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Artists before Columbus: A multi-method characterization of the materials and practices of Caribbean cave art

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A B S T R A C T

This study represents the first positive identification of plant gum binding media in pre-Columbian art, and the first dates from indigenous cave art in the Caribbean. Mona Island reveals an extensive and well-preserved pre-Columbian and early colonial subterranean cultural landscape with dense concentrations of newly-discovered cave art in up to 30 caves. A multi-method approach to the research of pigments and binding media, charcoal, and cave sediments was used to elucidate the technologies, chronologies and processes of indigenous art and artists. Analyses included on-site use of a portable X-ray fluorescence (P-XRF) device to inform sample selection, scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDX) on paint and charcoal samples, polarized light microscopy (PLM) for material characterizations, and gas chromatography - mass spectrometry (GC-MS) and X-ray diffraction (XRD) for detailed chemical analysis of paint structures and composition. In addition direct dates of cave art using radiocarbon (C14) and Uranium-thorium (U-Th) dating methods are discussed. Results demonstrate multiple centuries of cave use during indigenous occupation and multiple phases and techniques of mark-making in dark zone locations within extensive cave systems. Visitors set out on pre-meditated journeys underground, making rock art using pigments from the cave floors, which they mixed into complex paints with the addition of plant gums from outside. This study is the first of its kind in the Caribbean providing insight into native paint recipes, material choices, and mark-making techniques. The methods have scope for widespread application and advance the integration of cave art research in archaeology.

1. Introduction: integrating cave art and archaeology

Rock art, or the *in situ* and motivated marking of natural places often outside domestic settings, presents challenges in terms of basic archaeological characterization (Bahn, 2010; Chippindale and Taçon, 1998; Whitley, 2001). There are two reasons for this. Firstly challenges in connecting rock art to mainstream areas of social life, especially chronologically, and secondly in terms of the hermeneutical challenge, or meaning. In this paper we approach cave art as a form of place-based communication technology and focus on the context of indigenous art practices as a first step in addressing how such practices functioned within indigenous societies (Gell, 1998; Houston, 2004; Robb, 2015).

1.1. Caribbean cave art

In a treatise on indigenous religion written at the time of Columbus' first voyages to the Americas, Friar Ramón Pané named specific caves in Hispaniola from where indigenous peoples believed the first humans emerged, and where the sun and the moon originated. Pané also makes the first reference to rock art in the New World, describing a painted cave ("toda pintada a su

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modo"), much revered, called *Iguaboina*, where objects with ancestral agency (*zemies*) resided (Pané, 1999).

Across the islands, Caribbean cave art is characterized by a diverse yet widely-shared corpus of iconographic themes (Dubelaar, 1986), which also appear on other media. Iconography is rarely representational (an exception is the "Borbón school" in the Dominican Republic, Atiles, 2009), and depicts schematized human-animal-plant figures, prominent facial imagery, often sprouting appendages, and a range of iterated forms with internal patterning. Scholarly interpretation either relies on Pané's account as a crib sheet to translate motifs (Abreu et al., 2011), or dismisses the same as a Eurocentric perspective at best relevant to northern Hispaniola at the end of the 15th century.

Around the circum-Caribbean, rock art, mortuary rituals, artefact deposition, and oral histories underline the importance and shared conceptualisations of subterranean worlds across Mesoamerica, the southeastern United States, and the Caribbean islands (Brady and Prufer, 2005; Morales and Quesenberry, 2005). Despite a long history of Caribbean rock art research (Dubelaar, 1986; Hayward et al., 2009; Pagán Perdomo, 1978), interpretive progress is challenged by a lack of secure chronological data, and scientific analysis of production techniques, processes, and materials. Cave art and its attendant activities float disconnectedly alongside other aspects of daily life, as is the case in many world regions (Bahn, 2010; Chippindale and Taçon, 1998). In this paper we use multi-method analyses of materials and techniques to consider how and when Native Americans on Mona Island created cave art during the c.7000 years since the human colonization of the Caribbean. This is a first stage in building better interpretive hypotheses about what cave art *does* as a form of landscape communication technology (Houston, 2004).

1.2. Cavescapes of Mona Island — a preserved subterranean landscape

Mona is a limestone island, seven by five miles, jutting out of the sea halfway between Puerto Rico and the Dominican Republic (Fig. 1). The island has over 200 caves most of which trend around the perimeter of the island at the geological contact between the lower Mona Dolomite and upper Lirio Limestone (Frank et al., 1998; Mylroie, 2012; Kambesis, 2011). The inter-island region of the northern Caribbean, which includes Mona and its larger neighbours, was a centre of pre-Columbian cultural complexity (Rouse, 1992; Veloz Maggiolo et al., 1991).

The *El Corazón del Caribe* research collaboration[1] is developing a heritage management plan for Mona Island building on historical, speleological, and archaeological research (Dávila, 2003; Samson et al., 2015; Vieten et al., 2016). A primary focus of the project is to explore, record and interpret the cultural landscape within less visited and un-surveyed cave systems. Since the start of the project, 70 cave systems have been surveyed, 30 of which contain evidence for indigenous exploration, resource extraction, and mark-making.

1.3. Cave art on Mona

Mona's cave art is made using both additive and extractive techniques (Fig. 2). The application of pigments through painting and drawing with tools or hands (additive) has been found in 5 caves (Fig. 2A and C). This includes charcoal drawings, as well as the use of wet paints. However, the majority of cave art on Mona Island is made by the removal of the soft, moonmilk -like surface of the cave walls (extractive). Extractive mark-making occurs in 22 caves by dragging fingers (finger-fluting) and finger-sized tools through the soft corrosion deposits on cave surfaces leaving incisions between 1 and 10 mm deep (Fig. 2B and D). There is some cross-media similarity in iconography, execution, and location between additive and extractive techniques. Designs include clusters of figurative-geometric motifs, facial iconography, and animal/human bodies, similar to those found in caves on either side of the Mona Passage (López Belando, 2003; Roe, 2009). Cave art is usually located in areas devoid of natural light (dark zones), and closely related to water sources, whether seasonal drip pools, or underwater lakes (Lace, 2012; Samson et al., 2015). A key difference is that extractive designs are more diverse and extensive, with individual motifs ranging from a few centimetres to large space-filling meanders and schemes occupying entire surfaces covering tens of square metres. In the same chambers the systematic removal of the cave wall crust by horizontal and vertical scraping in continuous patches with the fingers/finger-sized tools (Fig. 2B) is interspersed with and sometimes inseparable from figurative and motif making extraction. The ubiquity of this practice, as a form of indigenous mining to extract calcium carbonate as well as the creation of complex iconography, brings into question the ontological status of rock art and blurs functional/ritual boundaries.

Mona's indigenous cave art, especially the pictography, has been recognised in previous studies (Dávila, 2003; Santana, 1973), however the majority, chiefly extractive activity, has remained hidden in plain sight due to its lack of precedent in Caribbean archaeology, its darkzone location, and its often apparent "fresh" appearance casting doubt on its authenticity as an indigenous practice.

2. Materials and methods

2.1. Sampling strategy

Five seasons of archaeological fieldwork were conducted to address where, when, how, and why native people made rock art and to integrate cave activities within the wider cultural landscapes of the Caribbean. Archaeological surveys were conducted to identify a representative range of cave art from different locations around the island. Visual inspection of mark-making and overlapping sequences, combined with pre-sampling screening with a P-XRF, assisted basic characterization and sample selection. Systematic and detailed photographic and laser scanning recording of modified cave chambers located on high-resolution speleological maps provided spatial contexts for the sampling. Samples of charcoal were collected from painted motifs for species identifications and radiocarbon dating; paints from cave art to understand pigment composition and preparation techniques; sediments from caves and the surface of the island for geochemical characterization and comparison to cave art paints; and flowstone samples from on top of cave art for U-Th dating (Table 1).

2.2. P-XRF data for pigment analysis

A Bruker Tracer III portable X-Ray Fluorescence Spectrometer was used in the field by Wrapson to provide *in situ* information and a basic characterization of the elemental composition of sediments, pigments, and cave features. The XRF analysis was part of a pre-sampling strategy to minimise destructive collection and to inform sample retrieval for more detailed, quantitative analysis (Section 2.2.2). Sixty assays were made overall including from surface locations with potential sources of pigments, such as

[1] Between the Department of Natural and Environmental Resources of Puerto Rico, the Institute of Puerto Rican Culture, the Centre for Advanced Studies of Puerto Rico and the Caribbean, the University of Puerto Rico, The British Museum, and the Centre for Historical Archaeology at the University of Leicester.

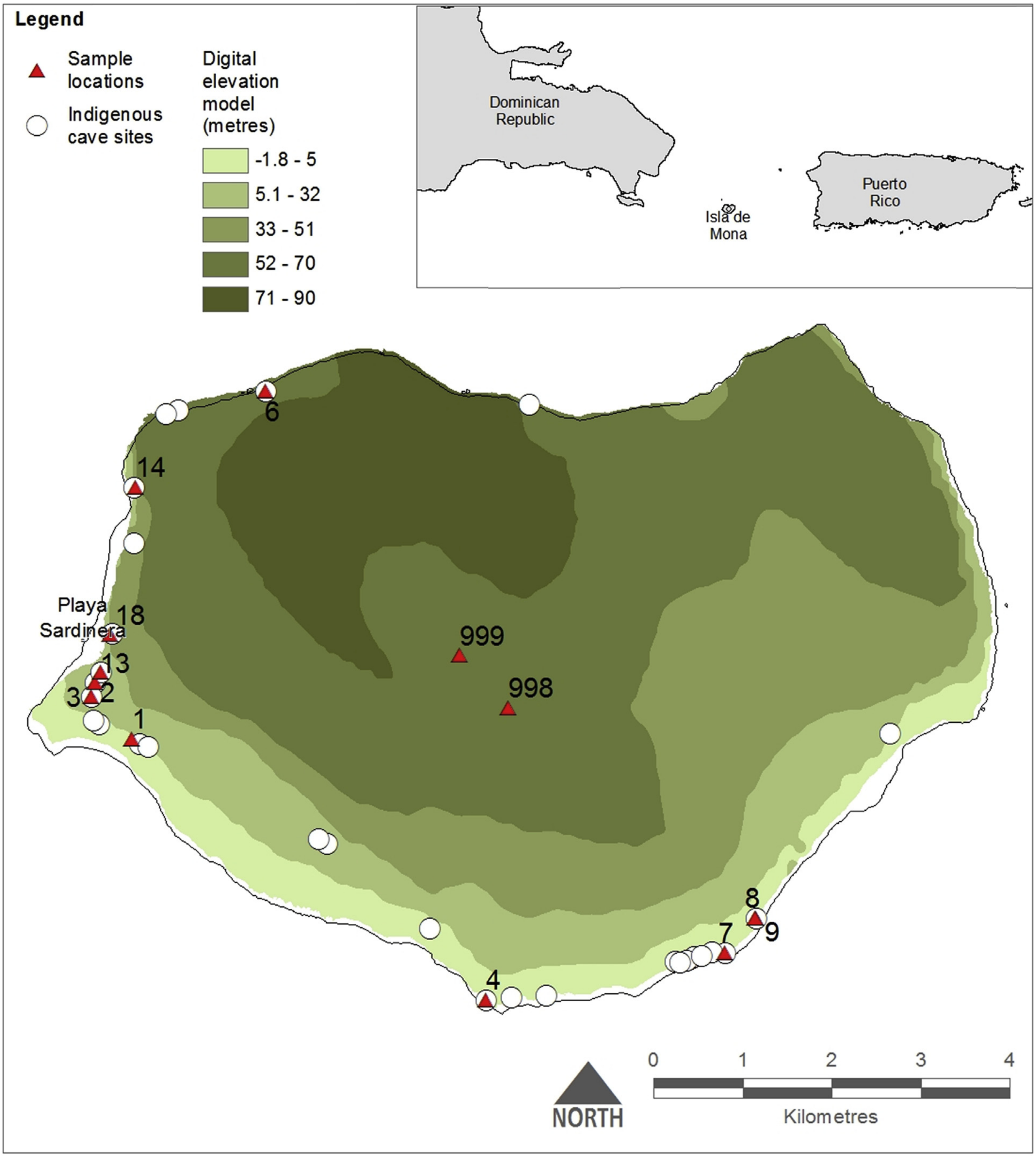


Fig. 1. Map of Mona island. Sample location numbers refer to Table 1. The Cave locations provided are only accurate to within 1 km in accordance with the Mona heritage management plan.

sediment traps in karstic depressions (*bajuras*), and from floors and pictographs from seven caves (see Table 1). Tests were typically undertaken at 25kV/35 µA without the use of a filter to facilitate broad-brush characterisations of fairly low molecular weight materials. Assays were initially 1 min in length, but this was reduced to 45 s when the spectra were observed to change little over time.

2.2.1. *Microscopic analysis of paint components and cross-sections*

Twenty nine samples (Table 1) were prepared and then examined in the Hamilton Kerr Institute by Wrapson using polarized light microscopy (PLM) to examine paint properties. Seventeen of these samples were naturally occurring sediments, eleven were taken from pictographs, and one from 19th century historical paint layers. Sample sizes were kept to a minimum and were typically no more than 2 mm^3 unless also scheduled for C14 analysis. All layers were sampled, ground in methyl ethyl ketone, then mounted on a slide beneath a cover slip and set in Meltmount™ resin. The slides were then examined using a Leitz Ortholux II polarizing microscope at 200 X magnification, and where possible the components identified.

The material used for paint cross-sections was taken from the same sample fragments as those mounted as dispersions. Eleven

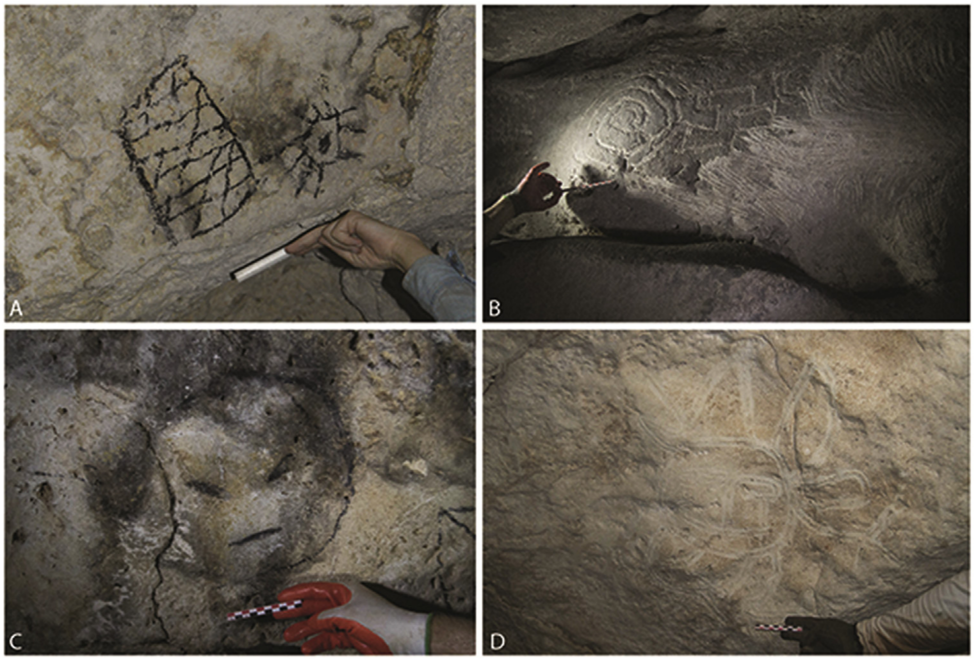


Fig. 2. Additive and extractive designs from the dark zones of three caves on Mona. A) charcoal drawn motifs; B) finger-fluted motifs and area of systematic extraction (right hand side); C) charcoal drawn face; D) finger-fluted face with limbs and appendages.

cross-section samples taken from pictographs were set in polyester resin cubes and reflected light microscopy was carried out on a Zeiss Axioskop™ microscope. Observations about layer structure and material content were made at 200 and 500 X magnification in normal light and bright field, and UV fluorescence was observed and photographically recorded. The main additional benefit of stereomicroscopy on cross-sections was the examination of stratigraphy on these samples, allowing the assessment of paint layering and/or multi-phase painting.

2.2.2. SEM/EDX

SEM/EDX analysis was undertaken by Wrapson to provide comparative quantitative data on the elemental composition of cave floor sediments, sediments from outside the caves, and cave wall paints to complement analysis from the P-XRF data and microscopic inspection. SEM/EDX analysis was undertaken using an Oxford Instruments Silicon Lithium EDX spectrometer with INCA software. Fourteen samples were examined (Table 1). Six of these were reference samples from cave floors, walls, and red and yellow ochre-rich soils from the top of the island. Eight were from pictographs.

2.3. Charcoal identification

Charcoal from three painted designs in two caves (Table 1) was analysed by Cartwright in the laboratories of the British Museum, Department of Scientific Research to examine species selection and to support dating assays. This was done using an Hitachi S-3700N variable pressure scanning electron microscope (VP SEM). Because of the three-dimensional nature of wood anatomy, each piece of charcoal, irrespective of size, was fractured manually to show a transverse section (TS), radial longitudinal section (RLS) and tangential longitudinal section (TLS) for examination (see Cartwright, 2013, 2015). Each TS, RLS and TLS charcoal sample was then mounted on an aluminium SEM stub and examined uncoated in the VP SEM. The backscatter detector was used at 20 or 15 kV, with an average working distance of 25 mm, at magnifications ranging from × 10 to × 600 and with a partially evacuated (40 Pa) chamber. Charcoal fragments that were particularly small or in poor condition were mounted using Leit-C Plast carbon cement (which is a proprietary brand of conductive material with low outgassing properties). Using the observed cellular features, comparisons were made with in-house reference collection specimens of wood and charcoal as well as computerised anatomical feature databases and checklists.

2.4. Binding medium analysis

Binding medium analysis was conducted by Stacey in the laboratories of the British Museum, Department of Scientific Research to determine whether the raw colorants were mixed with other ingredients to increase paint workability and its ability to stick to surfaces. Six paints were analysed from 4 caves (Table 1) including a historic paint sample, and five samples from painted motifs selected on the basis of variety in paint colour and consistency. The small size of the paint samples meant that only a few could be subject to multiple analytical methods targeting different types of organic binder. Analysis was targeted towards the detection and identification of carbohydrates (gum binders), amino acids (proteinaceous glues) and lipid/resin binders (detailed in Table 1).

2.4.1. Sugars (monosaccharides)

Samples were hydrolysed by adding 100 μl of 0.5 M methanolic HCl and heating at 80 °C for 18 h. They were dried under nitrogen and derivatised using 100 μl of Sigma-Sil A (1:3:9 ratio of trimethylchlorosilane (TMCS), hexamethyldisilazane (HMDS) and pyridine) and heating at 80 °C for 1 h. This procedure is based on the method described by Bleton et al. (1996) for analysis of plant gums.

2.4.2. Protein (amino acids)

Samples were hydrolysed with 100 μl of 6N HCl, heated overnight at 105 °C and then dried under nitrogen. The samples were dried again after agitation with 100 μl of deionised water and 100 μl of denatured ethanol. Prior to analysis, the samples were derivatised with *N*-(tert-butyldimethylsilyl)-*N*-methyl-trifluoroacetamide (MTBSTFA) + 1% tert-butyldimethylsilyl chloride (TBDMCS).

2.4.3. Lipids (waxes/fats/resins)

Samples were extracted with 100 μl of dichloromethane, assisted by gentle heating (45 °C) and ultra-sonication. After evaporation of the solvent under a stream of nitrogen, samples were derivatised with 50 μl bis(trimethylsilyl)trifluoroacetamide (BSTFA) + 1% (trimethylchlorosilane) TMCS.

2.4.4. GC-MS analysis

Samples (1 μl) were analysed using an Agilent 6890N GC fitted with an Agilent HP5-MS, 30 m × 0.25 mm, 0.25 μm film thickness column with 1 m × 0.53 mm retention gap and coupled to an Agilent 5973N MSD (sugars and amino acids) or an Agilent 6890N GC fitted with a SGE HT-5 12 m × 0.1 mm, 0.1 μm film thickness with 1 m × 0.53 μm retention gap and with an Agilent 5975C MS detector (lipids). The carrier gas was helium with a constant flow of 1.5 ml/min and samples were injected in splitless mode (purge time 0.8min) at 10psi and 250 °C (sugars) or 300 °C (amino acids). Lipid samples were injected on-column at 50 °C. Oven temperatures were programmed as follows: sugars - 40 °C to 130 °C at 9° C/min, then to 290 °C at 2° C/min final temperature hold 10 min; amino acids - 300 °C at 20 °C/min, after a 1 min isothermal hold at 80 °C with the final temperature held for 3 min; lipids - after a 1 min isothermal hold at 35 °C to 340 °C at 10° C/min. With the final temperature held for 20 min. The MS interface was held at 280 °C (sugars) and 300 °C (amino acids and lipids). In all cases the source temperature was 230 °C with acquisition in scan mode (29–650 amu/sec) after a solvent delay of 5 min. Mass spectral data were interpreted manually with the aid of the NIST/EPA/NIH Mass Spectral Library version 2.0 and by comparison with published data and reference standards.

2.5. Dating

2.5.1. Radiocarbon

In order to directly date the presumed indigenous cave art, two charcoal samples were collected from cave art pigments from caves on opposite sides of the island. Only two samples were taken in order to test the efficacy of dating very small charcoal pieces from rock art. These were charcoal flecks embedded within the paint matrix taken from areas of existing motif deterioration (Fig. 3A). The same samples were submitted for species identification, binding medium analysis, and compositional and paint structure analysis (Table 1).

2.5.2. Uranium-thorium

Extractive cave art, which accounts for c.95% of cave art on Mona cannot be dated using radiocarbon. However, calcite accretions, or flowstones, which form over the top of cave art are amenable to U-Th dating, a technique that is increasingly used in rock art research (Pike et al., 2016). U-Th dating provides a *terminus ante que*, or minimum age for the underlying cave art. Samples of white calcite accreted directly over finger-fluting were taken from four locations in three caves (Fig. 3D, Table 1). For each sampling location two adjacent samples of calcite were taken, weighing between 0.3 and 1.9 g. For each sample the whole cross section was taken, including the contact layer with the underlying archaeology.

The calcite samples were analysed by Sahy at the Natural Environment Research Council Isotope Geosciences Laboratory (NIGL), British Geological Survey, following the U-Th dating protocol outlined in Crémière et al. (2016). Subsamples for U-Th dating consisted of calcite adjacent to the contact between the accretions and the underlying cave art (Fig. 4). Samples were mechanically cleaned to avoid contamination with older carbonate from the cave walls and were spiked with an in-house $^{229}Th - ^{236}U$ isotopic tracer. Isotope ratio measurements on chemically purified (Edwards et al., 1987) U and Th fractions were carried out using a Thermo Neptune Plus multi-collector inductively coupled plasma mass spectrometer (ICP-MS).

Fig. 3. Sampling A) charcoal from cave paints; B) indigenous paint samples (note the finger marks in this paint "palette", sample 130); C) surface sediments, red ochre from the Vereda del Centro, sample location 998; D) calcite accretions on top of cave art. Note the sampled area which is a whiter patch ca. 3 m above the end of the 10 cm scale. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

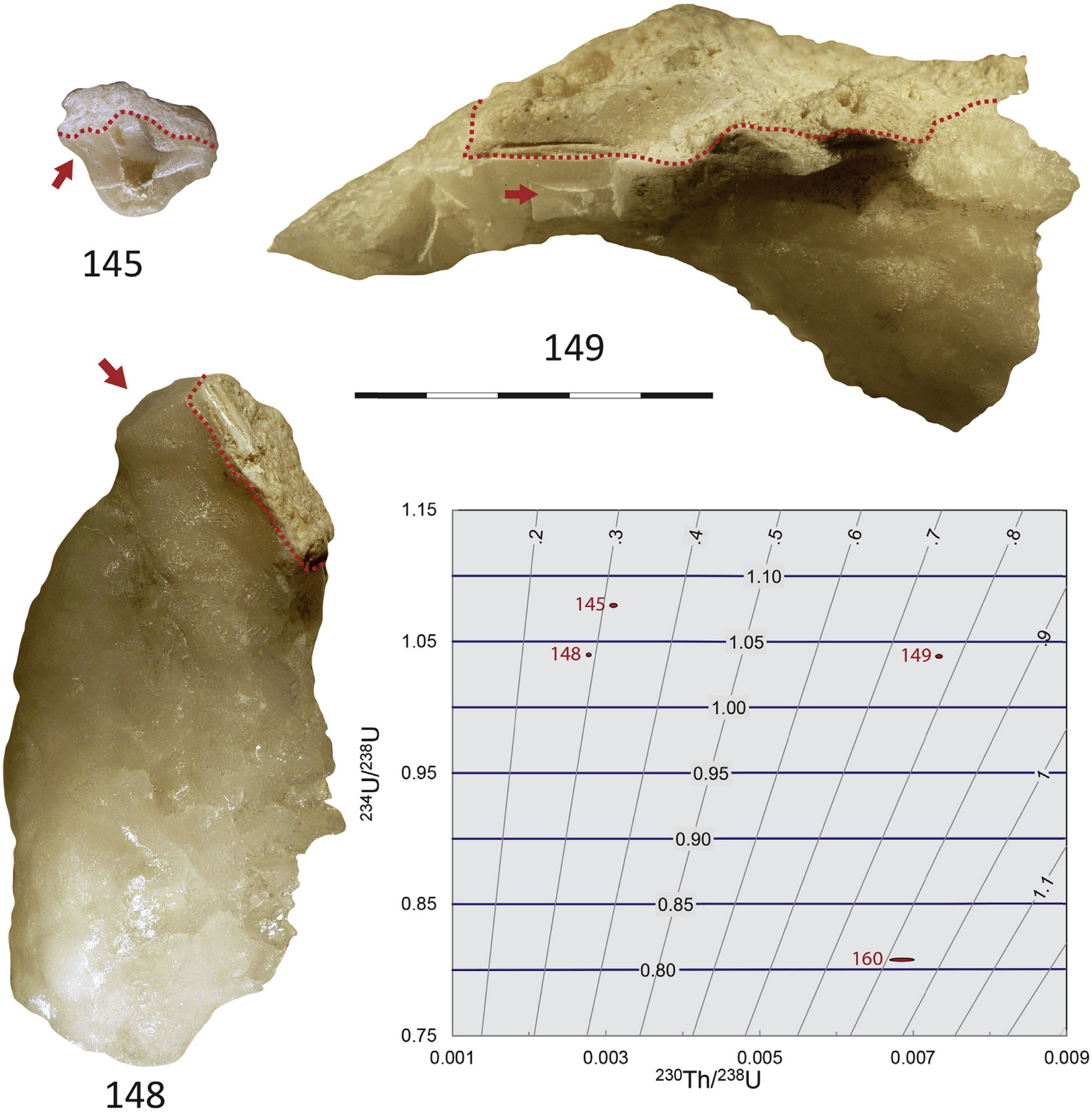


Fig. 4. Samples selected for U-Th dating. Red dashed lines show the contact between cave walls/moonmilk (above the line) and calcite accretions (below the line). Plot shows U-Th evolution diagram where blue horizontal lines trace the sample's [234U/238U] activity ratio over time, and grey oblique lines are theoretical isochrons labelled in kyr. Uncertainty ellipses are plotted at the 2σ level. Note that samples 148 and 149, which were collected from the same cave, have similar initial [234U/238U] values. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results

3.1. In situ P-XRF, visual and microscopic observation of cave art

Caves with greater colour contrast between the surface corrosion and the layer underneath attracted some of the larger and more elaborate designs (Caves 7, 13). These contrasts were demonstrated chemically by P-XRF analysis in 3 caves (Caves 3, 8, 13) where the browner wall crusts contained additional iron and manganese in comparison to the lighter colour of the pure calcium carbonate of the extractive designs.

P-XRF combined with visual examination indicated the repeated use of cave floor deposits in additive cave art. The dominant constituent of floor deposits appeared to be phosphorite, derived from mineralized bat or bird guano (Briggs, 1974; Kaye and Altschuler, 1959), later confirmed through SEM/EDX (Section 3.2). Floor deposits typically contained iron, and pigments including reddish ochres, yellow earths, and some manganese-containing brown earth pigments as minor components in admixtures.

At Cave 14, charcoal was observed both on the floor of the cave and mixed into the paintings. The mixing of charcoal and pigment is not thorough and appears incidental in some cases, whereas in others it forms a clear and deliberate paint film. Charcoal drawings and paints were, at times, applied in sequential episodes. Paints were observed in a deliberate layer structure in Cave 14 (Fig. 5D and E) and in one example in Cave 6. In some designs in Cave 6 the charcoal was applied first, before a phosphorite-based layer, in a process either indicative of deliberate underdrawing or the

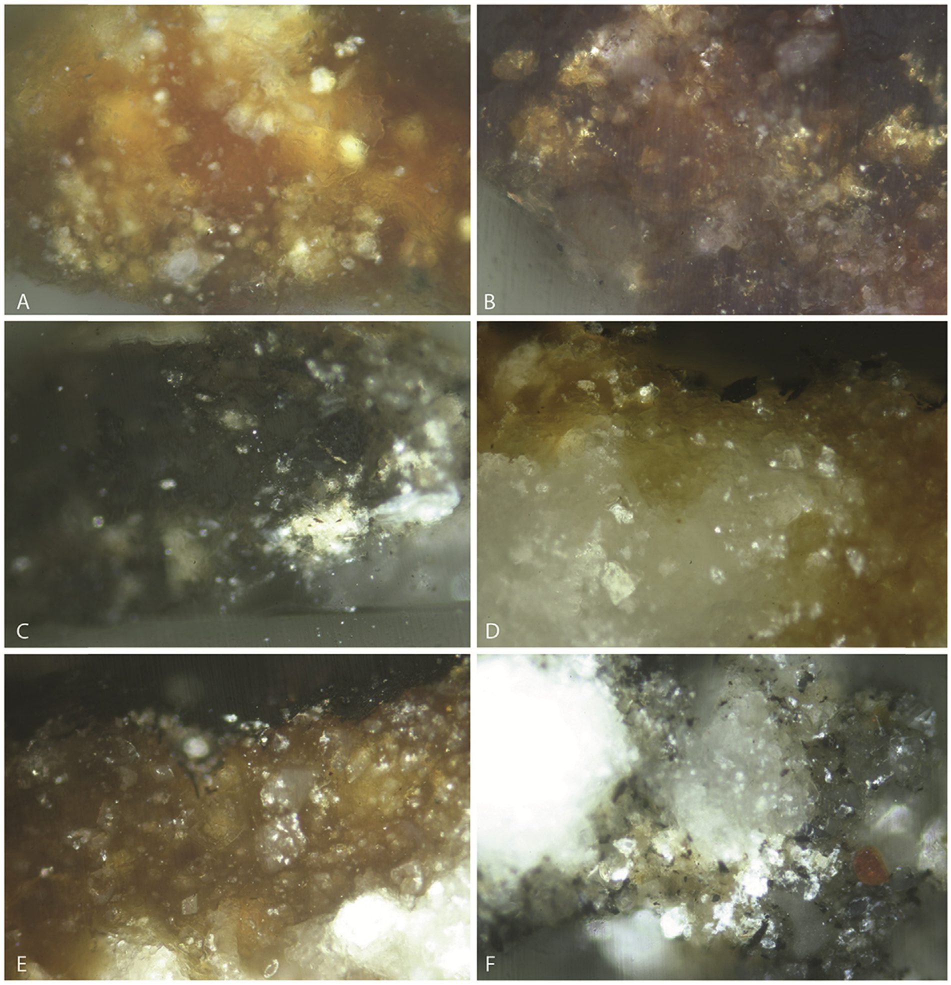


Fig. 5. Paint sample cross-sections, ×200 magnification. A) Sample 130, Cave 6. Paint from "palette", lemony yellow guano and calcite/dolomite (see Fig. 3B); B) Sample 126, Cave 8. Sample taken from pictograph, guano some plant-derived char black (identified as *Bursera simaruba*, Section 3.3), some calcite/dolomite; C) Sample 128, Cave 8. Sample taken from pictograph, a plant-derived char black (identified as *Bursera simaruba*, Section 3.3) and calcite/dolomite; D) Sample 137A, Cave 14. From pictograph. Note layer structure: bottom calcite/dolomite, middle yellowish guano, top plant-based char black; E) Sample 137B, Cave 14. Separate portion of same paint sample, also note the clear layer structure; F) Sample 138, Cave 14. Sample taken from pictograph, the layers are soft and have become mixed, slightly brown guano, with occasional ochre particle, plus calcite/dolomite and plant-based char black. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

retouching of a pre-existing image using a different colour. Cross-sections of paint samples also clearly demonstrate the softness of cave walls, for example in Cave 14 where it is smeared and blended in with the charcoal black (Fig. 5F). This contrasts with the harder, drier walls of Cave 6, and may account for the use of other paint ingredients in this instance (Section 3.3.2).

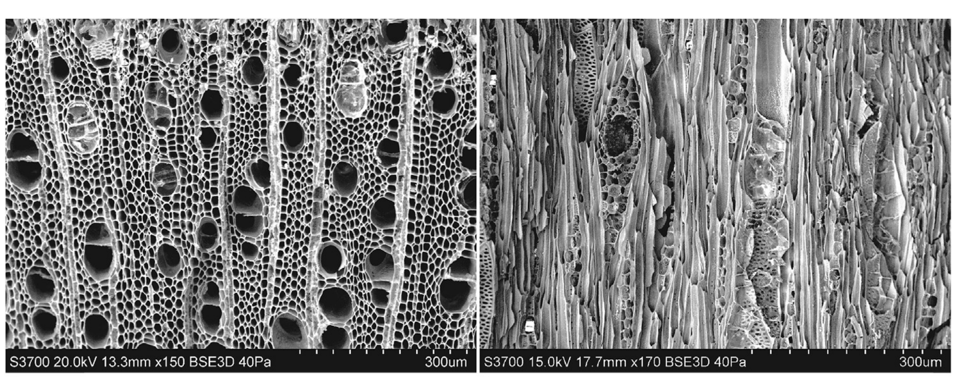
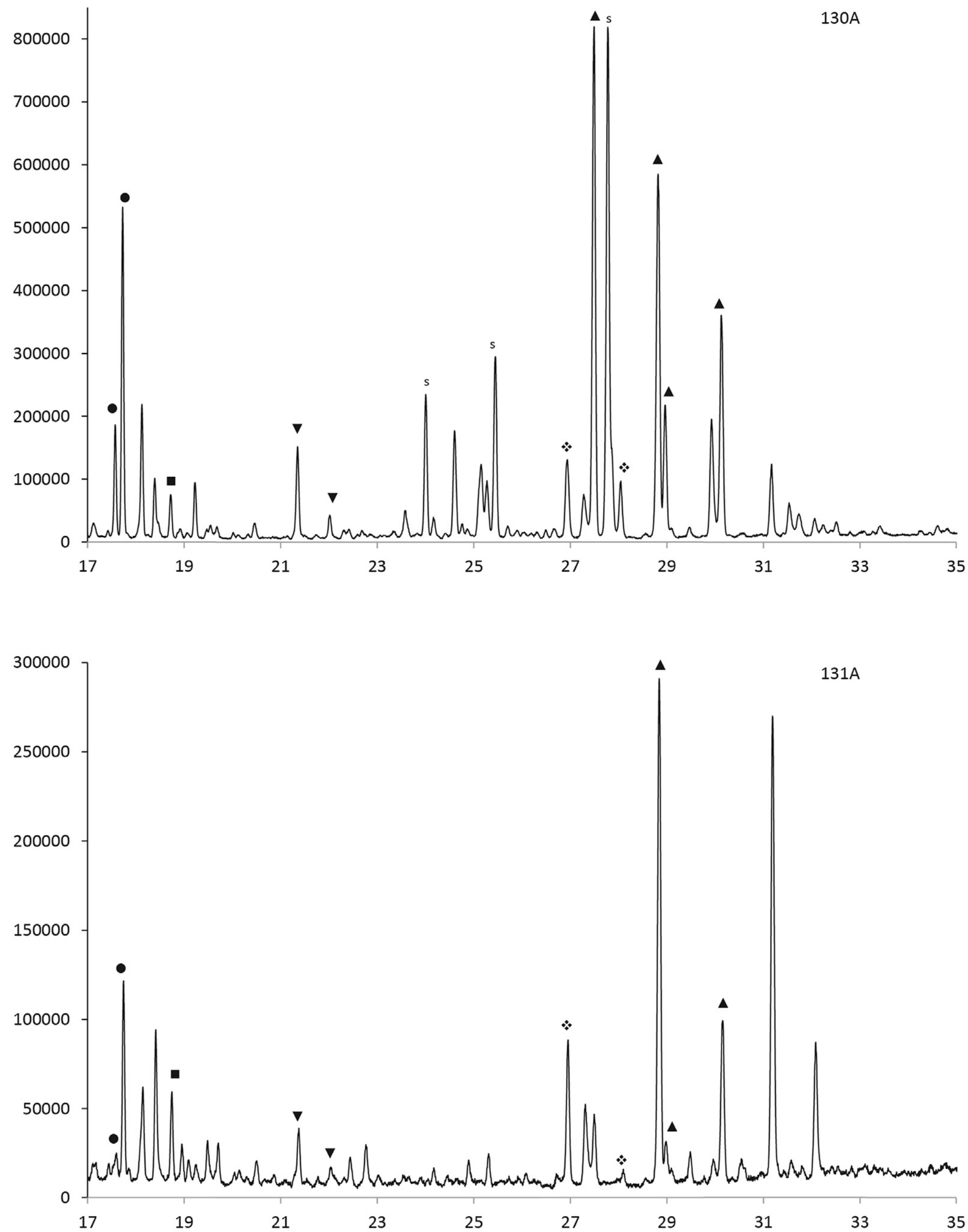


Fig. 6. A) SEM image of a transverse section of *Bursera simaruba* charcoal from Mona; B) SEM image of a tangential longitudinal section of *Bursera simaruba* charcoal from Mona. Images: Caroline Cartwright © The Trustees of The British Museum.



Sample ID	Arabinose	Rhamnose	Galactose	Mannose	Xylose
Peak label	●	■	▲	❖	▼
123			tr	tr	tr
126	tr	tr	tr		tr
128	◈	◈	tr	◈	◈
130	◈◈	◈	◈◈	◈	◈
131	◈	◈	◈◈	◈	◈
138	◈	◈	◈	◈	◈

Fig. 7. Partial (17–35 min) total ion chromatograms showing monosaccharide compounds detected in samples 130A (palette) and 131A (pictograph). Peak labels: ●-arabinose; ■ - rhamnose; ▲ - galactose; ❖ - mannose; ▼ - xylose; s – unidentified sugar compounds. Table indicates the relative abundance of monosaccharide compounds identified in the paint samples.◈◈ - more abundant;◈ - less abundant; tr – trace.

Also present in all paint samples were particles from the cave walls. Typically this was a very pure white calcium carbonate with evident marine origin. This contrasted with samples from Caves 6 and 14 which had a different cave wall type indicative of dolomite. This distinction may be significant in terms of art technique selection, and choice of ingredients, as well potentially account for differential preservation of cave art.

3.2. Inorganic paint constituents: SEM/EDX

SEM/EDX confirmed what was suspected from XRF analysis; that phosphorite deposits from the cave floors are the key inorganic constituent of pictograph paints. Moreover SEM/EDX confirmed compositional similarity between the materials found on cave floors and in pictographs on the cave walls. For example, samples from paintings and the cave floor in Cave 14 were predominantly calcium and phosphorous containing, but also contained fluorine, probably in the form of collophane, cryptocrystalline apatite, as well as traces of iron. Samples from the floor and walls of Cave 8 were compositionally similar, but additionally contained sodium. In Cave 6, samples from paintings contained significantly more chlorine (between two and twenty times as much) than was found in other samples, though again, calcium and phosphorous dominate.

A red ochre soil sample from the top of the island was composed elementally of alumina, silica, iron magnesium and titanium, containing comparatively little phosphorous in contrast with all paint samples which contained thirty times the quantity of phosphorous. This is a quantitative demonstration that cave floors are made up largely of phosphorite with some ochres, and that so too are the paintings, some with additional charcoal.

3.3. Paint additives

3.3.1. Charcoal identification in cave paints

In all three cases the charcoal from cave paints was identified as *Bursera simaruba*, almácigo rojo/indio desnudo (Fig. 6). This is an indicator species for dry tropical forest and native to the region (Newsom, 2010). *Bursera* has been identified at archaeological sites in Puerto Rico (Newsom, 2014). It makes a good torchwood as it is fine-textured and resinous. It is likely that the charcoal in the paints was derived from burnt torches used to illuminate the cave, as a secondary, rather than a primary ingredient.

3.3.2. Organic binding media

No compounds above normal background contamination levels could be detected by the amino acid and lipid analyses. This implies that animal-derived binders such as egg, and blood, or plant-derived oils and resins were not used in the paints sampled here, or that the sample sizes were not conducive to their detection by the analytical methods used.

Sugars were observed in all of the paint samples, but in most cases the range of monosaccharide compounds detected was limited and/or present at low or trace levels which may be background levels (Fig. 7). An exception is sample 130, a yellow paint from a pictograph in Cave 6, where the larger sample size allowed detection of a range of sugars including galactose, arabinose and mannose in an abundance distribution consistent with a plant gum origin (see Figs. 7, 3B and 5A). Importantly and notwithstanding the sample size, sample 131, a brown paint from another pictograph from an adjacent chamber, exhibits a similar composition (Fig. 7).

Qualitative analysis of sugars (and uronic acids) by the method used here can to some extent distinguish between different plant gums on the basis of occurrence and/or relative abundance of individual sugar components (Bleton et al., 1996). Nevertheless, caution is vital when interpreting archaeological material as aged gums can display considerable variation and there is evidence to suggest that the inorganic pigments present influence the survival of particular sugar species both during ageing (Daniels et al., 2004) and analysis (Lluveras-Tenorio et al., 2012). Future work will compare archaeological material to reference species from Mona. However, the presence of plant gums in more than one paint sample is a demonstration that binding agents were deliberately combined with inorganic ingredients to form complex paints.

3.4. Dating

3.4.1. Radiocarbon

Two direct dates were obtained from charcoal embedded in the paint matrix of pictographs. These dates support iconographic and archaeological evidence that cave-painting occurred within the timeframe of native occupation of the island. Sample 128/OxA-31348 (Cave 8) dates to cal 1302 CE–1413 (2σ), painted in the late pre-Columbian period, and sample 134/OxA-31199 (Cave 6) to cal 1478 CE–1637 (2σ), painted prior to European arrival or during the first century of Spanish colonization (Cooper et al., 2016) (Fig. 8). In both cases the charcoal in the paint is from *Bursera simaruba* (Section 3.3.1), from young, twiggy pieces less than 10 years old, representing the age of the branches at time of cutting.

3.4.2. Uranium-Thorium

U-Th assays performed on calcite accretions over the top of extractive designs, not dateable through conventional C14 methods, provide a *terminus ante quem*, or youngest possible date for the underlying activities. Two dates from Cave 2 are from the same panel, however it is the earlier which is closest to the production of the underlying cave art. Dates from Caves 2 and 18 are cal 1244 CE ± 8, and cal 1088 CE ± 18 respectively (2σ). This means the cave art from both caves was made in late pre-Columbian times. U-Th dates are consistent with the C14 dates for painted cave art. A fourth date of cal 1703 CE ± 4 from Cave 3 indicates the cave art was at least made in or before the 18th century. It should be noted that analytical U-Th age uncertainties (±4–18 years, see

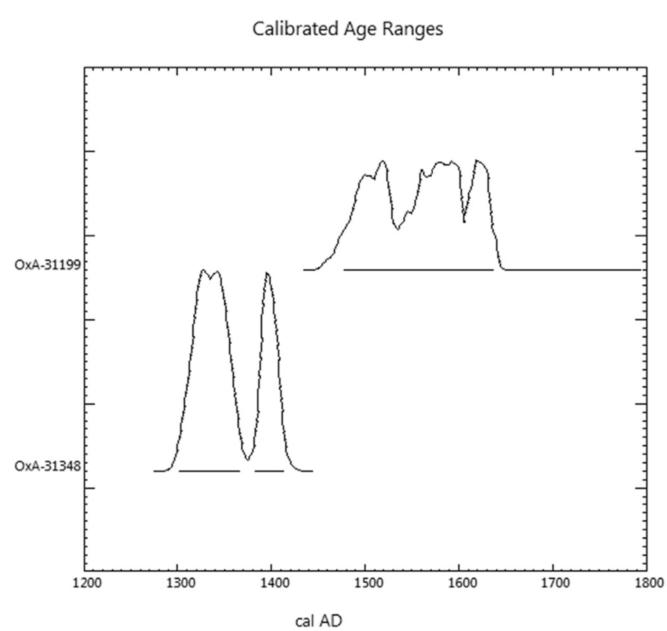


Fig. 8. Probability plot for C14 dating results from charcoal fragments embedded in paint matrix from pictographs, Caves 8 and 6.

Table 2) are likely to underestimate the true age uncertainty given the volume of calcite analysed. A more realistic age uncertainty estimate would be in the order of ±50–100 years, equivalent to a growth rate of 0.05–0.025 mm/year for a 5 mm thick calcite sample.

4. Discussion

Dates obtained from cave art demonstrate indigenous authorship and support a horizon of cave use in the late pre-Columbian period. Both radiocarbon and uranium-thorium dates are consistent with each other and with dates from the 13th to 15th centuries obtained from other archaeological materials from caves all around the island (Samson et al., 2015; in prep.). Dates from caves overlap with those from the indigenous village site at Sardinera (Dávila, 2003) suggesting its use as a base for cave exploration. This period of intensification of cave activity in the 13th to 15th centuries is consistent with the wider Late Ceramic Age Taino cultural development in Puerto Rico and Hispaniola on either side of the Mona Passage at this time. These activities in the caves did not stop with the arrival of Europeans, rather cave visitation continued into the 16th century (Cooper et al., 2016; Samson et al., 2015). Future work will build on the opportunities to integrate multiple chronometric methods for refining rock art chronologies.

Historic documents, ethnographic analogy, and visual appearance have suggested a variety of animal, vegetable and mineral based colorants and binders for Caribbean pictography (Greer, 2001; Hayward et al., 2009:119; Haviser, 2009:163; Vega, 1976:200). There has been very little scientific analysis conducted on the pigments used in rock art in the Caribbean or surrounding mainland regions (Li et al., 2012: Roosevelt et al., 1996; Sepúlveda et al., 2012; Simek et al., 2010). In archaeological contexts, ground red hematite and drops of tree resin were found at the Savonet site in Curacao (Haviser, 2009), and Veloz Maggiolo, anecdotally as the analysis of this finding is unpublished, reported the use of iron oxide and gypsum from pictographs in Cueva de las Maravillas, in the Dominican Republic.

Our research shows that indigenous populations on Mona were making paints from phosphorites, charcoal, and ochres from cave floors to apply to the cave walls, sometimes mixing them with plant gums which they brought into the caves. In addition charcoal was brought into the caves as torchwood and both incidentally and deliberately mixed with paints. Multiple phases of painting, whether steps in a related sequence, or retouching, indicate specific chambers were revisited. The elaborate phasing of pictography has been noted elsewhere in the Caribbean (Haviser, 2007; Roe, 2009: 222).

Particular to Mona is extraction on soft surfaces which is very different from conventional pecking and grinding of hard rock surfaces. Isolated exploitation of a soft substrate has been reported in Cuba, the Dominican Republic, and the southeast United States (DuVall, 2010; Gutiérrez Clavache et al., 2013; Simek and Cressler, 2005), but its abundance on Mona is unprecedented and suggests extraction was both a form of communication technology and a form of pre-Columbian calcium carbonate mining (Fig. 2B).

Despite the availability of high quality, strongly-coloured red ochres (Fig. 3C), neither intensity nor variety of colour appears to be the driver for choosing pigments. The inorganic stuff of painting, essentially phosphorite, came from within the caves. Added to this were plant-derived charcoal blacks, polysaccharide gums, and a red plant dyestuff, seen in several designs in Cave 6 and as yet unidentified. The incorporation of *Bursera simaruba* into mixed paints on Mona may be related to its use as a torchwood, or for other purposes. Several species in the Burseraceae family are utilized for copal, an aromatic resin which has use as glue and incense (Stacey et al., 2006). Charcoal particles identified from cave paintings in Nicaragua (Baker and Armitage, 2013; Cartwright, 2013; Li et al., 2012) also come from tree species that were a source of resin, for example *Hymenaea courbaril,* guapinol or jatobá tree (Fabaceae family) and *Pinus* sp., pine (Pinaceae family).

The finding of a gum binding medium is particularly important for the interpretation of the paints because, unlike the pigments opportunistically sourced from within the caves, the gum binder was brought in by the painters. To date, most of the research on characterization of gum binding media has focussed on Western art materials and Old World gum sources (Chiantore et al., 2009; Mills and White, 1994; Vallance et al., 1998). The comparative compositions of exudates from native Caribbean sources have not received the same attention although data can be found for some relevant genera (e.g. *Prosopis* sp., *Anacardium* sp. (Lluveras-Tenorio et al., 2012); *Anadenanthera* sp. (Delgobo et al., 1998); *Opuntia* sp. (Ribeiro et al., 2010).).

5. Conclusions

An important step in understanding rock art anywhere in the world is the reconstruction of the social and cultural context of its production and use. To this end the excellent preservation on Mona has shed light on a widespread practice allowing for the first time to date Caribbean cave art and reconstruct native paint recipes and techniques. A progression of mutually informed analytical steps from field observation, sample selection, through to analyses involving the application of multiple methods to individual samples is a parsimonious and conservation-minded approach which can be applied to rock art all over the world.

Indigenous artists on Mona combined expedient and premeditated practices in visits to the dark zones of caves, making designs by applying prepared mixtures, or scraping surfaces off to exploit colour contrast and harvest wall material. In extractive cave art the visual contrast between a darker background against lighter designs is reflected chemically in P-XRF signatures. For additive cave art, a sequence of visual inspection, P-XRF, and SEM/EDX analyses demonstrated that phosphorite (derived from mineralized guano), naturally occurring ochres from cave floors, and charcoal are the key constituents of paints. This preference for using materials found underground despite the presence of more vibrant colorants outside, indicates that engaging with speleo-substances, through scraping and painting, was both a means and an end.[2] Elaborating on this, we should not mistake the cave-centred practices for expediency as GC-MS and XRD revealed the deliberate addition of plant gums as binding media to make complex paints. This is evidence for the assemblage of a pre-prepared art-kit, and also the first evidence for pre-Columbian paint media from the Caribbean. The retouching and overpainting of some motifs, first a charcoal layer and second a paint layer indicates that cave art practices were temporally layered, whether in stages or episodes. The gathering of rock art in predominantly dark zone locations and the clustering of different media and iconographies references communities of practice formed through motivated visits to particular places.

The diversity and ubiquity of cave art in well-preserved environments like Mona is a physical manifestation of the cultural importance of subterranean places for Caribbean societies pre- and post-Columbus. Indigenous artists used their knowledge of the affordances of over 200 chemically and morphologically distinct

[2] As a counterpart to this, cave materials such as speleothems and soda straws have turned up in archaeological deposits in terrestrial contexts such as Sardinera, showing that people also brought cave speleothems back from their underground visits.

Table 1
Overview of samples per analytical technique. Sample location numbers correspond to map in Fig. 1.

Sample location (see map)	Location type	Sample_ID	pXRF	PLM	Reflected light microscopy (X-section)	SEM/EDX	Binding medium analysis			Wood species	C14	U-Th	Description
							sugars	amino acids	lipids				
Archaeological samples													
1	Cave	123	X	X	X		X	X					C19th historic paint sample
8	Cave	126	X	X	X	X	X	X		X			Pictograph, paint and charcoal
8	Cave	128	X	X	X	X	X	X		X	X		Pictograph, paint and charcoal
6	Cave	130	X	X	X	X	X	X	X				Yellow paint from "palette"
6	Cave	131	X	X	X	X	X	X					Brown paint from pictograph
6	Cave	132	X	X	X								Brown paint from pictograph
6	Cave	134	X	X						X	X		Pictograph, paint and charcoal
14	Cave	137	X	X	X	X							Brown paint from pictograph
14	Cave	138	X	X	X	X	X	X	X				Black paint from pictograph
6	Cave	167		X	X	X							Pictograph, paint and charcoal
6	Cave	168		X	X	X							Pictograph, paint and charcoal
6	Cave	170		X	X	X							Pictograph, paint and charcoal
3	Cave	145										X	Calcite on top of finger-fluting
2	Cave	148										X	Calcite on top of finger-fluting
2	Cave	149										X	Calcite on top of finger-fluting
18	Cave	160										X	Calcite on top of finger-fluting
Non-archaeological samples													
3	Cave	103	X	X		X							Wall surface (moonmilk)
4	Cave	107	X	X		X							Deposits from mining cut, brown
4	Cave	108	X	X									Deposits from mining cut, calcite
4	Cave	109	X	X									Deposits from mining cut, d. brown
4	Cave	110	X	X									Deposits from mining cut, orange
4	Cave	111	X	X									Sediments from wall depression
2	Cave	116	X	X	X								Deposits from mining pit, clay
2	Cave	118	X	X									Clay deposit
3	Cave	119	X	X									Surface floor sediments
13	Cave	120	X	X									Surface floor sediments
999	Baj. Cerezos	121	X	X	X								Brown ochre sample from surface
999	Baj. Cerezos	122	X	X	X	X							Red ochre sample from surface
998	VER. CENTRO	124	X	X									Ochre sample from surface
8	Cave	127	X	X	X	X							Cave floor
9	Cave	129	X	X									Cave floor
14	Cave	139	X	X		X							Clay from cave floor
3	Cave	152	X	X									Roof deposit under extraction

Table 2
U-Th dating results. Dates and activity ratios calculated using the decay constants of Cheng et al. (2013). 1 – measured activity ratio; 2- activity ratio corrected using the detritus U-Th composition of Kaufman et al. (1998): $[^{232}Th/^{238}U] = 0.5407 \pm 50\%$, $[^{230}Th/^{238}U] = 0.9732 \pm 50\%$, $[^{234}U/^{238}U] = 1 \pm 50\%$; 3 – modelled initial U activity ratio.

Sample ID	Site/cave	^{238}U (ppm)	^{232}Th (ppb)	$[^{230}Th/^{232}Th]$ (1)	$[^{230}Th/^{238}U] \pm 2\sigma$ (%) (2)	$[^{234}U/^{238}U] \pm 2\sigma$ (%) (2)	Age (AD $\pm 2\sigma$ abs)	$[^{234}U/^{238}U]_i \pm 2\sigma$ (abs) (3)
145	3	0.06	0.004	121.5	0.00309 ± 1.27	1.0778 ± 0.11	1703 ± 4	1.0779 ± 0.001
148	2	0.20	0.008	222.2	0.00277 ± 0.90	1.0401 ± 0.11	1725 ± 3	1.0402 ± 0.001
149	2	0.20	0.004	1257.8	0.00733 ± 0.48	1.0390 ± 0.11	1244 ± 8	1.0391 ± 0.001
160	18	0.14	0.040	74.1	0.00684 ± 0.78	0.8080 ± 0.12	1088 ± 18	0.8075 ± 0.001

caves across the island, selectively exploited speleo-substances, and enhanced materials in order to (re-)enact chthonic interventions over centuries.

The results of this research provide a foundation in building better interpretive hypotheses about human cave use in the Caribbean, and also in integrating rock art as a dataset which can contribute to wider questions in archaeology.

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