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UBSS EXPEDITION TO NORTHERN THAILAND 2003: *Breaking the Bad Air Barrier*

by

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ABSTRACT

The 2003 UBSS expedition to Northern Thailand tested the practical use of closed-circuit oxygen rebreathers as tools to explore, survey and analyse cave atmospheres in bad air passages of Tham Tab Tao, Chiang Mai Province. 80 m of new cave passage was explored and surveyed and 22 paired readings of CO_2/O_2 were obtained; the first such paired measurements made in Thailand caves. The ratio of CO_2 enrichment:O_2 depletion (1:1.2), combined with the maximum calculated CO_2 concentrations (5.1%) indicate that the microbial breakdown of organic matter is the source of bad air within the cave. The source of organic matter is largely from bat guano. It was found that although rebreathers were ideal for collecting uncontaminated cave atmosphere samples, on future expeditions lightweight carbon composite air cylinders with SCUBA regulators and nose-clamps may provide the safest and most practical way to extend future exploration.

BACKGROUND

In December 2000 - January 2001, a previous UBSS expedition (Farrant *et al*., 2001) explored and surveyed 2.5 km of caves in the Chiang Mai Province of Northern Thailand. Exploration of several caves in the area was stopped by the presence of bad, and in some cases unbreathable, air. Northern Thailand is renowned for having one of the largest concentrations of these 'bad air' caves in the world, thought to be due to the presence of high concentrations of CO_2 combined with low O_2 (Deharveng *et al*., 1986, 1988; Barrett, *et al.,* 2001). This paper describes a follow up expedition to the area in December 2003 - January 2004 to test self-contained breathing apparatus (oxygen rebreathers and SCUBA air cylinders) in order to explore these regions for the first time, and measure cave atmosphere concentrations (CO_2, O_2, NH_4, CH_4, H_2S) to determine the extent and source of the bad air.

LOCATION AND SITE DESCRIPTION

The main focus of the 2003 expedition was a temple cave called Tham Tab Tao (47 Q 0512718, UTM 2173791) (first described in White, 1988). The entrance of Tham Tab Tao is a fossil resurgence for the karst plateau to the west (termed the Central Plateau in Farrant *et al.* 2001), approximately 40 km north of the town of Chiang Mai (Figure 1). The current springs are over 1 km away in the valley below, at Tham Ngam (Figure 1). The karst is Permian limestone of the Rat Buri Group, in which cave development can be extensive (Hutchinson, 1989; Kiernan, 1988). The Central Plateau is located on the periphery of the Fang Basin, a known hydrocarbon reservoir with a high geothermal gradient and active thermal springs (Hutchinson, 1989; Ramingwong *et al*., 1978).

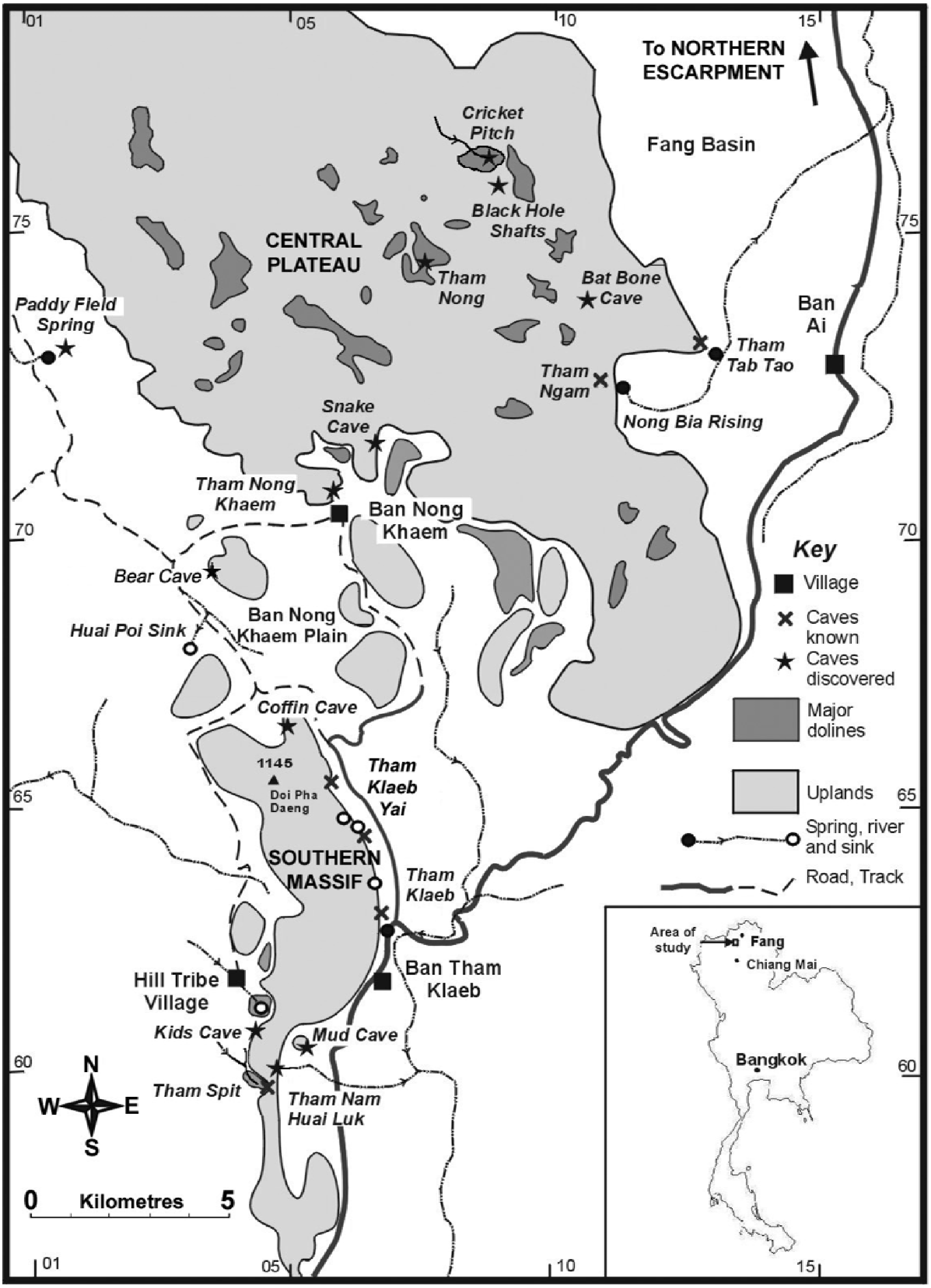

Figure 1. *Location of Tham Tab Tao (Chiang Dao Province, Northern Thailand) relative to known karst features Tham Tab Tao is an ancient resurgence for the large limestone plateau to the west.*

Reprinted from Farrant, *et al.*, 2001.

Tham Tab Tao can be divided into 3 main sections (Figure 2):

i) the working temple cave, closest to the entrance, lit by electrical lighting and containing many gold leaf covered statues of Buddha;
ii) the Monks' Extension, a series of tight passages and rifts connecting the temple cave to the Hell cave (so named by locals due to the presence of bad air);
iii) the Hell cave, a W-E trending passage (with other smaller passages leading off) with progressively worse air towards the known limit of exploration (White, 1988).

METHODS

Biomarine Biopak 60 closed-circuit oxygen rebreathers equipped with full-face masks were used to explore, survey and measure cave atmosphere concentrations from bad air passages in Tham Tab Tao. BioPak 60 rebreathers have an approximate 60 minute duration time, and contain a sodium phosphate coolant which melts at 34°C and ensures the recycled air remains below that of body temperature (37°C). Communication between cavers was made possible through a voice-projection diaphragm located in the AGA full-face masks. In addition, a nose-clamp and at least one 3 or 4 L compressed air cylinder with SCUBA regulator was carried at all times as a back-up, and additional air bottles were placed along the exploration route. Certain cave diving techniques were employed to ensure that the trips were conducted as safely as possible. A reel equipped with nylon (24 gauge) line was used to mark the route from the "good air" into the bad air. Line arrows were employed to mark the direction of exit. Any "jumps" from this "main line" were made with separate reels and line. The turnaround time was defined using the "thirds rule" of cave diving. The turnaround point was announced by the caver who had used up a third of their gas supply or if a third of the calculated equipment duration time was reached. This leaves one third of gas to exit the cave and another third to deal with emergencies, should they occur. During all trips, the theoretical duration of the equipment served as the limiting factor.

Surveying in bad air was conducted by taking the azimuth of the line laid and by estimating the distances. A compass reading of the overall passage direction (which, for the most part, was the same as the line direction) was also taken at frequent intervals.

Oxygen concentrations were measured (to the nearest 0.1%) using a DIVEX Mini-O2 analyser, while carbon dioxide levels were measured (to the nearest 0.1%) using an infrared Crowcon Safegard II personal CO_2 monitor, with a range of 0.0 to 5.0 %. Both readings were taken simultaneously from the same height to ensure paired readings of both gases. Additional measurements of CO_2 were obtained using a Drager handpump and tubes. In addition, concentrations of hydrogen sulfide (0.5 to 15 ppm), ammonia (2-30 ppm) and natural gas (qualitative) were also measured using Dräger pump and tubes. Temperature was measured using a digital thermometer (precision ±0.1°C).

One sample for isotope analysis was taken (in ~5% CO_2 environment) using a sterile syringe fitted with a sterile 3-way stopcock. The syringe was flushed three times before taking the gas sample and the stopcock was put into the closed position for its transport back to good air. Upon arrival at Base Camp II, the 3-way stopcock was fitted with a sterile needle and 10 ml of the gas sample was stored in a serum-crimp vial containing pH 1 10% KCl solution.

RESULTS

Use of rebreathers/compressed air for exploration of bad air caves

The use of BioPak 60 rebreathers proved ideal for taking uncontaminated cave air samples. However, their use for exploration purposes proved less satisfactory. Their limited duration of 60 minutes meant an exploration turn around time of just 20 minutes, while the additional weight of back-up air cylinders made scrambling and climbing arduous and difficult. In addition, the difficulty of carrying the rebreathers through the tight sections of the Monks extension necessitated the storage and cleaning of the rebreathers within the Hell cave, in significant CO_2 concentrations (> 1%). Despite the use of anti-fogging agent (possibly due to its use in the high humidity conditions of the cave), problems were encountered on every trip with mask fogging, severely hampering exploration and surveying.

The use of two 3 or 4L compressed air bottles and SCUBA regulator, combined with nose clamp, gave far greater mobility and flexibility of movement, and far better visibility, but with an even shorter turnaround time (c. 15 minutes).

Surveying

80 m of new survey was added to the White (1988) survey (Figure 2). Passage was seen to continue onwards in an eastern direction, but could not be explored due to the short time constraint of the rebreather combined with the steep, unstable and slippery nature of the passage floor in this region.

Cave atmosphere analyses

22 paired readings of CO_2/O_2 were taken throughout the cave, and both vertical and horizontal profiles were made. The results demonstrate that there is a good relationship (R^2=0.95, n=22) between oxygen depletion and enrichment in carbon dioxide relative to air concentrations (Figure 3).

In general, CO_2 concentrations in the Hell Cave became higher (and oxygen levels lower) from (S)E to (N)W, rising from 0.0±0.1 at the entrance to the Monks' Extension to greater than 5.0 at the limit of exploration, and coinciding with increasing quantities of bat guano. A series of CO_2 measurements taken at various heights above above bat guano in a relatively good air passage (0.85% CO_2 at 1.6 m - breathing height) showed a decrease in CO_2 and increase in O_2 with increased height (Table 1).

Height above bat guano (m)	CO_2 (%)	O_2 (%)
0	2	19.3
0.2	1.17	19.3
1	0.91	19.6
1.6	0.85	19.6

Table 1. *Change in carbon dioxide and oxygen concentrations with vertical distance from bat guano, Hell Cave, Tham Tab Tao.*

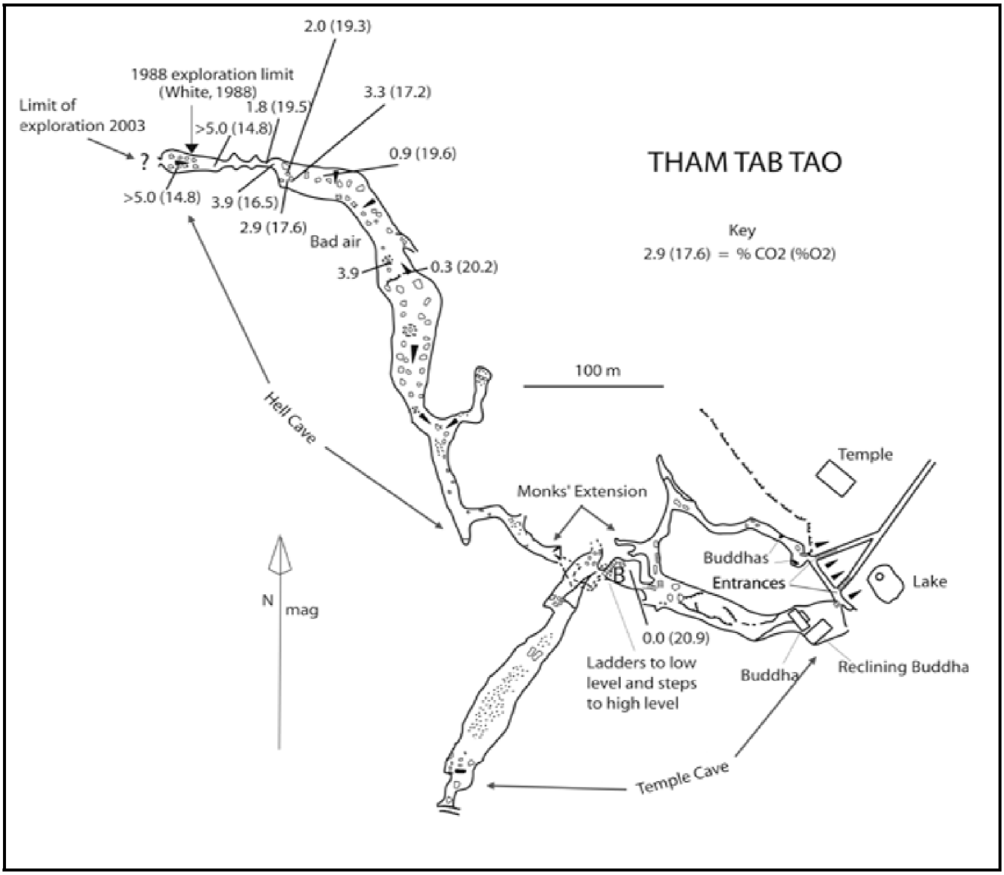

Figure 2. *Survey of Tham Tab Tao Survey drawn using hand compass and estimating distances. Dual numbers represent carbon dioxide and oxygen concentrations (%) measured in situ. Bad air (high CO_2; low O_2) is present in the NW 'Hell Cave' section of Tham Tab Tao.*
Adapted from White, 1988, courtesy of BCRA.

In addition, there was a logarithmic relationship between CO_2 and temperature ($r^2 = 0.67$; Figure 4).

Concentrations of hydrogen sulphide, ammonia and natural gas were all below their respective detection limits. The sample for ^{13}C analysis awaits analysis.

DISCUSSION

The source of the bad air

Probable reasons for the build-up of bad air in caves are the combination of poor air circulation combined with:

i) plant root/microbial respiration, which consumes O_2 and produces CO_2 in a roughly equal % volume ratio (Halbert, 1982);
ii) outgassing of CO_2 from cave waters (often associated with the precipitation of tufaceous deposits) (James, 1977; James et al., 1975; Smith 1996);
iii) geological phenomena (volcanic activity, deep-seated geothermal deposits) where other toxic gases such as H_2S may be present.

The combined O_2 and CO_2 analysis of cave atmospheres gives a good indication as to the source of the bad air, as defined by the Cave Air Index (C.A.I.) (Halbert, 1982). The C.A.I. is defined as:

$$\text{C.A.I.} = CO_2/(21-O_2)$$

Where CO_2 and O_2 are the percent volume values on a dry basis. A simple interpretation of C.A.I. values is shown in Table 2.

Cave Air Index (C.A.I.)	Interpretation
> 1	Input of additional CO_2 (e.g. cave water degassing)
0.7 - 1	Respiration $CH_2O + O_2 = CO_2 + H_2O$
<0.7	Geological sources (e.g. consumption of oxygen by pyrite oxidation, or migration of hydrocarbons).

Table 2. *Interpretation of the Cave Air Index (C.A.I).*

Although both CO_2 and O_2 have been measured separately in cave atmospheres in Northern Thailand (DeHarveng *et al.*, 1986; 1988; S.M.C.C., 2001) this is the first time combined CO_2/O_2 readings have been measured allowing the C.A.I. index to be determined. The results from the paired CO_2/O_2 readings demonstrate that Tham Tab Tao has a cave air index of 0.80 ± 0.10, indicating respiration (probably largely microbial) as the source of CO_2 and the cause of O_2 depletion. The only obvious source of organic matter within the cave was bat guano and a vertical profile of readings from an accumulation of guano upwards (Table 1) supports the hypothesis that the decomposition of bat faeces, resulting in increased CO_2 (and decrease in O_2), is the cause of the bad air in Tam Tab Tao. Although the CO_2 readings at the exploration limit were greater than the maximum range of the CO_2 meter (> 5%), the oxygen depletion of 6.1% (20.9% - 14.8%) gives a calculated CO_2 concentration of 5.1% (using the ratio of oxygen depletion:carbon dioxide enrichment derived from Figure 3). This value is close to the maximum expected from the breakdown of organic matter by respiration; CO_2 cannot accumulate until all O_2 is replaced as aerobic bacteria are killed at CO_2 concentrations around 6% (Drake, 1980). The lack of detectable H_2S and natural gas (CH_4) suggest that anaerobic respiratory processes (bacterial sulphate reduction and methanogenesis) are not active within the cave sediments, presumably due to the continued presence of oxygen. Anaerobic conditions could only occur in water-logged cave sediments, where the gaseous CO_2 would largely dissolve as carbonic acid, allowing the continued depletion of oxygen by aerobic bacteria.

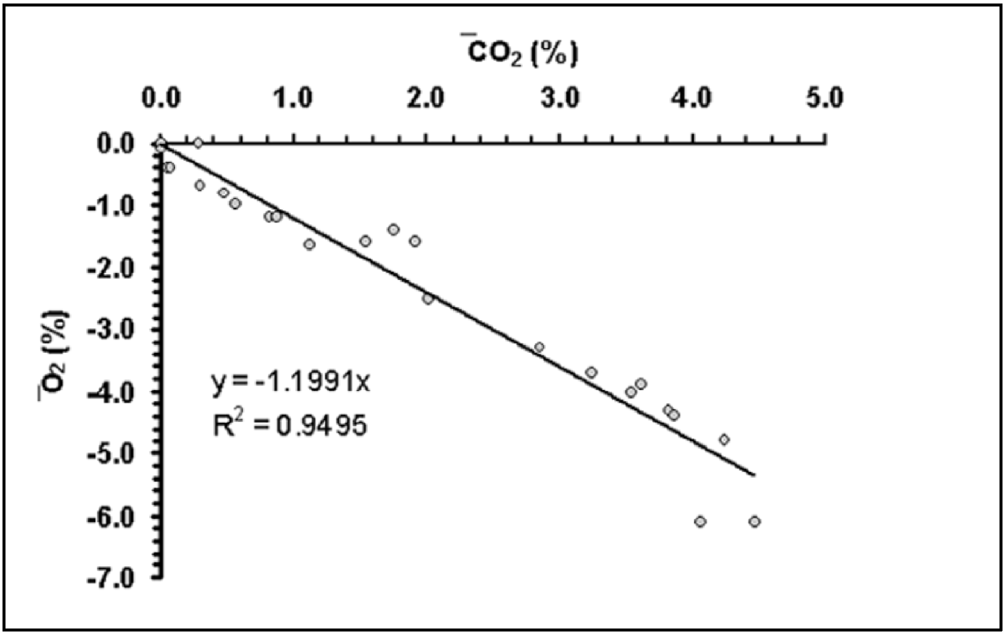

Figure 3. *The change in carbon dioxide (ΔCO_2) and oxygen (ΔO_2) concentrations in the cave atmosphere of Tham Tab Tao from that measured in air.*

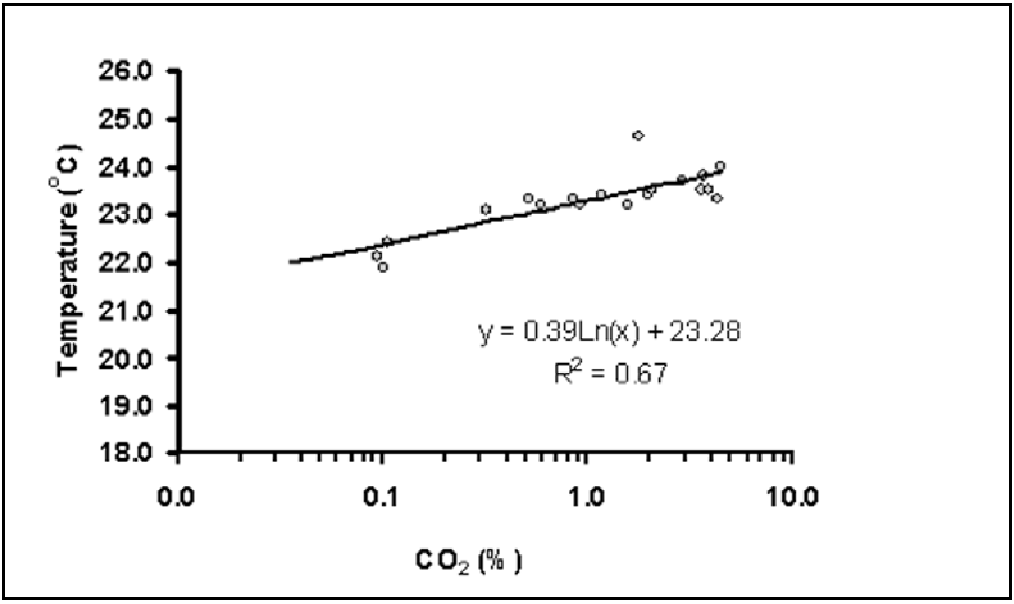

Figure 4. *Relationship between the temperature and carbon dioxide content of the cave atmosphere in Tham Tab Tao.*

The positive relationship between the CO_2 content of the cave atmosphere and temperature is likely due to the relatively low thermal conductivity of carbon dioxide compared to normal air, and supports the qualitative feeling that high CO_2 caves are hotter than low CO_2 caves.

FUTURE WORK

Although the rebreathers are ideal for taking uncontaminated scientific samples, their duration (60 minutes of gas/scrubber time) severely limited the amount of exploration possible during this expedition. For future exploration, double large (60 minute duration) light weight carbon composite cylinders with regulators and nose-clamps would allow significant exploration advances in Tham Tab Tao and other bad air caves in the area, with an estimated turnaround time of 40 minutes. For longer exploration trips, staged additional air bottles could be used. The use of compressed air would have the added advantage of breathing cooled air rather than the warm recycled air of a rebreather.

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REFERENCES

BARRETT, D., ELLIS, M. and KING, S. 2001. Thailand Expedition 2001, Umphang District, Tak Province. *Shepton Mallet Caving Club Occasional Publication*, **9.**

DEHARVENG, L. *et al*., 1986. Thai-Maros 85. *Rapport Speleologique et Scientifique. Assoc. Pyreneenne de Speleologie*. Toulouse. 215p.

DEHARVENG, L. *et al*., 1988. Expedition Thai ’87 – Thai’88. *Rapport Speleologique et Scientifique et Scientifique. Assoc. Pyreneenne de Speleologie,* Toulouse. 128p.

DRAKE, J.J. 1980. The effect of soil activity on the chemistry of carbonate groundwater. *Water Resources Res.* **16**. 2. 381-6.

FARRANT, A., FLOWER, S. and LEE, S. 2001. UBSS expedition to Northern Thailand. Proceedings of the University of Bristol Spelaeological Society. **22.** 2. 125 - 156.

HALBERT, E.J.M. 1982. Evaluation of carbon dioxide and oxygen data in cave atmospheres using the Gibbs triangle and the cave air index. *Helictite* **20.** 2. 60-68.

HUTCHINSON, C.S. 1989. Geological evolution of South-East Asia. *Oxford Monographs on Geology and Geophysics.* **36**. Oxford University Press. 368 p.

JAMES, J.M. 1977. Carbon dioxide in the cave atmosphere. *Cave Science the Transactions of the British Cave Research Association.* **4.** 4. 417-429.

JAMES, J.M., PAVEY, A.J. and ROGERS, A.F. 1975. Foul air and the resulting hazards to cavers. *Cave Science the Transactions of the British Cave Research Association.* **2**. 2. 79-99.

KIERNAN, K. 1988. Mangroves, mountains and munching molluscs: the evolution of a tropical coastline. *Helictite*. **26**. 1. 16-31.

RAMINGWONG, T., RATANASATHIEN, B. and SERTSRIVANIT, S., 1978 Geothermal resources of Northern Thailand: Hydrogeological considerations. *In*: Proceedings of the Third Regional Conference on Geology and Mineral Resources of Southeast Asia, Bangkok. (Ed. P. Nutalaya)

SMITH. G.K. 1996. Naked flame test for, and human tolerance to, foul air caves. *Helictite*. **34**.2. 39-47.

WHITE, T. 1988. Zen and the art of umbrella pointing. *Caves and Caving.* **40**. 14-17.

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