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VARIATION AND AGE OF THE GRAN MURAL ROCK PAINTINGS, BAJA CALIFORNIA SUR, MEXICO

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Abstract. This paper reports the results of a program carried out twenty years ago to explore the ages of rock art in the sierras of Baja California. The relatively unknown rock art of the Sierra de Guadalupe represented the main focus of an investigation aiming to discover new painting sites, to collect paint samples and date selected paintings using radiocarbon. Collecting paint samples from the Gran Murals was done in all the sierras to gain a regional perspective into the time range and geographical distribution of this rock art tradition and link it with archaeological evidence obtained from excavations. The results from the field campaigns indicate considerable age for some of the Gran Murals and their repainting and provide a stimulus for additional research.

Introduction

We report here on the results of a program initiated two decades ago to explore the relatively unknown rock art of the Sierra de Guadalupe, Baja California Sur, Mexico (Fig. 1). As a consequence of changes in career, ill-health and lack of funding, the investigation results given below were not published. The project aimed to discover unknown painting sites, collect paint samples from selected paintings for measuring their ages and establish associations with the archaeological evidence. Paint samples were collected from the Gran Murals in all the sierras to gain a regional perspective into this rock art tradition's time range and geographical distribution. The first results arising out of the initial field campaign of this project indicated considerable age for some of the Gran Murals (Watchman et al. 2002), which stimulated additional research.

Unfortunately, sustained funding could not be obtained to continue addressing the initial questions, such as the identities of the organic binders used in the paints and the origins of oxalate salts on protected surfaces within cuevas (compare with Livingston et al. 2009; Mazel et al. 2010). The lack of research money also prevented essential chronometric work, including the dating of different organic fractions within paints, analysing duplicate samples, identifying potential radiocarbon contaminants, confirming age determinations in separate laboratories, collecting multiple samples from large motifs and investigating the presence of micro-organisms. At the time of our research, we did not have access to the refinements of using oxygen plasma to eliminate possible organic contamination (Russ et al. 1990; Rowe 2005; Russ et al. 2017). However, permanganate oxidation was known and used to determine the age of the carbon in oxalate salts (Fullagar et al. 1996; Gillespie 1997) but was not adapted in our chronometric analyses.

In addition, the comparison between chemical constituents in succulent plants and the degraded organic components in paint samples was not completed at the Australian National University (David Harman pers. comm.). In 2005, funding for rock art research for one of us (AW) was not forthcoming, and our investigations ceased. However, two related articles were published and discussed aspects of the rock art (Gutiérrez 2000, 2001). A doctoral thesis on the region's archaeology also provides insights into the diversity of cultures over many thousands of years (Gutiérrez 2013).

Almost two decades after the fieldwork and research had ended, and because of what we regarded initially as outstanding and substantial preliminary results in interpreting global rock art, we feel compelled to release the findings of our work without having completed some fundamental aspects of our scientific investigations. We acknowledge these limitations and hope that readers will interpret and appreciate the results, bearing those constraints in mind. Our work represents a significant continuation of the history of scientific research of the rock art of Baja California and is therefore worthy of presentation despite its deficiencies. By publishing our results, we hope to stimulate other researchers to investigate this spectacular and significant corpus of rock art. Rock paintings known as the Gran Murals (Crosby 1997; Hambleton 1979) are found in cuevas or rockshelters

in the desert of central Baja California, Mexico: the Sierras de Guadalupe, San Francisco, San Juan and San Borja (Fig. 1). Site elevations range from near sea level to 1100 metres, and most of the cuevas are formed in volcanic and volcaniclastic sedimentary rocks on the steep sides of canyons or arroyos where water erosion has undercut structurally weak bedding planes. Dew, fog and occasional torrential rain in tropical storms bring moisture to a habitat of palms, cacti, agave and other succulent plants.

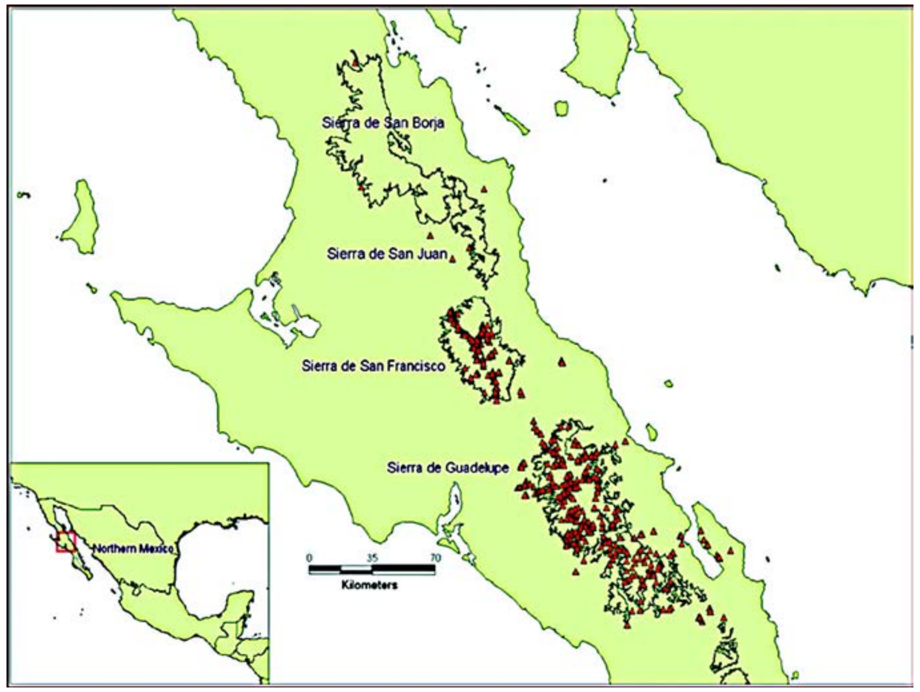

Figure 1. *Map of the Baja California Peninsula showing the four sierras and the locations of all the recorded rock art sites in the Sierras de Guadalupe and San Francisco and the locations of sites sampled in this study in the Sierras de San Juan and San Borja.*

The region was first inhabited by palaeo-Indian peoples at least 10 000 years ago, as evidenced by the presence of Clovis-type stone tools (Aschman 1952; Gutiérrez and Hyland 1994, 2002). At the time of European contact, three linguistic groups lived on the peninsula: the Pericu, Guaycura and Yumano (Laylander 1987). Hunter-gathering Cochimi people lived in the central mountainous region when the Jesuit missionaries first arrived in the 18th century (Barco 1973), but they denied having any connections with the rock art.

The Gran Murals consist of a diverse array of monochrome and polychrome images of land and marine animals, abstract designs, birds and humans. They range from small animals to larger than life-size 'deer', '*berrendo*', 'mountain sheep', 'mountain lions', 'sea lions' and 'humans'. Anthropomorphs, predominantly male, are generally presented in static poses, facing the viewer with arms outstretched in a 'hands-up' position with feet splayed outwards. Usually, 'arrows' (*flechas*) penetrate the sides of their bodies. In contrast, the large land animals are in profile and dynamic positions with characteristic horns and feet shown in twisted perspective. Depictions of 'turtles' and 'sea lions' are in plan perspectives, and birds with their wings open as if in flight or spread to dry.

In 1980 the Instituto Nacional de Antropología e Historia (INAH) started a long-term research program to study the archaeological context of the Gran Mural rock art phenomenon (Gutiérrez 2001; Gutiérrez and García-Uranga 1990). This program of field exploration and site document-ation was assisted by two major grants from the INAH and the Consejo Nacional de Ciencia y Tecnología (CONACYT) (Gutiérrez 2000). Field cam-paigns in the sierras of central Baja California were carried out during 2001, 2002 and 2004. These campaigns followed previous work by Gutiérrez and Hyland (2002) between 1992 and 1994 in a project titled 'Arte Rupestre de Baja California Sur' in the Sierra de San Francisco. During that period, UNESCO declared the Sierra de San Francisco a World Heritage site. Funding for field research and dating was also provided by the National Geographic Society (NGS). The Rafter Radiocarbon Laboratory in New Zealand collaborated in the dating of the paint samples from motifs of the Gran Murals and the excavated skeletal remains and organic artefacts (Gutiérrez 2013).

The question of the age of this majestic style of pre-Historic rock art has intrigued many people. However, scientific dating of the rock art was impossible until Southon et al. (1985) demonstrated the possibility of measuring micrograms of carbon-bearing substances using accelerator mass spectrometry radiocarbon (AMS ^{14}C). Later a research team from the University of Barcelona collected and dated paint samples from Cueva El Ratón in the Sierra de San Francisco (Fullola et al. 1993, 1994). They found that the carbon in their samples from paintings of 'humans', a 'mountain lion' and a 'deer' gave age estimates ranging from almost 5300 to 300 years ago. These results from randomly selected paint samples provided the first clues about the antiquity of the Gran Murals, but they also raised questions about possible stylistic sequences within and between the sierras. Other questions raised included whether the paintings constitute one or more pre-Historic periods, were repainted or retouched and were created by a particular population or multiple groups of people.

Sampling and dating methods

The Gran Murals' thick red, black, yellow and white paints have a hardened paste-like consistency of mixtures of earth colourants (haematite, pyrolusite, gypsum and anhydrite) and a voluminous binding agent. In contrast to thin paint films composed of an inorganic colourant and water mixture, the bulky Baja paints are thought to contain mucilaginous binders derived from plants, such as agave and cactus. Water is scarce across the peninsula, whereas succulents are widespread and found proximal to Cuevas. A moist and sticky binding agent growing near the painting sites would have been ideal for the painters. Mixing the naturally adhesive binders with finely powdered colourants would have produced paints with a paste-like consistency. The carbon contained in the organic binders provides the means for reliably determining the age of the paintings using AMS ^{14}C, but we did not carry out any non-invasive tests before sampling (Horn et al. 2020).

Sampling of the paintings relied on finding a partly detached flake of rock with some paint attached to each figure. The flake was gently levered from the surface and collected onto aluminium foil, where it was labelled and stored for later analysis. Emphasis was on the deliberate selection of parts of paintings where other images had not been superimposed. This was done to eliminate the possibility of contamination from two painting episodes at different times. Preference was given for paintings where secondary mineral salts had not formed over paints. Some of those coatings contained carbon (Magar and Davila 2004) and were removed physically and chemically before dating to avoid contaminating the age determinations.

The painted flakes of rock were unwrapped in the laboratory and examined under a stereo-microscope to determine the thickness and nature of the paints. Possible contaminants and the superimposition of paints (unobserved in the field) were also examined to eliminate any complicating issues. Once a suitable paint was selected for dating, it was physically removed by grinding with a portable electric drill. The resulting powdered paint was wrapped in foil and sent for processing directly to the Rafter Radiocarbon Laboratory, New Zealand. Four samples were submitted to the Australia Nuclear Science and Technology Organisation in Sydney to fulfil a research grant allocation of complimentary age determinations. The usual acid/base/acid treatment was carried out on the samples to remove potential contaminants, especially carbonate and oxalate salts and then the organic residues were combusted into carbon dioxide. The gas was then reduced to graphite and analysed in an accelerator mass spectrometer. Small portions of the gases were analysed for stable carbon isotopic values.

In 2004 samples from the stems and leaves of various juicy plants were collected from near the rock art sites. The moist vascular tissues were stored in sealed plastic vials. These were later subjected to chemical analyses to measure the nitrogen and carbon contents and ratios as well as the stable isotopic values ($\delta^{15}N$ and $\delta^{13}C$, Table 7). Before funding for the project ceased, a comprehensive program was investigating the organic chemistry of the plant extracts and presumed mucilaginous binders in paint samples. This was done using gas chromatography mass spectrometry (GC-MS) at the Department of Chemistry, Australian National University, but was not finished.

The GC-MS analytical techniques are ideally suited for identifying natural organic materials used in the field of Cultural Heritage Science (Mills 1966; Birstein 1975). GC-MS is a sensitive technique suitable for analysing natural organic substances to identify the compounds and their degradational products (Schneider and Kenndler 2001; Regert et al. 2001; Mejanelle et al. 2002). In the early stages of undertaking this research, it became evident that the methodology had advantages and drawbacks, especially considering the effects of degradation and the consequent generation of complex chromatograms. At that time, it was impossible to interpret the spectra unequivocally from fresh organic matter compared with those obtained from the paint samples. Therefore further research was needed to investigate the pathways and processes of the chemical degradation of compounds in the plants and extract DNA.

Results

Sixty-one radiocarbon determinations were measured on samples of rock art from the central Baja Peninsula. The bulk of those analyses was from the Sierra de Guadalupe 42 (69%) with only 12 (20%) from the Sierra de San Francisco, 5 (8%) from the Sierra de San Juan and 2 (3%) from the Sierra de San Borja.

The age of the earliest painting we dated was c. 9000 years and the youngest about 530 years bp (Fig. 2). A large error on the oldest painting reflects the small quantity of carbon in the paint. The youngest age determinations confirm the explanation by the Cochimi to the Jesuit missionaries; they said they did not paint the motifs. The youngest painting dated in this project was almost 300 years before the Spanish arrived. The extensive age range obtained from all the radiocarbon measurements reflects consistency and continuity in the painting of the Gran Murals through time. Recurring themes that endure throughout the long period showing cultural continuity include the presence of numerous 'arrows' penetrating anthropomorphs, the types of headdresses (Gutiérrez and Hyland 2002: 367–377), groups of birds in flight, and the association and superpositioning of 'deer' and 'human' figures. There is a possible break in the continuous nature of painting about 3000 years ago in the Sierras de San Francisco and San Juan (Fig. 2). This may either reflect an insufficient database, cultural transitions or environmental changes. The limited number of samples is probably the major factor indicating possible discontinuous painting activities

in these sierras. Additional dating of samples would provide insight into this potentially intriguing discontinuity.

The oldest dated paintings consist of figurative motifs of 'humans, mountain and sea lions, fish and snakes'. They are polychrome humans in red and black with white outlines, and the 'mountain lions' are black. The oldest figure dated in this study is a female 'human' at El Palmarito in the Sierra de San Francisco at 9100±2600 years bp. In contrast, the youngest motif is the remains of a 'deer' of 530±630 years BP at the Cueva de Guano in the Sierra de Guadalupe.

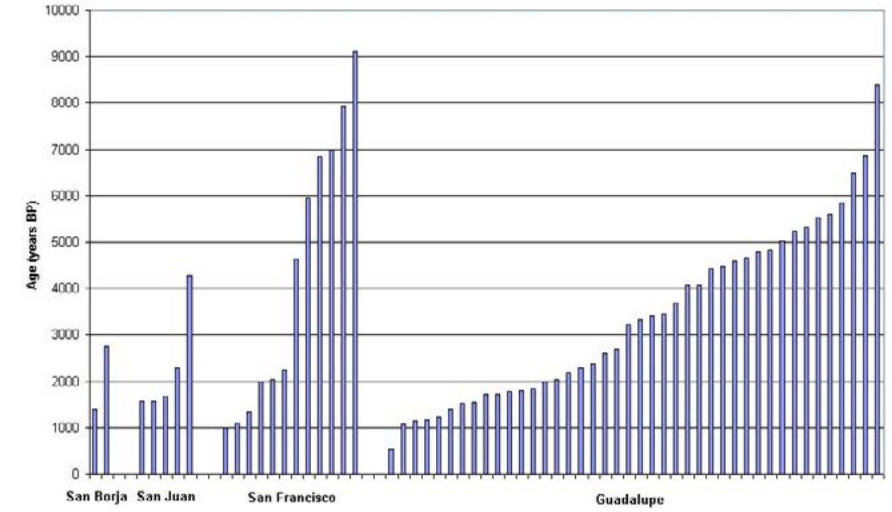

Figure 2. The chronological sequence of radiocarbon age distributions for the paintings in the Sierras de San Borja, San Juan, San Francisco and Guadalupe.

Abstract motifs collected in this study were from three sierras and range in age from 4630 to 1100 years ago (Table 1). A particular type of abstract painting called *tablero* or chequerboard first appears about 4600 years ago. This polychrome painting of red, yellow, white and black solid rectangles in a larger parallelogram was either an isolated motif (as at La Soledad) or later incorporated in the torso of 'human' figures, as at San Borjitas. An unusual feature of the red, yellow, brown and black *tablero* at the Cueva del Raton in the Sierra de San Francisco is the presence of white dots across the entire painted rectangle.

The range in age of abstract motifs includes an engraving from the Sierra de Guadalupe. This abstract engraving at El Pilo had been engraved into a rock surface c. 3700 years ago on a surface that had already developed a thin oxalate-rich coating. After the petroglyph had been pecked through the thin coating, a new oxalate layer formed in the grooves. It was presumed that micro-organisms that lived on the stable dusty surface used atmospheric carbon dioxide to produce the oxalate salt so that the resulting oxalate could be dated using AMS radiocarbon. Physical removal of the carbon-bearing substance from within the groove by using a battery-powered dental drill and burr resulted in a powder that was decomposed in the laboratory with acidified permanganate and then dated (Gillespie 1997; Watchman 2000; Watchman et al. 2005). The analysis indicated contemporaneity of abstract petroglyphs and painted abstract motifs.

Whereas relatively simple abstract motifs of zig-zag lines, dots and grids were painted in the last few thousand years, the age range for all abstract motifs falls within the broad spread for the Gran Mural tradition of painting large humans and animals. Abstract motifs were not confined to the geographic periphery of the locations of Gran Murals adjacent to the surrounding abstract styles in the north and south but are distributed throughout the sierras.

All of the paintings of 'deer' come from the Sierra de Guadalupe, and they span a period from 5225 to 530 years bp (Table 2). The two most recent paintings, remnants of relatively large bichrome motifs at the Cueva de Guano, do not have the same attributes as the other dated images. They are red and white, solidly infilled and of a style characteristic of the Sierra de San Francisco. Early paintings of 'deer' were monochrome

Site	ID	Motif, colour	Lab #	$\delta^{13}C$	Age (yr bp)	Error
Sierra de Guadalupe						
La Pingüica	LP7	Abstract dots, white	14675	-14.10	1550	±80
La Pingüica	LP5	Abstract line, black	14674	-13.20	2000	±60
El Pilo	EPE5	Abstract petroglyph	14722	-9.40	3680	±60
El Pilo	EPE7	Rock coating, petroglyph	14784	-9.80	4595	±55
Sierra de San Borja						
Montevideo	MVE5	Abstract, red	18084	-24.60	2760	±210
Sierra de San Francisco						
La Musica	LM2	Abstract grid, white	18090	-24.50	1100	±1200
La Soledad	LS 3	Abstract *tablero*, yellow	20637	-24.60	4630	±100

Table 1. *List of abstract motifs collected across the sierras in central Baja California showing their respective age determinations and stable isotopic values (the large error terms are likely attributable to the extremely small sample of paint).*

Site	ID	Motif, colour	Lab #	δ13C	Age (yr bp)	Error
Sierra de Guadalupe						
Cueva de Guano	CG5	'Deer', white	14667	-11.40	530	±60
Cueva de Guano	CG2	'Deer', red	14669	-15.40	1520	±75
La Trinidad	LT3	'Deer', white	15457	-4.00	1720	±70
El Pilo	EP1	'Deer', red	15460	-21.70	3410	±85
P. C. de Guadalupe	PCG 18	'Deer', white	20436	-19.00	3450	±75
El Pilo	EP3	'Deer', white	14668	-14.50	4790	±70
La Trinidad	LT5	'Deer', red	14664	-12.60	5225	±85

***Table 2.** List of paint samples from 'deer' motifs and their respective analyses collected from the Sierra de Guadalupe (the large error terms are likely attributable to the extremely small sample of paint).*

Site	ID	Motif, colour	Lab #	δ13C	Age (yr bp)	Error
Sierra de San Francisco						
Cueva Pintada	CP18	'Sea lion', white	18085	-25.00	990	±150
San Gregorio	SG 2.1	'Sea lion', red	20648	-26.50	7930	±120
Sierra de San Juan						
Los Paredones	LP7	'Fish', red	OZG819	n.m.	1560	±50
Sierra de Guadalupe						
San Patricio	SP3A	'Fish', white	15452	-8.90	1070	±70
San Borjitas	SB4r	'Fish', red	15448	-21.10	1150	±560
San Patricio	SP3B	'Fish', white	15453	-9.60	1170	±55
La Trinidad	LT1	'Fish', white	15455	-10.20	1390	±55
San Borjitas	SB 6*	'Fish', red	20641	-23.80	4430	±170
San Borjitas	SB 7*	'Fish', yellow	20642	-24.00	8390	±95

***Table 3.** Radiocarbon and stable isotopic data obtained from paints collected from marine animals.*

and depicted in a simple style using single lines and possible interior linear decorations but without infilling colour. These early deer images are consistent with the La Trinidad style, as described by Crosby (1997: 217).

Depictions of marine animals include 'fish' and 'sea lions', and seven samples from fish motifs span an age range of 8390 to 1070 years bp (Table 3). Two painting styles of 'fish' motifs occur in Sierra de San Juan (LP7) in the north and Sierra de Guadalupe in the south. The southern La Trinidad style consists of lines and monochrome paint and dominates our collection of samples. Bichrome solid infill painting typifies the northern style found at Los Paredones. Samples of paints from depictions of 'sea lions' at two sites in the Sierra de San Francisco (Cueva Pintada and San Gregorio) span almost 7000 years.

Repainting is observed on some motifs where newer paint infilled areas of flaked rock surface. This is evident because the newer paint's less faded colour and smooth texture contrasts with the weathered underlying layer. This is the case of the 'fish' motif at San Borjitas, and three distinct paint layers were sampled. A red paint layer (Table 3, SB6) was added almost 4000 years after the original yellow paint (SB7), and another red layer was applied 3000 years later (SB4r).

Two samples (Table 3, SP3A, B) from San Patricio were collected from a white 'fish' painting. The radiocarbon results of 1070±70 and 1170±55 years BP demonstrate the slight variation in age of the organic components within a single motif.

We did not draft maps or plan and section drawings of each Gran Mural site at every sampling location because our impecunious research curtailed further work. Ideally, given funds and time, we would have plotted each sample on a scale drawing and compiled Harris diagrams showing the relationships between superimposed images. We would have also carried out a DStretch digital enhancement with the tool created to enhance rock art images (Alley 1996; Harman 2005; Hoerlé et al. 2016).

Paint samples were collected from an arrow (*flecha*) painted penetrating a human body, two white hand stencils and a range of human forms (Table 4A). The painting of a red arrow was collected from the side of the depiction of a human at San Borjitas (HF28), and it was painted (4070±100 years bp), after the black chest (4820 years bp), the red finger on the right hand (5600±2100 years bp) and the black leg (6480±90 years bp). These age determinations from different parts of a single motif might indicate the repainting of motifs through time.

At San Borjitas the black leg of an anthropomorphous figure (HF28) is underneath the black leg of the adjacent human (HF2), whose age (SB4b1, 4480±110 years bp) is consistent with that superimposition (Table 4A). The side of HF2, painted in black (SB1b; 4070±90 years bp), is coincidentally the same age as the red *flecha* (SB4; 4070±100) which intersects HF28. This coincidence in ages might mean that both motifs were part of a synchronistic episode. Four thousand years ago, a painter prepared red and black paints and painted a red arrow to an existing black motif HF28 (SB4b2; 6480±90 years bp), and also used the black paint to repaint an adjacent figure HF2 (SB3, painted 5325±95 years ago and modified 845 years later, SB4b1).

Many more samples and age determinations are necessary to substantiate the claim for figures at San Borjitas and elsewhere on the peninsula. However, these preliminary findings seem to indicate a long cultural tradition, over almost 5000 years of touching up and adding new figures and elements to the extraordinary polychrome paintings. These modifications were apparently deliberate and for some specific purpose unknown to us, without totally obscuring the adjacent and underlying motifs. If the paintings symbolise specific deities or people, then the repetitive refreshing of the images, where pieces of paint and ceiling had been lost through spalling, represents an intentional act for maintaining the cultural significance of those motifs. Whether this was for story-telling and an essential part of oral tradition is unknown, but a purposeful effort was made to preserve the motifs.

The Gran Mural paintings of life-size and larger 'human' figures are spread across all sierras. The oldest figure (9100 ±2600 years bp), a female, is painted at the top of a frieze of paintings high on a cliff at Cueva El Palmarito in the Sierra de San Francisco (Fig. 3). The youngest 'human' figure (1400±1300 years bp) is at the Montevideo site in the northern Sierra de San Borja (Table 4B). The large error terms, likely attributable to the tiny amounts of paint collected and, therefore, the small quantities of carbon, cannot be otherwise explained without undertaking further research. Nevertheless, depictions of 'human' figures were painted over approximately 8000 years and are represented in several distinct styles: La Trinidad (linear forms), San Francisco (generally red and black solid infill), San Borjitas (white

Site	ID	Motif, colour	Lab #	δ13C	Age (yr bp)	Error
San Patricio	SP4w	Hand stencil, white	15454	-11.80	2290	±60
San Borjitas	0SB 1*	Fig. 28, black chest	20638	-26.00	4820	±130
San Borjitas	SB 32	Fig. 44, red	20643	-26.20	4655	±85
San Borjitas	SB 4*	Fig. 28 red *flecha*	20639	-26.30	4070	±100
San Borjitas	SB 5*	Fig. 28, finger, red	20640	-27.30	5600	±2100
San Borjitas	SB10	Fig. 52, yellow	14673	-11.10	2025	±65
San Borjitas	SB11	Fig. 52, black chest	14672	-16.00	5525	±75
San Borjitas	SB18	Fig. 4, black	18089	-24.80	1710	±200
San Borjitas	SB1b	Fig. 2, black side	15445	-20.40	4070	±90
San Borjitas	SB2r	Fig. 3, red	15447	-14.60	3220	±60
San Borjitas	SB2w	Fig. 2, white	15446	-17.70	1770	±60
San Borjitas	SB3	Fig. 2, black leg	14665	-19.30	5325	±95
San Borjitas	00SB4b1	Fig. 2, black foot	15449	-19.10	4480	±110
San Borjitas	SB4b2	Fig.28, black leg	15450	-18.90	6480	±90
San Borjitas	SB5	Fig. 46, red	14663	-13.80	5025	±75
San Borjitas	SB6	Fig. 48, white arm	14670	-13.30	1795	±65
San Borjitas	SB8	Fig. 48, white stripe	14671	-13.30	2605	±65
San Borjitas	SB09	Fig. 52, red	15451	-15.50	3335	±60
Guadalupe	PCG 12	'Human', red	20433	-11.50	2370	±35
Guadalupe	PCG 13	'Human', black	20434	-26.40	6870	±150
Guadalupe	PCG 6	'Human', red	20432	-22.50	5840	±80
La Trinidad	LT2	Hand stencil, white	15456	-12.50	1225	±60
La Trinidad	LT4	'Human', white	15458	-7.30	1835	±65
La Trinidad	0LT6	'Human', red	15459	-14.10	2190	±55

***Table 4A.** List of paint samples and their analytical data for the depictions of 'human' figures in the Sierra de Guadalupe (* = from the same motif; the large error terms are likely attributable to the extremely small sample of paint).*

Site	ID	Motif, colour	Lab #	δ13C	Age	Error
Sierra de San Borja						
Montevideo	MVG1.8	'Human', black	18087	-25.50	1400	±1300
Sierra de San Francisco						
Cueva Pintada	CP 21	'Female', white	18083	-25.00	2250	±210
Cueva El Palmarito	CEP 4	'Female', black	20644	-27.30	9100	±2600
Cueva del Raton	CR1	Red 'human' or chequerboard	14679	-6.00	2000	±70
Sierra de San Juan						
Campo de Monte	CMD2	'Human', red	18086	-24.10	4280	±190
Los Paredones	LP5	'Female', red hand	OZG816	n.m.	1680	±50
Los Paredones	LP6	'Human', small red	OZG817	n.m.	1560	±50

***Table 4B.** List of paint samples and their analytical data for the depictions of human figures in the Sierras de San Borja, San Juan and San Francisco (n.m. = not measured; the large error terms are likely attributable to the extremely small sample of paint).*

Figure 3. Scaffolding was required to examine and sample the frieze of paintings at Cueva El Palmarito.

Site	ID	Motif, colour	Lab #	$\delta^{13}C$	Age (yr bp)	Error
Sierra de San Francisco						
Cueva del Raton	CR3A	'Mountain lion', black	14666	-13.90	2040	±95
Cueva El Palmarito	CEP 6	'Mountain lion', black	20645	-25.00	5960	±150
Cueva El Palmarito	CEP 14	'Mountain lion', black	20646	-21.90	6960	±120

Table 5. List of samples and their analyses for depictions of black 'mountain lions'.

outline and stripes without infill), red-black-yellow chequerboard chest with variously coloured head, arms and legs, and solid red-on-granite with or without a white outline (Gutiérrez and Hyland 2002: 75–88). In this project, these contrasting painting styles of human figures accompanied by various head shapes and headdresses were not rigorously studied and sampled. However, we think such studies would likely provide fascinating temporal and spatial correlations.

Not all paintings of 'mountain lions' in the sierras are black, but red and yellow ones occur in the Sierras de San Francisco and Guadalupe. Three separate images, all from the Sierra de San Francisco, were dated and the ages range from almost 7000 to 2000 years ago (Table 5).

A range of ages was obtained in three sierras for depictions of a 'rabbit, turtle, lizard and snake' (Table 6). These radiocarbon results are within the same spread obtained for the Gran Murals and indicate a diversity of images within the general depictions of large animals and humans.

Discussion

In his research towards ob-taining a doctorate, Justin Hyland, as quoted by Laylander (2005: 178) noted, burials have recently been reported from the Sierra de San Francisco and Sierra de Guadalupe, including bones that had been painted with red ochre and black pigment within one non-Mural rock shelter (Hyland 1997: 279–280). The radiocarbon dates associated with the latter site, calibrated to about 1100–1700 BCE, are significantly earlier than most of the radiocarbon dates that appear to be associated with Great Mural activity itself, which postdate about 200 CE (Hyland 1997: 284).

Site	ID	Motif, colour	Lab #	$\delta^{13}C$	Age (yr bp)	Error
Sierra de San Juan						
Las Tinajitas	LT5	'Turtle', red	OZG820	-4.50	2280	±40
Sierra de San Francisco						
Cueva del Raton	CR2	'Rabbit', orange	14678	-10.50	1330	±60
San Gregorio	SG 1.1	'Snake', white	20647	-27.60	6840	±280
Sierra de Guadalupe						
P. C. de Guadalupe	PCG 14	'Lizard', white	20435	-14.50	2700	±50

Table 6. Analytical results for the depictions of various other land animals.

These radiocarbon results followed those obtained by Fullola et al. (1994), indicating a possible mid-Holocene time frame for the Gran Mural paintings. In our project, the dating results for paints collected from human motifs overlap the previous dating measurements obtained from samples collected at Cueva del Raton by Nelson (Gutierrez and Hyland 2002: 337) and others (Fullola et al. 1994). Two samples of black paint collected by Nelson from Cueva de la Palma and San Gregorio II and dated by Watchman (in addition to our sampling program), gave measurements of 3245±65 and 2985±65 years bp, respectively. At Cueva del Raton, Fullola's team obtained age determinations of 1325+435/-360 and 5290 ± 80 years bp for two 'human' figures. The AMS ^{14}C measurement by Fullola et al. (1994) for paint from the black 'mountain lion' at that site gave an age of 4845±60 years bp. The result compares with our sample CR3A (2040±95 years bp) from the same motif. The discrepancy in ages between samples of black paint from the same motif requires further study.

Paint from a 'deer' at Cueva de la Raton gave an age of 295±115 years bp (Fullola et al. 1994). It contrasts with our sample of white paint from a 'deer' at Cueva de Guano (CG5, 530±60 years bp). The youngest motif so far dated was painted immediately before the arrival of the Spanish Jesuit missionaries in 1697 (Chapman 1920). Perhaps it represents one of the Gran Murals' last paintings before the indigenous population's demise.

The oldest paintings we dated came from the Sierras de San Francisco and Guadalupe, and whereas the number of samples from the Sierras de San Juan and San Borja is low in comparison, the preliminary results indicate an early phase of painting of the Gran Murals in the southern sierras and a later continuation in the north.

All colours are represented throughout the entire age range except for the orange paint from a small 'rabbit', which was specifically sampled as it was thought one of the youngest motifs (CR2, Table 6). It seems apparent that black, red and white pigments were readily available for use as paint colourants throughout the entire period of occupation of the peninsula. The sources of the colourants were not thoroughly investigated as part of this project (compare with Váldez et al. 2008). White paint was used in linear paintings, in abstract motifs and as outlines of larger motifs after the other colours were applied.

The series of ages obtained from different coloured paints from one figure at San Borjitas would seem to indicate repetitive repainting and repairing of damaged motifs. It was observed that spalling of parts of the ceiling of cuevas occurs naturally with the consequential degrading of painted figures. Some motifs had experienced flaking of the underlying rock, and the blank areas had not been retouched to repair the scarred painting. A decision was made to test a figure that appeared to have been affected by flaking and then had been repainted. The patches of paint over the scars looked slightly different in colour and texture to the rest of the motif. As a result of selective sampling and radiocarbon dating, we found that our field observations were correct and that the figure chosen had been retouched over several thousands of years. As described previously, the leg of one large human figure was painted 6480 years ago, the hand 5600 years ago, part of the torso 4820 years ago and a *flecha* penetrating the torso 4070 years ago. Therefore, for approximately 2500 years, the same figure had been retouched and repaired to maintain its aesthetic and cultural value to the inhabitants.

Analysis of the binding medium in the pasty paints (and possible plant mucilaginous tissues) involved the measurement of the stable carbon isotopic values ($\delta^{13}C$) as well as radiocarbon ages (Rafter Radiocarbon Laboratory, New Zealand). The $\delta^{13}C$ value is conventionally expressed relative to the Pee Dee Belemnite (PDB) standard (Boutton 1996; Biedenbender et al. 2004), and the results are calculated on a *per mil* basis (parts per thousand, ‰). Boutton (1996) also noted that the $\delta^{13}C$ value is unaffected during plant decomposition, so measuring the stable isotopic ratios of paints should confirm possible plant binders.

Some of the samples collected from the older figures have larger and more negative stable isotope values (Fig. 4). Most stable isotope analyses for the

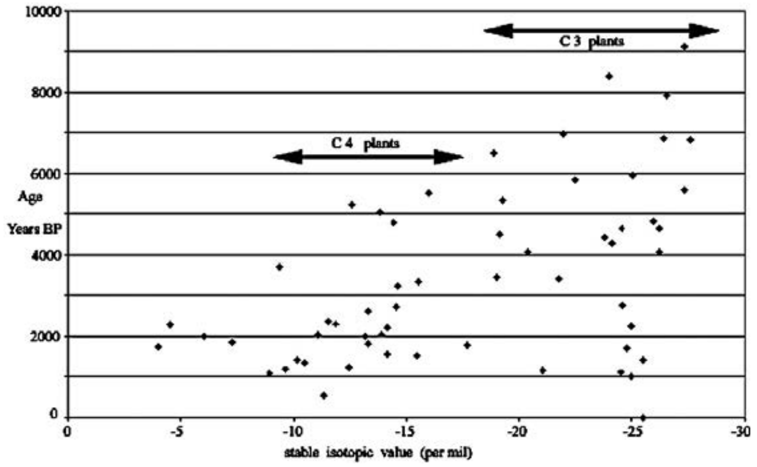

Figure 4. *A plot of radiocarbon age against stable isotope values for all dated paint samples and showing the temporal use of binding media from C3 and C4 plants.*

Plant	% Nitrogen	$\delta^{15}N$	% Carbon	$\delta^{13}C$	C : N ratio
C4-CAM plants					
Nopal	0.6	6.6	31.5	-9.0	51.8
Biznaga	0.4	4.8	33.8	-12.4	78.1
Cardon	0.8	6.4	30.9	-13.2	38.5
Pithaya dulce	0.4	3.7	34.3	-14.3	88.6
Pithaya agria	0.3	4.5	45.0	-14.5	160.5
Garambullo	1.3	9.0	38.7	-15.8	31.1
Candelilla	0.5	4.1	66.8	-16.1	130.9
C3 plants					
Lomboy	2.5	7.4	51.4	-25.5	20.4
Matacora	0.5	1.5	51.9	-27.2	112.6
Torote	0.4	3.5	63.1	-27.4	162.5

Table 7. *List of C3 and C4-CAM plants containing mucilaginous tissues sampled and analysed to determine possible binding agents used in the paints of Baja California (see Dimmitt et al. 2005 for a full list of plants identified in the region).*

paints are scattered across a range from -9.0 to -28‰, indicating that various binder compositions were used in the paints. This could imply the deliberate selection of organic compounds from various sources, such as different plants or the paints contain contaminated organic materials. The isotopic values fall in three ranges; less than -10‰, from -10 to -15‰ and between -20 and -30‰.

A tentative conclusion deduced from these results is that the bulky paint binders are most likely derived from sticky plant tissues obtained from various succulent plants. These three stable isotope categories possibly reflect differences in the photosynthetic and carbon cycling pathways of terrestrial desert plants. Plants fix atmospheric carbon dioxide in their structures in one of three key reactions: the Calvin-Benson Cycle (1948) or C3, the Hatch-Slack Cycle (1966; 1970), or C4 and the Crassulacean Acid Metabolism (CAM) pathway. The CAM process is typical of many succulent desert plants. In order to conserve water, carbon dioxide is fixed into organic acids during the night and released during the day for photosynthesis.

These photosynthetic reactions strongly fractionate the isotopes of carbon, so C4 plants possess $\delta^{13}C$ values ranging from -16 to -10‰, CAM succulents -20 to -10‰ and C3 plants -33 to -24‰ (*per mil*, Table 7). C3 plants dominate most temperate zone plant communities, and therefore their juices and saps should have higher stable isotopic values than the C4 plants. The latter is characteristically found in hot, arid environments because of the selective advantage that the C4 photosynthesis has in efficiently using water.

Nopal is a flat-leafed cactus, the stems of which contain mucilage and fibre. Biznaga is a barrel-type cactus containing a sweet juicy pulp. Cardon is a giant cactus with hard thick trunks and fleshy fruit. The species of Pitahaya (*dulce* and *agria*) grow as organ-pipe cacti and produce juicy fruit, and Cuatecomate and Guázuma also bear fruit with sappy pulp. Other possible plants providing substances suitable as binders are Garumbullo, a bushy cactus and Candelilla, a small waxy shrub. Gel is well-known to come from plants of the Aloe species. Another possible source of a suitable liquid organic binder is the Maguey (agave) plant. After many years of growth, a single agave plant can produce several litres of sap or *aguamiel* per day. The *aguamiel* can be consumed directly or left to ferment for several days into *pulque*, a milky alcoholic beverage with viscous consistency and a sour taste. The moist pulp, tissue, gel or sap from one or more of these plants could act as a binder, but much more analytical work is necessary to prove this assumption.

The stable isotopes of plants and soil organic matter have been used as indicators of palaeo-environmental change (Biedenbender et al. 2004; Boutton, 1996; McClung de Tapia and Adriano-Morán 2012). Therefore, it may be possible to use the stable isotopic values of the binders in paints to draw inferences about the environment when a painting was made. If reliable measurements can be obtained from residual juicy plant tissues in paint binders, then variations in climatic regimes may be reflected in paint compositions over time.

McAuliffe and Van Devender (1998) and Long et al. (1990), in their respective studies of proxy environmental indicators, suggested that succulents *Opuntia* (flat-jointed cactus), *Carneigiea* (tree-like cactus) and *Ferocactus* (barrel-like cactus) increased in abundance on the peninsula approximately 6000 years ago. This inference coincides remarkably well

with the presence of media in the paints less than 6000 years old with stable isotopic values characteristic of C4-CAM plants. Equivalent values are not measurable in paintings older than that age, indicating an environment with more moisture during the early Holocene Period. Pre-Historic painters apparently made a deliberate choice and selected moist binding materials from the available vegetation. In particular, they switched to using the familiar C3 sources and the more prevalent C4-CAM succulent plants in the last six millennia. Through time, various succulent plants became available for use as binding media, and in the last 2000 years, C4-CAM plants with isotopic values near -5‰ were being used for the first time. This latest change reflects a xeric habitat and one which may have been even drier than today.

On the other hand, the binding medium may be blood or some other organic substance, as in other archaeological occurrences (Cattaneo et al. 1991). Hunters could have drained the blood from an animal they killed and then mixed it with pigments to make pasty paints. This highlights another avenue of research that was not undertaken as part of this project. The challenges posed in identifying the binding agents in the paints of the Gran Murals are therefore considerable. The reservations expressed by Downs and Lowenstein (1995) regarding the identification of ancient blood must be noted.

Our simplistic interpretation of the environmental changes over the last ten thousand years is based on the stable carbon isotopic values from perceived organic binders and an abbreviated list of succulent plants. Nevertheless, it offers scope for a much more detailed investigation. Such research in rock art studies has never been attempted, and our pioneering endeavours are undoubtedly insufficient and incomplete. However, it demonstrates at a basic level the potential of linking pre-Historic people to plants and rock paintings during changes in climate and vegetation.

Conclusions

These dating and isotopic analyses are the first steps in establishing a reliable absolute chronology for the rock art of the central sierras of Baja California. Our work complements other rock art studies in Mexico (Esquivel 1994; Viñas et al. 1987, 2001; Murray et al. 2003; Martinez et al. 2009; Viñas 2010; Ritter et al. 2011; Anzures et al. 2008, 2012).

The data collected in this project are not comprehensive, and the results and observations are not definitive because the rock art phenomenon involves great complexities. Nevertheless, these preliminary observations and conclusions are important because they will guide the designs of future archaeological research. Essential chronometric work remains an exciting prospect as new discoveries are likely, and investigations are needed into the binding agents' nature and possible organic contaminants. Hopefully, the results described here will stimulate other researchers to obtain appropriate funding and continue to investigate these unique paintings. Projects such as (a) unambiguously identifying plant-derived binders by DNA characterisation, (b) determining the existence of different organic components within paints, (c) separating and dating specific organic fractions, (d) analysing duplicate samples, (e) confirming age determinations in different laboratories, (f) taking multiple samples from large motifs, (g) investigating the presence of micro-organisms, and (h) studying the possibility of the contamination of samples used for dating.

The paintings may contain remnant DNA from the binding agents because the paints are rarely exposed and damaged by ultraviolet radiation. Unless micro-organisms and chemical degradation have occurred, the DNA of thick paints may indicate the source of suspected plant binders. If traces of polynucleotides can be collected and replicated, they could be matched with living plant material for which DNA extraction techniques are known (Mondragon-Jacobo et al. 2000). A combination of stable isotope and DNA analyses should reveal the identities of the mucilaginous binders. If not, then other analyses will be required to explain why the paints have a bulky consistency.

Interestingly, the Gran Murals are located in the four sierras of the central Baja Peninsula and are bounded to the north and south by mostly abstract motifs. A hypothesis that needs testing is whether different art traditions correspond to at least three populations who occupied distinct regional habitats over a long time. Conflicts between these cultural groups might be reflected in the depictions of arrows penetrating the human motifs, but the combination might also be metaphors for death. The three cultural groups may have painted abstract designs and Gran Murals as themes restricted to each population, with subtle variations in techniques and styles within the Gran Murals.

The geographic spread of the Gran Murals throughout the sierras indicates viable access to the rugged terrain and the isolated cuevas, but the painted sites are not necessarily linked to migratory routes across the peninsula. However, the distribution of sites and the selection and volume of ochre, manganese, anhydrite and gypsum indicate relatively easy access to pigment sources. Trade of these materials from outside the four sierras was unnecessary. The sources of pigments were another incomplete aspect of our investigation owing to the parsimonious state of our research budget.

Whereas many of the sites are in rugged and remote locations and could reflect deliberate selection for spiritual or religious purposes (Hyland 1997; Laylander 2005), the Gran Mural paintings are large, occasionally more than life-size, and were meant to be seen from a distance. Therefore, the prominent visual paintings, though possibly sacred, may not have been secret.

One of the most important conclusions revealed by this project is the consistency in the process and care in the repainting of motifs over a long period. This is demonstrated at the San Borjitas site, where different coloured paints were applied to motifs to repair obvious losses from natural spalling of the ceiling. Certain paintings were not only repaired once or twice but many times over several thousand years, as evidenced by the observation of unpainted scars affecting several paintings. New elements were also added to motifs, possibly to embellish or update oral traditions relating to the figures. Such attention to detail and preservation shows that the murals had great value and significance to the population. This care and importance was a consistent and continuous theme throughout the Holocene period as each generation maintained and carried on their painting tradition.

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