QSCIENCE connect
A Qatar Foundation Academic Journal

Research article

Determining the age of Qatari Jabal Jassasiyah Petroglyphs

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Academic Editor: Dr. Robert G. Bednarik, International Federation of Rock Art Organisations, Australia

ABSTRACT

The petroglyph site in Jabal Jassasiyah Qatar is located approximately 60 km northeast of the capital city of Doha and has over 900 different types of petroglyphs. The most commonly found petroglyphs are cupules, which are almost always arranged in geometric patterns. A number of petroglyphs of boats are also found, usually seen from above, with a few seen in profile. As there is little evidence of what age to assign to these petroglyphs, samples of the calcium oxalate containing layers covering the petroglyphs were sent for radiocarbon dating to determine the minimum age they were created. The minimum ages of nine samples taken for analysis were found to be very short, the oldest minimum age being only 235 years BP (before present). No evidence was found for the petroglyphs dating back a few millennia as was previously postulated. Due to the lack of chronological data for Qatar's archaeological past, the study data cannot completely rule out the petroglyphs dating back to ancient times.

http://dx.doi.org/10.5339/connect.2012.4

Published: 10 April 2012

QSCIENCE.com
Member of Qatar Foundation

Cite this article as: Hassiba R, Cieslinski GB, Chance B, Al-Naimi FA, Pilant M & Rowe MW. Determining the age of Qatari Jabal Jassasiyah Petroglyphs, *QScience Connect* 2012:4
http://dx.doi.org/10.5339/connect.2012.4

INTRODUCTION

Qatar, a Middle Eastern emirate, is a very small peninsular desert state, extending northward off Saudi Arabia into the Arabian Gulf, as seen in Fig. 1. Figure 2 shows a map of an expanded view of Qatar. The Jabal Jassasiyah petroglyph site is shown approximately in the northeast corner of Qatar.

The terminology used for petroglyphs is often inconsistent and confusing.[2] Essentially, there are two different morphological types of petroglyphs, those defined by color contrast and those defined by relief depth. The first type of petroglyphs are created by rock removal from a dark, patinated surface exposing a lighter colored petroglyph. Most of the petroglyphs have been formed in this way. As for relief petroglyphs, the visual aspect is defined by the depth of the material or rock removed. The petroglyphs of Qatar are of this variety. Worldwide, petroglyphs are formed via surface removal using friction, percussion or rotation. The images produced as petroglyphs vary between abstract to depictions of animals and humans, they also vary immensely from site to site around the world. In Qatar, most of the petroglyphs are of cupules, some abstract designs, and a few that are more representational of boats viewed in profile and from above. Two of the most commonly asked questions about petroglyphs and rock art in general, are: (1) What do they mean? and (2) How old are they? For the most part, the meaning of petroglyphs still remains unclear. It is was the second question that this study sought to elucidate.

PETROGLYPHS: CUPULES DOMINATE

Petroglyphs in Qatar were first discovered by Glob [9]. Virtually all the introductory and general material reported here about the Qatar petroglyphs is based on Nayeem's [25] and Rice's [26] books. In fact, much has been written, but there is little known beyond a cataloging of the petroglyphs, and some suppositions about the function of the petroglyphs, which ironically were all ultimately rejected by both authors. The petroglyphs are found approximately 60 km north of the capital city of Doha, near the northeastern coast, nominally between the small villages of Safiyaa Fuwairit, Al Marrawnah and Al Huwailah. A total of more than 900 petroglyphs of different figures are formed on low-lying limestone outcrops (called jabals) among the sand dunes at the Jabal Jassasiyah site [25]. The outcrops are subtle, never rising more than a few meters above sea level and the sand dunes in which they are found. The entire site is encompassed in an area of about 1 × 5 km. Fig. 3a (on the left) shows a view facing east towards a rock art outcrop at Jabal Jassasiyah in the middle of the picture, with the Arabian Gulf in the background near the horizon. It can be seen just how close many of the petroglyphs are to the Arabian Gulf, only about 0.5–3 km from the seashore. Sand dunes alternating with more or less parallel limestone outcrops occur among flat caliche soil and stunted scrub brush. Fig. 3b (on the right) is the view to the west where jabals are seen in the background, as well as in the middle foreground.

The very low rise of the jabals can be seen above surrounding caliche and sand. The Jabal Jassassiyah petroglyph site is the most extensive of several sites in Qatar. There are various kinds of petroglyphs, including different kinds of boat images, geometric patterns and anthropomorphs or animal images. No anthropomorphs however have been reported in Qatar [8]; Rice 1994; [25,6]. As pointed out by Querejazu [27], "Cupules are one of the commonest forms of rock art throughout the world", and that is certainly true of the small country of Qatar. By far the most common types of petroglyphs in Qatar are cupules, usually in arrangements of double rows of seven to nine cupules and roseate shaped patterns usually made up of seven to nine cupules around a larger cupule. Gillespie [6] suggests that the rosette forms could possibly have been game 'boards' known as *Al Aila* in Qatar. However, she also contends the board game theory in the case of the Jabal Jassasiyah petroglyphs, primarily due to the great numbers of them. There are simply far too many 'boards', many more than would expected to be needed. It is unclear why a particular site was selected for the creation of petroglyphs as various other smooth jabals did not appear to be carved upon. This phenomenon occurs around the world and it is not known for certain why this is the case. The photograph in Fig. 4 shows cupules that are arranged in four typical roseate forms (rosettes), each rosette consisting of eight smaller cupules arranged in a circle around a larger central depression. Robert Bednarik, a world-renowned researcher in rock art commented (personal communication): "The arrangements of cupules you [MWR] mention ('rosettes', connected cupules) are very common in the southernmost parts of Saudi Arabia, where they occur in 'fairly oldish' contexts. Yours, on the

[2] For good discussions on petroglyphs refer to [24,2].

Figure 1. A map of the Middle East. Qatar is a peninsula arising to the north from Saudi Arabia into the Persian Gulf. Courtesy of the University of Texas Libraries, The University of Texas at Austin.

other hand, are clearly rather recent, being on limestone". One of the major differences in the cupules of Saudi Arabia is that they are usually produced in sandstone, while the cupules identified in Qatar are formed in limestone. Those produced in sandstone are thought to last a longer than those formed in the softer, more soluble limestone. Another more unusual petroglyph shown in Fig. 4 includes a crossed square. Overall, cupules at the Jabal Jassasiyah site vary in size from $\sim$ 1–25 cm in diameter and $\sim$ 1–15 cm in depth.

One striking depression was found no further than 100 m from the other petroglyphs that were studied. This circular feature was found to be 2 m in diameter and 6–10 cm deep, with a similar patina on the edges of many of the other, smaller, cupules. Patina is defined as "a visually obvious skin on rock surfaces which differs in colour or chemical composition from the unaltered rock whose development is a function of time" [2, 208]. Bednarik [3] describes cupules as, "small, cup-shaped feature …roughly hemispherical features … pounded into horizontal, inclined or vertical rock surfaces, probably constitute the most common motif in world rock art". According to Bednarik's definition, this very large diameter shallow depression found is something other than a cupule. At first, we had no idea what the feature could be. However, Bednarik wrote (personal communication, 2008): "The large basins [sic; there is only one and it is pictured in Fig. 5] you illustrate are clearly

Figure 2. **A map of Qatar is shown. The approximate location of the Jabal Al Jassasiyah rock art site is indicated on the map by the red crescent in the northeastern corner of Qatar.**

Figure 3. **(a and b) Petroglyphs are on the limestone outcrops of both photographs. The figure on the left is facing east. Low sand dunes, a jabal, trees next to a villa and the Gulf are on the horizon. The Figure on the right is facing west. Jabals, two women in the center of the photograph and low sand dunes are seen.**

kamenitza (kamenitsa, kamenica, Opferkessel, Verwitterungswanne, solution pan, pan hole, tinajita, Kamenitza, lakouva, ythrolakkos, bljudce, cuenco, tinajita, erime tavasi, skalne kotlice, scalba, skalnica), a typical karst [a region of carbonate rock characterized by underground drainage] phenomenon [such as caves, sinkholes, cenotes, kamenitzas, etc.] which archaeologists in the past claimed to be man-made and used for sacrifices. These various names are used for the same

Figure 4. Several grouping of cupules and other petroglyphs are depicted here. Roseates of cupules, eight circled smaller cupules around larger central ones are shown. A 10 cm scale is included for scale. It is anchored by a rock against the gusty winds.

phenomena that occur in many parts of the world but no single name has been adopted for overall usage in rock art research. These phenomena also occur on non-carbonate rocks in various forms, including sandstone and granite and also have appeared on Uluru (a sandstone megalith in Australia)". These features are discussed further in Bednarik's comprehensive paper (2008).

The next series of photographs shows some of the variety in the cupules that appear at the Jabal Jassassiyah site. Cupules, only slightly larger than average (about 5–10 cm), but much smaller than the kamenitza (Fig. 5) are shown in Fig. 6. The black deposit on the inside walls of both cupules contains calcium oxalate. It is unclear what gives the coating its black color, but it is often seen in petroglyphs in other parts of the world. There are several hypotheses on the origin of calcium oxalate coatings, which range from those that consider them the result of human activity [28], to those suggesting they are produced naturally by the metabolic activity of lichens, bacteria, and microbes living in the outer layers of rock faces [1,10–12]. We consider the metabolic activity of lichens a likely candidate for the origin of calcium oxalate crusts.

Figure 7 shows numerous rectangle petroglyphs, the largest surrounded by cupules. Rectangular forms similar to those shown are rare. A roseate form of cupules appears near the center of the photograph with a central larger cupule surrounded by nine smaller ones.

Figure 8 illustrates one of several images that feature a cupule with lines radiating outward in a down hill direction. A sample was extracted from one of the radiating lines containing calcium oxalate for the purposes of radiocarbon dating.

In an attempt to understand the purpose of the cupules that have been found in Qatar, three main propositions have been put forward by Rice (1994): (1) That they represent a "proliferation of vulvas"; (2) that they "were boards for playing the game called in Arabia *huwais*, but which is known throughout the world under different names and many forms" (see Fig. 9) and (3) that they "were associated in some way with the pearl trade", possibly used to sort pearls. Rice himself, however, rejects all three previous theories with convincing arguments. He also noted, as were seen by our own observations, that "They [the petroglyphs] seem to be distributed at random over the surface of the little hills; they appear to follow no evident orientation, neither solar, lunar or stellar". Fig. 9 shows a modern depiction of a game being played in Mozambique that involves 'cupules' made in sand.

Rarer at the Jabal Jassasiyah petroglyph site and of considerable interest, are the petroglyphs of boats. Most are depicted as they would be seen from above; few are depicted in profile. Examples of

Figure 5. This is a photograph of a likely kamenitza, i.e. a karst phenomenon.The villa in the background is the same one seen in Fig. 3. Brandon Chance, Raid Hassiba and Faisal Al-Naimi are standing near the kamenitza to provide scale.

Figure 6. A photograph showing two medium sized cupules. The black coating on the inside of the cupules contains calcium oxalate, the carbonaceous material used for dating. An AA battery is included for scale.

both types of views are shown in Figs. 10– 12. Figure 10 shows a detailed petroglyph of a boat as viewed from above, with 20 or so 'oars' emitting from the sides of the boat. The petroglyph is accompanied by a paired set of cupules with eight on a side. Radiating from the end of the boat a tail

Figure 7. A photograph showing some of a few rectangular petroglyphs identified at the site which are associated with a circle of cupules surrounding one (on the left center) and others nearby a roseate form with a larger cupule surrounded by nine smaller ones.

Figure 8. A photograph showing one of a few cupules that have lines radiating from them. These radiating lines generally follow a down hill direction in the petroglyphs. There is an IFRAO scale partially covered by a rock between the two right most lines.

is seen that ends in a cross. The tail is thought to represent a water trail. What is represented by the cross is not known. It is important to note however that the boat petroglyph is thought to be slightly altered from its original form, presumably due to casts being made of these images.

Figure 9. A photograph of a modern depiction of a game that has been played throughout the Arab world using 'cupules' made in sand with small pebbles. This photograph was taken in Mozambique and used with permission from Chase Nye, United States Peace Corps, Inhamussua, Mozambique.

Figure 10. One of the boat petroglyphs taken from above. Note the long 'tail' that trails from the rear of the boat and ends in a cross. It is assumed that the lines emitting from the sides of the boat represent oars. An AA battery is shown for scale.

Figure 11 shows a photograph with five or more boat petroglyphs taken from slightly above. Two of these were quite large in size, others being much smaller and some smaller boat petroglyphs not

Figure 11. A series of boat petroglyphs seen at the site. Note the presence of cupules inside the larger boats. Rachel and Josia Schrodl are shown and provide a rough scale of the size of these boat petroglyphs.

appearing to have been completed. This series of boats was found on one of the field trips by Rachel, and Josia Schrodl who are shown in Fig. 11 and illustrate the relatively large size of these petroglyphs.

The final type of petroglyph that was observed at the site was the boat petroglyph shown in profile (Fig. 12). Very few of these petroglyphs were found and only three had been seen during many field trips to the site. Samples of the the boat petroglyphs shown in Fig. 12 were not taken as they lacked the patina that might indicate the presence of calcium oxalate, which is necessary for radiocarbon dating.

AGES OF THE JABAL JASSASIYAH PETROGLYPHS?

The ages of the petroglyphs found in Qatar are thought to vary in the range from only a few hundred years old up to 3500 years old. Nayeem [25] wrote, "In Qatar there is no evidence of any kind to date these scores of cup-marks found at [sic] several places". This conclusion was also echoed by Rice (1994). Similar carved rows found elsewhere in the Middle East, however, are thought to be as old as the 15th century BC, but it is not known how the antiquity of these have been estimated. Cupules similar to those identified at the Jabal Jassasiyah site have been found in neighboring Bahrain. These are thought to date back to the third millennium BC (Rice 1994), again, it is not known how exactly the antiquity of these cupules were estimated and it is very difficult to assign an age for cupules based on other archaeological inference. The limestone outcrops on which the Qatari petroglyphs are made are soft and are likely to erode rapidly, especially due to the frequent sandstorms that occur in

Figure 12. This photograph shows one of the very few petroglyphs of boats that are shown in profile. A 10 cm scale is shown.

the region. Given the latter, petroglyphs dating back several millennia are unlikely to be found in limestone jabals in Qatar and neighboring countries.

DETERMINING MINIMUM AGES

In desert areas around the world calcium oxalate usually admixed with newly formed calcium carbonate (calcite) forms the layers over any petroglyph formation. Numerous attempts have been made to determine the age of rock art by radiocarbon analysis of oxalates [4,5,7,30–39].

A schematic representation depicting the process of oxalate formation is shown in Fig. 13. While the exact process for the production of oxalates is still unknown, there seems to be consensus that it forms from ambient carbon dioxide. One expert, Jon Russ (personal communication, 2009) wrote, "I'm starting to be convinced that the oxalates are produced almost entirely by microbes. While lichen could produce some, I'm more inclined to think more microbial". Such a process would mean that the carbon that is incorporated in the calcium oxalate (CaC_2O_4) can be used to provide information on the age of associated rock art. Before petroglyph production, natural weathering of the surface of limestone results in the formation of an oxalate crust, often mixed with more abundant calcite (calcium carbonate) (Fig. 13a). The effect of carving into the surface results in the oxalate crust being removed (Fig. 13b). A renewed layer of oxalate crust is deposited onto the exposed surfaces from natural weathering. Thus at the time in which a sample is taken for radiocarbon dating, the newly formed crust over the carved surface would give an indication when approximately the new oxalate layer was deposited, presumably starting soon after the petroglyph was made (Fig. 13c). Sometimes rock paintings are applied on other oxalate containing layers allowing maximum age constraints, but that is not the case with petroglyphs. So for petroglyphs, we were limited to obtaining minimum ages.

Jon Russ further added in personal communication that (2009), "…there will be a slow almost continuous (or sporadic) production of oxalates". In other words, the sporadic deposition of oxalates may occur continuously on an archaeological time scale of hundreds of years. These factors mean that the age determined of newly formed oxalates is only a *minimum* age and not an indication of the time in which the carving was actually formed. The age of the new oxalate layer, however, helps to narrow down or constrain the time the period in which the petroglyphs were formed.

EXPERIMENTAL PROCEDURE

DETECTING THE PRESENCE OF OXALATES IN THE QATAR PETROGLYPHS

Dating the production time, i.e., the age of petroglyphs is very challenging. There is no generally accepted method for determining the age of petroglyphs, especially those produced in limestone, as

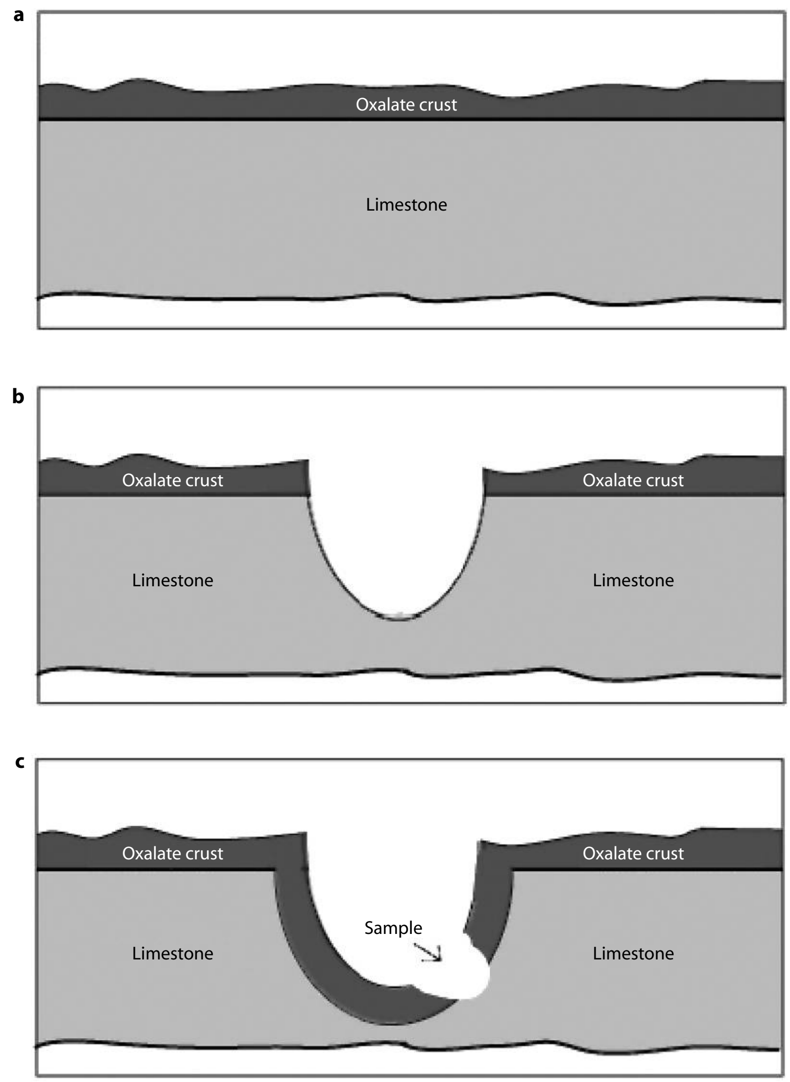

Figure 13. The schematic diagram is shown depicting the process of oxalate deposit on a petroglyph. The oxalate that forms over the newly exposed surfaces of removed rock material collects over time and provides a sample for radiocarbon dating. The radiocarbon date of the oxalate sample gives a minimum age of the petroglyph.

are the Qatar petroglyphs. With no accepted means for determining the age, we sought to constrain the ages using a technique of dating the oxalate layers coating the petroglyphs or paintings to obtain the minimum and sometimes the maximum ages of production. Researchers however have been successful in obtaining constraining dates from oxalates associated with rock art using these methods [4,7,30–39].

In order to detect the presence of oxalates of the Jabal Jassasiyah petroglyphs, nine samples were taken from the interior of some cupules, one from a radiating line, one from the kamenitza and one from two different boat surfaces. The samples were analyzed using the Perkin Elmer Spectrum One Fourier Transform Infrared (FTIR) Spectrometer, Serial Number 9700, with Universal Attenuated Total Reflectance Sampling Accessory. Spectra were taken using a 3 bounce diamond/zinc selenide crystal. The spectra were collected according to standard operating procedures of four scans in the range 4000–650 cm^{-1} with a resolution of 4 cm^{-1}. The detection of calcium oxalate in one sample is shown in Fig. 14; the spectrum shows distinct negative ‘peaks’ that are attributable to the calcium oxalate on the limestone surface. The presence of oxalate confirmed by the spectrography made it possible for the petroglyphs to be sent for radiocarbon dating.

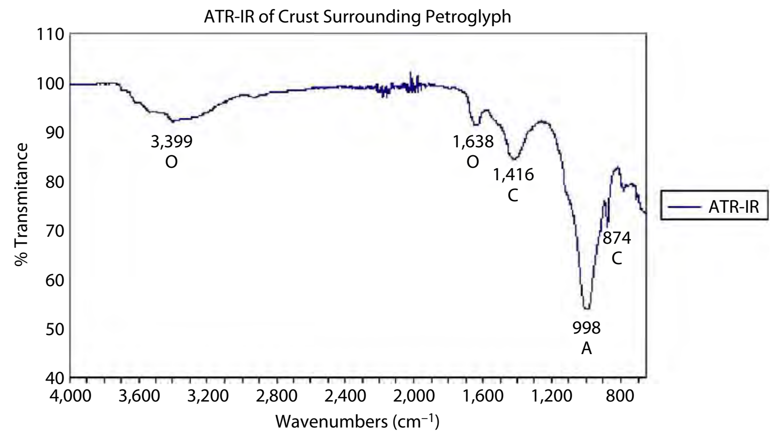

Figure 14. An FTIR-ATP analysis confirmed the presence of calcium oxalate due to the negative peaks seen. O: calcium oxalate; C: calcite (calcium carbonate); A: rock mineral, apatite ($Ca_5(PO_4)_3(F, Cl, OH)$).

RADIOCARBON DATING OF PETROGLYPHS

To obtain minimum radiocarbon ages of the Jabal Jassasiyah petroglyphs, samples were taken by scraping a small amount of the surface oxalate layer from nine different petroglyphs. The analysis was limited to petroglyphs, however, the same reasoning and procedure can apply to the analysis of paintings that also have oxalate coatings [4,7,30–39]. Carbonates were present in the samples taken of amounts much greater than oxalates. It was therefore necessary to remove these carbonates by placing the samples in a 1 molar (M) phosphoric acid (H_3PO_4) solution in order to dissolve the calcium carbonate. The resulting solution containing the calcium oxalate as an undissolved solid was then filtered to extract the solid oxalates, along with other extraneous solids such as calcium oxide and quartz that do not interfere with the dating procedure. The solid filtrate remaining was washed well with a 1.0 M NaOH solution, after which was rinsed with 1 M phosphoric acid to desorb any adsorbed carbon dioxide remaining in the sample solution. The calcium oxalate solution containing the associated inorganic minerals were sent to the Center for Accelerator Mass Spectrometry of the Lawrence Livermore National Laboratory for radiocarbon analyses.

As was previously mentioned, these measurements yield *minimum* ages, not the time of production. The samples were taken from the petroglyph surfaces, so the oxalate could only have begun to form after a clean new surface was exposed. Because the oxalate may be deposited from the time of carving into modern times, the 'age' obtained for the oxalate is a weighted 'average' that is less than the true age of the carving.

We calculated the radiocarbon date of what would be the minimum age of petroglyph production, assuming that the formation of the oxalate was constant and uniform and that the 'modern' radiocarbon content was that of 1950, i.e., before atomic bomb tests starting in the mid-1950s). Our calculations are shown in Fig. 15.

RESULTS AND DISCUSSION

The results of the radiocarbon analyses (Table 1) suggest the ages of the nine petroglyph samples tested are no more than a few hundred years old. Unfortunately, there is little archaeological inference with which to further estimate the ages of the Jabal Jassasiyah petroglyphs. However, Gillespie [6] has noted "that the boats depicted with metal anchors cannot be older than 700 years at the most", which is broadly consistent with the dates of the boat petroglyphs that were analyzed in this study. It is conceivable however that the ages of the petroglyphs tested could be much older than the results indicate. This may be due to the poor weather conditions which scour away newly formed calcium oxalate layers during sand storms. If this was recurrent throughout the past 1000 years, the remaining oxalates layers would only be those that have recently formed before the time of sampling. In this case, a younger chronology of the petroglyph would be indicated by the oxalate date, regardless of whether the petroglyph formation had occurred much earlier on in time.

Another scenario which is thought to indicate a younger age for a much older petroglyph event, may in part, be due to the geochemical environment that for some reason or another, may not have

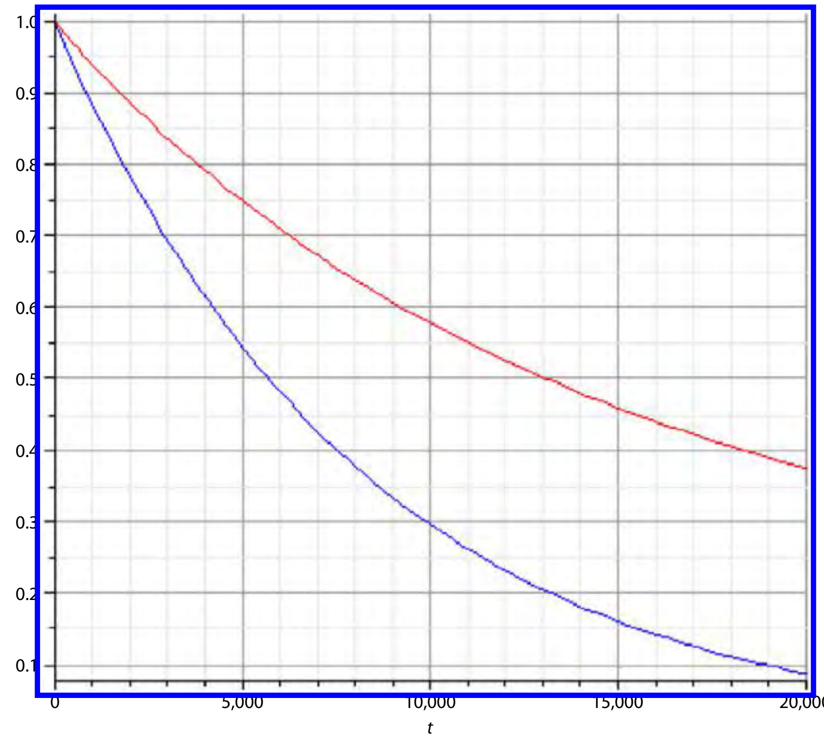

Figure 15. Calculation of the age of the petroglyph by using two assumptions: (1) The left-most blue line assumes that all the oxalate was deposited essentially instantaneously just after petroglyph formation. (2) The right-most red line assumes a continuous formation of the oxalate over the entire lifetime of the petroglyph.

Table 1. Results of the radiocarbon analyses of the petroglyphs at the Jabal Jassasiyah rock art site in Qatar. The results show no evidence of petroglyphs dating more than a few hundred years old.

Sample	Radiocarbon date	CAMS # [a]
Cupule 1 (Fig. 6)	Modern	141902
Cupule 2 (not shown)	170 ± 35 years BP [b]	141903
Cupule 3 (not shown)	115 ± 35 years BP	141904
Boat (Fig. 10 & Fig. 11)	Modern	141905
Cupule 4 (Fig. 4, upper roseate)	235 ± 35 years BP	141906
Cupule 5 (not shown)	Modern	141907
Cupule 6 (Fig. 8, radiating line)	Modern	150813
Cupule 7 (Fig. 5, kamenitza)	Modern	150814
Boat (Fig. 10 & Fig. 11)	Modern	150817

[a] This is the identification number of the Center for Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratory.
[b] BP Radiocarbon age estimates are typically expressed in years BP, i.e., years before present. By common agreement, the radiocarbon dating community defines A.D. 1950 as 0 BP.

been conducive to significant oxalate formation until very recently. As a result of the delayed oxalate formation, this process could misrepresent the actual age of a petroglyph event.

To obtain more accurate production dates of Jabal Jassasiyah petroglyphs is currently very difficult, requiring the development of new techniques for doing so. All current new techniques of which the authors were aware of, are aimed at dating the graffiti (defined as color contrast petroglyphs), not the relief type of petroglyphs that are found in Qatar [13–23,29].

ESTIMATING AGES FROM OXALATE DATES

1. Assume a uniform deposition rate of oxalate layer over time.
2. Assume at time $t = 0$ a cupule is carved out of the rock.
3. Assume that the current time $t = T$.
4. Assume that the rate of deposition of oxalate is $h(t)$, and the current thickness is H.
5. Assume that the sample taken has a cross section area A.

6. Assume that the density of carbon atoms is given by ρ.
7. Assume that the decay rate of ^{14}C is λ.

Discrete approximation: Assume a thickness Δh (Δ refers to a change in a quantity) is laid down in the first year. The number of ^{14}C atoms is equal to the volume $A\Delta h$ times the density ρ. After a length of time T, with decay rate λ, the number of atoms is:

$$(A\Delta h)\rho e^{-\lambda T}.$$

The second layer, at Δt later, contributes:

$$(A\Delta h)\rho e^{-\lambda(T-\Delta t)} \quad \text{and so on.}$$

The total number of ^{14}C atoms is given by the summation of the series:

$$(A\Delta h)\rho e^{-\lambda T} + (A\Delta \mathrm{h})\rho e^{-\lambda(T-\Delta t)} + (A\Delta h)\rho e^{-\lambda(T-2\Delta t)} + (A\Delta h)\rho e^{-\lambda(T-3\Delta t)} + \cdots + (A\Delta h)\rho.$$

In the limit of infinitely small changes in thickness and time, Δh and Δt, this becomes an integral:

$$\int_a^T A\rho e^{-k(T-1)}dh = \int_a^T A\rho e^{-k(T-1)}\frac{dh}{dt}dt.$$

Assuming a constant rate of deposition, and a final thickness H, then $\frac{dh}{dt} = \frac{H}{T}$ yields:

$$A\rho\frac{H}{T}\int_a^T e^{-k(T-1)}dt = \frac{V\rho}{T}\int_a^T e^{-k(T-1)}dt = \frac{V\rho}{T}e^{-kT}\int_a^T e^{kt}dt$$
$$= \frac{V\rho}{T}e^{-kT}\left(\frac{e^{kT}-1}{k}\right) = \frac{V\rho}{kT}\left(1-e^{kT}\right).$$

By way of comparison, a core sample of volume V and age T would have:

$$\frac{V\rho}{T}e^{-kT}.$$

Figure 15 below illustrates the difference between the two functions, e^{-x} on top, and $\frac{1-e^{-x}}{x}$ on bottom.

The y-axis measures the ratio of the radioactivity of the sample to a current sample (with the same volume).

Clearly, given two hypothetical samples with equal radioactivity—one deposited continuously over the entire time lapse after formation of the petroglyph, and one deposited immediately after the formation of the petroglyph in a short period of time (tens of years), the continuously deposited sample will yield an age that appears to be older. The decay rate of ^{14}C atoms is 1.21×10^{-4}/year, and has a half life of 5688 years. If the continuously deposited sample has half the radioactivity, it will appear over 13,000 years old, while the actual age of the petroglyph production would be under half that age.

CONCLUSION

The study of nine different petroglyphs at the Jabal Jassasiyah site in Qatar found dateable calcium oxalate in the samples taken. On radiocarbon analysis the dates of the samples were found to range from modern day to only a few hundred years old. Thus, no chronological evidence was obtained to suggest an antiquity of a few millennia for the petroglyphs analyzed. Although it cannot be ruled out by the present study, it would be surprising if the ages of any of the Jabal Jassasiyah petroglyphs could be dated back to 3000–3500 years ago as there is little other chronological data for Qatar's archaeological past. In order to obtain more accurate dates of petroglyphs will require the development of a new technique directed to relief petroglyphs made in limestone.

ACKNOWLEDGEMENTS
This work was funded by the Undergraduate Research Experience Program Fund of the Qatar Foundation grant # 5-3-3. We also thank Texas A&M University - Qatar for their support of this project. We are especially grateful to Robert Bednarik, whose insightful comments not only improved this paper, but saved the authors from making some mistakes. The comments of Jon Russ and Saffiyah Al-Nuaimi were also very useful in improving this paper. Several other people helped us in various ways: Emair Al-Naimi; Ashfaq Bengali; Lala Howard; Lacie Martin; Kathleen Rowe; Layne Sarvela, and Hans, Daniela, Rachel, and Josia Schrodl. We obtained permission from Himyan J. Al-Kuwari, and Dr. Faisal Abdulla Al-Naimi, Qatar Museum and Antiquities Authority, to conduct this research.

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