








## Research Article

# Re-evaluating Pleistocene–Holocene occupation of cave sites in north-west Thailand: new radiocarbon and luminescence dating

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Established chronologies indicate a long-term ‘Hoabinhian’ hunter-gatherer occupation of Mainland Southeast Asia during the Terminal Pleistocene to Mid-Holocene (45 000–3000 years ago). Here, the authors re-examine the ‘Hoabinhian’ sequence from north-west Thailand using new radiocarbon and luminescence data from Spirit Cave, Steep Cliff Cave and Banyan Valley Cave. The results indicate that hunter-gatherers exploited this ecologically diverse region throughout the Terminal Pleistocene and the Pleistocene–Holocene transition, and into the period during which agricultural lifeways emerged in the Holocene. Hunter-gatherers did not abandon this highland region of Thailand during periods of environmental and socioeconomic change.

Keywords: Mainland Southeast Asia, Thailand, Pleistocene–Holocene transition, hunter-gatherer, radiocarbon offset

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## Introduction

The highland regions of Mainland Southeast Asia are home to some of the earliest and longest records of hunter-gatherer activity. Recent studies from southern China indicate that hunter-gatherers had arrived in this region by at least 50 000–45 000 years ago (Ji *et al.* 2016). The incoming foragers used a lithic technocomplex (reduction sequence) known as the ‘Hoabinhian’ (characterised by unifacially flaked river-cobble stone tools, or ‘sumatraliths’; Reynolds 1990), and continued to occupy the region until approximately 3000 years ago (Forestier *et al.* 2013). Although the ‘Hoabinhian’ spans 40 000 years of hunter-gatherer activity throughout Southeast Asia, we lack fundamental details on variation in the foraging adaptations of its makers in both time and space (White 2011). Re-examination of ‘Hoabinhian’ chronologies in sub-regions, such as highland north-west Thailand, provides one way to increase our understanding of these adaptations, especially since many current chronologies rely on data from older fieldwork and dating programmes.

Archaeological excavations in 1966 and 1971 at Spirit Cave in Mae Hong Son Province, north-west Thailand (Figure 1), produced several of the first Pleistocene–Holocene transition

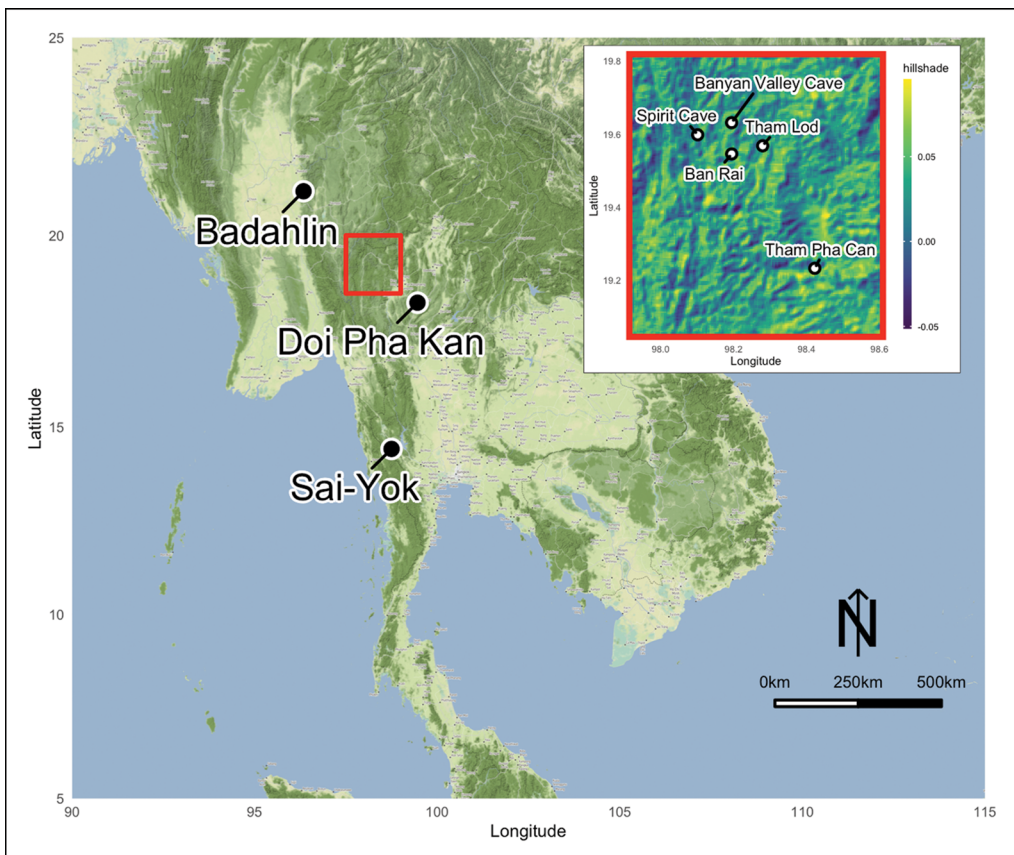


Figure 1. Map of key sites discussed in the text (map tiles by Stamen Design, under CC BY 3.0; data by OpenStreetMap, under ODbL).

radiocarbon determinations for the region (Gorman 1969, 1970, 1971a). Radiocarbon dates from early excavations at the nearby Myanmar site of Badahlin Cave (or Padah-Lin), among others, also indicated hunter-gatherer activity during the transition (Thaw 1971). These radiocarbon records, all derived from caves and associated with the ‘Hoabinhian’ technocomplex, were influential in establishing a chronology for the complex (Reynolds 1990). In addition, hunter-gatherer sites with sumatralith stone tool assemblages that lacked associated radiocarbon dates, such as Sai-Yok Rockshelter in western Thailand (van Heekeren & Knuth 1967), now included some probable temporal resolution. In the early 2000s, archaeologists obtained new radiocarbon and luminescence ages from sites in north-west Thailand that provided further temporal context for hunter-gatherer activities (Treerayapiwat 2005; Shoocongdej 2006; Marwick 2008). Radiocarbon- and luminescence-based chronologies from Tham Lod and Ban Rai rockshelters suggested forager occupations extending into the Late Pleistocene—over 30 000 years ago at Tham Lod—but only a sporadic Holocene occupation. More recent analyses show a similar trend: luminescence ages from Badahlin Cave in Myanmar indicate human occupation in the Pleistocene, and radiocarbon measurements from Doi Pha Kan in Thailand date to the Terminal Pleistocene (Imdirakphol *et al.* 2017; Schaarschmidt *et al.* 2019). Evidence for Holocene foragers in north-west Thailand is less well-established.

Here we re-examine the chronologies of three sites in north-west Thailand: Spirit Cave (*Tham Phi Man*), Steep Cliff Cave (*Tham Pha Chan*) and Banyan Valley Cave (*Tham Pung Hung*). We present new dates to investigate whether hunter-gatherers occupied this region of Mainland Southeast Asia primarily during the Terminal Pleistocene and Early Holocene, or whether there is also a longer-term Holocene record. Accurately dating these sites is crucial for contextualising their hunter-gatherer occupation and for further refining our understanding of forager adaptations in Mainland Southeast Asia.

## **Spirit Cave, Steep Cliff Cave and Banyan Valley Cave**

Chester Gorman excavated the sites of Spirit Cave, Steep Cliff Cave and Banyan Valley Cave in the 1960s and 1970s (Gorman 1963–1964, 1966, 1970, 1971a, 1971b, 1972, 1973). Spirit Cave, a small, shallow site, was excavated in 1966 and 1971 (Figure 2 and fig. S1 in Conrad *et al.* 2020a—an external research compendium). Excavation of eight units in the middle cave chamber revealed five stratigraphic layers (~1m deep in total; see Conrad 2018). Fourteen charcoal specimens collected in 1966 were submitted for radiocarbon analysis (Table 1). Conventional radiocarbon ages suggested hunter-gatherer occupation between  $11\,346\pm 560$  and  $7397\pm 320$  BP. In the early 2000s, however, researchers dated organic resin coatings from two ceramic sherds recovered from surface deposits, or Layer 1, at Spirit Cave (Lampert *et al.* 2003, 2004). These assays returned relatively late Holocene ages (Table 1). In short, Gorman’s original date for sherds at the site (FSU-317:  $7397\pm 320$  BP) suggested an Early Holocene appearance of ceramics in Mainland Southeast Asia, but the resin coating analysis suggested that ceramics probably dated to a much later period. White (2004) subsequently contested this new interpretation on stratigraphic grounds.

In early 1973, excavations took place at Steep Cliff Cave. Seven excavation units in this shallow rockshelter revealed a deep (~2m in total), fine-grained, loosely compacted sedimentary deposit. Although no stratigraphic profile drawings have been found in the site



Figure 2. Excavations at Spirit Cave (courtesy of the Institute for Southeast Asian Archaeology).

measurements on ceramic sherds (Table 1). These ages were internally consistent, with no evidence of stratigraphic mixing, and indicated a Mid- to Late Holocene hunter-gatherer occupation between  $5358 \pm 120$  and  $930 \pm 80$  BP. A single sherd from Layer 3 returned a date of *c.* 2000 BC, while a group of five sherds from higher stratigraphic contexts (probably Layers 1–3) yielded approximate ages between 900 and 500 BC. Rice (*Oryza* sp.) spikelets recovered from upper layers at the site—which potentially represented hunter-gatherer exploitation of wild forms of rice (Yen 1977, 1982)—would thus appear to date to the Late Holocene, given the dates indicated for Layers 1–3. Re-analysis of a sample of faunal remains and records from Banyan Valley Cave indicate that Gorman excavated at least seven layers (Conrad 2018). It is therefore possible that evidence for an older hunter-gatherer occupation exists at this site. Gorman never fully published the Banyan Valley Cave excavation (see Reynolds 1992).

## Approach and methods

We obtained 27 new radiocarbon determinations and four luminescence measurements in order to investigate the hunter-gatherer occupation of north-west Thailand. Samples were selected from curated legacy collections housed at the Penn Museum and the University of Otago. All stratigraphic and contextual information originate from Gorman's published

archive, surviving site descriptions (Gorman 1973) and photographs (see Conrad 2018; Figure 3 and Conrad *et al.* 2020a: fig. S2) suggest that five loosely differentiated stratigraphic layers were present. Radiocarbon analysis of two charcoal specimens returned Early to Mid-Holocene ages, but in reverse stratigraphic order (Table 1): the older date of  $7497 \pm 160$  BP comes from a layer (Layer 3) that lies higher in the stratigraphy than the younger date of  $5178 \pm 110$  BP (from Layer 4). Gorman never published his final interpretation of this site (see White & Gorman 2004).

Banyan Valley Cave, a large, deep cave, was excavated in 1972 (Gorman 1972; Figure 4 and Conrad *et al.* 2020a: fig S3). Eleven excavation units revealed a relatively shallow deposit ( $\sim 1$ m deep in total), with an internally complex stratigraphy and four identified layers. At Banyan Valley Cave, Gorman radiocarbon-dated two charcoal samples and obtained six thermoluminescence

Table 1. Original ages from the study sites (for numbered references, see compendium material in Conrad *et al.* 2020a). Dates calibrated (at 95.4% confidence) using OxCal v4.4.2 and the IntCal20 atmospheric curve (Bronk Ramsey 2020; Reimer *et al.* 2020).

Site	Unit	Layer	Material	Type	Uncalibrated radiocarbon age	±sd	Calibrated radiocarbon age (BP)	Laboratory number	References
Spirit Cave	C1–C2	Surface?	Resin coating	<sup>14</sup> C	3042	37	3362–3151	OxA-10271	1,2,3
	C1–C2	Surface?	Resin coating	<sup>14</sup> C	2995	40	3339–3008	OxA-10272	1,2,3
	B2–B3	1	Wood charcoal	<sup>14</sup> C	7397	320	8998–7619	FSU-317	4,5
	A2–B2	2	Wood charcoal	<sup>14</sup> C	7902	390	9717–7944	FSU-314	4,5
	A2–B2	2	Wood charcoal	<sup>14</sup> C	8547	200	10 166–9034	GaK-1846	4
	A2–B2	2	Wood charcoal	<sup>14</sup> C	7907	198	9399–8366	BM-501	6
	B2–B3	2a	Wood charcoal	<sup>14</sup> C	8265	140	9538–8783	TF-802	7
	B3–B4	2a	Wood charcoal	<sup>14</sup> C	8517	290	10 249–8724	FSU-318	4,5
	C2	3 or 4	Wood charcoal	<sup>14</sup> C	11 346	560	15 104–11 884	FSU-315	4,5
	B3	4	Wood charcoal	<sup>14</sup> C	10 096	310	12 702–10 793	TF-803	4
	C2 (North Wall)	4	Wood charcoal	<sup>14</sup> C	9073	112	10 565–9895	BM-502	6
	B2–C2	4	Wood charcoal	<sup>14</sup> C	9177	360	11 396–9478	GaK-1845	4
	B2	4	Wood charcoal	<sup>14</sup> C	10 896	580	14 306–11 162	FSU-316	4,5
	B3	4	Wood charcoal	<sup>14</sup> C	Contaminated	–	–	TF-804	8
	B2 (NW corner)	4	Wood charcoal	<sup>14</sup> C	9510	160	11 233–10 378	BM-503	6
	B2–C2 (fire pit)	4	Wood charcoal	<sup>14</sup> C	9202	106	10 658–10 190	BM-504	6
Steep Cliff Cave	E3	3	Wood charcoal	<sup>14</sup> C	7497	160	8597–7977	GaK-4531	9,10
	E2	4	Wood charcoal	<sup>14</sup> C	5178	110	6266–5660	GaK-4530	9,10
Banyan Valley Cave	F4	1	Wood charcoal	<sup>14</sup> C	930	80	961–682 BP	GaK-4340	11,12
	F4–E4	“Upper ground level 1”*	Sherds (n = 5)	TL	900–500 BC	NA	–	Oxford	11,13
	D4	3	Wood charcoal	<sup>14</sup> C	5358	120	6395–5906 BP	GaK-4341	11,12
	F4–E4	“Lower ground level 2”*	Sherd	TL	2000 BC	NA	–	Oxford	11,13

\* Layer notes for Banyan Valley Cave thermoluminescence samples taken from archived correspondence between C. Gorman and M.J. Aitken (University of Oxford) are on file at the Institute for Southeast Asian Archaeology.



Figure 3. Excavations at Steep Cliff Cave (courtesy of the Institute for Southeast Asian Archaeology).



*Figure 4. Excavations at Banyan Valley Cave (courtesy of the Institute for Southeast Asian Archaeology).*

records and unpublished field notes, the latter archived at the Institute for Southeast Asian Archaeology (ISEAA), Penn Museum.

We submitted four freshwater crab (*Indochinamon* sp.) dactyls from Spirit Cave to the University of Waikato Radiocarbon Dating Laboratory for AMS radiocarbon dating. Twenty-two additional radiocarbon samples, including plant charcoal, human and non-human mammalian bone apatite (structural carbonate), freshwater pearl mussel (*Margaritifera laosensis*) and rice spikelets (*Oryza sativa*) from Steep Cliff Cave and Banyan Valley Cave were analysed at the University of Georgia Center for Applied Isotope Studies (for background and methods, see the associated research compendium in Conrad *et al.* 2020a).

Our analysis includes a discussion of radiocarbon offsets in freshwater crab and mussel samples, given their predisposition to assimilate ancient calcium carbonate from dissolving limestone (Zhou *et al.* 1999; Ascough *et al.* 2005; Philippsen 2013; Bulbeck 2014; see also Conrad *et al.* 2020b). We calculated the freshwater reservoir correction (Culleton 2006) between *M. laosensis*, *Indochinamon* sp. and paired charcoal and bone apatite samples (e.g. Marwick *et al.* 2017). The reservoir correction is the difference between samples and their pairs by layer (see Stuiver *et al.* 1986).

Radiocarbon determinations for the figures were analysed and calibrated using the Bchron package in R (Parnell 2014; see Conrad *et al.* 2020a). All radiocarbon dates are standardised to the Libby 5568-year half-life (Godwin 1962; Stuiver & Polach 1977), including all legacy dates. Calibrated age ranges (at 95.4% confidence) provided in the tables were obtained using OxCal v4.4.2 and the IntCal20 atmospheric curve (Bronk Ramsey 2020; Reimer *et al.* 2020).

Finally, four ceramic specimens—two from Steep Cliff Cave and two from Banyan Valley Cave—were analysed by the Luminescence Dating Laboratory at the University of Washington for optically stimulated luminescence (OSL), thermoluminescence (TL) and infrared stimulated luminescence (IRSL) dating (see Conrad *et al.* 2020a).

## Results

Radiocarbon determinations on freshwater crab (*Indochinamon* sp.) from Spirit Cave's Layers 1, 2, 2a and 4 all date to the Early Holocene (Table 2; Figure 5). These ages, however, are in reverse stratigraphic order: the oldest sample, at  $9839 \pm 30$  BP, derives from Layer 1, while the youngest, at  $8551 \pm 25$  BP, derives from Layer 4. On average, freshwater crab dactyls are 970 years older than their paired charcoal samples, but the importance of this offset is diminished, given that the charcoal ages from Spirit Cave are in correct stratigraphic order and provide a clear chronological baseline.

Excluding Gorman's original dates, our new radiocarbon ages for Steep Cliff Cave are bracketed between  $11\ 160 \pm 30$  and  $7460 \pm 30$  BP (Table 2; Figure 6). Analysis of radiocarbon reservoir offsets in *M. laosensis* suggests that these dates are, on average, 1704 years older than their paired bone apatite and charcoal samples. Accounting for this offset, the earliest date at Steep Cliff Cave is  $9960 \pm 30$  BP. A direct bone apatite radiocarbon determination on a human bone specimen provides the youngest date for our new radiocarbon analysis at  $7460 \pm 30$  BP. One charcoal radiocarbon date of  $5178 \pm 110$  BP obtained by Gorman is



Table 2. New ages from Spirit Cave and Steep Cliff Cave. Calibrated ages are corrected for reservoir offsets. Dates calibrated (at 95.4% confidence) using OxCal v4.4.2 and the IntCal20 atmospheric curve (Bronk Ramsey 2020; Reimer *et al.* 2020).

Site	Unit	Layer	Material	Type	$\delta^{13}\text{C}$	Uncalibrated radiocarbon age	$\pm\text{sd}$	Calibrated radiocarbon age (BP)	Age (ka)*	% Error	Laboratory number
Spirit Cave	?	1	<i>Indochinamon</i> sp.	$^{14}\text{C}$	$-11.7\pm 0.2$	9839	30	11 313–11 197			Wk-40765
	?	2	<i>Indochinamon</i> sp.	$^{14}\text{C}$	$-13.9\pm 0.2$	9106	25	10 362–10 203			Wk-40766
	?	2a	<i>Indochinamon</i> sp.	$^{14}\text{C}$	$-13.4\pm 0.2$	8965	25	10 227–9921			Wk-40768
	?	4	<i>Indochinamon</i> sp.	$^{14}\text{C}$	–*	8551	25	9546–9487			Wk-40767
Steep Cliff Cave	E3	2	Cord-marked sherd	OSL/TL	–	–	–	–	8.4 $\pm$ 0.67	8.0	UW3680
	F3	2	Bamboo charcoal	$^{14}\text{C}$	$-27.6$	8300	30	9429–9141			UGAMS-29455
	G3	2	<i>M. laosensis</i>	$^{14}\text{C}$	$-8.7$	9800	30	11 252–11 189			UGAMS-29448
	D3	2	<i>H. sapiens</i> apatite	$^{14}\text{C}$	$-15.6$	7460	30	8355–8189			UGAMS-29451
	G3	2	Bovinae apatite	$^{14}\text{C}$	$-9.9$	8180	30	9270–9017			UGAMS-29452
	G3	4	Bamboo charcoal	$^{14}\text{C}$	$-24.7$	9960	30	11 609–11 260			UGAMS-29456
	E2	4	Ceramic sherd	OSL/IRSL	–	–	–	–	1.16 $\pm$ 0.05	3.9	UW3681
	E2	4	<i>Canarium</i> sp.	$^{14}\text{C}$	$-25.7$	9140	30	10 406–10 230			UGAMS-29447
	G2	4	<i>M. laosensis</i>	$^{14}\text{C}$	$-8.4$	10 510	30	12 661–12 471			UGAMS-29449
	G3	4	Cervidae apatite	$^{14}\text{C}$	$-8.3$	8100	30	9128–8986			UGAMS-29453
	F3	5	<i>M. laosensis</i>	$^{14}\text{C}$	$-8.3$	11 160	30	13 164–13 003			UGAMS-29450
F3	5	Bovinae apatite	$^{14}\text{C}$	$-4.4$	9020	30	10 241–10 171			UGAMS-29454	

\* See compendium material in Conrad *et al.* (2020a).

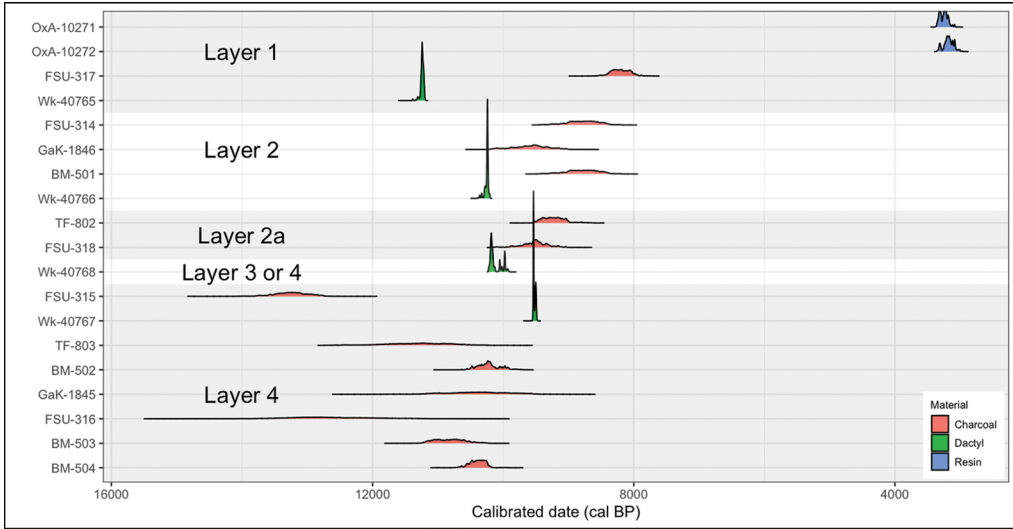


Figure 5. Calibrated radiocarbon age distributions from Spirit Cave. Age ranges were calibrated (at 95.4% confidence) using the *Bchron* package in R (Parnell 2014; see Conrad et al. 2020a) and the *IntCal20* atmospheric curve (Bronk Ramsey 2020; Reimer et al. 2020).

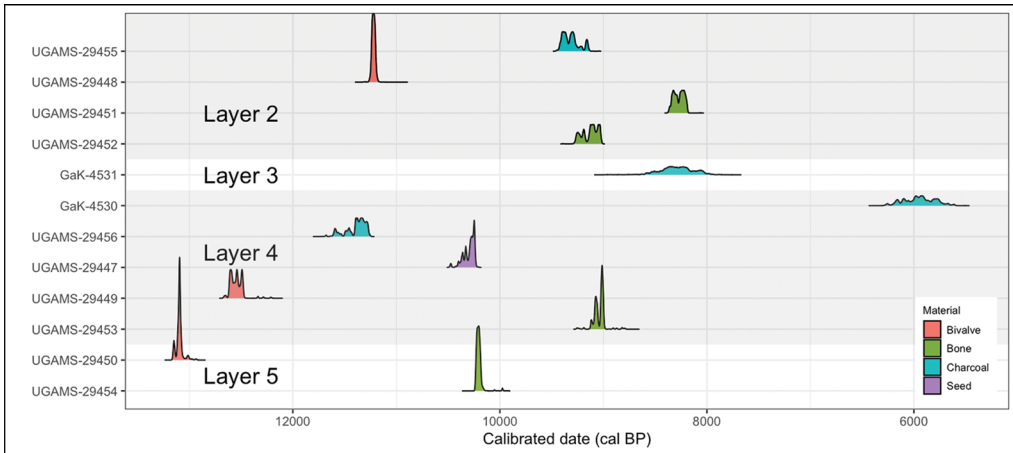


Figure 6. Calibrated radiocarbon age distributions from Steep Cliff Cave. Age ranges were calibrated (at 95.4% confidence) using the *Bchron* package in R (Parnell 2014; see Conrad et al. 2020a) and the *IntCal20* atmospheric curve (Bronk Ramsey 2020; Reimer et al. 2020).

also recorded for Steep Cliff Cave. Two new luminescence dates on ceramic sherds return ages of  $6390 \pm 670$  BC and  $AD 860 \pm 50$ , respectively.

Our 13 radiocarbon determinations from Banyan Valley Cave range between  $10\,680 \pm 30$  and  $2850 \pm 25$  BP. When radiocarbon offsets are considered, the earliest date for this site is  $9270 \pm 30$  BP (Table 3; Figure 7). On average, *M. laosensis* shells are 2612 years older than their paired bone apatite and charcoal dates. A direct apatite radiocarbon determination

Table 3. New ages from Banyan Valley Cave. Calibrated ages are corrected for reservoir offsets. Dates calibrated (at 95.4% confidence) using OxCal v4.4.2 and the IntCal20 atmospheric curve (Bronk Ramsey 2020; Reimer *et al.* 2020).

Unit	Layer	Material	Type	$\delta^{13}\text{C}$	Uncalibrated radiocarbon age	$\pm\text{sd}$	Calibrated radiocarbon age (BP)	Age (ka)*	% Error	Laboratory Number
F4–F5	1	Medium mammal apatite	$^{14}\text{C}$	–	Failed	–	–	–	–	UB-26417
C8	1	<i>Oryza sativa</i> spikelet	$^{14}\text{C}$	–26.4	280	20	430–289	–	–	UGAMS-38826
C8	2	<i>Oryza sativa</i> spikelet	$^{14}\text{C}$	–24.5	220	20	307–11	–	–	UGAMS-38827
C8	2	<i>Oryza sativa</i> spikelet	$^{14}\text{C}$	–26.4	220	20	307–11	–	–	UGAMS-38828
D5	2	Clay pellet (bullet)	TL	–	–	–	–	1.57 $\pm$ 0.22	14.1	UW3678
E5–F5	2	Bamboo charcoal	$^{14}\text{C}$	–25.4	3970	25	4523–4301	–	–	UGAMS-29437
F5	2	<i>M. laosensis</i>	$^{14}\text{C}$	–8.2	7300	30	8175–8027	–	–	UGAMS-29440
E5–F5	2	Large mammal apatite	$^{14}\text{C}$	–25.6	2850	25	3059–2876	–	–	UGAMS-29443
F4–F5	2	Medium mammal apatite	$^{14}\text{C}$	–	Failed	–	–	–	–	UB-26418
D5	3	Bamboo charcoal	$^{14}\text{C}$	–29.2	4060	25	4788–4425	–	–	UGAMS-29438
F5	3	Ceramic sherd	OSL/TL	–	–	–	–	4.37 $\pm$ 0.23	5.3	UW3679
F5	3	<i>H. sapiens</i> apatite	$^{14}\text{C}$	–16.6	6180	30	7165–6965	–	–	UGAMS-29444
F4–F5	3	Medium mammal apatite	$^{14}\text{C}$	–	Failed	–	–	–	–	UB-26419
F5	3 (Hearth on 4)	Primate apatite	$^{14}\text{C}$	–13.5	5900	25	6785–6664	–	–	UGAMS-29445
F5	3 (Hearth on 4)	<i>M. laosensis</i>	$^{14}\text{C}$	–8	7540	30	8410–8217	–	–	UGAMS-29441
D4–E4	5	<i>Canarium</i> sp.	$^{14}\text{C}$	–25.2	4620	25	5457–5300	–	–	UGAMS-29439
E5–F5	7	<i>M. laosensis</i>	$^{14}\text{C}$	–4.9	10680	30	12 736–12 625	–	–	UGAMS-29442
E5–F5	7	Large mammal apatite	$^{14}\text{C}$	–14.4	9270	30	10 568–10 300	–	–	UGAMS-29446

\* See compendium material in Conrad *et al.* (2020a).

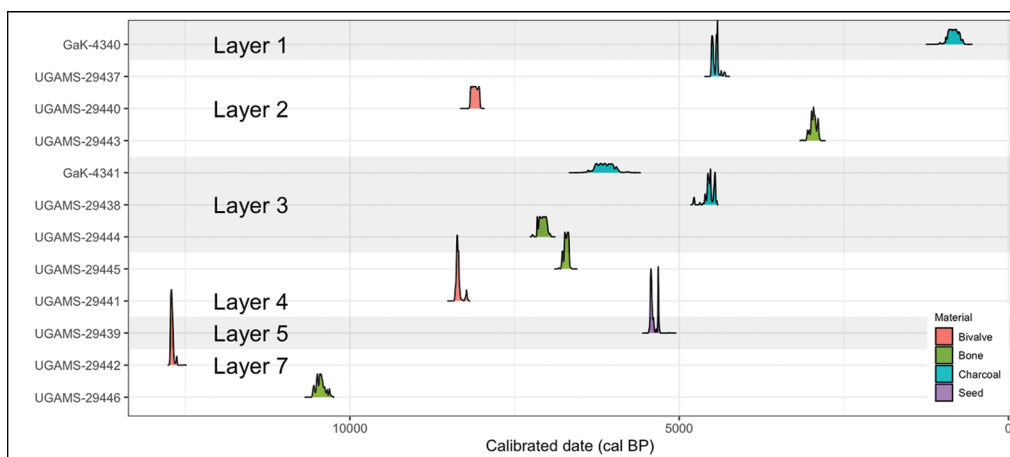


Figure 7. Calibrated radiocarbon age distributions, excluding rice determinations, from Banyan Valley Cave. Age ranges were calibrated (at 95.4% confidence) using the *Bchron* package in R (Parnell 2014; see Conrad et al. 2020a) and the *IntCal20* atmospheric curve (Bronk Ramsey 2020; Reimer et al. 2020).



Figure 8. Banyan Valley Cave rice spikelets: left) two examples of spikelets. Note the lack of awns (indicating a domesticated variety) and the broad width, also suggesting a domesticated length:width ratio; right) close-up of a spikelet base, demonstrating the torn, domesticated morphology (photographs by C.C. Castillo).

on a human bone specimen from Layer 3 returned a date of  $6180 \pm 30$  BP. All three rice spikelet samples, from excavation unit C8, yielded dates between  $280 \pm 20$  and  $220 \pm 20$  BP. The rice was re-examined before dating, following current spikelet base identification criteria (e.g. Fuller *et al.* 2009), and was identified as domesticated rice, as it lacks the awn which is present in all wild rice and the earliest cultivars (Figure 8). Two luminescence dates on a ceramic sherd and ceramic pellet (or bullet, used as a projectile in a pellet bow) provide ages of  $2350 \pm 230$  BC and AD  $450 \pm 220$ , respectively.

## Discussion

Radiocarbon and luminescence ages obtained from Spirit Cave, Steep Cliff Cave and Banyan Valley Cave help us build an important new chronological framework for understanding the lifeways of hunter-gatherers in highland Mainland Southeast Asia during the Terminal Pleistocene and Holocene.

Of the sites examined, Spirit Cave is the most controversial. While the original sequence was initially accepted by the academic community (Flannery 1973), ages obtained from organic resins on ceramic sherds in the early 2000s cast doubt on the accuracy of parts of the temporal sequence. Lampert *et al.* (2003) argued that because the radiocarbon dates from ceramic resins yielded Late Holocene ages, most of the ceramics from Spirit Cave did not, therefore, date to the Early Holocene, and thus the ceramic chronology for the site was inaccurate. This argument was quickly challenged, as field notes and site records indicate that the dated sherds were probably recovered from surface contexts, and were therefore unrelated to the original hunter-gatherer occupation and the initial appearance of ceramics in deeper layers (White 2004; see also Lampert *et al.* 2004).

Our new radiocarbon analyses of freshwater crab dactyls are compatible with an occupation of Spirit Cave during the Pleistocene–Holocene transition, but not without some caveats. While our results broadly match Gorman's (1970) original sequence, they are in reverse stratigraphic order. This indicates either that the deposits at Spirit Cave are disturbed or otherwise mixed, or that the provenance information for these dactyl specimens is inaccurate. Deposits at Spirit Cave are shallow, and there is evidence for prehistoric anthropogenic digging of pits into underlying layers (Gorman 1970, 1971b). Mixing of the deposits is therefore plausible (see also Treerayapiwat 2005). Moreover, the curation and storage of the archaeological assemblage from Spirit Cave is relatively poor (Conrad *et al.* 2016; Conrad 2018), possibly resulting in the freshwater crab dactyls being mislabelled, or information relating to their provenance being misassigned.

Whatever the explanation, our dates clearly support a hunter-gatherer occupation of Spirit Cave dating to the Pleistocene–Holocene transition. We also contend that the ceramic resin dates are analytically accurate, but are representative of much later Holocene re-use of this site by agricultural societies (i.e. the Log Coffin Culture, *c.* 350 BC–AD 1000; see Grave 1995). While we were unable to locate, and therefore directly date by OSL/TL/IRSL, the specific ceramic sherds from Spirit Cave that provided the basis for Gorman's original interpretation, we note that Gorman did observe ceramics on the surface of Layer 2:

Except for where animal disturbance was evident potsherds were limited in the site to the interface of layers one and two. The surface of layer two was closely examined in all of the eleven squares excavated and the same compacted conditions were found to prevail: concentrations of very fragmented pottery were impressed horizontally into this surface just as if the sherds had been broken *in situ* and walked upon for some time. This surface was the living floor circa 6800–5600 BC and all of the pottery evidently came into the site at this time. (Gorman *n.d.*)

This record is significant, as we obtained a single luminescence date of 6390±670 BC on a cord-marked ceramic sherd from Steep Cliff Cave (Figure 9)—a date which is within

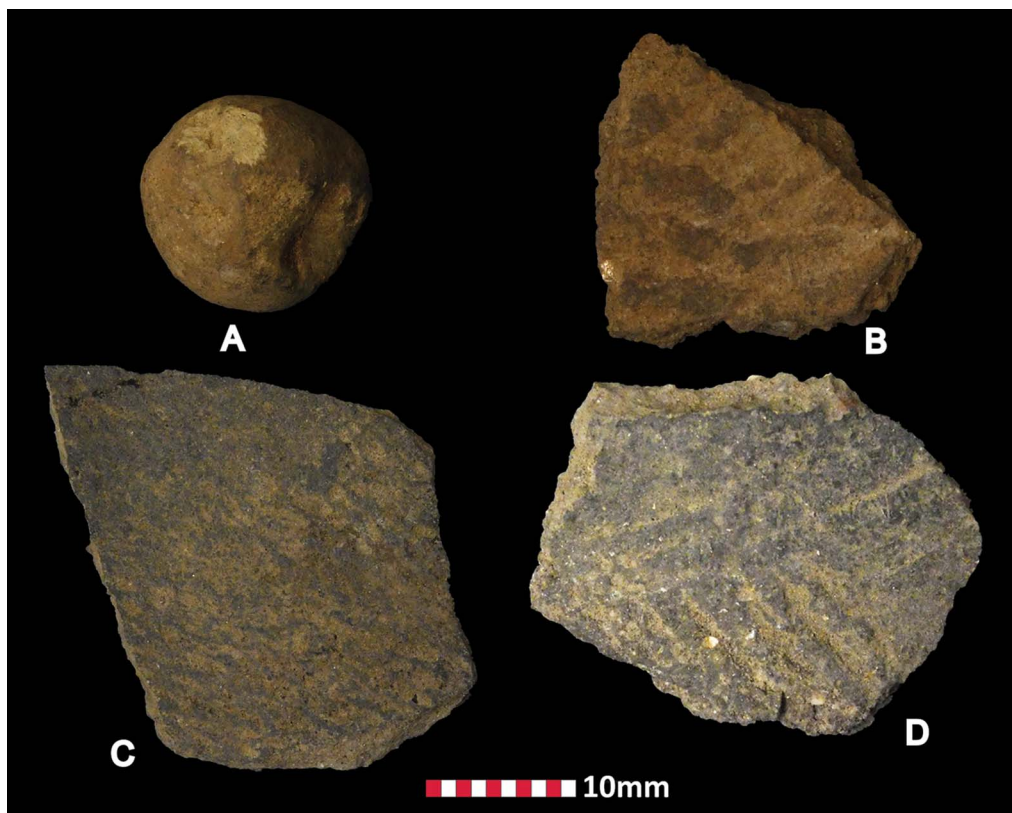


Figure 9. Dated ceramics: A–B) Banyan Valley Cave; C–D) Steep Cliff Cave. The oldest sherd (D) from Steep Cliff Cave dates to  $6390\pm 670$  BC (photographs by C. Conrad).

Gorman's original interpretation for the presence of the earliest pottery at Spirit Cave. Cord-marked sherds may represent the earliest form of ceramics to appear in Mainland Southeast Asia (Rispoli 2007). Given that it was not possible to re-examine the Spirit Cave specimens, and given the other dates for ceramics obtained in our study (a sherd from Steep Cliff dating to AD  $860\pm 50$ —over 7000 years later—and a sherd from Banyan Valley Cave dating to  $2350\pm 230$  BC), further research is required to resolve the question of 'Hoabinhian' ceramic use and manufacture throughout Mainland Southeast Asia.

The dates from the Steep Cliff Cave sequence provide additional evidence of hunter-gatherer occupation in north-west Thailand during the Early Holocene. Steep Cliff Cave appears to have a shorter occupation sequence than Spirit Cave. This is further supported by the Steep Cliff Cave faunal assemblage, which suggests that the site was only used as a hunting mass-kill location, where foragers drove large mammals off the cliff face above the cave and butchered them on the rockshelter floor (Conrad 2018). This is an unusual hunting behaviour for Mainland Southeast Asia and suggests that the use of Steep Cliff Cave may have involved a component of forager scheduling (e.g. the seasonal exploitation of animals; Shoocongdej 2000). Steep Cliff Cave's faunal assemblage is dominated by large ungulates, whose bones are burnt and cut-marked.

Our dates suggest a resolution of the issues concerning the chronology of Steep Cliff Cave. Gorman's charcoal radiocarbon determinations for this site, obtained from units E3 and E2 in the north-east, where dispersed human remains also occurred (Conrad 2018), were in reverse stratigraphic order. In our study, an apatite date on human bone from unit D32 (immediately adjacent to the source of Gorman's radiocarbon samples) provided the youngest date for the site's occupation ( $7460 \pm 30$  BP). This bone may therefore indicate the presence of an intrusive human burial. Burials dug into earlier hunter-gatherer deposits in cave and rock-shelter sites in Mainland Southeast Asia are often associated with later Holocene groups (Anderson 2005; Shoocongdej 2006; Bulbeck 2014; Lloyd-Smith 2014; Lewis *et al.* 2015). The relatively early age of this burial may suggest that this is not the case at Steep Cliff Cave (see also Zeitoun *et al.* 2013), but it is nonetheless apparent that these deposits have been disturbed.

The dates for Banyan Valley Cave suggest that hunter-gatherers occupied the cave during the same Early Holocene period as the foragers at Spirit Cave and Steep Cliff Cave; but they did so sporadically and continued to return to Banyan Valley Cave long after Spirit Cave and Steep Cliff Cave went out of use. The human remains from Banyan Valley Cave date to the Early to Mid-Holocene ( $6180 \pm 30$  BP), and therefore do not represent a later, intrusive burial. Anthropogenic deposits with artefacts post-dating these remains suggest that hunter-gatherers continued to occupy the site until the very recent past (Conrad 2018).

Rice spikelet dates and the luminescence-dated clay pellet from Banyan Valley Cave, which was probably used for hunting arboreal taxa, also suggest Late Holocene and historic-era occupation of north-west Thailand cave sites by agricultural populations or hunter-gatherer groups. Banyan Valley Cave thus provides evidence of both hunter-gatherer adaptations during the Holocene and occupation during the transition to agriculture in Mainland Southeast Asia.

## Conclusions

New radiocarbon and luminescence dates for Spirit Cave, Steep Cliff Cave and Banyan Valley Cave lead us to revise our understanding of human occupation in north-west Thailand in the Terminal Pleistocene and Holocene. Our results support the original chronology proposed for Spirit Cave, including possible early 'Hoabinhian' ceramics; an Early Holocene chronology for Steep Cliff Cave, with evidence of hunter-gatherer scheduling and burial activities; and a Holocene chronology for Banyan Valley Cave, with evidence of sporadic use of the site, including historic-era activity. Our results do not provide evidence for early agriculture, but highlight the importance of north-west Thailand as a centre of Pleistocene–Holocene hunter-gatherer activity in Mainland Southeast Asia. Resilient hunter-gatherer populations continued to exploit this highland region throughout periods of environmental change during the Pleistocene–Holocene transition and the process of Neolithisation thereafter. Our analyses support the need for further research into the processes of past forager-farmer relationships during this critical era in Mainland Southeast Asian prehistory.

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