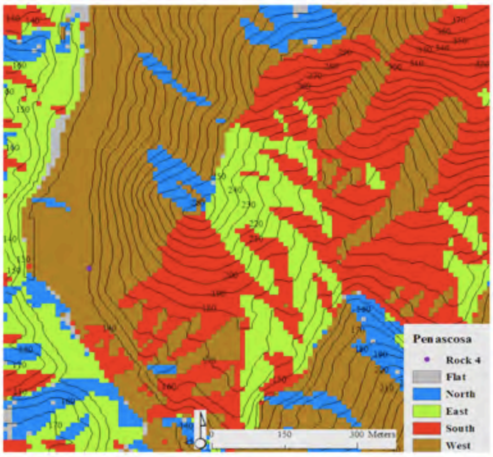
Date Created: 2010/04/26

Last Modified: 2012/06/14

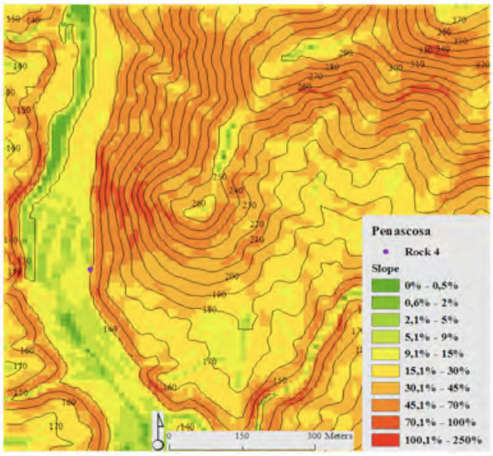
Rock: Penascosa 04

Nr: 16

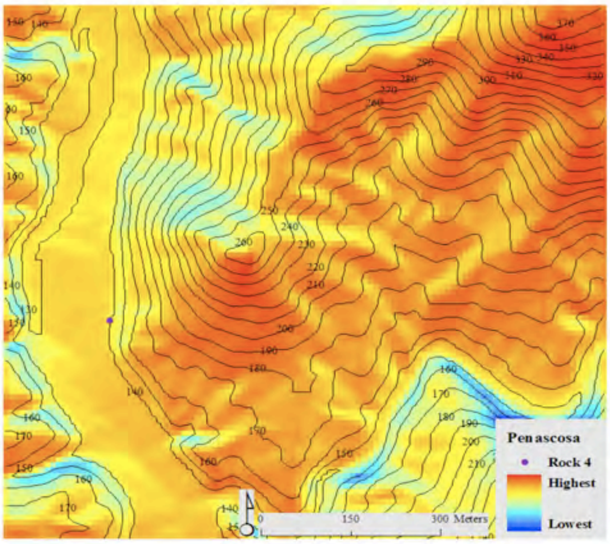
Aspect from DEM: 274º - W   Field: Same Value



Slope from DEM: 16%   Field: 40%



Solar radiation: 1168666 KW/M^2



Rock: Penascosa 04

Nr: 16

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 36 - WEAK

Rock mass strength : 78 - STRONG

Porosity:

Tilting of panel/outcrop: 9º BACK

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: INCIPIENT

Diaclase: VERY INCIPIENT

Fractures: VERY INCIPIENT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: VERY INCIPIENT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: VERY INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: MODERATE

Rock: Penascosa 04

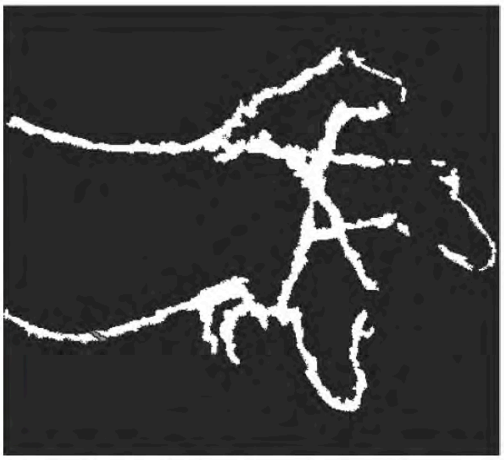
Nr: 16

- Biodeterioration

Lichens:	VERY INCIPIENT - CLEANED
Plants:	SIGNIFICANT
Insects:	VERY INCIPIENT

- Further photos

Area of the panel with the mating scene featuring the three-headed horse (50x30 cm). (Photo: AMB).



Detail of the three-headed horse. (Drawing: FB).

Horse's head motion decomposed. (Drawing: FB).

Engraved panel of Rock 4. (Photo: Post-Glaciar).

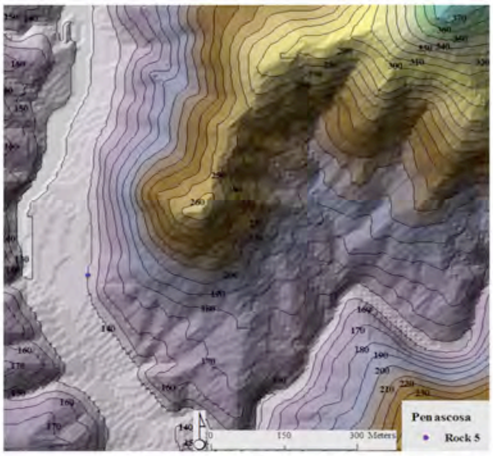
Rock: Penascosa 05 Nr: 17

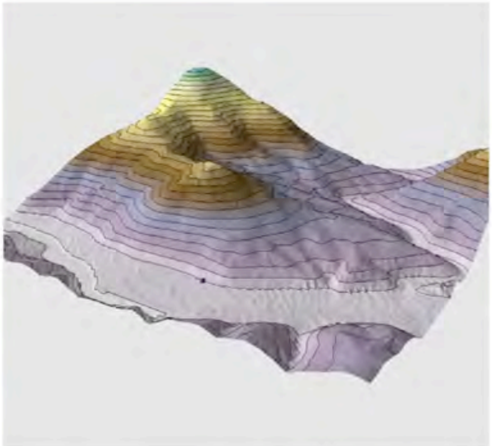
DESCRIPTION:

Medium sized outcrop containing Upper Paleolithic and Post-Glaciar engraved motifs. It is highly weathered measuring 5 m width and 2 m tall. The bottom part of the outcrops was covered by sediments that were removed in the course of an archaeological excavation that revealed the existence of a panel with a quite rare representation of a fish.

Penascosa is a site on the right margin of the Côa. Erosion and sedimentary deposits formed and ample fluvial beach. The 36 identified engraved outcrops, mostly of Upper Paleolithic chronology, are scattered along the steep slope located above this beach. Some of the largest panels found in the Côa are located in this site, such as Rock 5 and 10. Together with Quinta da Barca rock art site - located in the opposite bank - Penascosa constitutes the heart of the symbolic territory of the most ancient period of Upper Paleolithic art.

Location: -7,10504/41,00496





Altitude: 130 m

Risk from flooding episodes: Significant

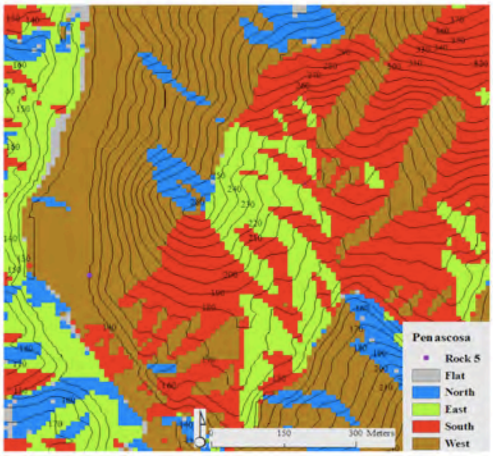
Date Created: 2010/04/26

Last Modified: 2012/07/09

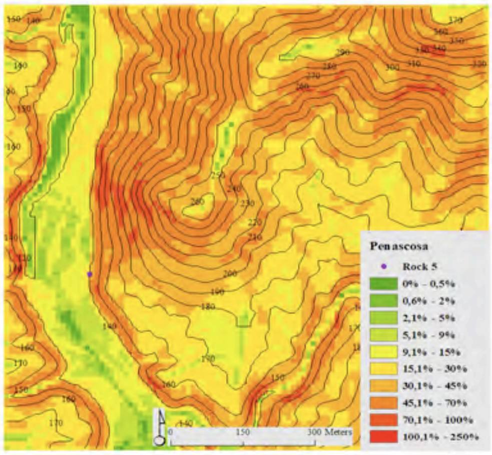
Rock: Penascosa 05

Nr: 17

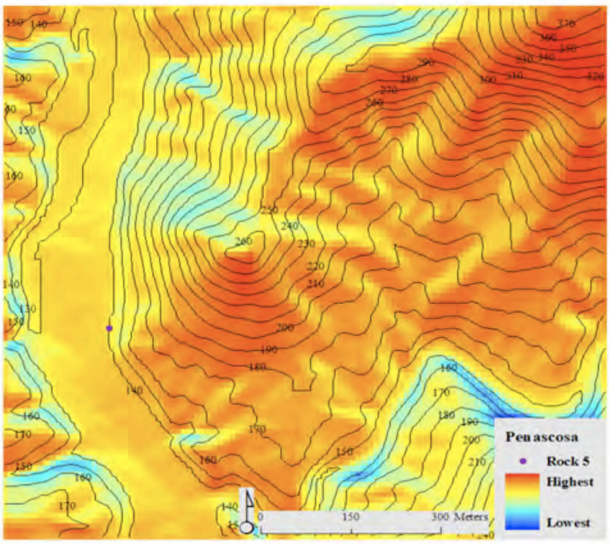
Aspect from DEM: 274º - W Field: Same Value



Slope from DEM: 19% Field: 40%



Solar radiation: 1165133 KW/M²



Rock: Penascosa 05

Nr: 17

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 44 - MODERATE

Rock mass strength : 73 - STRONG

Porosity:

Tilting of panel/outcrop: 20° FORWARD

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: VERY SIGNIFICANT

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: VERY SIGNIFICANT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: VERY SIGNIFICANT

Disintegration - Pulverization: VERY SIGNIFICANT

Toppling: MODERATE

Rock: Penascosa 05

Nr: 17

- Biodeterioration

Lichens: INCIPIENT - CLEANED

Plants: SIGNIFICANT

Insects: INCIPIENT

- Further photos

Upper Paleolithic goat motif in Rock 5 measuring 40x20 cm. (Photo: AMB).

Upper Paleolithic fish motif (salmonid) measuring 25x12 cm. (Photo: AMB).

Upper Paleolithic male ibex representation measuring 60x40 cm. (Photo: AMB).

Left panel of the outcrop affected by gaping, aveolization and fracturing. (Photo: MR).

Rock: Penascosa 06

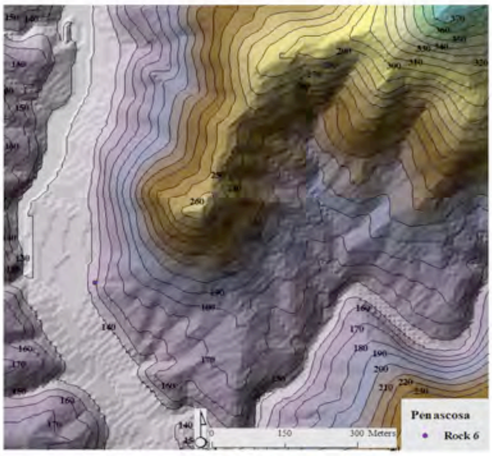
Nr: 18

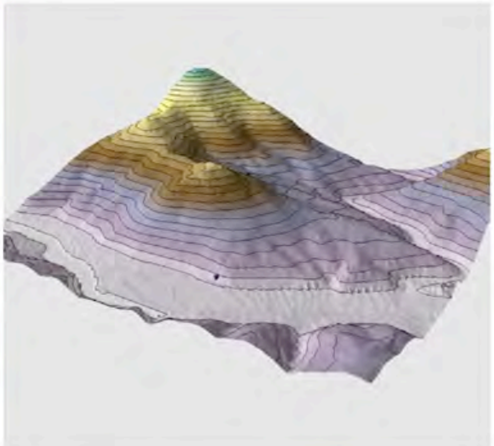
DESCRIPTION:

Medium-sized/large outcrop measuring 10 x 6 m featuring Upper Paleolithic representations of horses and goats in the upper area. It is crossed by a very noticeable quartz vein.

Penascosa is a site on the right margin of the Côa. Erosion and sedimentary deposits formed and ample fluvial beach. The 36 identified engraved outcrops, mostly of Upper Paleolithic chronology, are scattered along the steep slope located above this beach. Some of the largest panels found in the Côa are located in this site, such as Rock 5 and 10. Together with Quinta da Barca rock art site - located in the opposite bank - Penascosa constitutes the heart of the symbolic territory of the most ancient period of Upper Paleolithic art.

Location: -7,10487/41,00479





Altitude: 140 m

Risk from flooding episodes: Moderate

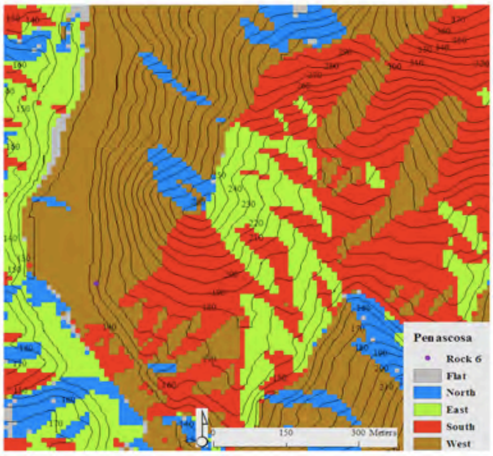
Date Created: 2010/04/26

Last Modified: 2012/07/09

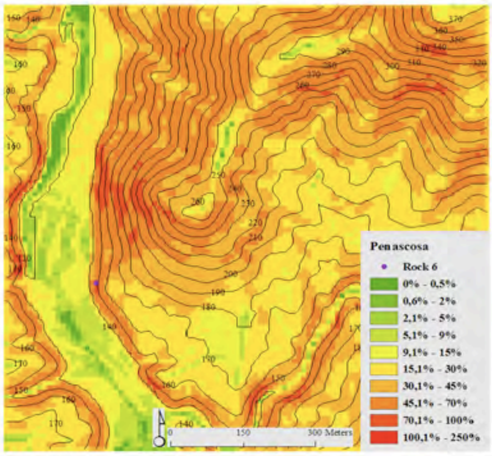
Rock: Penascosa 06

Nr: 18

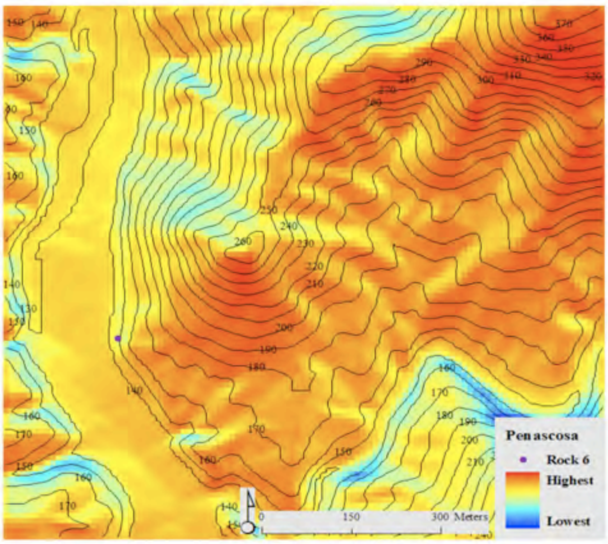
Aspect from DEM: 275° - W Field: Same Value



Slope from DEM: 67% Field: Same Value



Solar radiation: 1010253 KW/M^2



Rock: Penascosa 06

Nr: 18

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 48 - MODERATE

Rock mass strength : 75 - STRONG

Porosity:

Tilting of panel/outcrop: 30º FORWARD

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: INCIPIENT

Collapse: MODERATE

Fissures: INCIPIENT

Diaclase: SIGNIFICANT

Fractures: VERY INCIPIENT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: VERY INCIPIENT

Rock: Penascosa 06

Nr: 18

- Biodeterioration

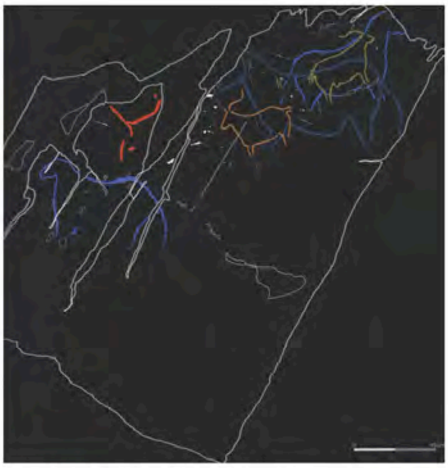
Lichens: SIGNIFICANT - CLEANED

Plants: SIGNIFICANT

Insects: VERY INCIPIENT

- Further photos

Some of the motifs in Rock 6, two pairs of horses and goats measuring 80x40 cm. (Photo: Post-Glaciar).



All motifs in Rock 6. (Drawing: FB).

Area featuring the incomplete horse shown in light blue in the previous image. Note lichens. (Photo: MR).

Rock 6. (Photo: MR).

Rock: Penascosa 10

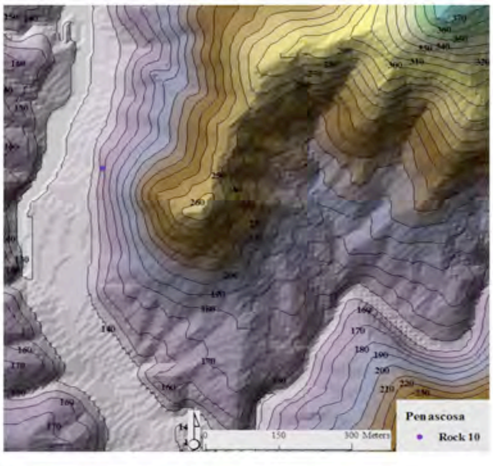
Nr: 19

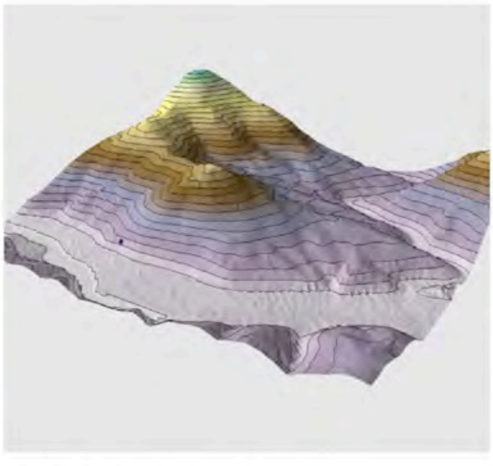
DESCRIPTION:

Medium-sized/large outcrop with several fine line incisions and one scraped deer representation, all from the Upper Paleolithic. It measures 6x2 m and it presents several black colored areas covered with of biological colonization in the form of cyanobacteria.

Penascosa is a site on the right margin of the Côa. Erosion and sedimentary deposits formed and ample fluvial beach. The 36 identified engraved outcrops, mostly of Upper Paleolithic chronology, are scattered along the steep slope located above this beach. Some of the largest panels found in the Côa are located in this site, such as Rock 5 and 10. Together with Quinta da Barca rock art site - located in the opposite bank - Penascosa constitutes the heart of the symbolic territory of the most ancient period of Upper Paleolithic art.

Location: -7,10466/41,00713





Altitude: 150 m

Risk from flooding episodes: None

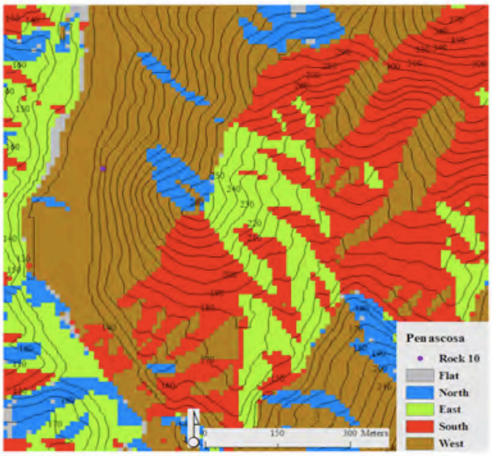
Date Created: 2010/04/26

Last Modified: 2012/07/09

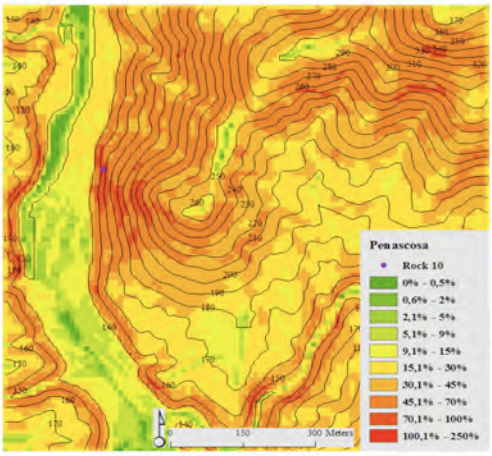
Rock: Penascosa 10

Nr: 19

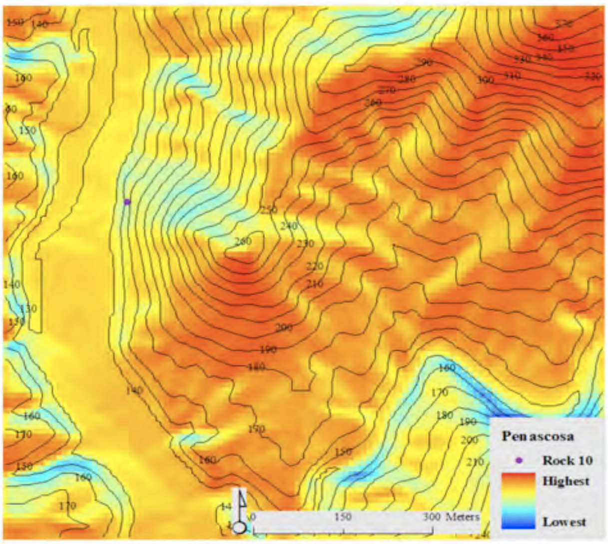
Aspect from DEM: 270º - W Field: Same Value



Slope from DEM: 95% Field: Same Value



Solar radiation: 945377 KW/M^2



Rock: Penascosa 10

Nr: 19

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 48 - MODERATE

Rock mass strength : 78 - STRONG

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: VERY INCIPIENT

Diaclase: SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: INCIPIENT

Disintegration - Pulverization: MODERATE

Toppling: INCIPIENT

Rock: Penascosa 10

Nr: 19

- Biodeterioration

Lichens: VERY INCIPIENT - CLEANED

Plants: SIGNIFICANT

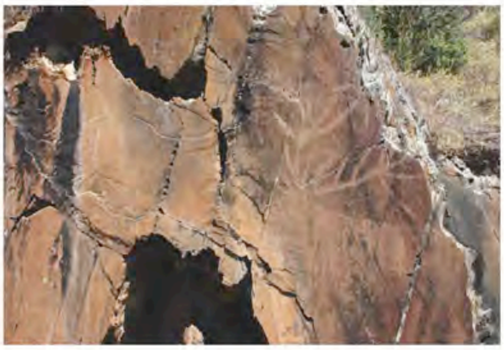
Insects: SIGNIFICANT

- Further photos

Rock 10. (Photo: MR).

Rock 10 in relation to the Penascosa site. (Photo: AMB).

Upper Paleolithic fine line incised figures depicting a horse and a deer measuring in total 30x25 cm. Note holes. (Photo: MA).



Abraded Upper Paleolithic deer motif. (Photo: MR).

Rock: Penascosa 17

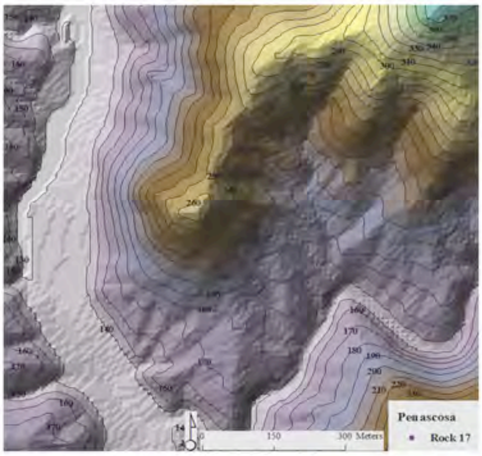
Nr: 20

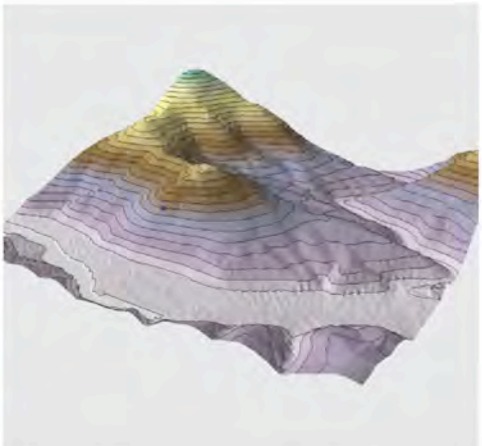
DESCRIPTION:

Medium-sized outcrop measuring 4 x 2 m. It features an Upper Paleolithic goat representation to which a Post-Glaciar ictyphalic anthropomorphic motif was added. An Historical Period graffiti was superimposed on top of these two older motifs. The vandalism incident was discussed in Fernandes (2010).

Penascosa is a site on the right margin of the Côa. Erosion and sedimentary deposits formed and ample fluvial beach. The 36 identified engraved outcrops, mostly of Upper Paleolithic chronology, are scattered along the steep slope located above this beach. Some of the largest panels found in the Côa are located in this site, such as Rock 5 and 10. Together with Quinta da Barca rock art site - located in the opposite bank - Penascosa constitutes the heart of the symbolic territory of the most ancient period of Upper Paleolithic art.

Location: -7,10383/41,00648





Altitude: 200 m

Risk from flooding episodes: None

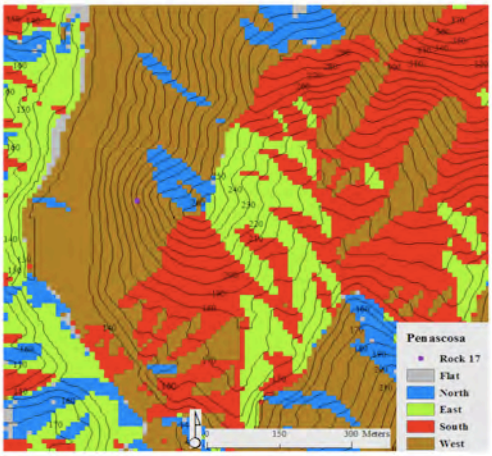
Date Created: 2010/04/26

Last Modified: 2012/07/09

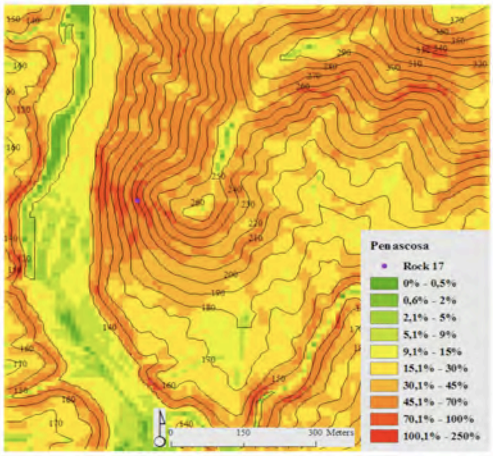
Rock: Penascosa 17

Nr: 20

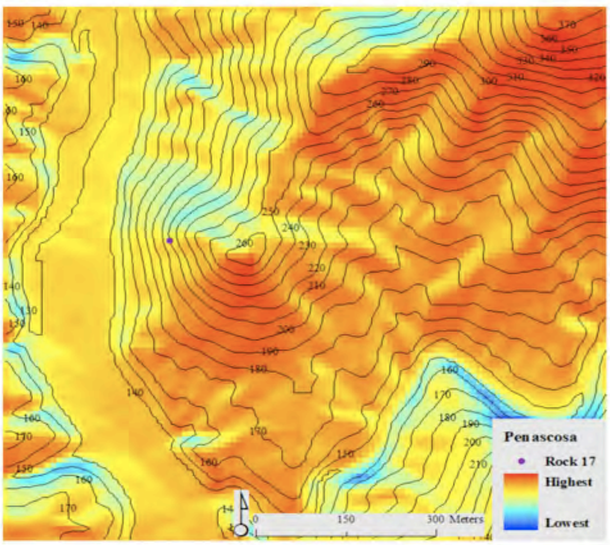
Aspect from DEM: 257º - W   Field: Same Value



Slope from DEM: 90%   Field: Same Value



Solar radiation: 1061656 KW/M^2



Rock: Penascosa 17

Nr: 20

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 52 - STRONG

Rock mass strength : 80 - STRONG

Porosity:

Tilting of panel/outcrop: 5º FORWARD

- Physical weathering

Aveolization: VERY INCIPIENT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: MODERATE

Diaclase: MODERATE

Fractures: SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: MODERATE

Scaling: INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: MODERATE

Rock: Penascosa 17

Nr: 20

- Biodeterioration

Lichens: INCIPIENT - CLEANED

Plants: MODERATE

Insects: INCIPIENT

- Further photos

Engraved area of the outcrop.

Motifs in Rock 17 prior to October 2001 (see Fernandes, 2010).

Drawing of motifs in Rock 17 prior to October 2001 (see Fernandes, 2010). (Drawing: FB).

Motifs in Rock 17 after October 2001 (see Fernandes, 2010).

Rock: Quinta da Barca 1 Nr: 21

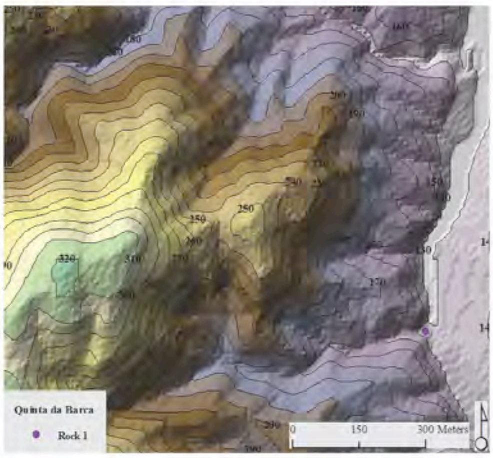
DESCRIPTION:

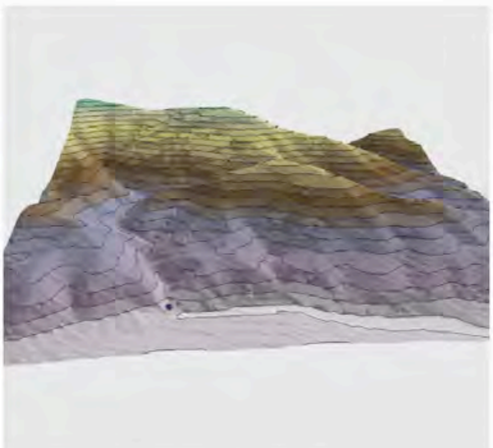
Small outcrop divided in three different panels being the largest 1x1 m and the smallest 0,15x0,40 m. The high number of superimposed Upper Paleolithic motifs (in fact, the ensemble is also know as 'spaghetti' rock) makes Rock 1 one of the most noteworthy panels in the region.

Site located on the left margin of the Côa opposite to Penascosa. It is the site with the largest concentration of panels from the most ancient phase in Upper Paleolithic art: 26 panels, of a total of 61. Moreover, 23 panels belong to the end of Pleistocene times and 2 to Late Prehistory. Modern times are represented by engravings done on the inside walls of an existent farmhouse.

Photo: PG

Location: -7,10670/41,00480





Altitude: 130 m

Risk from flooding episodes: Significant

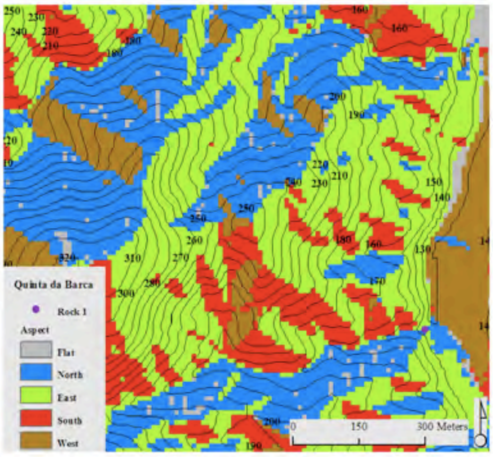
Date Created: 2010/04/26

Last Modified: 2012/07/09

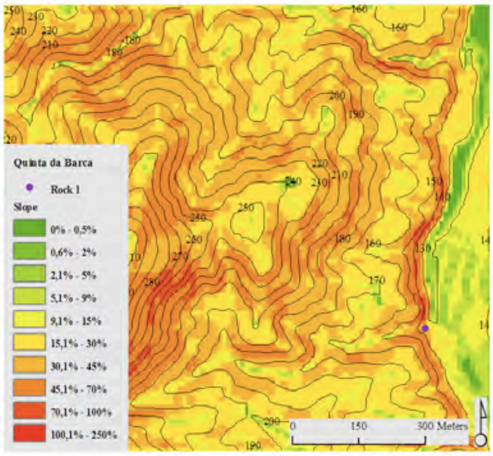
Rock: Quinta da Barca 1

Nr: 21

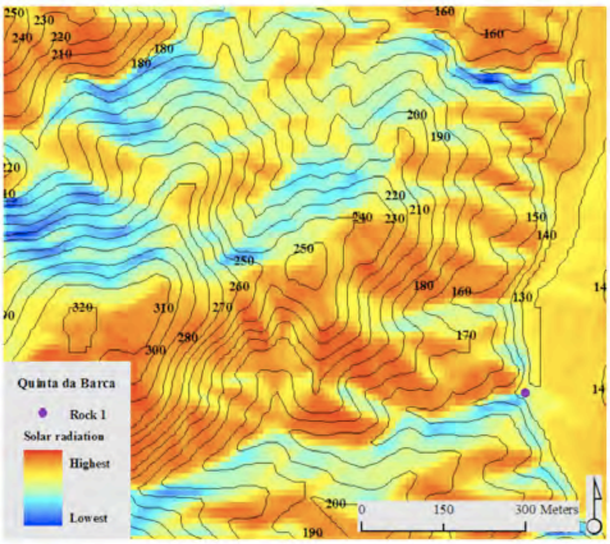
Aspect from DEM: 56º - E   Field: 100º



Slope from DEM: 29%   Field: Same Value



Solar radiation: 1047136 KW/M^2



Rock: Quinta da Barca 1

Nr: 21

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 40 - WEAK

Rock mass strength : 66 - MODERATE

Porosity:

Tilting of panel/outcrop: 10° BACK

- Physical weathering

Aveolization: VERY SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: VERY SIGNIFICANT

Fissures: MODERATE

Diaclase: SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: INCIPIENT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: SIGNIFICANT

Disintegration - Pulverization: VERY SIGNIFICANT

Toppling: MODERATE

Rock: Quinta da Barca 1

Nr: 21

- Biodeterioration

Lichens: MODERATE - CLEANED

Plants: SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Rock 1 comprising 4 different panels. (Photo: MR).

Right panel of Rock 1. (Photo: MR).

Motifs engraved upon the right panel of Rock 1. (Drawing: FB).

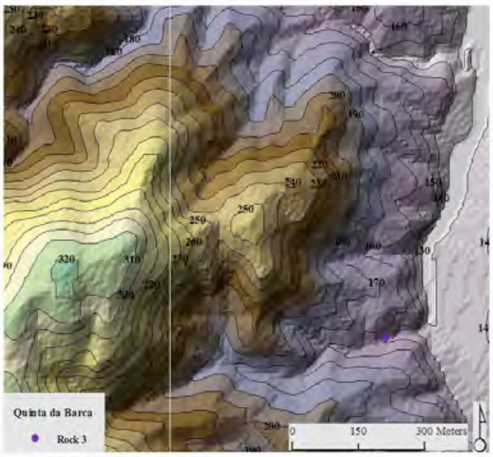
Rock: Quinta da Barca 3 Nr: 22

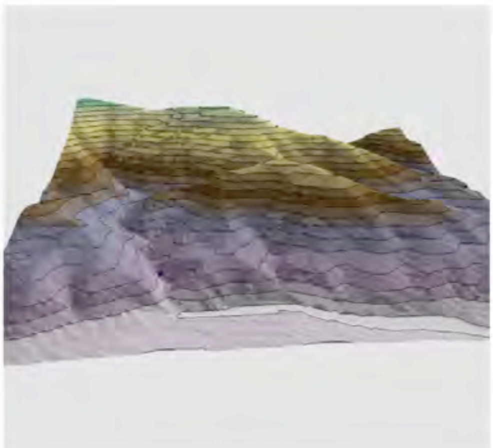
DESCRIPTION:

Small outcrop measuring 0,40x1 m. It is heavily fractured also due to the presence of two Holm Oaks (*Quercus ilex)* growing out of the outcrop. Rock 3 features an Upper Paleolithic male ibex with two heads, a way of depicting motion also composing a scene in which the male is looking at the two animals of the same species that are located behind and in front of the male.

Site located on the left margin of the Côa opposite to Penascosa. It is the site with the largest concentration of panels from the most ancient phase in Upper Paleolithic art: 26 panels, of a total of 61. Moreover, 23 panels belong to the end of Pleistocene times and 2 to Late Prehistory. Modern times are represented by engravings done on the inside walls of an existent farmhouse.

Location: -7,10774/41,00469





Altitude: 150 m

Risk from flooding episodes: None

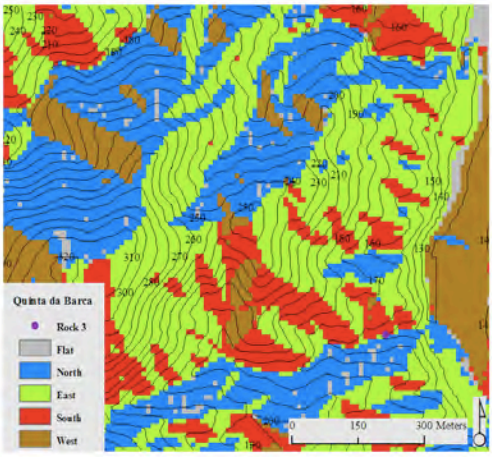
Date Created: 2010/04/26

Last Modified: 2012/05/29

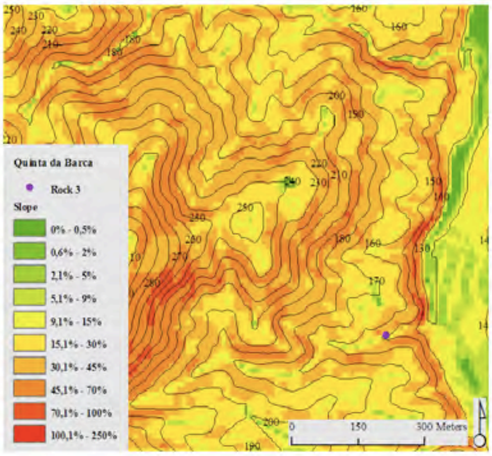
Rock: Quinta da Barca 3

Nr: 22

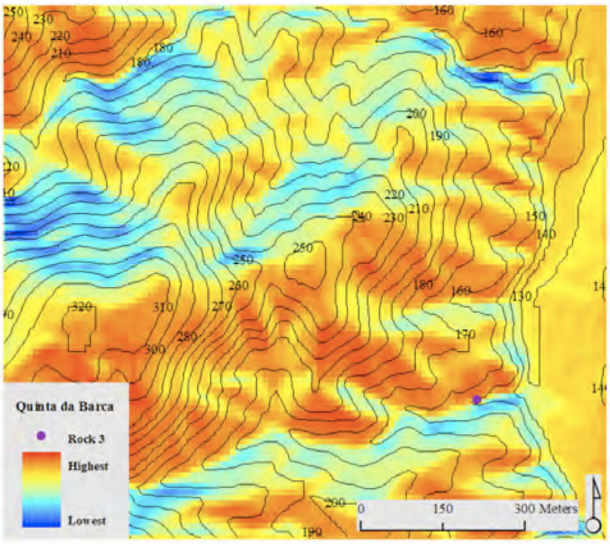
Aspect from DEM: 144º - S Field: Same Value



Slope from DEM: 35% Field: Same Value



Solar radiation: 1310252 KW/M^2



Rock: Quinta da Barca 3

Nr: 22

- Rock characteristics

Formation: PINHÃO

Petrology: SCHIST

Intact rock strength (Schmidt hammer rebound value): 32 - VERY WEAK

Rock mass strength : 50 - WEAK

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: VERY SIGNIFICANT

Fissures: SIGNIFICANT

Diaclase: VERY SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: VERY SIGNIFICANT

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Quinta da Barca 3

Nr: 22

- Biodeterioration

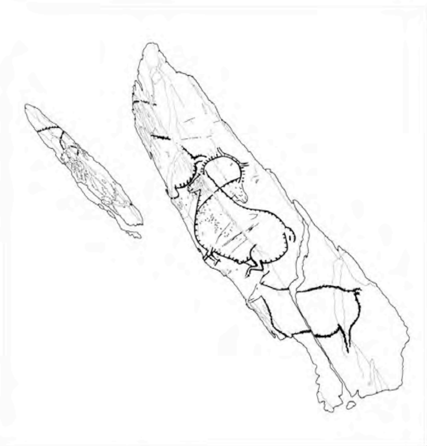
Lichens: VERY SIGNIFICANT - CLEANED

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Motifs in Rock 3. Male central goat measures 30x30 cm. (Photo: AMB).



Motifs in Rock 3. (Drawing: FB).

Fracture dividing one of the motifs in to two different planes. Note also spider web in the fracture.

Lichen colonization affecting mostly one of the heads of the ibex and the hind of the incomplete third motif.

Rock: Ribeira de Piscos 01

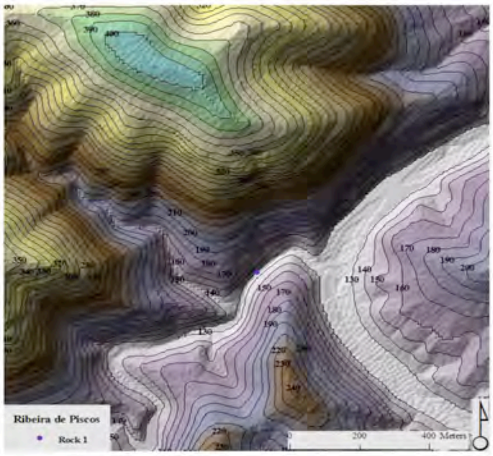
Nr: 23

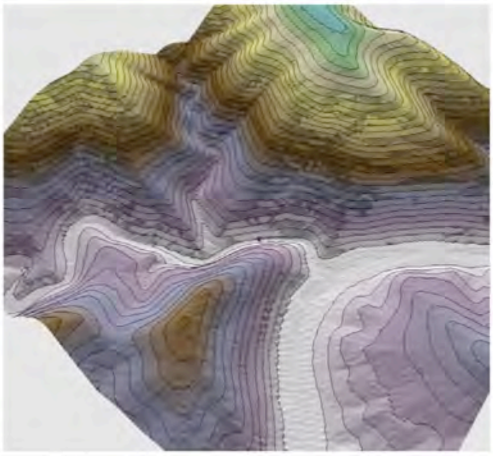
DESCRIPTION:

Large outcrop (13x3 m) heavily fractured and with many disconnected blocks. Located in a seasonally flooded area, it features the Upper Paleolithic representation of entwined horses, one of the most emblematic compositions of the Côa Valley rock art.

Ribeira de Piscos is located immediately upstream to Fariseu rock art site and on the Côa's left margin. The 33 identified panels are distributed along the last 2000 meters of this long creek. Most are located around its mouth but also in the margins of the Côa. Engraved figures date mostly from the last period of the Upper Paleolithic. This site possesses some of the most beautiful figures in the whole valley. This is also the site where more human representations have been found. In fact, a total of 17 anthropomorphic has been identified - an ithyphallic motif in Rock 2 and the remaining 16 in Rock 24.

Location: -7,11736/41,02858





Altitude: 130 m

Risk from flooding episodes: Significant

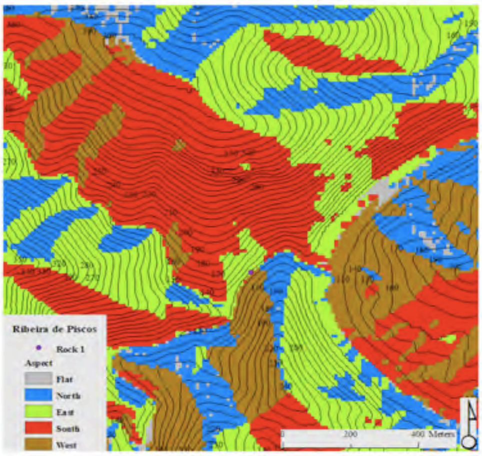
Date Created: 2010/04/26

Last Modified: 2012/07/09

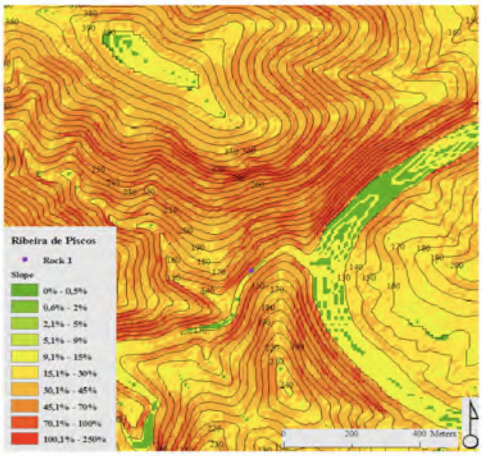
Rock: Ribeira de Piscos 01

Nr: 23

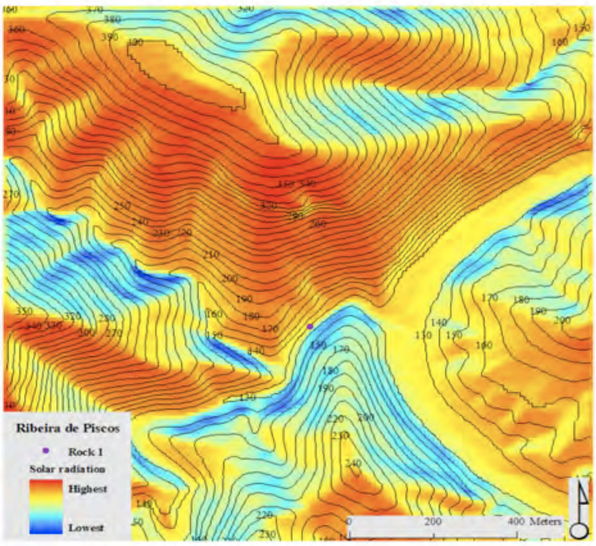
Aspect from DEM: 131° - E Field: Same Value



Slope from DEM: 25% Field: 60%



Solar radiation: 1186660 KW/M^2



Rock: Ribeira de Piscos 01

Nr: 23

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 57 - STRONG

Rock mass strength : 70 - MODERATE

Porosity:

Tilting of panel/outcrop: 17° FORWARD

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: MODERATE

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: VERY SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: INCIPIENT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: SIGNIFICANT

Disintegration - Pulverization: VERY SIGNIFICANT

Toppling: VERY SIGNIFICANT

Rock: Ribeira de Piscos 01

Nr: 23

- Biodeterioration

Lichens: VERY INCIPIENT - CLEANED

Plants: SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Rock 1 in 'its' landscape. Note the the amount of sediments deposited by seasonal flooding.

The entwined horses of Piscos measuring 1,30x60 cm. (Photo: Pedro Guimarães).

Fracture with 'turning' orientation that affects the hind area of the left represented motif.

Small hole in the wake of a fissure. Note that it is used by a species of insect for its lair.

Rock: Ribeira de Piscos 02

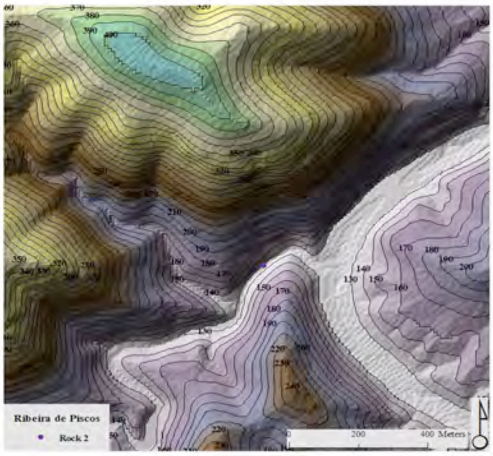
Nr: 24

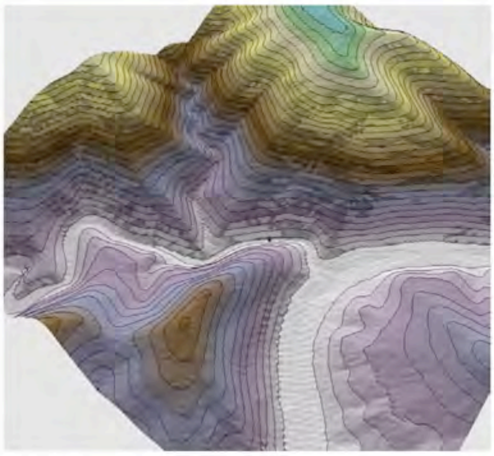
DESCRIPTION:

Relatively large outcrop measuring 4x0,70 m. It has Upper Paleolithic and Iron Age motifs, among which the famous Pleistocene anthropomorphic representation known as 'the Man of Piscos'.

Ribeira de Piscos is located immediately upstream to Fariseu rock art site and on the Côa's left margin. The 33 identified panels are distributed along the last 2000 meters of this long creek. Most are located around its mouth but also in the margins of the Côa. Engraved figures date mostly from the last period of the Upper Paleolithic. This site possesses some of the most beautiful figures in the whole valley. This is also the site where more human representations have been found. In fact, a total of 17 anthropomorphic has been identified - an ithyphallic motif in Rock 2 and the remaining 16 in Rock 24.

Location: -7,11710/41,02873





Altitude: 130 m

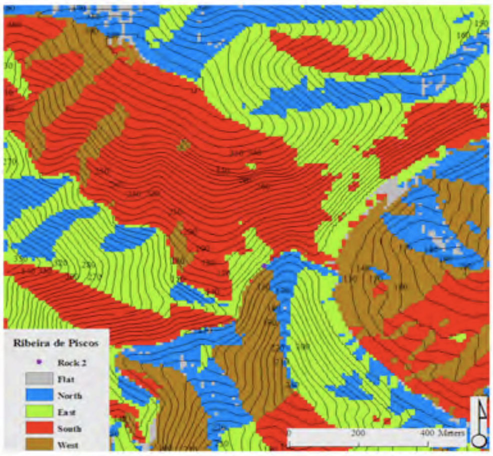
Risk from flooding episodes: Significant

Date Created: 2010/04/26

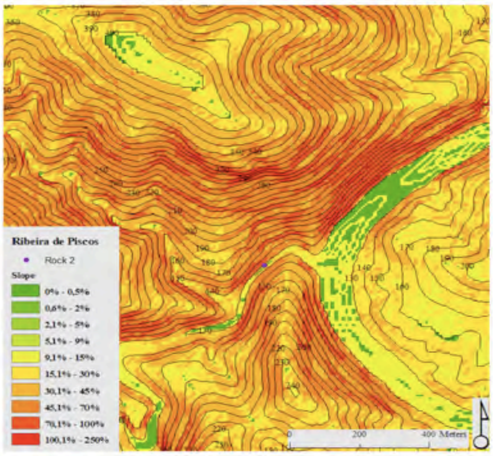
Last Modified: 2012/07/09

Rock: Ribeira de Piscos 02 Nr: 24

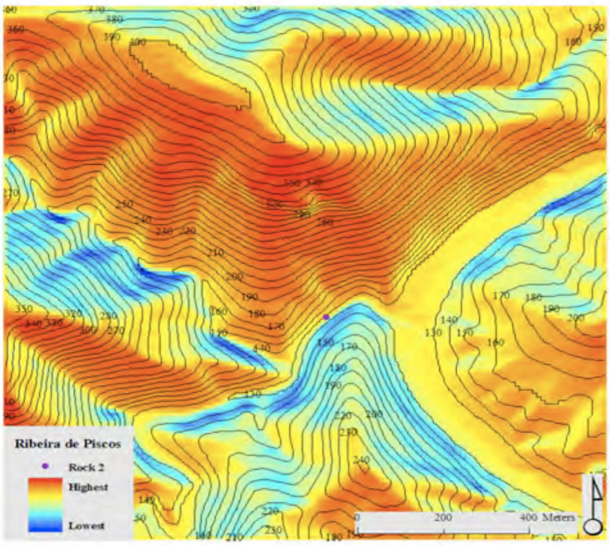
Aspect from DEM: 135º - E Field: Same Value



Slope from DEM: 21% Field: 65%



Solar radiation: 1200775 KW/M^2



Rock: Ribeira de Piscos 02

Nr: 24

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 54 - STRONG

Rock mass strength : 69 - MODERATE

Porosity:

Tilting of panel/outcrop: 2º BACK

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: VERY SIGNIFICANT

Collapse: INCIPIENT

Fissures: VERY SIGNIFICANT

Diaclase: INCIPIENT

Fractures: SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: MODERATE

Scaling: INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: INCIPIENT

Rock: Ribeira de Piscos 02

Nr: 24

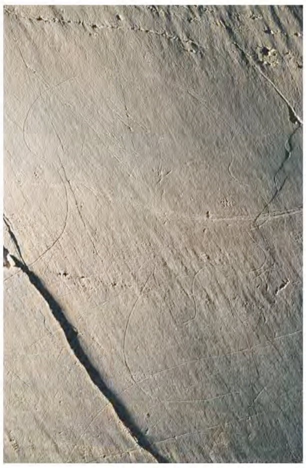
- Biodeterioration

Lichens: VERY INCIPIENT - CLEANED

Plants: INCIPIENT

Insects: SIGNIFICANT

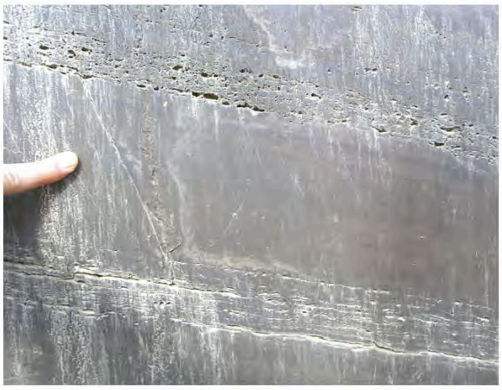
- Further photos



Head detail of the so-called 'Man of Piscos' (15x10cm. of the motif. (Photo: AMB).

Aurochs' head. Note the figure was done in two separate planes, proving the rock had this configuration in the UP.

Gap in Rock 2, fortunately located in an 'unengraved' of the panel.



Parallel weakness areas in Rock 2 motivated by different composition of the strata that form the outcrop.

Rock: Ribeira de Piscos 03

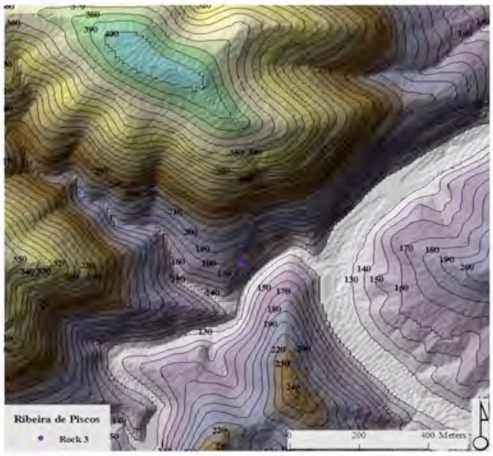
Nr: 25

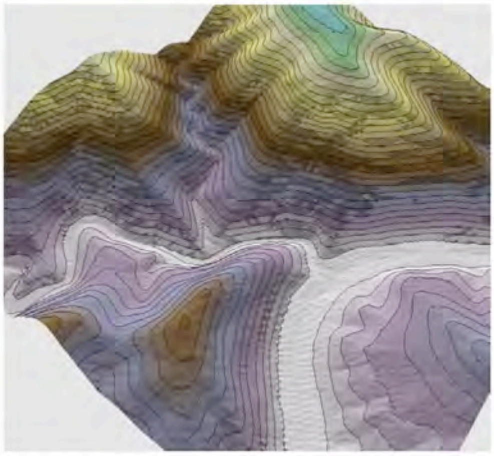
DESCRIPTION:

Small panel (0,50x0,50 m) belonging to a much larger outcrop that measures 10x4m. Condition evaluation was only carried out on the engraved panel and its immediate area. It only possesses an Upper Paleolithic composition depicting four interacting horses.

Ribeira de Piscos is located immediately upstream to Fariseu rock art site and on the Côa's left margin. The 33 identified panels are distributed along the last 2000 meters of this long creek. Most are located around its mouth but also in the margins of the Côa. Engraved figures date mostly from the last period of the Upper Paleolithic. This site possesses some of the most beautiful figures in the whole valley. This is also the site where more human representations have been found. In fact, a total of 17 anthropomorphic has been identified - an ithyphallic motif in Rock 2 and the remaining 16 in Rock 24.

Location: -7,11785/41,02879





Altitude: 150 m

Risk from flooding episodes: None

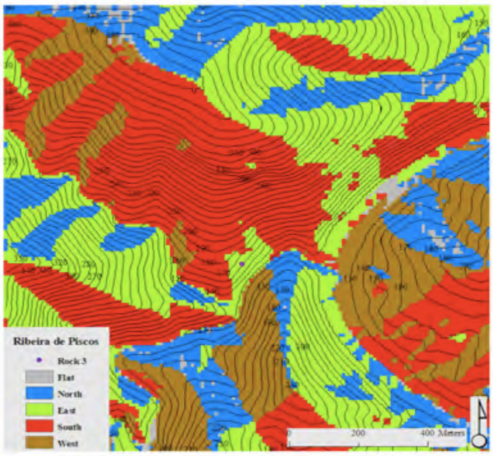
Date Created: 2010/04/26

Last Modified: 2012/07/09

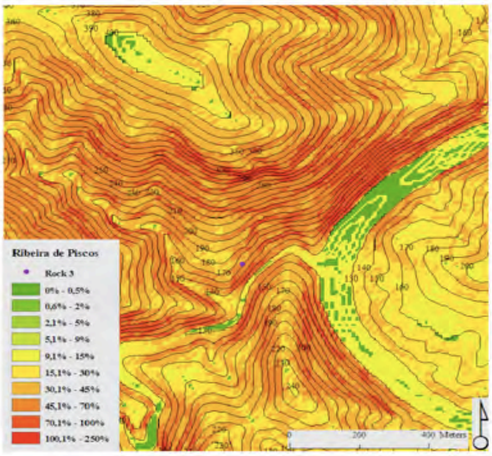
Rock: Ribeira de Piscos 03

Nr: 25

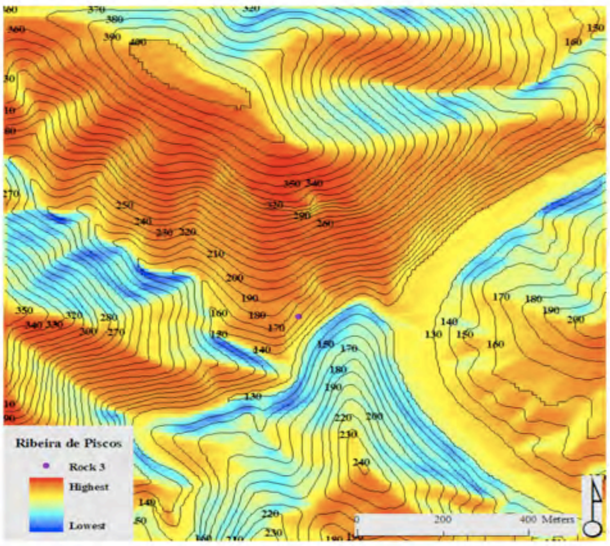
Aspect from DEM: 126º - E Field: Same Value



Slope from DEM: 56% Field: Same Value



Solar radiation: 1235289 KW/M^2



Rock: Ribeira de Piscos 03

Nr: 25

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 42 - MODERATE

Rock mass strength : 66 - MODERATE

Porosity:

Tilting of panel/outcrop: 2º FORWARD

- Physical weathering

Aveolization: VERY INCIPIENT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: VERY SIGNIFICANT

Diaclase: INCIPIENT

Fractures: VERY SIGNIFICANT

Differential Erosion: INCIPIENT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: INCIPIENT

Scaling: INCIPIENT

Disintegration - Pulverization: MODERATE

Toppling: INCIPIENT

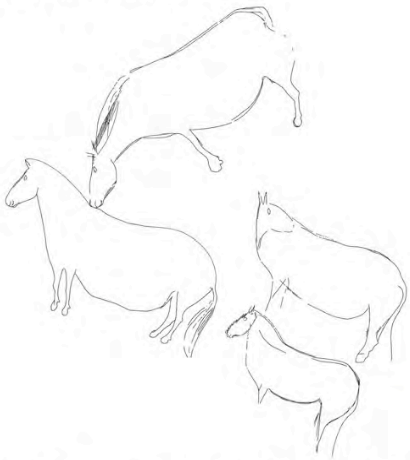
Rock: Ribeira de Piscos 03

Nr: 25

- Biodeterioration

Lichens:	VERY INCIPIENT - CLEANED
Plants:	INCIPIENT
Insects:	VERY SIGNIFICANT

- Further photos



Motifs in Rock 2. Scene measures 40x40 cm. (Drawing: Fernando Barbosa/CNART).

Detail of the left horse's head. Note the fracture separating the muzzle in to two distinct planes.

Detail of the right horse's head. Note the white organic remains (a cocoon?).

Weakness hollow area containing motifs where surface rock is detaching eventually originating a gap.

Rock: Ribeira de Piscos 24

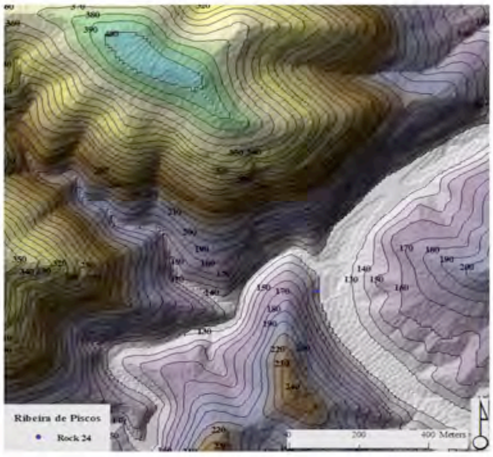
Nr: 26

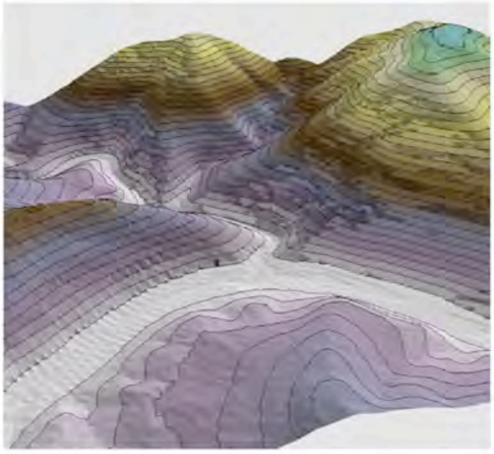
DESCRIPTION:

Large outcrop (15x2,50m.) containing numerous small panels, some of which have been engraved with Upper Paleolithic fine line incisions and a pecked motif. Very heavily physically weathered, it is and oddity in the Côa since its orientation is not parallel to the slope, but rather sub-perpendicular.

Ribeira de Piscos is located immediately upstream to Fariseu rock art site and on the Côa's left margin. The 33 identified panels are distributed along the last 2000 meters of this long creek. Most are located around its mouth but also in the margins of the Côa. Engraved figures date mostly from the last period of the Upper Paleolithic. This site possesses some of the most beautiful figures in the whole valley. This is also the site where more human representations have been found. In fact, a total of 17 anthropomorphic has been identified - an ithyphallic motif in Rock 2 and the remaining 16 in Rock 24.

Location: -7,11526/41,02798





Altitude: 130 m

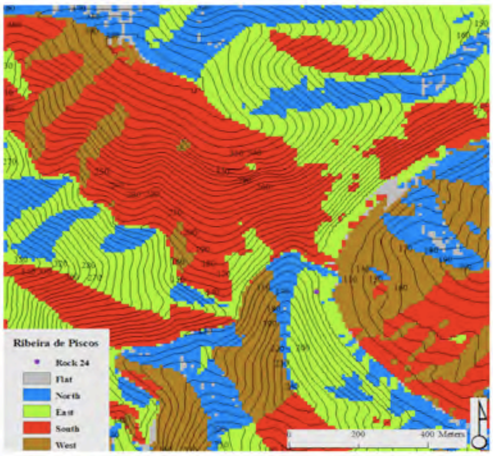
Risk from flooding episodes: Significant

Date Created: 2010/04/26

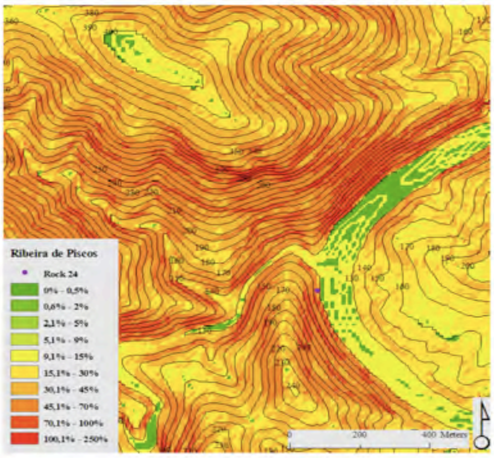
Last Modified: 2012/07/09

Rock: Ribeira de Piscos 24 Nr: 26

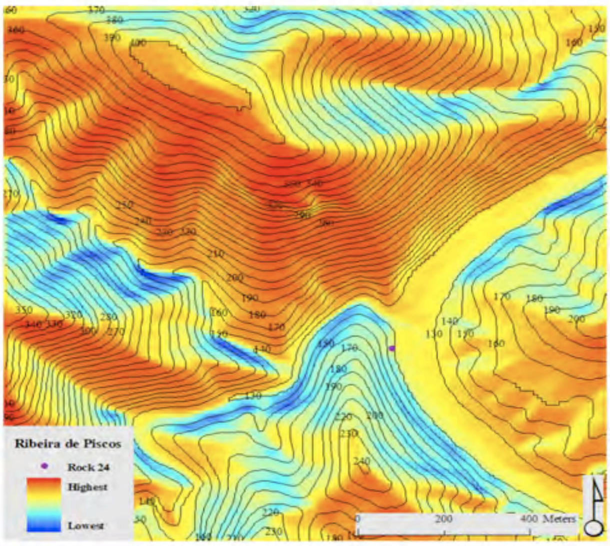
Aspect from DEM: 89º - E Field: 130º



Slope from DEM: 54% Field: Same Value



Solar radiation: 1067553 KW/M^2



Rock: Ribeira de Piscos 24 Nr: 26

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 47 - MODERATE

Rock mass strength : 55 - MODERATE

Porosity:

Tilting of panel/outcrop: 30° FORWARD

- Physical weathering

Aveolization: VERY SIGNIFICANT

Exfoliation: MODERATE

Collapse: VERY SIGNIFICANT

Fissures: VERY SIGNIFICANT

Diaclase: MODERATE

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: VERY SIGNIFICANT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: VERY SIGNIFICANT

Disintegration - Pulverization: SIGNIFICANT

Toppling: SIGNIFICANT

Rock: Ribeira de Piscos 24

Nr: 26

- Biodeterioration

Lichens: INCIPIENT - CLEANED

Plants: SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Fine line incised aurochs(15x8 cm.) 'cut' by fracture.

Staring Upper Paleolithic aurochs (total figure 15x7 cm.), Note fractures and gaping. (Photo: MA)

Area with small engraved panels such as the one used to place the aurochs in the previous image. Note fractures.

Note fractures that cross the outcrop in two distinct orientations.

Rock: Tudão 1

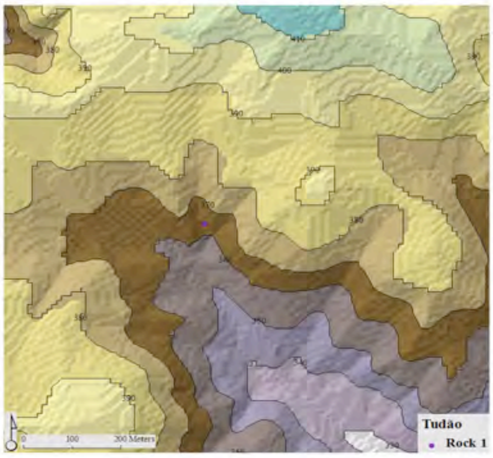
Nr: 27

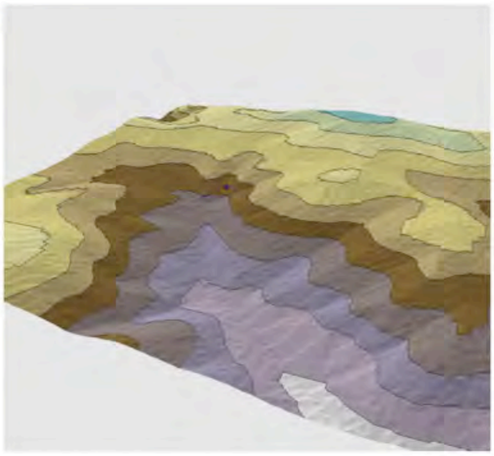
DESCRIPTION:

Medium sized outcrop measuring 8x 1,5m. It is located inside a farm area still in use. Despite this fact, no vandalism or other human action damage is noticeable. It possesses Upper Paleolithic and Iron Age imagery.

Tudão is one of the few rock art sites located in the plateaux which, in the Lower Côa region, 'surrounds' the Côa and Douro Rivers drainage system. It is also the site that is closest located to the municipality head city, Vila Nova de Foz Côa. Two outcrops with rock art have been identified. Rock 1 features Upper Paleolithic deer representations.

Location: -7,13198/41,09396





Altitude: 370 m

Risk from flooding episodes: None

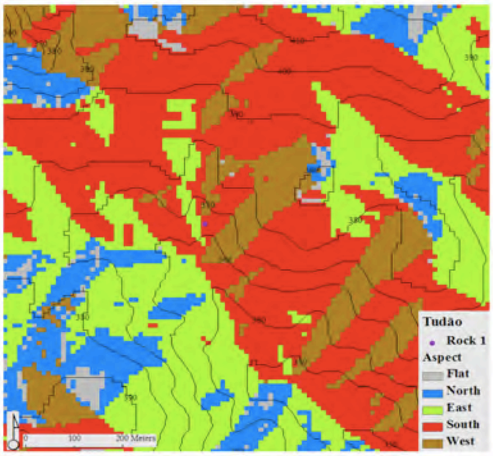
Date Created: 2010/04/26

Last Modified: 2012/05/29

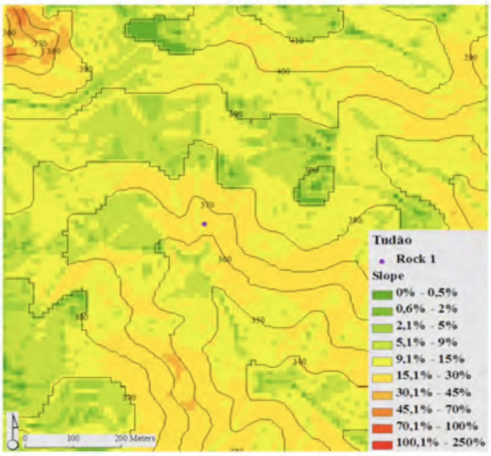
Rock: Tudão 1

Nr: 27

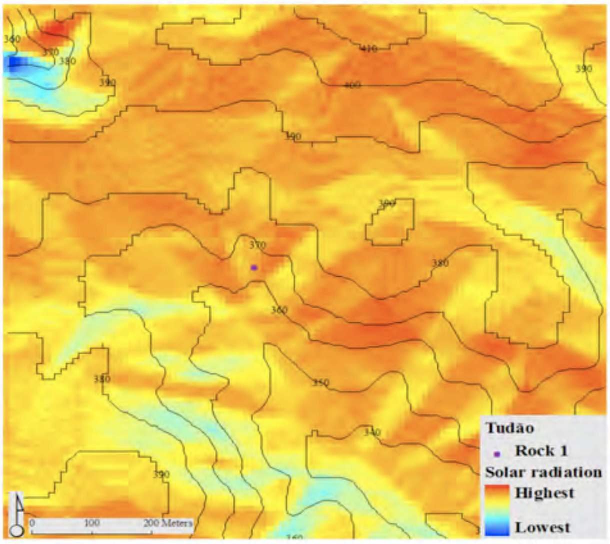
Aspect from DEM: 202º - S Field: 119º - E



Slope from DEM: 13% Field: Same Value



Solar radiation: 1310570 KW/M^2



Rock: Tudão 1

Nr: 27

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 37 - WEAK

Rock mass strength : 77 - STRONG

Porosity:

Tilting of panel/outcrop: 3º FORWARD

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: MODERATE

Collapse: INCIPIENT

Fissures: INCIPIENT

Diaclase: INCIPIENT

Fractures: MODERATE

Differential Erosion: MODERATE

Gapping - Splintering: VERY SIGNIFICANT

Dislocated Blocks/Elements: MODERATE

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: VERY SIGNIFICANT

Rock: Tudão 1

Nr: 27

- Biodeterioration

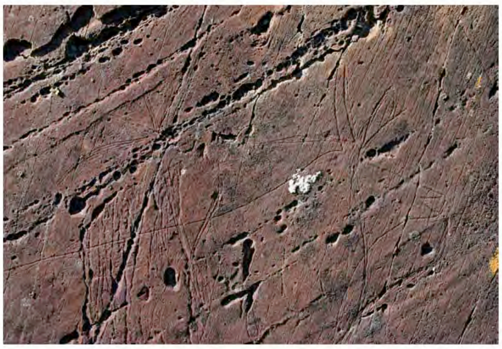
Lichens: SIGNIFICANT - CLEANED

Plants: VERY SIGNIFICANT

Insects: MODERATE

- Further photos

Location of Rock 1 in a middle of farming land. (Photo: MR).



Upper Paleolithic open mouth deer (25x10 cm). Note gaping, fissures and fractures. (Photo: MR).

Iron Age horse motifs. As motif in the previous image, these were done resorting to fine line incision (Photo: MR).

Rock: Vale de Cabrões 1

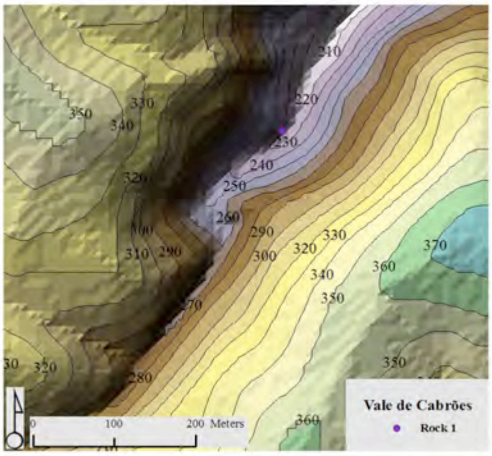
Nr: 28

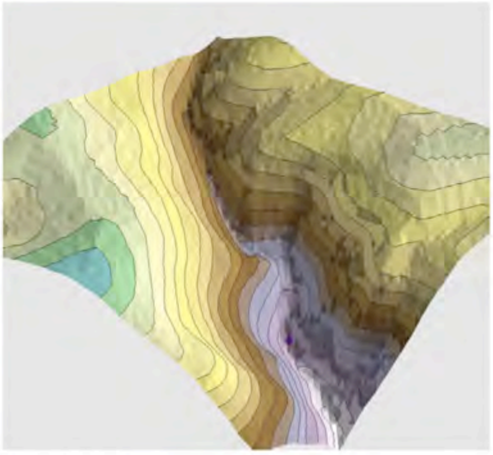
DESCRIPTION:

Large outcrop (10x 5 m) located in a very narrow valley. It only possesses one motif: a late Upper Paleolithic, or even Epipaleolithic pecked deer. This motif suggests what some of the already identified habitat sites in the region suggest, the continuity of human occupation after the end of the Pleistocene.

Steep and rocky valley on the Douro's left bank, located immediately upstream to Vale da Casa and downstream to Vermelhosa. 58 engraved outcrops are distributed along the valley's slopes. The site possesses Iron Age and Upper Paleolithic imagery. Among representations from the more ancient period, some of the most beautiful motifs in the Côa can be found here, namely in Rocks 5 and 32.

Location: -7,11615/41,09287





Altitude: 230 m

Risk from flooding episodes: None

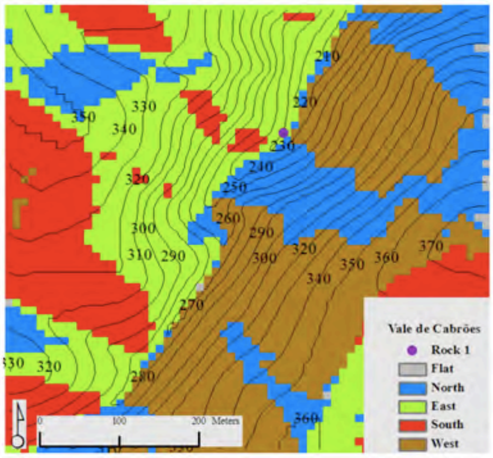
Date Created: 2010/04/26

Last Modified: 2012/06/05

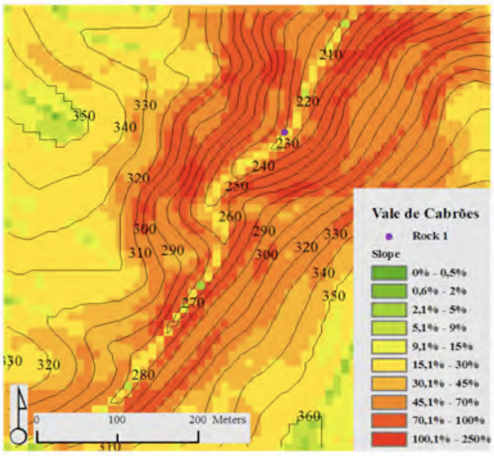
Rock: Vale de Cabrões 1

Nr: 28

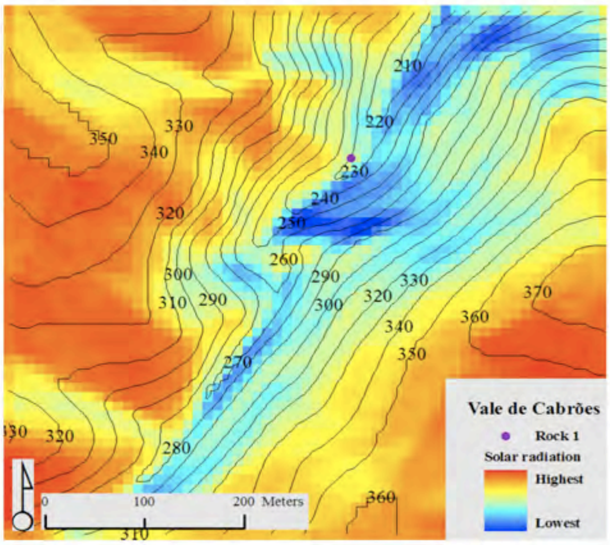
Aspect from DEM: 94º - E Field: Same Value



Slope from DEM: 19% Field: 65%



Solar radiation: 975254 KW/M²



Rock: Vale de Cabrões 1

Nr: 28

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 49 - MODERATE

Rock mass strength : 68 - MODERATE

Porosity:

Tilting of panel/outcrop: 5º FORWARD

- Physical weathering

Aveolization:	MODERATE	Exfoliation:	MODERATE
Collapse:	MODERATE	Fissures:	MODERATE
Diaclase:	SIGNIFICANT	Fractures:	SIGNIFICANT
Differential Erosion:	MODERATE	Gapping - Splintering:	SIGNIFICANT
Dislocated Blocks/Elements:	MODERATE	Scaling:	INCIPIENT
Disintegration - Pulverization:	MODERATE	Toppling:	MODERATE

Rock: Vale de Cabrões 1

Nr: 28

- Biodeterioration

Lichens:	MODERATE - CLEANED
Plants:	VERY SIGNIFICANT
Insects:	SIGNIFICANT

- Further photos

Hunted deer (60x45 cm.) just after being hit by a spear. (Photo: MA).

Engraved area of the outcrop. Note superficial water runoff evidences (black areas).

Gaping/splintering and exfoliated area just next to the engraved motif.

Area just above the engraved motif. Different colors due to water runoff, lichens and mineral surface migration.

Rock: Vale de Cabrões 4

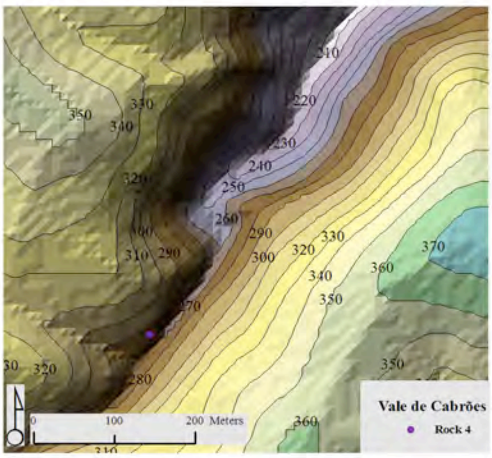
Nr: 29

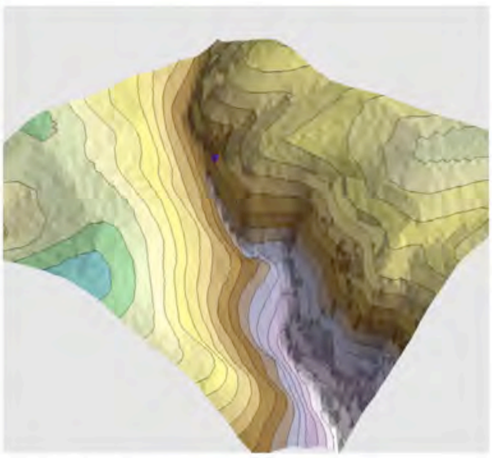
DESCRIPTION:

Large outcrop measuring 35x2 m on which only a very small panel (1x0,50 m) was engraved. It features 7 Upper Paleolithic goat motifs depicted as if forming a flock.

Steep and rocky valley on the Douro's left bank, located immediately upstream to Vale da Casa and downstream to Vermelhosa. 58 engraved outcrops are distributed along the valley's slopes. The site possesses Iron Age and Upper Paleolithic imagery. Among representations from the more ancient period, some of the most beautiful motifs in the Côa can be found here, namely in Rocks 5 and 32.

Location: -7,11813/41,09056





Altitude: 280 m

Risk from flooding episodes: None

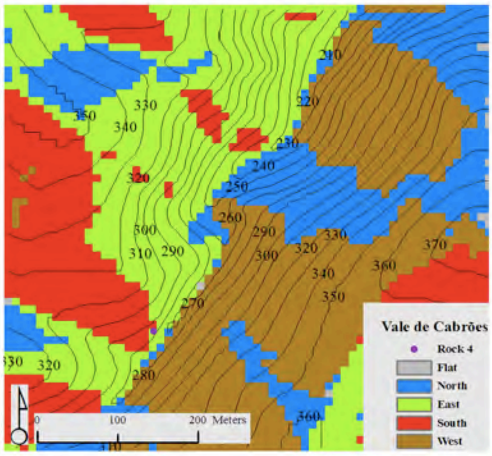
Date Created: 2010/04/27

Last Modified: 2012/07/09

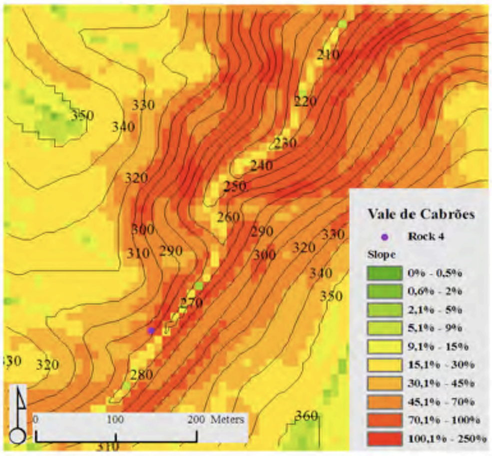
Rock: Vale de Cabrões 4

Nr: 29

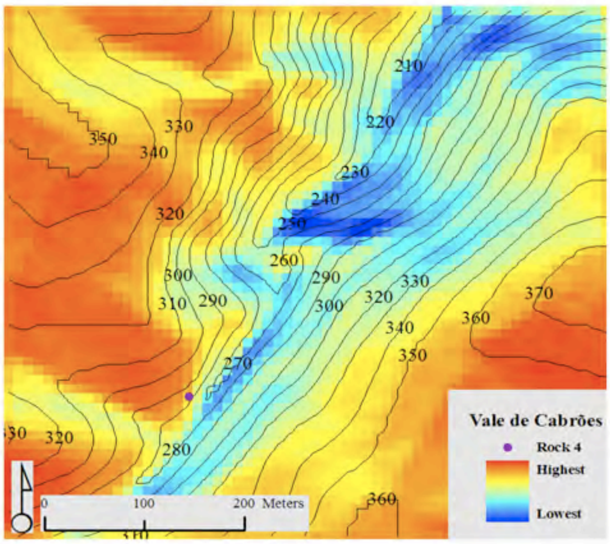
Aspect from DEM: 130 - E Field: Same Value



Slope from DEM: 76% Field: Same Value



Solar radiation: 1155771 KW/M^2



Rock: Vale de Cabrões 4

Nr: 29

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 45 - MODERATE

Rock mass strength : 80 - STRONG

Porosity:

Tilting of panel/outcrop: 2º BACK

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: MODERATE

Diaclase: MODERATE

Fractures: VERY SIGNIFICANT

Differential Erosion: INCIPIENT

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: INCIPIENT

Scaling: INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: MODERATE

Rock: Vale de Cabrões 4

Nr: 29

- Biodeterioration

Lichens: MODERATE - CLEANED

Plants: SIGNIFICANT

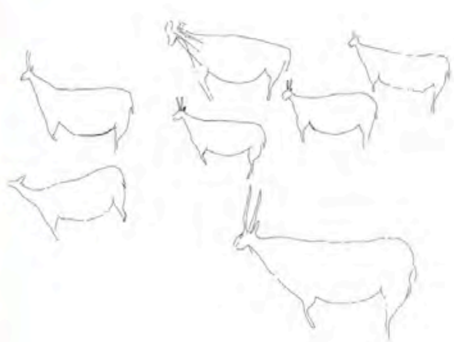
Insects: SIGNIFICANT

- Further photos

Engraved area of the outcrop.

One of the Upper Paleolithic engraved goats (15x8 cm.). Note the motif is cut by a fissure.

Another goat motif measuring 20x12 cm). (Photo: MA).



Goat flock measuring 50x25 cm. (Drawing: FB).

Rock: Vale de Cabrões 5

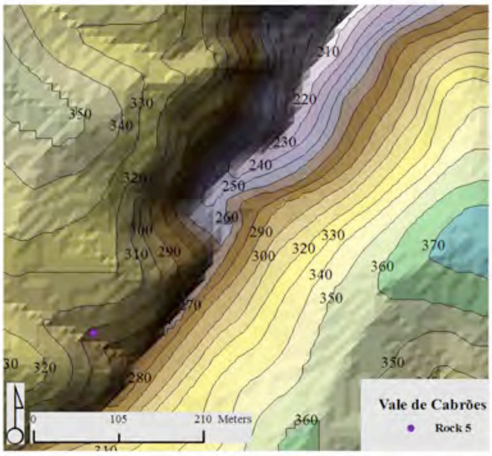
Nr: 30

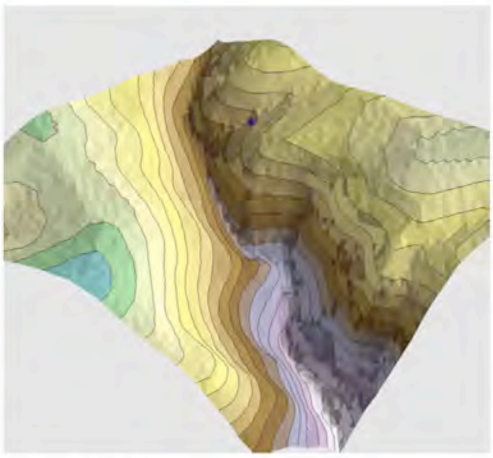
DESCRIPTION:

Medium sized outcrop measuring 6x2 m with a small wall built on top. Only two small panels were engraved with Upper Paleolithic fine line incised animal figures.

Steep and rocky valley on the Douro's left bank, located immediately upstream to Vale da Casa and downstream to Vermelhosa. 58 engraved outcrops are distributed along the valley's slopes. The site possesses Iron Age and Upper Paleolithic imagery. Among representations from the more ancient period, some of the most beautiful motifs in the Côa can be found here, namely in Rocks 5 and 32.

Location: -7,11896/41,09056





Altitude: 300 m

Risk from flooding episodes: .None

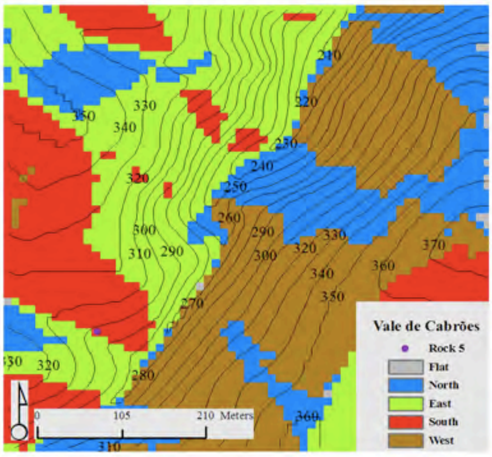
Date Created: 2010/04/27

Last Modified: 2012/07/07

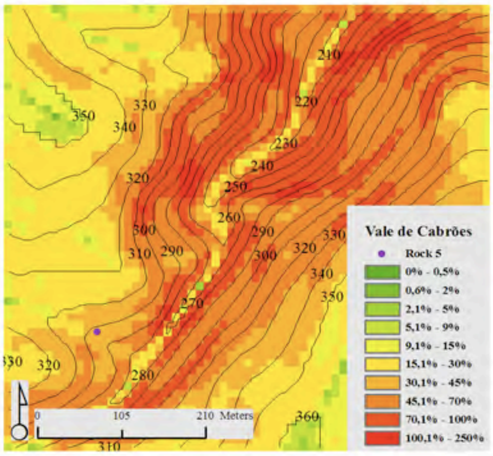
Rock: Vale de Cabrões 5

Nr: 30

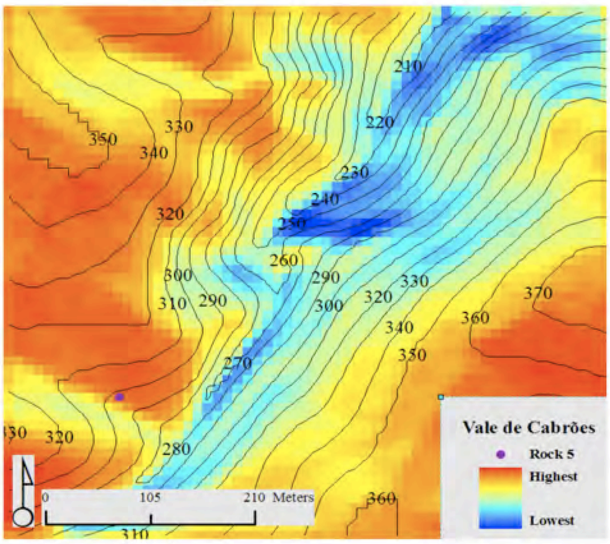
Aspect from DEM: 137º - S   Field: Same Value



Slope from DEM: 38%   Field: Same Value



Solar radiation: 1313619 KW/M^2



Rock: Vale de Cabrões 5

Nr: 30

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 44 - MODERATE

Rock mass strength : 76 - STRONG

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: MODERATE

Collapse: INCIPIENT

Fissures: SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: INCIPIENT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: INCIPIENT

Scaling: INCIPIENT

Disintegration - Pulverization: VERY SIGNIFICANT

Toppling: VERY INCIPIENT

Rock: Vale de Cabrões 5

Nr: 30

- Biodeterioration

Lichens: SIGNIFICANT - CLEANED

Plants: SIGNIFICANT

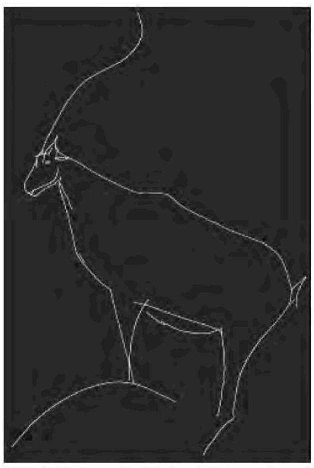
Insects: SIGNIFICANT

- Further photos

Gaps associated with fractures.

Weakness area due to aveolization,gaping and fracturing.

Engraved goat's head. Note micro-aveolization. (Photo: MA).



Total goat's motif measuring 15x22 cm. (Drawing: FB).

Rock: Vale do Forno I 1

Nr: 31

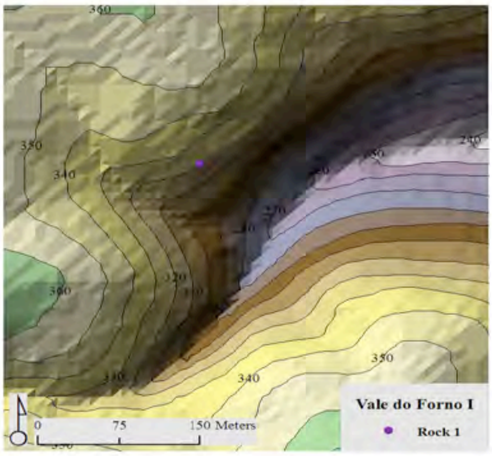
DESCRIPTION:

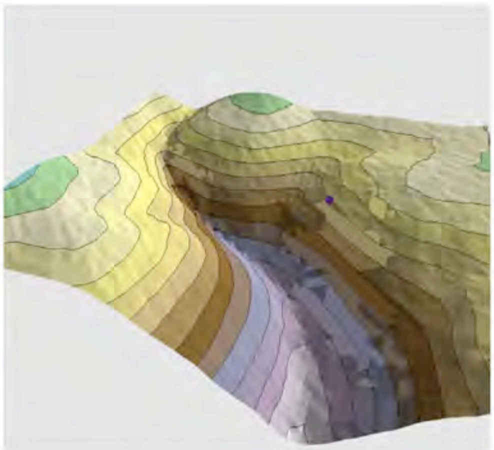
Medium sized outcrop (5x1,80m) in which fine line Iron Age motifs were engraved in different panels. A loose rock wall was built on top.

Site located between Foz do Côa and Moinhos de Cima. It is a very sinuous river valley of W-E orientation converging with the Côa, in its left bank, at an elevation of 130 m. Of the 79 known rock art outcrops, Modern and Iron Age figures stand out. In fact, although some excellent Upper Paleolithic motifs - namely, does in Rock 9 and signs in Rock 30 - the quantity and quality of Iron Age motifs - mostly warriors and signs - makes this site one of the most relevant for the period in the Côa. From Modern times, Rocks 31, 48 and 56 stand out due to the originality present in several motifs and compositions.

Note: due to the valley's considerable length, the site has been divided in to two distinct Sections (I and II). Rock 1 and 9 are located in Section I and rocks 5 and 6 in Section II.

Location: -7,12369/41,07610





Altitude: 320 m

Risk from flooding episodes: None

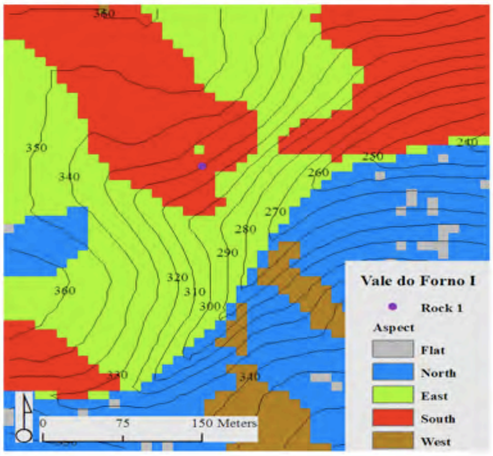
Date Created: 2010/04/27

Last Modified: 2012/06/14

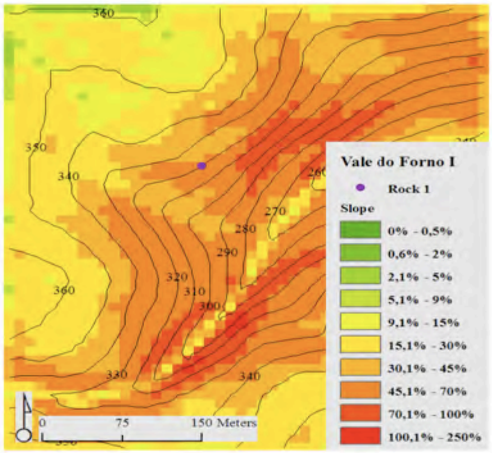
Rock: Vale do Forno I 1

Nr: 31

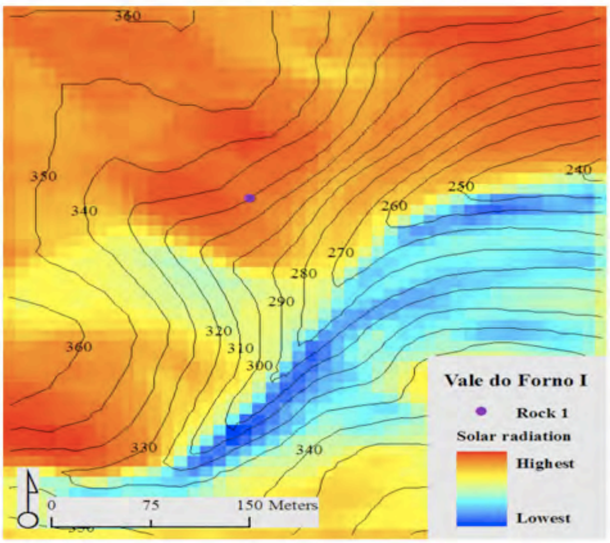
Aspect from DEM: 143º - S   Field: Same Value



Slope from DEM: 52%   Field: Same Value



Solar radiation: 1337873 KW/M²



Rock: Vale do Forno I 1

Nr: 31

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 51 - STRONG

Rock mass strength : 72 - STRONG

Porosity:

Tilting of panel/outcrop: 2º BACK

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: VERY SIGNIFICANT

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: MODERATE

Fractures: SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: MODERATE

Scaling: SIGNIFICANT

Disintegration - Pulverization: SIGNIFICANT

Toppling: MODERATE

Rock: Vale do Forno I 1

Nr: 31

- Biodeterioration

Lichens: MODERATE

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Exfoliation, gaping and fracturing in a weak area of the outcrop.

Plant coming out of a fracture.

Iron Age canine motif measuring 15x15 cm.

Iron Age warrior carrying a small shield. Motif 7x13 cm.

Rock: Vale do Forno I 9

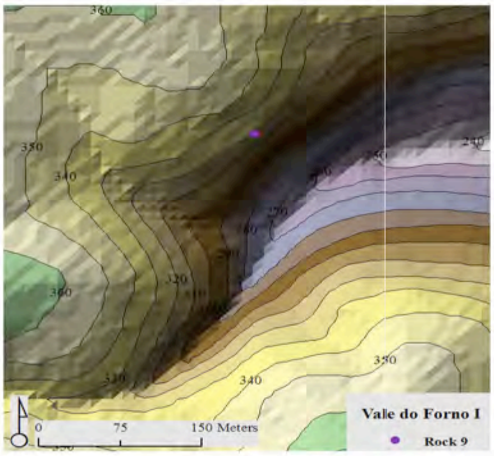
Nr: 32

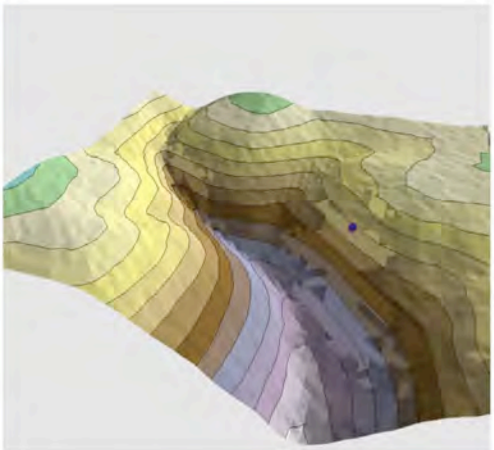
DESCRIPTION:

Small outcrop measuring 4x0,50 m. located in an abandoned agricultural area. It features 2 Upper Paleolithic fine line incised horse motifs.

Site located between Foz do Côa and Moinhos de Cima. It is a very sinuous river valley of W-E orientation converging with the Côa, in its left bank, at an elevation of 130 m. Of the 79 known rock art outcrops, Modern and Iron Age figures stand out. In fact, although some excellent Upper Paleolithic motifs - namely, does in Rock 9 and signs in Rock 30 - the quantity and quality of Iron Age motifs - mostly warriors and signs - makes this site one of the most relevant for the period in the Côa. From Modern times, Rocks 31, 48 and 56 stand out due to the originality present in several motifs and compositions.

Location: -7,12310/41,07642





Altitude: 320 m

Risk from flooding episodes: None

Date Created: 2010/04/27

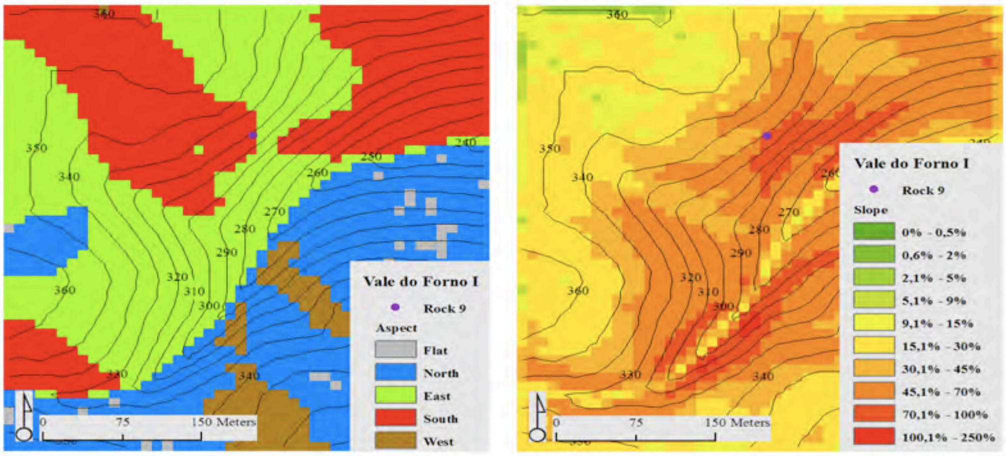
Last Modified: 2012/05/29

Rock: Vale do Forno I 9

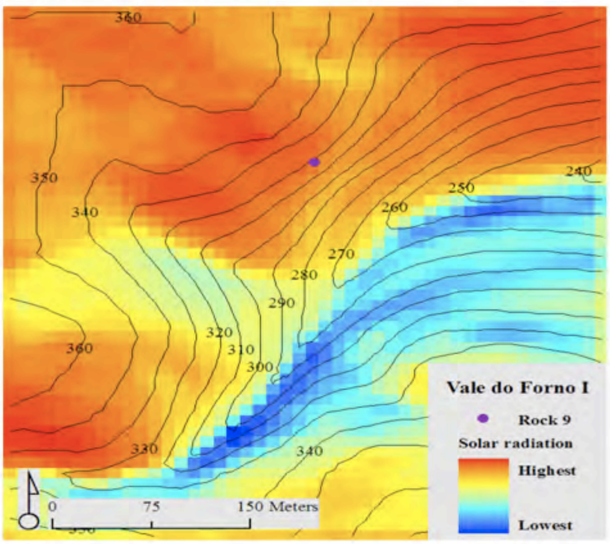
Nr: 32

Aspect from DEM: 139º - S Field: Same Value

Slope from DEM: 57% Field: Same Value



Solar radiation: 1325253 KW/M^2



Rock: Vale do Forno I 9

Nr: 32

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 44 - MODERATE

Rock mass strength : 72 - STRONG

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: MODERATE

Exfoliation: VERY SIGNIFICANT

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: MODERATE

Scaling: SIGNIFICANT

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Vale do Forno I 9

Nr: 32

- Biodeterioration

Lichens: MODERATE

Plants: MODERATE

Insects: SIGNIFICANT

- Further photos

Upper Paleolithic horse motif measuring 11x8 cm. (Photo: MR).

The other Upper Paleolithic horse motif (16x10 cm.) cut in two by a fracture. (Photo: MR).

Area where Rock 9 (center of the photo) is located. (Photo: MR).

Rock: Vale do Forno II 5

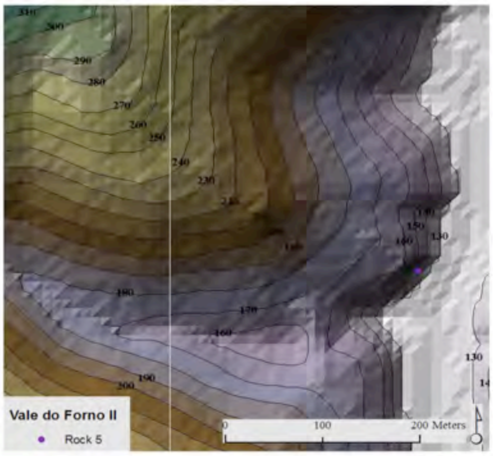
Nr: 33

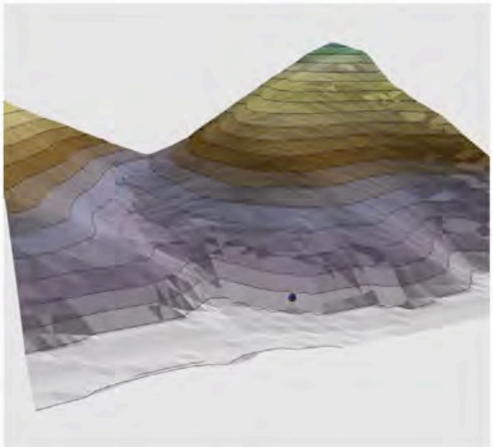
DESCRIPTION:

Very large outcrop (20x10 m) featuring Iron Age motifs. It is located almost below the modern road bridge that traverses the Côa. The steepness of the slope makes it very difficult to reach the engraved panel.

Site located between Foz do Côa and Moinhos de Cima. It is a very sinuous river valley of W-E orientation converging with the Côa, in its left bank, at an elevation of 130 m. Of the 79 known rock art outcrops, Modern and Iron Age figures stand out. In fact, although some excellent Upper Paleolithic motifs - namely, does in Rock 9 and signs in Rock 30 - the quantity and quality of Iron Age motifs - mostly warriors and signs - makes this site one of the most relevant for the period in the Côa. From Modern times, Rocks 31, 48 and 56 stand out due to the originality present in several motifs and compositions.

Location: -7,10859/41,0750





Altitude: 140 m

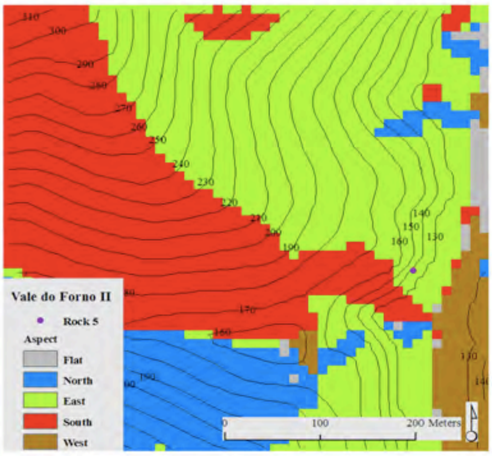
Risk from flooding episodes: None

Date Created: 2010/04/27

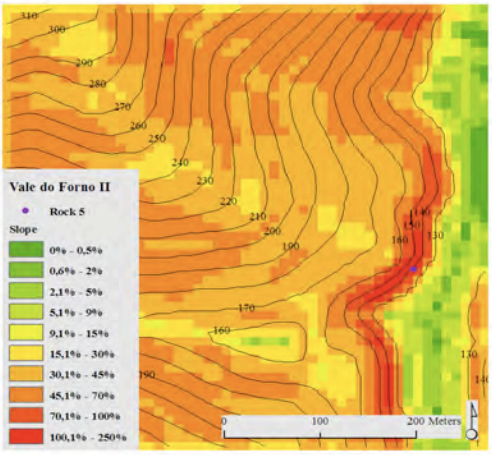
Last Modified: 2012/05/30

Rock: Vale do Forno II 5 Nr: 33

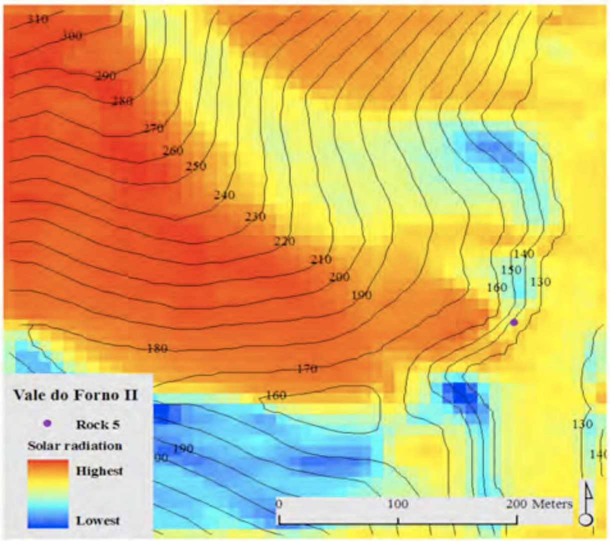
Aspect from DEM: 126º - E Field: Same Value



Slope from DEM: 75% Field: Same Value



Solar radiation: 1128579 KW/M^2



Rock: Vale do Forno II 5

Nr: 33

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 53 - STRONG

Rock mass strength : 71 - STRONG

Porosity:

Tilting of panel/outcrop: 10º FORWARD

- Physical weathering

Aveolization: MODERATE

Exfoliation: SIGNIFICANT

Collapse: MODERATE

Fissures: SIGNIFICANT

Diaclase: VERY SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: SIGNIFICANT

Disintegration - Pulverization: SIGNIFICANT

Toppling: MODERATE

Rock: Vale do Forno II 5 Nr: 33

- Biodeterioration

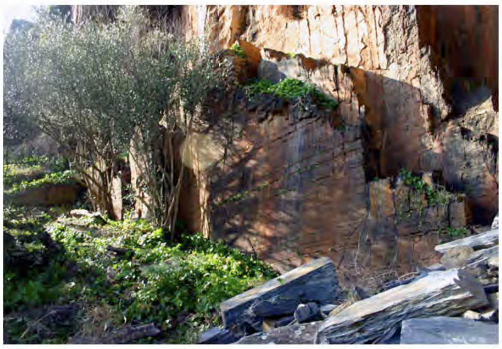
Lichens: MODERATE

Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Note the advancement of areas of the outcrop.



Frontal view of the of the engraved panel. (Photo: MR).

Loose engraved lines in Rock 5. Note fractures. (Photo: MR).

Rock: Vale do Forno II 6

Nr: 34

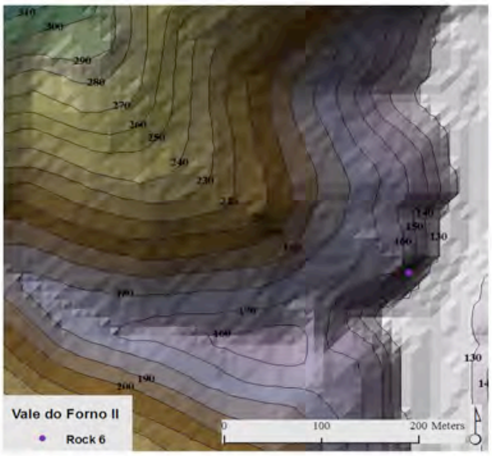
DESCRIPTION:

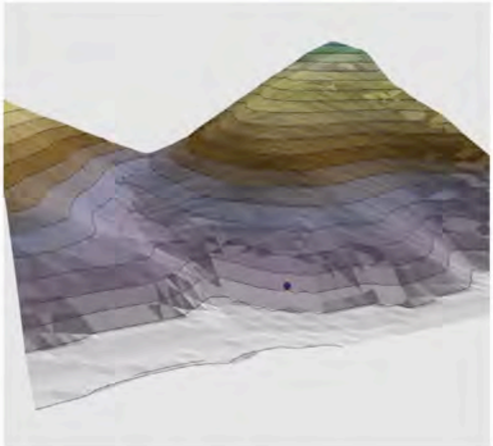
Large outcrop measuring 10x10 located very to Rock 5. It features Iron Age fine line incisions engraved in a semi-horizontal plane, the only case when such choice of surfaces was made in the Côa.

Site located between Foz do Côa and Moinhos de Cima. It is a very sinuous river valley of W-E orientation converging with the Côa, in its left bank, at an elevation of 130 m. Of the 79 known rock art outcrops, Modern and Iron Age figures stand out. In fact, although some excellent Upper Paleolithic motifs - namely, does in Rock 9 and signs in Rock 30 - the quantity and quality of Iron Age motifs - mostly warriors and signs - makes this site one of the most relevant for the period in the Côa.

Note: since the engraved panel is a an semi-horizontal plane, hence, the top of an outcrops which, in a rare occasion in the Côa, has a smooth engravable surface, field measurements regarding rock characteristics where carried out considering the total outcrop.

Location: -7,10865/41,07489





Altitude: 140 m

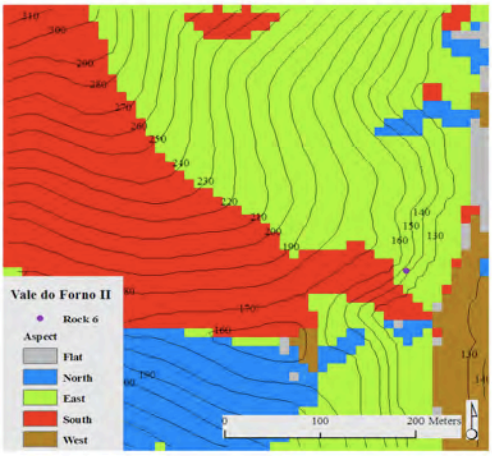
Risk from flooding episodes: None

Date Created: 2010/04/27

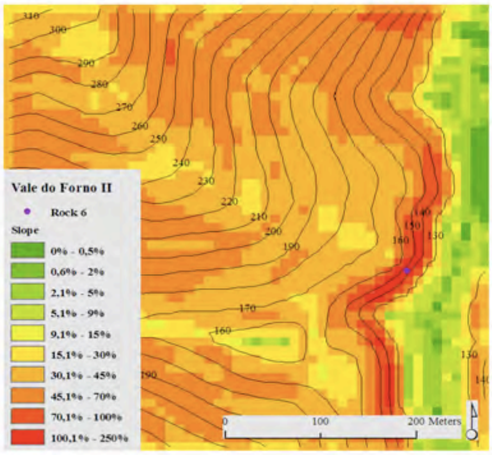
Last Modified: 2012/07/10

Rock: Vale do Forno II 6 Nr: 34

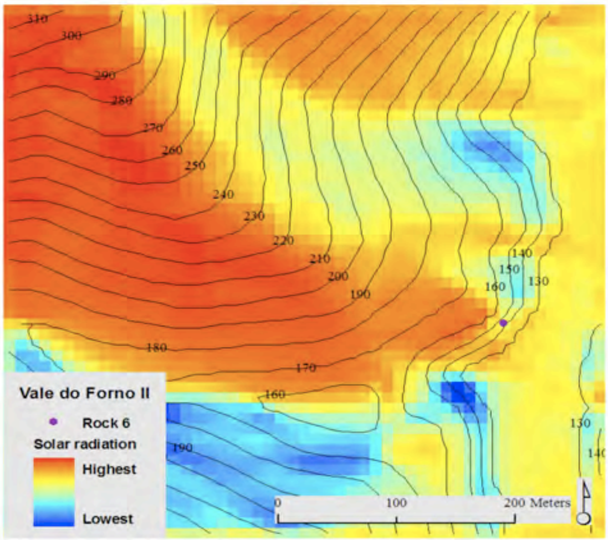
Aspect from DEM: 128º - E Field: Same Value



Slope from DEM: 121% Field: Same Value



Solar radiation: 1048119 KW/M^2



Rock: Vale do Forno II 6

Nr: 34

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 48 - MODERATE

Rock mass strength : 68 - MODERATE

Porosity:

Tilting of panel/outcrop: 10° FORWARD

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: INCIPIENT

Collapse: SIGNIFICANT

Fissures: SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: MODERATE

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Vale do Forno II 6

Nr: 34

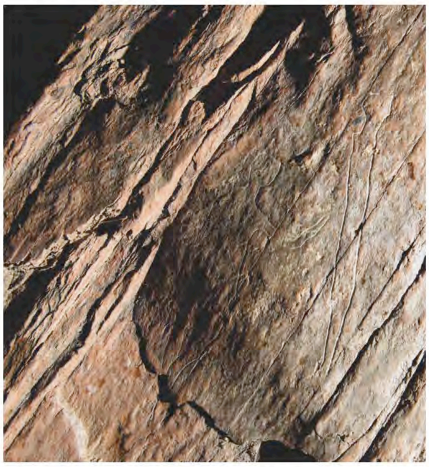
- Biodeterioration

Lichens: SIGNIFICANT

Plants: VERY SIGNIFICANT

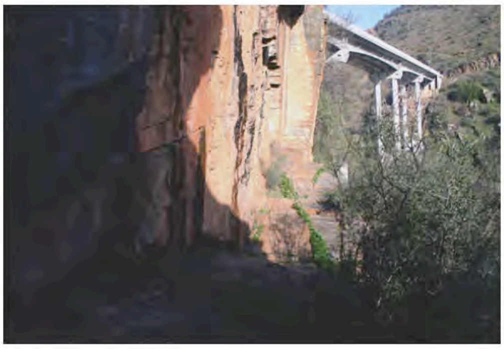
Insects: SIGNIFICANT

- Further photos

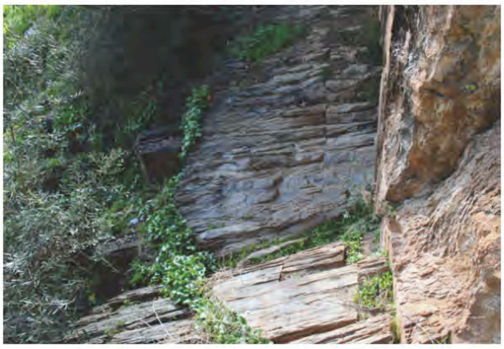


Iron Age warrior motif measuring 15x8 cm. (Photo: MR).

Motifs in Rock 6. Warrior shown in the previous photo is located in the far right of the image. (Drawing: FB).



The horizontal engraved surface is located in front of an outcrop and constitutes the top of the one located just below. (Photo: MR).



Another view of the engraved panel. Note joints, some possessing plants growing from the inside. (Photo: MR).

Rock: Vale do José Esteves 16

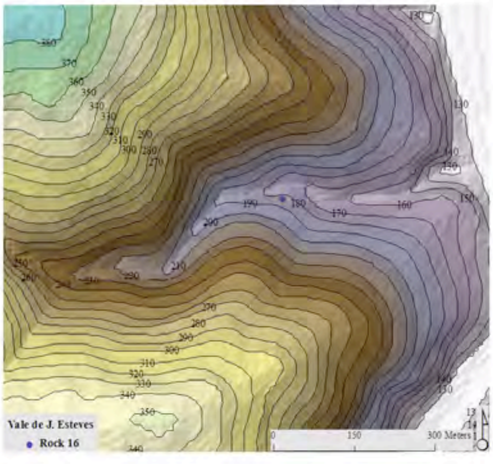
Nr: 35

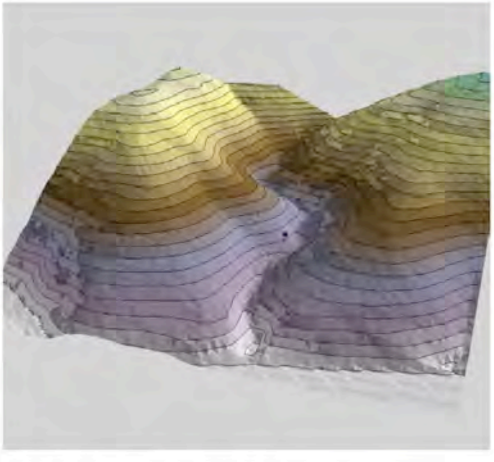
DESCRIPTION:

Medium sized outcrop measuring 10x2 m. It is partially covered by a large slab fallen (or made fallen by human action, since this is a farm area, albeit not being currently very exploited) from above making the engraved area protected by this sort of natural shelter. It presents Upper Paleolithic and Iron Age imagery.

Vale de José Esteves is a moderately steep valley located immediately downstream to Foz do Côa and upstream to Vermelhosa possessing 64 Rocks distributed along its slopes. There are motifs from the Iron Age and the Upper Paleolithic. Among motifs from the former period, we find warriors, weapons and animals including canines. As for Upper Paleolithic representations, some of the best ensembles of fine incised engravings can be found in Rocks 13 and 16, namely scenes where stripped deer seem to depict social behavior actions.

Location: -7,10961/41,0836





Altitude: 180 m

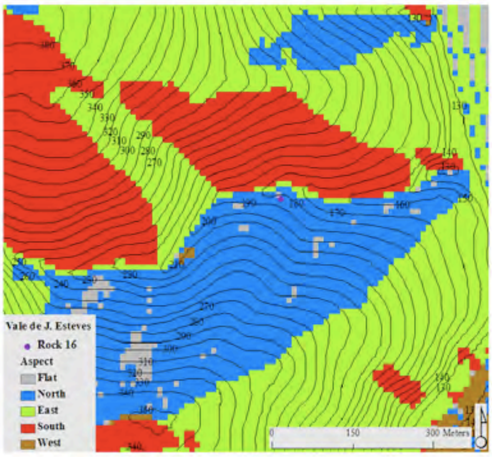
Risk from flooding episodes: None

Date Created: 2010/04/27

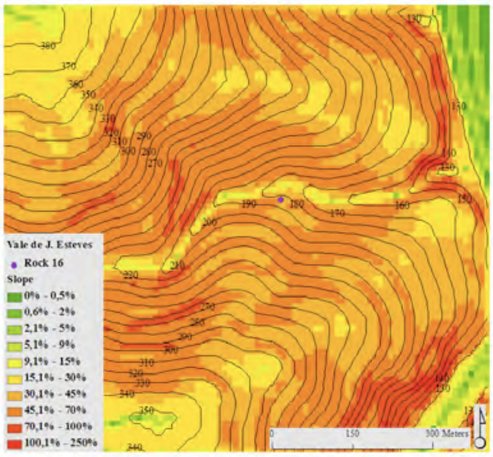
Last Modified: 2012/05/29

Rock: Vale do José Esteves 16 Nr: 35

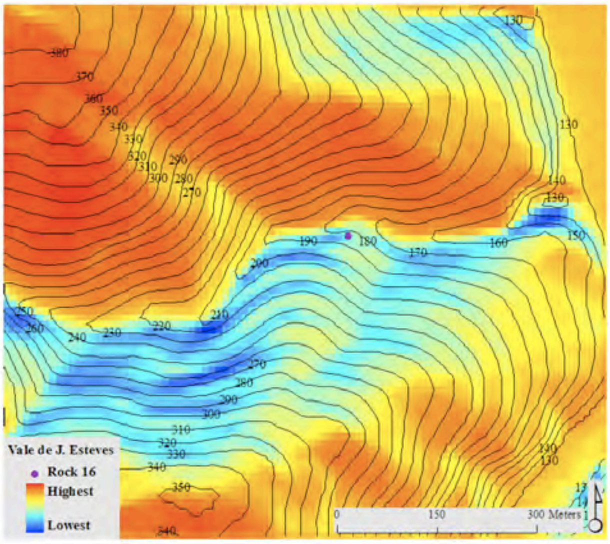
Aspect from DEM: 22º - N Field: 320º



Slope from DEM: 44% Field: Same Value



Solar radiation: 892280 KW/M²



Rock: Vale do José Esteves 16

Nr: 35

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 47 - MODERATE

Rock mass strength : 74 - STRONG

Porosity:

Tilting of panel/outcrop: 8º BACK

- Physical weathering

Aveolization: MODERATE

Exfoliation: VERY SIGNIFICANT

Collapse: INCIPIENT

Fissures: VERY SIGNIFICANT

Diaclase: INCIPIENT

Fractures: VERY SIGNIFICANT

Differential Erosion: VERY SIGNIFICANT

Gapping - Splintering: VERY SIGNIFICANT

Dislocated Blocks/Elements: VERY SIGNIFICANT

Scaling: SIGNIFICANT

Disintegration - Pulverization: SIGNIFICANT

Toppling: MODERATE

Rock: Vale do José Esteves 16

Nr: 35

- Biodeterioration

Lichens: VERY INCIPIENT - CLEANED

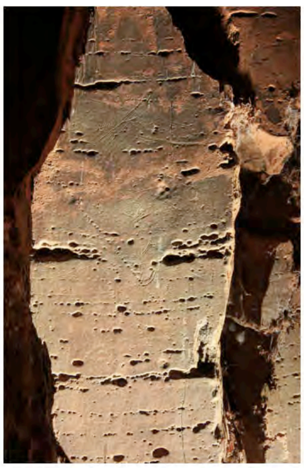
Plants: VERY SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

Rock 16 below the huge rock slab that covers it partially. (Photo: MR).

Upper Paleolithic fine line incised doe (16x8 cm.). Note gaping, fissures and fractures. (Photo: MR).



Small Upper Paleolithic horse (8x4 cm.) and deer motifs. Again note gaping, fissures and fractures. (Photo: MR).

Rock: Vale do José Esteves 17

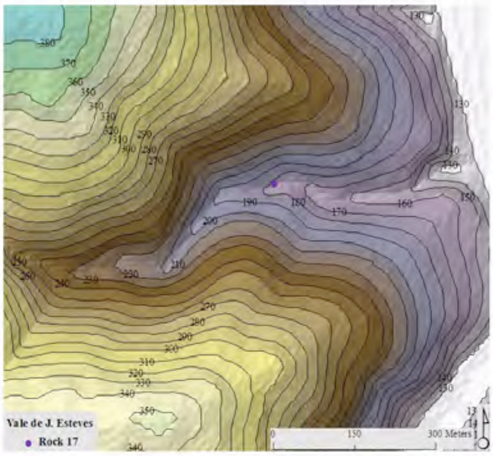
Nr: 36

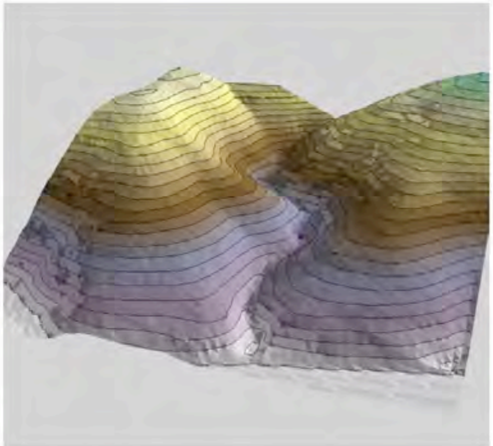
DESCRIPTION:

Quite small outcrop measuring 1x0,50 m. It features Upper Paleolithic an incomplete (due to fracture of the rock, or intentionally placed on the edge of the panel?) doe in a panel measuring 40x60 cm.

Vale de José Esteves is a moderately steep valley located immediately downstream to Foz do Côa and upstream to Vermelhosa possessing 64 Rocks distributed along its slopes. There are motifs from the Iron Age and the Upper Paleolithic. Among motifs from the former period, we find warriors, weapons and animals including canines. As for Upper Paleolithic representations, some of the best ensembles of fine incised engravings can be found in Rocks 13 and 16, namely scenes where stripped deer seem to depict social behavior actions.

Location: -7,10973/41,08376





Altitude: 180 m

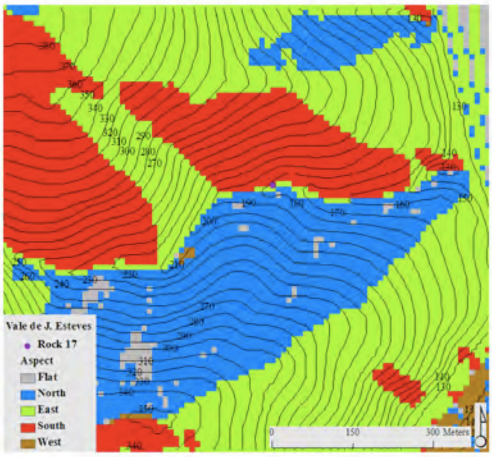
Risk from flooding episodes: None

Date Created: 2010/04/27

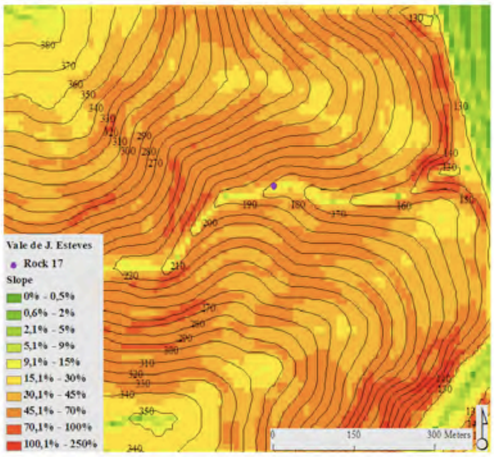
Last Modified: 2012/05/30

Rock: Vale do José Esteves 17 Nr: 36

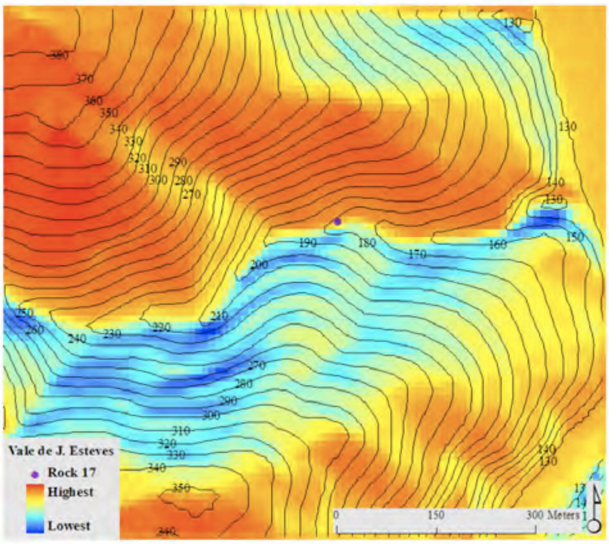
Aspect from DEM: 138º - S Field: Same Value



Slope from DEM: 32% Field: Same Value



Solar radiation: 1263667 KW/M^2



Rock: Vale do José Esteves 17

Nr: 36

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 44 - MODERATE

Rock mass strength : 75 - STRONG

Porosity:

Tilting of panel/outcrop: 10º FORWARD

- Physical weathering

Aveolization:	SIGNIFICANT	Exfoliation:	INCIPIENT
Collapse:	INCIPIENT	Fissures:	SIGNIFICANT
Diaclase:	VERY INCIPIENT	Fractures:	MODERATE
Differential Erosion:	SIGNIFICANT	Gapping - Splintering:	SIGNIFICANT
Dislocated Blocks/Elements:	SIGNIFICANT	Scaling:	SIGNIFICANT
Disintegration - Pulverization:	MODERATE	Toppling:	VERY INCIPIENT

Rock: Vale do José Esteves 17

Nr: 36

- Biodeterioration

Lichens: MODERATE

Plants: SIGNIFICANT

Insects: VERY INCIPIENT

- Further photos

Incomplete Upper Paleolithic doe motif measuring 12x10 cm done resorting to the fine line incision technique.

Detail of the doe's head. Holes motivated by aveolization can be observed.

Upper area of the outcrop (Photo: MR).

Whole engraved outcrop. (Photo: MR).

Rock: Vermelhosa 1

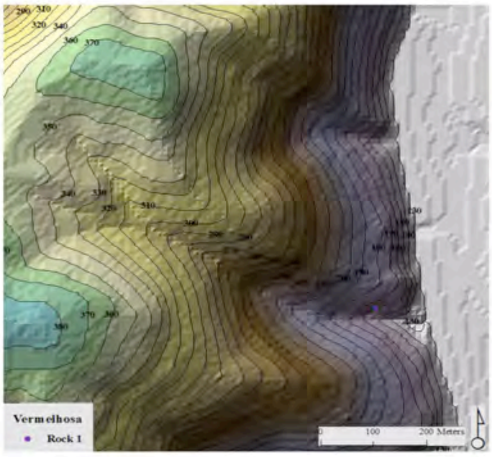
Nr: 37

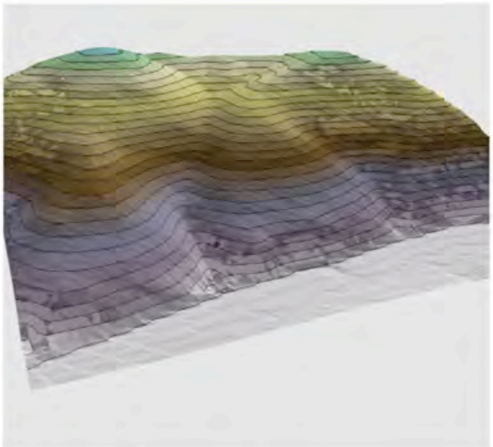
DESCRIPTION:

Relatively large outcrop measuring 10x2,5 m. It possesses a fair amount of UP and Iron Age fine line incised motifs. It presents an UP stripped doe that was superimposed by an Iron Age representation of a horseman, one of the few instances in the Côa in which a more recent motif was done on top of an older representation.

Vermelhosa is a site located in a small waterline valley that crosses a rather steep slope of the Douro's left bank and located between Vale de José Esteves and Vale de Cabrões. 12 Rocks have been identified, of Upper Paleolithic and Iron Age chronologies.

Location: -7,10719/41,08673





Altitude: 160 m

Risk from flooding episodes: None

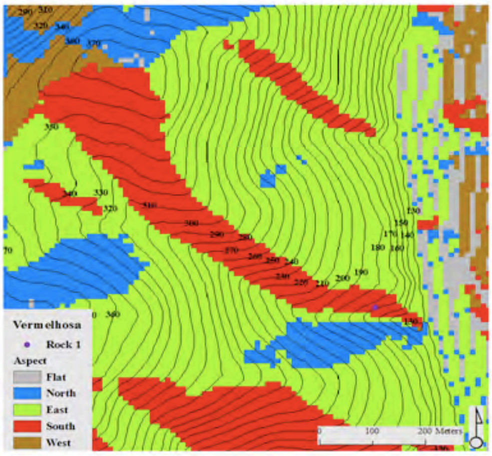
Date Created: 2010/04/27

Last Modified: 2012/07/09

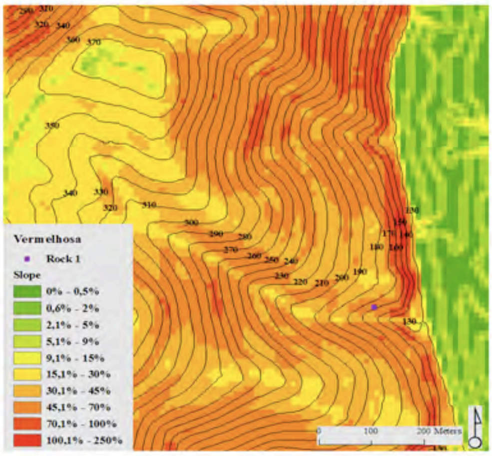
Rock: Vermelhosa 1

Nr: 37

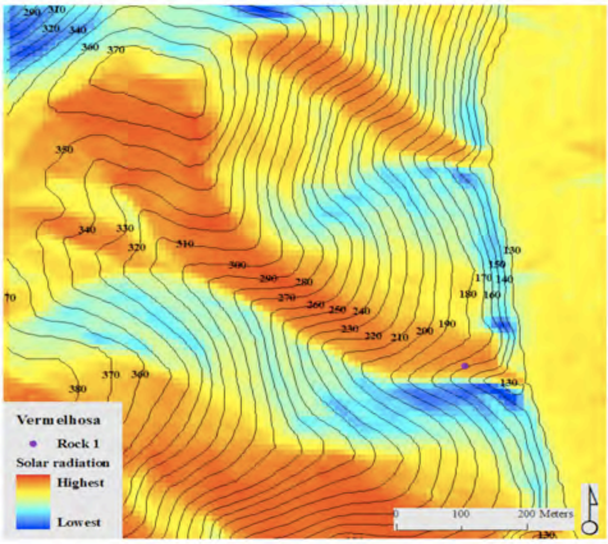
Aspect from DEM: 156º - S Field: Same Value



Slope from DEM: 64% Field: Same Value



Solar radiation: 1290995 KW/M^2



Rock: Vermelhosa I

Nr: 37

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 52 - STRONG

Rock mass strength : 74 - STRONG

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: VERY SIGNIFICANT

Disintegration - Pulverization: MODERATE

Toppling: MODERATE

Rock: Vermelhosa 1 Nr: 37

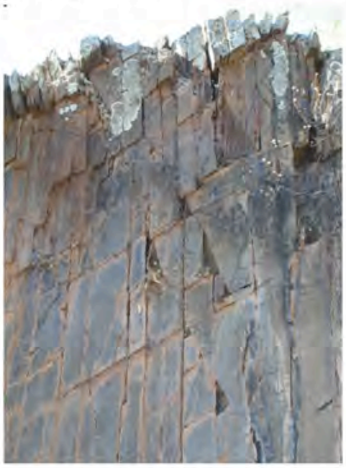
- Biodeterioration

Lichens: MODERATE - CLEANED

Plants: MODERATE

Insects: SIGNIFICANT

- Further photos



Non-engraved area of Rock 1 with with great profusion of fractures and fissures. Note also minor toppling.

Upper Paleolithic doe superimposed by an Iron Age horseman. (Photo: Post-Glaciar).

Upper Paleolithic doe superimposed by an Iron Age horseman. Total measures of both motifs: 20x25 cm. (Drawing: FB).

Upper Paleolithic doe engraving (25x13 cm.) done in an area affected by fractures. (Photo: Post-Glaciar).

Rock: Vermelhosa 2

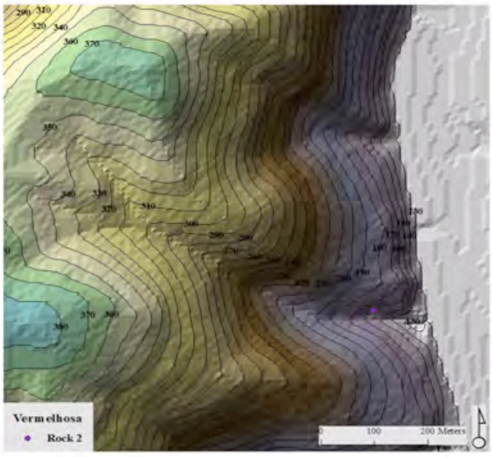
Nr: 38

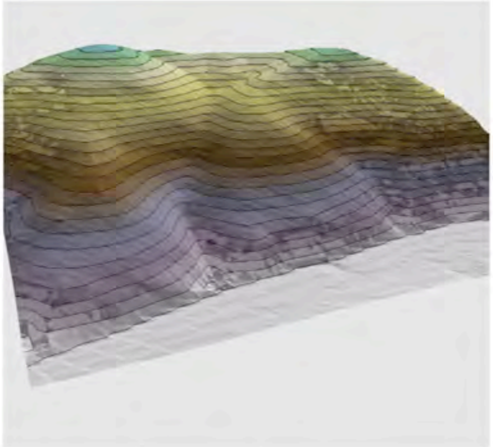
DESCRIPTION:

Relatively large outcrop measuring 10 x2 m featuring just one Upper Paleolithic fine line incised representation of a doe.

Vermlhosa is a site located in a small waterline valley that crosses a rather steep slope of the Douro's left bank and located between Vale de José Esteves and Vale de Cabrões. 12 Rocks have been identified, of Upper Paleolithic and Iron Age chronologies.

Location: -7,10729/41,08667





Altitude: 160 m

Risk from flooding episodes: None

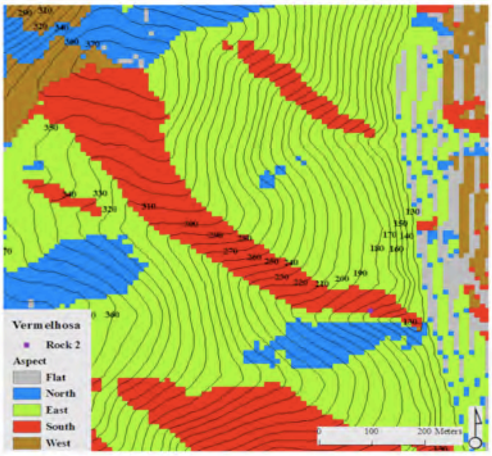
Date Created: 2010/04/27

Last Modified: 2012/05/29

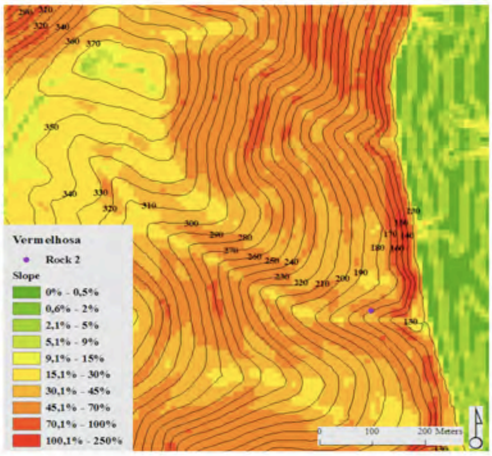
Rock: Vermelhosa 2

Nr: 38

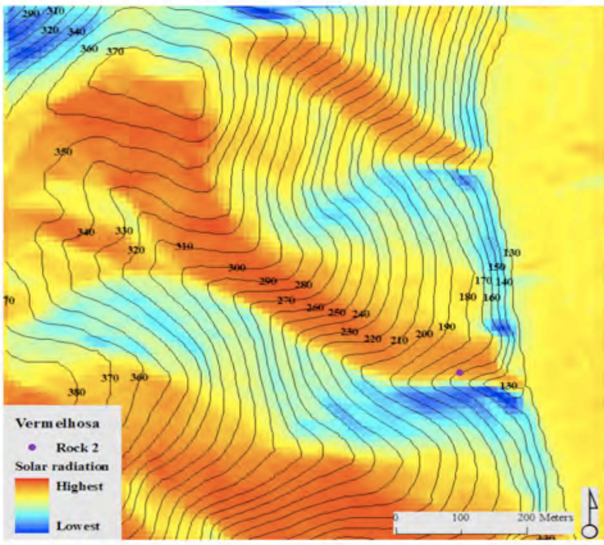
Aspect from DEM: 155º - S Field: Same Value



Slope from DEM: 62% Field: Same Value



Solar radiation: 1275807 KW/M²



Rock: Vermelhosa 2

Nr: 38

- Rock characteristics

Formation:

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 48 - MODERATE

Rock mass strength : 61 - MODERATE

Porosity:

Tilting of panel/outcrop: 0º

- Physical weathering

Aveolization: SIGNIFICANT

Exfoliation: INCIPIENT

Collapse: INCIPIENT

Fissures: VERY SIGNIFICANT

Diaclase: MODERATE

Fractures: VERY SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: MODERATE

Scaling: INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: INCIPIENT

Rock: Vermelhosa 2

Nr: 38

- Biodeterioration

Lichens: SIGNIFICANT

Plants: MODERATE

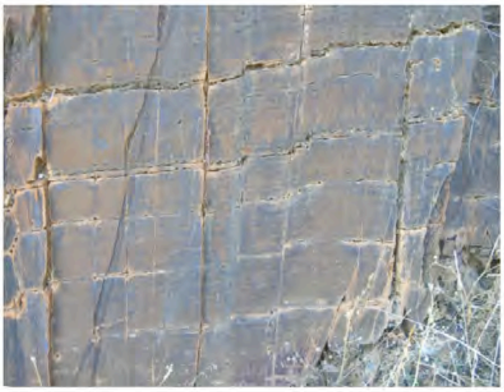
Insects: SIGNIFICANT

- Further photos

The only motif in Rock 2, a small Upper Paleolithic doe depiction measuring 15x10 cm. (Photo: MA).

Detail of the doe's head. Note the fissure that crosses the animal's mouth.

Lichen cover in an area of the outcrop. Note detachment and lowering of sections due to fracturing (see also next).



Matrix of fractures and fissures that cross the outcrop in a right angled orientation dividing it in to square panels.

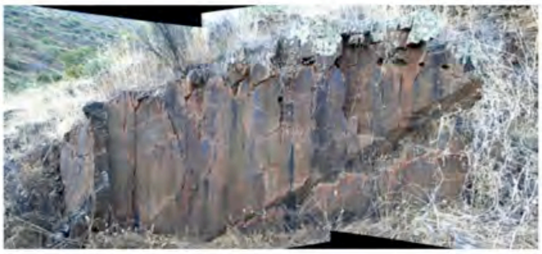
Rock: Vermelhosa 3

Nr: 39

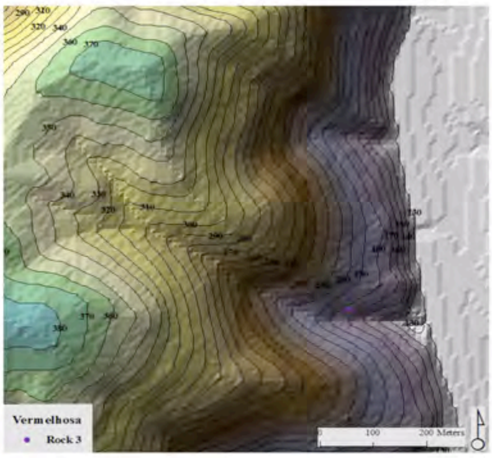
DESCRIPTION:

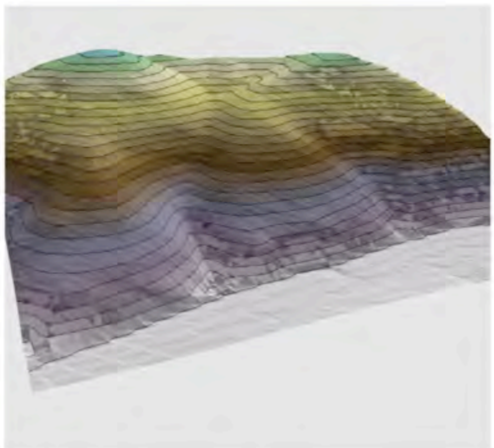
Relatively large outcrop measuring 7x2 m. It features an interesting Iron Age composition in which a large armed ithyphallic figure, with head in the shape of a bird's head, oversees a duel between two other warriors with similar characteristics but smaller in size. It also possesses Upper Paleolithic imagery.

Vermelhosa is a site located in a small waterline valley that crosses a rather steep slope of the Douro's left bank and located between Vale de José Esteves and Vale de Cabrões. 12 Rocks have been identified, of Upper Paleolithic and Iron Age chronologies.



Location: -7,10782/41,08674





Altitude: 180 m

Risk from flooding episodes: None

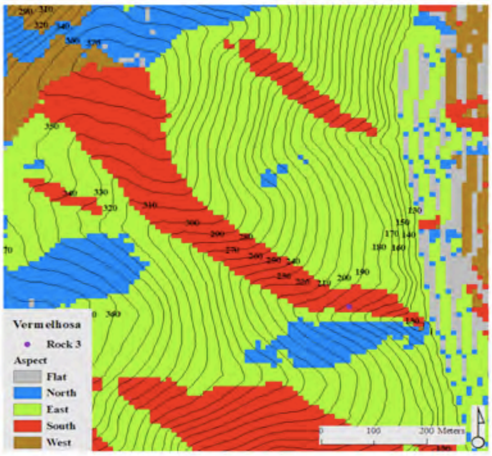
Date Created: 2010/04/27

Last Modified: 2012/07/09

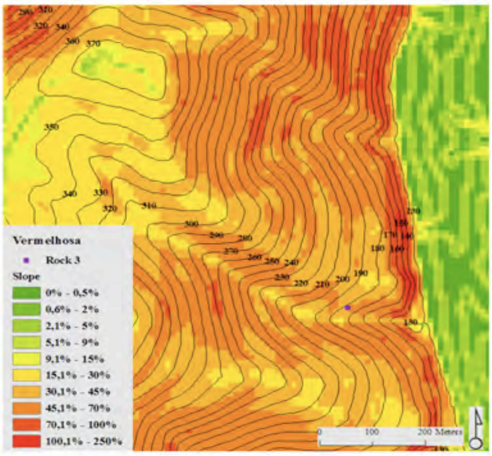
Rock: Vermelhosa 3

Nr: 39

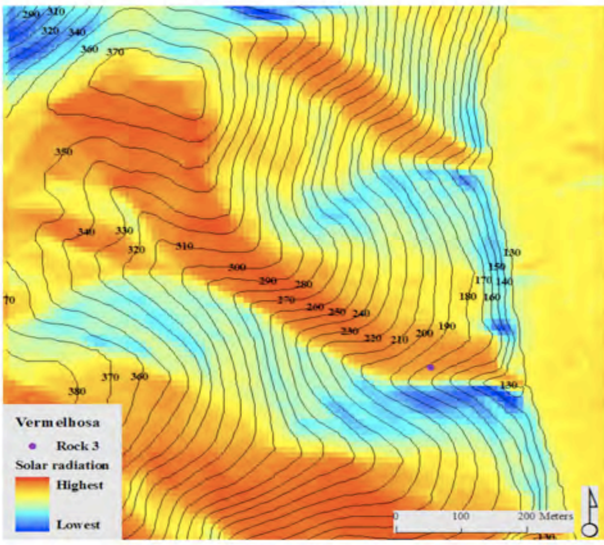
Aspect from DEM: 144º - S Field: Same Value



Slope from DEM: 45% Field: Same Value



Solar radiation: 1286211 KW/M^2



Rock: Vermelhosa 3

Nr: 39

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 41 - MODERATE

Rock mass strength : 65 - MODERATE

Porosity:

Tilting of panel/outcrop: 1º FORWARD

- Physical weathering

Aveolization: INCIPIENT

Exfoliation: MODERATE

Collapse: INCIPIENT

Fissures: VERY SIGNIFICANT

Diaclase: MODERATE

Fractures: VERY SIGNIFICANT

Differential Erosion: MODERATE

Gapping - Splintering: SIGNIFICANT

Dislocated Blocks/Elements: MODERATE

Scaling: INCIPIENT

Disintegration - Pulverization: INCIPIENT

Toppling: INCIPIENT

Rock: Vermelhosa 3

Nr: 39

- Biodeterioration

Lichens: VERY INCIPIENT - CLEANED

Plants: MODERATE

Insects: SIGNIFICANT

- Further photos

Iron Age depiction of birds (possibly vultures) eating a fish. Scene measures 20x10 cm. (Photo: Post-Glaciar)

Upper part of one of the Iron Age warriors depicting in the fighting scene. Full motif 30x20 cm. (Photo: MA).

Detail of the warrior's head. Note aveolization and gaping.

Transversal sub-horizontal fracture affecting Rock 3.

Rock: Vermelhosa 4

Nr: 40

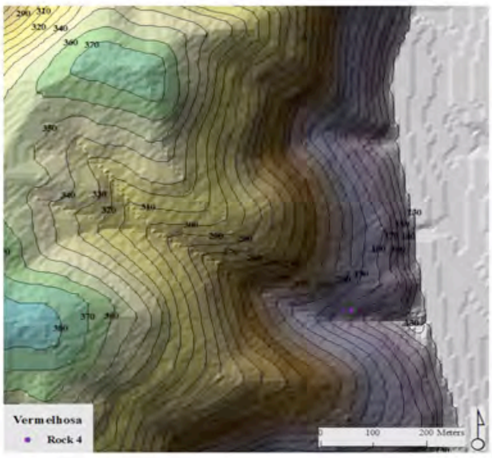
DESCRIPTION:

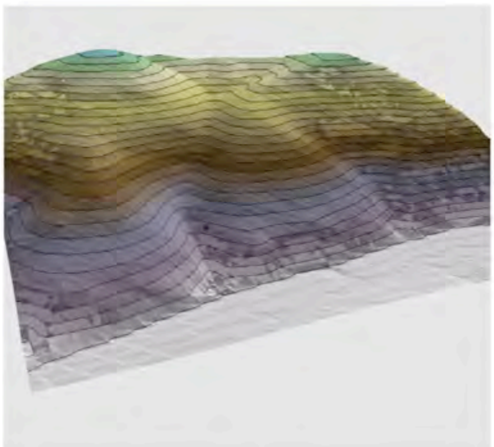
Small outcrop measuring 0,90x0,40 m. containing only Upper Paleolithic motifs. It has a dry stone wall built on top.

Vermelhosa is a site located in a small waterline valley that crosses a rather steep slope of the Douro's left bank and located between Vale de José Esteves and Vale de Cabrões. 12 Rocks have been identified, of Upper Paleolithic and Iron Age chronologies.

Photo: MR.

Location: -7,10776/41,08672





Altitude: 180 m

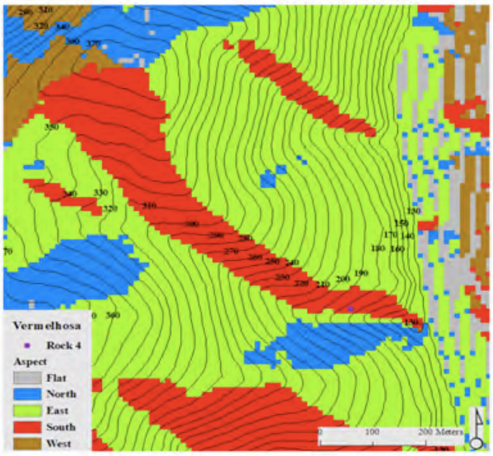
Risk from flooding episodes: None

Date Created: 2010/04/27

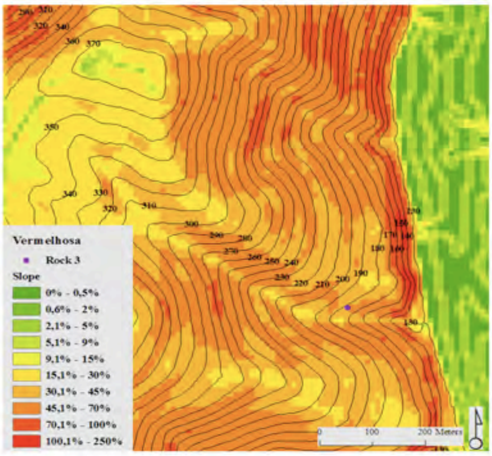
Last Modified: 2012/05/29

Rock: Vermelhosa 4 Nr: 40

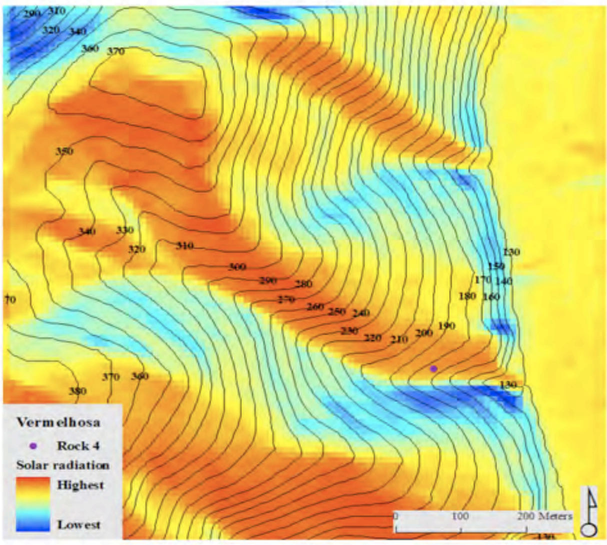
Aspect from DEM: 149º - S Field: Same Value



Slope from DEM: 45% Field: Same Value



Solar radiation: 1292848 KW/M^2



Rock: Vermelhosa 4

Nr: 40

- Rock characteristics

Formation: DESEJOSA

Petrology: GREYWACKE

Intact rock strength (Schmidt hammer rebound value): 50 - MODERATE

Rock mass strength : 69 - MODERATE

Porosity:

Tilting of panel/outcrop: 2º FORWARD

- Physical weathering

Aveolization: MODERATE

Exfoliation: MODERATE

Collapse: SIGNIFICANT

Fissures: VERY SIGNIFICANT

Diaclase: SIGNIFICANT

Fractures: VERY SIGNIFICANT

Differential Erosion: SIGNIFICANT

Gapping - Splintering: MODERATE

Dislocated Blocks/Elements: SIGNIFICANT

Scaling: MODERATE

Disintegration - Pulverization: MODERATE

Toppling: INCIPIENT

Rock: Vermelhosa 4

Nr: 40

- Biodeterioration

Lichens: MODERATE - CLEANED

Plants: SIGNIFICANT

Insects: SIGNIFICANT

- Further photos

The two engraved panels in Rock 4. (Photo: MR).

Upper Paleolithic fine line incised doe measuring 15x7 cm. (Photo: MR).

ANNEX B – ROCK SAMPLES FROM THE CÔA

A total of 25 samples have been collected. However, half have been lost in the mail. Therefore only 12 have been used. It should be noted that for the collection of the samples, small blocks already detaching from the main body of the outcrop were preferred. Hence, the sample is constituted by already quite weathered rock.

Sample 7 (Desejosa formation) – Location: In the road to Canada do Inferno rock-art site behind abandoned crane structure for the construction of the dam. Sample collected from a recent cut on the slope because of construction of the road that gives access to the crane.

Sample 9 (Desejosa formation) – Location: Above Vale do Forno II rock-art site from a new cut due to a national road construction (Photo 208, 209)

Sample 10 (Pinhão formation) – Location: Penascosa rock-art site from an outcrop located near to the parking lot.

Sample 14 (Pinhão formation) – Location: Penascosa rock-art site from an outcrop located to the right of Rock 5.

Sample 15 (Pinhão formation) – Location: Penascosa rock-art site from an outcrop located to the left of Rock 6.

Sample 16 (Pinhão formation) – Location: Penascosa rock-art site from an outcrop located to the right of Rock 7.

Sample 17 (Pinhão formation) – Location: Penascosa rock-art site from an outcrop located near PEN1 weather station.

Sample 18 (Pinhão formation) – Location: Penascosa rock-art site from another outcrop located near PEN1 weather station.

Sample 19 (Desejosa formation) – Location: Ribeira de Piscos rock-art site from an outcrop located to right of Rock 1.

Sample 20 (Desejosa formation) – Ribeira de Piscos rock-art site from an outcrop located between Rock 1 and Rock 2.

Sample 21 (Desejosa formation) – Ribeira de Piscos rock-art site from an outcrop located behind Rock 2.

Sample 24 (Desejosa formation) – Ribeira de Piscos rock-art site from an outcrop located above Rock 2 and flood area.

ANNEX C – SEM CHEMICAL ANALYSIS RESULTS

Sample 7

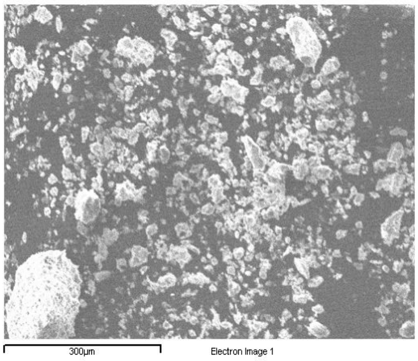
11/26/2009 3:57:29 PM

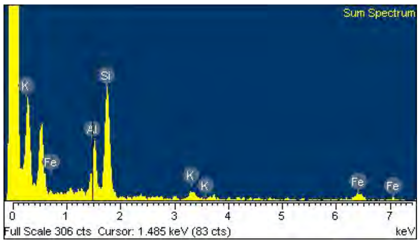
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	20.94	22.99
Si K	64.76	68.30
K K	4.93	3.74
Fe K	9.36	4.96
Totals	100.00	





Comment:

Sample 9

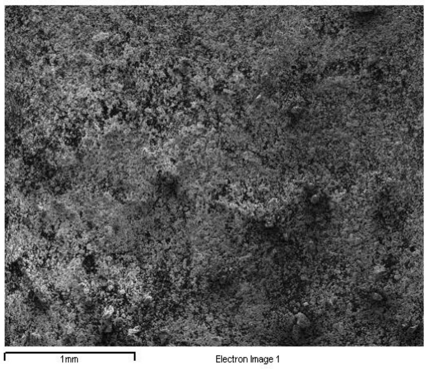
12/3/2009 1:55:54 PM

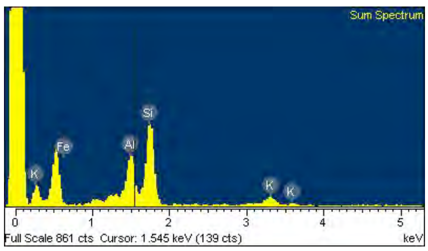
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	22.96	25.44
Si K	60.14	64.04
K K	6.41	4.90
Fe K	10.49	5.62
Totals	100.00	





Comment:

Sample 10

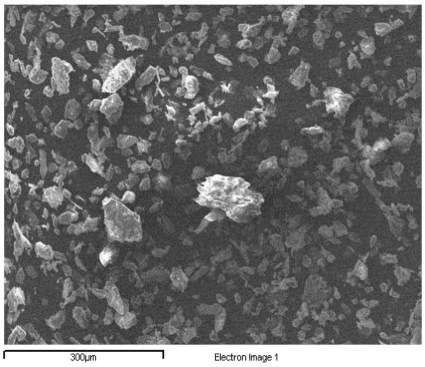
11/26/2009 3:44:13 PM

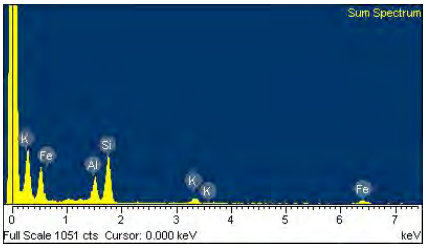
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	21.55	23.95
Si K	60.18	64.24
K K	8.72	6.68
Fe K	9.55	5.13
Totals	100.00	





Comment:

Sample 14

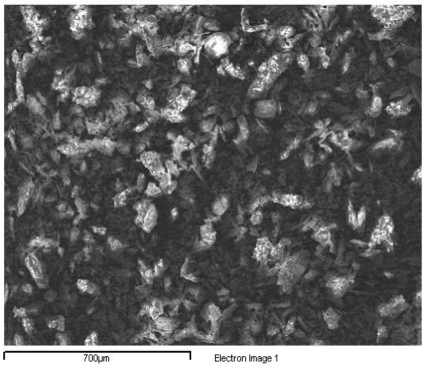
12/3/2009 11:27:45 AM

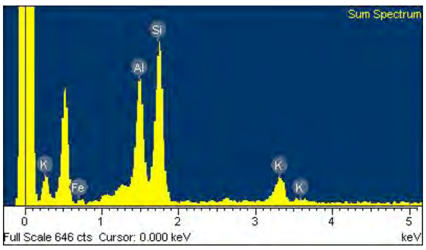
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	26.18	28.95
Si K	55.87	59.34
K K	9.30	7.10
Fe K	8.65	4.62
Totals	100.00	





Comment:

Sample 15

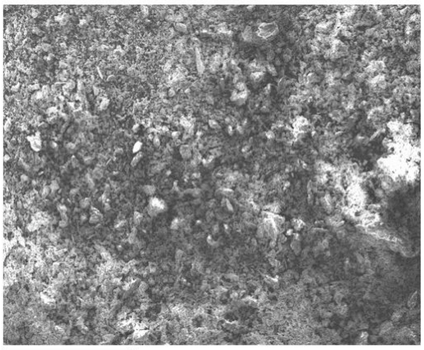
12/3/2009 1:07:15 PM

Spectrum processing :
No peaks omitted

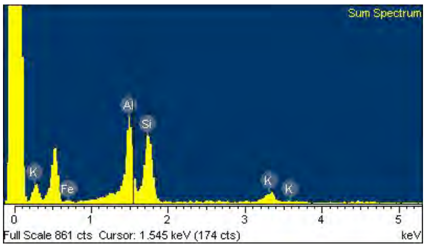
Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	34.68	37.70
Si K	50.99	53.26
K K	6.75	5.07
Fe K	7.57	3.97
Totals	100.00	



1mm Electron Image 1



Comment:

Sample 16

12/3/2009 12:40:11 PM

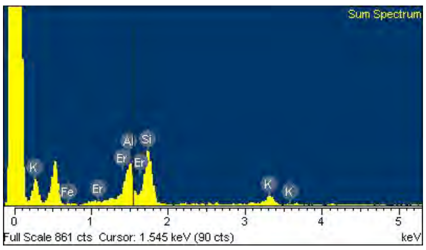
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM
Er ErF3 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	25.86	28.43
Si K	55.66	58.77
K K	11.85	8.98
Fe K	7.46	3.96
Er L	-0.83	-0.15
Totals	100.00	

1mm Electron Image 1



Comment:

Sample 17

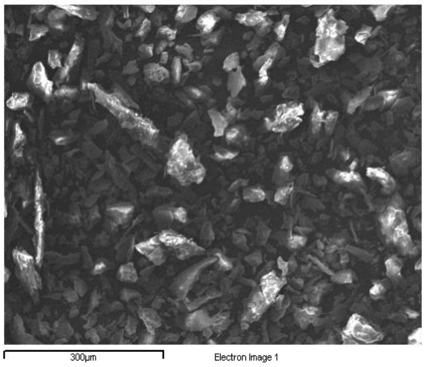
11/26/2009 1:20:17 PM

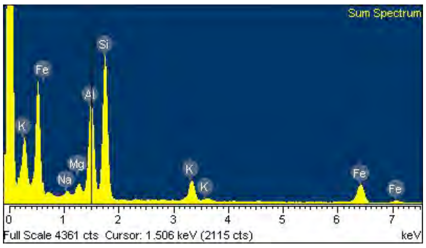
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Na Albite 1-Jun-1999 12:00 AM
Mg MgO 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Na K	2.42	3.16
Mg K	3.63	4.49
Al K	23.72	26.41
Si K	49.68	53.14
K K	7.60	5.84
Fe K	12.96	6.97
Totals	100.00	





Comment:

INCA

Sample 18

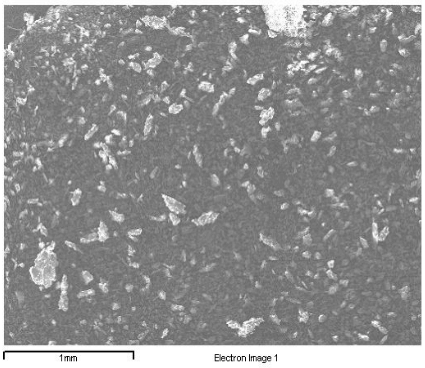
12/3/2009 3:30:02 PM

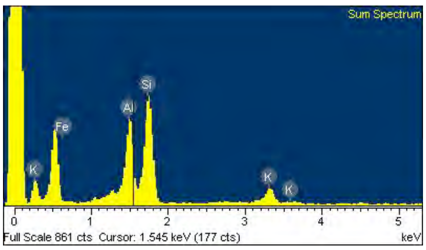
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	26.68	29.64
Si K	54.94	58.63
K K	8.08	6.20
Fe K	10.30	5.53
Totals	100.00	





Comment:

INCA

Sample 19

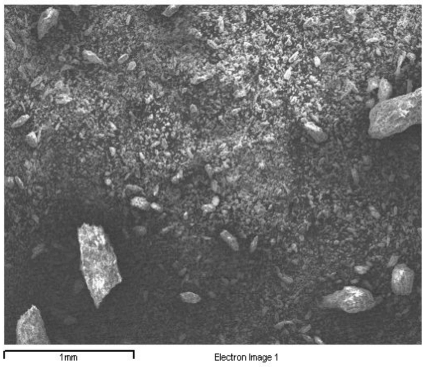
12/3/2009 12:19:01 PM

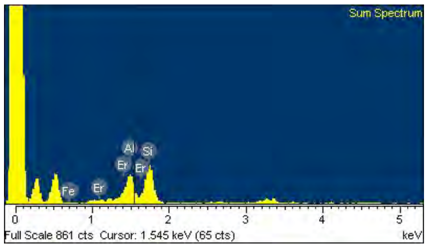
Spectrum processing :
Peaks possibly omitted : 0.267, 3.320 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM
Er ErF3 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	27.78	30.02
Si K	61.92	64.27
Fe K	11.28	5.89
Er L	-0.98	-0.17
Totals	100.00	





Comment:

Sample 20

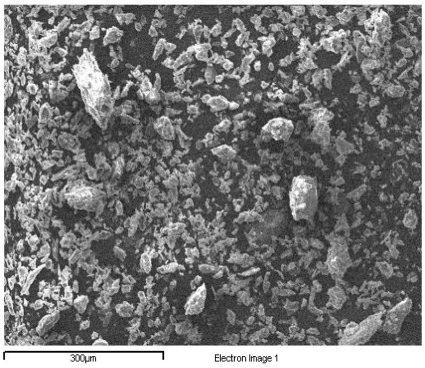
11/26/2009 3:28:12 PM

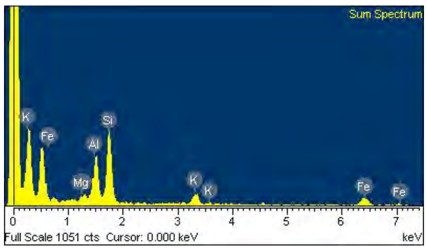
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Mg MgO 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Mg K	3.64	4.49
Al K	24.23	26.96
Si K	52.21	55.82
K K	8.78	6.74
Fe K	11.14	5.99
Totals	100.00	





Comment:

Sample 21

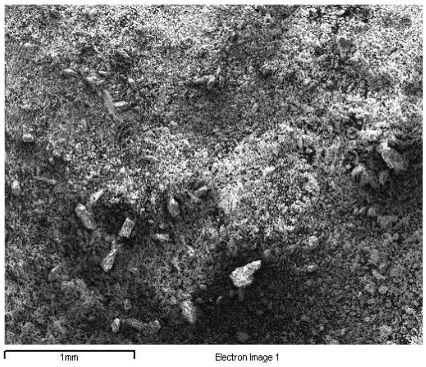
12/3/2009 3:55:35 PM

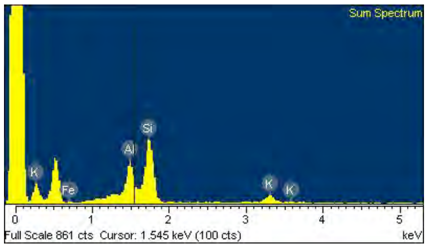
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al   Al2O3   1-Jun-1999 12:00 AM
Si   SiO2   1-Jun-1999 12:00 AM
K   MAD-10 Feldspar   1-Jun-1999 12:00 AM
Fe   Fe   1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	22.85	25.28
Si K	60.20	63.97
K K	7.41	5.66
Fe K	9.53	5.09
Totals	100.00	





Comment:

Sample 24

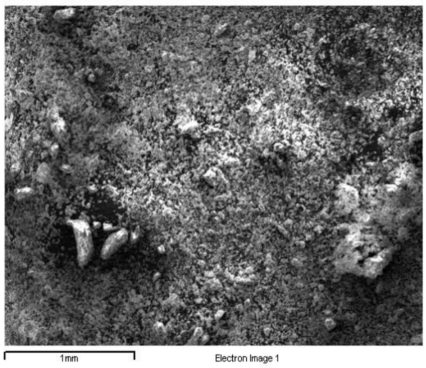
12/3/2009 1:34:39 PM

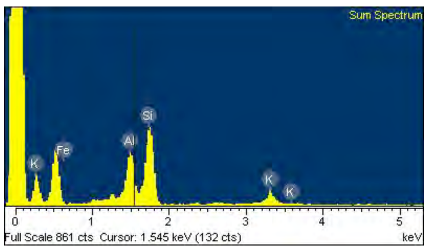
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Al   Al2O3   1-Jun-1999 12:00 AM
Si   SiO2   1-Jun-1999 12:00 AM
K   MAD-10 Feldspar   1-Jun-1999 12:00 AM
Fe   Fe   1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Al K	23.74	26.08
Si K	59.87	63.19
K K	8.89	6.74
Fe K	7.50	3.98
Totals	100.00	





Comment: