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ORIGINAL ARTICLE

Impacts of War on Geodiversity and Geoheritage: Case Studies of Karst Caves from Northern Laos

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Abstract While the role that some places have played during war has made them foci for legitimate commemoration of historical events, acquisition of this cultural heritage dimension has often occurred at considerable cost to natural heritage values that previously existed. Research is required to address the current deficiency in understanding of the impacts of war on natural geoheritage and their implications for management. This is likely to be most expeditious and effective if focused initially upon representative examples of environments of a kind that commonly figure in armed conflicts; if it targets specific sites in which various types of environmental impact have been focused in a physical area that can readily be encompassed by fieldwork; and if observable impacts involve a variety of vulnerable values. These criteria are amply met by karst caves; management of which encapsulates many environmental issues in microcosm. Review of the physical condition of some northern Laotian caves has enabled a range of impacts of war to be identified, and some probable further implications of these impacts to be inferred. Physical damage recognised includes compaction of cave floors by trampling, damage to speleothems, and deliberate physical modifications to cave floors and passages. Changes to atmospheric conditions that are likely to have been detrimental to cave ecosystems are implied by smoke staining of cave walls and ceilings from fires used for cooking, heating and lighting and from evidence for chemicals likely to have impacted cave ecology also having been used underground. A wide range of exotic substances were also introduced into these vulnerable environments, including foodstuffs, munitions and construction materials. Damage was also caused by attacks made upon caves, sometimes combined with resulting detonation of munitions stored within them. The partial survival of some natural values, and incipient recovery of others, now requires very careful cave management, and the same requirement is likely in relation to other types of geoheritage sites that have been damaged by war. Survival of remnant natural values may already be tenuous and is unlikely to continue unless post-conflict management is founded upon an holistic perspective rather than the sites involved being managed solely as cultural heritage monuments.

Keywords War · Environmental impact · Karst · Caves · Natural heritage · Cultural heritage

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Introduction

There are many potential adverse ramifications of war for nature conservation and natural heritage, some of which have implications for natural geoheritage phenomena as important features in their own right, for their underpinning of many natural system processes and for their utility to humans. From the latter, purely anthropocentric, perspective wartime damage may range from injury to those communities whose spiritual values and patrimony are harmed, to practical economic considerations. But any expressions of concern regarding wartime impacts on heritage values are typically confined to charismatic elements of natural heritage such as tigers or elephants (e.g. Eniang et al. 2007) or to damage caused to cultural heritage sites. Geoheritage seldom figures in such discussions, and the near-total neglect of this topic to date implies a deficiency in our knowledge, the redressing of which now presents a considerable challenge. Research to this end is likely to be most expeditious and most effective in guiding future initiatives if work is focused in the first instance upon representative examples of types of environments that commonly figure in armed conflicts, targeting specific sites in which various categories of environmental impact have been focused in a physical area that can readily be encompassed by fieldwork and where it is possible to observe impacts on a variety of natural values. This paper explores the potential to use karst caves as exemplars of the various types of damage that war may cause to geoheritage. It reviews observed impacts of war upon caves in the small southeast Asian nation of the Lao Peoples Democratic Republic, focusing on karst areas in the northeastern part of that country (Fig. 1).

Several factors suggest that caves are a potentially fruitful environment in which to initiate this process of better documenting the impact of war on natural geoheritage. The geographical distribution of the world's karst environments relative to the theatres within which various armed conflicts

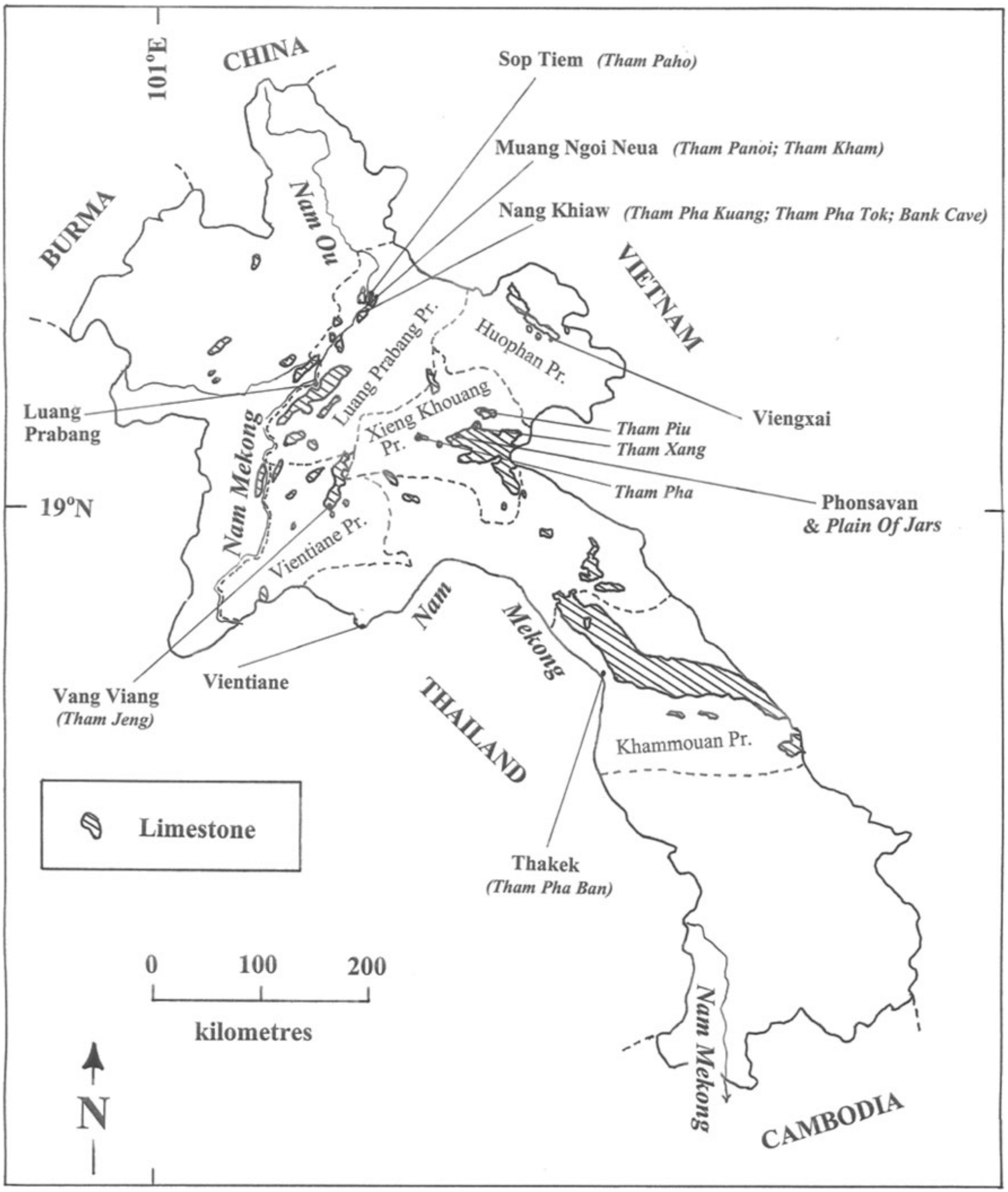

Fig. 1 Approximate extent of limestone in Laos and key locations mentioned in text

have occurred has meant that they have inevitably become part of the stage in those theatres and, hence, potentially bear environmental scars inflicted by the dramas there enacted (Gams and Habic 1987). Secondly, the characteristically complex topography of karst environments has often led to their becoming magnets for wartime activities because they have been perceived as being suitable locations for particular military operations, as bases for combatants or as places of sanctuary for civilians (Day and Kueny 2004). For example, in the Mediterranean region, a cave near Marsa Mutroh, Egypt, served as the base from which Rommell planned offensives against the Allied forces (Hassan 2011), and various Slovenian caves were adopted as depots and bunkers after World War II. Furthermore, people have utilised caves as natural shelters since prehistoric times, so it is hardly surprising that, in the circumstances of war, caves have often been adopted for civilian sanctuary. In addition, because the management of karst caves encapsulates a wide range of environmental issues in microcosm, they can be useful natural laboratories in which to isolate particular aspects of the sorts of damage that armed conflict implies for other components of geodiversity and geoheritage. But while historical accounts and anecdotal reports of wartime activity in caves are relatively common, and in some cases are evident from remaining artefacts, systematic analysis of the implications of wartime cave use in terms of the nature and magnitudes of the resulting environmental impacts appears lacking. However, damage to caves has sometimes resulted, such as occurred to the entrance section of Postojnska jama, Slovenia, when a German fuel dump was detonated in 1944 (Pretovsek 2011).

From a post-conflict geoheritage management perspective, one complicating factor can be the fact that in some cases the events that transpired at a particular place during a war have sometimes later been perceived as imparting cultural heritage value to that place. Such a situation can lead to their being proudly adopted as historical monuments, perhaps celebrating steps along the pathway to national independence. Indeed, they may come to be commodified by the tourism industry, even to the extent that sites where human tragedies have occurred may become incorporated into what Arunnapaporn (Arrunnapaporn 2011) has somewhat chillingly termed “Atrocity Heritage Tourism”, potentially superimposing the environmental impacts of tourism upon the environmental impacts of war. From a practical natural heritage management perspective, three principal rationales motivated the study upon which this contribution reports: (a) any failure to highlight the damage caused to the natural environmental values of areas used in wartime impedes recognition of the wider reality that serious damage is inevitably caused to sites that become theatres of war—a likelihood still further compounded by the tendency for war history sites to be almost celebrated rather than the circumstances of their creation being lamented; (b) any surviving natural values in an otherwise war-torn area are put at risk if its subsequent management focuses solely on this history and cultural heritage or addresses natural heritage in only a token and underinformed manner; and (c) unless the reality of wartime damage to geoheritage is better recognised, the likelihood of any measures being taken in a bid to avoid or reduce such damage in future conflicts is even lower than the circumstances of war already render it.

The intention of this contribution is to provide as objective an evaluation as possible of the types and magnitudes of environmental damage caused by war to some representative caves of northern Laos, irrespective of any other considerations such as their cultural heritage worth. My purpose here is simply to achieve an objective documentation of the physical harm caused to them by war, to advocate for such natural values as may still persist in its aftermath and hopefully to contribute in some small way to the prospect of perhaps reducing similar damage in the future. However, no matter where a study such as this may be undertaken, some of the sites to which reference would have to be made may now be considered by some people to be important not for any natural values that may once have existed there but instead solely by virtue of the events that transpired during wartime. While this paper focuses instead on the natural values, no insult is intended to any of the cultural values that may now be accorded to sites addressed in this study nor to the memory of those who may legitimately be considered patriots, martyrs or simply victims in relation to the events that occurred there. Indeed, it would be hard to spend any time exploring the history and impacts of war upon the people of Laos without developing considerable sympathy for their situation, and for the perspectives that are expressed locally, and I acknowledge fully the legitimacy of the perspectives they may now hold. But respectful management of cultural heritage does not have to be at the expense of natural heritage nor vice versa.

Karst Caves as Exemplars

Karst landscapes may be significant from a nature conservation perspective because of the natural system context in which they have evolved: by virtue of the particular landforms that now occur; because of dependent values such as palaeoenvironmental archives, archaeological remains or biota that are hosted within the primary landform; or by virtue of their utility to humans (Kirkpatrick and Kiernan 2006; DuChene 2006; Boston et al. 2006). Damage to natural geoheritage may compromise some forms of potentially sustainable economic use of nature conservation assets, such as exploitation as tourist attractions of scenic or otherwise interesting natural environments. In recognition of the importance of karst and caves, and their inherent vulnerability (Yuan 1988, Kiernan 1988, Ford and Williams 2007), specific management guidelines have been produced by The International Union for the Conservation of Nature and Natural Resources that emphasise the importance for conservation management of protecting the natural processes that sustain these environments (IUCN 1997).

It is important to maintain a clear intellectual separation between the *objective* process of determining whether damage has occurred to a landform such as a cave, and the quite separate *value-based* process of deciding whether that damage is significant. Identifying whether damage has occurred is intrinsically simple because geomorphology is physically defined by the contours of the natural feature, hence any artificial derangement of those natural contours, at whatever scale, must, by definition, represent damage. Artificial disruption of the natural magnitude and rate of geomorphological processes that occur under prevailing natural climatic conditions can also reasonably be defined as damage. Just as there are different types and communities of plants and animals, so too are there many different types and assemblages of landforms; some of which are common and some rare, some robust and some fragile. The second phase of the damage assessment process, determining whether the damage is significant, is far more complicated because human value judgements are inevitably involved. This phase typically requires case by case assessments that have regard to the perceived value of the feature involved, the extent to which it has been damaged, the degree to which the damage has compromised key dependent values such as palaeoenvironmental archives, scenic values or biota hosted by the landform and the potential for its natural recovery over a reasonable time frame. The full extent of any damage caused by a particular event may not be evident immediately because the ultimate degree of damage includes not only the immediate impact but also its secondary consequences, such as accelerated erosion unleashed by an initial disturbance (Kiernan 2010).

Several recurrent threads generally underlie inadequacies in cave conservation and management: the tendency of many people to perceive caves as being simply holes in the ground; a failure to recognise their intrinsic value as features in their own right; a failure to recognise the wide range of other values caves may host; a failure to comprehend the vulnerability of some values and the many ways these may be imperilled; and inadequate appreciation of the often subtle natural process systems that allow many values of caves to persist. The many different types of caves that exist vary in their frequency of occurrence, as do the various phenomena caves contain, but most are vulnerable to damage and often to actions that may not initially appear obvious threats (Kiernan 1989). For example, the natural vegetation and soil biota in karst areas play a critical role in sustaining the natural acidity of the seepage water that is responsible for dissolving limestone to form caves. Similarly, the formation within caves of speleothems such as stalactites involves the re-precipitation of dissolved carbonate from this source, together with maintenance of cave atmospheres in a condition that facilitates degassing of the seepage water that emerges into it (Ford and Williams 2007). Hence, modification of vegetation and soil on the surface can cause damage to speleothems inside underlying caves, which may even progress to their being re-dissolved if devegetation and resulting increased heating of the ground surface sufficiently increases carbon dioxide production by soil biota to increase seepage water acidity (Goede 1981). Reduction of atmospheric humidity in caves, due to changes in water seepage or to physical modifications that alter cave microclimates, can also result in dehydration and powdering of the surface of speleothems. Even before direct impacts associated with human activity inside caves is factored in, such broad controls on the functioning of the wider geo-ecosystems within which karst caves occur must be taken into account in considering the damage likely to be caused by war to caves and their contents, as may the possible entry of contaminants into karst aquifers.

Environmental harm caused by human activity within caves commonly includes incidental or deliberate damage to speleothems, which may occur simply through their being touched by human hands that leave dirt or discolouring body oils on their surface. In the case of actively growing speleothems, such contaminants may rapidly be sealed into the crystal structure such that they cannot be cleaned off even if it were possible to physically wash a fragile speleothem without breaking it. Inadvertent or deliberate interference with the natural pathways, quantities and qualities of waters flowing underground can also harm some physical attributes of the caves through which they flow and also other components of cave environments, such as invertebrate biota. Many elements of cave fauna are highly adapted to a subsurface environment that is nutrient-limited, lacks light and is often subject to such high levels of atmospheric humidity that even "terrestrial" cave invertebrates are classified as being aquatic fauna under the Ramsar Treaty. Such environmental conditions not infrequently result in the evolution of de-pigmented and eyeless species that are unable to exist on the surface. Particular species are often restricted to the separate caves in which they have evolved and in which the population size that can sustained may be so small that the loss of even a few individuals may cause genetic drift or even extinction. Changes to the entry of organic materials into caves can also be problematic for such biota and for broader ecosystem balances underground (Spate and Hamilton-Smith 1991; Elliott 2006). Equally, a reduction in external food sources available to cave dwelling bats that forage outside at night and bring critical energy back into the cave ecosystem in the form of guano can also be problematic, and not only for cave biota because guano also facilitates the formation of various phosphate minerals in caves (Hill and Forti 1997). Uncompacted earthy sediments that floor many caves are sometimes important egg laying sites for certain cave invertebrates, hence, trampling and compaction of such floors by human pedestrian traffic can also be a significant concern. All these various factors, and many more, need to be taken into account in assessing the potential damage that may be caused to the natural environmental value of caves during warfare.

Study Area and Methodology

The southeast Asian nation of Laos possesses many remarkable caves, and it has also endured a long history of armed conflict that has involved technologies ranging from very primitive ground-based warfare to massively sophisticated and powerful aerial bombardment of its karst landscapes. Hence, the karsts of Laos form a palimpsest upon which the impacts of successive phases of armed conflict have been superimposed. For example, Tham Jang (Chang) near Van Vieng in Vientiane Province, provided refuge against Jiin Haw (Yunnanese) invaders in the early nineteenth century. Tham Pha in Xieng Khouang Province was used to hide hundreds of Buddha statues, again to secure them against invading Haw, during conflict between Siam and the Lanexang Kingdom, and it was again utilised during the revolutionary conflict of the 1960s and 1970s. Further south, poljes and caves in Khammoun Province (Waltham and Middleton 2000; Mouret 2001, 2004a,b) similarly served as places of refuge from marauding Haw two centuries ago and doubtless also during earlier conflicts. Here, cave sediments in Tham Pha Ban (Tham Nyai, Tham Xang or Tham Phose), about 9 km east of Thak Hek near Ban Tham, were mined to obtain bat guano for Japanese manufacture of gunpowder during World War II. This cave again came into use during the revolutionary war during the 1960s and 1970s when a large number of Laotian caves were employed for military purposes by combatants in what became the Laotian theatre of the US war in Indochina (Lemmer 1961; Anthony and Sexton 1993; Correll 2005). Many areas were heavily bombed or subject to deliberate deforestation using chemical defoliants or napalm in a bid to deny cover and food crops to ground forces, and large non-combatant civilian communities sought sanctuary from the onslaught by abandoning their houses and inhabiting caves. Laotian villagers who abandoned their homes often emerged from the caves to tend their rice fields only under cover of night. This situation obviously implies massive social impacts being caused by this conflict (Teng 1994; Ruff 1994), not least being the probability that some children may have spent as long as the first 8 years of their lives largely hiding in shadows and darkness, which begs the question of the likely impact of such formative years on their later lives. However, it also implies significant impacts on the caves in which they sought refuge.

This study entailed detailed examination of sites subject to these kinds of impact in several locations (Fig. 1). Environmental impacts in caves are likely to have been greatest where large communities sheltered underground for extended periods and the natural floor topography was not convenient or suitable for a particular purpose and hence required modification. Study sites were selected to cover varying intensities of cave use. In addition to damage caused by people forced to seek shelter inside caves, the use or suspected use of caves by ground forces led to considerable targeting of caves by opposition ground fire and air power. Five caves known to have been targeted in this way were included among those studied in order to evaluate the nature and extent of the environmental damage caused by direct attacks. Written reference material and information obtained from local people was used to identify caves that had been used by troops, officials or as refuges for villagers. The types of damage observed in these caves was recorded under one or more of four broad categories: (a) incidental trampling of sensitive substrates; (b) damage involving deliberate physical modifications to cave morphology; (c) anthropogenic introduction of exotic materials into cave environments and (d) damage caused by attacks upon caves. Not all these categories are entirely mutually exclusive, for example, there is obvious overlap between the physical modification of the topography of some cave interiors and the fact that such modifications sometimes also involved the introduction of foreign materials into cave environments for construction purposes. Some environmental impacts can be recognised by simple observation, such as bullet holes, shell craters, graffiti written on cave walls and limestone rubble strewn in a direction that is consistent with its having been dislodged by recognised munition impact and detonation points. The physical presence of certain artefacts is also a reliable indicator of wartime impacts, including artificial structures installed underground that have obvious military function, such as anti-blast walls to safeguard cave occupants from projectiles aimed into cave entrances, unexploded ordnance (UXO), military clothing and footwear and other debris that is clearly of military origin.

Scientific assessment of Laotian caves remains in its infancy with not even the likely full extent of the nation's karst areas yet adequately documented in the scientific literature (LDGM 1991; Mouret 2004a,b; Kiernan 2009). Hence, one impediment to elucidating the precise magnitude of particular environmental impacts of war is the absence of any baseline data that records the natural pre-conflict physical condition of the caves studied. Some artefacts at least permit a degree of inference regarding probable wider implications of their presence, based on first principles. For example, physical phenomena clearly caused by detonation of explosives in caves imply the production of shock waves, gases and heat that, by analogy with studies undertaken in comparable karsts elsewhere, can reasonably be interpreted as having been injurious to certain speleogens, speleothems or cave biota. Because inventories of cave biota and cave ecosystem structure and function prior to conflict phases are also lacking (Deharveng 2004), no attempt has been made in this study to address the exact impacts of war on the biota of the caves examined. However, chemicals that may have gained entry to subsurface waterways may have caused persisting damage to aquatic cave fauna, even though any such contaminants may no longer be directly detectable. Once again, by analogy with studies that have demonstrated biological impacts due to contamination of underground waters elsewhere, evidence recorded during this study that is indicative of chemicals having gained entry into cave waters can also reasonably be interpreted as evidence of probable damage to those Laotian cave ecosystems where spillages occurred.

The written records compiled were supplemented by extensive photo documentation. In most cases, only qualitative record was made of some of the more visually self-evident damage, but in other cases some quantitative data were also obtained. The latter entailed measurements being obtained using hand-held tapes, compasses and clinometers. It included recording the spatial extent of substrate trampling evident in 4×4 m quadrats recorded from areas of cave floor that were judged to be broadly representative of the wider areas of the cave that had been subject to similar damage. In order to facilitate assessment of the persistence of some of the types of damage recorded, and hence its likely longevity henceforth, estimates of its likely age were made from consultation with local informants and reference to some written sources, including a now-declassified database on United States Air Force (USAF) bombing that is being used to aid in local efforts to decontaminate areas where unexploded remnants of war present a continuing hazard to village communities (UXO Lao 2009). Finally, in order to evaluate the potential to protectively manage significant natural environmental values that may exist in these caves despite the impacts of war, evidence of any such values having survived was also recorded, together with any evidence of natural healing of the scars left by war, such as deposition of new secondary carbonate speleothems upon them.

Results and Analysis

Trampling of Sensitive Substrates

Tham Paho (Luang Prabang Province)

Located on a steep hillside overlooking the Nam Ou near the village of Sop Tiem, this spacious cave complex provided shelter for an entire village of several hundred people for some years (Fig. 2a). Inspection here revealed generalised

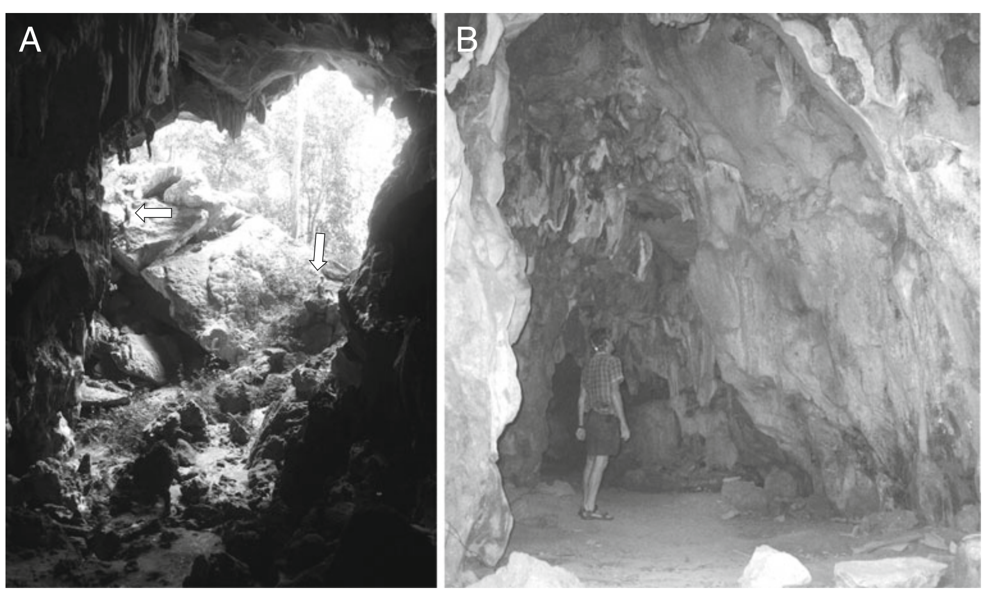

Fig. 2 Contrasts in cave size and morphology: **a** view outwards from the entrance chamber of Tham Paho—note human figures (*arrowed*) for scale; **b** confined main passage in Tham Panoi

trampling to have heavily compacted large areas of the earthy sediments that carpet parts of the cave floor and elsewhere the heavy muddying of crystalline flowstone floors. The mean extent of earthy cave floor compacted by trampling in the occupied areas, as derived from three quadrats, was 70 %. Breakage of speleothems is also evident, and extensive staining of cave walls and ceilings by smoke from fires lit for cooking, warmth and light also persists. These various impacts have resulted in severe degradation of the natural environment of Tham Paho. Some remnant UXO implies use of this cave by soldiers in addition to non-combatant civilians, but the trampling impacts left by troops are likely to have been far outweighed by those caused by the very much larger number of villagers who sought sanctuary here.

Tham Panoi (Luang Prabang Province)

Beyond the inconspicuous entrance to Tham Panoi, located high in a limestone hill close to the Nam Ou a few hundred metres upstream from Muang Ngoi Neua, is a small cave system that was heavily used by guerrilla fighters, and concerted aerial attacks upon this site are attested to by numerous bomb craters in soft sediments at the foot of the hill, together with evidence obtained from the USAF bombing database. In contrast to Tham Paho, this cave comprises narrow linear passages; hence, the quadrats were located on the only possible access route (Fig. 2b). The mean proportion of three quadrats damaged by surface trampling was 80 %. Dreybrodt and Laumanns (2005) record that this cave was avoided by local people after the war due to “bad spirits”; hence, only very low levels of post-conflict impact are likely, notwithstanding a very few religious artefacts of unknown age that suggest some likelihood of continuing modest use of the site by monks from a nearby wat (temple). However, current development of an access path to the cave entrance for tourist use is likely to dramatically increase pressures on this site.

Tham Kham (Luang Prabang Province)

Located ~1 km east of Tham Panoi and inland from Muang Ngoi Neua on the Nam Ou, this spacious outflow stream cave was also heavily used for civilian refuge. The mean extent of trampled substrate in the daylight zone of this cave, as derived from four quadrats, was 80 %. While much of this trampling damage is likely to have been caused by civilians seeking sanctuary, once again there is physical and anecdotal evidence for some past military use, to which bomb craters near the cave entrance and evidence garnered from the USAF bombing data base both attest. The in-cave wartime impacts here have in part been over-printed by more recent informal tourist use, but most tourists tend to bypass habitable side alcoves near the entrance *en route* deeper into the cave where their impacts are focussed around scenic speleothems. For this reason, the quadrats used to assess trampling damage in this cave were located in habitable but less scenic alcoves that are off the main route and which have been observed to attract little tourist interest.

Tham Xang Medical Cave Complex (Xieng Khouang Province)

Tham Xang is one of several caves located near the village of Ban Ta, a few kilometres north of Ban Nam Ka on national route 7. These caves provided refuge for civilians and were also used by Pathet Lao (PL) forces as a hospital and medicine depot and for stockpiling of munitions. Once again there has been significant overprinting of some of the wartime damage to this cave by the impacts of relatively small numbers of tourists, but the trampled and compacted floors in this cave extend very much more widely than simply the main route that links those specific parts of the cave that are of interest to tourists. For this reason, the quadrats used to obtain a quantitative estimate of the extent of cave floor damage during wartime were obtained mainly from habitable but scenically uninteresting alcoves, the mean proportion of trampled substrate determined from three quadrats here being 72 %.

Tham Jeng (Chang) (Vientiane Province)

Given the persistence of trampling effects dating from the middle of the twentieth century that remained visually evident in various caves, Tham Jeng was examined in a bid to establish whether any evidence remained of its much earlier (nineteenth century) use as a sanctuary against Haw invaders. Extensive floor trampling and some breakage of speleothems was observed, but it proved impossible to reliably discriminate between impacts potentially initiated during this early episode of armed conflict and impacts that may have instead resulted from later activities, notably informal tourist use prior too more recent installation of concrete pathways, lighting and other infrastructure to support mass commercial tourism. Nevertheless, given the trampling damage caused to other caves used for sanctuary during the revolutionary war, it is probable that similar impacts were generated in Tham Jeng. The fact that subsequent tourism impacts generated during peacetime have effectively masked any of these early wartime impacts emphasises the need to recognise the impact tourism may itself cause if it is not carefully managed. Such post-conflict pressures may imply damage not only to such natural heritage values that may have survived war but also to physical cultural heritage.

Deliberate Physical Modifications to Caves

Tham Paho

In several parts of Tham Paho, there is evidence of excavation into cave sediments, sometimes coupled with construction of flat surfaces using the excavated spoil, in order to produce benches that are generally 2–2.5 m long and up to 3 m wide (Fig. 3a). These are interpreted as sleeping platforms and some have involved excavation as deep as 70 cm into flowstone-capped sediment banks. Even given the large numbers of people who sought sanctuary here, the areas affected by this excavation are relatively limited, presumably because significant areas of natural floor topography were already suitable for sleeping or because bamboo bunks were constructed to elevate cave occupants above the cold ground.

Tham Panoi

Anthropogenic excavation and filling of sloping surfaces is also evident in this cave. Three and possibly four locations of such activity remain readily discernible. Some additional flat areas of ambiguous origin seem slightly anomalous relative to surrounding natural cave floor topography, but an anthropogenic origin for these could not be demonstrated unequivocally.

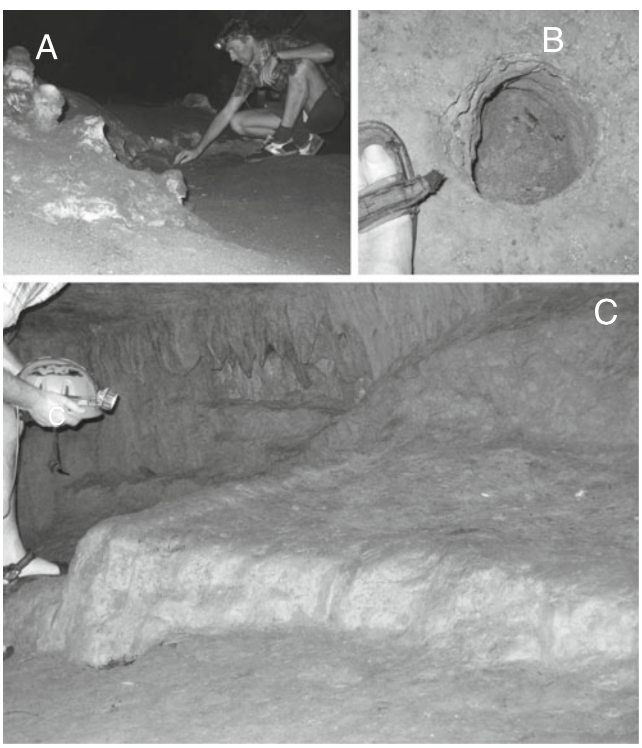

Fig. 3 Deliberate physical modification of cave floors: **a** sleeping platform excavated into earthy sediments in Tham Paho; **b** posthole in the Tham Kham cave sediments; **c** sleeping platform excavated into the earthy floors of Tham Kham

Tham Kham

Post holes where structures were previously constructed, probably from bamboo, also remain visible in this cave (Fig. 3b). Several sleeping platforms have been excavated into the earthy sediments that floor entrance areas and range in size from ~2–6 m^2 (Fig. 3c). Much of the entrance chamber comprises steep slopes, boulders or the active stream channel and hence was not amenable to conversion into sleeping platforms.

"Bank Cave" (Luang Prabang Province)

This cave lies at the foot of a hill known as Pha Tok, which is located near present day Nang Khiaw on the Nam Ou. It housed the provincial bank during the war years when the seat of the PL provincial government was based in another larger cave in the same limestone hill. Access into "Bank Cave" is gained via a narrow entrance close to the foot of the hill. Much of the cave has suffered heavy trampling impacts. Localised cutting of steps and flattening of floor surfaces remain apparent in a few areas. Clay stains on the lowermost parts of some cave walls hint at the possibility that some original passage connections that later became blocked by natural sediment influxes may have been dug open again when this cave was in wartime use.

Tham Pha Tok (Luang Prabang Province)

Tham Pha Tok near Nang Khiaw served as the seat of the provincial PL government during the revolutionary war. Securely located 20 m up the steep limestone tower Pha Tok, access into this cave was possible only by means of bamboo ladders. The three entrances to this strategically located cave each command sweeping views over a narrow pass that provides the key overland access from the east towards the Nam Ou and hence Luang Prabang. The spacious chambers of Tham Pha Tok provided abundant and secure room for people and supplies, together with administrative and medical infrastructure (Fig. 4). Re-contouring of the cave floor to facilitate these uses included the construction of terraces using excavated sandy sediment combined with limestone flakes and bamboo poles and stakes. One protective embankment, 2–3 m high and 3–4 m thick, appears designed to enhance shelter of people or supplies or to provide some measure of protection in case of any accident involving stored munitions—a recent interpretative sign erected at the site bears the ambiguous explanation "Sand unit to protect bullets". Different parts of this cave were dedicated to particular government functions. For

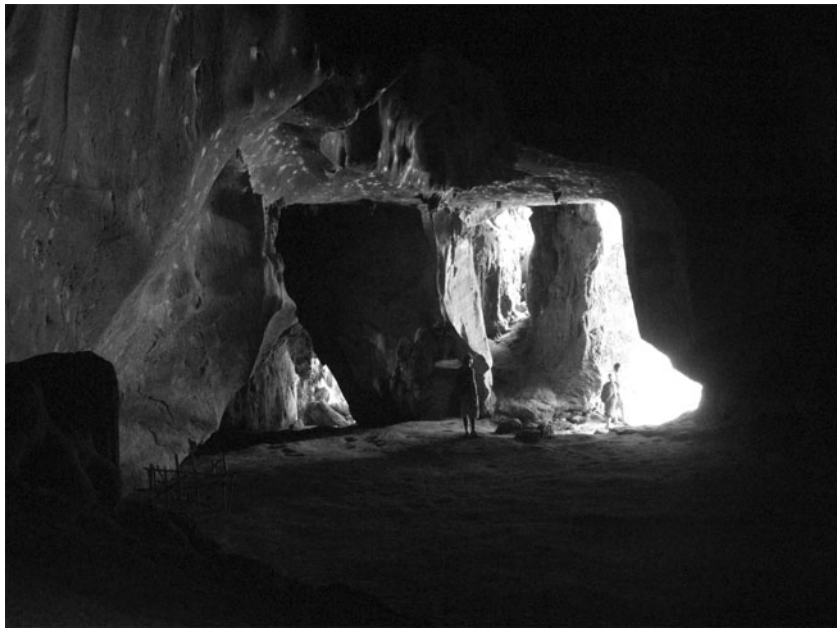

Fig. 4 The spacious main chamber of Tham Pha Thok, which for several years served as the seat of the Pathet Lao provincial government

example, the most protected corner housed the governor's office, while hospital facilities were provided in a lower level chamber to which access was possible via a separate entrance. Smoothing of the floor to facilitate these various functions has largely erased the original cave floor topography, virtually no part of which remains in a natural condition. Hence, superficially at least, the natural heritage value of this cave now appears confined to just the broad form of the cave itself rather than involving any natural values that it may previously have housed, although more detailed analysis is warranted, particularly in regard to invertebrate cave biota. In this transformed state, Tham Pha Tok is now recognised in Laos as having major cultural heritage significance.

Viengxai Area (Huophan Province)

Of all the Loation caves used during wartime, by far the most heavily modified are those in the Viengxai area, within which the PL government came to be based. These modifications were initiated in the early 1960s when the PL leadership shifted its base from more vulnerable Xieng Xeu to the Nakai area (now Viengxai), 7 km distant, where the military high command was established in the Xanglot cave complex. The caves around Viengxai served a variety of functions from 1963–1975. Ultimately a "hidden city" that catered for about 20,000 people was developed, involving the use of over 200 caves located in an area that stretched from west of present day Viengxai eastwards to near the Vietnam border. In marked contrast to the cave modifications previously discussed, those undertaken in the Viengxai area involved major underground engineering works that included not only the remodelling of cave floors but also major impacts upon the natural bedrock architecture enclosing caves. Removal of bedrock speleogens that obstructed or complicated comfortable access by people or equipment were significant impacts that have left indelible scars (Fig. 5a), and in-cave construction activities (discussed later) have probably masked many additional impacts of this kind. In addition, many existing cave chambers were enlarged by blasting or other means, generating new rock rubble that was often used as fill or to construct flattened floors, resulting in the burial of natural cave floor topography (Fig. 5b). Even entire new chambers were excavated into the bedrock. Examples recorded in this study include rectangular artificial cavities up to 15 m long, 8 m wide and 4–5 m high. Perhaps the most profound of the impacts caused by this underground engineering were the construction of artificial tunnels linking previously separate sections of the cave, with recorded examples sometimes exceeding 50 m long, 3–4 m high and 2–3 m wide (Fig. 5c). Although some of these tunnels might conceivably have been excavated along small natural voids, at least in part, in geomorphological terms their net effect was the creation of large volumes of additional void space that completely deranged the natural speleogeography. While these various passage enlargements, coupled with the gouging of water-gathering infrastructure into bedrock or sediment floors (Fig. 5d), involved much direct damage to original cave morphologies and speleothems by blasting and manual removal of rock, they also caused additional damage to natural cave values via other changes they facilitated. Such artificial passages have changed the flows of air and water through the cave complexes, causing increased dehydration of the atmosphere underground, which is likely to have impacted both speleothem processes and cave biota.

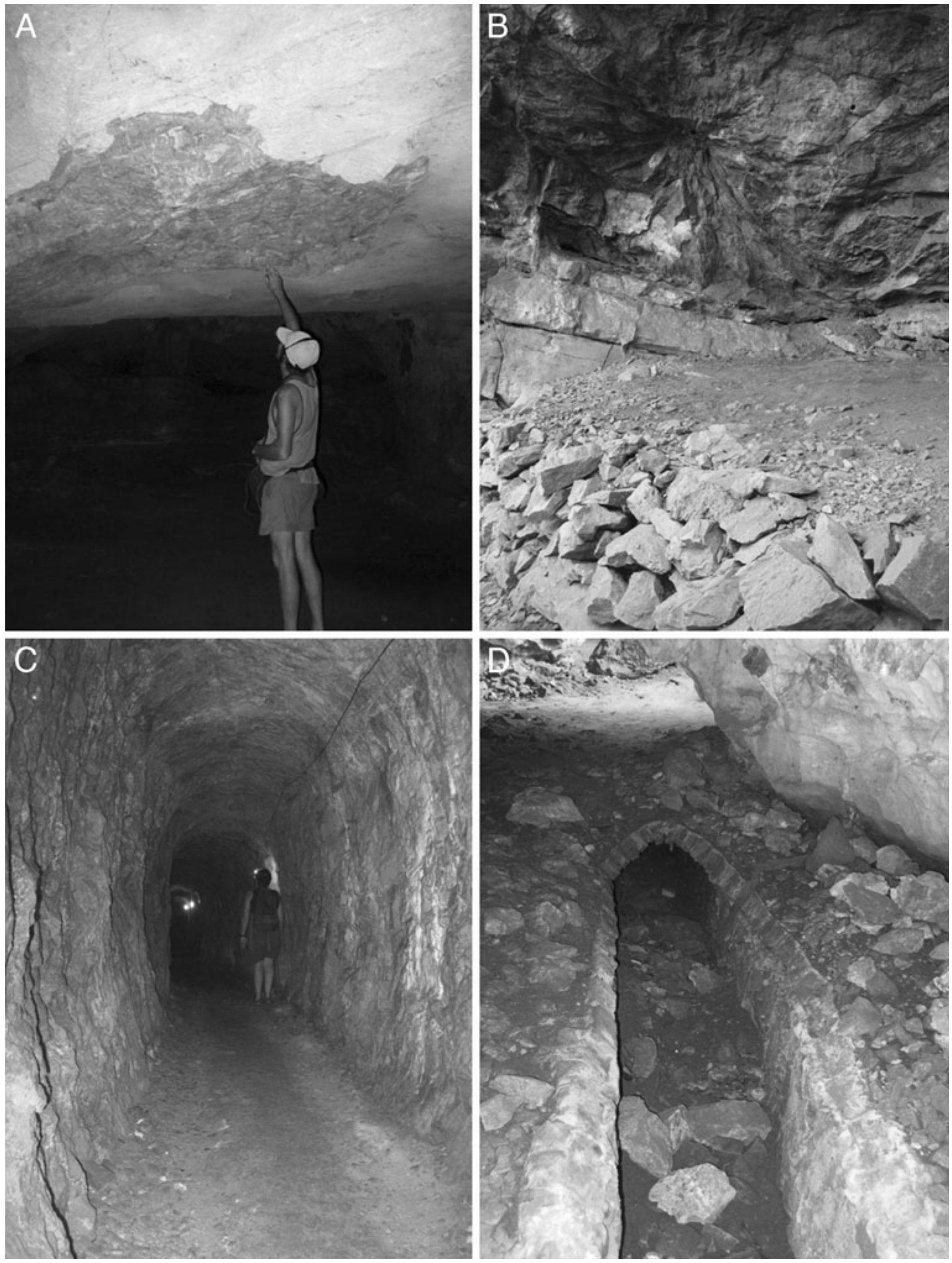

Fig. 5 Damage to the enclosing bedrock architecture of caves at Viengxai, and engineering works that involved major disruption of natural drainage of fluids through the karst (**a**) scar remaining on the ceiling of a cave; **b** blasted-out alcove and constructed dry-stone terrace at a gun emplacement in Artillery Cave; **c** artificially cut tunnels linking segments of natural karst cave and thereby altering patterns of air circulation and the condition of the cave atmosphere; **d** artificial drains in caves inevitably imply damage to the quality and quantity of water permitted to enter natural circulation routes and able to sustain natural speleogenetic and ecological processes

Introduction of Exotic Materials into Cave Environments

Organic Materials

Wood that is still partly charred from partial consumption as firewood, and remnants of wood or bamboo that appears to have been used for construction of structures, proved common in some of the caves inspected. In many cases, it now occurs as dispersed debris, while it occurs as terrace supports in the Pha Tok "Bank Cave" and in Tham Pha Tok itself, where bamboo is present throughout the unconsolidated cave sediments, much of it remnant from construction of terraces and protective sandbanks (Fig. 6a). A bamboo ladder, reportedly dating from wartime when it was used to gain access into Tham Pha Tok, still remained at one entrance to this cave in November 2009 but had been removed by June 2011. This seems an unfortunate loss of "in situ" cultural heritage from an exterior position in which no threat was posed to the natural cave environment by its retention. Some of the bamboo debris on the floor of the hospital chamber in Tham Pha Tok probably includes fragments of original ladders used to descend into this part of the cave, a separate entrance to which still contained at least remnants of old bamboo access structures in mid-2011. In Xieng

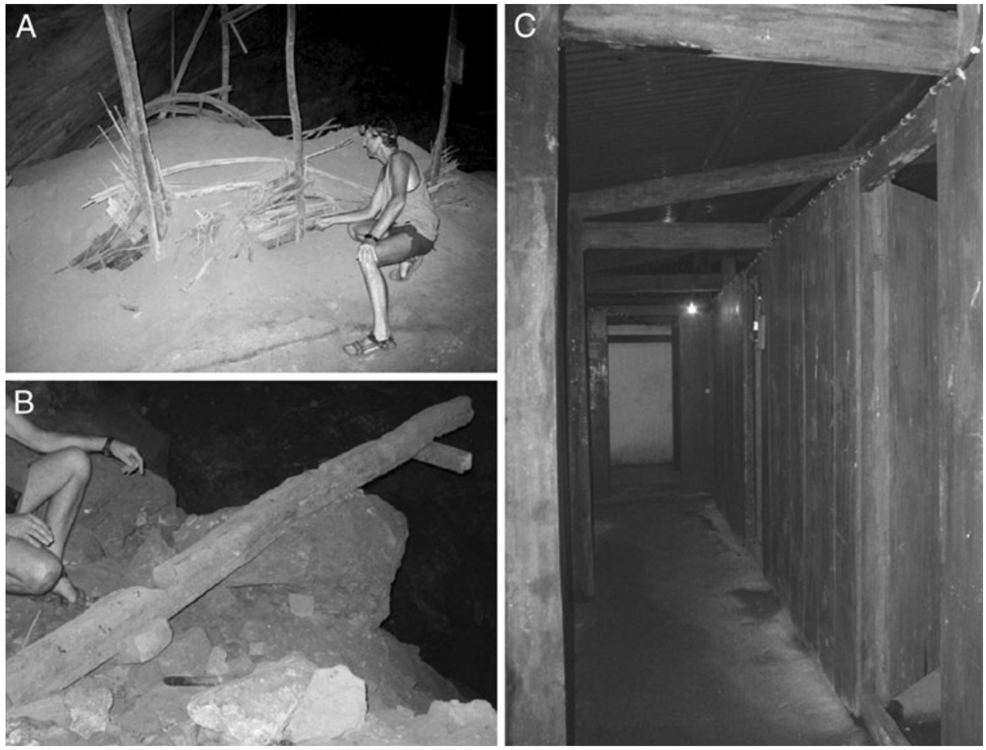

Fig. 6 Introduction of wood into cave environments. **a** Bamboo and fabric components of protective sandbanks constructed in Tham Pha Tok; **b** structural timber remnant from bunks constructed in Tham Piu; **c** wooden dividers separating a cave chamber into separate rooms at Viengxai

Khuang Province, considerable dispersed bamboo and wood debris was recorded from Tham Pha and very considerable remnant structural timber remains in Tham Piu, (Fig. 6b), consistent with illustrations in Lao displays at a nearby memorial that depicts hospital bunks and other timber structures as having previously existed in this cave. Some wood also appears to be remnant from containers, as in Tham Pha Kuang where fragments of what appears to be an ammunition box bear stencilled labelling in English. Timber is also common in the caves around Viengxai in Huophan Province, where some of the more developed caves contain intact wooden walls that divided the living quarters of senior PL officials into separate rooms (Fig. 6c). A few of the Viengxai caves also contain wooden furniture, either renovated originals or more recent facsimilies thereof. Cloth fabric was also found in many caves (e.g. Tham Kham, Tham Xang). This mostly comprised remnants of clothing, but in Tham Pha Tok it also includes larger fragments that were used in conjunction with bamboo to assist in retention of protective sandbanks. Discarded footwear was recorded from some caves.

Predictably, given the time that has elapsed since these various caves were occupied, no spilled foodstuffs were detected, but their former presence is inevitable given the large number of people who previously lived in these caves or temporarily sought shelter within them. However, rusting food tins are widespread in caves. There is also evidence suggestive of human faeces having been disposed of underground (Fig. 7). Bone material was also recorded from a few caves. At sites such as Tham Kham and Tham Paho, occasional bones are probably the remains of meals. However, in Tham Piu, small bone fragments that lie scattered among shattered limestone rubble that floors of the entrance chamber are almost certainly the remains of human occupants of this cave who were killed by rocket fire into its entrance (Fig. 8). While it may appear crass to include these here merely as organic sediment rather than highlighting the

Fig. 7 Asian-style toilets installed in caves at Viengxai suggest the disposal of human faeces directly into cave environments

Fig. 8 Memorial statue erected outside Tham Piu

human distress and trauma these tragic fragments represent, for present purposes this human bone material is recorded in this way, not out of any disrespect but simply for the sake of completing as objective record of environmental impacts caused to caves by wartime activities as it seems possible to achieve. However, human dimensions of this attack and its aftermath are discussed at greater length later in this paper. From an environmental impacts perspective, the introduction into caves of organic materials in unnaturally large volumes implies not only unnatural alteration of cave sediment composition, including delayed impacts caused by reworking of this material into slope and alluvial cave facies, but perhaps also the disruption of cave ecosystems by unnaturally elevated levels of organic nutrients.

Metal

Debris remaining in Tham Panoi includes rusting tins, eating utensils, batteries and digging implements, and similar artefacts are present in nearby Tham Kham (Fig. 9a). Similarly, in Xieng Khuang Province various scraps of metal remain in Tham Piu, including nails from old wood and bamboo structures erected in this cave and a metal fuel drum lies crushed beneath a large slab of limestone loosened from the cave entrance by rocket fire. Tham Pha, which was used as an underground hospital, still contains an old metal hospital bed trolley and other metal scrap. Significant volumes of metal were used as reinforcement of structures built in caves around Viengxai (Fig. 9b). Much of this metal is now heavily oxidised and rust stains that extend towards water courses highlight the potential anthropogenic intervention in natural geochemical processes and balances caused by introduction of these materials. Unexploded remnants of war (see below) add to this load of unnatural metals.

Glass and Ceramics

Dozens of small glass medicine bottles litter the floor in one entrance chamber at Tham Pha in Xieng Khuang Province (Fig. 10) and similar bottles occur in Tham Pha Kuang in Luang Prabang Province. Many medicine bottles also remain in the hospital chambers of Tham Xang and Tham Pha Tok and some also occur in Tham Piu. Bottles of other kinds were recorded in the hill-base notch caves at Phnom Pha Tok and elsewhere.

Chemicals

While no introduced chemical substances were directly recorded during this survey, ample evidence of their wartime carriage into cave environments is available. For example, decaying batteries were recorded from Tham Panoi, Tham Kham, Tham Pha Kuang and Tham Pha Tok in Luang Prabang Province; in a small cave at Plain of Jars archaeological site 1 in Xieng Khouang; and in caves around Viengxai in Huophan. These imply the introduction of potentially harmful battery chemicals into cave environments. Similarly, the many small medicine bottles found in caves such as Tham Pageo, Tham Pha Tok, Tham Pha, Tham Piu and Tham Xang imply medicinal chemicals having been introduced into caves. That many of these bottles now lie in pools of water or small

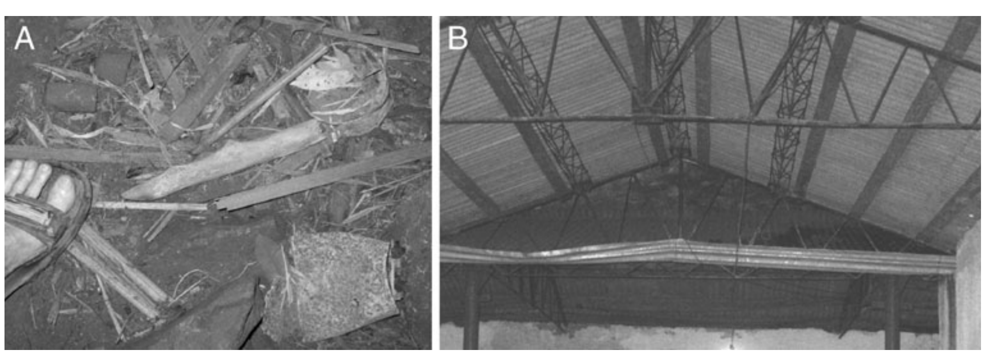

Fig. 9 Metal introduced into caves: **a** old food cans, bowls and batteries in Tham Kham; **b** iron sheeting installed to give protection from dripping cave ceiling at Viengxai

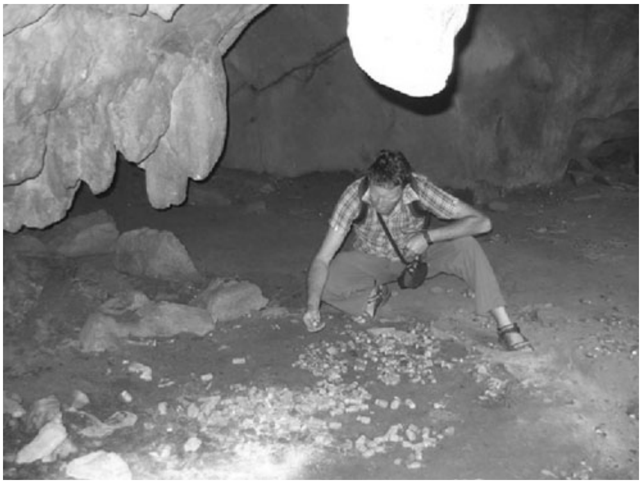

Fig. 10 Medicine bottles in a cave adjacent to Tham Pha that housed wartime medical facilities

streamlets also implies at least minor quantities of chemicals having entered and potentially damaged aquatic cave ecosystems. The use of paint, probably lead-based, to preserve artificial structures inside the caves, or to reflect light, also implies potential harm to cave biota. The crushed metal drum in Tham Piu and the inevitable need for various chemical materials to sustain the human presence underground similarly imply chemical introductions into caves. The latter is likely to have been very pronounced at Tham Pha Tok where the provincial government structure had to be maintained underground for several years, and above all at Viengxai where the entire apparatus of national government was housed in caves. Evidence for large explosions having occurred within cave entrances at sites such as Tham Pha Kuang and Tham Piu also implies contamination of the cave atmosphere by gases. Blasting to modify caves for military or government purposes, and smaller explosions associated with rocket fire or the discharge of firearms underground, all imply similar effects of varying magnitude. The walls of Tham Paho and various other caves have also been locally blackened by fires lit underground for cooking, heating and light. The use of petroleum-powered generators for production of electricity, and other underground use of internal combustion engines, is also likely to have contaminated cave atmospheres. The significance of this atmospheric contamination can reasonably be evaluated against informed management of tourist caves in most developed countries today where even the smoking of cigarettes is prohibited in recognition of the potential impacts upon sensitive cave biota. Contamination of cave environments is similarly implied by some caves or their immediate environs having been used to secure motor vehicles or for storage of fuels or other automotive requisites.

The introduction of chemicals associated with weaponry is also implicit from recorded physical evidence such as in the presence of ammunition case fragments in Tham Pha Kuang (Fig. 11a); from evidence of previous troop presence in caves such as Tham Panoi, Tham Kham and Tham Pha Tok; and from structures to shelter troops guarding cave entrances in the Viengxai area. Remnants of old hand grenades, land mines and other munitions were encountered in Tham Panoi (Fig. 11b). UXO was formerly present in Tham Kham until cleared by UXO Lao and now-deactivated UXO remnants also remain in the Tham Pha cave complex. Such remains are undoubtedly widespread in various caves used during the revolutionary war, and they are significant for several reasons. Firstly, UXO in caves is likely to pose a continuing hazard of both percussive and gaseous injury to geodiversity and biodiversity values should it detonate. Secondly, its presence implies the likelihood of exotic materials being leached into cave environments even if detonation does not occur. Thirdly, UXO poses risks for humans who venture into caves where it may be present, whether as villagers, cavers, tourists, scientists or protected area managers, including risks to the tourism image of Laos should an accident occur to a tourist. Given the huge scale of the UXO problem that exists in Laos (Lovering 2001), and the focusing of much past military activity around caves, the issue of UXO in their vicinity is of serious concern, as is the potential environmental impact associated with some methods of UXO decontamination (Kiernan 2007). However, clearance of UXO is a very expensive and time-consuming process, hence it has hitherto been undertaken only in a very

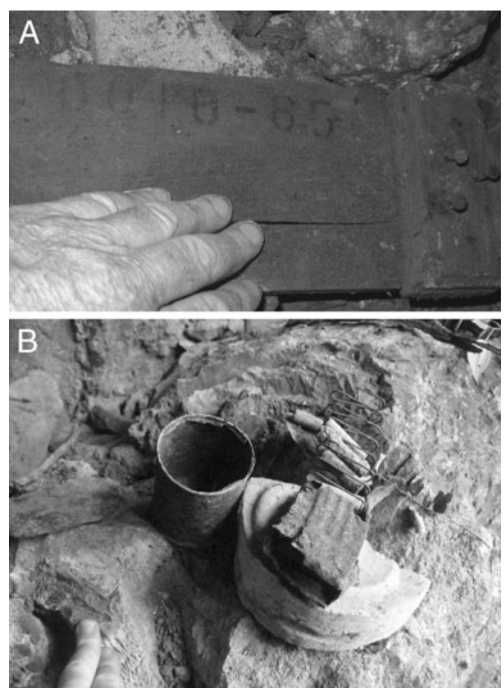

Fig. 11 Evidence for the introduction of munitions into cave environments, implying a variety of environmental hazards: **a** fragments of wooden munitions box found in Tham Pha Kuang; **b** remnants of ammunition and land mines in Tham Panoi

few very localised areas and is probably destined never to occur over much of the country.

Non-Metallic Minerals

Whereas internal modification of most caves involved redistribution of cave sediments and reinforcement of terraces with bamboo, wood and fabrics, more substantial construction also occurred in some caves, epitomised in the Viengxai area where the PL established its capital. Cement and building stone were used to provide protection for guards at cave entrances (Fig. 12a) and to construct blast-protection walls (Fig. 12b). Massive volumes of cement were also taken deeper underground to construct foundations for factory equipment, internal walls to divide cave chambers into separate rooms and artificial ceilings to deflect dripping water. Such modifications facilitated establishment of residences, offices, storage areas, bakeries, schools, gun emplacements and other facilities. Other key facilities established in the caves of the wider area included the large Friendship Hospital 7 km east of Viengxai in caves at Xieng Luang which included three wards and several operating rooms. No attempt has been made to quantify the total amount of cement and rock introduced into caves during this process of anthropogenic infill, but some insight may be gained by considering the approximate volume evident at just one or two of the many sites where it was used. For example, anti-blast walls constructed in the entrance to some of the caves comprise ~2–6 m^3 of concrete. Concrete bunkers equipped with air filtration equipment that were constructed in some leaders' caves, imply use of up to ~30 m^3 of concrete at those sites examined (Fig. 13a). Vast areas of paved floors, artificial walls and other concrete infrastructure were established (Fig. 13b, c), burying the natural cave floors entirely.

Environmental Damage Caused by Attacks upon Caves

Small Cave at the Foot of Pha Tok (Luang Prabang Province)

This small cave, located a few hundred metres from Tham Pha Tok, bears physical evidence of gunfire and impacts by some larger munitions and was examined in order to characterise the nature and magnitude of environmental damage that typically results from this cause (Fig. 14). Pitting of rock surfaces that is interpreted as having been caused by small arms comprises numerous pock marks that are typically 1–1.5 cm in diameter and seldom more than 0.5–1.0 cm deep, within which the rock surface is fresh and unweathered compared to the surrounding natural rock surface. Pit asymmetry and the occasional detachment of small rock flakes from some position on the rim of some pits appear to reflect the angle of incidence of the projectile. The density of these bullet holes is typically ~10/m^2 at this particular site. There are also numerous larger indents in the form of small craters 8–15 cm in diameter and sometimes 3–4 cm deep that were produced by larger, possibly explosive, ordnance. In some cases, the area of rock surface defaced by the blasting away of bordering rock fragments was at least equivalent to the area of the impact crater itself. The types and magnitude of environmental impact generated by small munitions fire at this site are broadly representative of similar evidence observed at several other sites during the course of this study. However, in some other locations the density of bullet holes was as high as 30/m^2 or more, and such damage was sometimes not restricted merely to the cave entrance as at this site but was also found to have occurred well inside caves in positions where it could not have been caused by weapons having been fired into the cave entrances. The latter implies that the interior of some caves was subject to actual combat operations that added to

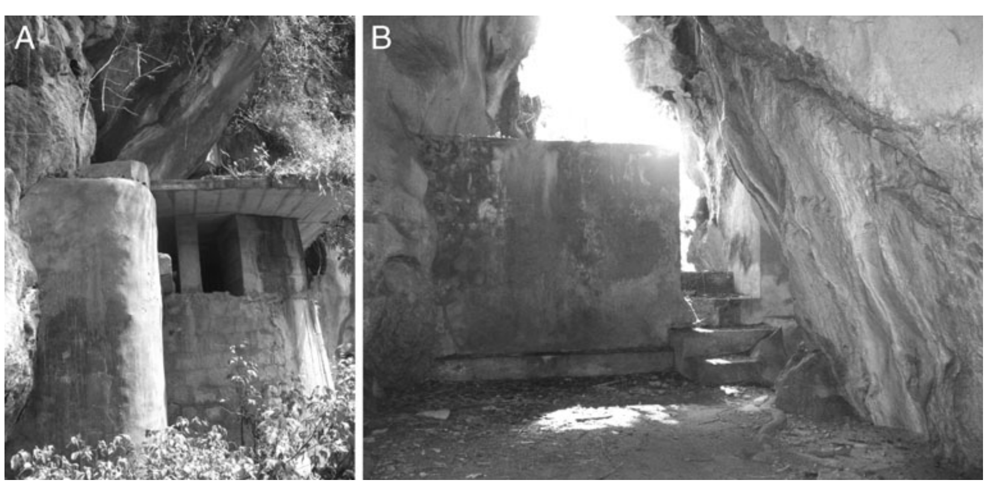

Fig. 12 Defensive structures established at cave entrances in the Viengxai area: **a** pill boxes and **b** anti-blast walls at cave entrances

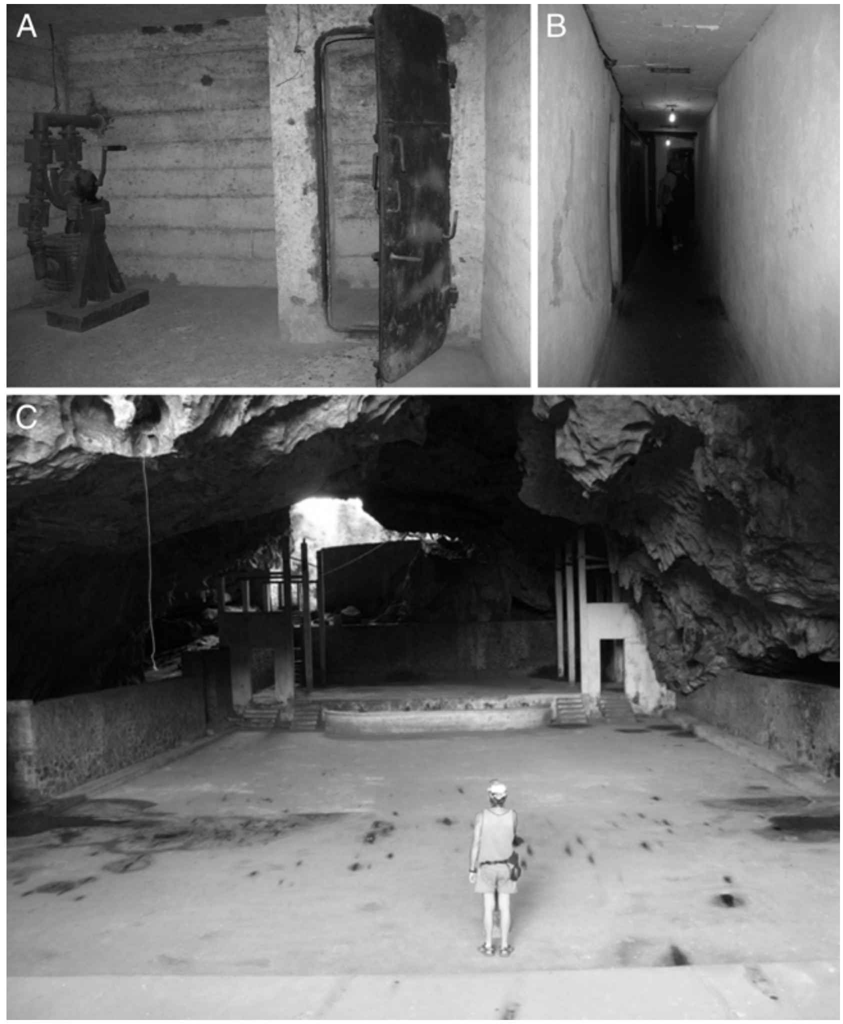

Fig. 13 Large quantities of cement imported from Vietnam used deeper underground at Viengxai to construct **a** bunkers equipped with oxygen equipment in case of gas attacks; **b** passageways; and **c** a large meeting facility and theatre

the environmental harm they suffered. Such operations and impacts may not have been restricted merely to gunfire.

Tham Kham

Although the now-declassified USAF bombing database indicates 265.5 tonnes of bombs were dropped at Tham Kham between June 1969 and October 1970, field inspection during this study revealed no evidence for any direct hits on the cave portal itself, and that the most conspicuous landform damage is confined to the blasting of bomb craters on the alluvial plain outside the cave entrance. Accurate targeting of caves at the foot of steep limestone hills using gravity bombs is likely to have been a particularly difficult endeavour and especially so where the rock face in which a cave entrance occurred was overhanging.

Tham Pha Kuang

The entrance chamber of Tham Pha Kuang exhibits extensive fresh scarring caused by dislodgement of rock fragments from the walls. This rock debris now lies scattered across the cave floor, often some distance away from the freshly scarred points on the cave wall from which it appears to have been derived. The remaining rock surfaces throughout this chamber are very much more thoroughly and heavily blackened by carbon deposits than occurs in most other occupied caves such as Tham Paho. A few tens of metres inside Tham Pha Kuang are the remains of an historical shrine. Here, fragments of bricks and brightly painted stucco are intermixed with limestone rubble similar to that which occurs nearer to the cave entrance, and this debris also occurs beneath fresh wall scars (Fig. 15). This physical evidence suggests that the shrine was demolished, or its earlier decay completed, by a large explosion or multiple explosions in the entrance chamber. The USAF bombing database indicates that between 1968 and 1970 "caves" at this site were targeted by 81.9 tonnes of bombs, but field inspection during this study revealed a distribution of bomb craters and a pattern of surface rock scarring that indicates most of these bombs apparently landed well wide of their target. However, local anecdotal reports suggest that

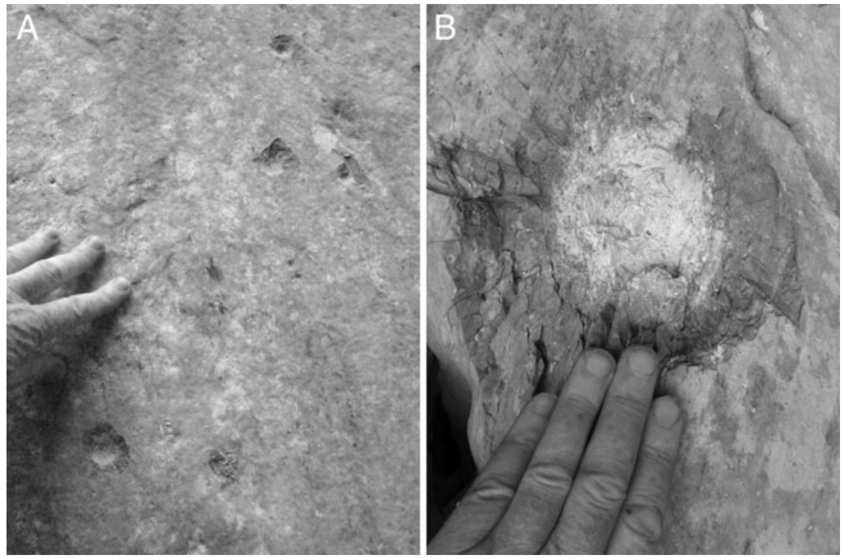

Fig. 14 Damage caused to cave entrances by projectiles: **a** bullet holes in the wall of the small cave at the foot of Pha Tok and **b** damage caused to the same site by larger munitions

ordnance stored in this cave was detonated during one rocket attack, and this seems consistent with the scale and pattern of the observed damage, and with the remnants of an ammunition box found among the debris. In addition to the physical damage such an occurrence is also likely to have harmed cave biota.

Tham Piu

Massive damage has been caused by shelling of the entrance chamber of Tham Piu on the northern edge of the Plain of Jars. Here slabs of limestone up to several metres in length have been detached from the cliffs at the cave entrance (Fig. 16) while the floor of the large entrance chamber is carpeted with smaller limestone rubble comprised of clasts that are mostly <15 cm long but with a few larger blocks up to 3 m long. Some of this material rests upon artefacts of wood and timber implying that this damage occurred during or subsequent to human occupation of the cave. Blackening of rock surfaces by carbon extends deep into the cave, although some remnant structural timbers found a short distance inside the cave lack evidence of charring. Fresh detachment scars 6–8 m high are evident at the cave entrance where there are also large slabs of partially detached limestone that lack the surface blackening typically present further inside. This suggests that there was more than a single attack, or else detachment at some later time, possibly in response to structural weakening caused by the initial shelling. This damage does not appear to have concluded as yet because there are significant areas of destabilised bedrock that remain only partially attached to the cave walls and mouth, and some of these masses appear destined to collapse in the relatively near future.

Fig. 15 Limestone rubble blasted from the wall of Tham Pha Kuang, together with brick and stucco debris from a former cave shrine

The exact timing and circumstances of the attack on this cave remain contentious. Local sources record it as having occurred on 24 November 1968. However, according to Robbins (1989, p. 226), in late 1969 the US seventh Air Force determined that attacks using Bullpup missiles should made on a daily basis against caves on the northern side of the Ban Ban Valley, the general area in which this cave is located. Although the USAF bombing database does record missions against a cave in this area, none is indicated as having taken place on the date that is locally recorded for the Tham Piu attack. Perhaps surprisingly given the controversy that this attack generated, there are no clear references whatsoever to attacks here in the now-declassified (albeit still censored) official USAF history of its operations in northern Laos (Anthony and Sexton 1993), although reference is made to an attack on 21 April 1969 against a cave on the *southeastern* [my emphasis—as opposed to *northern*] edge of the Plain of Jars when a flight of F-105 s put a

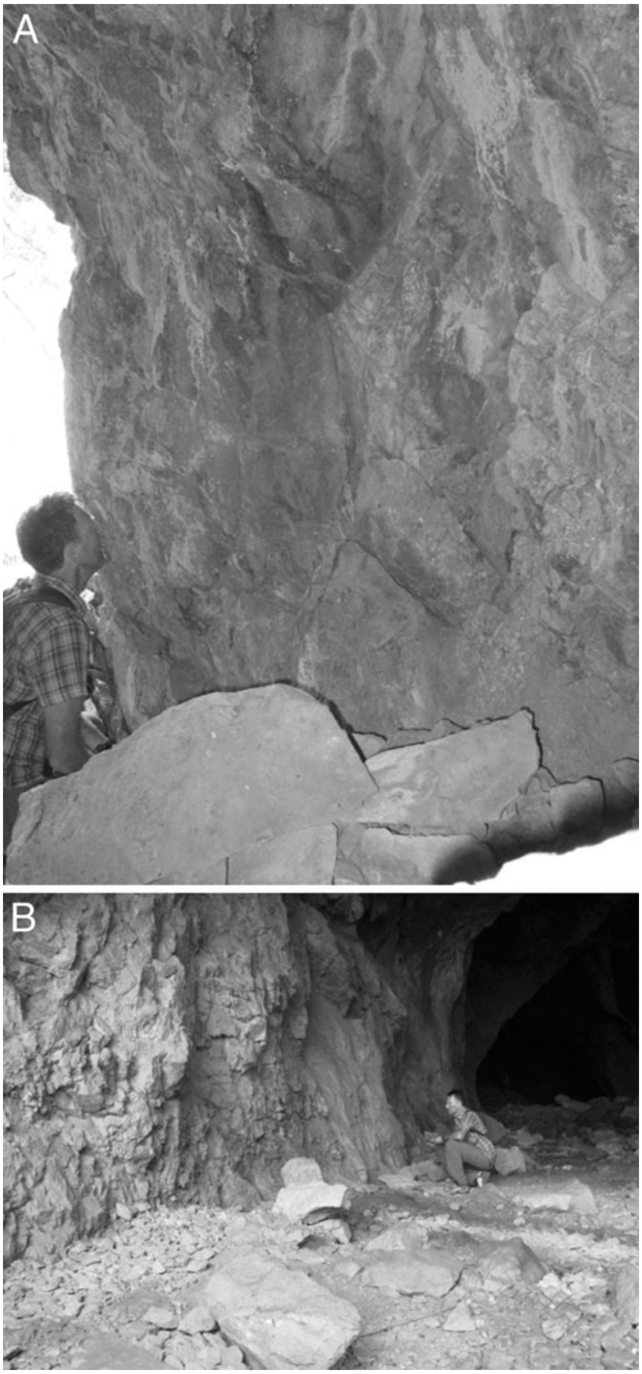

Fig. 16 Damage caused to Tham Piu: **a** fresh detachment scars remaining after rocket attack on the cave entrance; **b** limestone rubble detach from the side walls of the entrance chamber

Bullpup missile into its entrance (Anthony and Sexton 1993, p. 301).

Varying perspectives adopted by different parties in relation to this attack highlight the extent to which differing value judgements regarding the circumstances of historical events inevitably condition the cultural heritage significance that may be attributed to such a site. Locally, the attack on Tham Piu is described as a war crime against resident civilians and patients in an underground hospital, during which hundreds of people were slaughtered (Fig. 17). Local informants and the bones that still lie among the rock debris despite later attempts to retrieve and properly treat the bodies both attest to the fact that very great loss of life occurred, most accounts concluding that from 200–400 people were killed. However, opposing voices in the US have argued that this was a military facility, or at least a military hospital, and the subsequent removal of some human remains from the site by Vietnamese authorities has also been claimed (Burke and Vaisutis 2007). Nor were all local people of like mind with respect to the politics of the conflict and the side they supported. In an interview given to the producers of a documentary film on the war, one villager recollects that the intense heat in the cave entrance restricted entry into it for some days after the attack. Such protracted heat seems inconsistent with detonation of just "a" rocket and would suggest secondary detonation of flammable or explosive materials stored inside the cave. However, any such materials that may have been present need not necessarily have been for military purposes if a large civilian population was being housed and a medical facility was in operation. That this was a scene of great human tragedy and loss can hardly be questioned, but its circumstances, and hence the cultural heritage significance attached by different parties to both the event and the site, and any aspirations they may hold concerning its ongoing management show some disparity.

The account by Anthony and Sexton (1993) of the attack on a cave that took place on 21 April 1969 indicates that the forward air controller considered the resulting explosion to have been the largest he had ever witnessed, with explosions issuing both from the cave mouth and from "ventilator shafts on the top of the mountain" for 16 hours and that "a

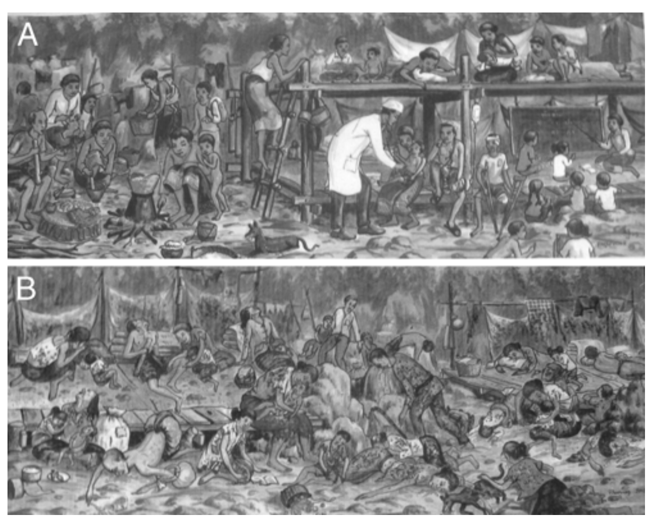

Fig. 17 Interpretation signs depicting Lao version of **a** the function of Tham Piu and **b** the aftermath of its shelling

village over half a mile away erupted in a ball of fire—the communists had dug an access tunnel from the village to the cave". If this account is not coloured by hyperbole, propaganda or deliberate disinformation, it suggests some similarity to the reported attack at Tham Piu, but it is in the wrong geographical location and it refers to a different date to that commemorated locally for the Tham Piu tragedy. The reference to "ventilator shafts" might well reflect the presence of natural karstic vadose invasion shafts rather than any artificial excavation, and the suggested artificial "tunnel" might also equally imply a natural karst feature. Hence, whether this account indeed refers to Tham Piu, or instead to an attack on some other cave site, remains unclear.

Cave at Plain of Jars Site 1 (Xieng Khuang Province)

Numerous bomb craters occur outside a cave entrance in a small limestone hill at Plain of Jars Archaeological Site 1, a few kilometres south of Phonsavan. Shattered rock surfaces that surround artificially modified holes in its roof indicate that the cave itself was directly targeted by bombing, and other shattered rock surfaces beneath the slightly overhanging hill margin indicate that the main entrance to this cave also came under shell-fire or rocket attack. Blackened by soot, this cave was once locally reputed to have been the kiln in which some of the large urns on the Plain of Jars were manufactured, a legend inconsistent with the reality that these urns have all been carved from natural rock (Baldock and van den Bergh 2009). This cave is located much closer to the "southeastern edge of the plain" than is Tham Pui, and hence it may conceivably be the site referred to in the Anthony and Sexton (1993) account of the rocket attack upon a cave that resulted in a major conflagration. Its upper entrances would also facilitate the chimney effect described in that account, although this cave occurs in a very small hill only a few tens of metres high rather than in a "mountain". Although there are remnants of trenches in a couple of locations between this cave and an airfield a few hundred metres to the west, fieldwork conducted during this study found no evidence of any continuous tunnel such as was suggested by the air controller referred to in the Anthony and Sexton account.

Surviving Natural Values and Recovery from Wartime Damage

The nature and magnitude of some of the damage to these caves is such that natural processes have been derailed. Given the impossibility of natural system function now being recovered, this change means that damage is effectively continuing to be sustained, notwithstanding the fact that four decades have now passed since the cessation of combat activities (Fig. 18). In this sense, it is not yet possible to provide a full accounting of the damage caused by war and nor is it ever likely to become so.

On the other hand, notwithstanding the very severe impacts of war upon these various caves, some natural values have survived, due either to their being relatively robust to the forms of human impact generated, to their being located away from the key foci of the impacts to which the caves have been subject, to the specific impact having been of only moderate intensity, or to some combination of these factors. The actual gross form of caves, that is, simply as holes in the ground, typically persists. Many bedrock speleogens also survive, even at Viengxai. A few speleothems have even survived in remarkably intact condition in Tham Panoi (Fig. 19), due perhaps to a relatively small number of people having resided there or perhaps to the naturally high levels of atmospheric carbon dioxide that have been reported from the innermost parts of this cave (Dreybrodt and Laumanns 2002) having dissuaded frequent human entry into them. If surviving natural values such as these speleothems are to be retained then it is critical that their existence is recognised, their significance is acknowledged, that any necessary management protocols to safeguard them from further damage are developed and implemented effectively and that these tasks be completed in a timely manner.

The question also arises as to whether any measures are practicable or desirable to try to somehow undo some of the damage that has occurred to these caves or others that have suffered similar fates. Any attempt to artificially reconstruct the original form of a cave, or any feature that previously existed within it, cannot really be considered as being environmental restoration and especially if it involves importing foreign materials because it would simply be production of a facsimilie or counterfeit copy that has no real integrity. True restoration lies in eliminating destructive pressures and harnessing natural processes in a manner that allows for a degree of natural healing. This is only possible if the natural processes responsible for producing the original landform are still operative. This is not possible if, for example, the feature involved was the product of environmental conditions that prevailed under a climatic regime that no longer exists, such as those associated with the Glacial Climatic Stages of the late Cainozoic and which drove geomorphological processes or process magnitudes that are no longer possible under the present Holocene climate (Kiernan 2007). Given the probability that the gross karst topography, cave architecture, cave sediments and cave biota of Laos have developed over multiple Cainozoic climatic oscillations, restoration of many attributes to their original condition is no longer possible at a gross scale. However, some other natural values of these caves are much younger and may be more amenable to careful rehabilitation.

Fig. 18 Destabilised rock faces that surround the mouths of shelled caves such as Tham Piu highlight the fact that not all the damage caused by war has yet run its full course, and that further cave collapse and the implications of changed natural process pathways inevitably persist long after active combat has ceased

It is now four decades since hostilities ceased, implying relief from the most pronounced pressures under which these caves were placed. This has allowed incipient recovery from some types of damage caused by war. For example, there has been some precipitation of fresh secondary carbonate speleothems in some caves, and the potential exists for this to eventually at least mask some of the damage previously caused. In a sense, this might be regarded as a form of geomorphological scar tissue that over geological time even has the potential to infill some artificial cavities underground. Similarly, if any invertebrate cave fauna survived in microcaves distant from the larger caves used for war but connected to them, the potential may exist for some populations to have rebuilt and recolonised more spacious parts of the cave systems from which they were previously driven. But if any recovery is to occur a variety of time scales will inevitably be involved, and it is essential to ensure that the recovery process is not sabotaged by a failure to protect recovering phenomena.

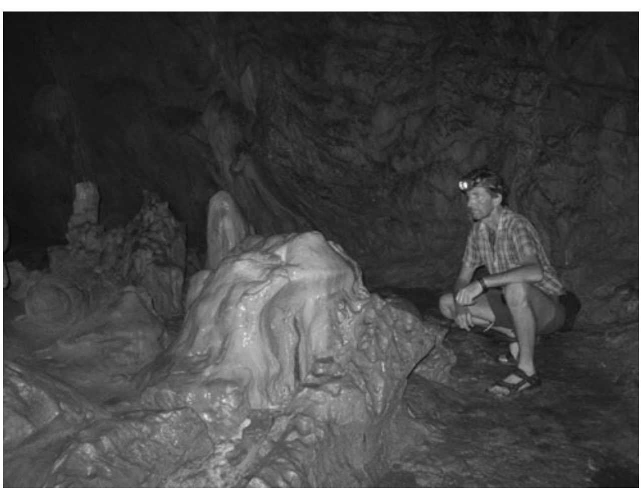

Fig. 19 Notwithstanding heavy previous use, less frequented parts of Tham Panoi and various other caves retain some well-preserved speleothems. However, these are now potentially open to degradation by unguided tourist traffic and will not survive intact unless their significance and vulnerability is recognised and appropriate management protocols are put in place

Evidence of cave floor compaction by trampling remains pronounced more than four decades after the end of combat and this highlights the likely longevity of even this relatively low level impact. That the rate of anthropogenic wartime sedimentation considerably exceeded the mean rate of natural sediment accumulation is clear from the fact that litter left in caves retains visible topographic relief above natural cave floors four decades after it was deposited. Subsequent accumulation of secondary carbonate upon war-damaged surfaces in the caves examined proved very rare and also highly localised, even though it is quite visually striking in one or two cases. In a few places, carbonate has started to coat artefacts of wood and metal but not yet to the extent of masking their identity (Fig. 20). But few artefacts have as yet even been merely discoloured by secondary carbonate, and this highlights the fact that natural "full" recovery of even just the aesthetic character of those caves least affected by wartime damage will not occur over a human time frame.

Artificial voids described earlier from Viengxai include individual chambers that exceed 160 m^3 and also connecting tunnel systems that sometimes involved "anthropogenic erosion" of >500 m^3 of limestone bedrock. In contrast, the maximum recorded thickness of flowstone deposited on the floor of any such artificial chamber is only ~2 mm, spread over ~2 m^2, with some very rare incipient stalagmites up to 8 mm high and 60–80 mm wide (Fig. 21). The maximum recorded thickness of flowstone deposited down the wall of any of these artificial voids was ~ 3 mm and confined to less than 1 % of the void wall on which it occurred. These accumulations are insignificant relative to the size of the artificial voids in which they occur, and they indicate that any natural infill of these wounds by this means alone would take hundreds of millennia, even if it were likely that such accumulations would naturally occur in all parts of the void. Nevertheless, such evidence of healing constitutes an intriguing new value of these sites in its own right, as well as providing a sobering and readily visible reminder of just how much better it is to prevent damage occurring to geoheritage than to rely on trying to remediate any such damage afterwards.

Notwithstanding these sobering if perhaps predictable conclusions, such recovery as has occurred with respect to particular environmental values of war-ravaged caves warrants safeguarding. Continuation of natural repair is unlikely unless measures are adopted to ensure that the repair processes are not jeopardised by post-conflict cave management. Those

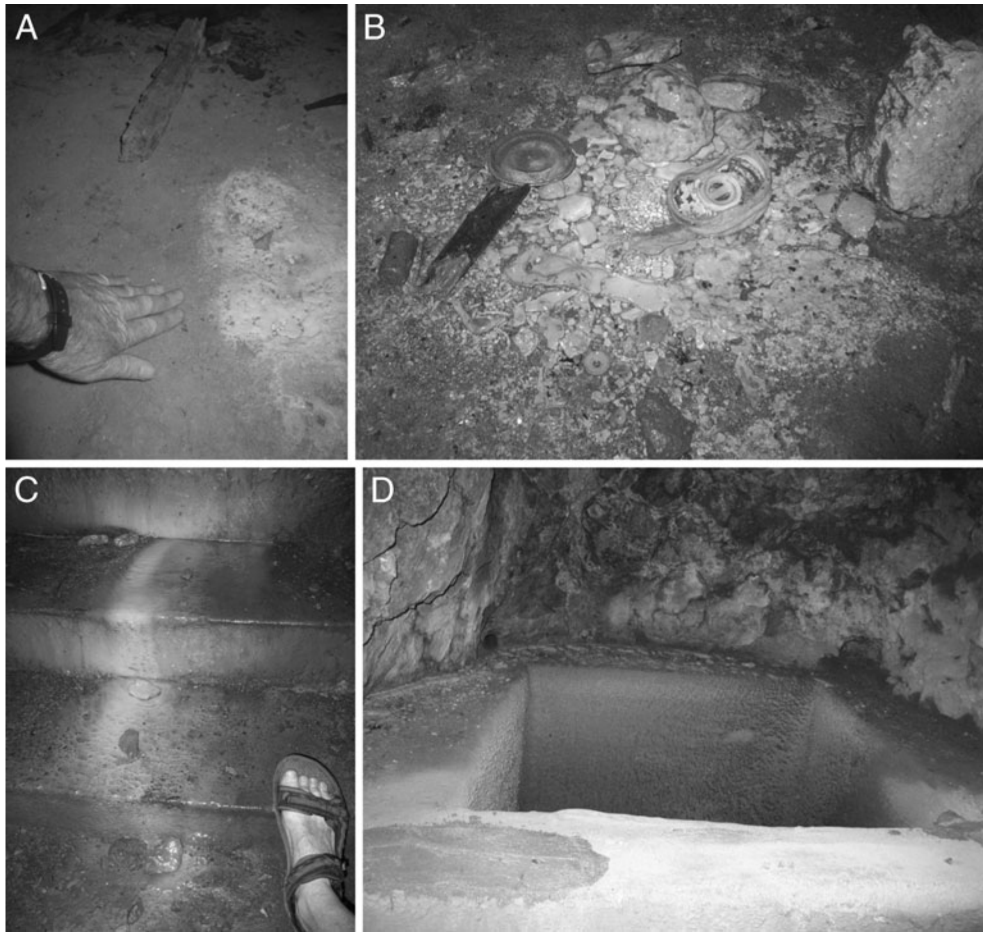

Fig. 20 New speleothem carbonate accumulating on **a** previously trampled floors in Tham Panoi; **b** wartime debris in Tham Panoi; **c** a concrete stairway in a cave at Viengxai; and **d** more pronounced carbonate accumulation at Viengxai, around a water storage tank where relatively rapid carbonate precipitation is favoured by a relatively abundant and persistent supply of carbonate-rich water

values that have survived despite war are also unlikely to be retained if appropriate management strategies are not formulated and implemented effectively.

Conclusions

Several types of environmental damage caused to caves by their wartime use have been recognised. They range from floor sediment compaction and trampling of flowstone floors to breaking of speleothems and gross damage to natural cave architecture by excavation of entirely new artificial chambers and linking passage systems. The latter has also triggered derangement of some natural environmental processes with major implications for both geodiversity and biodiversity, such as changes to flows of water and air and the humidity of cave atmospheres. To these, visually evident physical impacts must be added now indecipherable but nevertheless inevitable environmental outcomes that have resulted from underground use of a variety of substances harmful to natural environmental values. The rates of change involved in these transformations over a very short span of years are far in excess of natural rates of change under prevailing environmental conditions and in that sense would be considered entirely unacceptable by most present day cave managers, irrespective of any historical interest that might subsequently accrue to the sites subject to such interventions.

The use of caves during wartime also commonly results in their being targeted by opposing forces, and in the Laotian case, this has entailed massive bombing campaigns that have sometimes caused structural damage to caves, but which more widely resulted in damage to the natural environment on the surface. In many cases, even the latter implies inevitable impacts upon subsurface environments, such as changes to soil stability and to the quantity and quality of water and sediments that infiltrate underlying caves. In the absence of baseline data that would allow comparison of pre-conflict and post-conflict condition of the study sites, the precise impacts of these changes cannot be quantified, but from first principles, and given the extent of the bombing and herbicide operations across the Laotian karstlands, major damage to in-cave geodiversity and biodiversity values was inevitable. While the proximal cause of most of the damage recognised in this study involved the activities of local people rather than the direct result of enemy attacks, it was the massive and sustained nature of those attacks, and the need for security from them, that was

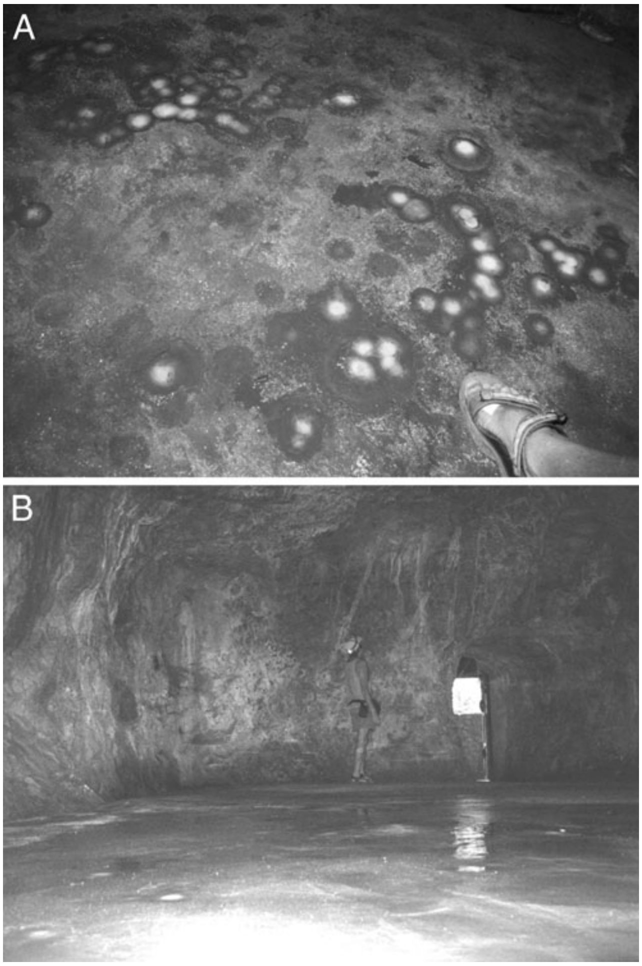

Fig. 21 Notwithstanding some very superficial **a** burial of artificial floors and **b** secondary carbonate accumulation on the walls of some artificial tunnels since active conflict ceased, both illustrated here at the maximum observed anywhere around Viengxai, the trivial extent of this natural infill during the half century since these facilities were constructed, relative to the large size of some of the artificial voids then created, highlights the reality that at least hundreds of thousands of years are likely to be required for effective natural closure of such voids

the principal driver of the in-cave environmental damage. The net result is that damage to the natural cave geoheritage of Laos has been severe and widespread, and it will also be extremely long-lasting. The magnitude of that damage is such that, in the very few cases where any degree of healing by natural karst processes is possible, the observations of recovery to date made within the studied caves, coupled with wider scientific knowledge of the pace at which such karst processes occur, imply that in most cases the timescale required for any meaningful recovery will range from thousands to many hundreds of thousands of years.

Hence, while the military history to which the foregoing caves have been subject may have imbued them with varying degrees of cultural heritage significance, and however noteworthy their military history may be, it has also resulted in often massive damage to natural environmental values. This is hardly surprising because environmental damage seems intuitively likely to be a major and persistent legacy of war, even if its impact on geodiversity and geoheritage has remained undocumented. In this case the damage has already been done and lamentation over the fate of these caves now cannot undo history. Moreover, lamentation may also be misinterpreted as disrespectful to the locally perceived heroism of partisans and their allies, or a threat to respectful remembrance of such intensely felt historical human tragedies as occurred with the shelling of Tham Piu. But what is important here is that we should learn from these occurrences. There are occasional initiatives aimed at minimising unnecessary destruction of cultural heritage during armed conflicts, such as the 1954 Hague Convention for the Protection of Cultural Property in the Event of Armed Conflict (Chamberlain 2004; Hladik 2005). The results obtained in this study highlight a need to work towards wider recognition of the impacts of war on geoheritage and towards initiatives aimed at reducing its incidence and severity. There is a strong case for international protocols and the fostering of personal ethics among the practitioners of war to discourage the destruction of natural heritage. If this challenge goes un-met, the results of geomorphological evolution over countless millennia through geological time will continue to be undone relatively instantaneously during brief outbursts of human conflict, obliterating landforms of great worth in their own right, and in the process of removing any possibility of inter-generational equity. Additional challenges need to be met even after overt conflict ceases, including effectively responding to the fact that governance is commonly deficient in the immediate post-war phase, as Lucic (2011) has described from the Dinaric karst where important natural values still remain endangered by a poorly functioning political system and lawlessness as Bosnia and Herzogovina work through their post-war transition—although these deficiencies in governance may be only temporary, the damage they cause is likely to be permanent.

Notwithstanding the onslaught to which these Laotian caves have been subjected during war, a few remnant natural environmental values have been recognised within them, such as some attractive speleothems. Some other values may also persist, at least to some degree, such as some elements of the original invertebrate cave biota. These surviving values warrant careful nurturing, particularly since some may now persist even more tenuously than the natural cave environments within which they evolved already allowed their existence. Such surviving values must be taken into account in cave management henceforth, and that implies a need for studies of such war-ravaged caves to establish what natural values remain present and what is required for their long-term retention. Thus far there has been only limited investigation of the prehistoric sites of northern Laos (Sayavongkhamdy et al. 2000; White et al. 2009) but given the rich prehistoric archaeological record contained in the caves of countries neighbouring Laos (Gorman 1972; Kiernan et al. 1988; Reynolds 1990; Sidisunthorn et al. 2006; Yi et al. 2008), it may be that retention of older cultural heritage may also be well-served by a balanced and scientifically based holistic approach to ongoing cave management.

During a protracted post-war period, Loatian caves of proven military utility remained a tightly guarded secret and especially those at Viengxai. However, with a newer generation with fresh ideas coming into power, continuing endemic poverty across much of Laos and growing recognition of the economic benefits obtainable from tourism, the potential for the historical significance of some military caves to make them a tourist drawcard has seen the advent of formalised commercial-guided cave tours in some caves at Viengxai and self-guided commercial tourism at Tham Pha Tok. In both cases, the focus is entirely on the cultural heritage of the caves, and the interpretation services provided for visitors also focus on cultural heritage alone. Similarly, at Tham Panoi, where a new tourist venture has been initiated within recent months, the human history of the cave is promoted but no measures have been put in place to prevent or discourage damage even to speleothems, let alone other less visually conspicuous natural environmental values. A similar deficiency exists at Tham Kham where informal self-guided tourism has been promoted as a useful means of deriving revenue with which to support local community development and schools. Here too, such natural environmental values as have survived wartime impacts are rapidly being degraded by visitors who typically have no experience of environmentally sensitive caving techniques but have free reign to wander anywhere at will. The problem is compounded by the fact that such visitors are permitted to venture underground using light sources that are inadequate to allow them to avoid sensitive areas even if they had been forewarned of their vulnerability, which they are not. Protection of cave values under such a loose regime is also dependent on whether the personal environmental ethics of the tourists inclines them to minimise their personal impacts by giving priority to protecting the environment rather than satiating curiosity or a quest for safe "adventure", which regrettably is also not always the case. There is every likelihood that the eventual outcome of this lack of environmentally protective cave management will be further damage the natural environmental values of these caves that in some cases is likely to be even more profound and widely pervasive than the damage caused to them during war.

The wartime fate of caves in Laos highlights the fact that the natural environment is inevitably among the key casualties of war, notwithstanding the dearth of literature regarding the injuries that it suffers. And caves are but a canary in the coal mine. Cave management encapsulates many wider environmental issues in microcosm, and many of the types of damage recorded in this study have counterparts in other types of geomorphological environments. In this sense, the concerns raised in this study represent the tip of a very large iceberg. To melt this iceberg of ignorance will require a concerted effort to bring about a change in the climate of opinion. While daunting, this task may actually be less challenging than gaining the consensual political action necessary to address the change in atmospheric climate with which the managers of geodiversity and biodiversity worldwide are also currently confronted. And just as climate change and its environmental implications are not likely to go away, sadly neither will war and the challenges it presents for geoheritage management.

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