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The hand and footprints at Qiusang in Tibet: Recommendations for dating rock art by U–Th

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ABSTRACT

The claims that children's hand and footprints on formerly soft travertine at Qiusang, Tibet, are about 200 ka old and are the earliest rock art on the planet are reviewed. The uranium-thorium results are inconsistent with a previous age estimate of another set of such prints nearby, which is itself at odds with finger-drawn Tibetan letters at that site. The claims also ignore the high susceptibility of open-site calcite travertine to surface retreat by weathering and the likely removal of uranium by rainwater. Similarly, deposition of detrital thorium can occur in such porous and weathered carbonates. Both processes are known to increase age estimates of reprecipitated carbonate deposits significantly. There is no evidence that hominins of the Middle Pleistocene occupied the central Tibetan Plateau during the penultimate glacial period. Several issues are considered, and recommendations are made for resolving the controversy.

1. Introduction

Recent years have seen a proliferation of rock art age claims based on $^{230}Th/^{234}U$ data derived from reprecipitated carbonates such as speleothem skins and travertines. Such results do not attempt to define rock art ages, but they are, in most instances, secured to provide minimum or maximum estimates, depending on whether samples were collected stratigraphically above or below the rock art evidence most often paint residues sandwiched by such deposits. In several cases, U–Th results were cited in presenting sensationally great ages for the rock art concerned, contradicting previous appraisals or archaeological expectations. In this, it was disregarded that ever since this method was first applied to rock art traces in this way (Bednarik 1984, 1997, 1999), it had been observed that U–Th age estimates were often significantly higher than ^{14}C dates from the same samples (Holmgren et al., 1994; Labonne et al., 2002; Plagnes et al., 2003; Taçon et al., 2012; Quiles et al., 2014; Valladas et al., 2017; Tang et al., 2020; Pons-Branchu et al., 2020). This was particularly evident in Pleistocene deposits, and the apparent age differences seemed to increase exponentially with antiquity. Whereas Holocene samples sometimes yield relatively similar results by the two methods (but see Garnett et al., 2004, who demonstrated significant contamination in Holocene tufas), those of about 30 ka secured by ^{14}C can produce results 20 ka higher by U–Th analysis (Holmgren et al., 1994), but the difference can be much greater still (Tang et al., 2020; Tang and Bednarik 2021).

For more than a decade, many dozens of authors have questioned Pleistocene $^{230}Th/^{234}U$ dates from thin carbonate speleothem skins or travertine (e.g. Bednarik 2012; Clottes 2012; Pons-Branchu et al., 2014; Sauvet et al., 2015; Aubert et al., 2018; Slimak et al., 2018; Tang et al., 2020; Tang and Bednarik 2021; White et al., 2019; Bednarik et al., 2022; Bednarik 2022). Those who have applied the method and detected various irregularities have cautioned against its uncritical use or suggested testing its results with another method. For instance, Tang et al. (2020) and Tang and Bednarik (2021) have tested the $^{230}Th/^{234}U$ method by various means. This included splitting samples, processing the splits at different laboratories, and taking two samples of the same deposit just centimetres apart. In both cases, it was demonstrated that the results varied so wildly that no common factor was evident. For example, a calcite skin at a Yunnan site in China delivered different ages from two laboratories, 20,077 ± 2742 years BP from one and c. 400 years BP from another. Two samples from the same calcite skin at the Yilin site in Heilongjiang, China, differed by more than 110,000 years

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in their respective U–Th estimates (Tang et al., 2020). Such massive variations are thought to be attributable to the deviations in U concentrations, which can vary more than 100% within a few millimetres in coeval deposits (e.g. Hoffmann et al., 2009).

Particularly poignant are the results secured from Nerja Cave in Spain, from below and above a soundly dated charcoal mark of ~20–18 ka (Sanchidrián et al., 2017). The older sample yielded a ^{230}Th/^{234}U date of 86.9 ka, whereas the sample *younger* than the charcoal layer provided 118.9 ka (Pons-Branchu et al., 2014, 2020). Many such examples have been listed in Bednarik et al. (2022). Significantly, in nearly all published cases of U–Th and ^{14}C dates derived from the same Pleistocene samples, the U–Th dates have been greater than the corresponding radiocarbon results or archaeological expectations, often very considerably so (Fig. 1).

The authors most ardently advocating rock art dating by subjecting reprecipitated calcite to ^{230}Th/^{234}U analysis (e.g. Pike et al., 2017) have presented excessively great, sensational dates in several instances. For example, such age estimates from thin speleothem skins in Spanish cave art sites have been presented as evidence that the rock paintings in question were made by Neanderthal people given their great ages (e.g. Hoffmann et al., 2018). Evidence that *Homo sapiens neanderthalensis* has produced both rock art and mobiliary art-like productions has been reported since the early 20th century, so this is hardly a new idea. For instance, presumed Neanderthal petroglyphs have been described from La Ferrassie (Peyrony 1934), Baume Latrone (Bednarik 1986), Gorham's Cave (Rodríguez-Vidal et al., 2014) and La Roche-Cotard (Marquet et al., 2023).

The most recent precipitous claims based on U–Th analyses are from the surfaces of travertine deposits at the hot springs of Qiusang, central Tibetan Plateau, China. It is contended that juvenile hand and footprints made while the travertine was still soft are of the penultimate Ice Age phase (the Riss, MIS 6 or 7) and, at an age of around 200 ka, constitute the oldest rock art ever found in the world (Zhang et al., 2021). Again, an extraordinary age proposition derived from the contentious application of the method provides the basis of a bold claim. We wish to emphasise two points: the present paper is not intended as a direct response to any specific work but rather as a constructive proposal to untangle the complex relevant issues and to offer a path to their resolution. Secondly, this paper is not a critique of uranium-thorium analysis of reprecipitated carbonate per se but only considers its application to such deposits that are subjected to frequent wetting episodes, specifically open-air travertine and thin speleothem skins. It also needs to be noted that the problems posed by travertine samples are not necessarily the same as those posed by the thin layers of $CaCO_3$ covering cave walls.

2. The Qiusang case

The Qiusang hot spring travertine site features a ~24 m succession of hydrothermal carbonate interbedded with colluvium and alluvium that extends about ~0.6 km^2. The long duration of this sequence, of ~500 ka, has been demonstrated by U–Th dating, and it was emphasised that the hand and footprints occur at its very top (Wang et al., 2016: Fig. 4). Subsequently, Meyer et al. (2017) provided a further series of age estimates for the uppermost 8 m of this deposit, of U–Th, ^{14}C and OSL results. These range from ~7 to ~16 ka and would place the rock art in the Holocene.

Zhang and Li (2002) had previously described the dating by thermoluminescence (TL) analysis of the panel of 18 hand and footprints just south of the Qiusang Hot Springs (QHS). They proposed that these features were in the order of 20 ka old. In 2018, Zhang and colleagues discovered another panel of hand and footprints about 1.2 km to the west. Let us call this the Qiusang West site (QW). This time they used the U–Th method to determine how long ago the precipitate bearing these prints crystallised (Zhang et al., 2021). They have claimed this occurred in the Middle Pleistocene, between 169 and 226 ka ago, even though the panels at the two sites are identically and exceptionally well preserved. Indeed, the panel at QW could not have been covered and protected by a more recent, now eroded deposit because it is located at the edge of a rock spur near its top. It has, in fact, already slipped down precariously by about 1 m.

Tang et al. (2022) have reported the presence of two Tibetan writing characters on the hardened surface of QHS (Figs. 2 and 3). Suggesting that they should be less than 1300 years old, they have presented evidence that the symbols were made before the travertine had crystallised. We concur with Zhang and colleagues that this hardening occurs quickly, within a year or two. Therefore, we can reasonably assume that the historical inscriptions and the hand and footprints are about the same age. However, more detailed morphological analysis and dating on the rock surface with the Tibetan inscriptions would be desirable.

This means that the TL date of the travertine is somewhere in the order of twenty times too high. To complicate matters further, Wang et al. (2023) have more recently reported U–Th age estimates of the QHS hand and footprints of the early or middle Holocene. Are these prints now 20 ka, 5–10 ka or under 1300 years old? The last version should be correct because they can only be the same age as the inscriptions.

Secondly, how can we explain that if two sites of body prints (QHS and QW) demonstrate identical behaviour (hand and footprints by juveniles) and are of virtually matching preservation states, one should be in the order of 200 times older than the other? If the prints at QHS are

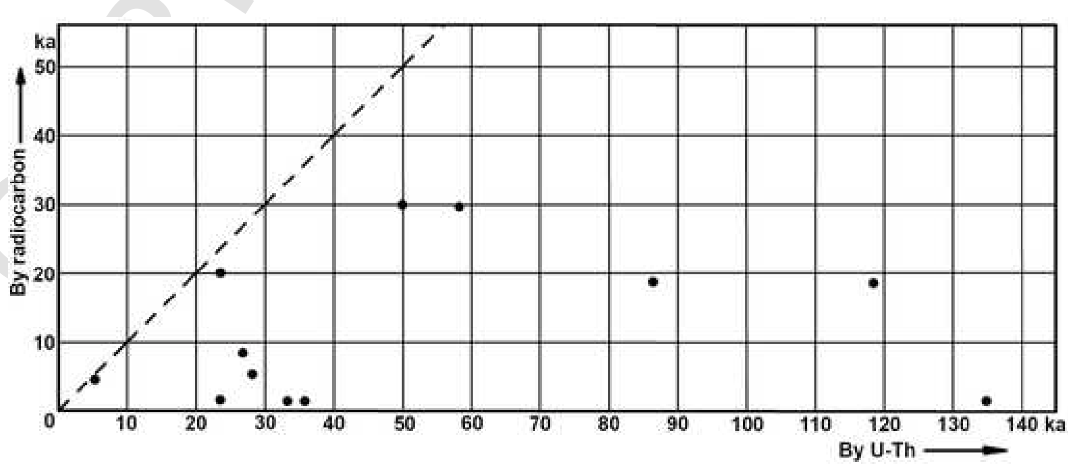

Fig. 1. U–Th age determinations of speleothems compared with archaeologically realistic or radiocarbon ages of these deposits. The dates listed have been extracted from Bednarik (1984), Bard et al. (1990), Holmgren et al. (1994), Plagnes et al. (2003), Quiles et al. (2014), Sanchidrián et al. (2017), Valladas et al. (2017), Tang et al. (2020) and Pons-Branchu et al. (2020). Image by RGB.

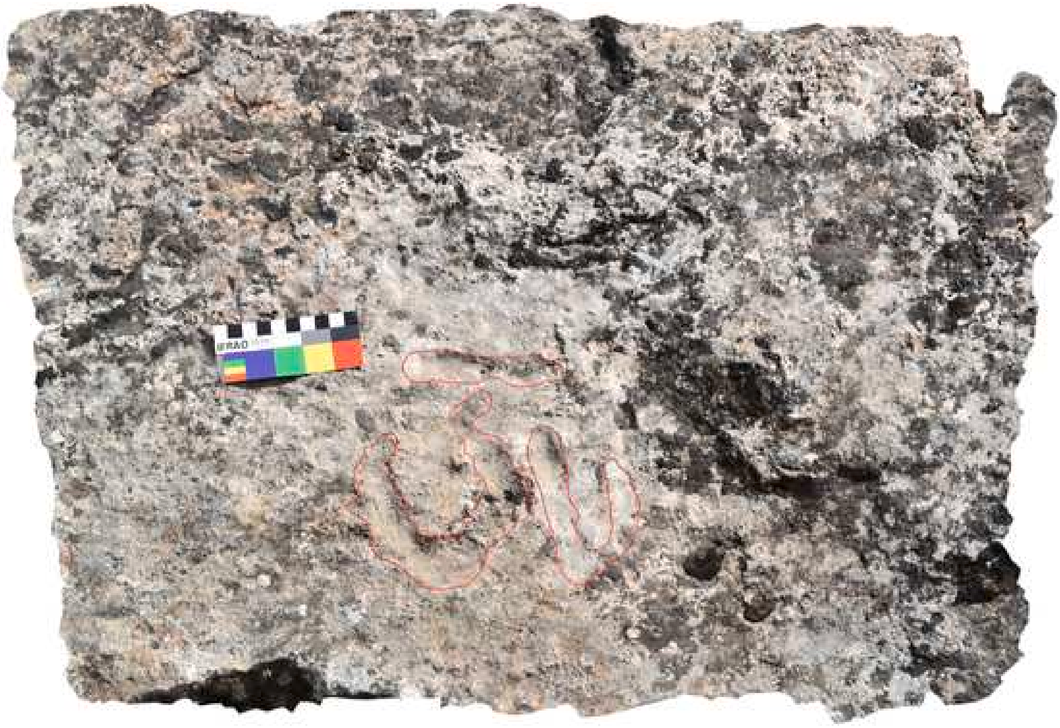

Fig. 2. Qiusang Hot Springs finger marking, made by an adult when the travertine was still soft, represents the Tibetan script a . Image by TH.

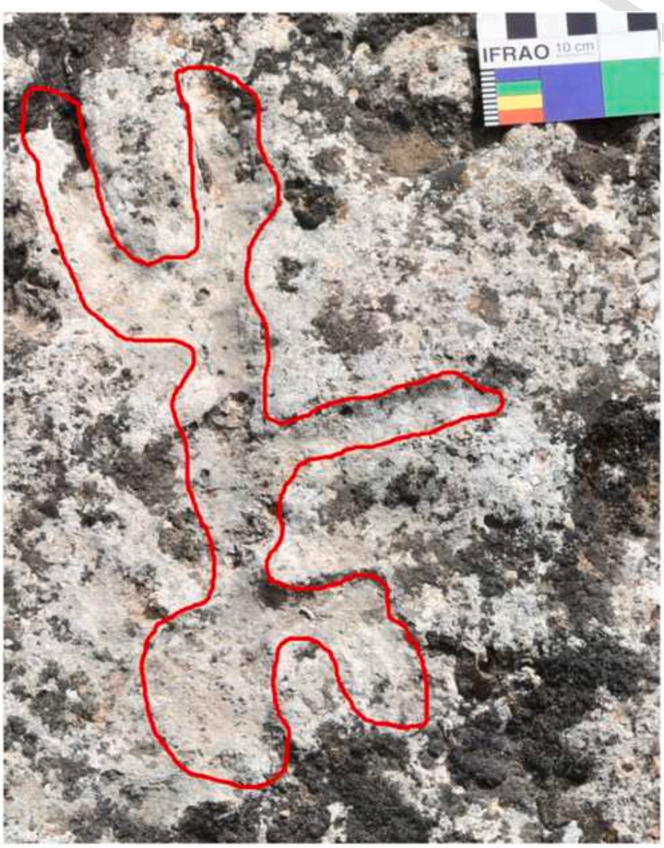

Fig. 3. Qiusang Hot Springs finger marking, probably representing part of a six-character Tibetan mantra. Image by TH.

the same age as the writing characters, as we need to assume, they can only be < 1300 years old, i.e. postdate the introduction of Tibetan script. Moreover, even well-crystallised limestone exposed to rain retreats up to 20 mm per millennium (Bednarik 2007: 61). Contrary to Zhang et al. (2021), the travertine of the uppermost 8 m of the Qiusang sequence is described as quite porous in Wang et al. s (2016) much more comprehensive analysis. Its porosity is ~20–40%, and even the porosity of the lower half of the sequence, with its denser laminated travertine, ranges up to 5 vol%. Pores are widespread in the upper layered travertine lithofacies and are mostly 1–10 mm in size. Precipitation, freezing and regelation induce rapid weathering in such a severe environment. How can we explain that the markings at QHS survived in excellent condition for 20 millennia or those of QW for 200 millennia?

The evidence for the presence of children at Qiusang is effectively placed into a glacial period by Zhang et al. (2021), estimated to have been almost as frigid as the LGM. At that time, the Tibetan uplift was almost complete (An et al., 2001), so the site's elevation of ~4270 m asl would not have differed much. The area would have been subjected to either glacial or periglacial hypoxic conditions and would have been most marginal or inaccessible to Lower Palaeolithic hominins. Bearing in mind that the earliest proposed human presence on the central Tibetan Plateau, attributed to the Nwya Devu site, is of the Final Pleistocene (Zhang J.-F. and Dennell, 2018; Zhang X. L. et al., 2018), Zhang et al. s (2021) claim that Middle Pleistocene children lived at the Qiusang site during a glacial is extraordinary. It requires extraordinary proof, but its only support derives from a controversial application of a dating method.

In response to an attempt to engage the original Qiusang team in a discussion of the issues faced by the application of U–Th analysis to certain reprecipitated carbonates (Bednarik et al., 2022), Zhang et al. (2023) reminded us that their dates from QW concur with the stratigraphy of the four layers they reported. This is based on Figure S11 of their 2021 paper (Supplementary). However, the apparent regularity in that table is illusory. To be meaningful, the results must be arranged according to their relative stratigraphical depth, as in Wang et al. (2016) and

Meyer et al. (2017), not simply presented in the numerical order of their ages. Moreover, all samples were taken from between 1 and 3 mm depth from the present surface to minimise the effects of weathering . Travertine that is millennia old has weathered very much deeper than 1 mm, and it stands to reason that if one sampled the surfaces of four strata of rock subjected to a similar precipitation regime, their subsurface $^{230}Th/^{234}U$ ratios would all be systematically distorted by uranium removal.

The critical issue on which the authors' dating attempts depend entirely is whether the U and Th ratios have been preserved in a closed system. Since all samples were collected less than 3 mm from the travertine's present surface, i.e. well within the zone affected by the penetration of precipitation moisture, that cannot be the case. As Zhang et al. note themselves, if the surface uranium element is lost, the age results should be older on top and younger at the bottom . That is true, but the surface layer affected by uranium loss is not under 1 mm thick; its loss of the parent isotope would extend as deeply as prolonged exposure to precipitation and diagenetic processes can mobilise it. Indeed, Zhang and colleagues should have tested their hypotheses by securing core samples inside the massive travertine deposits. We predict that if that were done (of course, away from the hand and footprints), they would have found that the deep interior of a given stratum delivered younger ages than the surface-nearest sample. That would have served as a proper test to check that there was no loss of ^{234}U or deposition of detrital ^{230}Th, but unfortunately, it was not attempted.

Zhang et al. (2023) state that the sediment samples were determined to be dense calcite crystals without recrystallisation phenomena . Calcite crystals always become crystals through a crystallisation process. The travertine of the site derives from a saturated solution of calcite that has been dissolved by carbonic acid, a weak acid temporarily formed by water and carbon dioxide, according to the reversible reaction

$$CaCO_3(s) + CO_2(g) + H_2O(l) \leftrightarrow Ca(HCO_3)_2(aq) \quad (1)$$

This is important because the carbon dioxide derives from the atmosphere, so about one-half of the calcium bicarbonate's carbon comprises a given component of ^{14}C, which remains upon re-precipitation (crystallisation) back to $CaCO_3$. That is why reprecipitated carbonate is usually amenable to radiocarbon analysis (Bednarik 1999). A valid counterargument would be that the CO_2 that helped dissolve and mobilise the limestone was of volcanic origin, but its isotopic origin is still to be determined here. What is certain is that the precipitation of the carbonate solute occurred because of the changed conditions as it emerged at the surface. Both temperature and pressure had to adjust to atmospheric conditions, and the carbonate recrystallised.

3. The generic issues

In the several Spanish cases of excessively great ages for parietal rock art, the researchers sought to demonstrate that Neanderthals made the cave paintings. These authors were apparently unaware that in several instances, for over a century, it has been credibly shown that these and even earlier extinct humans had produced art-like creations. However, Zhang et al. (2021) went further than their European peers. They proposed a Middle Pleistocene antiquity for rock art in a region where human presence at that time was not even demonstrated and is not likely to be proven. Their extraordinary claim is made simply on the strength of dates derived from a method that is contentious when applied to travertine fully exposed to precipitation. Moreover, they claimed that the Qiusang markings are the oldest known art-like productions in the world. To support that postulate, they mentioned four instances said to be between 73 and 40 ka old (mistakenly defining the Blombos Cave mobiliary art as rock art). If these are all the examples of art-like productions older than 40 ka they know, it would indicate carelessness. Mentioning four randomly selected sites and implying that these are the oldest known instances is inadequate for such a bold claim.

The number of such specimens claimed and thought to be over 40 ka old is in the many hundreds. We do not attempt to count them or claim that we have a complete list of them, but many have been summarised (Bednarik 2017). Concerning art-like manifestations earlier than 40 ka we just mention in passing a few find sites and the suggested ages of their evidence: Trinil (500 ka), Xinglongdong (150–120 ka), Auditorium and Daraki Chattan Caves (both Mode 1 tool industries), Gesher Benot Ya'aqov (Acheulean), Berekhat Ram (470–233 ka), Qafzeh Cave (100 ka), La Ferrassie, Tata, Axlor, Abri Suard, Petit Puymoyen, Montgaudier, Peyrere 1 Cave, La Quina, Abri Blanchard, Tagliente Shelter, Cueva Morín, Schulen, Bacho Kiro, Temnata Cave, El Castillo, Grotte Vaufrey, Gorham's Cave, Zarzamora Cave, Arcy-sur-Cure (all Mousterian or Middle Palaeolithic), Oldisleben and Prolom 2 Cave (both Micoquian/Keilmesser tradition), Whylen (230 ka), Bruniquel (176 ka), Biddenham (Acheulean), Kozarnika Cave (1.4–1.2 Ma), Bilzingsleben (~400–300 ka), Stránská skála (ditto), Kathu Pan 1 (1.3 Ma–800 ka, also 540 ka), Kabwe (<800 ka), Nooitgedacht (~500 ka), Canteen Koppie (~500 ka), Wonderwerk Cave (>350–280 ka, also 500–280 ka and ~1.1 Ma), Site GnJb-15 (509–284 ka), Tan-Tan (~500–300 ka), Twin Rivers Kopje (>400 ka, also 270–170 ka), Zombepata Cave (~200 ka), Pomongwe Cave (>200 ka), Bambata Cave (>200 ka), Sai Island (~200 ka), Mashwening (800 ka), El Greifa (200 ka), Potholes Hoek (~410 ka, also ~120 ka), Nchwaneng (ditto), Klipbak (~120 ka), Rhino Cave (85–65 ka), Corner Cave (>50 ka), and so forth. If we also include the category of manuports (as we should), the earliest example dates from almost 3 million years ago. In short, the purported age of 226–169 ka does not remotely qualify the Qiusang markings as the earliest known rock art. We emphasise that we are not necessarily advocating the validity of all the proposals listed here; we merely point out that they would need to be considered in the context of a claim of earliest art .

Zhang et al. (2021) presented detailed reasons why the hand and footprints of Qiusang should be accepted as a form of rock art. Perhaps they anticipated their status as art would be challenged, noting that there is currently no widely recognised definition of art . We concur: the status of an artefact as work of art results from the ideas a culture applies to it, rather than its inherent physical or perceptible qualities. Cultural interpretation (an art theory of some kind) is therefore constitutive of an object's arthood (Danto 1988). Certainly, the prints of Qiusang are exograms, so they are a form of art-like production. However, they are not parietal art , as the Zhang team continues to insist. Parietal refers to a cavity wall, as in anatomy and botany. Therefore, parietal art defines the type of rock art on the walls or ceilings of limestone caves or cavernous rock-shelters (*Glossary, International Federation of Rock Art Organizations*, http://www.ifrao.com/ifrao-glossary/). It is relatively rare globally, accounting for under 1% of all rock art. For instance, in Australia, with literally hundreds of thousands of rock art sites, we currently know of only 51 parietal art sites in limestone caves.

It also needs to be investigated whether travertine deposition would have occurred during the glacial phase proposed by Zhang et al. s (2021) dating attempt, which would likely have seen reduced degassing and decreased level of supersaturation of the solution. Low temperatures and snow deposition would have also inhibited the extensive dendrite growth observed by Wang et al. (2016: 228) in the Qiusang travertines, even if there had been no ice cap.

4. Discussion

The Qiusang controversy is not unique. The discourse concerning the Australian cupule site Jinmium in the Northern Territory is a prominent precedent. An excavation below a shallow and small rock-shelter had yielded an exfoliated fragment of the rock art and other artefacts, and thermoluminescence (TL) analysis was applied to the sediments to estimate their ages. The lowest TL date implied that humans had first occupied Australia 176 ka ago, at least three times as long as previously assumed. The stratified cupule fragment was said to be deposited sometime between 75 and 58 ka BP (Fullagar et al., 1996). Subsequent testing by optically stimulated luminescence (OSL) and radiocarbon analyses proved that the entire sediment deposit is of the Holocene, and the exfoliated petroglyphs had fallen from the wall only about 4000 years ago (Roberts et al., 1998). The greatly excessive ages secured by TL derived from the decomposing (regolithic) sandstone grains that had not been exposed to light before they were covered by sediment. In contrast to TL, in OSL, single grains are evaluated (Bednarik 2016: 61–62, 99–100).

Another example involves the same age-estimating method applied in the Qiusang case, U–Th analysis. Some painted rock art in several Spanish caves has been minimum-dated to sensationally early times (e.g. Pike et al., 2012, 2017), contradicting archaeological narratives (e.g. Bednarik 2012; Clottes 2012; Pons-Branchu et al., 2014; Sauvet et al., 2015; Tang et al., 2020; Tang and Bednarik 2021; White et al., 2019; Bednarik et al., 2022). The Qiusang controversy resembles both the Jinmium claims and those from the Spanish caves. It was foreshadowed by Wang et al. (2016: 232) when they noted that several aspects of the Qiusang travertine render U–Th dating problematic: the widespread recrystallisation of primary fabrics likely resulted in open-system behaviour and thus gain or loss of radionuclides; recrystallisation might have caused mixing and intermingling of different crystal fabrics of different isotopic composition; and many calcite samples likely contain detrital Th.

In summary, the hand and footprints at the QHS site were made at the same time as Tibetan inscriptions, no earlier than 1300 years ago, because both were made in the still-soft precipitate. That renders the age estimates of Zhang and Li (2002) and Wang et al. (2023) redundant. Could the similar hand and footprints at the nearby QW site be in the order of 200 times older? Their excellent state of preservation contradicts that sensational proposition emphatically. Other major concerns are the complete lack of archaeological support for a Middle Pleistocene age of the imprints and the improbable presence of children at an altitude of over 4200 m asl during the penultimate Ice Age.

To test the results presented, radiocarbon and uranium-series analyses would need to be conducted at both sites using core samples rather than sub-surface samples. It also needs to be determined how deeply precipitation moisture penetrates the travertine, creating open C, U and Th systems. Weathering causes mobilisation of U and possibly deposition of detrital Th, which substantially increase apparent U–Th age. We predict that the weathering zone is significantly more than 1 mm, rendering Zhang et al. s (2021) U–Th results from Qiusang irrelevant. We also need to mention that one of the two laboratories providing the conflicting results Tang et al. (2020) and Tang and Bednarik (2021) reported was the same Zhang et al. (2021) used in their work. We suggest that what they define as a mature method is still experimental in this context, as are all methods currently used for rock art age estimation (Bednarik 2002), including those we use. The issue is not the method but its application to deeply weathered travertine, i.e., an unsuitable medium.

Uncited references

Fullagar et al., 1996, Tang and Xiagewangdui, 2022, Zhang and Dennell, 2018

Declaration of competing interest

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

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References

An, Z., Kutzbach, J.E., Prell, W.L., Porter, S.C., 2001. Evolution of asian monsoons and phased uplift of the himalaya-Tibetan plateau since late miocene times. Nature 411, 62–66.
Aubert, M., Brumm, A., Huntley, J., 2018. Early dates for Neanderthal cave art may be wrong. J. Hum. Evol. 125, 215–217.
Bard, E., Hamelin, B., Fairbanks, R.G., Zindler, A., 1990. Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U–Th ages from Barbados corals. Nature 345, 405–410.
Bednarik, R.G., 1984. Die Bedeutung der paläolithischen Fingerlinientradition. Anthropologie 23, 73–79.
Bednarik, R.G., 1986. Parietal finger markings in Europe and Australia. Rock Art Res 3, 30–61.
Bednarik, R.G., 1997. Direct dating results from rock art: a global review. AURA Newsl 14 (2), 9–12.
Bednarik, R.G., 1999. The speleothem medium of finger flutings and its isotopic geochemistry. Artefactum 22, 49–64.
Bednarik, R.G., 2002. The dating of rock art: a critique. J. Archaeol. Sci. 29 (11), 1213–1233.
Bednarik, R.G., 2007. Rock Art Science: the Scientific Study of Palaeoart. Aryan Books International, New Delhi.
Bednarik, R.G., 2012. U–Th analysis and rock art: a response to Pike et al. Rock Art Res 29 (2), 244–246.
Bednarik, R.G., 2016. Myths about Rock Art. Archaeopress Archaeology, Oxford.
Bednarik, R.G., 2017. Palaeoart of the Ice Age. Cambridge Scholars Publishing, Newcastle upon Tyne.
Bednarik, R.G., 2022. The dating of rock art and bone by the uranium–thorium method. Rock Art Res 39 (2), 195–204.
Bednarik, R.G., Jin, A., Chao, G., 2022. The travertine hand and footprints at Qiusang, Tibet. Rock Art Res 39 (2), 215–218.
Clottes, J., 2012. U-series dating, evolution and Neandertal. Int. Newsl. Rock Art 64, 1–6.
Danto, A.C., 1988. In: Vogel, S. (Ed.), Artifact and Art. An Exhibition Catalogue for ART/artifact. Center for African Art, New York, pp. 18–32.
Fullagar, R.L.K., Price, D.M., Head, L.M., 1996. Early human occupation of northern Australia: archaeology and thermoluminescence dating of Jinmium rock-shelter, Northern Territory. Antiquity 70, 751–773.
Garnett, E.R., Gilmour, M.A., Rowe, P.J., Andrews, J.E., Preece, R.C., 2004. ^{230}Th/^{234}U dating of Holocene tufas: possibilities and problems. Quat. Sci. Rev. 23 (7–8), 947–958.
Hoffmann, D.L., Spötl, C., Mangini, A., 2009. Micromill and in situ laser ablation sampling techniques for high spatial resolution MC-ICPMS U-Th dating of carbonates. Chem. Geol. 259, 253–261.
Hoffmann, D.L., Standish, C.D., García-Diez, M., Pettitt, P.B., Milton, J.A., Zilhão, J., et al., 2018. U–Th dating of carbonate crusts reveal Neanderthal origin of Iberian cave art. Science 359 (6378), 912–915.
Holmgren, K., Lauritzen, S.-E., Possnert, G., 1994. ^{230}Th/^{234}U and ^{14}C dating of a late Pleistocene stalagmite in Lobatse II cave, Botswana. Quat. Sci. Rev. 13, 111–119.
Labonne, M., Hillaire-Marcel, C., Ghaleb, B., Goy, J.L., 2002. Multi-isotopic age assessment of dirty speleothem calcite: an example from Altamira Cave, Spain. Quat. Sci. Rev. 21, 1099–1110.
Marquet, C., Freiesleben, T.H., Thomsen, K.J., Murray, A.S., Calligaro, M., Macaire, J., Robert, E., Lorblanchet, M., Aubry, T., Bayle, G., Bréhéret, G., Camus, H., Chareille, P., Egels, Y., Guillaud, É., Guérin, G., Gautret, P., Liard, M., Peyrouse, B., Thamó-Bozsó, E., Verdin, P., Wojtczak, D., Oberlin, C., Jaubert, J., 2023. The earliest unambiguous Neanderthal engravings on cave walls: La Roche-Cotard, Loire Valley, France. PLoS One 18 (6), e0286568.
Meyer, M.C., Aldenderfer, M.S., Wang, Z., Hoffmann, D.L., Dahl, J.A., Degering, D., Haas, W.R., Schlütz, F., 2017. Permanent human occupation of the central Tibetan Plateau in the early Holocene. Science 355, 64–67.
Peyrony, D., 1934. La Ferrassie. Préhistoire 3, 1–92.
Pike, A.W.G., Hoffmann, D.L., García-Diez, M., Pettitt, P.B., Alcolea, J., de Balbín, R., et al., 2012. U-series dating of Paleolithic art in 11 caves in Spain. Science 336 (6087), 1409–1413.
Pike, A.W.G., Hoffmann, D.L., Pettitt, P.B., García-Diez, M., Zilhão, J., 2017. Dating Palaeolithic cave art: why U–Th is the way to go. Quat. Int. 432, 41–49.
Plagnes, V., Causse, C., Fontugne, M., Valladas, H., Chazine, J.-M., Fage, L.-H., 2003. Cross dating (Th/U-^{14}C) of calcite covering prehistoric paintings in Borneo. Quat. Res. 60 (2), 172–179.
Pons-Branchu, E., Bourrillon, R., Conkey, M.W., Fontugne, M., Fritz, C., Gárate, D., et al., 2014. Uranium-series dating of carbonate formations overlying Paleolithic art: interest and limitations. Bull. Soc. Préh. Franç. 111 (2), 211–224.
Pons-Branchu, E., Sanchidrián, J.L., Fontugne, M., Medina-Alcaide, M.A., Quiles, A., Thiel, F., Valladas, H., 2020. U-series dating at Nerja Cave reveal open system. Questioning the Neanderthal origin of Spanish rock art. J. Archaeol. Sci. 117, 105–120.
Quiles, A., Fritz, C., Medina, M.A., Pons-Branchu, E., Sanchidrián, J.L., Tosello, G., Valladas, H., 2014. Chronologies croisées (C-14 et U/Th) pour l étude de l art préhistorique dans la grotte de Nerja: méthodologie. In: Medina-Alcaide, M.A.,

Romero Alonso, A., Ruiz-Márquez, R.M., Sanchidrián Torti, J.L. (Eds.), Sobre Rocas Y Huesos: Las Sociedades Prehistóricas Y sus Manifestaciones Plásticas. Fundación Cueva de Nerja, Córdoba, pp. 420–427.

Roberts, R.G., Bird, M., Olley, J., Galbraith, R., Lawson, E., Laslett, G., Yoshida, H., Jones, R., Fullagar, R., Jacobsen, G., Hua, Q., 1998. Optical and radiocarbon dating at Jinmium rock shelter in northern Australia. Nature 393, 358–362.

Rodríguez-Vidal, J., d Errico, F., Pacheco, F.G., Blasco, R., Rosell, J., Jennings, R.P., et al., 2014. A rock engraving made by Neanderthals in Gibraltar. Proc. Natl. Acad. Sci. USA 111 (37), 13301–13306.

Sanchidrián, J.L., Valladas, H., Medina-Alcaide, M.A., Pons-Branchu, E., Quiles, A., 2017. New perspectives for ^{14}C dating of parietal markings using $CaCO_3$ thin layers: an example in Nerja Cave (Spain). J. Archaeol. Sci.: Repura 12, 4–80.

Sauvet, G., Bourrillon, R., Conkey, M., Fritz, C., Garate-Maidagan, D., Rivero Vila, O., Tosello, G., White, R., 2015. Answer to Comment on uranium-thorium dating method and Palaeolithic rock art by Pons-Branchu et al. Quat. Int. 432, 86–92.

Slimak, L., Fietzke, J., Geneste, J.M., Ontañón, R., 2018. Comment on U-Th dating of carbonate crusts reveals Neandertal origin of Iberian cave art . Science 361 (6408). https://doi.org/10.1126/science.aau1371w.

Taçon, P.S.C., Aubert, M., Gang, L., Yang, D., Liu, H., May, S.K., Fallon, S., Ji, X., Curnoe, D., Herries, A.I.R., 2012. Uranium-series age estimates for rock art in southwest China. J. Archaeol. Sci. 39, 492–499.

Tang, H., Bednarik, R.G., 2021. Rock art dating by $^{230}Th/^{234}U$ analysis: an appraisal of Chinese case studies. Arch. Anthrop. Sc. 13 (1), 1–10. https://doi.org/10.1007/s12520-020-01266-0.

Tang, H., Kumar, G., Jin, A., Bednarik, R.G., 2020. Rock art of Heilongjiang province, China. J. Archaeol. Sci.: Repura 31, 102348.

Tang, H., Xiagewangdui, Lv H., 2022. Hand and foot prints at Qiusang in Tibet and related issues. J. Hebei Normal Univ. (Philos. Soc. Sci. Ed.) 45 (5), 77–85.

Valladas, H., Pons-Branchu, E., Dumoulin, J.P., Quiles, A., Sanchidrián, J.L., Medina-Alcaide, M.A., 2017. U/Th and ^{14}C crossdating of parietal calcite deposits: application to Nerja Cave (Andalusia, Spain) and future perspectives. Radiocarbon 59, 1955–1967.

Wang, L., Zhang, H., Zhang, D.D., Cheng, H., Zhang, S., Li, T., Zhang, Y., Wang, X., Wu, Z., Wang, Y., Chen, F., 2023. New evidence of prehistoric human activity on the central Tibetan plateau during the early to middle Holocene. Holocene. https://doi.org/10.1177/09596836231183060.

Wang, Z., Meyer, M.C., Hoffmann, D.L., 2016. Sedimentology, petrography and early diagenesis of a travertine–colluvium succession from Chusang (southern Tibet). Sediment. Geol. 342, 218–236.

White, R., Bosinski, G., Bourrillon, R., Clottes, J., Conkey, M.W., Corchón, S., Cortés-Sánchez, M., De La Rasilla, M., Delluc, B., Delluc, G., Feruglio, V., Floss, H., Foucher, P., Fritz, C., Fuentes, O., Garate, D., González, J., González-Morales, M., González-Pumariega, M., Groenen, M., Jaubert, J., Martinez-Aguirre, M.A., Medina Alcaide, M.A., Moro, O., Ontañón, R., Paillet-Man-Estier, E., Paillet, E., Petrognani, E., Pigeaud, R., Pinçon, G., Plassard, F., Ripoll, S., Rivero, O., Robert, E., Ruiz-Redondo, A., Ruiz, J.F., San Juan-Foucher, C., Sanchidrián, J.L., Sauvet, G., Simón-Vallejo, M.D., Tosello, G., Utrilla, P., Vialou, D., Willis, M.D., 2019. Still no archaeological evidence that Neanderthals created Iberian cave art. J. Hum. Evol. 144, 102640.

Zhang, D.D., Bennett, M.R., Cheng, H., Wang, L., Zhang, H., Reynolds, S.C., Zhang, S., Wang, X., Li, T., Urban, T., Pei, Q., Wu, Z., Zhang, P., Liu, C., Wang, Y., Wang, C., Zhang, D., Edwards, R.L., 2021. Earliest parietal art: hominin hand and foot traces from the middle Pleistocene of Tibet. Sci. Bull. https://doi.org/10.1016/j.scib.2021.09.001.

Zhang, D.D., Cheng, H., Wang, L., Zhang, H., Zhang, S., Bennett, M., 2023. Response to Remark on related issues of the hand and footprints at Qiusang in Tibet . J. Earth Env. 14 (1), 1–8.

Zhang, D.D., Li, S.H., 2002. Optical dating of Tibetan human hand- and footprints: an implication for the palaeoenvironment of the last glaciation of the Tibetan Plateau. Geophys. Res. Lett. 29 (5), 16–21.

Zhang, J.-F., Dennell, R., 2018. The last of Asia conquered by *Homo sapiens*. Science 362 (6418), 992–993.

Zhang, X.L., Ha, B.B., Wang, S.J., Chen, Z.J., Ge, J.Y., Long, H., He, W., Da, W., Nian, X.M., Yi, M.J., Zhou, X.Y., Zhang, P.Q., Jin, Y.S., Bar-Yosef, O., Olsen, J.W., Gao, X., 2018. The earliest human occupation of the high-altitude Tibetan Plateau 40 thousand to 30 thousand years ago. Science 362 (6418), 1049–1051.