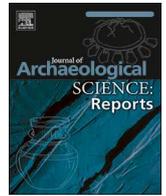




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Rock art of Heilongjiang Province, China

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ABSTRACT

The work and results of an exploratory expedition to a series of rock painting sites in the Heilongjiang Province of NE China are reported. All rock art surveyed occurs as paintings and is considered to be relatively recent. Preliminary age estimates were secured from four of the sites. In two instances, the ages were delimited by the antiquities of their support surfaces. In the two others, four re-precipitated carbonate samples were subjected to uranium-series analyses. The results are discussed in the light of the current debate concerning the need to check U–Th dates obtained from carbonate crusts against the findings of other methods.

1. Introduction

The northernmost province of China is Heilongjiang in the country's far northeast. Its northern border is formed by the Amur River, which separates the state from the very similar environment of southern Siberia. With an area of 454,800 km² the sixth-largest state of China, Heilongjiang has one of the country's smallest province populations, 38.3 million inhabitants. It features the most extensive remaining original forests of China, still home to the Siberian tiger and the black bear, among other north-Asian megafauna. Heilongjiang occupies about half of the Dongbei Plain, surrounded on three sides by low mountain ranges. Those of the northwest, the northern fringe of the Da Xingan Range, are mostly of igneous rocks, while the geology of the Xiao Xingan Range is more complicated. Its northern part is of granite, basalt and metamorphic rocks; its south is composed of various folded strata. The broad lower valleys feature extensive marshes and bogs.

It is in this environment that the rock art of Heilongjiang occurs, which has not been described before in English. In contrast to several other provinces of China, this state features only a low density of known sites, in the order of a few dozens. In June 2017, we visited nine of them at the invitation of the Propaganda Department of Daxinganling Prefectural Committee of Heilongjiang. The purpose of the project was to initiate the scientific investigation of Heilongjiang rock art. Here we describe and interpret the sites roughly in order of their location from north to south in this report of our results.

2. The sites

Mohe Station Rock Art Site is located in Mohe County, c. 3 km

southeast of Mohe, overlooking the railway line downstream from the town (Fig. 1). Mohe is the northernmost town in China in an essentially Siberian environment. The site consists of a vertical cliff above a steep slope of about 50 m, immediately above the railway track. Its rock is well-metamorphosed schist trending towards the hornfels phase, with poor foliation development. Carbonate seeps out in select places from vertical and horizontal fissures and precipitates on the surface. The floor below the cliff has been excavated about 1 m deep, which exposed further such accretions on the rock surface. These occur together with traces of clearly applied red pigment that forms undecipherable motifs. Pigment extends over a height of about 1.5 m and is frequently concealed by the white carbonate coating. There does not appear to be any carbonate accretion under any of the pigment.

However, microscopically the deposition history of the carbonate is rather complicated, with alternate phases of deposition and degradation. The older deposits are yellowish and under magnification appear shiny, eroded and of 'gnarled' surface appearance. The more recent accretions are white, porous and sometimes appear patterned. The presence of these various phases renders the dating issue rather complex in that separation of the older and newer deposits seems arbitrary. All of them are very thin, mostly less than 1 mm in thickness.

Nevertheless, two samples were removed. One was a 6-mm core sample of two discs on the upper left of the panel where pigment is coated by a very thin carbonate deposit, from well above the former sediment deposit (samples MOHE 1 and 2). The other was from 50 to 60 cm below the top of the steep sediment floor. Here the carbonate over the pigment is better developed, and we secured a loose chip of bedrock bearing both pigment and accretion (sample MOHE 3). As we had no HCl in the field, selected samples were later acid tested in the

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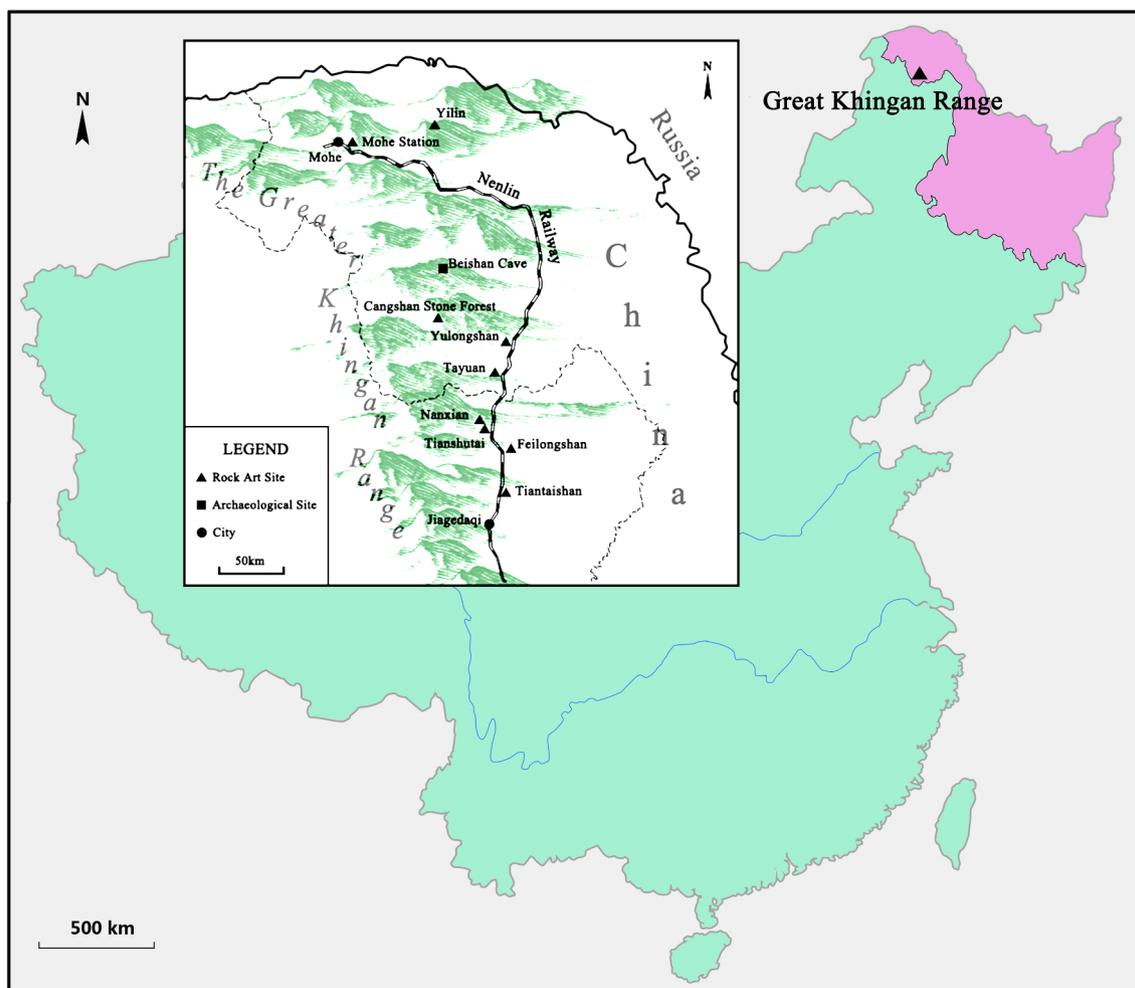


Fig. 1. Map of China showing Heilongjiang Province and locations of the sites examined.

laboratory.

Yilin Rock Art Sites, Amur Forest. Located deep in the protected forest, this site comprises a series of three locations along a cliff, separated from a forest road only by a series of ponds. It overlooks an extensive swampy environment, and the cliff is well-metamorphosed schist. It also gives rise to whitish carbonate encrustations locally where interstitial moisture seeps from fissures. Site 1 is at a small rock outcrop, a single small panel with red pictograms, drawn with wet pigment by fingers. No recognisable motif is discernible, and no sampling was attempted.

The other panels at Yilin are at Site 2, located a few hundred metres further east where the cliff is 35–40 m high and quite steep. At that location, three panels occur in close vicinity. The left (western) panel is on an undercut section near the cliff's base, the roof of which features rock art. Several single lines can be discerned. There is no carbonate accretion suitable for sampling. To the immediate right, the next panel features no such detail of line work, only patches of red pigment, some of them eroding, others quite well preserved. It is not clear how much of the carbonate accretion has been mobilised and redeposited, or even how it is physically related to the pigment traces. Although minor accretion deposits might predate the pigment, this cannot be demonstrated conclusively, and it is apparent that most of the very thin (less than 50 μm) calcite veil residues postdate the pigment. The film is so thin and discontinuous, as well as re-worked by solution and re-deposition, that sampling was abandoned. Both these panels offer no prospects for successful sampling.

Some 7 m further to the right is another panel, located several

metres above the level ground, but reachable via an easy to medium-grade climb. This panel is protected by a minimal natural roof and therefore slightly better preserved. Also, the carbonate layer, up to 0.5 mm thick, is of a somewhat better condition and was sampled twice, albeit with considerable difficulty in this precarious position several metres up the cliff (Fig. 2). An exfoliating rock fragment bearing both pigment traces and carbonate accretion was first removed (YILIN-1), then a 6-mm core sample (YILIN-2) was drilled a few centimetres from the first sample.

Cangshan Stone Forest Geopark, Xinlin District. This developed geopark with walkways and some signage features a plutonic dyke dominated by feldspar and biotite. The remaining *shilazi* (rock towers) are around 8 m high, the thickness of the main dyke seems to be 4–5 m, and there are outliers from the central alignment of numerous rock towers. The prominent site still plays a role in the ceremonial activities of the local ethnic group as attested in two places. Numerous sticks and saplings leaning against rock towers have been placed ritually by traditional people to secure supplication magic: curing of diseases, fertility rituals and similar appeals were made to the spirits by placing the items against the rock. In one location of the park occurs a tiny panel of three poorly preserved red paintings protected by a Perspex shield, which was not carefully examined by us.

Tayuan Rock Art Site, Xinlin District, is located north of the Yilehuli Shan range. This is a very small site of two panels on the wall of a granite tor on a hillside, 9 km from the main road on a guarded track requiring access permits. A short climb through dense forest leads to the site. All paintings are in red, the main group is slightly protected by a



Fig. 2. Sampling at Yilin 2 Site for U–Th analysis.

narrow ledge and comprises an apparent anthropomorph, two possible zoomorphs that are vertically arranged and a few indistinct marks. Examination of the rock panel shows that it is the result of two successive mass exfoliation events, the second resulting in the formation of the now painted panel. This triangular panel, 60 cm wide at the base, was formed when a 12 cm thick slab exfoliated from the wall. The edges around the panel are therefore the same age as the panel, thus providing a *terminus post quem* for the rock art. Along these several rock edges, numerous fractured quartz crystals were observed by binocular microscope. The micro-wane widths of those shattered at an angle of 90° were measured and averaged close to 15 µm. A few wane widths on feldspar were in the order of 120 µm. However, there is very slight silica lacing present that precedes the pigment, implying a somewhat younger maximum age than the one implied by microerosion. More extensive silica occurs next to the main crack on the right of the panel.

The significance of these observations is that one of the two putative zoomorphs has been suggested to depict a woolly rhinoceros. However, the pareidolic effect creating that impression is attributable to two areas of evidently recent percussive damage at the ‘head’ of the ‘animal’. One flake scar measuring approximately 30 mm truncates the lower end of the motif, having been created by impact from the edge of the panel, i.e. from below. The other damage consists of four or perhaps five small impact scars occasioned by a metal tool. These form a horizontal alignment that creates the impression that the remaining pigment might depict a horn (Fig. 3). Both areas of damage postdate the application of the paint and lack even microscopic traces of weathering or patination, looking practically fresh. The modern alteration thus appears to have been intended to create a rhinoceros image.

Yulongshan is a small rock art site about 5 km south-east of Xinlin Town. A single painting panel bearing a limited number of red motifs occurs on a cliff immediately next to the Tahaer river. However, we were unable to cross the fast-flowing river and could only observe the



Fig. 3. Tayuan Rock Art Site imagery; note the recent damage at ‘head’ of zoomorph to resemble a rhinoceros faintly.

pictograms through binoculars.

Zhuangzhi Nanxian Rock Art Site is located c. 40 km northwest of Jinsong Town. High up on a steep slope, at the foot of a low schistose cliff of 4–5 m height, occur a few dozen red paint markings. The rock ledge in front of the panel slopes down steeply and tends to be wet and slippery, so the access to the pictograms is precarious. The area over which the rock paintings are distributed is in the order of 7 m wide. There are few iconic images, notably a relatively detailed zoomorph on the first panel on the left (Fig. 4). To the right of this panel occur extensive carbonate accretions, which are 2–3 mm thick in many places and would be well suited for sampling. These run down in several streaks, in a few cases concealing pigment. However, the slippery floor rendered examination difficult.

Zhuangzhi Tianshutai is located 1.7 km west of Jinsong Town. A cliff of 5–8 m height, of intrusive rock, probably diorite, providing minimal shelter, has given rise to five rock art panels. The rock is mostly composed of dark minerals (hornblende, pyroxene?) with 5–10% of very angular quartz and feldspar. The first panel on the left is dominated by what seem to be two connected anthropomorphs. Like the rest of the site, it has been extensively vandalised, mostly by scratched designs. However, this panel also bears one scar of a thin flake that was removed by a flat chisel with a very sharp edge, as demonstrated by two impressions of the edge on the left upper part of the scar. Notably, the ages of the paintings vary considerably, with some very well preserved while others are quite faded. This also applies to the next panel to the right, dominated by a series of anthropomorphs (‘stick men’) in the upper part. The lower part, however, has lost most of its surface by very thin



Fig. 4. A zoomorph and some anthropomorphs at Zhuangzhi Nanxian Rock Art Site.

laminar exfoliation. This might have been occasioned by heat (grass fire more likely than insolation) or frost, but the scars resemble those of 'blistering' through fire. The exfoliated flakes were often less than 1 mm thick and rarely more than 2 or 3 mm. The uniform surface condition of these many scars suggests that a single event caused them. Since the effect is limited to one location, this could be attributable to anthropogenic fire. Alternatively, it could have been caused by the region's catastrophic forest fires of 1987 that killed 211 people and were fought by 50,000. Unfortunately, a good deal of rock art was destroyed because most of the remnants of the surface bear paint remains. Two more but smaller panels are further to the right, and another one is located around further right. Because of the extensive vandalism, the entire site is enclosed by a fence with a lockable gate and supervised.

Guyuan Rock Art Site, c. 17 km southeast of Guyuan Town. The name of the hill is Feilongshan. This site consists of a series of panels along a row of granite towers. The rock art panels occur over about 60 m. Some are at ground level, some at a few metres above ground but reachable by easy climbing. In one location whitish silica has run over paint traces and formed quite extensive deposits that might be datable via organic content. Similar recent silica can be found elsewhere, but it is not as extensive. Another panel was formed by the spalling of a slab of rock, and at its lower margin, the inner edge of the remaining rock would offer an opportunity to attempt microerosion analysis along what appears to be a reasonably sharp edge, securing a maximum age for the exposure. The site is generally free of vandalism, but it is protected by two permanent wardens installed at the entrance to the 400 m path leading to the site.

Tiantaishan Rock Art Site, Jagedaqui Forest. This minor site occurs at the top of a hill formed by an extensive series of granite tors, probably of extrusive origin (dyke). In a central part of this formation occurs a single small panel of red paintings that are relatively well protected from above by a natural overhang. The figures are all arranged in a single file, except one that occurs above the others. The vertical support panel was formed when a 15 cm thick slab exfoliated, causing new edges to form. Along the horizontal lower edge, which is accessible to microscopic inspection, fractured crystals can be observed in the granite. Although in some cases, the fracture edges are coated by minor silica precipitate; others have remained free of it. The uncoated quartz fractures exhibit micro-wane widths of between 10 and 15 μm . Bearing in mind the effect of partial shelter, this should correspond to an approximate age of the rock panel of about 2000 years. The paintings are claimed to be Neolithic, which on this basis is very unlikely to be correct. It is also claimed in the site explanation that the rock formations are of glacial origins. They are not glacial erratics, but consist of in-situ bedrock: extrusions from which all contiguous rock has eroded. There is a second rock art panel about 60 m from the first, consisting of two very faint motifs. We were informed that there is no further rock art in the Jagedaqui Forest Park.

Finally, we also conducted a thorough examination of a cave in

Xinlin District, *Beishan Cave*, to establish whether any rock art might be present in this site. Occurring along a vertical fault in intensely metamorphosed schist, the cave was formed by freezing and regelation. Its steeply rising passage is about 20 m deep, and its sediments have mostly been excavated. It was occupied about 15,000 years ago and again during Neolithic times. Its most notable and unusual features are extensive silica speleothems. However, we found no trace of rock art, the only human wall markings being some recent hammered graffiti.

3. Results

With average annual rainfalls of 613 mm at Mohe in the north and 492 mm at Nenjiang in the south of the region investigated, we assume a cline across the area placing the Tayuan Rock Art Site at roughly 550 mm. This would correspond to a microerosion coefficient of 7.15 $\mu\text{m}/\text{ka}$ on the universal calibration curve for quartz (Bednarik 2019: Fig. 1). Therefore, we can deduce that the site's main rock art panel is on a surface that came into existence roughly about E2100 years BP (i.e. before 2017). However, as noted, the execution of the pictograms, including the 'rhinoceros' image, was preceded by the deposition of a light silica veil, which suggests that we can safely presume that the surface was subjected to pigment application less than two millennia ago. Judging by the condition of the described recent impact scars relative to the faded pigment deposits, and based on known erosion rates of applied ferruginous pigments (e.g. Trezise and Wright 1966; Donaldson 2012: 23–29), a minimum age of a century can be safely ascribed to the paintings. Although this finding does not amount to a conventional age estimate, it does exclude the possibility that one of the two zoomorphs depicts a woolly rhinoceros.

A preliminary attempt to estimate the age of a pictogram panel was also made at Tiantaishan Rock Art Site, based on the same reasoning of delimiting the maximum age of the rock art by estimating the age of exposure of the rock support. In this instance, the partial shelter of the panel from rain renders the estimate of c. E2000 years BP much less reliable.

Samples of authigenic (precipitated inorganically in situ) calcite were secured from two sites, Mohe Station and one of the Yilin sites. John Hellstrom processed them at the uranium-series laboratory of the Geology Department of Melbourne University. The results (Table 1) are briefly reviewed.

The Mohe site was examined during light rainfall on 6 June 2017, at which time the cliff face was wet from both meteoric water and re-emerging interstitial solution. This illustrated the significant effects of mobilisation and re-precipitation of the accretions. Microscopy showed that the pigment deposit is eroding markedly and can only be a very recent feature, at most a very few centuries old. The U–Th raw age estimates secured from superimposed carbonate accretions at two different locations of the panel are 32.9 ka (MOHE 1/2) and 35.34 ka (MOHE 3) respectively, clearly unacceptable: that magnitude is

Table 1

Series of four U–Th dating attempts of re-precipitated calcite samples from rock art sites in northern Heilongjiang, determined by John Hellstrom.

Sample →	YILIN-1	YILIN-2	MOHE 1/2	MOHE 3
Lab number	UMD190211-409	UMD190211-414	UMD190211-418	UMD190211-433
U (ngg^{-1})	1227	1454	1821	3456
$[\text{}^{230}\text{Th}/\text{}^{238}\text{U}]^{\text{a}}$	0.258(11)	0.749(11)	0.405(12)	0.4446(24)
$[\text{}^{234}\text{U}/\text{}^{238}\text{U}]^{\text{a}}$	1.3383(1 2 7)	1.0479(37)	1.5306(71)	1.5780(19)
$[\text{}^{232}\text{Th}/\text{}^{238}\text{U}]$	0.2605(34)	1.296(14)	0.4771(60)	0.4616(64)
$[\text{}^{230}\text{Th}/\text{}^{232}\text{Th}]$	0.99	0.58	0.85	0.96
Age (ka) ^b	7.6–20	0–113	0–28	0–30.6
Raw age (ka) ^c	23.1(1.1)	134.6(4.1)	32.9(1.1)	35.34(0.23)

^a Activity ratios determined after Hellstrom (2003) and Drysdale et al. (2012).

^b Corrected 95%-confidence age range in ka before present using equation 1 of Hellstrom (2006), the decay constants of Cheng et al. (2013) and a $[\text{}^{230}\text{Th}/\text{}^{232}\text{Th}]$, range of 0.15–0.69 (Yilin) or 0.15–1.02 (Mohe).

^c Uncorrected U–Th age in ka before present calculated using the decay constants of Cheng et al. (2013); 2- σ uncertainties in brackets are of the last two significant figures presented.

undoubtedly impossible to reconcile with the environment and the recent origin of the rock art. Given the sequential complexity of the precipitates noted above, the difference between these two results is not of concern. Their massive tolerance margins at $\pm 95\%$ probability of 0–28 ka and 0–30.6 ka respectively are attributed to uncertainty in the isotopic composition of the thorium that contaminated these samples at their time of formation, which must be propagated into the ages when these are corrected for the effect of that thorium.

The discrepancies are even more significant at the second site sampled for U–Th analysis, the Yilin site. Two samples were taken of the same carbonate accretion covering pigment within a few centimetres of one another, one as a rock fragment (YILIN-1), the other as a drilled core (YILIN-2). However, while the first yielded an age estimate of 7.6–20 ka, the core sample yielded 0–113 ka. The first result is much too high from a poorly protected locality such as this; the second is of little utility: no open pictogram sites of the Pleistocene are known in the world. The raw age estimates are again of limited efficacy.

4. U–Th analyses of re-precipitated carbonate accretions

These results may seem surprising to those who have subscribed to the uncritical use of this method in ‘dating’ rock art. However, these issues have been known for decades. The first attempted direct dating of rock art (in 1981) not only applied U–Th analysis to a thick (15–20 mm) calcite speleothem but subjected the same samples simultaneously to radiocarbon analysis (Bednarik 1984, 1985, 1986, 1997, 1998, 2007: 125, Bednarik et al., 2012). A conservative minimum U–Th age estimate of $28,000 \pm 2000$ years BP (MAL-1) for petroglyphs on the ceiling of Malangine Cave in South Australia was severely contradicted by a radiocarbon date of 5550 ± 55 years BP (Hv-10241) from the same sample. Since then there has been a pattern of similar results reported by authors who also applied carbon and uranium isotope analyses in tandem to investigate rock art-related carbonate speleothems and who secured greatly differing findings from the two methods (Bard et al. 1990; Holmgren et al. 1994; Plagnes et al. 2003; Causse et al. 2003; Taçon et al. 2012; Quiles et al. 2014; Sanchidrián et al. 2017; Valladas et al. 2017; cf. Labonne et al. 2002). Several sensationalist claims promoting excessively high ages of rock art based on just one method, U–Th analysis, have appeared in recent years. Numerous writers have queried these (e.g. Bednarik et al., 2012; Clottes 2012; Pons-Branchu et al. 2014; Sauvet et al. 2015; Aubert et al. 2018; White et al., in press) and have suggested that results obtained by U–Th analysis need to be checked by applying another analytical method — especially if the results are ‘extraordinary’, i.e. run against conventional archaeological evidence.

The method of U–Th ‘dating’ demands that the initial ratio of $^{230}\text{Th}/^{234}\text{U}$ at the time of sample formation must be known or determined. Thorium is not soluble in water under naturally occurring conditions, whereas uranium is, and the optimistic assumption is made that freshly formed carbonate precipitates are free of Th. As uranium-234 decays at a half-life of 245,000 years, thorium-230 accumulates in the accretion. The latter element has a half-life of about 75,000 years. The sample age is derived from the difference between the supposed initial ratio of $^{230}\text{Th}/^{234}\text{U}$ and the one determined in the sample, thus assuming a closed system, i.e., no exchange of ^{230}Th or ^{234}U with the environment. The decay of ^{234}U continues until secular equilibrium is reached. Then the decay rate of ^{234}U and hence the production of ^{230}Th is approximately constant because of the much longer half-life of the former nuclide. However, if there is no initial presence of thorium, full equilibrium usually takes several half-lives of it to establish. At that point, the number of decays of ^{230}Th per time unit equals the number produced, as well as the number of ^{234}U decays per that time unit. Thus carbonate precipitates that contain ppb to ppm levels of uranium can be dated by the $^{238}\text{U}/^{234}\text{U}/^{230}\text{Th}$ and $^{235}\text{U}/^{231}\text{Pa}$ disequilibrium techniques, provided the initial concentrations of Th and Pa are well constrained. The system has remained closed to a post-depositional

exchange of U, Th and Pa. Sensitivity of age error to uncertainties in the initial $^{230}\text{Th}/^{232}\text{Th}$ ratio decreases with increasing U concentration, increasing age and decreasing detrital contamination (Dorale et al. 2007).

It has long been suggested that Pleistocene U–Th results are systematically older than corresponding carbon dates. Bard et al. (1990) submitted that at about 20,000 years BP, the difference is in the order of 3500 years. However, the differences are often dramatically higher. In the first case recorded, in Malangine Cave, the U–Th age of a thick speleothem layer was five times greater than the ^{14}C age from the same sample. More than twenty years later, Plagnes et al. (2003) reported their very similar results from speleothem overlying a hand stencil in a cave in Borneo. The uranium–thorium age was 27 ka, the corresponding ^{14}C age between 8 and 10 ka cal BP. In Nerja Cave, Spain, re-precipitated calcite skin covering a dot of red pigment yielded a U–Th age of between 60 and 56 ka, and radiocarbon age of between 33 and 27 ka cal BP (Quiles et al. 2014; Sanchidrián et al. 2017; Valladas et al., 2017). Indeed, all researchers who have applied two analytical methods in tandem (^{14}C or TL) to speleothem samples physically related to rock art have reported such discrepancies since the early 1980s. Therefore, the comment, “open-system behaviour of speleothem calcite is the exception rather than the rule” (Pike et al. 2017: 42) is misleading if it is intended to refer to very thin skins, as were sampled in nearly all cases. The uranium–thorium method has been applied to many alternative materials, where it is likely to be much more pertinent. Carbonate speleothems occur in various forms, and stalagmitic deposits are far more amenable to this method. Just as radiocarbon analysis of speleothems has long been known to be most reliable in stalagmites, because of their densely crystalline structures (Franke 1951; Franke et al. 1958; Geyh 1969; Hendy 1969; Franke and Geyh 1970; Geyh and Franke 1970; Drysdale et al. 2004, 2005, 2007), that same characteristic is likely also to preserve the ratio of $^{230}\text{Th}/^{234}\text{U}$ much better. A recent example of careful use of U–Th analysis is provided by Hongxia et al. (2019). They dated a series of stalagmites on the floor of Xinglong Cave, China, to secure a very conservative minimum age for an engraved stegodon tusk from near the base of the floor sediments on which these carbonate speleothems had formed. This shows that with suitable samples and conservative interpretation of results, the method is decidedly useful.

Pike et al. (2017) misunderstand the concerns of those opposing their interpretations: there are no “detractors of U–Th dating of cave art” (2017: 48) nor are “naive or incorrect rumours” (2017: 49) being spread about the method. Their adversaries merely exercise their obligation as scientists to test propositions about the results of the method. Rock art age estimation has always been recognised as being a “ferociously complex” subject, and *all of its currently applied methods* have significant shortcomings (Bednarik 2002). It is well-known that the concentrations of uranium in coeval calcite skins can vary greater than 100% on a millimetre scale (e.g. Hoffmann et al. 2009). This is reminiscent of the variations in concentrations of cations used in the ill-fated cation-ratio method of rock art dating, long discarded because of such significant variations, among other factors (Bednarik 2007: 141–2). To illustrate, at La Pasiega, Spain, a tripartite rectangular motif considered to be of the Magdalenian has yielded three minimum ages by U–Th analysis, ranging from 3070 to 64,860 years (Hoffmann et al. 2018). However, the samples all come from a continuous, very thin, translucent speleothem skin. Here we have reported even greater differences from the Yilin site in Heilongjiang, where the ‘raw ages’ of two adjacent and *very young* samples differ by more than 110 ka. Repeated samplings of the same deposit confirm what has been known for some time: that significant variations in the compositions of coeval strata are evident.

There are many potential explanations for the systematic disparities between radiocarbon and U–Th results. The most probable are: (1) that uranium is mobilised by moisture, which would render the age estimates too high; (2) contamination by the presence of detrital thorium;

(3) the inclusion of geological material in the samples (as detected by Fontugne et al. 2013); or (4) the transformation of aragonite in calcite (Lachniet et al. 2012; Bajo et al. 2016). Numerous other possibilities also exist, as well as error sources in the ^{14}C results. The thin calcite 'veils' or 'skins' that have provided the very early 'dates' from Spanish caves announced in recent years should not even be assumed to meet the preconditions for credibility. Very moist conditions are required for these accretions to form in the first place and their composition at any point in time is the result of exceedingly complex taphonomic histories. The carbonate in question derives from calcium bicarbonate solution formed by carbon dioxide-enriched water percolating through rock (Bednarik 1998, 1999). The CO_2 is mostly provided by vegetation above the cave, which has either obtained it via photosynthesis and subsequent oxidation to dead plant matter or has given rise to a community of mycorrhizal soil micro-organisms that respire the gas. The solution is very effective in mobilising calcite due to the high pressure within the rock, but upon entering the atmospheric pressure of the cave space it must relinquish most of the solute, precipitating it on the cave wall (for details see Mills and Urey 1940; Craig 1953; Franke and Geyh 1970; Hendy 1971).

Precipitation, however, does not occur as a single event or process but takes place over an extended period that usually includes many phases of deposition, solution and re-deposition. These are governed by myriad local conditions (e.g. of hydrology, topography) and can occupy many millennia. As the accretion is recycled or added to, cations may be leached out or accumulating, and the longer this process continues, the less can any part of the deposit reflect its chronology. Continuing exposure to calcium bicarbonate flow likely removes U and deposits detrital Th. Since many forms of speleothems are of a very porous structure, they experience precipitation of further solute and detrital matter in crystal lattice voids. The patterns of analytical results then determined, by both methods, simply reflect taphonomic past and the effects of an open system.

Our work in Heilongjiang confirms the observed pattern reflected in significant questions raised about U–Th dates from thin carbonate crusts or 'veils' (Pons-Branchu et al. 2014). The determinations of the Mohe and Yilin samples are massively excessive for pictograms exposed to rain and thought to be at most a few centuries old. However, these samples provide a realistic explanation for the dilemma faced by the advocates of exclusive U–Th dating of calcite skins. The thin laminae we report from the Chinese sites are subjected to extensive degradation and mobilisation processes through frequent water runoff, and thus very probably affected by a persistent solution of uranium in this open system. Much the same is likely to occur in thin laminar calcite speleothems in caves, which not only form through water seepage in the first place but then tend to be affected by it for long periods.

The recent series of rock art dating claims based exclusively on U–Th analyses of speleothems began with the unfortunate presentation of the "most richly carved and engraved ceiling in the whole of cave art" (Ripoll et al. 2004) in Church Hole, England. It has led to controversial propositions and their increasingly acrimonious defence. Pike et al. (2017) are right to cite the difficulties with radiocarbon analysis of certain speleothems, but their refusal of using the still significantly better-proven method to check the less reliable results is puzzling (especially as it may detect the effects of open systems). The main problem with ^{14}C dating of these deposits is not, as White et al. (in press) surmise, the uncertainty on the dead carbon fraction but the presence in many such speleothems of interstitially precipitated solute. The better response, surely, is not to generate controversial assertions from inadequate data but to set about designing better protocols and methods for dating the rock art in question. Innovative new approaches would be of more help to the discipline than adherence to existing but unsuitable procedures. No innovation can be expected to happen by itself, and what rock art dating needs most is not proclamations of sensational results, but new *non-invasive* methods in addition to those we already have. In short, the attention given to sensationalist

announcements and the efforts of responding to them is damaging to the science of rock art age estimation. Instead of quarrelling about contentious applications of one method, we should remember that these difficulties will be overcome eventually by new approaches.

5. Conclusions

A preliminary examination of Heilongjiang rock art suggests that this phenomenon is rare in China's northernmost state. All sites examined so far are minor rock painting occurrences, i.e. of fewer than 100 motifs. These are mostly schematised or geometric depictions; they are found at unprotected or poorly sheltered places; they appear to be of uniformly recent origins. Of particular interest is the lack of petroglyphs at this stage, which contrasts sharply with the rock art traditions found north of the Amur River, in southeast Siberia. For instance, the prominent 'face' or 'mask' petroglyphs found in the Siberian part of the lower Amur basin (e.g. Ponomareva 2018) seem absent on the Chinese side, although they are quite common in Inner Mongolia, Xinjiang Uygur Autonomous Region (Tang et al. 2018) and further west. However, considerably more detailed fieldwork is required to test these preliminary observations.

Nevertheless, this project has provided the first direct dating evidence for rock art in the region. Maximum ages were established for pictograms at two sites, Tayuan and Tiantaishan, confirming by microerosion analysis that the rock art can only be of relatively recent origin. At Mohe and Yilin, carbonate precipitates superimposed over red pigment have been sampled and were analysed to determine their uranium and thorium activities. The results imply massive detrital thorium contamination and very probably uranium removal by runoff. If these distorting factors are fully taken into account, such results from thin carbonate skins tend to provide only archaeologically meaningless information. On their own, such outcomes should not be cited in support of archaeological claims — be they controversial or not.

To see the discussion of the U–Th data from thin calcite laminae as a contest between ^{14}C and U–Th advocates does not facilitate understanding of the issues. Both approaches have their weaknesses; both are much more suitable for some applications than for others. Both of them are unlikely to yield credible dates from thin speleothem 'veils'. It is also erroneous to assume that if results are stratigraphically in sequence, they must be correct. As White et al. (in press) note, "if uranium loss occurs regularly with time, the outer layers have less time to lose uranium". Our overriding consideration, however, relates to the policies of the International Centre for Rock Art Dating (at Hebei Normal University). They limit the definition of 'scientific' to falsifiable results; i.e. those testable by resampling or repetition of experiments. "The records made in any determination must be presented in such a way that another researcher can try to duplicate (or refute) the reported results" (Bednarik 2017). This policy has been applied for several years by that agency, but there is every expectation that it cannot be applied to experimentation with a method providing hugely differing data from coeval strata on a millimetre scale. From our perspective, the results presented by advocates of the sole use of U–Th analysis to thin calcite speleothems are only scientific to the extent of being falsifiable.

We have confirmed the finding of others that samples taken from a single stratum can produce vastly different age estimates, and that these are significantly at odds with archaeological reality. Besides, we have also conducted blind tests to check the compatibility of results from two different U–Th laboratories processing splits of the same samples. Several samples from a cave in Yunnan Province were independently analysed in two institutes, and in all cases, the results differed significantly. In the worst case, one result was $20,077 \pm 2742$ years BP, the corresponding result from the second laboratory was c. 400 years BP. It is on this basis that we wish to add some recommendations to those already listed by White et al. (in press) in conclusion, expressing sentiments with which we concur:

- 1) Future U–Th datings of thin veneer accretions of calcite speleothem should be obtained from at least two adjacent locations to assess local variations in the deposit.
- 2) We recommend that sample splits (portions of the same samples) be provided to different laboratories, and the results are made available.
- 3) Work of this nature needs to include in-situ binocular microscopy of the accretions to understand their taphonomic history better. Photographs of cross-sections of the calcite accretions should be taken. SEM/EDXA to determine variations in major element chemistry in cross-sections might also clarify the homogeneity of layers.
- 4) Since methods of future centuries will be vastly more sophisticated than today's, we suggest that further site damage be limited by reducing the incidence of destructive sampling not only of cave art but of all rock art.
- 5) The use of experimental rock art dating methodology (all currently used methods are experimental) to support far-reaching hypotheses placed in fashion journals (Schekman 2013) should be avoided. We emphasise that this is not to discourage the argument that *Homo sapiens neanderthalensis* produced rock art; that has long been established (at least since 1934). Premature claims to make this point can only discredit that notion.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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