

PALAEOART  
AND  
MATERIALITY

THE SCIENTIFIC STUDY OF ROCK ART

edited by

**Robert G. Bednarik, Danae Fiore,  
Mara Basile, Giriraj Kumar  
and Tang Huisheng**

ARCHAEOPRESS ARCHAEOLOGY

# ARCHAEOPRESS PUBLISHING LTD

Gordon House  
276 Banbury Road  
Oxford OX2 7ED

[www.archaeopress.com](http://www.archaeopress.com)

ISBN 978 1 78491 429 5  
ISBN 978 1 78491 430 1 (e-Pdf)

© Archaeopress and the authors 2016

Cover image: Part of the Huashan site in Guangxi Province, southern China,  
the largest rock painting site in the world. Photograph by R. G. Bednarik.

All rights reserved. No part of this book may be reproduced, in any form or  
by any means, electronic, mechanical, photocopying or otherwise,  
without the prior written permission of the copyright owners.

Printed in England by Oxuniprint, Oxford  
This book is available direct from Archaeopress or from our website [www.archaeopress.com](http://www.archaeopress.com)

# Contents

<b>Contents</b> .....	i
<b>Relevant Issues for the Design of a Protocol for the Interdisciplinary Study of Rock Art</b> .....	1
Eugenia P. Tomasini, Mara Basile, Marta S. Maier, Norma Ratto	
<b>Superimpositions and Attitudes Towards Pre-existing Rock Art: a Case Study in Southern Patagonia</b> .....	15
Anahí Re	
<b>Pigments Used in Rock Paintings from the East and West of the Iberian Peninsula Analysed by X-ray Fluorescence: Analogies and Differences</b> .....	31
A. Martín Sánchez, C. Roldán García, M. J. Nuevo, J. Oliveira, S. Murcia Mascarós, C. Oliveira	
<b>The Material Scientific Investigation of Rock Art: Contributions from non-Invasive X-ray Techniques</b> .....	41
Jillian Huntley, Clive Freeman Galamban	
<b>Methodological Approach to the Materiality of Rock Paintings Based on Their Physicochemical Characterisation. Proposal and Reflections from Their Study in Chile</b> .....	59
Marcela Sepúlveda	
<b>Step Forwards in the Archaeometric Studies on Rock Paintings in the Bogotá Savannah, Colombia. Analysis of Pigments and Alterations</b> .....	73
Judith Trujillo T.	
<b>What Should We Do or Not Do for the Preservation or Remedial Action in Prehistoric Painted Caves?</b> .....	85
F. Bourges, P. Genthon, D. Genty, M. Lorblanchet, France, E. Mauduit, D. D’Hulst, E. David, N. Ferrer	
<b>Forensic Replication Work with Australian Cave Art</b> .....	99
Robert G. Bednarik, Yann-Pierre Montelle	
<b>Experimental Rock Art Studies. Replication of Pictographs from La Primavera Locality (Santa Cruz, Argentina)</b> .	113
Rocío V. Blanco, Natalia G. Barreto	
<b>Measurements and Replications of Hand Stencils: a Methodological Approach for the Estimation of the Individuals’ Age and Sex</b> .....	129
Natalia Carden, Rocío Blanco	
<b>Time and Rock Art Production: Explorations on the Material Side of Petroglyphs in the Semi-arid North of Chile</b> .....	147
Francisco Vergara, Andrés Troncoso, Francisca Ivanovic	
<b>Taphonomy of the Early Petroglyphs at Daraki-Chattan and in the Region Around It in Chambal Basin, India</b> ....	161
Giriraj Kumar, Ram Krishna, Robert G. Bednarik	
<b>The Tribology of Petroglyphs</b> .....	171
Robert G. Bednarik	
<b>Understanding the Technology of Very Small Cupules in Daraki-Chattan, India</b> .....	187
Ram Krishna, Giriraj Kumar	

<b>Evidence of Collaboration Among Art-Makers in Twelve Upper Palaeolithic Caves.....</b>	<b>195</b>
Leslie Van Gelder	
<b>A Survey of Developments in Dating Australian Rock-Markings.....</b>	<b>205</b>
Graeme K. Ward	
<b>A New Cold Plasma System for Pictogram <sup>14</sup>C Sampling.....</b>	<b>217</b>
Marvin W. Rowe, Eric Blinman, John C. Martin, J. Royce Cox, Mark MacKenzie, Lukas Wacker	
<b>Direct Dating of Bolivian Petroglyphs Using Indirect Microerosion Analysis.....</b>	<b>225</b>
Robert G. Bednarik	
<b>Use of Theodolite and Photographic Techniques in the Recording and Analysis of the Geographical and Astronomical <i>Entorno</i> (surrounding) .....</b>	<b>235</b>
Patricio Bustamante, Ricardo Moyano, Daniela Bustamante	

# Direct Dating of Bolivian Petroglyphs Using Indirect Microerosion Analysis

Robert G. Bednarik

Australia, robertbednarik@hotmail.com

*Although it offers wide applications in estimating the ages of many types of geomorphic exposures, microerosion analysis has traditionally been applied only to petroglyphs. This paper presents a new approach, in which it is not the rock art that is being analysed, but the hammerstones used in its production, or small spalls recovered from such tools. This new approach, applied for the first time anywhere, has been possible at four Bolivian sites: Iscay Rumi, Thojya Rumi, Ph'alta Rumi (near Cochabamba) and Toro Muerto (in the Mizque valley). The method is briefly described and the results are presented, being among the first direct rock art datings in South America.*

## Datación directa de petroglifos de Bolivia mediante el análisis microerosion indirectos

*A pesar de que ofrece una amplia aplicación en la estimación de la edad de muchos tipos de exposiciones geomorfológicos, análisis microerosion se ha aplicado tradicionalmente sólo a los petroglifos. Este trabajo presenta un nuevo enfoque, en la que no es el arte rupestre que se está analizando, pero el martillo utilizado en su producción, o astillas pequeñas recuperado de estas herramientas. Este nuevo enfoque, aplicado por vez primera en todo el mundo, ha sido posible en tres sitios de Bolivia: Iscay Rumi, Thojyc Rumi, Ph'alta Rumi (cerca de Cochabamba) y Toro Muerto (en el valle de Mizque). El método se describe brevemente y se presentan los resultados, siendo uno de los primeros dataciones directas de arte rupestre en América del Sur.*

### Introduction

The methodology of microerosion analysis, which includes a number of existing as well as potential techniques, has been applied to questions of rock art chronology since 1990. One of these methods involves the interpretation of micro-wanes on petroglyph surfaces. It requires calibration curves based on known variables, secured from surfaces of known ages of specific minerals in the region in question. The rationale of microerosion analysis is that, after a new rock surface has been created, by either natural or anthropic agents, it is subjected to chemical weathering processes. This applies especially in unsheltered locations, and it results in cumulative effects that are a function of time, among other factors. While this is a fairly self-evident principle, the difficulty in using the results of such processes in estimating the age of a rock surface is that our understanding of them, of their effectiveness on different rock types, and of their susceptibility to environmental factors remains limited. We know that rock surfaces retreat with time, be it by solution (Acker and Bricker 1992; Busenberg and Clemency 1976; Lin and Clemency 1981; Oxburgh et al. 1994; Rimstidt and Barnes 1980; Williamson and Rimstidt 1994), physical wear (e.g. aeolian or fluvial erosion), or a combination of the two. Empirical engineering data for natural building stone tells us that the amount of retreat differs greatly according to rock type (Schwegler 1995). Macroscopic

rock erosion ranges up to 50 mm each 1000 years for poorly cemented sandstone, but can be as little as fifty microns on the non-quartz components of granite, and much less again on quartz. This process of weathering is *surface retreat* (by granular exfoliation or solution) and has sometimes been called 'micro erosion' (two words), although its products are certainly visible at the macroscopic level (Smith 1978).

### The principles of microerosion

The term '*microerosion*' (one word, unhyphenated) refers exclusively to solution processes whose effects can be seen only at the microscopic level. Hence, for the time-spans relevant in dating petroglyphs, only comparatively erosion-resistant rock types are of interest. In most cases this excludes especially sedimentary rocks. It must also be emphasised that microerosion analysis is not one specific method, but a cluster of possible methods around a basic concept. Two have so far been applied practically: the measurement of micro-wanes on fractured crystals (Bednarik 1992, 1993), and the selective, often alveolar retreat in certain rock types of components that weather at vastly different rates (Bednarik 1995). The effectiveness of the second approach has been confirmed by Pope (2000) when he tried to negate it. Pope effectively failed to appreciate the difference between these two approaches, perceiving microerosion analysis as a tangled combination of the

## PALAEOART AND MATERIALITY

two. There is no doubt that various alternative indices of microerosion may also prove to be useful, but their potential remains unexplored so far.

Macro-wanes on rock are the results of progressive rounding of freshly broken rock edges. Černohouz and Solč (1966) claimed to be able to estimate the ages of such wanes to within 10–20% accuracy on two rock types. Observation of similar rounding at the microscopic scale, on individual mineral crystals that had been fractured, implied that these phenomena were likely to obey universal physical laws. These fundamental laws were explained geometrically and mathematically (Bednarik 1992, 1993), which made it possible to attempt dating by measuring wane sizes. These laws explain how, under ideal conditions, wane development is related to time. They explain also many other things in nature, for instance the geometry determining the course of temperature transfer within a solid object, the geometry explaining how a solid body melts, or how a liquid penetrates a porous body.

The 'radius' of rock wanes (strictly speaking, wanes are not equi-circular in section, but hyperbolic), at whatever magnitude of size, increases as a function of age. In wane formation (Figure 1), the ratio  $h : r$  is constant for any angle  $\alpha$ , irrespective of distance of retreat of the faces and the edge. Ratio  $x : z$  is a function of  $\alpha$ , and at  $\alpha = 60^\circ$ ,  $x = 2z$ . Dimension  $x$  can be expressed in algebraic fashion:

$$x = \frac{z^2}{\tan 0.5\alpha + z^2} \quad (1)$$

This leads to the prediction of  $\beta$ , the angle expressing the rate of wane development relative to surface retreat:

$$\beta = 2 \sin^{-1} \left( \frac{r}{x + h + r} \right) \quad (2)$$

The relationship wane width  $A$  with age, irrespective of actual retreat, is ultimately determined by the ratio  $\alpha : \beta$ , which must be established empirically. It follows that the dimensions  $A$ ,  $r$ ,  $z$ , and angles  $\alpha$  and  $\beta$  are all related geometrically and algebraically, and that the variables  $A$ ,  $r$ ,  $x$ ,  $z$  and  $h$  are all proportionally equivalent, and increase linearly with age. Of these,  $A$  is most easily measured physically. It is therefore the variable used in micro-wane measurement. The analyst scans the rock surface microscopically to locate crystals that have been truncated (either fractured by impact or truncated by abrasion) by the event to be dated (e.g. the petroglyph production). A statistically significant sample of micro-wane widths along the edges of such truncation surfaces is recorded for a selected fracture angle (preferably  $90^\circ$ ), and placed in a calibration curve. Age estimates

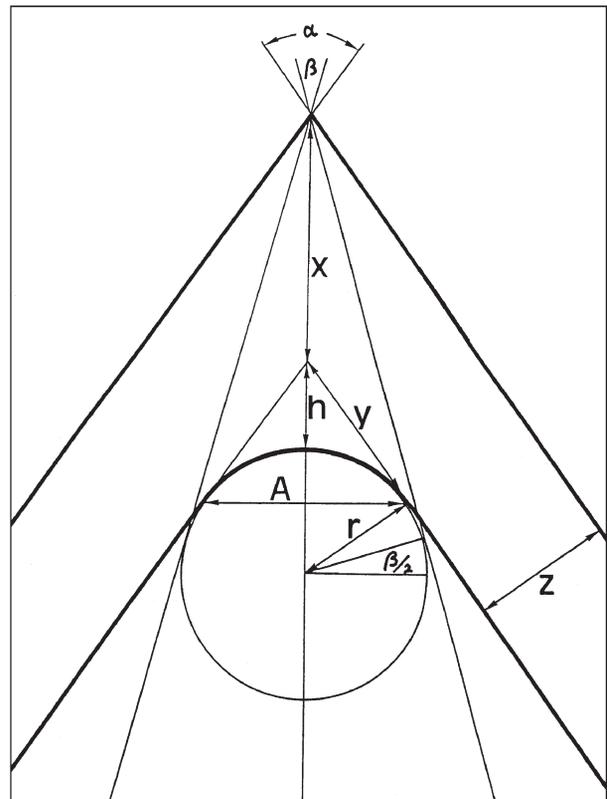


FIGURE 1. DIAGRAM DEPICTING THE LAWS OF WANE FORMATION IN A SIMPLIFIED FASHION.

are prefixed with a capital E, indicating that the result is erosion derived.

Until we know much more about solution rates of common and suitable component minerals, we need to establish these rates regionally with calibration curves. In microerosion analysis, the use of two (or more) curves for two (or more) different component minerals is recommended. Since it is unlikely that different minerals would all react similarly to past environmental changes, one would expect to detect irregularities because the corresponding values of a sample would appear displaced in the calibration graph's ordinates. If solution of one component mineral had slowed down or accelerated sufficiently to render the distortion detectable by such a comparatively coarse method, it would be reflected in the misalignment of the corresponding ordinates on the curve. No other dating method currently used in archaeology offers such a self-checking mechanism.

The precision of the method is probably poor at this early stage, because it depends entirely on the number and precision of calibration points. The principal potential variables in microerosion are temperature, pH and moisture availability. The first two are regarded as unimportant: variations in mean temperatures were probably minor, even as far back as glacial peaks of the Pleistocene; they would not have affected solution

rates appreciably. Variations in pH would have applied through time, but in the case of both amorphous silica and quartz, there is almost no change in solubility below pH 9. For alumina it is negligible in the central region of the pH scale, which coincides with most natural conditions. Quartz, then, can serve as a control against which to check the effects of pH changes on other minerals (Rimstidt and Barnes 1980).

There is no doubt that precipitation would have varied at any site in the past, and it varies between different sites today. However, it is expected that significant changes in moisture availability would affect component minerals differently, and should thus be detectable by calibration against another mineral. In this respect, the unknown sample — the surface to be dated — provides one of the points one can use to check reliability of the calibration curves, because its multi-mineral values, too, must lie on the same ordinate in the diagram.

The microerosion method by micro-wane measurement has been used on petroglyphs in six blind tests, in Russia, Portugal, Italy and Bolivia (Bednarik 1992, 1993, 1995, 1997, 2000). Archaeological expectations were matched in all cases except one, where, however, results matched those of other scientific analyses (Bednarik 1995; Watchman 1995, 1996). Calibration curves are now available from Lake Onega (Russia), Vila Real (Portugal), Grosio (Italy), the eastern Pilbara (Australia) and China (Tang and Gao 2004; Tang 2012) and several more have become available from China recently (Tang et al. 2014). The method has a practical time range from the present to perhaps 50,000 years BP, which renders it particularly suitable for rock art. Results ranging from a few centuries to almost thirty millennia have so far been obtained.

While microerosion analysis is not thought to provide great accuracy, it is probably more reliable than most alternative methods of dating petroglyphs, and it requires no laboratory backing; the results can be determined in the field. It provides not a single result, but clusters of age-related values (the micro-wane widths) that can be converted into various statistical expressions — a luxury that nearly all other dating methods have to do without (OSL on individual mineral grains and multiple targeted applications of AMS  $^{14}\text{C}$  to the same lamination might be broadly comparable). Importantly, it does not attempt to determine the age of some accretion or other feature somehow related to the rock art; it focuses on the age of the actual petroglyph, the ‘target event’ of Dunnell and Redhead (1988). No other method currently available does this. Moreover, it is the only dating method that offers a means of internal checking, that is, of checking the validity of the result without recourse to another method (although luminescence dating has a limited feature of this type, i.e. the possibility of checking whether the uranium and thorium decay chains are in

equilibrium). Finally, microerosion analysis involves no removal of samples, or even contact with the rock art, being a purely optical method.

The valid arguments *against* microerosion analysis are that we have inadequate calibration curves for it, that its accuracy is inherently limited, that it can only be applied to certain rock types (principally those comprising crystalline quartz, until minerals of quartz-free rock types are calibrated, which has so far not been attempted), and that it is unsuitable where the rock surface may not have been continuously exposed to precipitation (i.e. where it may have been concealed in the past by sediment, mineral accretion etc.). An objection raised by (Dorn 2001: 171) is that there are different types of crystalline quartz, and only the weathering of alpha-quartz is well understood. However, beta-quartz, the mineral’s high-temperature polymorph, can only exist at temperatures above 573° at atmospheric pressure, therefore this objection is irrelevant. Dorn also fears that pre-existing weathering might be present in samples, which is a valid objection only where deep fractures truncated crystalline quartz veins and exposed them to water flow. Such an instance from one of the Penascosa panels in Portugal has been identified (Bednarik 1995), which suggests that his fear is unfounded because such prior exposure is readily detectable.

Perhaps the most telling example of the method’s versatility is its recent use to date not petroglyphs, but the tools used in their production. This is an alternative application with *indirect* implications for rock art dating, but using a ‘*direct* dating’ method. Quartz was frequently utilised as the material of petroglyph hammers, and in such cases where these tools remained on the surface, exposed to weathering, their fractured edges (or those on tiny spalls detached during their use) certainly lend themselves to microerosion analysis. This method has so far been used only at Bolivian sites, and this work is described here.

### Direct dating of Bolivian petroglyphs

As in the rest of South America, reliable information about the antiquity of pre-Historic rock art has remained elusive until recently in Bolivia. We are better informed about recent rock art corpora of Bolivia, i.e. of the Colonial and Republican Periods (Querejazu L. 1992). But for the time before the Spanish conquest, beginning in 1532, clues for the age of all Bolivian rock art have been limited to archaeological speculation, except for the rock art with the trident motif at the end of zoomorphic legs, and in some cases tails, which correspond to the Late Intermediate period (1100–1438 CE), and more concretely to the ‘Mizque regional culture’. In 1987 it was attempted at the then newly discovered site Cabracancha to estimate the age of its petroglyphs using geomorphological criteria, resulting in an age estimate

PALAEOART AND MATERIALITY



FIGURE 2. SOME OF THE EARLY CUPULES AT INCA HUASI, CENTRAL BOLIVIA, ON QUARTZITE DYKE, SEEN AGAINST THE UYUCHAMA RIVER BELOW.

of 500–1000 years BP (Bednarik 1988). The petroglyphs at this small site are also dominated by the distinctive ‘trident’ design which is prominently found on ceramic remains in the River Mizque basin. Such remains were subsequently excavated in a stratified context at Camacho Tunal Mayu, where they occurred together with charcoal, which in 1996 provided a radiocarbon date of  $560 \pm 70$  years BP.

The first South American rock art site subjected to direct dating analysis is Inca Huasi, one of the many sites along the river Mizque, which flows along the eastern flanks of the Andes towards the tropical lowlands. The Department of Cochabamba, where the river is located, has several cupule traditions (Querejazu L. 1998). Inca Huasi is located 4 km from the town of Mizque, immediately above the Uyuchama River (Figure 2), and there are several more cupule sites in the region. Dominated by a prominent quartzite dyke, the site features two distinctive petroglyph traditions, both of which have provided no quantifiable microerosion data: no fractured quartz grains could be located. However, immediately upslope from the petroglyphs is a sandstone pavement covered by horizontal polished grinding dishes, each around 50 or

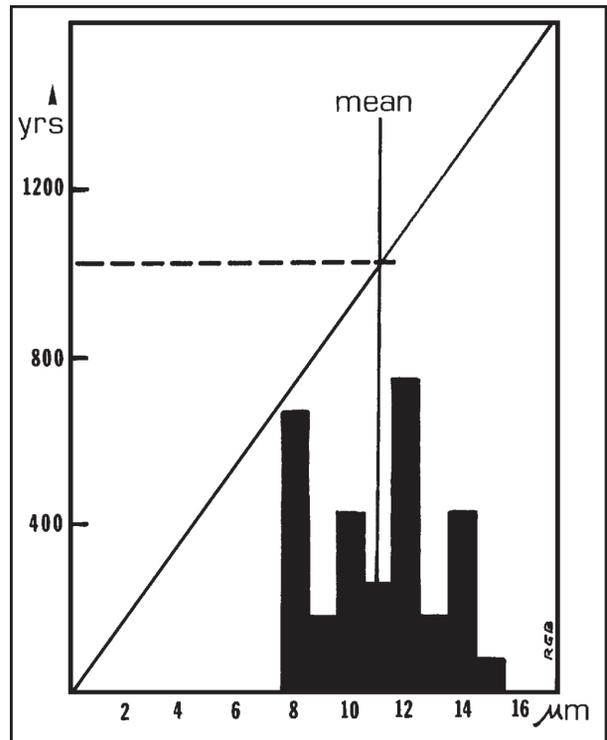


FIGURE 4. HISTOGRAM OF 35 MICRO-WANE WIDTHS FROM THE POLISHED SURFACE ANALYSED AT INCA HUASI, PROJECTED ONTO THE GROSIO CALIBRATION CURVE FOR CRYSTALLINE QUARTZ.

60 cm long. These provided ample potential to apply the method because at the surface, all quartz grains had been truncated horizontally by abrasion (Figure 3). The retreat of the amorphous silica matrix relative to these polished grain surfaces amounts to about 30% (as measured under the microscope) of that found on the more recent of the two petroglyph traditions at the site, suggesting that it is at least three times as old. One of these ground surfaces yielded 35 micro-wane width measurements (Bednarik 2000, 2001a; cf. 1992, 1993), summarised in a histogram that places the abrasion event at  $E1028 \pm 300$  years BP if the Grosio calibration curve is applied (Figure 4). Of the six calibration curves currently established (in

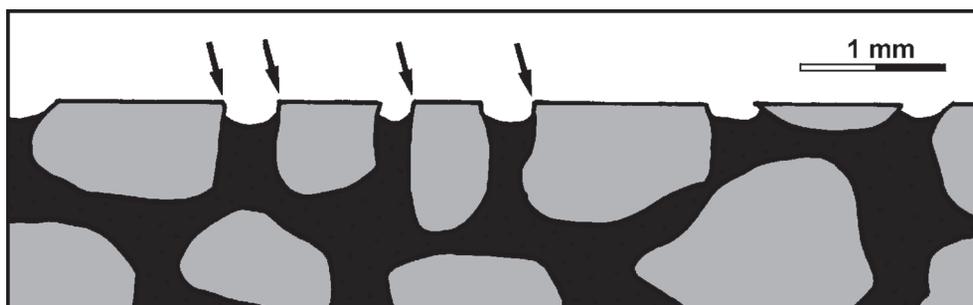


FIGURE 3. SCHEMATIC SECTION THROUGH POLISHED DISH SURFACE AT INCA HUASI, SHOWING THE ABRASION-TRUNCATED QUARTZ GRAINS, THE RETREATING AMORPHOUS SILICA CEMENT, AND THE LOCATIONS (ARROWS) OF MICRO-WANES MEASURED FOR ANALYSIS.



FIGURE 5. PETROGLYPHS IN TORO MUERTO CAVE, MIZQUE VALLEY, CENTRAL BOLIVIA.

Karelia, Portugal, Italy, Australia and China), the one from Grosio in the Italian Alps is climatically the most compatible. The difference in matrix retreat, between this polished dish and the younger of the Inca Huasi petroglyphs, suggests an age of about 3000–3500 years for the latter, while the older tradition, on the more weathering-resistant quartzite dyke, is probably of the early Holocene.

At one of the nearby cupule sites, Lakatambo 2, a cupule on a rock stele has provided adequate microerosion data to estimate its age at  $E700 \pm 150$  years, again using the climatically comparable Grosio calibration. Another rock art site near Mizque, the small siliceous sandstone cave Toro Muerto, had also been investigated since the 1980s, but because its extensive petroglyphs (Figure 5) are all protected from the weather, microerosion analysis was out of the question. However, in 1997, five hammerstones presumably used in the production of the rock art were recovered immediately outside the cave's entrance (Figure 6). Since they had been fully exposed to rainwater solution, their microerosion was determined. Three of them date from about the same time, c. 500 years ago; one is almost twice as old; while the fifth has clearly been used on two different occasions, 500 BP and about 3500 years previously. Thus petroglyphs have been produced at the site for about 4000 years, and at least three discrete episodes of use can be recognised from the tools alone (Bednarik 2010). This was confirmed by Alan Watchman (pers. comm. 1997), who on the basis of his examination of the accretionary deposit over some

of the petroglyphs at the site estimated that they may be 2000–4000 years old. Obviously it remains unknown which specific petroglyphs were created with the dated hammerstones, and rock art may have been created outside the range these imply.

The same approach, of estimating the time when stone tools were used to create petroglyphs, has been applied to the extensive cupule complex of Kalatrancani, near Cochabamba. Here it was not the sheltered location of the rock art that prevented application of microerosion analysis directly to the petroglyphs, but the nature of



FIGURE 6. FIVE HAMMERSTONES FROM TORO MUERTO, USED IN THE CREATION OF PETROGLYPHS IN THE CAVE.



FIGURE 7. ROY QUEREJAZU LEWIS AT ISCAY RUMI, KALATRANCANI PETROGLYPH COMPLEX, SEEN AGAINST MT TUNARI.

the lithology. All of the approximately twenty-eight sites forming this complex are on schists and phyllites, metamorphic rocks that typically contain neither quartz nor feldspar, the minerals to which calibration has been applied so far. Schists are highly erodible (Bednarik 2012) and any rock art on these facies is unlikely to be of very great age. At Kalatrancani, all petroglyphs occur on rock outcrops or glacial erratics rising 2–5 m above an alluvial fan below the foothills of Mt Tunari, typically separated by a few hundred metres. The rock art comprises predominantly cupules, but a variety of linear designs also occur, and some of the sites feature large numbers of abraded incisions as well.

In order to secure materials susceptible to microerosion analysis, two strategies were employed. The immediate vicinity of the outcrops was searched for hammerstones with distinctive evidence of having been used in the production of percussion petroglyphs (Bednarik 1998, 2001b); and the crevices on the rock platforms, adjacent to the rock art, were carefully searched for tiny spalls of quartz that may have become detached from the tools during impact. The first strategy resulted in finding one white quartz hammerstone at Thojya Rumi ('Broken-up Stone') and three specimens at Ph'alta Rumi ('Flat Stone'). The tool from the first site yielded a tentative age of E700 years BP, but those from the second site offered no suitable fractures. However, one of the Ph'alta Rumi hammerstones, of quartzite, had become so heavily weathered after it had been used that it can



FIGURE 8. SOME OF THE WHITE QUARTZ SPALLS FROM THE TOP OF ISCAY RUMI, RESULTING FROM THE PRODUCTION OF PETROGLYPHS.

safely be assumed to predate any of the present rock art at that site.

The second strategy yielded seven white quartz splinters from cracks on top of the Iscay Rumi ('Two Stones') outcrop, found within centimetres of petroglyphs, and four more from Ph'alta Rumi (Figure 7). Because these rock platforms are elevated above the alluvium and the white crystalline quartz chips are clearly the result of kinetic impact, their relationship with petroglyph

TABLE 1. RESULTS OF MICROEROSION ANALYSIS OF FOUR QUARTZ SPALLS FROM ISCAI RUMI, KALATRANCANI PETROGLYPH COMPLEX.

Grain No.	Size, mm	Wane widths, microns	Mean, microns	Age, years
KA1	8.09	2, 3, 3, 2, 2	2.40	E225 +56/-37
KA2	8.18	4, 3, 3, 3, 4, 3, 4, 4, 4, 4	3.60	E338 +37/-57
KA3	6.20	3, 4, 2, 4, 3, 3	3.17	E297 +78/-109
KA4	7.08	3, 2, 2, 3, 3, 3	2.67	E250 +31/-62

TABLE 2. RESULTS OF MICROEROSION ANALYSIS OF FOUR QUARTZ SPALLS FROM PH'ALTA RUMI, KALATRANCANI PETROGLYPH COMPLEX.

Grain No.	Size, mm	Description	Wane widths, microns	Mean, microns	Age, years
RF1	0.74	Highly corroded, no fracture	None available		
RF2	5.86	Well fractured, many edges available for analysis	2, 2, 2, 3, 2, 1, 2, 2, 3	2.111	E198 +83/-104
RF3	6.70	Part crystal, edges of different ages; most recent are measured	6, 6, 5, 6, 4, 6, 5, 6, 4, 6	5.40	E506 +56/-131
RF4	9.31	Complex arrangement of corroded crystals, no kinetic damage	None available		

production can safely be assumed, even though they cannot be related to any specific motif. Four of the spalls from Iscaï Rumi yielded suitable edges for microerosion analysis (Figure 8), which date from approximately E225–338 years (mean values; Table 1); while two of those from Ph'alta Rumi provided mean dates of E198 and E506 years respectively (Table 2).

This confirms that the petroglyphs of this complex are of relatively recent antiquity, and especially in the case of the first site they may all date from the Colonial Period. Even Ph'alta Rumi (Figure 9) has so far presented no evidence of pre-Colonial rock art, although the site appears to have been used much earlier. Its extensive petroglyphs are eroding and in many cases exfoliating relatively rapidly, and it is evident that its use extends beyond the rock art that still survives today. The rock's history is complex, having been submerged below sediment before it became accessible to anthropic use (Querejazu L. et al. in prep. a). However, the presence of knapped stone tools and a large quartzite core, a c. 35 cm manuport with numerous flake scars, implies much earlier occupation of the site. This is also indicated by a deeply weathered hammerstone, which was used thousands of years ago, certainly beyond the life span of any surviving petroglyph at the site. The sequence evident from the remaining rock art begins with large linear motifs, parallel wave lines and circular shapes, as well as cupules and small to medium abraded grooves. Later additions are dominated by cupules, and in the most recent period, mainly large abraded grooves were



FIGURE 9. PH'ALTA RUMI, KALATRANCANI PETROGLYPH COMPLEX, NEAR COCHABAMBA, CENTRAL BOLIVIA.

added. The earlier petroglyphs are fully patinated by ferromanganese accretion, and weathering has exposed the wafered fabric of the schist and accentuated its laminar structure. This site, therefore, appears to have a long history of human use, the rock art evidence of which is truncated by the relative susceptibility of the schist to deterioration by weathering.

In 2012, preliminary examination of the Santivañez petroglyph complex, also in the Departamento de Cochabamba, has provided the first age estimation

## PALAEOART AND MATERIALITY



FIGURE 10. ONE OF THE FOUR PETROGLYPH PANELS OF BOLA CHANKA, SANTIVANEZ PETROGLYPH COMPLEX, NEAR COCHABAMBA.

evidence from this corpus. The complex is centred on the remains of a major pinkish quartzite dyke crossing a valley, surviving as impressive rock-stacks up to several tens of metres high (Querejazu L. et al. in prep. b). The main site, Bola Chanka, overlooks the river and comprises four panels of petroglyphs (Figure 10). One of them features a pothole of c. 25 cm depth, indicating that the river was 30–35 higher at the time it was formed. The rock art of two panels features cupules, many of which are connected by hammered sloping grooves that suggest that the arrangements functioned as irrigation systems (although an alternative explanation is available). The two other panels are comprised entirely of cupules. The rock is extremely hard and has been extensively quarried for stone tools, as evident from numerous flake scars along selected edges. Nevertheless, an extensive search of several cupules for fractured grains proved fruitless, and it appears that this evidence has been obliterated by granular exfoliation. This would suggest a considerable antiquity, and the rock art-producing behaviour is reminiscent of that evident in the early phase of Inca Huasi. However, one cupule yielded a single fracture with a tentative microerosion age of E3500–4000 years BP. In view of the lack of corroborating data it may be that this is attributable to a single impact event postdating the initial production of the rock art. It would then represent merely a minimum age for the petroglyphs, but the issue needs to be further investigated. There are several other petroglyph sites in this area.

### Discussion

Bearing in mind that the carbon isotope analysis of inorganic paint residues does not yield dates that are relevant to the age of rock paintings (Bednarik 1979, 2001b), the currently available information about the age

of South American rock art is very limited. The archaic petroglyphs in Cueva Epullán Grande, Argentina, appear to be of the final Pleistocene (Crivelli Montero and Fernández 1996). They feature cupules and linear grooves, and some of the latter occur on the site's bedrock floor, which was concealed by part of a hearth that is carbon-dated to  $9970 \pm 100$  years BP (LP-213). The Epullán Grande petroglyph repertoire resembles Late Pleistocene cave art in Australia very closely, and the combination of cupules and linear grooves is a universal feature of the oldest surviving rock art form in various continents, extending back to the Lower Palaeolithic in at least one (Bednarik et al. 2005), possibly two (Bednarik 2013). Another solid minimum dating of South American rock art refers to numerous red paintings at Perna 1 in southern Piauí, Brazil (Bednarik 1989), excavated by Niède Guidon, Anne-Marie Pessis and their associates. Dense deposits of charcoal dating to about 10,000 years ago concealed the lowest of these faded paintings.

Thus the series of age estimates for Bolivian rock art is the most comprehensive credible dating information currently available from South American rock art (Table 3). The basis and magnitude of these results has been reported here, indicating that petroglyphs at several sites range in antiquity from the Colonial Period through to at least 4000 years BP, with some indications of early Holocene ages. Some of these age estimates were secured directly from petroglyph surfaces; some are direct dates from hammerstones that had been used in creating petroglyphs; and some even are direct dates from tiny spalls of white quartz found lodged in cracks next to petroglyphs, which evidently became detached during petroglyph manufacture. In the latter two cases, these *direct* dates provide *indirect* evidence of petroglyph age, and it cannot be known which of the petroglyphs this evidence refers to. Nevertheless, it does provide an indication that during a given time span, petroglyphs were produced at a site. Interestingly this would even apply in cases where the petroglyph itself may no longer exist, having been erased by weathering or exfoliation, because the quartz or quartzite implements used weather at vastly slower rates and can easily survive petroglyphs on such rock types as schists.

It is to be emphasised that this report is only preliminary, that much more work is required to determine the full chronological range of Bolivian petroglyphs, and that more substantial publications are in preparation. Moreover, it is evident from at least one site, Inca Huasi, that significantly older rock art is present in addition to that which has provided age estimation data. This may also apply at Bola Chanka, but much more research is essential. On this basis it is anticipated that early Holocene petroglyphs will eventually be demonstrated to exist in some Bolivian sites, most especially those located on thoroughly metamorphosed quartzites.

TABLE 3. DIRECT DATING RESULTS FROM BOLIVIAN ROCK ART.

<b>Inca Huasi</b> (blind test)	Abraded dish surface: E1028 ± 300 years Geometric petroglyphs: c. 1500 – 4000 years Cupules on quartzite: earlier
<b>Toro Muerto</b>	Minimum 3 traditions by tools, c. 500 – 4000 years
<b>Lakatambo 2</b> (blind test)	Cupule: E700 ± 150 years
<b>Thojya Rumi</b>	Single petroglyph tool: c. E700 years (tentative)
<b>Iscay Rumi</b>	Four chips from tools: E225 – 338 years
<b>Ph'alta Rumi</b>	Two chips from tools: E198 and 506 years
<b>Kh'elgata Rumi South</b>	Hammerstone was used E2840 +160/-220 years ago, and again E2270 +170/-210 years ago
<b>Bola Chanka</b>	Probably predating 4000 years

### Acknowledgments

None of the work reported here would have been possible without the dedication and steadfast support of Professor Roy Querejazu Lewis. Some of this work has also greatly benefited from the help and co-operation of many other members of the Asociación de Estudios del Arte Rupestre de Cochabamba (AEARC), most especially David Camacho and Favio Vargas Mujica.

### References

- Acker, J. G. and O. P. Bricker 1992. The influence of pH on biotite dissolution and alteration kinetics at low temperature. *Geochimica et Cosmochimica Acta* 56: 3073–3092.
- Bednarik, R. G. 1979. The potential of rock patination analysis in Australian archaeology – part 1. *The Artefact* 4: 14–38.
- Bednarik, R. G. 1988. El arte rupestre Boliviano visto desde el exterior. *SIARB Boletín* 2: 22–28.
- Bednarik, R. G. 1989. On the Pleistocene settlement of South America. *Antiquity* 63: 101–111.
- Bednarik, R. G. 1992. A new method to date petroglyphs. *Archaeometry* 34: 279–291.
- Bednarik, R. G. 1993. Geoarchaeological dating of petroglyphs at Lake Onega, Russia. *Geoarchaeology* 8: 443–463.
- Bednarik, R. G. 1995. The age of the Côa valley petroglyphs in Portugal. *Rock Art Research* 12: 86–103.
- Bednarik, R. G. 1997. Microerosion analysis of petroglyphs in Valtellina, Italy. *Origini* 21: 7–22.
- Bednarik, R. G. 1998. The technology of petroglyphs. *Rock Art Research* 15: 23–35.
- Bednarik, R. G. 2000. Age estimates for the petroglyph sequence of Inca Huasi, Mizque, Bolivia. *Andean Past* 6: 277–287.
- Bednarik, R. G. 2001a. Inca Huasi: the first dating of Bolivian rock art. *Rupestre: Arte Rupestre en Colombia* 4: 48–55.
- Bednarik, R. G. 2001b. *Rock art science: the scientific study of palaeoart*. Brepols, Turnhout (2nd edition 2007, Aryan Books International, New Delhi).
- Bednarik, R. G. 2010. Some analytical observations of Bolivian rock art. *Quellca Rumi* 1(1): 33–38. Algunas observaciones analíticas sobre el arte rupestre Boliviano. *Quellca Rumi* 1(1): 39–42.
- Bednarik, R. G. 2012. The use of weathering indices in rock art science and archaeology. *Rock Art Research* 29: 59–84.
- Bednarik, R. G. 2013. Pleistocene palaeoart of Africa. In R. G. Bednarik (ed.), *World rock art, special issue of Arts* 2(1): 6–34; <http://www.mdpi.com/2076-0752/2/1/6>.
- Bednarik, R. G., G. Kumar, A. Watchman and R. G. Roberts 2005. Preliminary results of the EIP Project. *Rock Art Research* 22: 147–197.
- Busenberg, E. and C. V. Clemency 1976. The dissolution kinetics of feldspars at 25°C and at 1 atm CO<sub>2</sub> partial pressure. *Geochimica et Cosmochimica Acta* 40: 41–50.
- Černohouz, J. and I. Solč 1966. Use of sandstone wanes and weathered basaltic crust in absolute chronology. *Nature* 212: 806–807.
- Crivelli Montero, E. A. and M. M. Fernández 1996. Palaeoindian bedrock petroglyphs at Epullán Grande Cave, northern Patagonia, Argentina. *Rock Art Research* 13: 112–117.
- Dorn, R. I. 2001. Chronometric techniques: engravings. In D. S. Whitley (ed.), *Handbook of rock art research*, pp. 167–189. AltaMira Press, Walnut Creek, California.
- Dunnell, R. C. and M. L. Readhead 1988. The relation of dating and chronology: comments on Chatters and Hoover (1986) and Butler and Stein (1988). *Quaternary Research* 30: 232–233.
- Lin, F. and C. V. Clemency 1981. The kinetics of dissolution of muscovites at 25°C and 1 atm CO<sub>2</sub> partial pressure. *Geochimica et Cosmochimica Acta* 45: 571–576.

## PALAEOART AND MATERIALITY

- Oxburgh, R., J. I. Drever and Y.-T. Sun 1994. Mechanism of plagioclase dissolution in acid solution at 25°C. *Geochimica et Cosmochimica Acta* 58: 661–669.
- Pope, G. A. 2000. Weathering of petroglyphs: direct assessment and implications for dating methods. *Antiquity* 74: 833–843.
- Querejazu Lewis, R. 1992. El Tunari: montaña sagrada. In R. Querejazu Lewis (ed.), *Arte rupestre Colonial y Republicano de Bolivia y países vecinos*, pp. 52–66. Contribuciones al Estudio del Arte Rupestre Sudamericano 3, SIARB, La Paz.
- Querejazu Lewis, R. 1998. Tradiciones de cúpulas en el Departamento de Cochabamba. *SIARB Boletín* 12: 48–58.
- Querejazu Lewis, R., R. G. Bednarik and D. Camacho in prep. a. The Kalatranconi petroglyph complex, near Cochabamba, Bolivia.
- Querejazu Lewis, R., R. G. Bednarik and D. Camacho in prep. b. The Santivanez petroglyph complex, near Cocabamba, Bolivia.
- Rimstidt, J. D. and H. L. Barnes 1980. The kinetics of silica-water reactions. *Geochimica et Cosmochimica Acta* 44: 1683–1699.
- Schwegler, U. 1995. Datierung von Felszeichnungen und Schalensteinen. *Mitteilungen der Anisa* 16: 99–123.
- Smith, D. I. 1978. The micro erosion meter: its application to the weathering of rock surfaces. In C. Pearson (ed.), *Conservation of rock art*, pp. 44–53. Institute for the Conservation of Cultural Material, Sydney.
- Tang H. 2012. New discovery of rock art and megalithic sites in the Central Plain of China. *Rock Art Research* 29: 157–170.
- Tang H. and Gao Z. 2004. Dating analysis of rock art in the Qinghai-Tibetan Plateau. *Rock Art Research* 21: 161–172.
- Tang H., G. Kumar and R. G. Bednarik 2014. Preliminary report of the 2014 rock art dating expedition of China. *Purakala* in press.
- Watchman, A. 1995. Recent petroglyphs, Foz Côa, Portugal. *Rock Art Research* 12: 104–108.
- Watchman, A. 1996. A review of the theory and assumptions in the AMS dating of the Foz Côa petroglyphs, Portugal. *Rock Art Research* 13: 21–30.
- Williamson, M. A. and J. D. Rimstidt 1994. The kinetics and electrochemical rate-determining step of aqueous pyrite oxidation. *Geochimica et Cosmochimica Acta* 58: 5443–5454.
- Robert G. Bednarik, Convener's office, International Federation of Rock Art Organisations (IFRAO), P.O. Box 216, Caulfield South, Melbourne, VIC 3162, Australia; [robertbednarik@hotmail.com](mailto:robertbednarik@hotmail.com)