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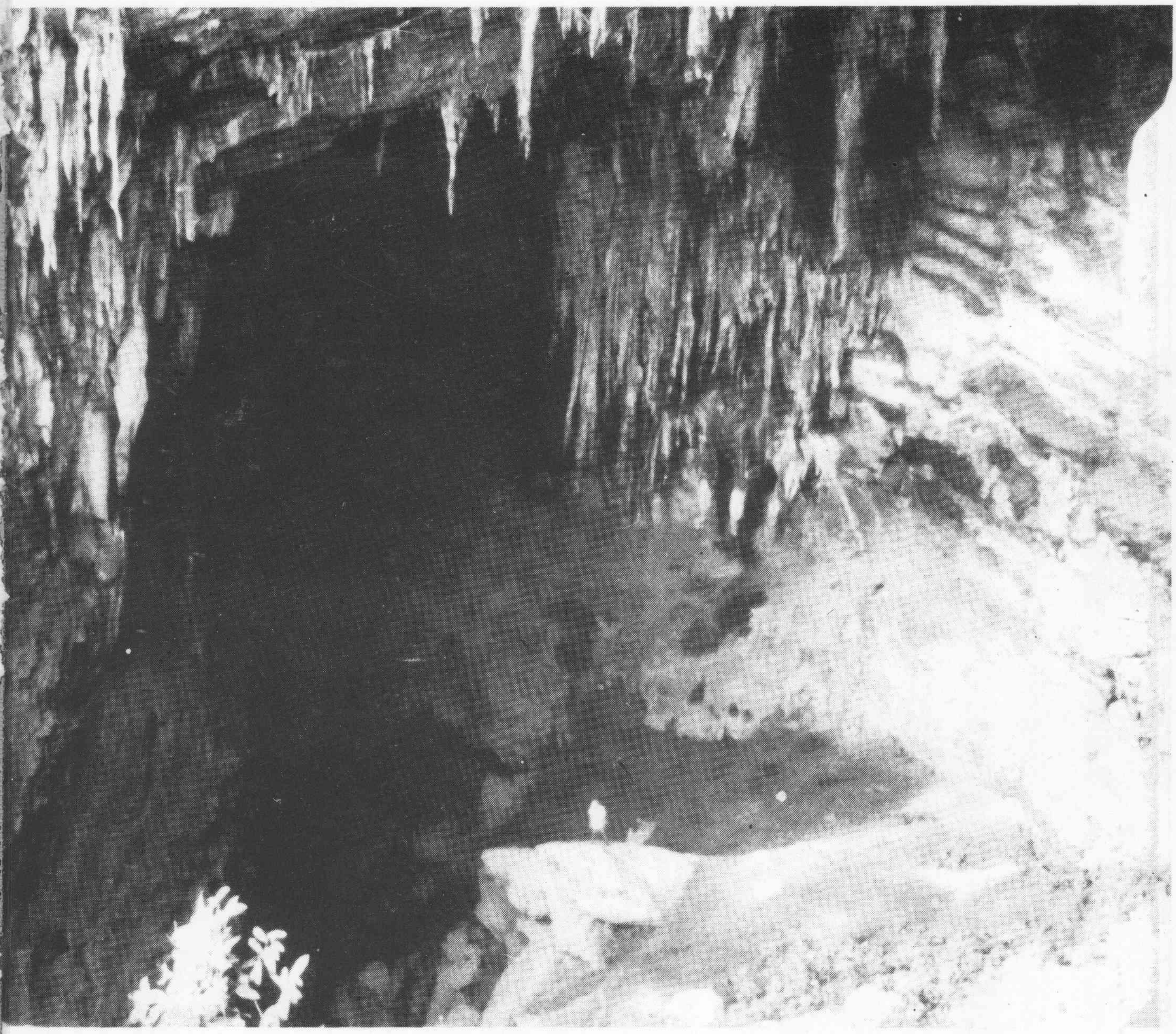

Tham Nam Lang, Thailand
Photograph by John Dunkley

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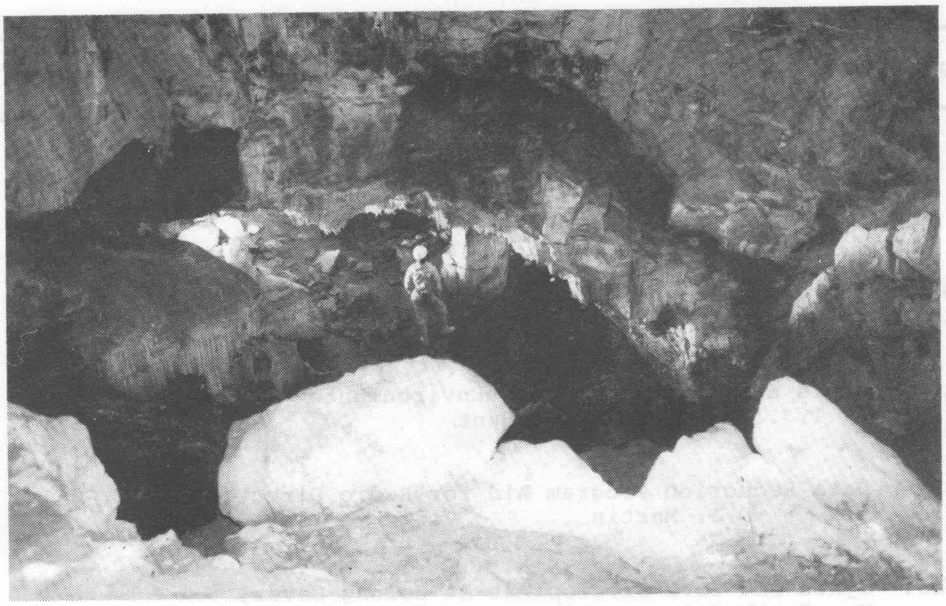

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KARST AND CAVES OF THE NAM LANG - NAM KHONG REGION, NORTH THAILAND

John R. Dunkley

Abstract

The Nam Lang - Nam Khong Karst Region, located in a thinly populated, remote part of Mae Hong Son Province, north-west Thailand, comprises about 1,000 km^2 of massive Permian limestone. Over much of the area is developed a characteristic polygonal karst dominated by over 300 closed depressions, with an assemblage of forms including dolines, uvalas, poljes, streamsinks, through caves, springs and blind valleys.

Speleological exploration commenced only in 1983 and the major discovery is Tham Nam Lang, the longest cave reported on the mainland of South-east Asia with nearly 7km of passages. Cave development is strongly influenced by regional strike and fault orientation and by base level incision into impermeable sediments underlying the limestone. The largest caves are formed where aggressive water collects on impervious rocks before entering the limestone. Elsewhere cave development is limited. Several caves are important archaeological sites, and a number have tourist potential.

INTRODUCTION

In recent years the karsts of the humid tropics have received increasing attention from speleologists. Most exploration and research has concentrated on caves located in tower karst and in the continuously wet karsts of New Guinea and Sarawak, and has entailed large, well-organized and expensive expeditions.

In 1983 the author began exploration of an extensive and previously hard-of-access karst in the north-west of Thailand, and a brief report was issued of the discovery of a large cave, Tham Nam Lang (Dunkley & Greenfield 1983). Four expeditions have now covered the area and Tham Nam Lang has become the longest cave known on the mainland of South-East Asia. The karst of the Nam Khong basin comprises singularly attractive mountain scenery, particularly when the opium poppies are in bloom, and the caves make up in grandeur and mystery what they lack in numbers. In contrast with what appears to be the modern trend, exploration has proceeded very much in the self-contained tradition of mountaineer Eric Shipton, and in the fervent belief that it is better to travel hopefully than to arrive. Scientific observations have likewise been conducted in a leisurely manner incidental to the main journey.

This paper presents a preliminary description and observations on a karst and related caves markedly different from those elsewhere in Thailand, and expresses an early plea for the survival of a small but significant part of wilderness Asia.

PREVIOUS SPELEOLOGICAL RESEARCH IN THAILAND

Approximately 15-20% of Thailand is underlain by limestone bedrock. Along the Kra Peninsula and in south Thailand much of this is extensively alluviated with numerous tower karst residuals, each up to a few square kilometres in area. North and west of the Chao Phraya basin much larger areas of folded limestone with relief of 1,000 metres and more are exposed. Preliminary reports on representative samples of these karsts have appeared in the last few years. Troll (1973) described the tower karst marginal to the Chao Phraya valley, Manfred (1976) drew attention to the 'karst ridges' characteristic of much of northern Thailand, while Delannoy (1981, 1982) and Odell (1983) have discussed different parts of the karst of the River Khwae basin in western Thailand, Odell also describing aspects of the tower karst near Phangnga in southern Thailand. Deharveng & Gouze (1983b) identified several types of karst in the Chiang Mai area, notably around the well-known tourist cave at Chiang Dao. Extensive doline fields are known to exist in Thaleban National Park near Satun on the Malaysian border (Jennings 1972) but have not been studied in detail. Finally, Odell (1985) has drawn attention to an occurrence of what he refers to as bogaz (which may in fact be crevice karst) at an altitude of about 1600m in central Thailand. Although polygonal karst as extensive as that described in this paper has not been reported in Thailand. smaller areas may exist (Odell 1983).

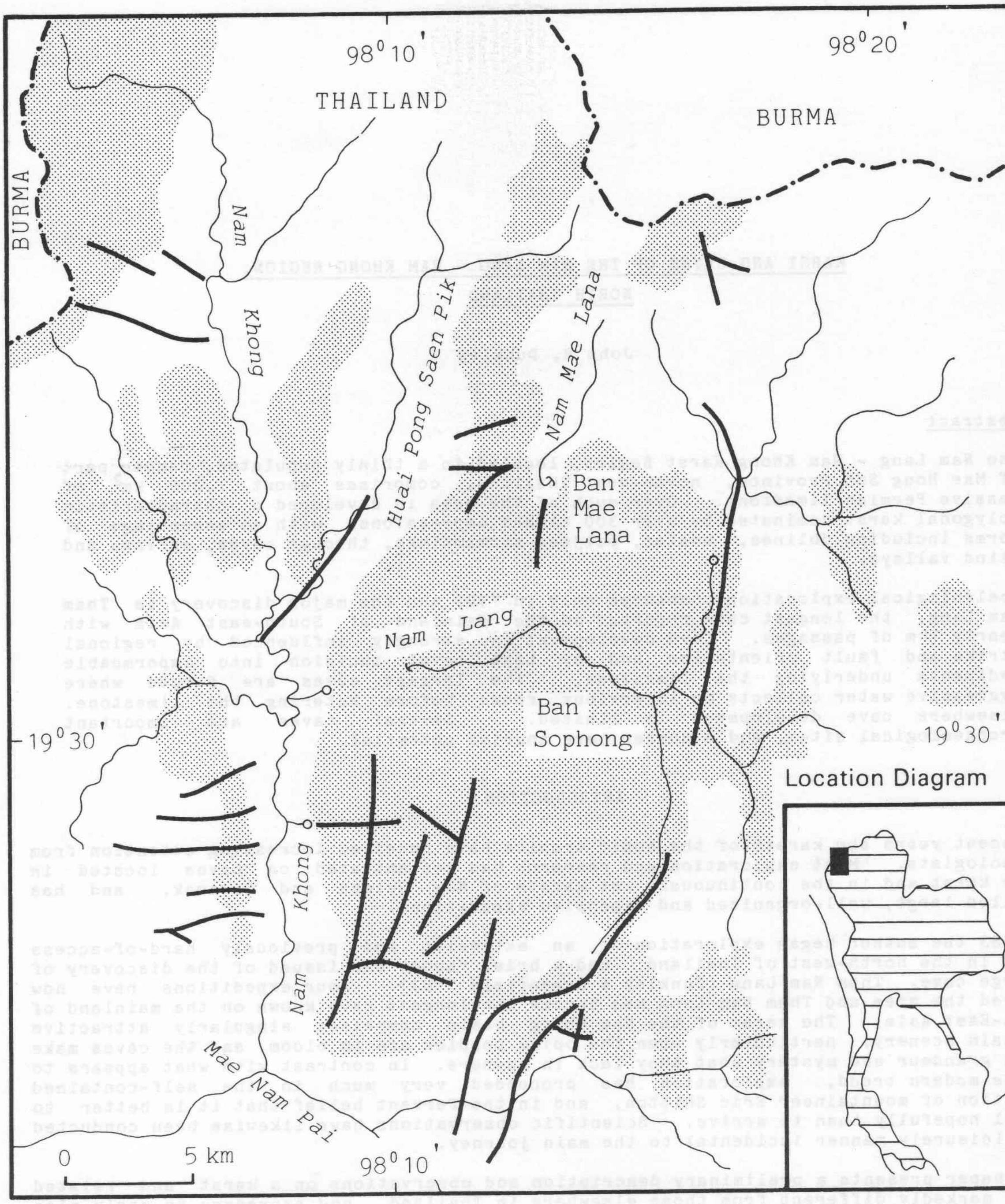


Figure 1

Limestone deposits and known faults, Nam Khong basin

Plate 1

View to north-east from extreme south-west corner of map above

THE REGIONAL ENVIRONMENT

The Nam Lang - Nam Khong Karst is located in Mae Hong Son Province, north-west Thailand, and abuts the border of Burma to the north. Centered at 19°30'N, 98°14'E, it forms part of a series of long, narrow limestone outcrops following the tectonic axis of mountain ranges which extend the length of Thailand from Malaysia to the Shan States of Burma (being probably equivalent to the "Plateau limestone" there).

The climate is markedly monsoonal, with three distinct seasons: cool-dry (December-February), hot-dry (March-June) and hot-wet (July-November). At higher altitudes mean cool season temperatures fall below 18°C, and occasional frosts are reported. Detailed meteorological records are unavailable within the region, but annual precipitation exceeds 2,000mm (Gaussen, Legris & Blasco 1967).

Drainage is along structural troughs running generally north-south, separated by deep, narrow east-west gorges. The Nam Khong gathers water from several karst and non-karst sources, draining south to the Pai River which flows west across the Burmese border and joins the Salween River.

Although local relief does not exceed 1,000 metres, the terrain is extremely rugged (Table 1), covered in primary and secondary monsoon teak (Tectona grandis) and bamboo forest. Secondary growth is increasing due to shifting cultivation and teak culling. Lower montane forest dominated by pines clothes the higher slopes. A single road, frequently requiring four-wheel drive during the wet season, traverses the region from east to west and has several short spurs to outlying villages. Elsewhere numerous walking tracks connect hill-tribe villages. The most rapid and convenient access is to Mae Hong Son by air from Chiang Mai, followed by a 2-hour road journey and as much walking as time and energy permit.

The population of the area is about 6,000, comprising Lahu (43%), Lisu (25%), Shan (19%), Karen (8%) and Chinese (1%). Less than 5% are Thai, concentrated in the Kings Project and in Ban Sophong, soon to be upgraded to district (amphoe) administrative status.

Land use consists primarily of shifting (slash-and-burn) and sedentary subsistence agriculture, practices which may contribute to sedimentation in some caves. Opium poppy is a common cash crop and it thrives on the terra rossa soil which is found particularly in depressions. Much of the area, especially along the Nam Khong and south of Nam Lang, is of a wilderness nature although often dominated by secondary forest growth. Tourist potential is considerable, though restricted at present by border insecurity and relative remoteness.

Total exposed limestone in the drainage basin of the Nam Khong is approximately 1,000 km^2. Some of this is in the insecure zone bordering Burma and has not been explored speleologically.

About 25 caves are known. With almost 7km of large passages, including 5.4km of active streamway, Tham Nam Lang is the longest cave in Thailand and with a volume of perhaps 2 million cubic metres ranks among the most spectacular in the world. It carries the drainage from a closed depression some 400m deep, draining 425 km^2.

This paper deals primarily with the karst east of the Nam Khong and Huai Pong Saen Pik, particularly that drained by the Nam Lang (Fig. 1). Notes are included on several karst phenomena isolated from this main body by gorges entrenched in underlying non-carbonate rocks.

Table 1 : Distribution of Slope Classes, Nam Khong Basin

Slope Class	Area (km)	% of total area
0 -- 8 %	8	0.9 %
8 - 16 %	17	2.0 %
16 - 35 %	159	18.1 %
35 - 60 %	285	32.3 %
over 60 %	412	46.7 %
TOTAL	881	100.0 %

Source: Thai-German Highland Development Program

Figure 2 : Surface and underground relationships near windgap of Nam Lang polje

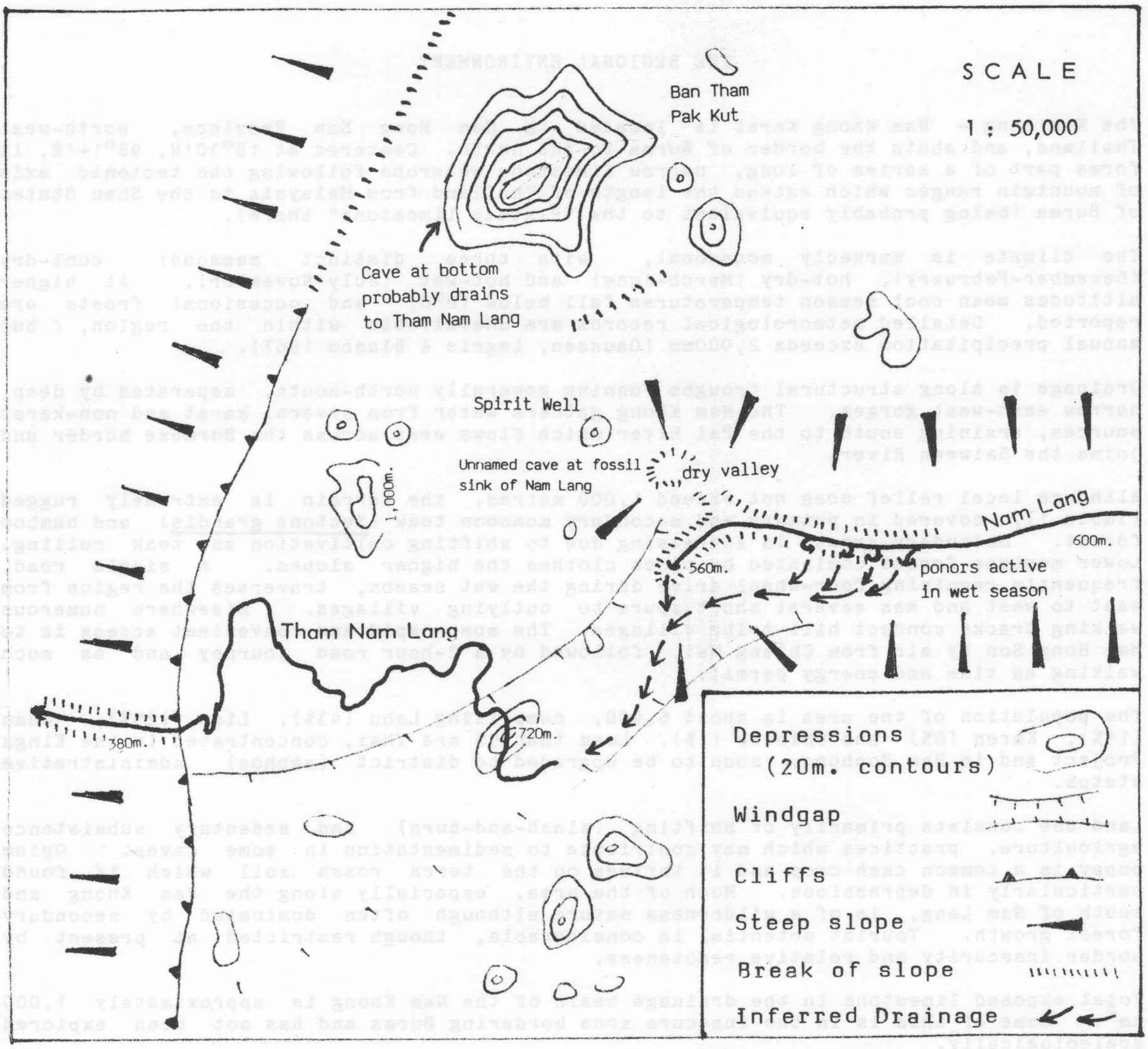


Table 2 : Distribution of Depths of Closed Depressions, Nam Khong Basin

Range of Depth (m.)	no. of depressions
20 - < 40	165
40 - < 60	75
60 - < 80	36
80 - < 100	26
100 - < 120	4
120 - < 140	2
140 - < 160	0
over 160	1

(Excludes poljes of Nam Lang (400m) and Nam Mae Lana (150m) and all depressions west of Nam Khong)

Source: Thai-German Highland Development Program

REGIONAL GEOLOGY

Until recently only reconnaissance geology was available (Brown 1953), but more detailed mapping has now been carried out (German Geological Mission in Thailand 1972). Even so, only a broad description of the geology is yet possible.

Summarized by Sternstein (1976), the geologic structure of northern Thailand may be regarded as resulting from a series of adjustments to compressive forces from the west in Burma acting on the resistant, stable block or massif immediately to the east in Laos and Vietnam. The parallel ranges developed from sedimentary rocks folded longitudinally and intruded by igneous rocks, mainly granite. Erosion has revealed the granitic cores and left the hard, pure limestones and quartzites as towering ranges.

Regional geology consists of severely folded belts of Paleozoic sediments (limestone, sandstone, shale, chert, conglomerate and greywacke), varying in age from Ordovician to Permian. Although thin beds of limestone occur in older units which surround it, known karst development is restricted to the predominantly limestone Ratburi group of Middle to Lower Permian age. The Ratburi limestone outcrops widely throughout Peninsular, Western and Northern Thailand and in hills marginal to the Chao Phraya valley. It has an exposure exceeding 1,000 metres in this region and reaches a maximum stratigraphic thickness of more than 2,000m at Doi Chiang Dao, 75 km. east of the Nam Khong.

A widespread orogeny resulting in intensely folded rocks occurred during late Devonian to early Lower Carboniferous times, and was followed by a long period of denudation. The Ratburi group has been deposited unconformably atop these earlier sediments. Another orogeny at the end of the Paleozoic resulted in the limestone being folded and somewhat recrystallized, though generally to a lesser extent than underlying rocks, to an extent best described as marmorized. It varies in colour from mid- to light grey through to nearly white.

Triassic plutons occur south-east of the region, restricted to a few square kilometres in the headwaters of the Nam Lang - Nam Khong drainage basin. Otherwise a long stratigraphical break exists between the Permian and some Neogene sediments occurring north of Tham Lot. The youngest geological units are Pleistocene terraces and alluvial cover in troughs and basins throughout the area. These are everywhere limited in extent, reaching a maximum width of about 1 km.

The region appears to have been above sea level throughout the Mesozoic and Cenozoic eras, in common with most of Thailand. High accordant summits preserved in ridge lines suggest that an erosion surface may have formed by the middle Tertiary and that a widespread peneplain truncating previously folded rocks may have existed. Uplift occurred at the end of the Tertiary accompanied by widespread folding and faulting and in its general outlines the present configuration of the drainage system was probably initiated at this time.

Regional strike is SSW-NNE along the tectonic axis with highly variable dips, and the area is intersected by numerous faults trending generally E-W and SSW-NNE. Preliminary evidence suggests that underground drainage and cave development are strongly influenced by strike orientation and fault location.

Present landforms thus reflect geomorphic processes operating on structurally deformed rocks of diverse physical and chemical character in a humid tropical environment.

KARST MORPHOLOGY

The main body of limestone is contiguous over an area up to 30km x 18km. Local relief of outcropping limestone ranges up to 1,000 metres, the highest peaks being Doi Khu, 1,332m in the north, and a conspicuous peak 1245m high on the southern margins of the karst. Prominent cliffs up to 800m high line the east side of the Nam Khong and its tributary Huai Pong Saen Pik, and overlook the north bank of the Nam Mae Pai. Overall the topography is very rugged (Table 1).

Between the Nam Lang and the Nam Mae Pai a characteristic polygonal karst is developed with no perennial streams and totally underground drainage. Although very little of the surface is level or near-level, the divides between depressions are more or less accordant, giving the semblance from an oblique aerial perspective of a broadly dissected plateau (Plate 1). This is quite dissimilar from the surrounding deeply dissected hills of sedimentary and plutonic rocks. North of the Nam Lang local relief is greater and the surface more dissected. Occasional remnant cone-like hills protrude from the general level; the significance of these and a possible ancient surface drainage system is discussed later.

Grikes and minor solution features occur only occasionally on exposed limestone, which is rare except on very steep slopes. However a few examples have been noted of small caves up to 10m deep belling out below vertical entrances in grikes about 0.5m in diameter. The tufa curtains on steep and overhanging slopes which are common in the tower karst of southern Thailand, are not to be found in this region.

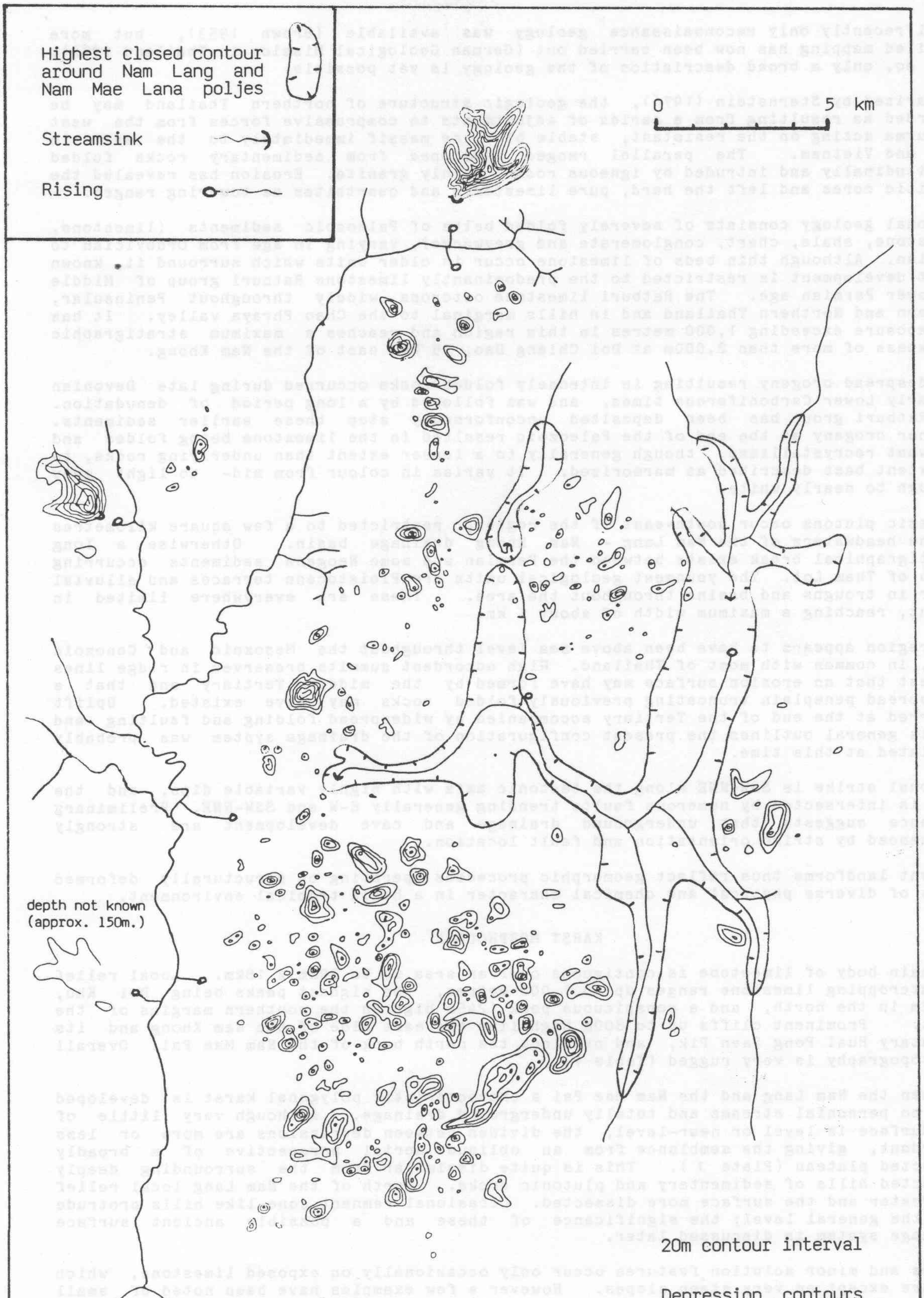


Figure 3. Location of closed depressions, Nam Khong basin

Closed Depressions

A variety of closed depressions occurs in the region, from a few metres to many kilometres in size: dolines, uvalas and poljes together with blind valleys.

The largest closed depressions are those of the Nam Mae Lana and Nam Lang, probably best described as border poljes (Gams 1978). Both have catchments partly on non-carbonate rocks and their lower ends are level, being floored with allogenic alluvium. Sharp breaks of slope exist between floor and sides, with piedmont slopes frequently reaching back to discontinuous vertical cliffs.

With an apparent asymmetrical strike aligment, the Mae Lana polje resembles a structural trough and receives drainage from approximately 30 sq. km. of mostly non-carbonate rocks. At present the stream sinks in an impenetrable hole on the eastern margin of the polje and there are one or two other intermittently active sinking points further south.

The Nam Lang polje is more complex. Its drainage basin comprises 425 sq. km. of country as much as 40km upstream of its final sinking points. Its windgap (fig. 2) is about 400m above the lowest sinking point and the highest closed contour encloses an area of 70 sq. km. This implies that a minimum of 14 cubic kilometres of dissolved limestone must have passed through the cave system. Upon reaching limestone its main northern tributary flows through a large cave (Tham Lot). Above Tham Lot the valley is alluviated, below it is incised for two or three kilometres before reaching the alluviated floor of the main polje.

A statistical analysis of depressions deeper than 20m in the main contiguous limestone mass was conducted using 1:15000 topographic base maps with a contour interval of 20 metres. The results are set out in Table 2. Field observations along with extrapolation suggest the likelihood of there being 1,000 depressions or more exceeding 5-10 metres in depth (Fig. 3). Of the 309 depressions, at least 33 are uvalas.

Depression slopes are commonly steep-sided, sometimes with near-vertical cliffs, particularly above the lowest points. Nevertheless they carry well-drained soil, ideal for opium poppies, from which fines have been washed out and are found at the bottom as clays in caves and crevices (Plate6). As a result, depression floors often become swampy in the wet season. Few of the depressions are stellate in outline. The deepest are noticeably asymmetrical with second and third order drainage nets, however perennial streams are uncommon, occurring in perhaps 10 cases. Obvious collapse features are equally uncommon, the largest known being the Spirit Well (Nam Bor Phi) whose near vertical walls are from 80 to 120m high. Interfluves between depressions are seldom level.

Structural control has possibly affected doline alignment on the karst plateau south of Nam Lang, but the available scale of geological compared to topographic mapping is too coarse to confirm this.

Particularly deep depressions characterize three limestone masses isolated from the main body by non-carbonate rocks. On the Burma border near Ban Pang Kham (19°41', 98° 13'), practically the entire limestone outcrop is contained by a 160m deep doline draining south through a prominent ridge. Similarly large dolines occur on the west bank of Nam Khong above and below the road.

KARST HYDROLOGY

Water tracing has not been carried out and this description is based on local enquiry and flow observations. The conclusions are therefore speculative.

The largest karst stream is the Nam Lang, with tributaries rising on non-limestone Devonian and Carboniferous rocks to the north-east and south-east. The main stream traverses Tham Lot, a large through cave, then flows on the surface for 15km. Below Ban Nam Lang several impenetrable streamsinks engulf the water successively over a distance of 5km, the final one being completely blocked by logs and debris. After an underground course of about 4km in a straight line, the water rises at the foot of a massive rockfall beneath 400m high cliffs 1km east of the Nam Khong. Dry season base flow is about 0.3-0.5 $m^3 s^{-1}$, but there is ample evidence that neither the sinks nor the rockfall at the resurgence are able to cope with high flow in the wet season, which possibly exceeds 100 $m^3 s^{-1}$. At such times the upper entrance of Tham Lot, with a cross-sectional area exceeding 100 m^2, is reliably reported to completely fill with water.

By local repute the Nam Mae Lana, with a base flow of 0.2 $m^3 s^{-1}$, drains west to the Huai Pong Saen Pik. This would accord with the presence of a known fault line, and furthermore the deep depression 1.5km west of the streamsink reputedly operates as an estavelle in the wet season. However the spring has yet to be located. A topographic low suggests that drainage was once to the south, but no large risings are known on the Nam Lang. A small resurgence near the Kings Project is too small, and corresponds in flow to the known inflow cave near Ban Ya Pai Nae.

Tham Su Sa, a major outflow cave with estimated base flow of 0.5 $m^3 s^{-1}$, has been followed for 600m at which point two waterfalls stopped exploration. The stream is saturated with calcium carbonate and below the spring has built an extensive delta of travertine supporting dense forest. It falls into the Nam Khong over 2-metre high travertine waterfalls along a 400 metre front. Numerous sinking streams are reported on the plateau above; indeed one village, Ban Nai Kut Sam Sip means "Village where 30 streams go underground" and small caves are known to exist. The plateau has not been prospected speleologically and exploration and local enquiries have failed to locate any other springs to the south or west along the Pai River or Nam Khong, or to the east or north in the Nam Lang catchment. It therefore seems that most drainage off the karst plateau is to Tham Su Sa. With a catchment area only one quarter that of Tham Nam Lang, the dry season base flow of Tham Su Sa is about the same or slightly greater. This anomaly in regimes may be attributed to the diffuse drainage net of the latter, with a correspondingly longer subterranean transit time.

Two moderate perennial inflow caves are known in the north near the villages of Ban Pha Puak and Ban Pha Daeng and detailed maps show other non-perennial streamsinks nearby. These apparently rise as tributaries to the Huai Nam Pong.

The known springs to the north and south of the Huai Nam Pong are located in deep narrow gorges and have yet to be explored for caves. However caves are known in other isolated limestone masses at 19°36', 98°06', and 19°28', 98°06'. Both are relatively small (3-4m in diameter with evidence of large-scale seasonal flooding) and in the former case a rumoured through cave has been entered at both ends but not yet fully explored.

HERITAGE SIGNIFICANCE OF THE CAVES

Most caves are located on communally owned land and are thus effectively in the public domain. For a number of reasons they deserve recognition as part of the natural and historical heritage of Thailand.

Until about 1980 tourism in the region was virtually non-existent but this is changing following opening of air services to Mae Hong Son and improvements in road access. Tham Lot is in a recently established National Park and has received publicity in national outdoors magazines and in hotels in Chiang Mai and Mae Hong Son. It receives a small but growing visitation both from the burgeoning Thai middle class and from trekking companies oriented to foreign travellers. This traffic has already extracted a visible toll on the more sensitive parts of the cave. However the need for sympathetic management is recognized and the traditional lighting method of burning reeds has already been banned.

The caves along the Nam Khong, especially Tham Nam Lang have potential as part of a wilderness experience associated with outdoors activities such as camping and canoeing, which are rapidly increasing in popularity.

Several caves are of major archaeological significance and deserve appropriate management. The only known serious excavation was that conducted in Spirit Cave (Gorman 1970) which was a seminal demonstration of the existence of early agricultural communities in South-east Asia. Pebble tools were also seen in Tham Susa during a very cursory examination in 1985. As Pope et al. (1978) have pointed out, northern Thailand is favourably situated in the geographical centre of the known distribution of the majority of Plio-Pleistocene Asian Hominidae, as well as being located in the centre of past and present major migration routes of Asian mammals. They emphasize also that karst features are highly conducive to the preservation of fossil faunas.

A number of caves, particularly some small ones, contain hollowed teak coffins about 2.5m long, sometimes arranged in tiers of two or three. While mostly still in an excellent state of preservation testifying to the resistance to weathering of teak, some of the more accessible ones, such as in Tham Lot, have been vandalised. John Spies (pers. comm.) reported that a team of Thai archaeologists had obtained a radiocarbon date of 1250 years BP for one of these sites, but the author has been unable to confirm this or to locate published references. The coffins play no part in the folklore of the present-day hilltribes, many of whom arrived only during this century. They are locally believed to be associated with the Mon, a people of whom little is known except that they occupied much of Thailand before the arrival of the Thais. The location of some of the best-preserved coffins is not widely known but others are regularly shown to tourists and are vulnerable (Plate 5).

It seems likely, therefore, that the caves of the region and of northern Thailand generally have significance both for the prehistory of South East Asia and possibly for an understanding of the movement of the Thai and Shan (Thai Yai) people from Yunnan over 800 years ago.

CAVE DESCRIPTIONS

Tham Nam Lang

19 31', 98 09' Passage length: surveyed 4547m, estimated 2170m. Total 6717m.

Tham Nam Lang drains the Nam Lang polje and is the longest cave reported on the mainland of South-East Asia. Located at the resurgence of the Nam Lang, the existence of an entrance high in huge rocks above the spring was known only to a handful of local Shan people (though denied by many more). The cave beyond the entrance chamber was first entered in January 1984 by the author, John Spies, Mark Macpherson and a Shan guide.

A massive rockfall nearly 30m high dominates the front of the entrance chamber, which is 30-40m high, up to 50m wide and 80m long, heavily vegetated in the first 60m, much of it illuminated by late afternoon sun. A descent is made over dried mud and boulders to the stream which is followed to the limit of daylight well over 200m inside. Shortly afterwards a climb is made across a barrier of flowstone and rimstone pools nearly 60m wide. Beyond this the stream passage is again encountered and can then be followed continuously for at least a further 5km. The end has not been reached.

The stream passage is remarkably constant in width, seldom being less than 10 nor more than 20m wide. Heights have been estimated, never being less than 10m, usually exceeding 20m and occasionally reaching 80-100m. An allogenic gravel train forms the floor for about 3km, the remainder being water with mud sediment. Superb vistas of underground grandeur open in several stretches where line of sight approaches 200m.

Up to Neung Kilo the cave closely parallels the limestone boundary and passage direction is controlled by the regional strike. In this section the stream occasionally runs over marmorized bedrock. More commonly, the first 3 kilometres is characterized by delightfully long stretches of meandering stream channel with sand and gravel banks, broken by regular rockfalls up to 6-8m high and a few hundred metres long. Bedrock runnels and chutes, often containing recent sand and gravel deposits evidence rapid, turbulent vadose corrasion well above floor level. Over the innermost 2.5km so far explored long stretches of slowly-moving water up to 1.5m deep are encountered, along with extensive mud, and a boat is needed for comfortable exploration. At 4.5km a dry abandoned bypass 300m long occurs 10m above stream level.

The walls are usually scalloped. Decoration is sparse but massive where it does occur, forming stalactites and wall flows up to 30m high. Large expanses of flowstone and rimstone pools occur at 0.3 (Tham Kaeng-Khao) and 1.3km (Phra Racha Wang Mekhala), forming ramps up to 10m above the stream. Both are deposited by small tributaries which were active in January but inactive in May. Both tributaries appear to be strike-oriented, associated with major changes in main passage direction. Several other tributaries are encountered, all but the first entering from the north and none of which can be followed for more than 50m or so.

The stream passage beyond Si Kilo trends at approximately right angles to the general orientation of drainage between the Nam Lang ponors and the resurgence. It maintains this divergent trend over a linear distance of about 1km with only minor excursions along the strike.

This change in orientation coincides with a slackening in the stream gradient, this part of the cave being characterized by deep water requiring swimming or boating. The passage is considerably smaller here than further downstream, though generally still at least 10m high. Small rapids occur in one or two places, mostly tumbling through rockfall blocks. The passage grows a little larger again upstream of the dry bypass.

Near Ha Kilo the cave shows signs of flooding to the roof, with silty floor, ceiling hollows and vegetable debris on the ceiling. At the upstream end of this area the passage briefly narrows and the ceiling drops to within a few metres of the water. Beyond Ha Kilo the cave may again be strike-oriented.

The stream passage beyond Si Kilo is also noteworthy for giving access to higher level passages - the generally smaller dimensions of the stream passage here may be partly due to successive stream levels being laterally displaced rather than superimposed to form one large passage. The most upstream of these upper levels is a 300m long dry bypass of the stream passage. It is generally of large size and features excellent flowstone, fossil gravel beds and small white fish in some pools.

Several extensive, unstable rockfalls suggest higher levels to the cave. The first, at 1.1km has not yet been thoroughly explored although climbed to a height of about 50m. Beginning at 1.8km, the second (Doi Hin Yai) is about 120m long, 80m wide and from its top at 50m a large shaft (Ban Khong Ramasura) can be seen extending upwards beyond the limits of torchlight, a trickle of water dropping over a long ledge 60m up. Fresh vegetable matter was noted at the foot of the shaft, approximately 300m below the surface, and it seems clear that much more water descends during the wet season.

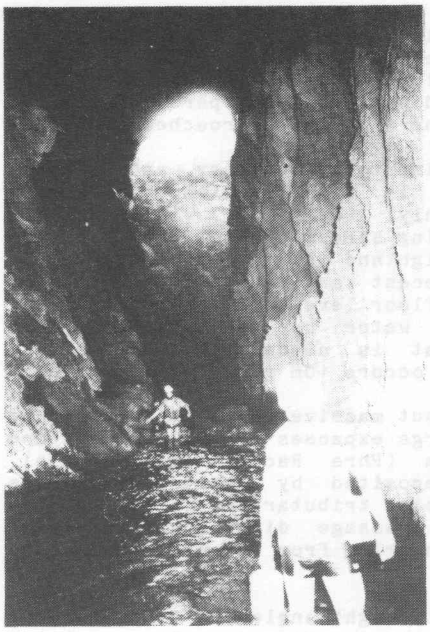
The most extensive upper level explored, Tham Ban Khong Kwan commences with a steep rubble slope near Si Kilo. From a trunk passage about 70-80m up, a chamber to the east gives access to at least one large passage that terminates in a big vertical drop edged by flowstone, with a strong draught. From the downstream end of the trunk passage a magnificently decorated, very large chamber (Sala Khan Thai) leads off to the left, containing stalagmites up to 25m high, massive flowstone walls and other decoration. The lowest part of the floor is polygonally cracked mud. Oolites occur in one attractive alcove. To the west the chamber leads to an estimated 50m drop back down to the main stream passage, while at the other end a muddy passage about 5m in diameter leads to a small tributary (Huai Khwae Noi) which sumps at both ends. Small white fish are also present here. This tributary probably joins the main stream at the foot of the initial rubble slope where trickling water is audible.

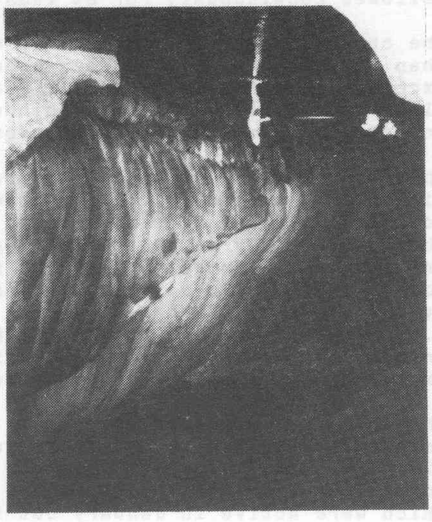
Beyond the explored limit at 5.4km the streamway continues, only a little narrower and lower and with no end in sight.

Cave temperature is comfortable. A breeze is particularly noticeable 2 to 3km inside and in the upper level passages. Cave fauna, both adapted and adventitious, is plentiful throughout, noticeably more so in January than at the end of the dry season in May, and includes bats, white fish (apparently with reduced sight), centipedes, millipedes, slaters, springtails, mayflies and dragonflies. Samples are presently being identified by Graeme Smith.

Plate 2

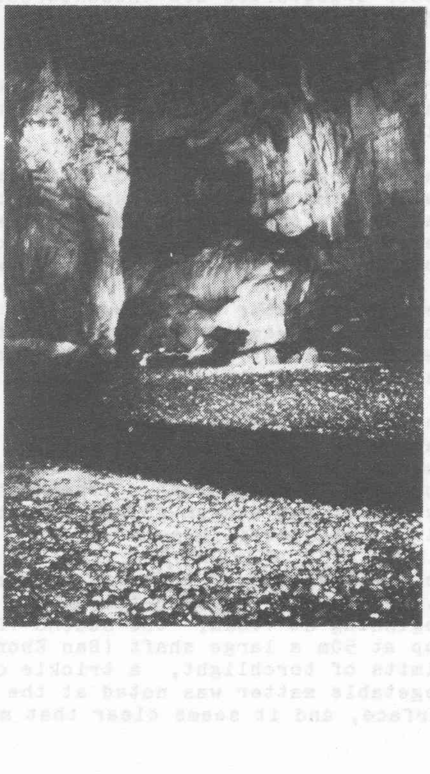
Tham Nam Lang





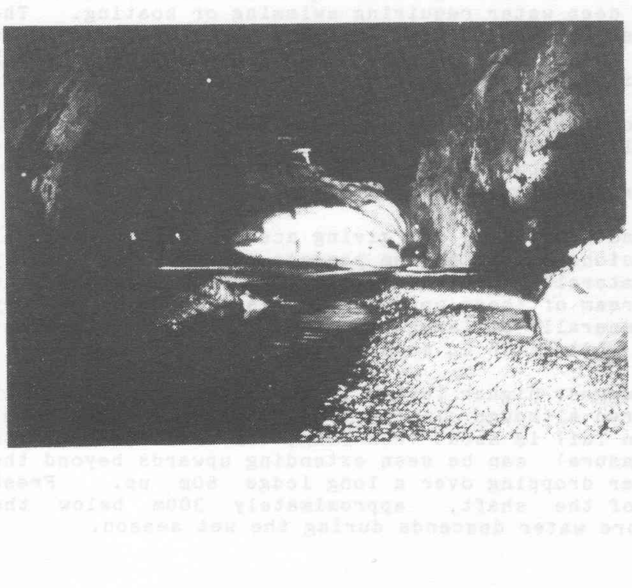
Surveying below Wang Mekhala

Looking back to entrance from Mum Mok



Stream passage at Tham Kruat, near 2km point

Passage leading to Wang Mekhala (note figures above and below flowstone approx. 100m away)



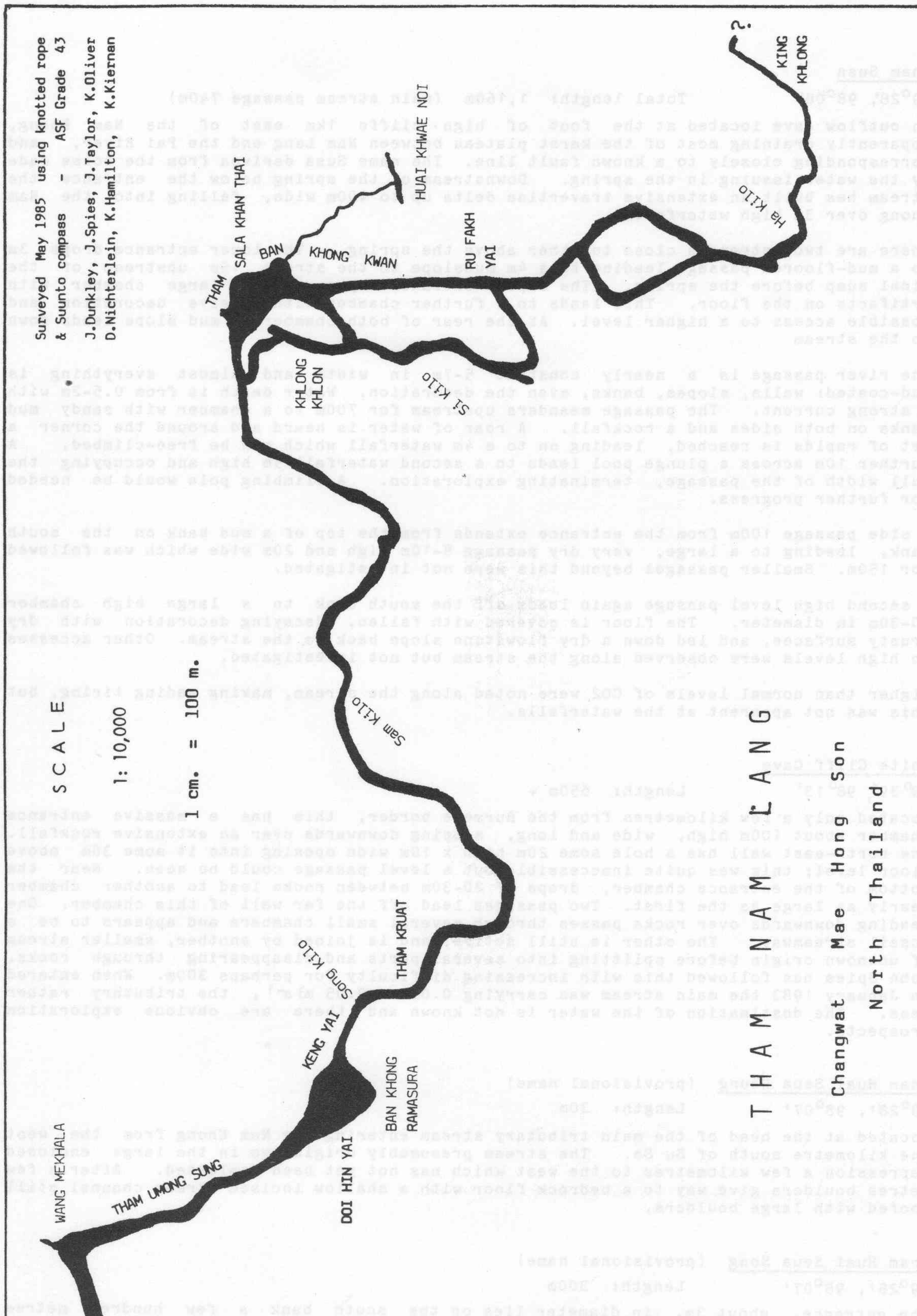


Figure 4 : Tham Nam Lang

Tham Susa

19°28', 98°08' Total length: 1,160m (main stream passage 740m)

An outflow cave located at the foot of high cliffs 1km east of the Nam Khong, apparently draining most of the karst plateau between Nam Lang and the Pai River, and corresponding closely to a known fault line. The name Susa derives from the noise made by the water issuing in the spring. Downstream of the spring below the entrance the stream has built an extensive travertine delta up to 400m wide, falling into the Nam Khong over 3m high waterfalls.

There are two entrances close together above the spring. The lower entrance drops 3m to a mud-floored passage leading to a 4m mudslope to the stream 15m upstream of the final sump before the spring. The upper entrance opens to a large chamber with artifacts on the floor. This leads to a further chamber with massive decoration and possible access to a higher level. At the rear of both chambers a mud slope leads down to the stream

The river passage is a nearly constant 5-7m in width and almost everything is mud-coated: walls, slopes, banks, even the decoration. Water depth is from 0.5-2m with a strong current. The passage meanders upstream for 700m to a chamber with sandy mud banks on both sides and a rockfall. A roar of water is heard and around the corner a set of rapids is reached, leading on to a 4m waterfall which can be free-climbed. A further 10m across a plunge pool leads to a second waterfall 5m high and occupying the full width of the passage, terminating exploration. A climbing pole would be needed for further progress.

A side passage 100m from the entrance extends from the top of a mud bank on the south bank, leading to a large, very dry passage 8-10m high and 20m wide which was followed for 150m. Smaller passages beyond this were not investigated.

A second high level passage again leads off the south bank to a large high chamber 20-30m in diameter. The floor is covered with fallen, decaying decoration with dry crusty surfaces, and led down a dry flowstone slope back to the stream. Other accesses to high levels were observed along the stream but not investigated.

Higher than normal levels of CO_2 were noted along the stream, making wading tiring, but this was not apparent at the waterfalls.

White Cliff Cave

19°39', 98°13' Length: 650m +

Located only a few kilometres from the Burmese border, this has a massive entrance chamber about 100m high, wide and long, sloping downwards over an extensive rockfall. The north-east wall has a hole some 20m high x 10m wide opening into it some 30m above floor level; this was quite inaccessible but a level passage could be seen. Near the bottom of the entrance chamber, drops of 20-30m between rocks lead to another chamber nearly as large as the first. Two passages lead off the far wall of this chamber. One leading downwards over rocks passes through several small chambers and appears to be a fossil streamway. The other is still active, and is joined by another, smaller stream of unknown origin before splitting into several parts and disappearing through rocks. John Spies has followed this with increasing difficulty for perhaps 300m. When entered in January 1983 the main stream was carrying 0.03 - 0.05 $m^3 s^{-1}$, the tributary rather less. The destination of the water is not known and there are obvious exploration prospects.

Tham Huai Seua Neung (provisional name)

19°28', 98°07' Length: 30m

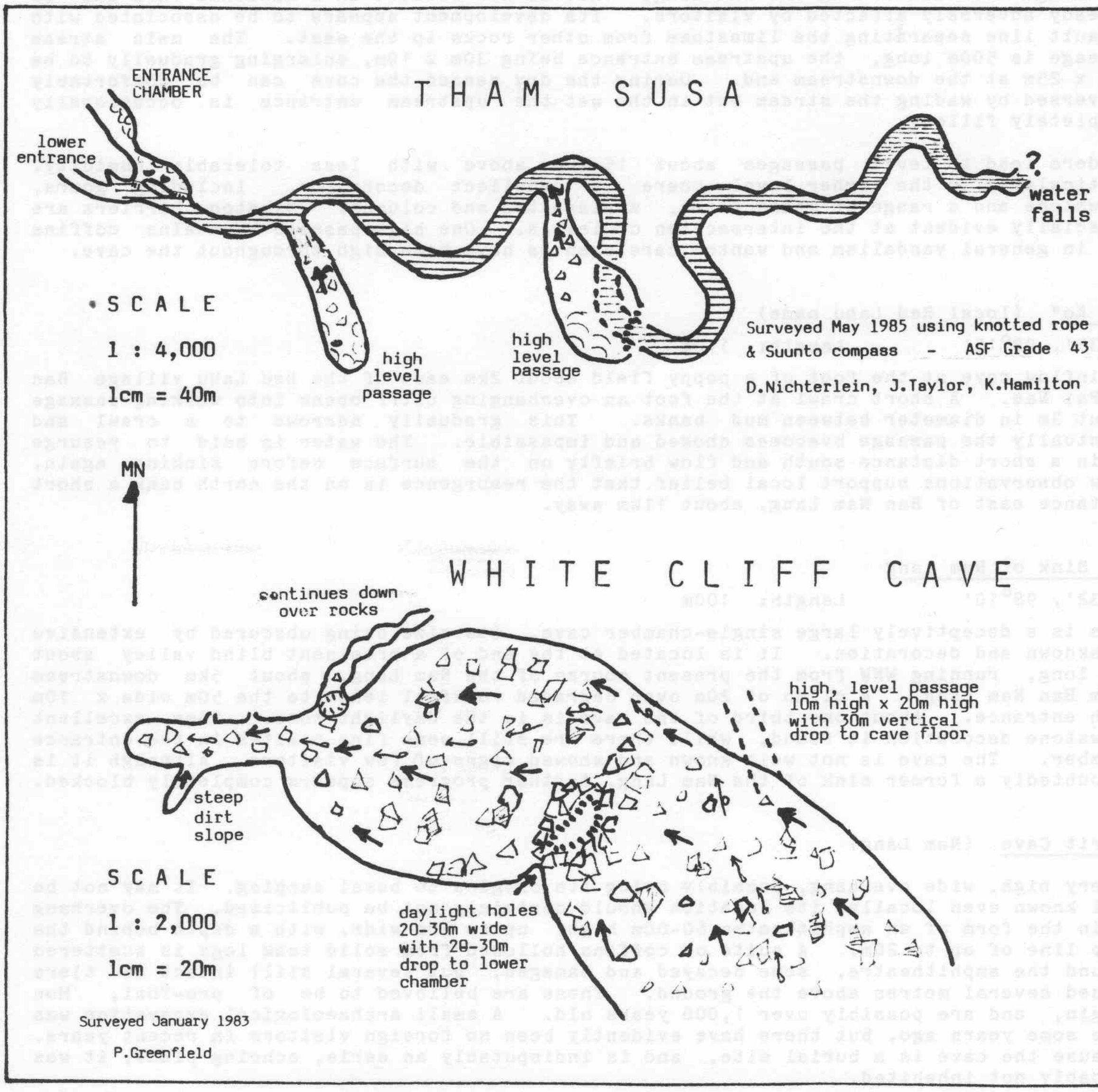
Located at the head of the main tributary stream entering the Nam Khong from the west one kilometre south of Su Sa. The stream presumably originates in the large enclosed depression a few kilometres to the west which has not yet been explorted. After a few metres boulders give way to a bedrock floor with a shallow incised stream channel still roofed with large boulders.

Tham Huai Seua Song (provisional name)

19°28', 98°07' Length: 300m

The entrance, about 3m. in diameter lies on the south bank a few hundred metres downstream of Tham Huai Seua Neung, behind a sizeable pool backed by a boulder maze. A spacious pressure tube passage 3-4m in diameter leads horizontally for 300m to an easy climb which was not explored. A strong draught is evident throughout the cave. Much of the floor is sand but there are minor rock heaps and small logs in places, and small crickets were noted. A very promising exploration prospect.

Figure 5 : Tham Susa and White Cliff Cave



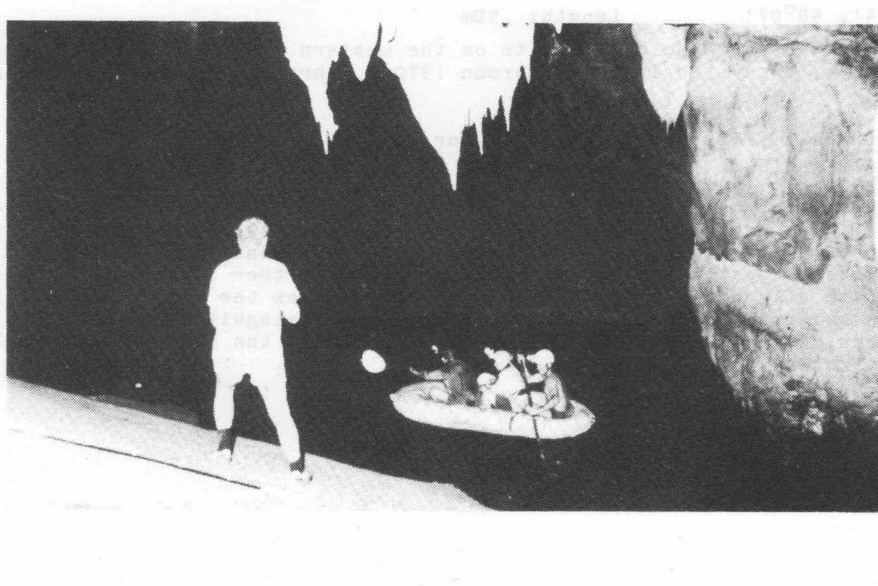


Plate 3

Main stream passage in Tham Susa

Tham Lot

19°34', 98°17' Total length: 1,030m (main stream passage 500m)

A through cave containing the Nam Lang, this is now located in a National Park and is already adversely affected by visitors. Its development appears to be associated with a fault line separating the limestone from other rocks to the east. The main stream passage is 500m long, the upstream entrance being 30m x 10m, enlarging gradually to be 45m x 25m at the downstream end. During the dry season the cave can be comfortably traversed by wading the stream but in the wet the upstream entrance is occasionally completely filled.

Ladders lead to level passages about 15-20m above with less tolerable humidity. Particularly in the higher level there is excellent decoration, including gours, flowstone and a range of stalactites, stalagmites and columns. Rimstone barriers are especially evident at the intersection of levels. One high passage contains coffins but in general vandalism and wanton carelessness have been high throughout the cave.

"Ha Ko" (local Red Lahu name)

19°35', 98°15' Length: 172m

An inflow cave at the foot of a poppy field about 2km east of the Red Lahu village Ban Ya Pai Nae. A short crawl at the foot an overhanging cliff opens into walking passage about 3m in diameter between mud banks. This gradually narrows to a crawl and eventually the passage bvecomes choked and impassible. The water is said to resurge again a short distance south and flow briefly on the surface before sinking again. Flow observations support local belief that the resurgence is on the north bank a short distance east of Ban Nam Lang, about 11km away.

Old Sink of Nam Lang

19°32', 98°10' Length: 100m

This is a deceptively large single-chamber cave, its size being obscured by extensive breakdown and decoration. It is located at the end of a prominent blind valley about 2km long, running WNW from the present course of the Nam Lang, about 5km downstream from Ban Nam Lang. A climb of 20m over degraded rockfall leads to the 50m wide x 10m high entrance. About one third of the cave is in the daylight zone. Some excellent flowstone decoration is found, while there are still some fine oolites in the entrance chamber. The cave is not well known and showed signs of few visitors. Although it is undoubtedly a former sink of the Nam Lang, further progress appears completely blocked.

Spirit Cave (Nam Lang)

A very high, wide overhang, possibly owing its origins to basal sapping. It may not be well known even locally; its location should certainly not be publicised. The overhang is in the form of an amphitheatre 60-80m high, up to 50m wide, with a depth behind the drip line of up to 20m. A suite of coffins hollowed from solid teak logs is scattered around the amphitheatre, some decayed and damaged, but several still intact in tiers raised several metres above the ground. These are believed to be of pre-Thai, Mon origin, and are possibly over 1,000 years old. A small archaeological excavation was made some years ago, but there have evidently been no foreign visitors in recent years. Because the cave is a burial site, and is indisputably an eerie, echoing place, it was probably not inhabited.

Spirit Cave (Nam Khong)

19°34', 98°07' Length: 50m

An important archaeological site on the western side of Nam Khong, upstream from Ban Mae Suya, excavated in 1966 (Gorman 1970). Three small connected chambers.

Spirit Well (local Lahu name: Nam Bor Phi)

19°32', 98°10' Depth: 100m

A spectacular collapse located on a sloping hillside, completely surrounded by vertical walls, was explored by Kerry Hamilton and John Taylor. On the higher side an enormous cave entrance 100m high is overhung with long stalactites and vines. On the low side a 70m pitch drops to a scree sloping steeply a further 30m or so drops through rainforest trees to a 1m diameter x 3m deep tube which takes the drainage. A climb up an earth slope under the cave entrance leads to large stalagmite to a guano floored sloping chamber, with no way on. The other low point of the doline has a small dark area under large rocks (Plate 4).

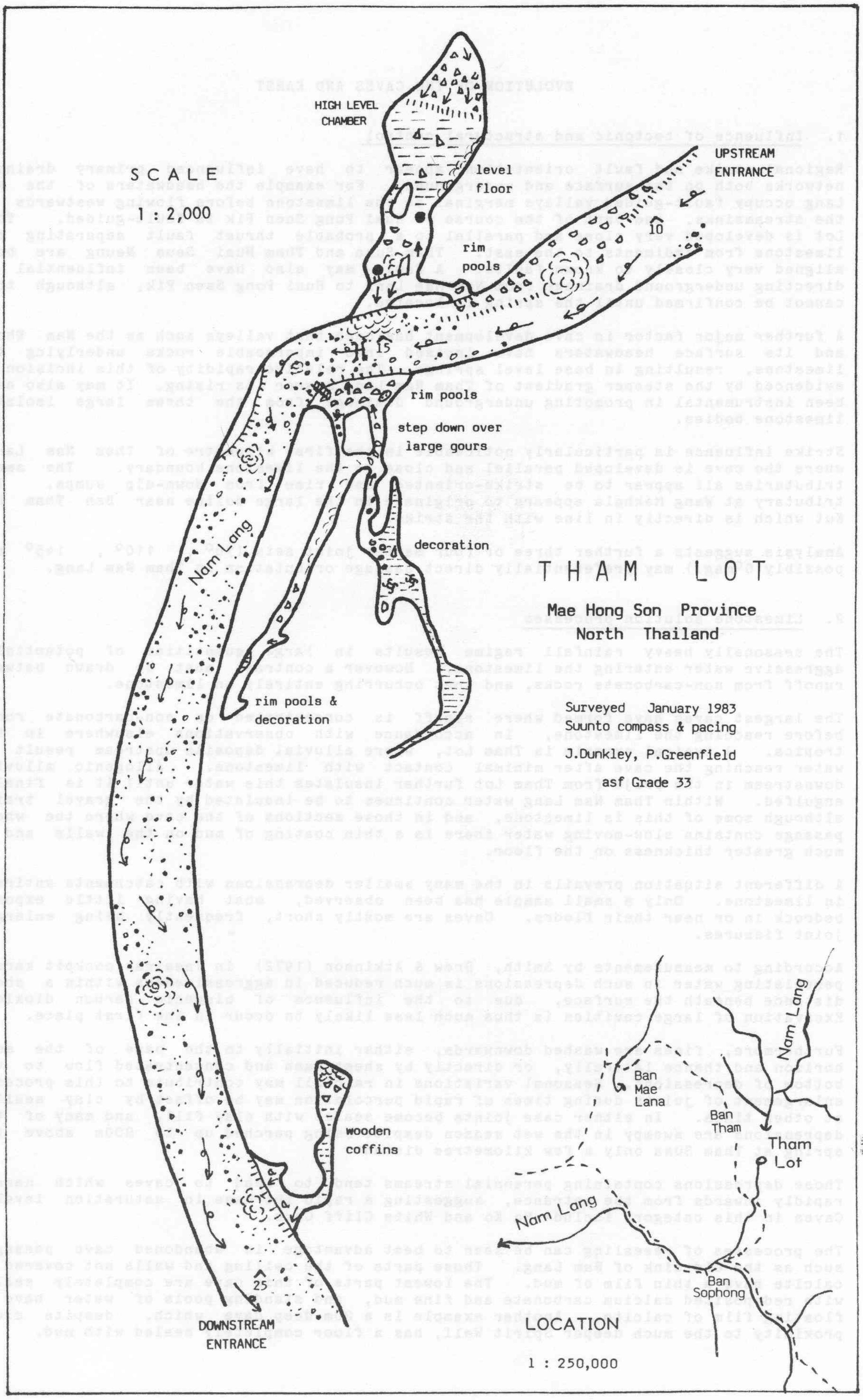


Figure 6. Tham Lot

EVOLUTION OF THE CAVES AND KARST

1. Influence of tectonic and structural control

Regional strike and fault orientation appear to have influenced primary drainage networks both on the surface and underground. For example the headwaters of the Nam Lang occupy fault-guided valleys marginal to the limestone before flowing westwards to the streamsinks, and part of the course of Huai Pong Saen Pik is fault-guided. Tham Lot is developed very close and parallel to a probable thrust fault separating the limestone from sediments to the east. Tham Susa and Tham Huai Seua Neung are both aligned very closely to known faults. A fault may also have been influential in directing underground drainage from Nam Mae Lana to Huai Pong Saen Pik, although this cannot be confirmed until the spring is located.

A further major factor in cave development has been that valleys such as the Nam Khong and its surface headwaters have incised into impermeable rocks underlying the limestone, resulting in base level springs. The relative rapidity of this incision is evidenced by the steeper gradient of Tham Nam Lang nearer its rising. It may also have been instrumental in promoting underground drainage from the three large isolated limestone bodies.

Strike influence is particularly noticeable in the first kilometre of Tham Nam Lang, where the cave is developed parallel and close to the limestone boundary. The small tributaries all appear to be strike-oriented and rise from down-dip sumps. The tributary at Wang Mekhala appears to originate in the large doline near Ban Tham Pak Kut which is directly in line with the strike.

Analysis suggests a further three or four master joint sets (70°, 110°, 145° and possibly 0°mag.) may preferentially direct passage orientation in Tham Nam Lang.

2. Limestone solution processes

The seasonally heavy rainfall regime results in large quantities of potentially aggressive water entering the limestone. However a contrast must be drawn between runoff from non-carbonate rocks, and that occurring entirely on limestone.

The largest caves have formed where runoff is concentrated on non-carbonate rocks before reaching the limestone, in accordance with observations elsewhere in the tropics. A typical example is Tham Lot, where alluvial deposits upstream result in water reaching the cave after minimal contact with limestone. Allogenic alluvium downstream in the polje from Tham Lot further insulates this water until it is finally engulfed. Within Tham Nam Lang water continues to be insulated by the gravel train, although some of this is limestone, and in those sections of the cave where the whole passage contains slow-moving water there is a thin coating of mud on the walls and a much greater thickness on the floor.

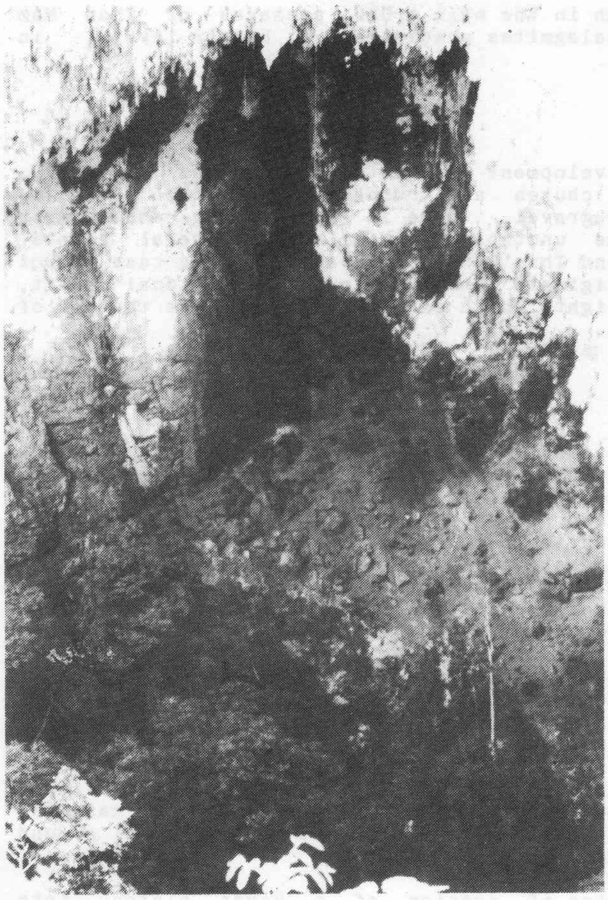
A different situation prevails in the many smaller depressions with catchments entirely in limestone. Only a small sample has been observed, most having little exposed bedrock in or near their floors. Caves are mostly short, frequently being enlarged joint fissures.

According to measurements by Smith, Drew & Atkinson (1972) in Jamaican cockpit karst, percolating water in such depressions is much reduced in aggressiveness within a short distance beneath the surface, due to the influence of biogenic carbon dioxide. Excavation of large cavities is thus much less likely to occur in the first place.

Furthermore, fines are washed downwards, either initially to the base of the soil horizon and thence laterally, or directly by sheet wash and concentrated flow to the bottom of depressions. Seasonal variations in rainfall may contribute to this process: enlargement of joints during times of rapid percolation may be offset by clay sealing at other times. In either case joints become sealed with clay fill, and many of the depressions are swampy in the wet season despite being perched up to 800m above the spring at Tham Susa only a few kilometres distant.

Those depressions containing perennial streams tend to lead to caves which narrow rapidly inwards from the entrance, suggesting a rapid increase in saturation levels. Caves in this category include Ha Ko and White Cliff Cave.

The processes of resealing can be seen to best advantage in abandoned cave passages such as the old sink of Nam Lang. Those parts of the ceiling and walls not covered in calcite have a thin film of mud. The lowest parts of this cave are completely sealed with redeposited calcium carbonate and fine mud, and standing pools of water have a floating film of calcite. Another example is a 20m deep cave which, despite close proximity to the much deeper Spirit Well, has a floor completely sealed with mud.



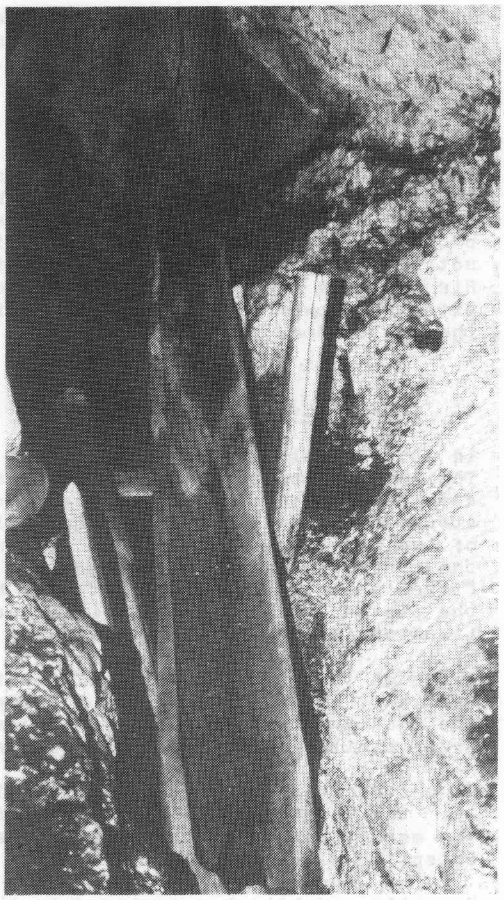


Plate 4: Spirit Well (note figures)

Plate 5: Coffins in a cave near Nam Lang

Plate 6: Closed depression with poppy fields near Mae Lana

Although stalactitic flows are common enough in the main trunk passages of Tham Nam Lang and Tham Lot, large, even massive stalagmites predominate at higher levels, in common with most dry tropical caves.

3. Mechanical processes

Corrasion must be accorded a role in the development of Tham Lot and Tham Nam Lang. Apart from the evidence of vadose bedrock chutes and runnels, and the train of sediments varying from fine mud to sand and gravel, there is an ongoing undermining process at stream level resulting in large unstable rockfalls at several points, notably Thi Arahn Klang Wan, Doi Hin Yai and Tham Ban Khong Kwan. In the case of Doi Hin Yai (Big Rock Mountain), the rocks originate from a large corrosional shaft, extending upward beyond the limit of torchlight, which carries water even at the end of the dry season.

4. General Evolution of the Karst

In its general outlines the present configuration of the drainage system of northern Thailand was probably inherited from the uplift during late Tertiary times. Drainage developed on an erosion surface truncating earlier folded rocks, and was initially structurally guided. Limestone solution occurred preferentially at the intersections of two or more joint or fault planes, initiating the depressions and in time deranging the surface drainage. Topographic lows suggest for example that the Nam Mae Lana once flowed south as a tributary to the Nam Lang, and that a similar stream flowed north off the plateau to join the Nam Lang near its present windgap. The occasional cone-like limestone masses on the plateau may date from this period.

Although in their present configuration the depressions need not be dated back to the Tertiary, there is no reason to suppose that they differ significantly in age. Despite the much greater depth of the poljes, their ratio of volume to catchment area is of an order similar to that for the smaller depressions.

At the macro-scale, especially as viewed by low-angle oblique aerial photography (Plate 1), the karst has the appearance of a plateau deeply dissected only at the margins. The meso-topography, on the other hand, is very rugged with almost no near-level ground except on alluvium (Plate 6).

Recently, debate has centered on the dynamics of erosion of a karst plateau into residual forms. Jakucs (1977) asserted a priori that because they concentrate corrosive action, depressions in a tropical plateau karst are self-enhancing, leaving residual towers close to the level of the former plateau. This conclusion relies on the assumption of a positive feedback loop between depth of soil and rate of lowering of depression floors. This model was supported by Day (1976). Gunn (1981) has identified six flow components of depression hydrology, a detailed study of which would aid understanding of the processes at work.

Finally, Crowther (1984) has produced evidence from Malaysia suggesting that small soil-filled depressions of the type found in the Nam Lang area tend in fact to be self-limiting rather than self-enhancing. He believes that the landscape is lowered more or less evenly, presenting an equilibrium form at the meso-scale. At the macro-scale, the principal agencies of dissection are seen as regional joints and faults. The thick sediments and soils in depressions must then be regarded as secondary features resulting from, rather than causing, intense localized erosion.

Summary

The Nam Lang - Nam Khong karst has been evolving since uplift of northern Thailand in the late Tertiary. Initial surface drainage was determined by tectonic and structural controls and at this stage the Nam Mae Lana may have been a tributary of the Nam Lang. Underground drainage was guided by these major structural lineations. Depressions were most likely to form initially at the intersection of two or more joint or fault planes, a process which was autocatalytic because as their catchments enlarge, so they attract more runoff and grow faster. In time surface drainage became deranged except where allogenic streams such as the Nam Lang maintained some of their course on the limestone. However, the basic geometry of the karst was maintained as the limestone mass was reduced by lowering of both depressions and divides.

Development of large depressions and caves was favoured where aggressive water concentrates on non-carbonate rocks before reaching the limestone, and was further enhanced both by rapid lowering of base level springs and by gravel trains in the caves. Cave development in the smaller depressions is limited and is subject to negative feedback processes.

DISCUSSION

Further exploration, particularly in Tham Susa and in the upper levels of Tham Nam Lang should add to an understanding of cave development. Close attention should be paid to geological structure both within the caves and on the surface, to establish the influence of structure and of stratigraphical variations.

All speleological exploration to date has been carried out during the dry season, since the caves are inaccessible for much of the wet season. However as Williams (1972b) emphasizes, fluvial processes are central to an understanding of the evolution of polygonal karst, and these processes will be most evident at the height of the wet season, particularly the relative significance of overland, through- and subcutaneous flow. The plateau south of the Nam Lang in particular needs to be prospected in such conditions.

GLOSSARY

Features in Tham Nam Lang and Tham Susa have been named using transliterated Thai, employing the romanized system recommended by the Royal Institute, Bangkok:

BAN: village, home of (a person)
BAN KHONG RAMASURA: Home of Ramasura (a mythological demi-god half-ogre half-divine
HIN: rock, stone
KENG: rapids
KHWAE: tributary
KHLONG: canal, waterway
MAE NAM: large stream, river
NAM: water
(PHRA RACHA) WANG MEKHALA: Palace of Mekhala (beautiful goddess of Thai mythology)
SAI: sand
THAM: cave, or cavern or chamber within a cave
THI ARAHN KLANG WAN: lunch-eating place
THI THA RUA LUANG: place for launching the yellow boats
THAM BAN KHONG KWAN: Cave home of Kwan (a spirit residing in the head, responsible for health, wealth and general comfort)
UMONG: tunnel
DOI: mountain
HUAI: stream, creek
KHAENG-KHAO: bat
KHLON: mud
KRUAT: gravel
MUM MOK: foggy corner
NOI: small
SUNG: high
YAI: large, big

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HISTOPLASMOSIS AND AUSTRALIAN CAVE ENVIRONMENTS.

T. J. Harden and P. J. Hunt

Abstract

Histoplasma capsulatum is a fungus which is the causative agent of histoplasmosis, a disease of worldwide distribution. The prevalence of this disease and its manifestation in clinical cases of disease in humans are described. The association of this fungus with dung enriched soil is discussed, particularly in relation to caves which are frequented by colonial bats. *H. capsulatum* has been associated on several occasions with the respiratory form of histoplasmosis in Australia but has only been isolated from the Church Cave. It is suggested that although *H. capsulatum* in Australia has been found in association with only *Miniopterus schreibersii*, other genera of bats may also harbour this fungus.

INTRODUCTION

The disease histoplasmosis has for many years been recognised by speleologists as "cavers' disease" or "cave sickness". Although commonly found in many overseas countries, particularly America, there have been only two reported outbreaks of this disease in Australia and each of these has been associated with a visit to the Church Cave (Isbister et al., 1976; Hunt et al., 1984). This paper reviews the disease histoplasmosis and its association with bats and caves.

THE CAUSATIVE AGENT OF HISTOPLASMOSIS

Histoplasmosis is a very common disease of worldwide distribution caused by inhaling the spores of the fungus *Histoplasma capsulatum*. Fungi are most commonly found in decaying organic matter and very few cause disease in humans. Fungi are microscopic in size and usually exist in one of two forms. The mycelial form grows to produce hair-like strands which intertwine until they form a mycelium which is large enough to be seen with the naked eye. The other form of fungi are the yeasts. These are unicellular in structure, reproduce by budding, and cannot normally be seen with the naked eye. Some fungi are dimorphic i.e. they can convert from the unicellular yeast form to mycelial growth, or vice versa, in appropriate environments. *H. capsulatum* like all other fungi, requires abundant moisture and a supply of both organic matter and oxygen for growth. It also grows best at normal room temperature (20-25°C) and reproduces by releasing millions of spores into the atmosphere. These spores are rapidly distributed by wind currents and can then be inhaled by animals or humans.

H. capsulatum is a dimorphic fungus. At room temperature it grows on laboratory culture media as a fluffy mycelial colony either white or buff-brown in colour producing numerous spores. However when the spores are inhaled by a susceptible animal species, it grows as a small budding yeast in the tissues of that individual. In its natural soil environment *H capsulatum* grows in the mycelial form but is not visible to the naked eye as the fungal strands are dispersed throughout the soil particles.

THE DISEASE HISTOPLASMOSIS

H. capsulatum causes symptoms of widely varying severity with approximately 95% of cases being inapparent or subclinical and only a few infections terminating fatally (the latter cases usually occur in individuals whose immune system is not functioning competently or who are predisposed to such infections due to other illness). The number of individuals who have been infected by *H. capsulatum* in the United States, where the disease is recognised as a public health problem, is estimated in the millions and surveys have revealed areas where the infection rate may be larger than 80% (Goodwin and Des Prez, 1978). It is estimated that 500,000 persons acquire histoplasmosis each year in the United States and a recent outbreak (1978-1979) involved an estimated 100,000 residents of Indianapolis, Indiana (Wheat et al., 1981). In certain parts of the mid-United States, histoplasmosis is commonly called "Summer flu" since the infection occurs in the upper respiratory tract following inhalation of the fungi from dry dusty soil.

Histoplasma infections most frequently involve the respiratory tract and infection is initiated after inhalation of spores of the organism. The term "cavers' disease" refers to a mild to severe form of acute pulmonary histplasmosis, the symptoms of which may begin gradually or abruptly, 10 days - 3 weeks after inhalation of the fungus. The symptoms of this form of the disease are a non-productive cough, fever, night sweats, weight loss, malaise, headache and shortness of breath. An X-ray of the lungs of the affected individual shows a picture very similar to that produced by an acute form of tuberculosis. Both the X-ray picture and the symptoms of the disease generally clear after 4 - 6 weeks. Treatment of the acute pulmonary form of the disease with antifungal agents is very rarely necessary and there are usually no long term ill-effects from having contracted the disease.

Although this fungus has been isolated from a variety of animals, there is no evidence of animal-to-man or man-to-man spread of the disease. However animals chronically infected with *H. capsulatum* (e.g. bats) may be an important source for seeding the soil with the fungus (Klite and Diercks, 1965).

THE ASSOCIATION OF *HISTOPLASMA CAPSULATUM* WITH CAVES

is found throughout the world but grows in abundance only in relatively restricted environmental conditions. Furcolow (1958) and Fonseca (1971) found that the climatic conditions favouring growth in an "open" environment were a mean temperature of 22 - 29°C, an annual rainfall of approximately 1000 mm and a relative humidity of 67 - 87%. Outside of these areas with the appropriate environmental conditions are the "closed" environments e.g. caves inhabited by bats and birds. Thus, although the surrounding countryside may be too dry or cold for the sustained growth of the fungus, the protected and relatively stable conditions inside the caves allow such growth.

H. capsulatum is capable of growth and proliferation in soil and many of the organic materials that normally accumulate in the surface layers of soil can serve as substrates for this fungus. However, . has been shown to have a predilection for dung-enriched soils (Goos, 1965) and is thus commonly found in soil contaminated with the droppings of birds, fowls and bats.

THE ASSOCIATION OF *HISTOPLASMA CAPSULATUM* WITH BATS

Available evidence indicates that certain bat species play a role in the epizootiology of *H. capsulatum* (Hoff and Bigler, 1981). It is thought that the faeces of bats and birds serve as a source of nutrients to fungi in the soil and provides a competitive advantage to *H. capsulatum* so that it can develop with greater success than it would in another habitat. Indeed, extracts of chicken and starling manure have been shown to have a stimulating effect on the production of spores by *H. capsulatum* (Smith and Furcolow, 1964).

It is believed that *H. capsulatum* from bat, to guano, to bat and that the bat acquires its initial infection by the respiratory route (as in man) by inhaling infectious particles that are produced by the growth of *H. capsulatum* in their roosting habitats (Hasenclever et al., 1969). This is supported by the many isolations of the organism from the lungs of bats (Di Salvo, 1971). There is also evidence that the bat intestine contains the yeast form of this organism in its tissues, however the effect on a normal chiropteran host harbouring the fungus is not known. Emmons et al., (1966) have shown that *H. capsulatum* can grow in ulcers in the intestinal tract of bats and these infected bats can then contaminate the environment as they migrate to new caves and seed them with this fungus. However, the presence or absence of bat or bird dung in the environment does not solely govern the occurence of *H. capsulatum* in nature. Other ecological factors must be at play since there are many areas throughout the world populated with bats and birds that are apparently free from

The actual role of bats in human histoplasmosis contracted outside cave environments is probably limited given the high infection rates observed in bats in areas where there are low rates of human infection (Di Salvo et al., 1969). However the majority of bat-associated cases of human histoplasmosis have been traced to discreet environments e.g. caves and trees, where exposure to fungi infested soil and guano can be more intense (Hoff and Bigler, 1981). The exact role of the bat in the ecology of *H. capsulatum* particularly in Australia, remains uncertain and additional knowledge of the physiology, migration and other habits of bats is essential before it can be determined whether the bat is either a vector or victim, or both.

In Australia, *H. capsulatum* has been isolated from the soil and air of the Church Cave at Wee Jasper (Hunt et al., 1984) which is a recognised nursery site for the bent-wing bat *Miniopterus schreibersii* (Dwyer, 1966). *M. schreibersii* is but one of 51 species belonging to the 19 genera of bats found in Australia and 5 of these genera are the same as those from which *H. capsulatum* has been previously isolated outside Australia (Hoff and Bigler, 1981). Dwyer (1965) has reported several breeding caves and maternity colonies of *M. schreibersii* other than in Church Cave, which have not yet been tested for the presence of

HISTPLASMOSIS IN AUSTRALIA

H. capsulatum has been isolated in Australia on six occasions from patients showing the signs and symptoms of the chronic or systemic form of histoplasmosis (Dowe et al., 1953; Inglis and Powell, 1953; Ridley and Nowell, 1959; Murphy and Rao, 1968; Nicholls et al., 1980; Guard and Symes, 1981). Fewings et al., (1970) also reported a case of chronic histoplasmosis and subsequentially isolated the fungus from the soil of a chicken coop in the Mt. Lofty Ranges near Adelaide. Hunt et al., (1984) isolated the fungus from the sputum of a cave investigator who contracted the acute pulmonary form of the disease and also from the soil and air of the Church Cave. Chest X-ray films coupled with the symptoms of acute pulmonary histplasmosis were also reported by two other investigators from the Riverina-Murray Institute of Higher Education during a 7-year period of investigation of the Church Cave (Hunt et al., 1984). In 1976, Isbister et al., reported that 13 of 16 people who visited the Church Cave were clinically diagnosed as having acute pulmonary histoplasmosis although the fungus *H. capsulatum* was not isolated. Also, a survey carried out on 80 speleologists from Australia and New Zealand showed 25 positive reactions, indicating that the fungus is present in the local environment (Frey,1974).

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A SURVEY DATA REDUCTION PROGRAM AID FOR RADIO DIRECTION FINDING WORK

D.J. Martin

Abstract

A computer program that calculates the horizontal distance, magnetic bearing and difference in elevation between the current point on a survey traverse and a specified end point is described. It has been designed to assist in the survey location of surface points designated for radio direction finding work in difficult terrain. The program has been adapted from a conventional cave survey data reduction program and is suitable for field use on a hand held microcomputer.

INTRODUCTION

Radio Direction Finding (RDF) is a technique that allows an underground point to be located on the surface (see for example Glover, 1976). Normally a transmitting coil is positioned at the underground point (Point B in Fig. 1). This coil will produce a magnetic field of varying strength when fed with an oscillating current. If this coil is positioned vertically the line of force from the north to the south pole of the transmitter has infinite curvature and hence passes through the point directly above it on the surface (Point E in Fig. 1). This line is unique as it is the only vertical line of force produced by the coil. The oscillating magnetic field will induce a voltage in a receiving coil which is placed in the field. If the receiver is turned until its plane is parallel to the lines of force a null point will be obtained where there is no induced voltage.

The receiving coil will have located point E when a null is obtained for all receiver orientations about a vertical axis. At any other location only one null point can be obtained when the coil is held vertically. The vertical plane containing the receiver held in this null position passes through point E. A triangulation or other similar process is used to approximately locate point E via a triangle of error. The accurate location of point E can then be made. The limited range of this type of equipment would, in some circumstances, make it imperative to first obtain an approximate surface location of the point before any RDF work can be started. This could be achieved by surface surveying.

If the coordinates of the underground point (Point B in Fig. 1) are known then the equivalent surface point (Point E) could be located by surveying from the cave entrance or other known point (Point A). This would be a trial and error process if conventional survey data reduction methods were used. A programmable calculator or hand held microcomputer provides a means of eliminating the trial and error process. A conventional cave survey data reduction program (Martin, 1985) can be modified to calculate the horizontal distance and magnetic bearing between a survey station and a nominated end point. This paper describes such a program. The program RDFSURVEY was developed for a particular application in Papua New Guinea where the nature of the karst terrain (grykes, dense rainforest) made it impossible to traverse from points A to E on a single bearing.

RDFSURVEY PROGRAM DESCRIPTION

The initial data required by the program are the coordinates (eastings, northings and heights) of points A and E in Fig. 1. The program then calculates the straight line magnetic bearing and horizontal distance from A to E. Difficult terrain may mean that it is not possible to follow the bearing calculated by the program. The survey team takes the easiest route and the first leg of the survey becomes A to C1, the second C1 to C2 and so on.

The survey data for each leg is entered into the microcomputer as it is surveyed. At each new survey station C the program calculates the straight line bearing (BRG in Fig. 1) and horizontal distance (HRZ in Fig. 1) from C to E. This process is repeated until point E is reached; the last survey leg will be along the bearing calculated by the program.

In Fig. 1 the dashed line with bearing BRG and length HRZ from C terminates not at point E but at point D. The program and the survey will locate point D. The horizontal distance between point D (the end of the survey) and point E (the true surface point above B) is the total plan misclosure of the survey.

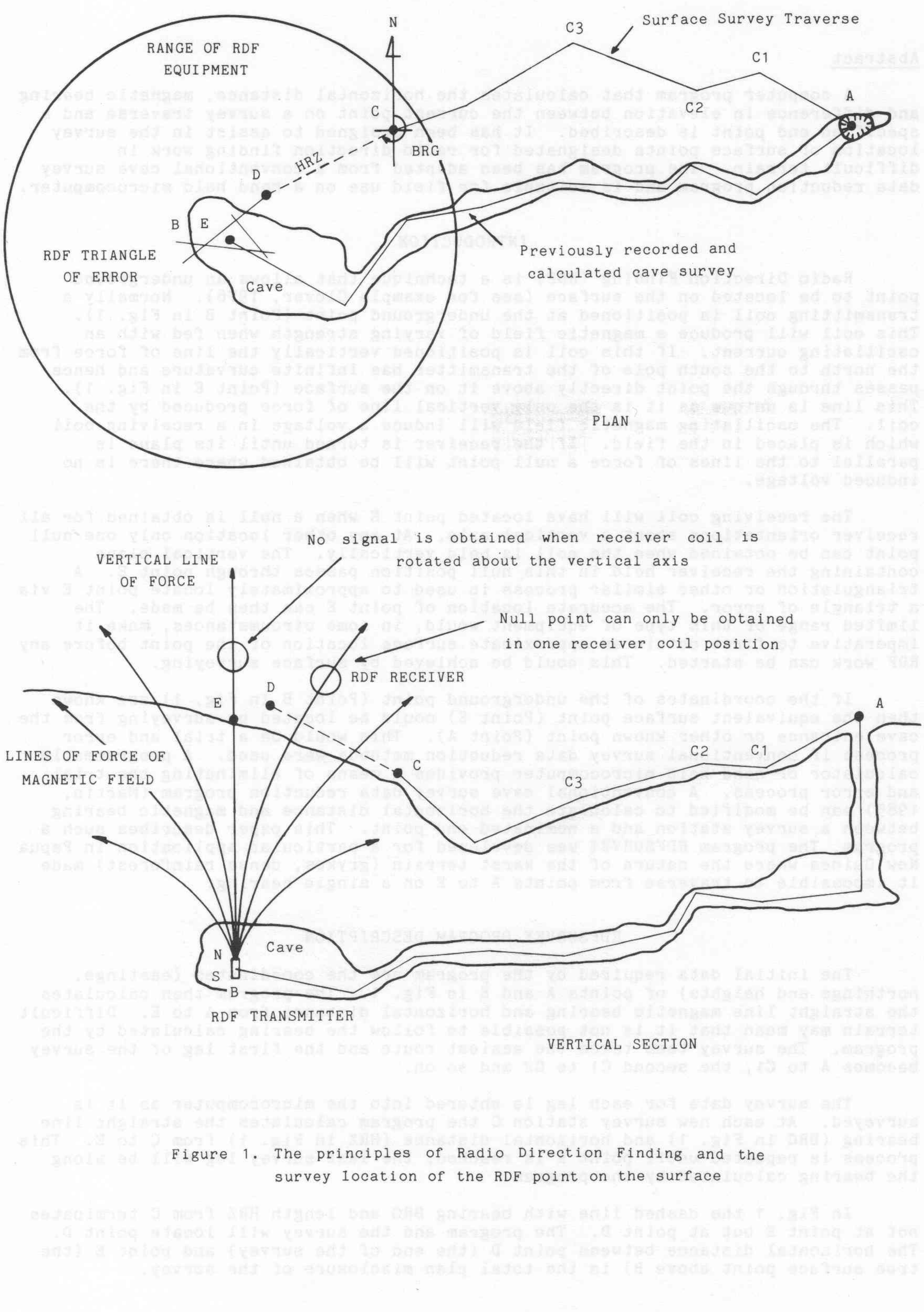

Figure 1. The principles of Radio Direction Finding and the survey location of the RDF point on the surface

The method described relies on knowing the coordinates of the underground point in question relative to a nearby accessible point. If the original survey data is not available the location of the designated point relative to the cave entrance could be scaled from the cave map.

RDFSURVEY PROGRAM OPERATION

The program RDFSURVEY (Fig. 2) has been written specifically for the Casio PB-100 but could be easily modified to suit other microcomputers with similar specifications. The PB-100 is programmed in a simplified version of BASIC. With the memory expansion kit, which this program requires, it has 1.5 kBytes of random access memory. Its dimensions are 165 mm x 71 mm x 10 mm and its weight is about 120 g. Its small size and long life lithium batteries make it suitable for field use.

A simplified flow chart of program execution is given in Fig. 3. Messages (prompts) are displayed whenever a data input is required. Data input prompts are always indicated by a question mark. An input of either Y or N is required to indicate yes or no in response to specific questions. After each set of numeric data (coordinates or traverse data) is entered it is displayed on the the screen. If a mistake has been made the data may be re-entered by using the N option at the OK (Y/N) ? prompt. This feature is not shown on the flow chart. The command DEFM 52 is needed to allocate sufficient memory to variables.

The first data required by the program is the survey station labels and coordinates of the point that has to be located (END STN ?, X ?, Y ? and Z ? prompts) and the point where surveying is to commence (START STN ?, X ?, Y ? and Z ? prompts). The survey station labels may be alpha-numeric strings of up to 7 characters. An axis offset (AXIS OFFSET ? prompt) may also be specified; this is in degrees and is added to all compass bearings. The offset will be zero unless a compass calibration or the use of a non magnetic coordinate system (eg map grid) is required.

Once the start and end coordinates have been entered the horizontal distance (HRZ in program outputs), bearing (BRG) and difference in elevation (DZ) between the two points are calculated and displayed. Traverse data for up to 15 consecutive survey legs may then be entered. For each leg the order of data input prompts is; NEXT STN ?, TAPE ?, COMP ? and CLINO ?. NEXT STN refers to the next new station in the traverse. Usually this will be the station the surveyor is sighting to. In the case of a backsight when using the leapfrog method it will be the station the surveyor is sighting from. Backsights are indicated by entering TAPE as a negative number. The program will then calculate the backbearings. The prompts COMP ? and CLINO ? refer to compass and clinometer readings in degrees.

After the data for each leg has been entered and verified as correct the distance, bearing and difference in elevation between the current station and the end station are calculated and displayed. When data for 15 survey legs has been entered or if END is entered at the NEXT STN ? prompt each survey station and its coordinates may be displayed. This output may be bypassed (PRINT COORDS (Y/N) ? prompt) or displayed a second time (PRINT AGAIN (Y/N) ? prompt) if desired. After the coordinates have been displayed the total tape traverse length (LGTH) and average survey leg length (AV L) for that set of data are given.

Program execution may be ended by entering Y at the next prompt (END (Y/N) ?). An N entered here allows more traverse data to be entered; this must follow on from the last entered station. The coordinates of this station are automatically saved. The whole program must be re-executed if the traverse contains junctions.

Fig. 4 gives the meanings of the single character variable names used in the program. Given the limitations on naming and using arrays in Casio BASIC it is easier to use the array A for all coordinates and A$ for survey station labels.

Memory capacity limits data storage to 15 survey legs. A conventional cave survey data reduction program written for the Casio PB-100 can store coordinates for up to 30 survey legs (Martin, 1985). With more memory the program could be enhanced to store more coordinates and provide for the possibility of branching traverses. Other enhancements which could be used with the PB-100 include the addition of a printer and a cassette. These, however, make field use a little more difficult.

DISCUSSION

At the start of program execution the user must enter coordinates for the end point of the survey. In normal circumstances the coordinates of point B and therefore the plan coordinates of point E are known. The elevation of point E will not be known. The program therefore cannot calculate slope distances and clinometer readings to point E. It is suggested that the elevation of point B be used as the end point. The value of DZ calculated at each step of the program is therefore the vertical separation between the current survey point and the underground point. In some cases the elevation of point E could be determined from a topographical map.

Both the underground traverse used to determine the RDF point's coordinates and the traverse used to help locate this point on the surface are subject to the usual random and systematic errors of cave surveying. Random errors for a given traverse may be determined given traverse length, number of survey legs, average leg length and survery grade (see for example Irwin and Stenner, 1975). Surface surveying can only locate the RDF point to within the limits of accuracy of the surface and underground surveys. This would normally be sufficiently accurate to place the RDF receiver in range of the transmitter.

Radio direction finding methods locate the surface point with an accuracy that is independent of the length of the survey traverse to the underground point. Glover (1976) suggests a plan accuracy of 1 to 2 m at depths up to 100 m in ideal conditions. Bonwick (pers comm) has reported that null points may be located with a resolution of the order of ± 0.04 m for depths up to 30 m. RDF also allows a determination of the vertical separation between the two points to be made via a measurement of the distance from the vertical line of force to a point where the angle of the magnetic field is known (usually 45 or 90 degrees) and an appropriate equation. A null point is obtained with the receiver held at the nominated angle. For these reasons RDF is used to check the accuracy of conventional cave surveying.

The combination of underground and surface surveys with the RDF data completes a loop. The distance between the end of the surface survey (Point D) and the point located by RDF (Point E) may be taken as the plan misclosure of the survey. There is now sufficient information available to correct the plan of the cave survey for misclosure. Apart from being an aid in approximately locating the RDF point the surface survey also provides necessary information for correcting the underground survey.

The vertical misclosure cannot be determined as accurately due to the limitations of the RDF depth determination. Glover (1976) suggests that depth may be determined to within 5 m at depths up to 100 m. When the null point for the depth determination is found the vertical plane perpendicular to the receiver must pass through the vertical line of force. Generally this geometric condition must be judged by eye and some inaccuracies will inevitably occur. An indication of the vertical misclosure could be obtained by determining the expected random error for the survey in the vertical direction and by looking at the difference between the vertical separations obtained by RDF and surveying.

In some circumstances the surface survey could be carried out by methods of more sophistication and greater precision than conventional cave surveying. The method and program described here were designed for use in remote areas containing difficult topography by people familiar with conventional surveying techniques.

CONCLUSIONS

A program for a microcomputer to assist with the surface survey location of points designated for RDF work has been described. Apart from providing a means of bringing the RDF receiver into the range of the transmitter it also provides necessary information for the adjustment of the cave survey for misclosure.

The program may be used for similar purposes not related to RDF work without modification. A surface feature, for example, may need to be reached from information obtained from either topographical maps or aerial photographs. The method would be very useful for these purposes in areas such as dense rainforest where it is difficult to obtain either an overview of the landscape or be able to see where you are heading. The location of the desired points by surveying from a known point is one way of solving the problem presented by the terrain.

ACKNOWLEDGEMENTS

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```
100 INPUT "END STN ",K$:G=0
110 FOR D=1 TO 2
120 INPUT "X ",A(26+D)
130 INPUT "Y ",A(43+D)
140 INPUT "Z ",A(60+D)
150 SET N:PRINT "STN ";A$(9+D)
160 SET F1:PRINT "X= ";A(26+D)
170 PRINT "Y= ";A(43+D),"Z= ";A(60+D)
180 INPUT "OK (Y/N) ",F$
190 IF F$="N" THEN 120
200 IF D=1;INPUT "START STN ",L$
210 NEXT D
220 INPUT "AXIS OFFSET ",H
230 FOR D=0 TO 15
240 IF D=0;A=0:B=0:C=0:E=1:GOTO 370
250 INPUT "NEXT STN ",A$(11+D)
260 IF A$(11+D)="END" THEN 490
270 INPUT "TAPE ",A,"CØMP ",B,"CLINO ",C
280 SET N:PRINT "TO STN ";A$(11+D)
290 SET F1:PRINT "TAPE= ";A
300 PRINT "COMP= ";B,"CLINO= ";C:SET N
310 INPUT "OK (Y/N) ",F$
320 IF F$="N" THEN 250
330 IF A>0 THEN 360
340 A=-A:B=B+180:C=-C
350 IF B>360;B=B-360
360 B=B+H:G=G+A:E=D
370 A(28+E)=A(27+E)+A*COS C*SIN B
380 A(45+E)=A(44+E)+A*COS C*COS B
390 A(62+E)=A(61+E)+A*SIN C
400 I=A(27)-A(28+E):J=A(44)-A(45+E)
410 A=(I*I+J*J)^0.5
420 B=ATN(I/J):C=A(62+E)-A(61)
430 IF J<0;B=B+180:GOTO 450
440 IF I<0;B=B+360
450 PRINT "FROM ";A$(11+D),"TO ";K$
460 SET F1:PRINT "HRZ= ";A
470 PRINT "BRG= ";B-H,"DZ= ";C
480 NEXT D
490 INPUT "PRINT COORDS (Y/N) ",F$
500 IF F$="N" THEN 580
510 FOR D=0 TO E
520 SET N:PRINT "STN ";A$(11+D)
530 SET F1:PRINT "X= ";A(28+D)
540 PRINT "Y= ";A(45+D),"Z= ";A(62+D)
550 NEXT D
560 INPUT "PRINT AGAIN (Y/N) ",F$
570 IF F$="Y" THEN 510
580 PRINT "LGTH= ";G,"AV L= ",G/E:G=0
590 INPUT "END (Y/N) ",F$
600 IF F$="Y";END
610 L$=A$(11+E):A(28)=A(28+E)
620 A(45)=A(44+E):A(62)=A(62+E)
630 GOTO 230
640 END
```

Figure 2. Program Listing for the CASIO PB-100 Program RDFSURVEY

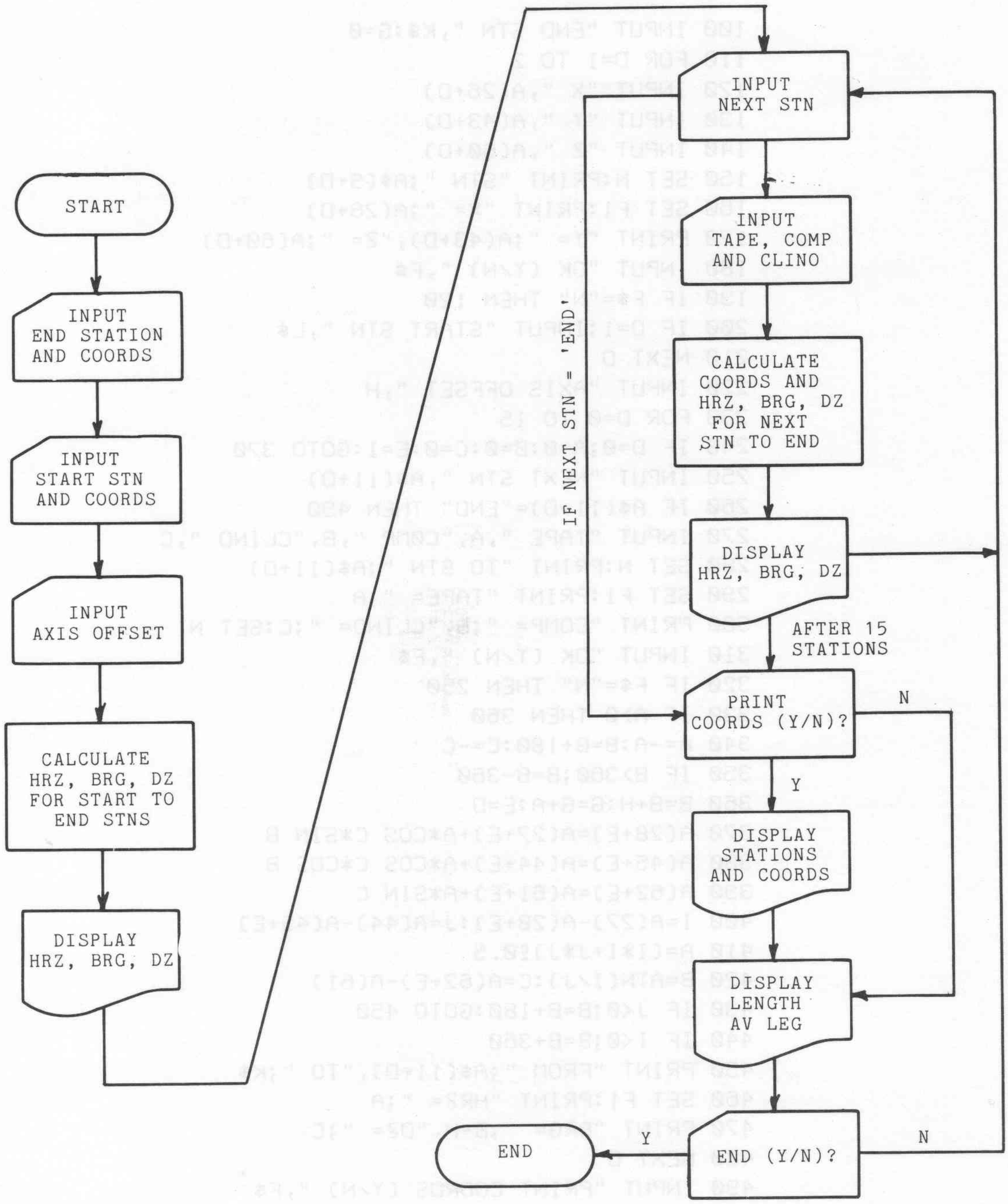

Figure 3. Simplified Program Flow Chart for RDFSURVEY

A	TAPE and then HRZ	L$ = A$(11)	START SURVEY STATION
B	COMP and then BRG	A$(12) to A$(26)	SURVEY STATION LABELS
C	CLINO and then DZ	A(27)	END STATION EASTING
D	LOOP INDEX	A(28)	START STATION EASTING
E	COUNTER	A(29) to A(43)	SURVEY STATION EASTINGS
F$	FLAG FOR INPUT PROMPTS	A(44)	END STATION NORTHING
G	SUMMATION OF TAPE READINGS	A(45)	START STATION NORTHING
H	AXIS OFFSET	A(46) to A(60)	SURVEY STATION NORTHINGS
I	CHANGE IN EASTING	A(61)	END STATION HEIGHT
J	CHANGE IN NORTHING	A(62)	START STATION HEIGHT
K$ = A$(10)	END SURVEY STATION	A(63)	SURVEY STATION HEIGHTS

Figure 4. RDFSURVEY Program Variable Assignments.

LETTER

DYKES AND CAVE DEVELOPMENT AT COLONG CAVES, NEW SOUTH WALES

The main cave system at Colong Caves, with an aggregated passage length of about 6 km is developed over a strike length of about 1 km within a large body of massiv- Silurian limestone bounded by Caves Creek on the north and by Lannigans Creek on the south and west.

The limestone has a well developed north-south vertical cleavage which has controlled cave development.

The cave is divisible morphologically into two distinct sections (Fig. 1).

The northern section extending from the entrances to the Amber Cave consists of a series of roughly parallel strike controlled passages at different levels and includes active stream passages. In three places, near the entrances, in the Kings Cross-Maze region, and at the end of the northern section in the Amber Cave-Landslide area the cave becomes more complex and exhibits distinct east-west development.

The southern section, from the Amber Cave to the end of the cave in the Far Chamber of Woofs Cavern has more complex development, lacking the simple elongate passageways found in the northern section.

Comparison of cave maps with the surface topography indicated that the boundary between these two sections of the cave coincides with a prominent east-west rift in the limestone (Fig. 2). Investigation of the rift showed it to be the surface expression of a 1.5 m wide highly altered basic dyke. Other smaller dykes are also exposed on the top of the outcrop.

Dykes have not been previously reported in Colong Caves and the coincidence of the large dyke with the change in cave morphology at the Amber Cave sugggested that dykes might be an important influence on the development of the cave.

A preliminary investigation, on which this note is based, has revealed that dykes have exercised significant control over the development of Colong Caves. Three dykes, the largest being betweeen 0.5 m and 1 m thick, were identified in the Amber Cave area (Fig. 3).

The first and largest dyke is exposed in the north western wall and roof of the Amber Cave and the wall of the Sharks Mouth Cave. It strikes towards, and is exposed in, small side passages near the Landslide Cavern. This large area of collapse is probably related to the intersection of the dyke with the western boundary of the limestone.

The second dyke has controlled the development of The Cleft.

The relationship between dykes and cave development is well illustrated by the third and smallest dyke exposed in the Low Tunnel. Here a dyke 270 mm thick (Fig. 4) has, at first, blocked the passage of water through the limestone, resulting in the development of a passage along the upstream face of the dyke. Eventually the dyke was breached and cave development continued along the strike of the prominent cleavage.

Other dykes are found at the end of the Terraces Cave, in the Rockfall Chamber near Woofs Cavern and in a river passage below Kings Cross. The dyke near Kings Cross is only 100 mm thick and rather than inhibiting cave development it has provided a plane of weakness along which the limestone could be dissolved. Only a tiny fragment of this dyke remains (Fig. 5).

A detailed examination of the cave, locating and mapping all the dykes, will greatly assist understanding of its morphology, hydrology and development.

The author would like to thank M. Scott, V.J. Morand, and A. Skea for their assistance in the field, the Director, National Parks and Wildlife Service for permission to undertake research in Kanangra-Boyd National Park, and M.G. Hooppell for use of unpublished cave maps.

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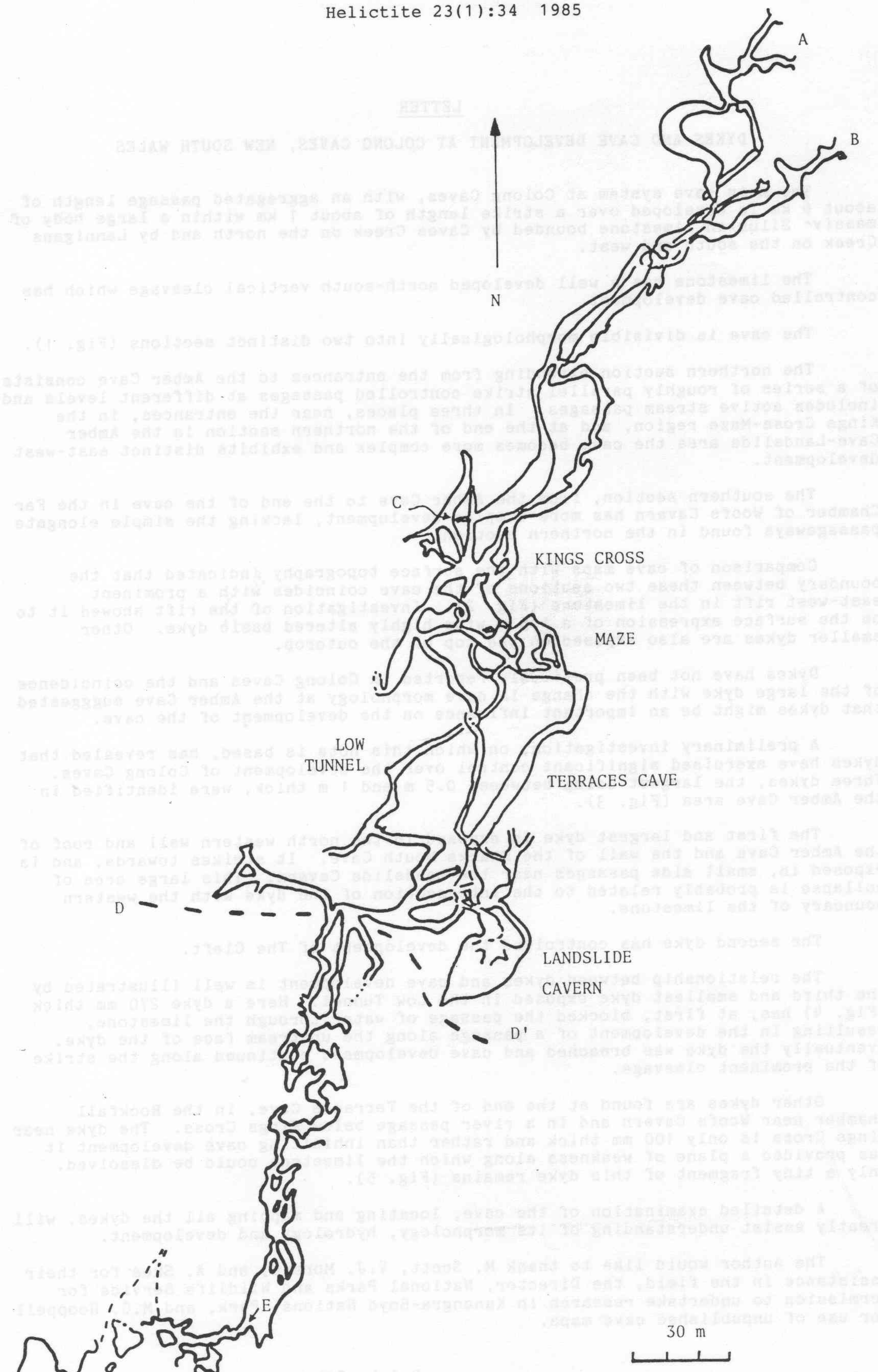

Figure 1. Simplified map of the main Colong Cave system. A, Lower Entrances; B, Upper Entrance; C, Location of dyke near Kings Cross (Figure 5); D-D' Boundary between northern and southern sections of the cave; E, Location of dyke near Woofs Cavern. Base map courtesy M.G. Hoopell.

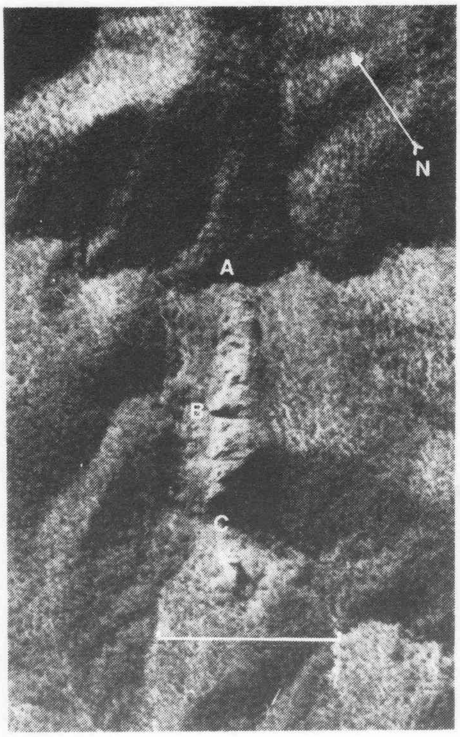

Figure 2. Enlarged air photo of the Colong Limestone outcrop showing prominent east-west rift. A, Caves Creek; B, Rift; C, Lannigans Creek. Cave system runs approximately between "A" and "C". Scale bar = 500m.

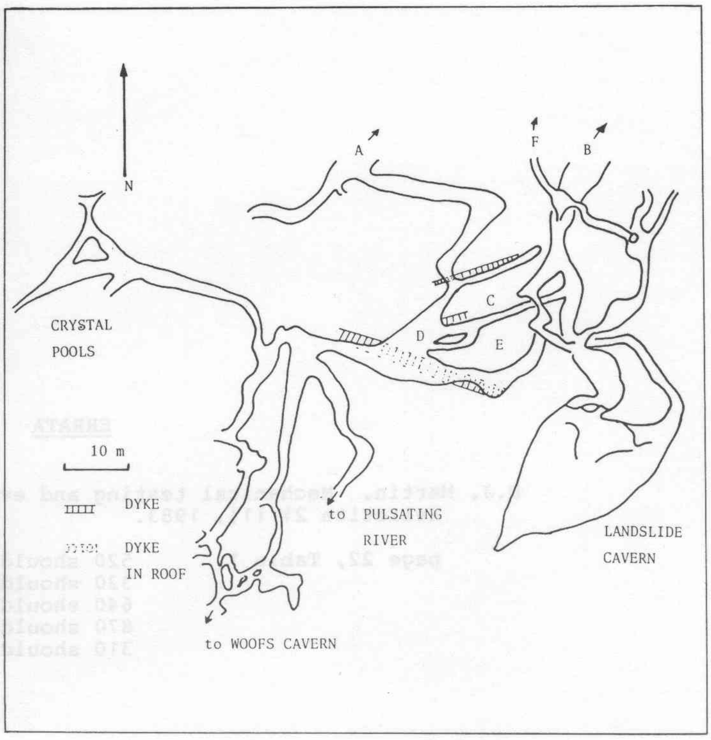

Figure 3. Sketch map showing dykes in the Amber Cave section of Colong Caves. A, Low Tunnel to Kings Cross; B, Terraces Cave to Kings Cross; C, The Cleft; D, Amber Cave; E, Sharks Mouth Cave.

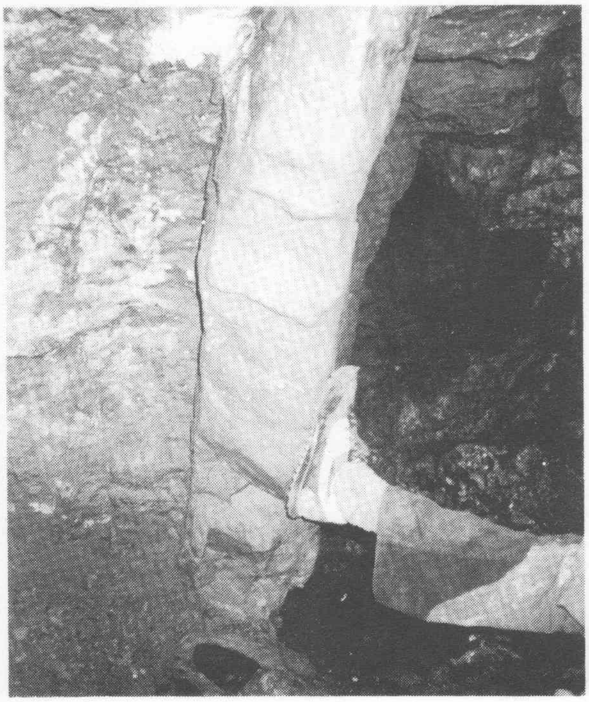

Figure 4. Outcrop of dyke in the Low Tunnel (most northerly dyke in Figure 3). Note how the side passage has developed along the upstream face of the dyke.

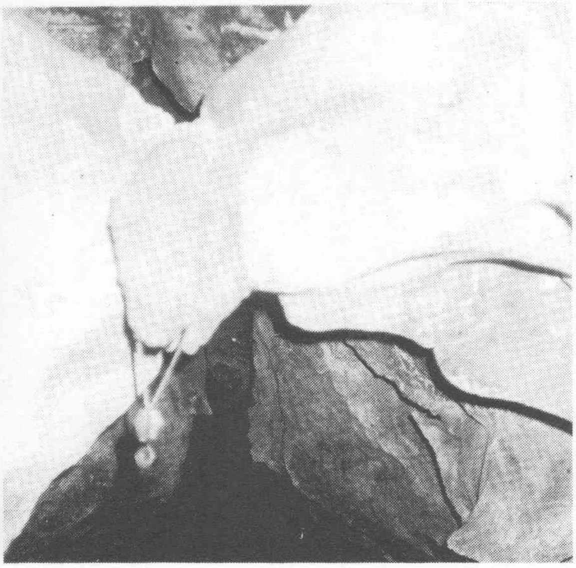

Figure 5. Remnant of thin dyke below Kings Cross ("C" in Figure 1). Note cave development along dyke. Hand lens 70mm.

ERRATA

D.J. Martin. Mechanical testing and evaluation of screw-links. Helictite 21 (1), 1983.

page 22, Table 1,

520 should read 260	
320 should read 160	
640 should read 320	
870 should read 435	
310 should read 155	

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WIGLEY, T.M.L. and WOOD, I.D., 1967 Meteorology of the Nullarbor Plain caves. In: J.R. DUNKLEY and T.M.L. WIGLEY (eds), Caves of the Nullarbor. A Review of Speleological Investigations in the Nullarbor Plain. Southern Australia: 32-34. Speleological Research Council, Sydney.

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