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DIRECT DATING OF PETROGLYPHS IN RIO GRANDE DO NORTE, BRAZIL

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Abstract. This article presents the first attempts to secure direct dating of Brazilian rock art. Its results point to a sequence of petroglyph reuse and modification. On the basis of current evidence, petroglyph making in the studied area ranges from the middle of the Holocene up to the beginning of European colonisation of the region. The age estimates so far obtained by microerosion analyses are broadly in agreement with the relevant archaeological information from the sampled area, the Brazilian Northeast region. Its petroglyphs are generally found on exposures of granite, the rock type most suitable for microerosion studies.

1. Introduction

In some countries, the application of direct and indirect dating methods in rock art studies is already a common reality, mainly related to pictograms. However, in Brazil little advance has occurred in that direction.

One exception to that state could be posited for the Serra da Capivara archaeological area, Piauí state, north-eastern Brazil, where indirect dating of rock paintings and petroglyphs by stratigraphic association with dated archaeological layers has been postulated (e.g. Pessis 1999, 2002; Lage 1999). For Minas Gerais state, south-eastern Brazil, indirect datings following similar procedures were also obtained for petroglyphs (e.g. Prous 1999; Neves et al. 2012). The difference between 'direct' and 'indirect' age estimation approaches is that in direct dating, a direct physical relationship of the rock art and the dating criterion needs to be established, together with falsifiable propositions concerning that relationship. Examples would be criteria that are demonstrably older, younger or the same age as the rock art in question. Indirect dating of rock art relies on recursive deductions from a series of untestable propositions. An example would be the assumption that a sediment layer postdates the rock art, that charcoal from that sediment represents the sediment's age, and therefore provides a *terminus ante quem* age for the rock art. These conjectures may well be false: for instance, in a sediment subjected to trampling and other taphonomic processes, charcoal tends to rise in the sediment; and the radiocarbon age of such charcoal, assuming that it is correct, does not tell us the age of the charcoal (it marks the event of assimilation of carbon by a living tree, therefore it may

actually be earlier than the rock art rather than later).

Since the 1970s, rockshelters with pictograms and petroglyphs in these areas have been excavated allowing for the establishment of a chronological frame for the human occupation evidence likely associated with rock art production. Because of those efforts in Piauí region, the 'Nordeste Tradition' of rock paintings was bracketed between 12 000 and 6000 years BP (Guidon and Pessis 2000). For petroglyphs, however, chronological contextualisation remains elusive and its production was proposed to have occurred around 7000 BP at just one site (Pessis 2002).

In general, more pronounced advances observed in the indirect dating of pictograms in such contexts are attributable in part to the research traditions established in those areas. Most of the sheltered rock art sites known and excavated in north-eastern Brazil (the Nordeste) are decorated with rock paintings while considerably fewer possess petroglyphs. Petroglyph sites, although occurring also in sheltered conditions, are more common in open-air riverine situations, seasonally subjected to flood and fluvial erosion of sedimentary deposits, rendering the recovery of archaeological data by excavation more difficult.

The bias introduced by selective choices, focused on sheltered sites with iconic rock paintings, seems to have resulted in the unbalanced priorities of rock art archaeologists in Brazil, more orientated towards the analytical treatment of iconic pictograms than aniconic petroglyphs, especially when it comes to age estimation.

Such non-iconic formal properties more often found among petroglyph samples in the north-east region

also contributed to the idea that petroglyph formal patterns are not as easily translated into archaeological taxonomies as are iconic pictograms, such as the already mentioned Nordeste Tradition. Thus lack of iconicity and recognisable formal properties was posited as another discouraging factor of such specific studies (e.g. Martin 1999; Pessis 2002; Valle 2003).

No matter how many causes are pointed out, petroglyph research is sparse in Brazil and up to the present no direct dating has been attempted. Rare petroglyph dating efforts occurred through relative dating by stratigraphic association to sedimentary or organic deposits superimposed upon or situated below cultural debris related to rock art, allowing for relative minimum and maximum dating, *terminus ante quem* or *terminus post quem*. Therefore, in Brazil, chronological data based on direct dating procedures for petroglyphs have remained non-existent until now.

2. Current status of rock art dating in Brazil

Efforts for rock art dating in Brazil have been based on indirect methods. In Minas Gerais, Prous provides information concerning results obtained since the 1970s by the Franco-Brazilian Mission in Lagoa Santa area, but a particularly interesting result concerning petroglyphs came from Lapa do Boquete site, Peruaçu valley. It comprises a stratified deposit covering a boulder with petroglyphs (incised lines and cupules) that were carefully excavated and a sequence of layers were dated by radiocarbon, yielding a chrono-stratigraphy ranging from 9350 years BP to 7810 years BP (Prous 1999: 32), apparently placing petroglyph making within that time span.

More recently, an excavation conducted in Lapa do Santo site, a limestone cave at Lagoa Santa region, yielded the earliest known date for a petroglyph in Brazil's archaeological record. Quartz grains of a sediment sample from an archaeological layer were dated by optical stimulated luminescence (OSL) and confirmed by AMS of carbon content of the same layer. These sediments covered the rock floor of the cave under a stratigraphic column of 4 m, and executed on the cave floor a schematic pounded anthropomorph was found. The age determinations of the archaeological layer ranged from 11760 cal. years BP to 9960 cal. BP, and as it was placed on the cave floor, the petroglyph could be older than the earliest result (Neves et al. 2012: 3).

Pessis provides information concerning several results obtained in 30 years of systematic excavations in painted rockshelters in Serra da Capivara National Park. Particularly well evidenced was the case of a painted panel of Nordeste Tradition pictograms in the Toca do Perna I site that were covered by stratified sediments. At the base of the panel the respective sediment stratum covering it was radiocarbon dated in 10 530 years BP (Pessis 1999: 43). This rendered possible the finding that some of the paintings of that panel must be around ten thousand years old.

Also in Serra da Capivara National Park, in the

Toca dos Oitenta site, the excavation results revealed two petroglyph panels, one fully buried, and another partially buried by sediment strata. The radiocarbon dating obtained from a concentration of charcoal spatially associated to the fully buried panel of tridactyl petroglyphs covered by a black deposit yielded results from 7840 cal. BP to 7600 cal. BP (Pessis 2002: 42). This is the oldest published date associated with petroglyphs for that area, up until the present. In another sector of that excavation, a lithic tool was recovered bearing facets of abrasion and percussive actions, the scars of which appear to match the dimensions of some abraded grooves in the site. Therefore, the artefact was interpreted as a tool used to produce some of those apparently non-iconic petroglyphs, but the stratigraphic relation between the tool and the dated sample was not clarified in the publication.

Regarding older results in Piauí state of ochre pigment use and manipulation, but not necessarily related to pictogram production, the work of Conceição Lage (1999) is of interest. In her analysis of the ochre contents in the Pleistocene levels of Boqueirão da Pedra Furada site, she reported a sequence that extends back as far as 29 860 years BP, for fallen fragments of rock wall with stains of red pigment, and a date of 26 300 years BP associated with a fragment of wall bearing an 'ancient depiction' (Lage 1999: 50).

Results like those above are not confined to Minas Gerais and Brazilian north-eastern states, and in the Amazonian region some preliminary work has been and is still being conducted (e.g. Roosevelt 1999; Cavallini 2014; Valle 2017). Roosevelt informs of her effort to date pigments of pictograms from Pedra Pintada Cave site, in Monte Alegre region, Lower Amazonas Basin. She undertook archaeometric analysis to correlate the chemistry of some pictograms and ochre samples, pigment drops on lithic tools and on fallen fragments of rock wall deposited in archaeological sediments dated between 11 200 years BP and 10 500 years BP (Roosevelt 1999: 39). Both sets of samples collected, from the pictograms on the cave walls and from archaeological deposits, presented the same ratios of iron and titanium, implying that they came from the same geological source, and establishing a chemical index of correlation. Roosevelt used these results to sustain her claim that pictograms were of the same age as the ¹⁴C, TL and OSL-dated deposit, that is, final Pleistocene to early Holocene, and she related some of that rock art production to a Palaeoindian period in Amazonia.

More recently, in the Caretas site, an alluvial terrace on the lower Urubu river, middle Amazon Basin, charcoal samples were collected from sediments deposited upon a sandstone boulder full of cephalomorphic petroglyphs. The samples yielded two radiocarbon dates of 1110±30 BP and 1170±30 BP respectively (Cavallini 2014). They might be indications of a maximum age for the sediment deposition.

Also from Brazilian Amazonia, in southern Roraima state, promising data came from a preliminary

excavation undertaken in 2014 in a small, semi-dark granite rockshelter with two highly distinct phases of petroglyph production. A majority of non-iconic and severely weathered petroglyphs on the north-east wall constitutes an earlier phase. A later phase is considerably younger in appearance, a technologically and morphologically different set of non-iconic petroglyphs on a southern, adjacent boulder. An excavation of one m² in the intersection zone of both sets of petroglyphs provided two vertically separated charcoal samples trapped inside different levels of an anthropogenic structure of arranged rock slabs deposited upon the base of the southern boulder. The lower sample was AMS radiocarbon dated in 9485 to 9410 cal. BP (Beta 400861) and the upper sample yielded 4290 to 4140 cal. BP (Beta 400859) (Valle 2017: 16; Valle et al. in prep.). Although not related to petroglyph making, these dates suggest that the site was occupied in two distinct events, c. 9000 BP and c. 4000 BP, rendering possible a match between the two combustion events and both phases of petroglyph making during early Holocene and in mid-Holocene. This would match the early petroglyphs' old appearance, considering its weathering-resistant lithology and sheltered geomorphology. The near-absence of light inside the shelter might account for the two combustion events.

Taking this sample of rock art dating efforts in Brazil, although not exhaustive, it becomes clear that all of them were not directly related to rock art, that is, they were not direct dating procedures. Another conclusion is that almost all these results point to a Holocene rock art production, with minor rock art creation possibly at the border of 12 000 to 11 000 years BP. Older evidence remains isolated or inconclusive.

3. Methods

'Direct' methods of estimating the ages of rock art motifs can be divided into those providing minimum ages, maximum ages, or what Dunnell and Readhead (1988) defined as the 'target event'. There are intrusive methods (those involving interference with the rock art, e.g. for sample removal) and those that are entirely non-intrusive. The latter, obviously, are greatly preferable, but unfortunately very few of them have so far been applied. Only two of the potentially direct methods so far proposed (Bednarik 2012: Table 1) deliver target event age estimates and are also fully non-intrusive: colorimetry of patina and microerosion analysis.

For the present study the latter was chosen because of these advantages, and because the Rio Grande do Norte sites occur on the most favourable lithology, granite exposures. This rock contains both of the minerals subjected to calibration work so far, quartz and feldspar. The method is among the most reliable applied to rock art, in the sense that significant contamination or reversal in the process providing the 'dating criterion' (the erosion process) are both impossible. Certainly the method's disadvantages render results imprecise, but statistical sampling requirements are

well catered for and internal crosschecking is available where two component minerals can be considered. One of the shortcomings of microerosion analysis, the need for regional calibration, has recently been overcome when it was discovered that the most reliable calibration values known in the world correspond almost perfectly with the annual precipitation means of their sites (Beaumont and Bednarik 2015: Fig. 14). In other words, if calibration cannot be achieved for a particular place, the microerosion coefficient (wane-width/millennium) can be estimated from a universal curve. Indeed, in the case of the present study, the only available calibration value is so imprecise (providing a very short-range value) that it was preferred to resort to the universal curve.

'Microerosion analysis' refers to a group of geomorphic methods designed to estimate the age of rock exposures, including those formed when percussion petroglyphs were made. The most common approach is based on the geometry of microscopic wanes forming on initially sharp edges of mineral crystals that were fractured by the impact occurring when the petroglyph was created. This gradual rounding as material is dissolved has been shown to be a linear expression of age (Bednarik 1992, 1993). If it can be calibrated against time (through the availability in the region of a crystal of the same mineral that was fractured at a known time) it becomes an expression of the approximate age of the petroglyph. However, there are several limiting factors: only fractures of similar angles may be considered; only fractured crystals of minerals already calibrated may be used; and the rock surface in question must have been continuously exposed to precipitation since the petroglyph was made and not been concealed by any substance (e.g. the water of a lake or an accretionary deposit extensive enough to inhibit erosion). There are also practical limitations: the width of a micro-wane can only be measured effectively if it can be viewed front-on with a suitable binocular light microscope, and logistically there is a strong preference for horizontal panels over vertical. The method involves the use of especially adapted microscopes equipped with an ocular scale capable of measuring microns. It is preceded by a thorough search of the rock art panel, at low-magnification, scanning it for suitable micro-wanes. In this, any prospective sites are marked with tiny 'pointers' (c. 3 mm) of pressure-sensitive adhesive putty to assist in their location by microscope.

The method has been applied in all continents except Antarctica, in several cases in the form of 'blind tests': the analyst did not know the archaeologically derived age estimates of the petroglyphs in question. With one exception, the results in these blind tests matched archaeological predictions closely. For instance, at Inca Huasi, Mizque river basin, Bolivia, three events of petroglyph production were identified and the age estimates were similar to three occupation phases (Bednarik 2000). In Valtellina, Italian Alps, similar efforts have yielded dates agreeing with archaeological estimates

No.	Archaeological site	Municipality	Micro-region	State
1	Açude das Flores III	Afonso Bezerra	Angicos	RN
2	Serra do Papagaio III	Santana do Matos	Serra de Santana	RN
3	Santa Cruz	Angicos	Angicos	RN
4	Pedra Pintada	Caraúbas	Chapada do Apodi	RN
5	Serrote do Urubu	Pedro Avelino	Angicos	RN

Table 1. Archaeological sites where microerosion measurements were taken in Rio Grande do Norte, north-eastern Brazil, in 2016.

(Bednarik 2001; cf. Anati 1994; Fossati 1995). However, in the Côa valley of western Iberia, results differed sharply from archaeological predictions, but matched those of radiocarbon and cosmogenic radiation analyses by three other archaeometrists (Bednarik 1995; Watchman 1995, 1996). Eventually it was shown conclusively that the supposedly Pleistocene petroglyphs of the nearby Siega Verde site could not be more than two centuries old (Bednarik 2009). The microerosion method has been applied most successfully in Saudi Arabia and China, where chronological frameworks of large petroglyph corpora based on almost one hundred results were derived largely from this method, supplemented by ^{14}C , OSL and Th/U analysis (Bednarik and Khan 2002, 2005, 2009, 2017; Tang and Gao 2004; Tang and Mei 2008; Tang 2012; Tang et al. 2014, 2017, 2018).

4. Results

In July 2016 it was possible to conduct a fieldwork campaign in order to obtain microerosion data on petroglyphs from five archaeological sites situated at Rio Grande do Norte state, north-eastern Brazil (see Table 1 and Fig. 1).

For an improved understanding of the direct-dating results from the sample of petroglyphs analysed in this article, site data will be individually presented in sequence, following the respective order of sites in Table 1. In each site, specific microerosion readings will be presented following a codified data sequence, as shown in the following key:

AÇUDEFLORESIII-1: site denomination code and numerical sequence of petroglyph per site;
6, 7, 7, 7, 6, 6, 6, 6: eight measured micro-wane widths in microns (μm);
51/8: total sum of the eight widths (51) in microns divided by total number of readings taken (8);
6.37 μm : result in microns;
E1011 bp: translated result as estimated age in years before present (2016);
+100/-59 years: error margin (tolerance) according to primary data spread.

4.1. Açude das Flores III site

The Açude das Flores III archaeological site is located at the municipality of Afonso Bezerra, Angicos Micro-region, Rio Grande do Norte, Brazil. Geologically, it is constituted by a granite and metamorphosed gneiss open-air outcrop, surrounded by similar formations distributed across a smoothly irregular landscape characterised by semiarid rocky terrain, punctuated by higher scattered igneous outcrops. Cactaceae species abound, as well as other adapted spiky bush vegetation. Petroglyphs were executed in three different sectors of the outcrop pavement at higher portions of its surface, approximately 1.2 m from ground level (Fig. 2).

The importance of this site in the sample chosen is that it bears a pounded (and possibly scraped) historical date of 1856 (i.e. 160 years BP) juxtaposed to an older petroglyph. This historical date was endeavoured to use as a calibration basis for the microerosion of

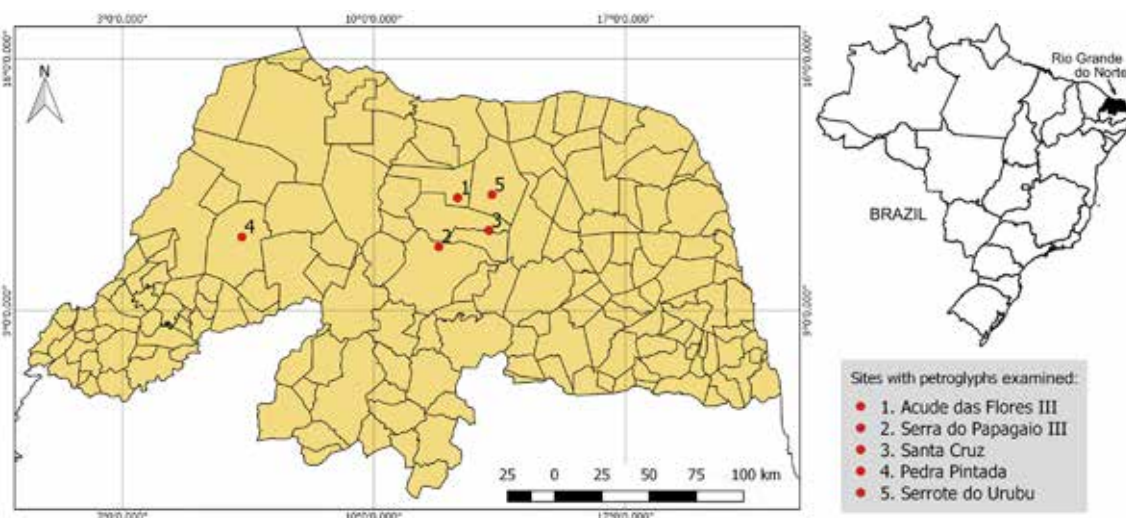


Figure 1. Map showing the location of sites where petroglyphs were dated by microerosion analysis, Rio Grande do Norte, north-eastern Brazil.

crystalline quartz in the area. However, the timespan of 160 years provides very limited precision and this information could merely be accepted as supplementary information. The engraved date showed a micro-wane width of c. 1 micron, which implies a regional microerosion coefficient of $6.25 \mu\text{m}/\text{millennium}$. It was decided to instead rely on the universal calibration curve. The local annual mean precipitation is 501 mm, which on the universal curve corresponds to a coefficient of $6.35 \mu\text{m}$. The similarity of the two alternatives confirms the authenticity of the 1856 date and also suggests that the assumed coefficient is reasonably accurate, prompting the adoption of a regional calibration coefficient of $6.30 \mu\text{m}$.

One of several petroglyphs occurring on the same sloping granite outcrop in this site presented a fractured quartz crystal bearing several edges, some of them of 90° angle with micro-wanes of erosion. Measurements of one of these edges gave the following eight wane-widths:

AÇUDEFLORESIII-1: 6, 7, 7, 7, 6, 6, 6, 6 = $51/8 = 6.37 \mu\text{m} = E1011+100/-59$ years bp.

4.2. Serra do Papagaio III site

Serra do Papagaio III is an archaeological site located in the municipality of Santana dos Matos, Serra de Santana micro-region, Rio Grande do Norte. Topographically it is dominated by an elongate, cigar-shaped granite boulder of 4.64 m length and maximum width of 1.20 m that rests on a flat granite platform, approximately 0.5 m above present ground level, adjacent to a dry, sandy, drainage channel. Mineralogically, the boulder is dominated by feldspar (around twice the volume of the quartz present in the rock matrix). This characteristic would have favoured cupule making on its surface (Fig. 3).

The morphology, lithology and specific positioning on the granitic platform (minimal contact area) indicate the acoustic properties, suggesting a possible function of the structure as a lithophone, or a ringing rock. Such features are known in the traditional knowledge of the Brazilian Nordeste as *pedra de sino* (literally, a 'bell rock'), as they are also in many other parts of the world (Bednarik 2008). When struck with hard



Figure 2. Sub-horizontal rock support of small elevation in gneissic granite with representations of petroglyphs from the archaeological site Açude das Flores III, municipality of Afonso Bezerra, Rio Grande do Norte, north-eastern Brazil (most photographs by VSJ, 2016).

materials such as rocks, such lithophones produce characteristic sounds that can be heard at a great distance from its source. Therefore, the possibility of its use by Native Americans as an acoustic communication device, to be activated percussively, is a very likely one.

Cupules constitute the most representative category of anthropogenic markings in the general site and are responsible for virtually all the markings on the presumed lithophone boulder. These cupules were made by direct percussion, with diverse numbers of blows



Figure 3. Elongate boulder bearing numerous cupules, at Serra do Papagaio III, municipality of Santana do Matos, Rio Grande do Norte.



Figure 4. Microphotograph of micro-wane PAP2, located on the vertically aligned fracture edge immediately to the left of the black dot. Photograph by RGB, 2016.

and at different times. No microscopic abrasion striae were found within any of the cupules, indicating that their very smooth floors are not the result of abrading action. This is consistent with all the world's cupules on hard rock types. Indeed, on certain sedimentary rocks, extremely high intensity of percussion can effect an annealing process forming tectonite layers through a process of kinetic energy metamorphosis and these can become almost inert to further impact (Bednarik 2015a, 2015b, 2016).

There is a major concentration of cupules in the boulder's upper surface, from its central part to its south-eastern extremity. Some of the cupules there were made on the boulder's 'belly', especially in the inferior part of the SE extremity, not without painstaking difficulty. These upside-down cupules as well as those arranged vertically are difficult to explain as utilitarian. This factor emphasises the likelihood that the rock was used as a lithophone, specific parts of which were favoured because they yielded the best sounds.

The first cupule examined in detail was on a horizontal upper surface of the boulder's north-east side. Its dimensions were $70 \times 70 \times 5.3$ mm; the focal point of attention was a large quartz crystal on its NE slope, bearing three sub-parallel edges, indexes of stress, below which there were fracture edges of the favoured 90° angle, suitable for measuring. The uppermost micro-wane, $170 \mu\text{m}$ in length, provided the following wane-width measurements, starting from the right: PAP1: 16, 16, 17, 15, 16, 17 = $97/6 = 16.17 \mu\text{m} = \text{E}2567 \pm 131/-186$ years bp.

A second micro-wane immediately below, $80 \mu\text{m}$ long, presented the following readings (Fig. 4): PAP2: 20, 18, 17, 15 = $70/4 = 17.5 \mu\text{m} = \text{E}2778 \pm 397$ years bp.

Just below this feature was a platform forming six points, with a 90° angle along more than half of its edge, bounded by a body of black mica that would have receded significantly. The measurements were made on the lower edge, from left to right, along a mi-

cro-wane $160 \mu\text{m}$ long, providing a third age estimate for the same cupule:

PAP3: 18, 18, 15, 17, 16, 16 = $100/6 = 16.67 \mu\text{m} = \text{E}2646 \pm 211/-265$ years bp.

Another cupule analysed is located on a second, smaller boulder, 1.5 m north-east of the 'lithophone'. A few cupules occupy the top face of this boulder and inside one of them is a concentration of black mica close to a quartz crystal bearing a curved fracture of $120 \mu\text{m}$ length. The micro-erosion analyses of this fracture secured the following readings, from left to right:

PAP4: 6, 7, 7, 8, 8, 8, 7, 6 = $57/8 = 7.12 \mu\text{m} = \text{E}1130 \pm 140/-178$ years bp.

A third measured cupule is located at 151 cm from the north-western extremity of the main boulder (the lithophone), where only few cupules occur. Its dimensions are $55 \times 55 \times 7.1$ mm. This sample was observed in the west-south-west sector of the cupule, about 15.3 mm from a 20 mm long prominent fracture at the cupule's rim. Two micro-wanes about 1.5 mm apart were measured in this cupule. The first, one of three in the vicinity, was c. $60 \mu\text{m}$ in length and yielded the following wane widths, commencing from the top: PAP5: 5, 6, 6, 7 = $24/4 = 6 \mu\text{m} = \text{E}952 \pm 158$ years bp.

The second wane measured in this same cupule is located 1.55 mm below the first and only $30 \mu\text{m}$ long: PAP6: 6, 6, 5, 5 = $22/4 = 5.5 \mu\text{m} = \text{E}873 \pm 79$ years bp.

In Papagaio III site, it was thus possible to obtain chronometric readings through the microerosion method applied to micro-wanes of three cupules, two on the 'lithophone' structure and one in the second, smaller boulder:

- In the first cupule in the main boulder ('lithophone') dating results varied between $\text{E}2778$ years bp (oldest result) and $\text{E}2567$ years bp, with margins of error situated at $+131/-186$ years, ± 397 years and $+211/-265$ years;
- In the second cupule measured, on the smaller boulder, the dating result was $\text{E}1130$ years bp with an error margin of $+140/-178$ years;
- In the third cupule, back at the lithophone, it was possible to obtain two chronometric readings of $\text{E}952$ bp and $\text{E}873$ bp with margin of error of ± 79 years and ± 158 years, respectively.

Considering only the absolute numbers of the readings (without their margins of error), the analysis of these data suggests a persistence of cupule making on the 'lithophone' structure for a time span of 1905 years, that is the difference between the oldest date ($\text{E}2778$ years bp) and the newest ($\text{E}873$ years bp). This scenario brings to mind the idea of a persistent action sequence in the same place, for almost 2000 years; therefore, it opens the theoretical possibility for thinking in terms of 'a place that is used repeatedly during the long-term occupation of a region' (Schlanger 1992: 92).

4.3. Santa Cruz Archaeological Site

The Santa Cruz archaeological site is located in the municipality of Angicos, Angicos Micro-region, Rio

Grande do Norte, Brazil. It is constituted by two rocky hills, with an altitude of approximately 150 m above a dry drainage channel separating their bases, surrounded by spiky bush and Cactaceae vegetation. These hills are known by locals as 'serrotes' and are structured as accumulations of granite blocks stacked to form pyramid-like aspects. The sandy creek bed that runs between the hills is called Pajeú river (Fig. 5).

Petroglyph occurrence is almost continuous from the bases of the hills up their tops and many panels in both hills were created on boulder faces looking towards west. The subject matter represented in the petroglyph imagery is constituted by a majority of iconic motifs with figurative elements that permit identification of anthropomorphs, zoomorphs and phytomorphs, despite a minor occurrence of aniconic imagery in the site. This observation contradicts a long-held and accepted notion in Brazilian rock art archaeology that petroglyph imagery in the Nordeste region is difficult to study iconographically because of its 'hermetism', that is, forms are mostly, not to say almost entirely, constructed in non-iconic manner to Western perception, or in geometric-abstract styles. Other sites in this region present the same attribute, a majority of iconic petroglyphs.

It was possible to obtain two microerosion dating results in this site. A first age estimate came from a broken granite slab, c. 5 m long and below a vertical panel bearing an extensive reticulated cupules arrangement, near the peak of one hill. The sampled motif is a prominent spiral apparently held by an anthropomorph. It was produced by shallow bruising of the light-brown, degraded weathering zone, as were the majority of the site's petroglyphs. Quartz crystals were relatively small but it was possible to locate a single micro-wane of 60 μm length that offered the following few wane widths:

SANTACRUZ1: 5, 5, 5, 5, 6 = $26/5 = 5.2 \mu\text{m} = \text{E}825+127/ -31$ years bp.

The second microerosion age estimate derives from a petroglyph situated on a sloping rock floor approximately 10 m west of the first boulder analysed and below it. The sampled petroglyph presents a long vertical line with many attached shorter lines, forming a branching pattern of arboriform morphology. Its deep grooves presented an excellent



Figure 5. Fragmented rock formations of granite tors bearing petroglyphs, Santa Cruz Archaeological Site, municipality of Angicos, Rio Grande do Norte.

fracture of a quartz crystal offering a micro-wane of 270 μm length, yielding nine sound micro-wane width measurements:

SANTACRUZ2: 5, 5, 5, 6, 5, 5, 5, 6, 6 = $48/9 = 5.33 \mu\text{m} = \text{E}846+106/-52$ years bp.

The results of both samples measured point to a chronometric similarity for the execution of petroglyphs in different parts of the site, respectively E825 years bp and E846 years bp (not considering margins of error that also show little time variation).

Another microscopically examined feature of the site was a panel with faded abstract red pictograms as well as numerous shallow cupules, the former surprisingly well preserved in the open-air semiarid context by the precipitation of a whitish silica skin over much of the vertical panel (Fig. 6). The deposition of soluble



Figure 6. Rock paintings protected by a layer of silica, Santa Cruz Archaeological Site, municipality of Angicos, Rio Grande do Norte.

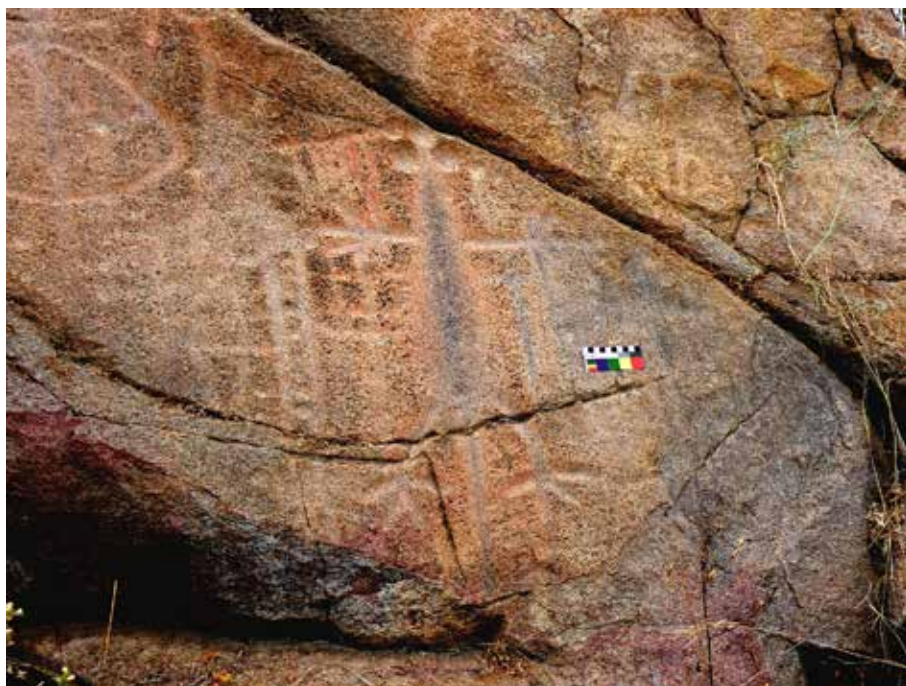


Figure 7. Anthropomorphous, zoomorphic or therianthrope representation, Fazenda Pedra Pintada, municipality of Caraúbas, Rio Grande do Norte.

siliceous material had created a protective coating over the paintings, preventing the remains of pigments from weathering out, and in spite of rain, wind and solar exposure, pictograms have been preserved under this amorphous silica skin.

4.4. Fazenda Pedra Pintada site

The Pedra Pintada rock art site is located in the municipality of Caraúbas, Chapada do Apodi Micro-region, Rio Grande do Norte. Two granite outcrops separated by a dry creek, which is part of the local intermittent drainage system, constitute the morphology of the site. The granite outcrops are approximately 10 to 15 m in height, the riverbed between them is 12 to 15 m wide.

Among the boulders with petroglyphs, a vertical panel was chosen where cupules had been superimposed over iconic imagery. An ambiguous anthropo-zoomorph (or therianthrope?) 83 cm in length and of 15 cm maximum width bears five deep cupules in its upper part, corresponding to its head (Fig. 7).

The analysis was focused on this specific petroglyph for its clear chronological significance, with cupules superimposed on an extant figure. At least three steps of *technographic* production took place in that set of petroglyphs: (1) first, direct percussion was applied to set the primary shape, bruising the rock's weathered cortex for colorimetric, volumetric and textural contrasts; (2) then, fine and intensive abrasion was used to effect polished smoothness in the internal surface of the figure; (3) significantly later, cupules were executed by direct percussion on the uppermost area of the abraded surface, suggesting by their positioning and morphology a head structure with eyes. This chrono-

logical sequence was visible to the naked eye and confirmed by microscopy.

Following the objective of focusing on the temporal relationship of the original figure and the cupules, analysis initially concentrated on the five cupules on the top of the anthropo-zoomorphic figure, two of which are deeper than the two others. Two of the deep cupules are positioned centrally over the abraded surface of the biomorph body, both possessing diameters of 52 mm. The left cupule is 11.6 mm deep and the right 13.1 mm.

In focusing on the residual pits in the upper part of the 'body' of the biomorph, at the height of the attached 'arms', one 60 μm long fracture edge yielded the following micro-wane widths:

PEDRAPINTADA1: 32, 33, 31, 31 = $127/4 = 31.75 \mu\text{m} = \text{E}5040 \pm 198/-119$ years bp.

The left of the two central large cupules forming the 'head' proved to be considerably more recent, providing the following values from a much longer wane, 160 μm long:

PEDRAPINTADA2: 17, 16, 17, 15, 15, 16 = $96/6 = 16.0 \mu\text{m} = \text{E}2540 \pm 158$ years bp.

These measurements were taken from the horizontal edge along the lower margin of a large, brown-coloured quartz crystal that is located close to the rim of the cupule. Thus the microerosion age estimates corroborated the visually inferred chronological sequencing, revealing that the cupules were about half the age of the original petroglyph.

4.5. Serrote do Urubu site

The Serrote do Urubu site is located in the municipality of Pedro Avelino, Angicos Micro-region, Rio Grande do Norte. It is situated on a rocky hill formed of granite blocks, projecting above the surrounding, almost flat semiarid landscape, adjacent to an intermittent riverbed called Garrancho. Petroglyphs are scattered among the boulders of the highest part of the hill and present significant thematic variation, comprising zoomorphs, anthropomorphs and non-iconic imagery (Fig. 8).

During fieldwork the petroglyph assemblage of this site called attention to particular formal properties of some motifs, differing markedly from the repertoire of more common petroglyph graphic patterns and styles in Rio Grande do Norte region. Such formal uniqueness or stylistic peculiarity arises from repeated variations of a geometric motif type constituted

by oblique zigzag lines structuring two to four sequences of convergent stepped lines connected to each other at the top and base by horizontal lines. These motifs, despite their oddity compared to the neighbouring regional styles, resemble other forms present in the Amerindian iconographic record, and the association with the *Chakana* design, or the Quechuan celestial Southern Cross (e.g. Urton 1980) arises intuitively. Schaafsma (1980) refers to a very similar design pattern as the 'terraced corn cloud motif', related in Pueblan cosmology to corn/rain symbolism in the south-western region of United States and northern Mexico. Furthermore, this author associates it to Jornada and Rio Grande styles of rock art, chronologically situated from 1100 to 1400 CE and 1300 to 1900 CE, respectively (according to Fig. 10 in Schaafsma 1980: 18–19).

Beyond the formal specificity of these geometric patterns and style there were also slight but perceptible, colorimetric differences in patination shades inside the marks of the Andean cross-like motifs (Fig. 9). This indicates diachronic selective retouch, or renewal of some parts of the petroglyphs; that is, these motifs, as visible as they are today, were executed at least in two separate moments in time. This suggests some type of semiotic re-signification of the first marks by further observers who, in reaction to them, introduced new interventions upon previous traces, apparently without significant changes to the earlier shapes.

A panel with such particular motifs and patina differences was chosen for the microerosion analysis, taking into consideration the issue of chronological differences marked by patination within individual motifs. Two of such superimpositions were particularly contrastive and, thus, were targeted for analysis. One is the superimposition of a complex linear arrangement by a rectangular pattern; the other refers to an older zigzag line that was later framed by a zigzag rectangular arrangement incorporating the older pattern centrally. The first sample was taken from the older line that was partially re-engraved by the more recent work. A micro-wane measuring 150 μm along its curved course yielded these values:

URUBU1: 4, 4, 4, 5, 5, 5, 4 = $31/7 = 4.43 \mu\text{m} = \text{E703}+91/-68$ years bp.

A second location, immediately next to where the two generations overlap, proved unsuitable. Further below in the groove of the younger tradition, c. 8 cm below the corner of the design, a suitable fracture edge was found. A large complex body of irregularly fractured clear quartz featured a flat platform of 70 μm edge length at 90° angle, yielding the following wane widths:

URUBU2: 3, 3, 3, 4, 3 = $16/5 = 3.2 \mu\text{m} = \text{E508}+127/-32$ years bp.



Figure 8. Hill comprised of granite tors, Serrote do Urubu, municipality of Pedro Avelino, Rio Grande do Norte.

Some 50 cm to the right of the second sampled zone is a zigzag line that has attracted a reaction some time after it was made, resulting in a rectangularly structured surround that reflects the layout of the older design. At the first bend from the upper end of the older zigzag line is a prominent white area formed by a battered cluster of clear quartz crystals. To its immediate south is a distinctive fracture edge, orientated SW to NE, on translucent grey-brown quartz, and the edge is 460 μm long:

URUBU3: 4, 4, 4, 4, 4, 5, 4 = $29/7 = 4.14 \mu\text{m} = \text{E657}+137/-22$ years bp.

Only about 5 cm from this location, in the more recent groove forming the surround, is a triangularly fractured clear quartz crystal offering two edges at 90° cleavage angles. The northern of these two micro-wanes is 190 μm long and provided the following widths:

URUBU4: 4, 3, 3, 3 = $13/4 = 3.25 \mu\text{m} = \text{E516}+119/-40$ years bp.



Figure 9. Andean cross-like petroglyph motif, Serrote do Urubu. Photograph by RV, 2016.

Archaeological site	Municipality	Sample	Date
Açude das Flores III	Afonso Bezerra	AÇUDEFLORESIII	1011+100/-59 bp
Serra do Papagaio III	Santana do Matos	PAP1	2567+131/-186 bp
		PAP2	2778±397 bp
		PAP3	2646+211/-265 bp
		PAP4	1130+140/-178 bp
		PAP5	952±158 bp
		PAP6	873±79 bp
Fazenda Pedra Pintada	Caraúbas	PEDRAPINTADA1	5040+198/-119 bp
		PEDRAPINTADA2	2540±158 bp
Santa Cruz	Angicos	SANTACRUZ1	825+127/-31 bp
		SANTACRUZ2	846+106/-52 bp
Serrote do Urubu	Pedro Avelino	URUBU1	703+91/-68 bp
		URUBU2	508+127/-32 bp
		URUBU3	657+137/-22 bp
		URUBU4	516+119/-40 bp
		URUBU5	476 bp

Table 2. Direct dating results obtained by microerosion analysis from petroglyphs in Rio Grande do Norte, Brazilian Northeast.

The southern micro-wane offered the following result:

URUBU5: $3, 3, 3 = 03/09 = 3 \mu\text{m} = \text{E}476$ years bp.

Although the more recent grooves on this panel could be interpreted as having involved some abrasive action, there is a complete absence of microscopic evidence (abrasion striations) of such treatment. Both petroglyph traditions present do not penetrate beyond the deeply weathered zone of the granite that is so typical for the region. It consists of deeply alveolar remnants of silica, with greatly receded mica and corroded feldspar and it is coloured a light brown.

Two conclusions were obtained through the observation of this panel in Serrote do Urubu site:

- The existence of two phases of petroglyph creation. The first production event was situated between the 13th and 15th centuries CE (considering variation within margin of error). The second episode occurred between the later 15th century and the beginning of the 17th century CE.
- The second generation of petroglyph elaboration was carried out through highly controlled direct percussion to renew older forms while promoting some minor observed morphological changes in former imagery. Despite its appearance, abrasive actions, such as surface scraping or intense polishing, were not microscopically evident in the analysed sample.

5. Discussion of results

The chronological frame derived from the sixteen direct age estimates obtained in five granite rock art sites sampled in the 2016 fieldwork in Rio Grande do Norte can be organised as shown in Table 2.

The general time variation of petroglyph production in the sampled area of the total assemblage ranges

from E5040+198/-119 years bp, as the earliest result, to E476 years bp, as the latest result. Therefore, the sample falls entirely inside a mid- to recent Holocene time span, necessitating a brief characterisation of archaeological research in Rio Grande do Norte respective to that time frame.

Archaeological research in the last three decades, mainly focused in the central-southern part of the state (Seridó Micro-region), has allowed the establishment of a chronological frame for ancient regional Indigenous occupation starting at 9400 years bp from Pedra do Alexandre and Mirador de Parelhas sites, associated to funerary contexts of infant burials (Martin 1999). Late occupation events have been dated by research conducted up to the 1990s and in the early 21st century, providing results ranging from 2500 years bp to 1000 years bp.

However, a recently obtained radiocarbon date from Casa Santa rockshelter of 479±27 (530–455 cal. BP, CSIC-2062), and undated but apparently more recent litho-ceramic sites with surface features indicate continuity of Indigenous ancient historical trajectories up to a later colonial period (Mutzemberg 2007; Martin and Borges 2008; Borges 2010).

The above-mentioned chronological data imply that the results presented here concerning the time span of 476 to 5040 years bp shown by microerosion analysis fall entirely into a mid- to late Holocene sequence and, thus, are coherent with the archaeological understanding and reasonability concerning the process of precolonial Indigenous occupation for that region.

Moreover, considering a South-American scale, the age range suggested by this present research also points to a coherent scenario with other microerosion-dated sites. In Inca Huasi, Bolivia, for instance, within the three moments of petroglyph creation identified (10 000–7000 bp; 4000–1500 bp; 1330–730 bp [Bednarik

2000: 282]), the two latter periods fall in the same mid-to late Holocene time span. Concerning the colonial period, Bolivia has provided extensive evidence of the continuation of petroglyph production from the major site complex of Kalatranconi, for the period of 500 years bp right up to the present time (Querejazu et al. 2015). Therefore, at both the regional and continental levels, the present results seem to indicate correspondence with well-established time sequences for petroglyph production.

The cupules of Serra do Papagaio III site show an important temporal persistence of a specific typology of petroglyphs spanning the period of $E2778 \pm 397$ bp (earliest date) and $E873 \pm 79$ bp (latest date), with variable patination degrees and dimensions, evidencing in the order of 1905 years of a persistent practice of cupule making (not considering margins of error). Recent experimental work of cupule replication in India has shown the high level of elaboration effort demanded for the production of cupules on very hard rock types (Kumar and Krishna 2014). Near the Daraki-Chattan Lower Palaeolithic petroglyph site, on a non-rock art outcrop of the same lithology (quartzite), Giriraj Kumar has conducted a well-controlled experiment. According to his report, in order to produce a cupule with the dimensions of $55.7 \text{ mm} \times 55.0 \text{ mm} \times 9.0 \text{ mm}$ it was necessary to apply 17 300 direct percussion blows over 138 minutes, divided into two days' sessions (ibid.: 183). On that basis the large and deep cupules at Serra do Papagaio III demonstrate a massive investment of labour.

Another observable characteristic in the sample examined here was the renewal of petroglyphs. For conceptual purpose, renewal is treated here as a specific type of superimposition (cf. Lorblanchet 1980). It is characterised by remaking previous lines and shapes with minor morphological changes of earlier motifs, which worked as graphic models that were continually re-enacted. Sometimes it can occur selectively, that is, just some parts of the motif are chosen to be retouched. Therefore, it can be considered a type of superimposition that implies some sort of continuity rather than rupture in the relation of time and morphology.

The best evidence for that practice was located in Serrote do Urubu site. Its earliest date was $E703 \pm 91$ / - 68 bp while the latest date was $E476$ bp. Two generations of petroglyph making were detected through patina differences within the same motifs, selectively promoting slight changes in parts of the graphics' morphology, but flowing in the same 'stylistic' genre. Therefore, c. 150 to 300 years after the first production a second graphic event resulted in only minute changes to the morphology of the petroglyphs. This behavioural continuity adopting previous shapes could be theorised as a type of semiotic re-signification process that would imply a graphic metaphor for the Darwinian notion of *descent with modification* (e.g. Hall 2003).

In Fazenda Pedra Pintada site occurred a similar but not identical phenomenon, although not dated in

its full steps because the intermediate event was an abrasive one, in between the direct percussions of the zoo-anthropomorph shape and the cupules. Therefore, it is considered that graphic continuity in shape structure had possibly occurred between the two first graphic episodes despite the significant technological variation (percussion vs abrasion). The first measured graphic event occurred $E5040 \pm 198$ / - 119 years ago (residues of percussion pits not entirely erased by successive abrasion) obtained in one of the 'arms' of the motif. A later date of $E2540 \pm 158$ bp was obtained from the third production event, of cupules that seem to form a schematised representation of a head with eyes in the upper section of the previous motif.

Microerosion coefficients are mostly determined by predominant precipitation regimes. Among arid or semi-arid regions such coefficients tend to be rather similar when compared to the ones obtained in tropical humid or temperate climate zones. The reliability of microerosion analysis resides in the initial acquisition of secure regional coefficients for the retreat process. The coefficient of $6.25 \mu\text{m}$ obtained from the measurement of the micro-wane in the 1856 historical date of Açude das Flores III site (which generated the mid-value of $6.3 \mu\text{m}$ applicable for Angicos, Serra de Santana and Chapada do Apodi Micro-regions) is also consistent with those of other regions of the world with similar climate regimes as the Brazilian Northeast. This confers a good confidence level for the Rio Grande do Norte microerosion dating results. For instance, in Xiaofangyan and Songlongshan rock art sites, Xianju county, China, the microerosion coefficient of $8.6 \mu\text{m}/\text{ka}$ was obtained comparing an ancient inscription of a historical date of 1203 CE in a granite monument located at the Wufubei's tomb, in Shirentan, north-east of Houliwu village, Guanlu town (Jin et al. 2016). The lack of precision introduced by the very short range of the calibration criterion at Açude das Flores III prompted a greater reliance on the universal calibration curve that has been recently developed.

For a proper application of direct dating methods a rigorous and detailed verification of accretionary or erosional processes occurring in petroglyphs is necessary. Some of the main techniques so far applied involve observation of fractures in crystals on rock surfaces by microerosion and varnish micro-lamination analysis in archaeological sites on desert areas and manganese patina analysis also applied on petroglyphs in desert areas. Ideally, the combination of several techniques is the most adequate scenario for the possibility of mutual calibration among dating procedures. As convergent results provide more confidence they will prompt greater reliance on petroglyph age estimation (e.g. Bednarik 1984, 1992, 2002, 2007; Rogers 2010; Rowe 2012; Ruiz and Rowe 2014). The results reported here are only preliminary; further work is planned, including a diversification in the dating methods used.

6. Conclusions

The results obtained by the microerosion direct dating method from Rio Grande do Norte petroglyphs executed on granite surfaces indicate that these were made from E5040+198/-119 bp (earliest date) to E476 bp (latest date). Thus, on present evidence, the time span of petroglyph production in that region seems to be limited to the mid- to late Holocene period and reflects very similar results obtained by indirect archaeological methods in other Brazilian sites. These are the first direct datings for petroglyphs obtained in Brazil. This situation is possibly caused by two factors:

- a) Petroglyph direct-dating procedures are relatively recent and are still being developed by researchers in other countries (e.g. Bednarik 1992; Watchman 2000).
- b) The minimal number of researchers dedicated to petroglyph investigation in Brazil (e.g. Pessis 2002; Valle 2003, 2012; Santos Junior 2005, 2013; Correia 2009; Cavallini 2014).

In sum, besides the preliminary chronological sequences identified in Rio Grande do Norte petroglyph sites by direct dating means, it was also possible to detect through this research:

- a) The diachronic reuse of petroglyphs by renewal and other procedures in the same sites, panels and graphic units.
- b) The preservation of pictograms in petroglyph sites facilitated by the natural superimposition of silica coatings upon those painted graphics.

It is obvious that the data presented here, and inferences derived from them, are in an embryonic state, considering the current status of petroglyph chronometric research in Brazil. However, the dates obtained from this work are in full agreement with standard archaeological research results regarding the process of human pre-Historic occupation in Rio Grande do Norte, north-eastern Brazil.

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