Journal of Archaeological Science 39 (2012) 492–499

Contents lists available at SciVerse ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Uranium-series age estimates for rock art in southwest China

Paul S.C. Taçon [a,*], Maxime Aubert [b], Li Gang [c], Yang Decong [d], Liu Hong [e], Sally K. May [f], Stewart Fallon [g], Ji Xueping [d,h], Darren Curnoe [i], Andy I.R. Herries [j]

[a] PERAHU, School of Humanities, Gold Coast campus, Griffith University, Queensland 4222, Australia
[b] School of Earth & Environmental Sciences, University of Wollongong, Wollongong 2522, Australia
[c] Diqing Tibetan Autonomous Prefecture Cultural Relics Administration Office, Zhongdian, Yunnan, China
[d] Yunnan Institute of Cultural Relics and Archaeology, 15-1, Chunmingli, Chunyuanxiaoqu, Kunming, Yunnan 650118, China
[e] Yunnan Institute of Geography, Yunnan University, No. 20 Xue Fu Road, Kunming, Yunnan 650223, China
[f] Research School of Humanities and Arts, Australian National University, Canberra 0200, Australia
[g] Research School of Earth Sciences, Australian National University, Canberra 0200, Australia
[h] History Department, Yunnan University, Kunming, Yunnan 650223, China
[i] School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney 2052, Australia
[j] Archaeology Program, School of Historical and European Studies, La Trobe University, Melbourne, Victoria 3086, Australia

ARTICLE INFO

Article history:
Received 21 May 2010
Received in revised form
30 September 2011
Accepted 6 October 2011

Keywords:
China
Rock art
Dating
U-series
Radiocarbon
Jinsha River

ABSTRACT

We report the first uranium-series age estimates for rock art in China. Calcite bracketing a paint layer was used to constrain the age of a naturalistic outline hunter-gatherer painting in the Jinsha River area of northwest Yunnan Province (southwest China). The rock paintings in this region are unique in style and content compared with other bodies of rock art in China, which are dominated by Neolithic subject matter. The minimum and maximum ages were determined using isochron techniques on multiple samples of calcite from above and beneath the paint layer. A large painted deer head was dated to between 5738 and 2050 years. This painting and underlying flowstone are superimposed on older paintings that suggest the older paintings are at least 3400 years old, if not older than 5738 years. The results indicate for the first time that Jinsha River rock art is older than other forms of rock art in the region and show that rock art likely extends back to at least the transition from the Palaeolithic to Neolithic in this part of China.

1. Introduction

One of the greatest challenges facing rock art research at present is the reliable application of dating methods, especially numerical (geochronological) approaches (Bednarik, 1995, 2002; Chippindale and Taçon, 1998; Pettitt and Pike, 2007). Since 1980 (see Bednarik, 1984) there has been an international push to trial various techniques, particularly Accelerator Mass Spectrometry (AMS) radiocarbon and uranium-series dating, sometimes with controversial results (see Pettitt et al., 2009). Most of this research has occurred in Australia (Langley and Taçon, 2010), Europe (e.g. Clottes, 1998; Pettitt and Pike, 2007), the Americas (e.g. Rowe, 2000) and, recently, South Africa (e.g. Mazel, 2009; Mazel and Watchman, 1997, 2003). There have, however, been few attempts to date the rock art of East Asia despite the apparent great density, diversity and potential significance of the record of this region.

In China, the few published geochronological studies suggest that the rock paintings and engravings of this country, consisting of stylised human figures and animals, are less than 3000 years old (Bednarik, 1992; Bednarik and Li, 1991). However, in the Jinsha River region of northwest Yunnan Province rock paintings have been reported which are unlike the art found in other regions of China or neighbouring countries (Deng, 2004; Peng, 1995, 1996; Taçon et al., 2010b). Paintings in this region include naturalistic animal-outline images, superficially resembling Magdalenian paintings and engravings on portable art objects from France and Spain, as well as the rock art of some parts of India (Taçon et al., 2010a) and elsewhere. At some Jinsha River sites, paintings are sometimes encrusted with flowstone of varying thickness, partially obscuring paintings. Moreover, many Yunnan paintings show clear signs of extensive weathering hinting at their antiquity (Taçon et al., 2010b). In this paper, we present the results of dating research combining two methods (^{14}C and U-series) on flowstone for

* Corresponding author. Tel.: +61 (0) 7 55529074; fax: +61 (0) 7 55528141.
E-mail addresses: p.tacon@griffith.edu.au (P.S.C. Taçon), maubert@uow.edu.au (M. Aubert), dqwwbh@sohu.com (L. Gang), decong66@hotmail.com (Y. Decong), hongliu@ynu.edu.cn (L. Hong), sally.may@anu.edu.au (S.K. May), stewart.fallon@anu.edu.au (S. Fallon), jxping@public.km.yn.cn (J. Xueping), d.curnoe@unsw.edu.au (D. Curnoe), a.herries@latrobe.edu.au (A.I.R. Herries).

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doi:10.1016/j.jas.2011.10.004

paintings in Yunnan Province. U-series dating of rock art as outlined above has until now not been undertaken in East Asia but has been successfully applied to sites in Timor (Aubert et al., 2006; O'Connor et al., 2010). Our results provide new evidence extending the age of rock art in East Asia.

1.1. *Jinsha River and its rock art*

Jinsha River (Fig. 1), the upper part of the Yangtze River, flows from the Tanggula Mountains of the Qinghai-Tibet Plateau, abruptly changing direction at several key locations between Zhongdian (Shangri-La), Lijiang and Ninglang, and passing through the spectacular Tiger Leaping Gorge as it winds its way over 1560 km east (Deng, 2004). In the process, it forms a large north-south open triangle shape in this area and it is here, and along the banks of its adjacent tributaries, that most Jinsha River rock art is located. This is an area of high mountains and deep valleys, with an average valley depth of about 2000 m. The terrain consists of plateau, hillsides and valley floors, in addition to snow-covered peaks. The highest mountain in the region is Yulong (Jade Dragon) Snow Mountain at 5600 m above sea level. Hillsides typically exhibit an altitude of 3000–5000 m while valley floors are located at an altitude of 1100–3000 m.

The geological structure along the Jinsha River banks is frequently difficult to negotiate, comprising steep limestone cliffs. The river widens with varying water heights and a narrow valley zone. Outcrops of carbonate rocks are of Devonian, Carboniferous, and Permian ages, appearing along Jinsha River frequently.

Jinsha River rock art was 'discovered' by the outside world in 1988. This led to a number of small site specific studies, mostly by local Naxi researchers (Bao and He, 1999; Duan, 1989, 1991; He, 1993, 1996, 2005; Zhang, 2001). In 2005, one of us (Li Gang) began a comprehensive study of Jinsha River rock art. This work became part of a much larger Chinese-Australian collaborative research project that began in 2008 (Taçon et al., 2010b).

Between 1976 and 2008 fifty-five rock art sites were located within the Jinsha River region. Three of these consist of engravings on boulders in the open air, characterised by lines, abstract geometric designs and plant-like figures; seemingly part of a late Holocene engraving and painting tradition found in many nearby parts of China. A few sites contain painted depictions of people, including on horseback, human hands and other subjects that are similar to recent schematised art (less than 3000 years of age) found in other parts of Yunnan Province (such as at Cangyuan; see Wang, 1984). Thirty-eight sites contain naturalistic paintings of wild animals and human-like forms, mostly in outline and these are the focus of the present investigation. Common subject matter includes various species of deer, wild goat, bison, wild cattle (aurochs), horse and human-like forms. Large deer heads were painted over smaller naturalistic humans and animals at several sites and may be much younger.

Colour varies from orange to red and brown to dark purple. At many sites there are clusters of overlapping designs. Their condition ranges from very poor (highly weathered) to fair (exhibiting mild weathering) but with a few paintings relatively well preserved. At many sites paintings are so faded that they can

Fig. 1. Map of the Jinsha River study area highlighting its flow through traditional Naxi land. The rock art sites are located near the banks of the river and its tributaries (1 = Luodjihekou, 2 = Baiyunwan, 3 = Lamajugu, 4 = Huajizhu, 5 = Wanrendong).

only be viewed adequately using digital enhancement techniques. At other sites, rock walls are heavily weathered, cracked and crumbling, with only fragments of some paintings left *in situ*. In a few locations flowstone obscures parts of paintings, with the obvious potential for providing constraining dates.

During 2008 our team recorded eight sites, including Wanrendong and two nearby localities, Huajizhu (two sites), Lamajugu, Baiyunwan and Luodjihekou (Taçon et al., 2010b). Baiyunwan was sampled for U-series dating and the results are presented and discussed herein.

1.2. Site description

The Baiyunwan rock art site (Fig. 2) consists of a long limestone rock shelter about half way up the slope of a mountain and a few hundred metres above the Jinsha River, on a very steep gradient. Baiyunwan faces due south, measuring 22 m long and up to 5.7 m high. Its depth varies between 4.0 and 4.9 m (Fig. 3).

Baiyunwan art includes a diverse range of subjects. Fifteen paintings were identifiable: 3 large red outline deer heads; 3 small red outline deer heads; a dark red partial outline deer; an unidentified red outline quadruped/animal; a red outline bison with arrows piercing its body; a dark red outline deer; a red outline male goat; a red outline horse with lines for hair on its back; a purple-red outline male goat head; a red outline bull (aurochs) with solid infill horns; and a small red outline deer, partly under the bull. There are also many unidentifiable paintings, including some linear and snake-like designs with line infill and a patch of finger print marks (dots).

2. Materials and methods

At Baiyunwan, a thick band of flowstone was identified covering much of the limestone rock face, and masking (overlying) some paintings. A large sample was taken for U-series and radiocarbon dating (see Fig. 3 for sample location). When the sample was collected it became clear that a significant amount of flowstone from both on top and beneath a dark red painting (Fig. 4) – later identified as part of a large deer head with thick outline using digital enhancement via Photoshop® and DStretch® (Harmon, 2008) (Figs. 5–8) – had been fortuitously sampled. Beneath the deepest flowstone layer is another red layer. But this may relate to a natural red stain on the shelter wall, rather than representing a painting as such. The sample was obtained from a location 4 m from the western end of the shelter, with a height of 1.6 m above the shelter floor.

2.1. Uranium-series dating

The U-series dating method is based on the radioactive decay chain which includes the parent ^{238}U, the intermediary isotope ^{234}U and the daughter ^{230}Th (Bourdon et al., 2003). Because ^{238}U and ^{234}U isotopes are soluble in aqueous solutions but ^{230}Th is not, calcium carbonate crystals that are precipitated in flowstone will initially contain ^{238}U and ^{234}U, but generally not ^{230}Th. Subsequently, ^{234}U decays to ^{230}Th. The measurement of the ^{230}Th, ^{238}U, and ^{234}U isotopes allows calculation of the age of the carbonate host because the decay rate is known.

Unfortunately, it is common for carbonate to be contaminated by detrital materials – such as aeolian dust or water transported silts and clays – and as such can lead to U-series ages that are erroneously older than the true age of the sample. This is due to the fact that the detrital fraction will contribute to the overall amount of U-series nuclides so that the sample does not reflect a radioactive disequilibrium related to the time of carbonate formation. The effects of detrital contamination can be corrected by measuring the activity of ^{232}Th that is solely present in the detrital fraction but which plays no part in the decay chain of uranium. This is normally achieved using isochron techniques in which cogenetic sub-samples having different amounts of contamination are analysed and the activity ratio of the different isotopes in each of the sub-samples are plotted against each other. This enables the determination of the ^{232}Th-free end-member activity ratios of $^{230}Th/^{238}U_{carbonate}$ and $^{234}U/^{238}U_{carbonate}$ (Ludwig and Titterington, 1994).

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used to determine the amount of uranium (U) and

Fig. 2. Baiyunwan rock shelter (left and just below centre) is located in rugged terrain.

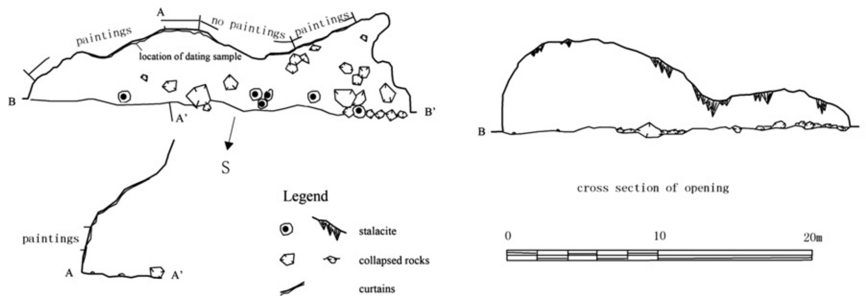

Fig. 3. Plan and cross-section of Baiyunwan rock shelter.

thorium (Th) in the sample and gain information about sub-sample size requirement for U-series dating (Fig. 9). Analyses were conducted using a custom-built laser sampling system interfaced between an ArF Excimer laser and a Quadrupole Varian-820 ICP mass-spectrometer. Details of this system and its capabilities have been described previously (Eggins et al., 1998a,b). Data reduction followed established laser ablation ICP-MS protocols (after Longerich et al., 1996), using the international glass reference materials NIST SRM610.

Under 30 times magnification eight samples (four each from above and beneath the paint layer) were cut into pieces using a micro-drill and dental saw blade. Each sample was then dissolved in acetic acid, spiked and prepared according to the method described by Luo et al. (1997). Isotopic ratio measurements were made on a Finnigan Neptune multi-collector ICP-MS equipped with desolvating nebuliser.

2.2. Radiocarbon dating

Radiocarbon dating of rock art usually involves removing charcoal used to draw or paint an image for dating (e.g. Valladas et al., 1992). Sometimes the organic binder in a paint layer can be extracted for ^{14}C analysis (e.g. Russ et al., 1990, 1992). But at some locations carbon-bearing crusts can contain carbon material like plant debris and micro-organisms that can be dated. Unfortunately, there are various factors complicating the radiocarbon dating of rock art and unless the source of carbon can be identified, radiocarbon dates on art should be taken as of unknown accuracy (Pettitt and Pike, 2007).

^{14}C dating used in speleothem and calcite coating chronology is also considered problematic, principally because of potential variability in the contribution of geological 'dead' carbon from the host rock (Harmon and Wicks, 2006). This will result in an overestimated radiocarbon age. Therefore, to obtain reliable calendar ages with flowstone ^{14}C dating, the fraction of incorporated 'dead' carbon is required to be estimated.

Five samples were micro-milled for AMS radiocarbon dating: three on top of the paint layer and two underneath. Sub-samples weighing ∼12 mg were pre-treated with 0.1 M HCl to remove ∼20% of the outer surface. The remaining sample (∼10 mg) was placed in individual reaction chambers, evacuated, heated and acidified with orthophosphoric acid at 90 °C. The CO_2 (∼1 mg Carbon) was then converted to graphite in the presence of Fe powder and H_2 gas, water being removed during reaction with $Mg(ClO_4)_2$. Samples were run on the Single Stage Accelerator Mass Spectrometer (SSAMS) at the Research School of Earth Sciences, The Australian National University. Samples were normalized to Oxalic Acid-I and a calcite blank was subtracted from the individual samples.

3. Results and discussion

3.1. U-series and AMS radiocarbon

Initial analysis showed low uranium concentration and high Th/U ratios. This means that relatively large samples would have to be extracted and that contamination from detrital material

Fig. 4. Flowstone covering red painting and sample taken for U-series and radiocarbon dating. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 5. The painted panel sampled for dating. The deer can barely be seen without digital enhancement.

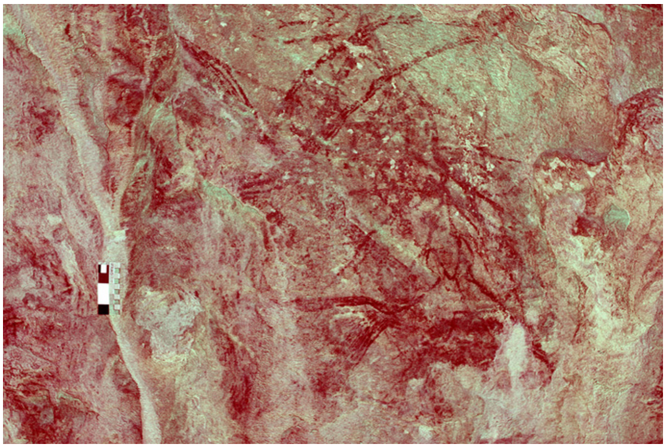

Fig. 6. Digitally enhanced picture, using the DStretch® program, of a large dark red thick outline deer head which lies over small thin-lined naturalistic deer and other animals. Sample was taken from above scale. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

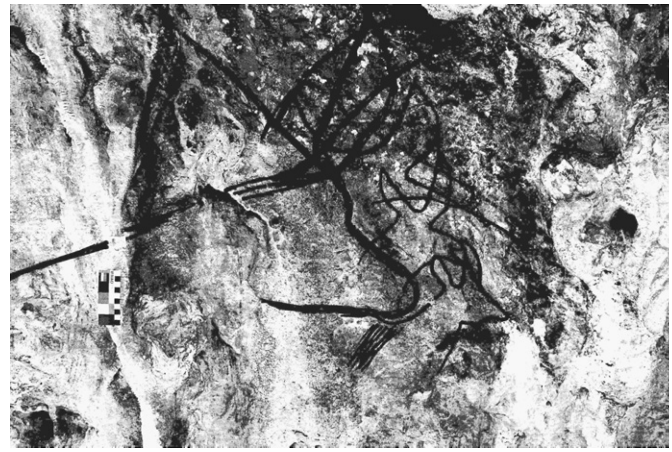

Fig. 8. Line drawing of overlapping figures and location of sample. Sample was taken from above scale.

would be a serious issue for U-series dating. Indeed, the eight U-series sub-samples are all characterised by low $^{230}Th/^{232}Th$ ratios indicating contamination by detrital materials. Therefore, the ages presented in Table 1 are overestimated and represent maximum ages.

To correct for the effects of detrital material the two sets of four cogenetic sub-samples were individually plotted against each other so as to produce isochron ages using the ISOPLOT program (Ludwig, 2001). Isochrons are given in Fig. 10 for both calcite layers. Isochron ages for the top and bottom layers indicate a minimum age for the painting of 2.3 ± 0.25 ka and a maximum age of 9.4 ± 6 ka. Therefore, the results of U–Th analyses suggest the painting most likely dates to between 9400 and 2050 years, but could be significantly older (up to 15,400 years).

Five samples were also micro-milled for ^{14}C dating (three on top of the paint layer and two underneath). The dating results are presented in Table 2. The samples are not corrected for dead carbon and are therefore overestimated and represent maximum ages. However, the samples are in stratigraphic order and they suggest a major hiatus during which the rock art was painted. This would seem to be the case whatever the offset for old carbon.

The minimum age for the deer head painting as indicated by U-series dating of flowstone overlying the painting is 2.3 ± 0.25 ka (2550–2050 years old). This result is considered both reliable and accurate. The same flowstone layer is dated to 4010 ± 30 (4475 ± 57 cal yr BP [4532–4418 cal yr BP] with IntCal 09) using radiocarbon dating. However, we do not know the amount of geological 'dead' carbon in the sample and as such this represents a maximum age for this flowstone. Comparing the two results suggests a 45–55% correction to radiocarbon results is in order. Unfortunately, there were no active flowstones to calculate the dead carbon fraction.

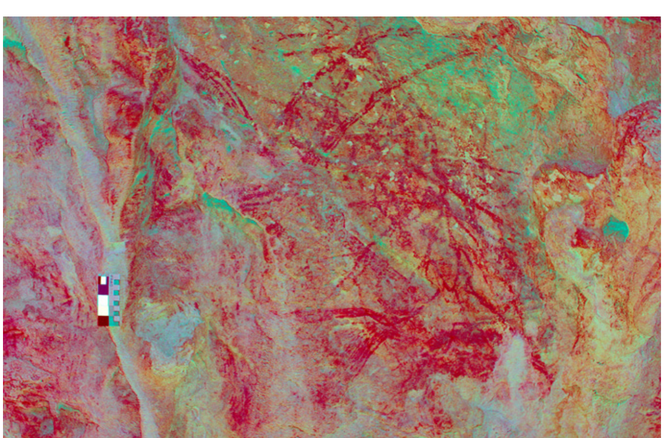

Fig. 7. Second digitally enhanced picture, using DStretch® program.

The maximum age for the painting as indicated by U-series dating is 9.4 ± 6 ka, which means it likely dates to anywhere between 15,400 and 3400 years ago. However, the radiocarbon result is 9170 ± 40 (10,335 ± 97 cal BP). Therefore the absolute maximum age is about 10, 432 years ago. However, if we assume the amount of dead carbon is constant throughout the layers then a 55–45% correction gives a maximum age range of 5738 to 4694 years ago.

3.2. Previous dating attempts, subject matter analysis and discussion

Until now, rock art at only two sites in China had been dated; in Yunnan and Guangxi Provinces. At Huashan, Guangxi, 'Dating was secured from the radiocarbon content of stalactite (reprecipitated calcium carbonate) physically related to the art' (Li, 1991: 29) with a result of between 2370 (maximum) and 2115 (minimum) years BP (Qin et al., 1987: 230–232; and see Bednarik, 1992). At Cangyuan, Yunnan, layers overlying and beneath a painting were also dated, indicating the art to be between 2960 (minimum) and 3100 years (maximum) of age. This result was supported by an analysis of pollen grains in the dated paint layers, revealing plant species typical of the region about 2500–3500 years ago, and charcoal dated to about 2700–2900 years ago obtained from an archaeological excavation of the site (Bednarik, 1992; Bednarik and Li, 1991: 27–28). However, the fraction of incorporated dead carbon does not appear to have been taken into account, suggesting that these results may be overestimations.

Extinct animals have been used to assign rock art from other parts of China to different periods with varying degrees of success (Tang, 1993); although Bednarik (2002) cautions using this method in isolation. The bison, large deer, wild horse, aurochs and other creatures depicted at Baiyunwan (see Taçon et al., 2010b: 75) are believed to have been extinct for thousands of years, but Jinsha River shelters have not yet been excavated for evidence of extinction events. However, faunal remains from neighbouring areas can provide clues. For instance, in nearby Sichuan, other

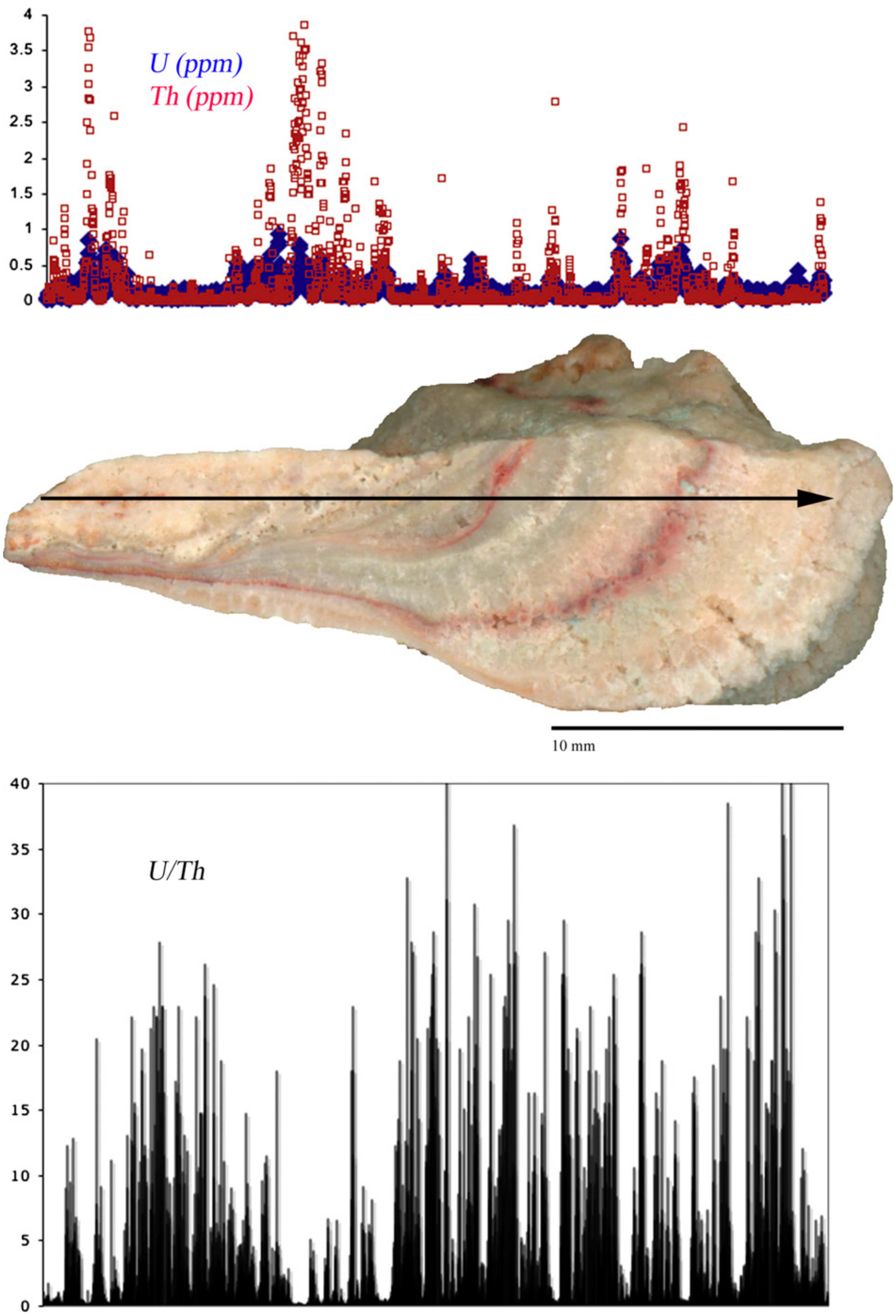

Fig. 9. Laser ablation ICP-MS analysis showing low uranium and high thorium concentrations indicating contamination from detrital materials.

Table 1
U-series dating results for the eight sub-samples (four over the paint layer and four beneath). These are contaminated by detrital materials as shown in the low $^{230}Th/^{232}Th$ ratios and represent maximum ages.

Sample	U ppm	Delta ^{234}U	±Delta ^{234}U	$[^{230}Th/^{238}U]$	$\pm[^{230}Th/^{238}U]$	$[^{230}Th/^{232}Th]$	Age (ka)	±Age (ka)	Initial Delta ^{234}U	±Initial Delta ^{234}U
Top 1	0.079	22.1	4.2	0.0652	0.00117	2.70	7.170	0.135	22.6	4.3
Top 2	0.068	22.2	2.6	0.0885	0.00152	2.46	9.840	0.170	22.8	2.7
Top 3	0.047	22.7	6.9	0.0808	0.00185	2.60	8.940	0.230	23.0	6.9
Top 4	0.060	23.5	3.2	0.1233	0.00174	2.22	13.960	0.215	24.5	3.3
Bottom 1	0.058	37.4	6.9	0.1061	0.00142	5.01	11.730	0.185	39.0	7.0
Bottom 2	0.059	38.7	3.8	0.1085	0.00167	4.71	11.980	0.195	40.1	3.8
Bottom 3	0.114	41.6	2.7	0.1031	0.00220	4.63	11.330	0.245	43.0	2.8
Bottom 4	0.057	36.7	4.0	0.1039	0.00260	5.24	11.470	0.305	37.9	3.8

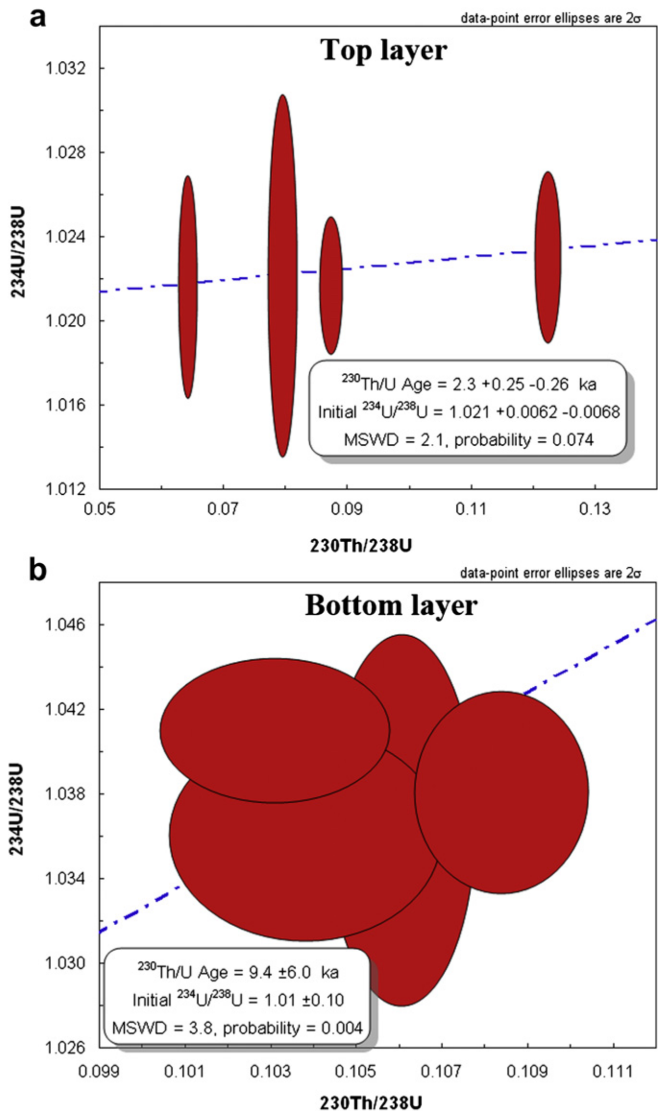

Fig. 10. Isochrons for two calcite layers from the on top and underneath the paint layer. Best fit lines were calculated using the ISOPLOT program (Ludwig, 2001).

parts of China and Siberian Russia, to the northeast, bison survived into the early Holocene in some locations (Huang and Zhang, 2003; Kalke, 1985; MacPhee et al., 2002), as did aurochs (Pushkina, 2007). Palaeontological evidence also suggests that wild horse and large deer disappeared during the Pleistocene in China (Louys et al., 2007; Pushkina, 2007).

At Maludong, in the south of Yunnan, large deer species died out during the late Pleistocene to early Holocene (Wu and Poirier, 1995: 207–209). At a second rock art site (Luodjihekou), 25 km to the north of Baiyunwan, we have noted an outline painting of the head and part of the back of a tapir in the same naturalistic style (see Taçon et al., 2010b: 77). The tapir depiction is important as the most recent remains of a tapir date to about 8000 years ago and were excavated by one of us (Ji Xueping along with Nina Jablonski in 2003, unpublished) at the Tangzigou site in Boashan, east of the Gaoligongshan Mountain, Yunnan, about 260 km to the southwest of Baiyunwan.

The depiction of these creatures at some Jinsha River sites suggests that they may have survived well into the Holocene in this region. Alternatively, some paintings underlying the Baiyunwan deer head and at other sites may have an early Holocene or late Pleistocene age, with our dates for the deer head not relating directly to them.

At several Jinsha River sites there are also depictions of human figures in the same naturalistic outline style as seen at Baiyunwan. Three of them hold bows and some depictions of animals show arrows piercing their bodies. While human figure depictions appear to reflect a hunting lifestyle caution is required as farming groups are also known to hunt. A recent review of the origins and spread of rice agriculture within China has concluded that ‘In southwest China, agriculture occurred in Sichuan *c.* 3000 BC and then spread into Guizhou and Yunnan *c.* 2500 BC’ (Zhang and Hung, 2010: 22). Thus, hunting and foraging may have persisted in Yunnan until about 4500 years ago, with rice agriculture, millet and other forms of domestication quickly spreading across the region. Farming populations probably expanded rapidly soon after, with Neolithic cultures then spreading into Southeast Asia (Zhang and Hung, 2010).

Much of the rock art across southwest China is dominated by stylised human figures, domesticated animals and abstract circle symbols. Overwhelmingly, it has a Neolithic character that is very different to the naturalistic outline art of northwest Yunnan at key sites like Baiyunwan. Previous dating attempts, as outlined above, have suggested this art to be between 2000 and 3000 years old (Bednarik, 1992; Bednarik and Li, 1991; Li, 1991; Wang, 1984). When similar figures do occur at Jinsha River sites they are found either overlying naturalistic figures or at other sites, on their own. The small naturalistic outline humans and animals are therefore likely to be older than the stylised figures. And as large deer heads are consistently found lying on top of small naturalistic outline figures at several sites, including Baiyunwan, the small figures are possibly older than 5738–3400 years of age.

Thus our results indicate that large outline paintings of deer heads at Jinsha River sites are the same age or older than previously dated rock art in China and that underlying small outline animals and human figures are likely to be even more ancient. Long extinct animals depicted at Baiyunwan and other Jinsha River rock art sites broadly support our dating results that the small naturalistic paintings may be older than the mid-Holocene; possibly much older. Alternatively, our dating results could support the idea that these species survived much later than has been found in the fossil record to date. This would be unsurprising given the patchiness of the fossil record and small number of sites found in East Asia from the later Pleistocene (Louys et al., 2007).

Table 2
^{14}C dating results for the five sub-samples (three over the paint layer and two beneath). These are affected by geological (dead) carbon and represent maximum ages.

Sample	$d^{13}C$	±	(pMC)	±	^{14}C age	±	^{14}C age (cal. Yrs)	±
Top 1	−14	3	60.73	0.21	4010	30	4475	57
Top 2	−14	2	60.26	0.21	4070	30	4574	73
Top 3	−14	3	59.47	0.19	4170	30	4580	79
Bottom 1	−17	3	31.95	0.14	9170	40	10,335	97
Bottom 2	−13	3	31.12	0.13	9380	30	10,607	87

4. Conclusion

Our research is only the third attempted absolute dating of rock art in China, but the first uranium-series approach. We conclude that the outline animal paintings of the Jinsha River region are a hunter-gatherer form of art older than other bodies of surviving Chinese rock art, which is generally agreed to be less than 3000 years old. A large painted deer head was dated to at least 2050 years ago based on U–Th ages of capping flowstone. The best age estimate for the maximum age of this painting based on the ^{14}C dating of underlying flowstone is around 5738 to 4694 years ago, although it could be older based on a uranium-series date of 9.4 ± 6 ka and variation in the amount of dead carbon incorporated into the flowstone during its formation. Various forms of evidence, including the dating of these flowstone layers above and below the large painted deer head that overlies small outline paintings, as well as an analysis of subject matter that includes long extinct animal depictions, indicates that small outline animal depictions of the Jinsha River region are likely to be at least 3400 years of age, and potentially more than 5738 years of age. Given the lack of scientifically dated rock paintings in this region, this new age estimation is significant. It allows, for the first time, for Chinese rock art to be extended back to a period of environmental and cultural transition, in scientific terms from Palaeolithic to Neolithic.

As all sites are threatened by natural deterioration and human impacts, such as the construction of a dam for a hydro-electric power plant and other forms of development, the full recording of all sites and further sampling for Uranium-series dating should be made a research priority.

Acknowledgements

In 2008 Taçon, May and Aubert were the first Westerners to visit Jinsha River sites with Li, Yang and Liu forming the rest of the field team along with Naxi guides Zhu Ziming, He Zhanglin, He Wenzhang, Zhu Jianlong and Yang Yaolong. We are most grateful to the Naxi people of the Jinsha River region of Yunnan Province, China for safely guiding us to rock art sites, sharing information and insights, their generosity and their hospitality. This research was supported financially and logistically by the Australian Research Council (Discovery Grant DP0877603), the Yunnan Institute of Cultural Relics and Archaeology (Kunming, China), Griffith University (Gold Coast, Australia), the University of New South Wales (Sydney, Australia) and the Cultural Relics Administrative Institute, Diqing Zang Autonomous Prefecture (Zhongdian, China). We also thank two anonymous referees whose comments helped improve the paper.

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