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The Khammouan karst of Laos

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Abstract: The limestone hills of central Laos constitute a karst with landscapes that are notable in a worldwide context. They contain a number of large cave passages, including the Hinboun River Cave, which offers a through-trip of 6.3km entirely by powered boat.

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INTRODUCTION

Midway along the length of Laos, the province of Khammouan contains a swathe of limestone mountains that extend eastwards from the Mekong Valley across the border into Vietnam (Fig.1). A lush forest cover thrives in the warm climates and high monsoonal rainfalls, and provides the ideal environment for rapid limestone dissolution. The karst landscapes are mature and spectacular.

Laos is a sleepy country, where a succession of introverted governments has stifled development. Most of the people live in a countryside that is dominated by a higher proportion of uncleared forest than any other nation in the world, and even the alluvial plains support only small patches of rice paddy. Restrictive politics have meant that Western visitors have only been able to visit rural areas for the last few years, and numbers of tourists are still very small.

This short report has been compiled after a visit by the authors to a mere handful of the karst sites in Khammouan. There are just a few tarred roads that branch off the highway along the Mekong Valley. Away from these, travel is over very rough roads or by long river journeys in fishtail-powered canoes.

LIMESTONE GEOLOGY

The Khammouan karst forms a block over 200km long and about 30km wide (Fig.2). It is all formed in thick Permo-Carboniferous limestones that are similar in age and lithology to those in the karstlands of southern China. In Khammouan, the limestones are in a series of tight folds orientated NW-SE. Erosion of the anticlines has exposed cores of underlying sandstone that form small 'islands' of allogenic drainage sources within the karst. The northeastern boundary of the limestone is against Mesozoic sedimentary rocks that form higher ground, mostly fringed by a sandstone escarpment that overlooks the karst. Underlying Palaeozoic sandstones rise to an outcrop that forms the southwestern boundary of the karst, and faults bring Mesozoic sandstones down to floor the Mekong Valley and form low hills southeast of Thakhek. There is little allogenic drainage onto the karst from either side.

THE KARST GEOMORPHOLOGY

The dominating landscape style of Khammouan is one of karst massifs that are almost completely bordered by bare limestone walls rising up to 500m above intervening alluviated plains and sandstone-floored basins (Plate 1). Summit surfaces of the massifs are rather inaccessible beneath a mantle of thick forest on chaotic surfaces of limestone pinnacles and deep fissures. Maps compiled from air photographs indicate an egg-box terrain of steep cones and deep dolines that is a classic fengcong karst of clustered cones.

The massif margins are precipitous walls of limestone blackened by the blue-green algae in its surface crust. Many surfaces are bare rock, and these are fretted into long and spectacular karren, whose knife-edge interfluves break into successions of narrow pinnacles (Plate 2). Skeletal trees cling to parts of the cliffs. White patches of freshly exposed limestone are scars of the rockfalls by which the walls retreat. Wedges of talus, now clad in vegetation, have accumulated along the bases of most walls, but notches and foot caves can be seen where

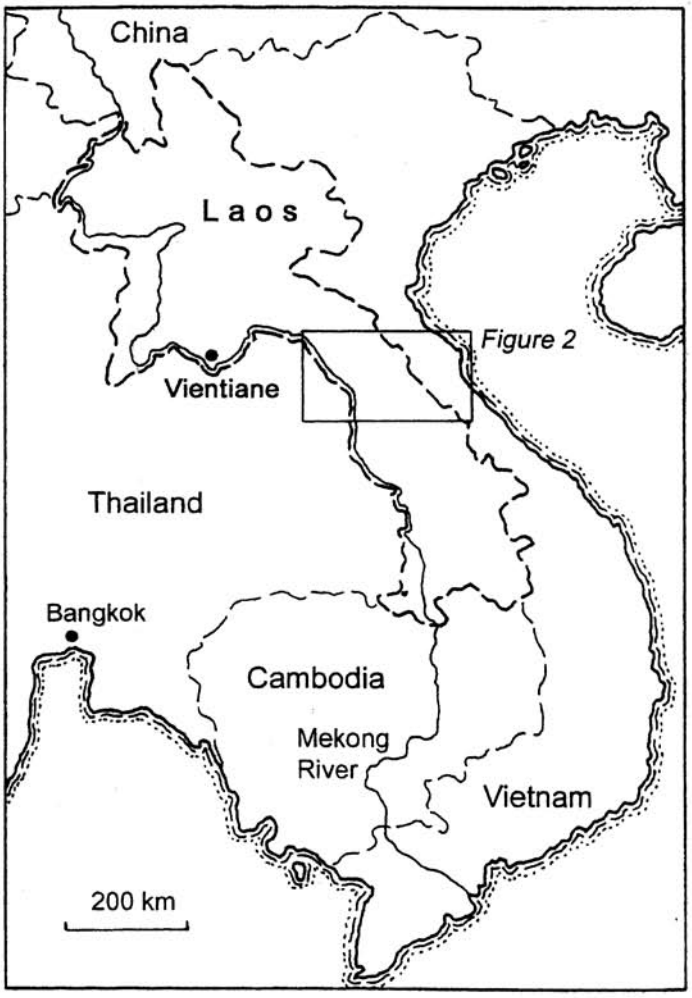

Figure 1. Location map of Laos.

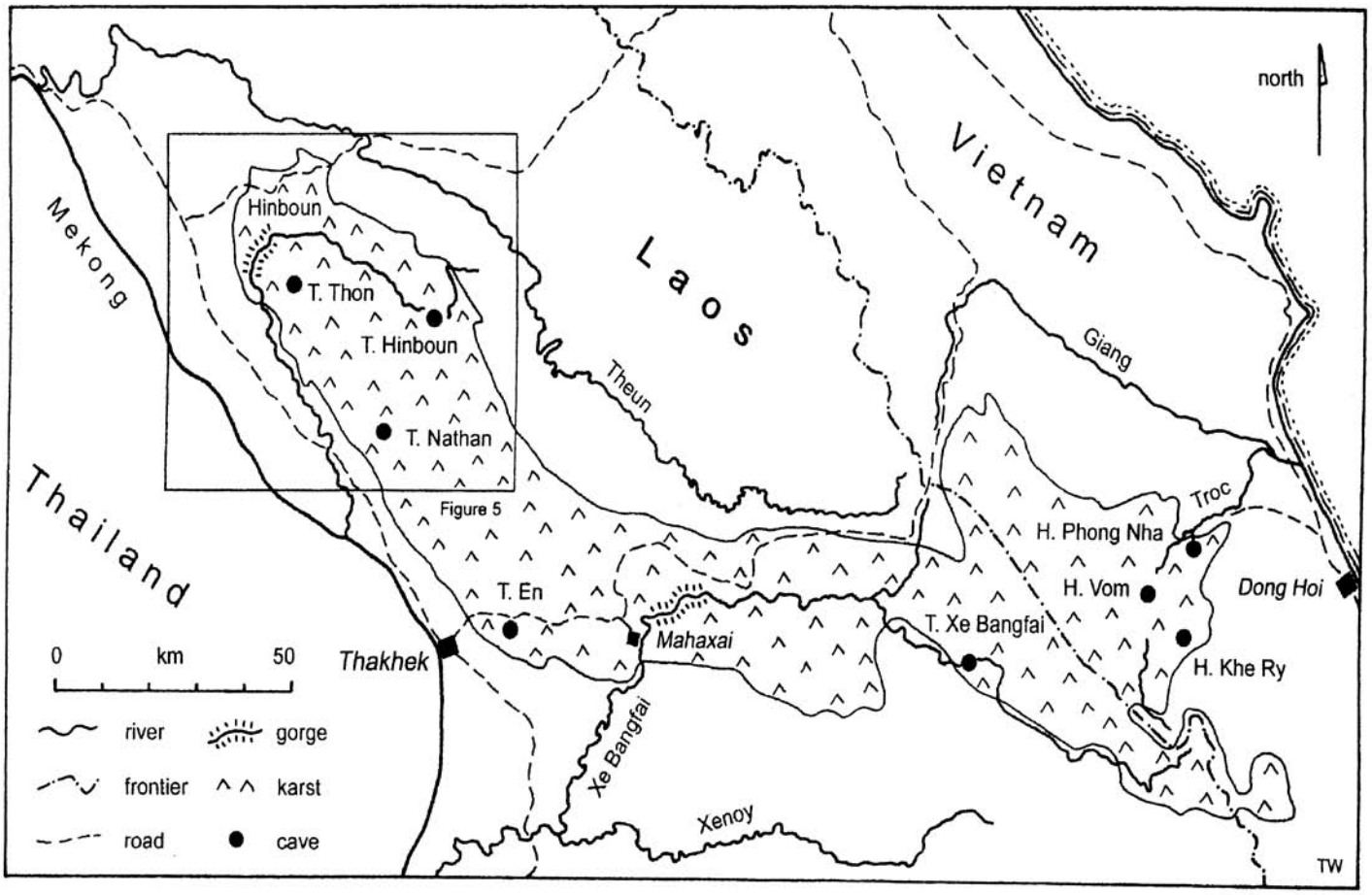

Figure 2. The Khammouan karst and its eastward extension into Vietnam.

streams and rivers on the alluvium have removed the talus and now undercut the limestone.

Basins that have developed by erosion and planation, inwards from the edge of the karst, take the form of marginal poljes. Two of the largest basins are on the Hinboun River (Fig.3). The upper, eastern basin gathers drainage partly from the overlying shales beneath the fringing sandstone escarpment to the northeast. Its western and southern margins are steep limestone walls and its floor is alluviated, with no exposure of the underlying limestone. It is a true polje, as it drains out through the Hinboun River Cave (see below), into the larger basin.

The main Hinboun basin gathers more drainage from shale slopes along its northern edges, but most of its floor is an alluviated karst plain; small exposures of limestone are largely on the remains of large rockfalls from the fringing cliffs. It is not a true polje, as the Hinboun flows out to the southwest, through a gorge entrenched between limestone peaks that rise 300 to 500m above the river (Plate 3). Below the Hinboun Gorge, the river traces the axis of another marginal polje, before draining off onto the sandstones.

Extending southeast of Mahaxai, between the Xe Bangfai and Xenoy rivers (Fig.2), a broad alluviated plain is largely floored by Palaeozoic sandstones. Scattered across it are isolated limestone hills, but these are residual outliers, and are not true towers that arise from a karst

Plate 1. Limestone cliffs rise over 300m above the floor of the Hinboun basin.

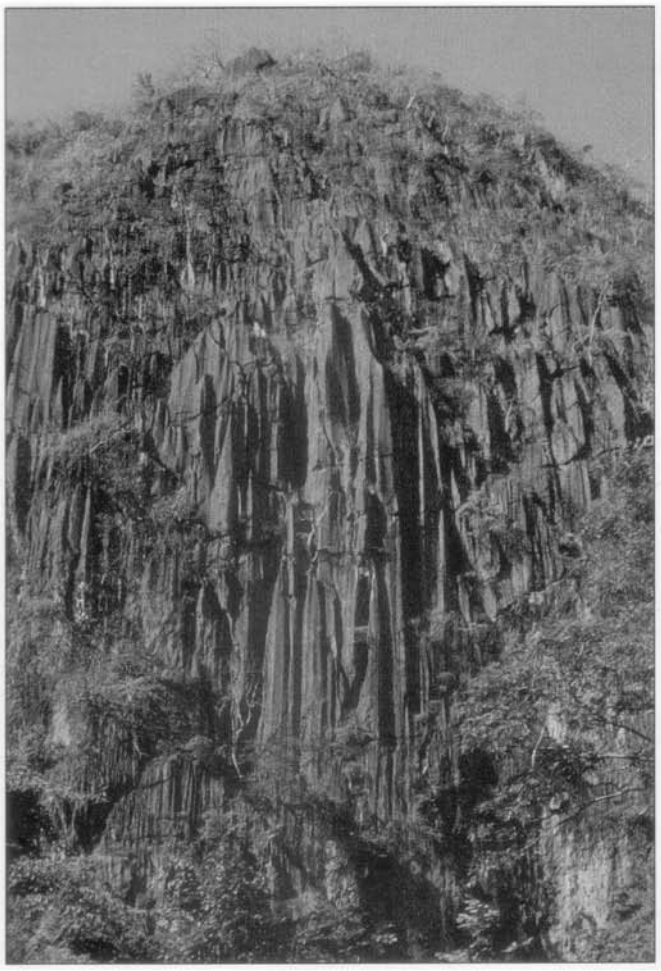

Plate 2. Giant karren, more than 100m long, fret the cliffs above the Hinboun River.

plain. The Xe Bangfai River emerges on to the plain from another fine limestone gorge upstream of Mahaxai. The isolated limestone hills, scattered across both this plain and the smaller poljes, create a fenglin style of karst, but the hill profiles are not as steep as the true towers of the Yangshuo type, and their talus aprons indicate the lack of active undercutting. Though not a classic tower karst, they do create spectacular karst panoramas that contrast with those of the adjacent fengcong massifs.

There are many interior basins, within the karst, most of which are developed on the breached cores of anticlines where the basement sandstone floors are exposed. Dissolutional planation has worked outwards to undercut the limestone and thereby create precipitous marginal cliffs. The Pathene basin is the largest (Fig.3). It lies on an anticline, with the underlying sandstone exposed as low hills within the southwestern half of the basin. Adjacent to the sandstone hills, the basin is floored by alluvium, containing cassiterite that is worked by the Phontiou tin mine. The margins of the basin are spectacular limestone cliffs (Plate 4) that have retreated as the basin floor has expanded by undercutting. Their line is unbroken except where the Pathene River drains out of the basin through a narrow valley cut between fault blocks in the limestone. The source of the Pathene water is a number of caves draining from the limestone along its northern side; these include Tham Thon with 7.9km of passage.

Just to the southeast of the Pathene basin, the Boumlou basin is a totally enclosed polje (Fig.3) that drains out through the cave of Tham Nathan (see below). Ringed by high limestone cliffs, its floor is largely covered by a pocket of untouched rain forest, whose isolation ensures the survival of its resident wild animals (reputed to include leopards and gibbons).

THE CAVES

It is clear that the mature karst limestone of Khammouan is riddled with caves. Streams and rivers flow in and out of the base of the massifs, open entrances are visible in the high cliffs, and there must be many sinkholes and shafts hidden in the forest cover of the massif-top fengcong.

Access and exploration high on the massifs is not easy, and most of the known caves are entered at or close to the foot of the cliffs. Local villagers first entered many of the open caves long ago, and still use some as the easiest route through the karst terrain. The important modern explorations, all within the last ten years, have been by French cavers. In 14 expeditions to Khammouan they have mapped over 100km of cave passage. They have another expedition in 2001, and are currently exploring a cave northeast of Thakhek, where they have already mapped over 20km of passage. Claude Moret has published various short items (1993 – 1998 among others), and is preparing a major report (intended as a Karstologie Memoire in 2002). A British team led by Adrian Gregory (1996) made some more modest discoveries, and a list of Laos caves was compiled by Brouquisse (1999).

The Khammouan caves are characterised by large passage dimensions, with large streamways and river passages at base level. Of the caves visited by the authors, three are worthy of note.

Plate 3. The gorge carrying the Hinboun River out of its main basin.

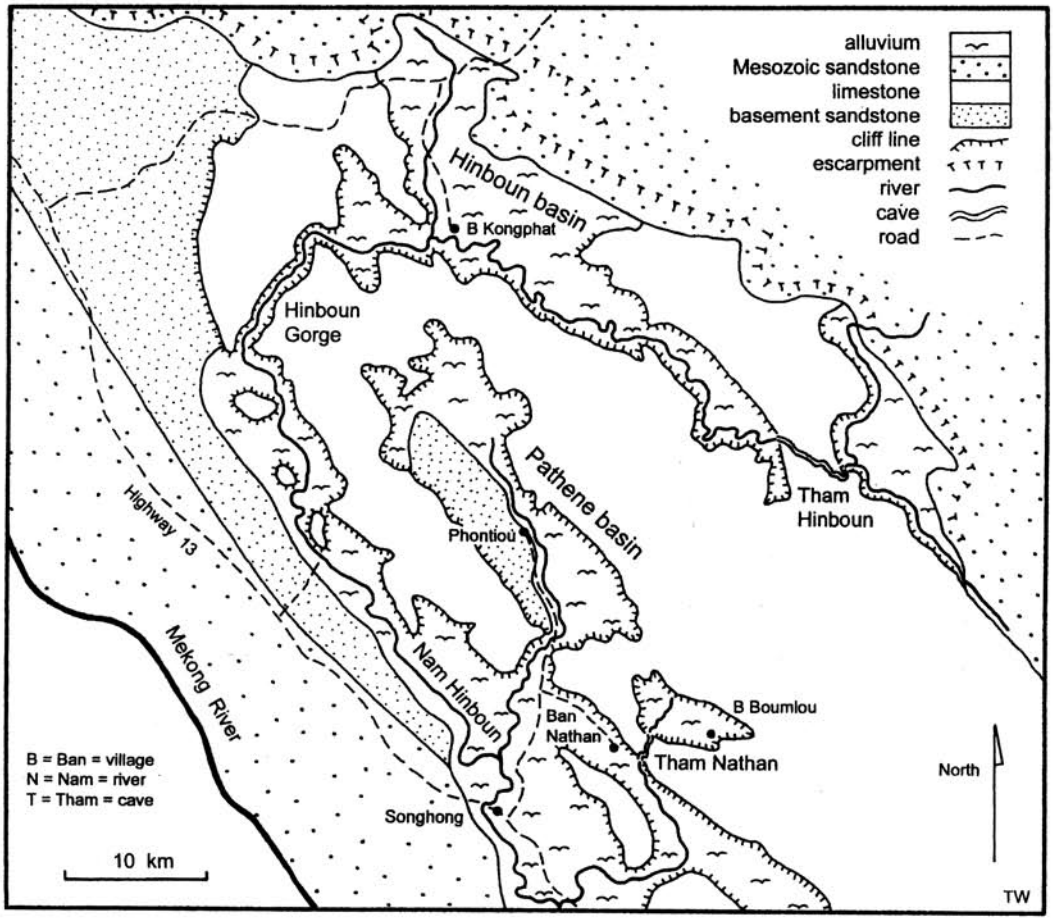

Figure 3. Main elements of the geology and geomorphology of the Hinboun River area at the northwestern tip of the Khammouan karst.

Tham Hinboun

The Hinboun River flows underground between two marginal poljes on the northern edge of the karst (Fig.4). The river passage is 6,300m long, and is navigable by fishtail-powered longboats right the way through. Village boatmen use the cave regularly as the easiest way between villages and farms in the two poljes; travellers have to get into the water at just four places to drag the boats up short sets of rapids over calcite-cemented pebble banks. The Hinboun River Cave (Tham Hinboun) offers one of the world's great underground journeys - armchair caving in its true sense.

The middle section of the cave is a passage at least 30m wide and 20m high, except where it expands into chambers containing piles of collapse that relate to large, old high-levels. Beds of cobbles indicate where the river flowed in the past, but there are few stalagmite

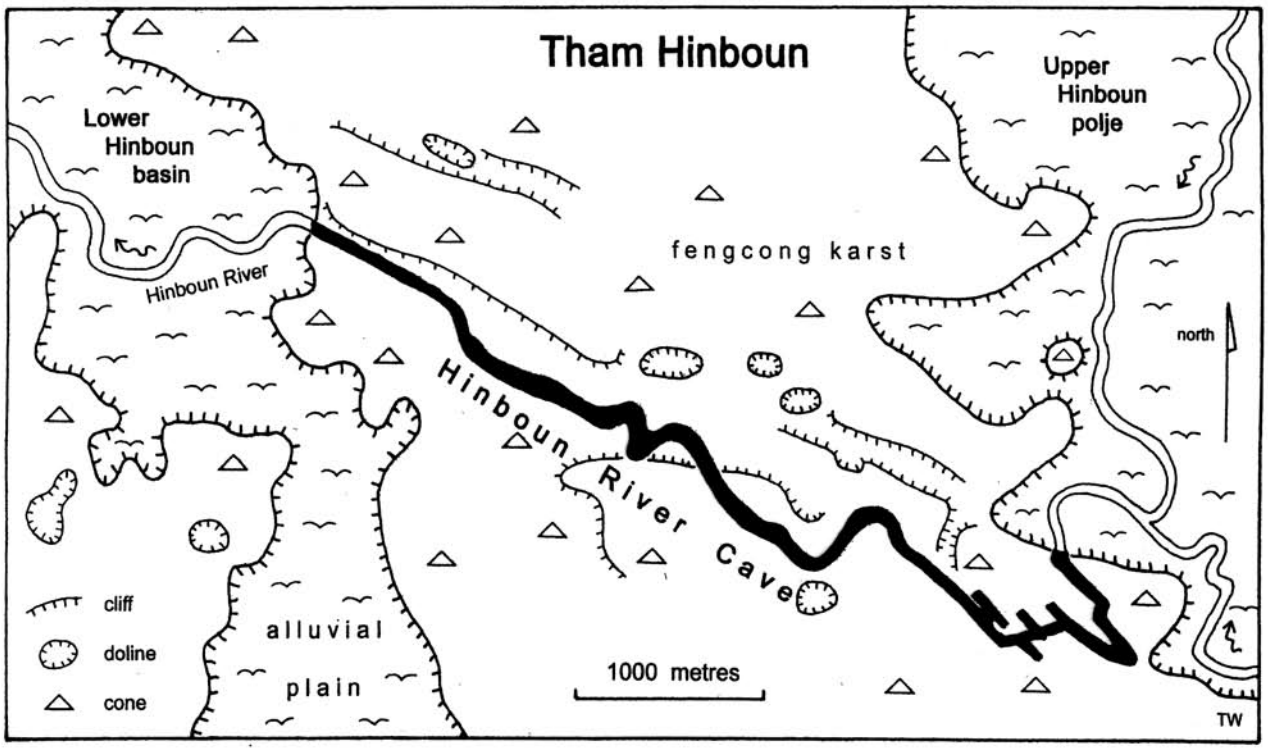

Figure 4. Outline map of the river passage in Tham Hinboun.

Plate 4. Limestone cliffs around the eastern end of the Pathene basin.

deposits. The modern river meanders between gravel banks (Plate 5) and has a dry-season flow of less than 1 cumec. Remnant flood debris suggests that flows are at least ten times as great during the monsoons. Much of the river's length is through wide lakes; its gradient is low, with a fall of just a few metres through the cave's length.

Both end sections of the river passage are smaller. The upstream kilometre includes some high joint-guided rifts less only 15m wide, and sections of half-flooded phreatic tube that cut across the joints and narrow to 15m wide between the cross rifts. High-level passages are conspicuous on many of the joint alignments. The downstream kilometre of passage, to the resurgence, is around 25m wide, but its arched roof rises only about 5m above water level (Plate 6). It appears to be just the top part of a large phreatic tube; sediment totally masks the floor and could well be many metres deep.

It appears that the cave has developed as an efficient drain between the two poljes. Where the river enters the limestone from the upper polje, dissolution has created a maze of phreatic rifts on the major joints, and throughflow subsequently expanded the most efficient route into the river passage. Further into the limestone, the system of rifts has coalesced into a single passage, and this has matured into a conduit with a profile graded close to the local base level. The lower end appears to represent a shallow phreatic loop, which may have suffered paragenetic roof enlargement over an accumulating pile of sediments. It has now been exposed as the river has entrenched into the sediment floor of the downstream polje. The cave lies beneath a ridge where the limestone cones rise to 700m above river level, with intervening doline floors not many metres above the cave roof (and almost certainly providing extra entrances).

The river cave was surveyed as part of the planning for a hydro-electric scheme. Under this the cave would have carried up to 100m^3/sec of water diverted from the Theun River where it is perched on the sandstone plateau (Fig.2), but this part of the scheme has not come to fruition. The cave plan in Fig.4 is based largely upon the engineer's survey. French cavers have explored high-level side passages that take the cave's total length to more than 12.4km (Mouret *et al.*, 1997).

Five years ago the Hinboun was a seriously remote site. It was even difficult for foreigners to leave Vientiane, but access has since improved following publicity over the French expeditions. Local transport is still minimal, and a casual visit to Hinboun would not be easy. However, a trip through the cave (Plate 7) is on the programme of adventurous travel agents in Vientiane.

Plate 5. The river passage midway through Tham Hinboun.

Plate 6. The partially drained phreatic tube at the lower end of Tham Hinboun.

Tham Nathan

Just 20km south of the Hinboun cave, the Boumlou polje drains out to the southwest through a cave under a high limestone ridge (Fig.3). The main passage of Tham Nathan is around 1,700m long. At its downstream end it is about 40m wide and 20m high (Plate 8). Round two bends and into darkness, the cave develops into a broad canyon below a phreatic tube that is 30m wide with its roof probably 50m high. Banks of cemented gravel 10m above stream level mark a stage in the cave's entrenchment. The upstream portal is over 50m wide, rising above a pile of blockfall (derived from the roof and the cliff above) that is towards 100m high, with the water filtering through its base. In the dry season the cave carries only a tiny stream, which is, however, ponded in three sizeable lakes. Floodwater marks suggest that monsoon flows are well over $1m^3$/sec.

The village of Ban Nathan lies close to the cave exit. Another village, Bam Boumlou, lies in a small patch of cleared forest near the eastern end of the polje, 4km from the cave entrance. Virtually the only link from Bam Boumlou to the outside world is through the cave, and the villagers have worn a path that is also marked by two short ladders and two short footbridges, all made of local hardwood. The path winds over boulder piles, round the lakes and along some fine ledges. It is easily followed - by the trail of burnt shavings from the bamboo flares that provide the locals' only light. Though the cave is clearly well-known, there is no published record or survey of it. Sadly, this was not appreciated at the time of the authors' brief visit, so no survey was then made.

Tham En

Phou Khiao is an anticlinal sandstone hill that supplies run-off streams into the base of the limestone on its north side. Tham En is one of the caves that carries an allogenic stream through the flanking limestone ridge into an interior polje (Fig.2).

The cave consists of little more than a single through-passage (Fig.5) about 1,300m long. The downstream end has been developed as a show cave, easily accessible from the tarred road between Thakhek and Mahaxai. The tourist path climbs above the stream to end on a balcony 150m in, with a branch out to a small high-level exit. Anyone continuing upstream has to swim for about 500m along a splendid flooded canyon entrenched beneath a larger phreatic tube. Beyond the canals, there is a short walk up a delightful stream passage, to where the water emerges from the toe of a pile of blockfall, with a glimmer of daylight above. The climb up the block pile is fantastic, as the walls recede until the passage is 150m wide. This huge ramp of fallen blocks rises to the cave entrance, which is spanned by a low arch, with a view out to the forested sandstone slopes of the stream catchment. The tops of many blocks on the lower

Plate 7. Three kilometres from daylight in Tham Hinboun.

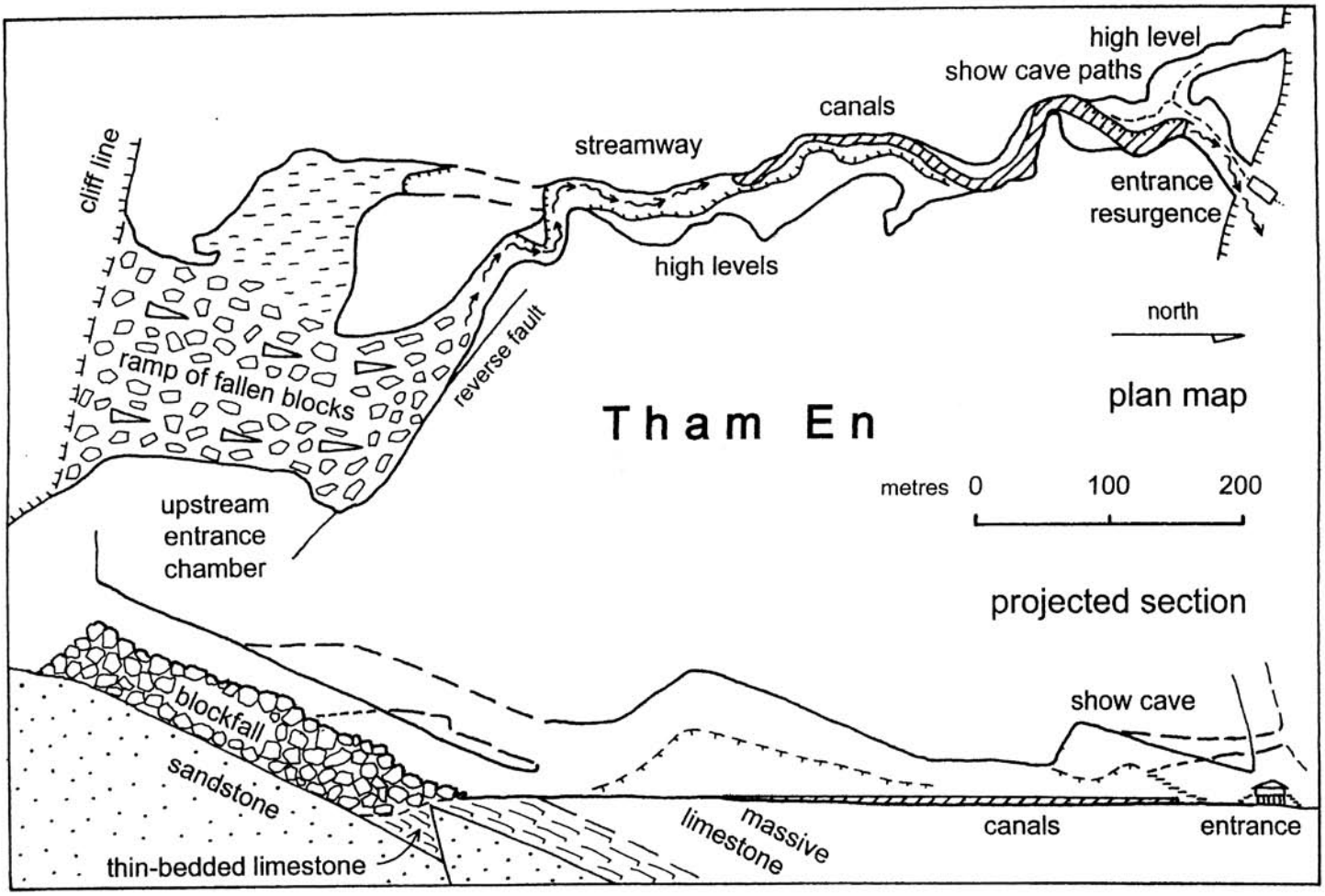

Figure 5. The main features and geology of Tham En (topography based on Mouret, 1993).

part of the ramp are fretted with phytokarst, with the pits aligned with the distant daylight. The cave has its resident swift population, and nest-collectors' poles stand against the entrance's eastern wall.

Tham En was initiated by vadose drainage down the dip at the base of the limestone. A zone of thinly bedded limestone at this position became a locus of lateral undercutting and cave widening. It is likely that multiple input routes then coalesced into a single, very wide passage, which extended as far as a phreatic lift on a small reverse fault that now defines the inner end of the chamber. Downstream, a single phreatic tube climbed stratigraphically into massive limestone. The up-loops of this tube survive in the roof of the streamway, in some high-level branches and in the high-level exit, whereas the down-loops have been modified into the canyon that gives the modern stream its graded profile.

The upstream entrance chamber is unusual because its roof structure can be seen in daylight, and there are few cave passages this wide that are so clearly visible. Its roof appears to have matured into a stable arch, where rock has fallen away along identifiable tensile stress fractures. These developed beneath the zone of compressive stress that forms naturally in the rock and now forms the stable, self-supporting

Plate 8. Looking into the resurgence end of Tham Nathan, with one of the authors standing on the rocks beyond the pool.

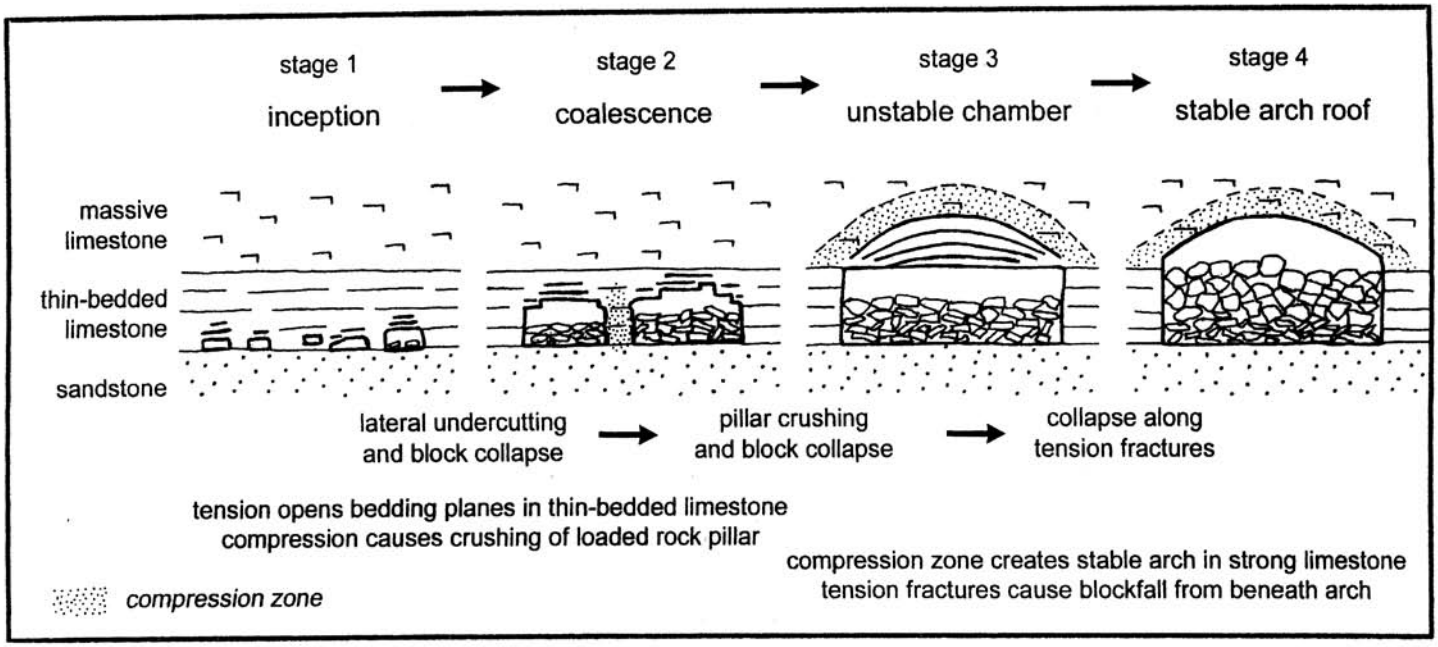

Figure 6. A sequence of sketch profiles across the upstream daylight chamber of Tham En, showing its progressive development towards a roof that is a stable arch developed on stress fractures independent of the bedding. Zones of compressive stress are marked by stippling, and zones of tensile stress are indicated by the tension fractures drawn bold. The views are looking up the dip of about 10° towards the entrance.

arch (Fig.6). The original passage roof was probably 40-50m below the present roof, and progressive upward collapse has allowed maturation from an unsupported, unstable, undercut slab into the stable, self-supporting arch. The roof fractures have formed by tensile stress, largely independent of bedding planes and tectonic joints. This is unusual, as it is only in extremely wide caves that stress patterns are large enough and bold enough to dominate over the nets of fractures that normally control blockfall and roof failure in strong, cavernous limestone. Tham En may be the best indicator of the roof structure of other very large cave chambers, including Sarawak Chamber in Lubang Nasib Bagus (Sarawak).

KHAMMOUAN IN CONTEXT

The limestone belt of Khammouan continues eastwards across the border from Laos into the Quang Binh province of Vietnam. There, the fengcong karst landscape is not quite so dramatic, rising more gently above the river valleys, with less of the high fringing cliffs that so distinguish the Lao karst. Many of the longer and larger caves lie in the eastern sector, on both sides of the border (Fig.2). In Laos the Tham Xe Bangfai is another giant river passage, 9km from sink to rising, but it is not traversable in the comfort of a boat. The mean flow on its underground river is well over 50m^3/sec, and flood flows are estimated at over 500m^3/sec (Mouret *et al.*, 1997) - which must be some form of world record. The Vietnam sector contains the splendid long river caves of Hang Phong Nha (7.7km), Hang Khe Ry (18.9km) and Hang Vom (14km), all mapped by the British teams led by Howard Limbert (1992, 1999). These extensive caves in the eastern karst appear to have developed where the regional drainage pattern provides long river routes over the wide limestone outcrop, instead of just across the narrow dimension of the more mature karst massifs in the western Khammouan.

The collection of fengcong massifs, poljes and magnificent caves in Khammouan, together with its extension into the river caves of Quang Binh, constitutes a karst region that is of geomorphological significance in a worldwide context. Though now divided between two nations, and only recently accessible for study after decades of political isolation, this great karst of what was once Indo-China deserves to be widely known and appreciated.

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