Cave and Karst Science

The Transactions of the British Cave Research Association

BCRA

Volume 27 Number 2 August 2000

Insoluble limestone residues and soils, North Wales
Travertine flora: Juizhaigou and Munigou, China
Protected karst landscapes in Southeast Asia
Vein cavities, Castleton, UK
Bivalves in English caves
Subaqueous stalagmites

Cave and Karst Science

Authors are encouraged to submit articles for publication in the *Transactions of the British Cave Research Association* under four broad headings:

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Scientific papers, normally up to 6,000 words, on any aspect of karst/speleological science, including archaeology, biology, chemistry, conservation, geology, geomorphology, history, hydrology and physics. Manuscript papers should be of a high standard, and will be subject to peer review by two referees.

2. Reports
Shorter contributions, normally 500-3,000 words, on aspects of karst/speleological science, as listed above, or more descriptive material, such as caving expedition reports and technical articles. Manuscripts will be reviewed by the Editorial Board unless the subject matter is outside their fields of expertise, in which case appropriate expert assessment will be sought.

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Personal statements, normally up to 1,000 words, on topical issues; discussion of published papers, and book reviews. Where appropriate, statements should put forward an argument and make a case, backed-up by examples used as evidence.

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Manuscripts may be sent to either of the Editors: Dr D J Lowe, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, and Professor J Gunn, Limestone Research Group, Department of Geographical and Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK. Intending authors are welcome to contact the Editors, who will be pleased to advise on manuscript preparation. Enquiries by E-mail are welcomed, to: djlo@bgs.ac.uk or j.gunn@hud.ac.uk.

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Authors will be provided with 20 reprints of their own contribution, free of charge, for their own use.

If any problems are perceived regarding the nature, content or format of the material, please consult either of the Editors before submitting the manuscript.

Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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Contents

Cover photo:
Deer Cave (Gua Payau), Mulu National Park, Sarawak
The spectacular southern (downstream) entrance to Deer Cave (Gua Payau). The entrance is some 175m wide and 120m high and leads to one of the largest cave passages in the world, nowhere less than 90m high and wide. The passage goes right through the hill to an enclosed valley, the 'Garden of Eden'. This is one of several 'giant caves' in the Mulu National Park, Sarawak (see article by Day and Urich).
Photo by David Gillieson.

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Prof. J Gunn — Limestone Research Group, Department of Geographical & Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK.

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EDITORIAL

Dave Lowe and John Gunn

Yet again, despite the best efforts of all those involved in its production, publication of this issue of *Cave and Karst Science* has lagged significantly behind its cover date. Whereas we do not intend to give any specific explanations of, or excuses for, this delay, we do wish to emphasise that it is not a reflection of any shortage of material being submitted for consideration and eventual publication. In fact the situation with regard to "material to hand" is relatively healthy. However, this rosy statement must be qualified in two ways. First of all, a greater and greater proportion of the material received covers "new" aspects of cave and karst related topics, effectively pushing back the limits of the subject areas potentially suitable for inclusion. This in itself presents no problem as, to date, we have received no adverse criticism of our decisions to broaden the scope of the publication. Yet, there are additional problems, in terms of identifying suitable experts to act as referees. Then we have to make contact, introduce ourselves and the journal, and attempt to persuade the incipient referees to give up their valuable time to carry out the work required. Even when co-operation is promised, and even in these days of almost instantaneous e-communication, there are delays. Tasks are given lesser or greater priority, individuals (authors, editors or referees) are absent for weeks or months at a time for a variety of reasons, and text and illustrations, sent in good faith, become garbled in the ether or are unrecognised by inappropriate or outdated software.

The second area of concern relates to our own standards, and the ever increasing difficulties of abiding by them, when faced with the pressures mentioned above and the need always to strive to regain the idealised publications schedule. On taking over *Cave and Karst Science* we made various decisions relating to the format of future issues. Various aspects of these decisions have evolved over the years as we have tried to impose and stabilise a distinctive *"house style"*. From time to time we allow significant departure from the norm, to allow sensible publication of material that would not fit easily into our pre-conceived template, yet we strive wherever possible to hold back the potential anarchy and *"ad hocery"* that could be inevitable from such a broad author-base. To this end, right from the start, we have included *Notes for Contributors* on the inside front cover of the journal. However, it would appear that some of our intending contributors have either never bothered to read these, have forgotten the guidelines provided, or have simply decided to ignore them. Whereas on the one hand the electronic revolution has led to immense improvements in the quality of the text submitted, there is a downside, most obvious in lists of references. We receive not only immense lists, obviously lifted intact from another source and not reformatted to our *"house style"*, but also lists that are cobbled together from several sources, mixing styles and introducing a plethora of abbreviations, most of which are as obscure to us as they will be to eventual readers.

Overall, the quality of most non-photographic illustrations has also improved in recent years, though even before this some contributors always managed to supply high quality input. This partly reflects a gradual adoption of more widely available digital drafting/lettering techniques, and in part simply reflects the better quality and wider accessibility of "low-end" technology, such as reducing/enlarging photocopiers. However, putting aside the occasional figure that breaks most of the *"house style"* rules, there is still a gap between what contributors actually produce, and what would be seen as more helpful to produce, if they took the time to examine a few back issues of the journal. Whereas we prefer not to be totally prescriptive in specifying preferred formats, it requires very little effort to realise that certain sizes and formats of illustrations are more suitable than others, and hence to "design" appropriate figures accordingly.

These days we are well able to cope with most types of photographic material, whether colour or monochrome, whether prints or transparencies, but again there are limits to how far the miracles of modern technology can stretch. We welcome suitable photographs that add understanding to the text, but it is clearly a requirement that these should not be of the *"black cat in a coal cellar"* variety. Equally, we would welcome a wider selection of "impressive" colour photographs to form a pool of material for front cover shots, which are not always available from within the content of any particular issue. However, to date, this pool has neither developed nor filled and, more often than not, if there is no suitable illustration among the featured papers, we have to fall back upon our own photographic collections.

Returning to the question of another delayed issue, we have to say that such delays do, on occasion, lead to advantages. On this occasion, the delay has allowed the initial planning of the 2001 BCRA Cave Science Symposium, which will take place on Saturday 3rd March 2001 at Oxford. The programme is not yet finalised, but even the interim list of presentations on a broad spectrum of subjects sounds fascinating. The event will take place at Oxford University - Pauling Human Sciences Centre, 58 Banbury Road. (First presentation 10am, finish 5pm). Further details can be obtained from the Lecture Secretary: Dr Andy Baker, Department of Geography, University of Newcastle, Newcastle, NE1 7RU. Tel: +44 (0)191 222 5344. Fax: +44 (0)191 222 5421 andy.baker@ncl.ac.uk. The event is hosted by Oxford University Cave Club, and the BCRA meetings secretary (meetings-secretary@bcra.org.uk) can provide local information on accommodation and travel. Admission charge (payable at the door) is £7 (BCRA members £6, undergraduate students £4). This charge includes tea/coffee in the morning and afternoon. The cost of lunch is not included, but there are suitable venues within walking distance in Oxford City Centre.

Another item of 'work in progress' that may be of interest to readers of *Cave and Karst Science* is an ***Encyclopedia of Caves and Karst Science***. The project has been commissioned by the publishers Fitzroy Dearborn, under the overall editorship of John Gunn. The Encyclopedia will be c.1,000 pages in length and will consist of c.450 A-Z entries. There will also be comprehensive indices and cross-referencing to allow readers to follow through particular themes. Most entries will amount to about 1,000 words, plus a 'further reading' list of 5-10 related articles. However, there will also be some 'Overview' entries (c.4,000 words), and some topics will require 'Expanded' entries (2,000-4,000 words, plus a more detailed reading list). It is envisaged that normal articles will contain up to 2 diagrams and other articles *pro rata*.

An editorial advisory board has been established, and it has been decided that the Encyclopedia will be devoted mainly to entries on carbonate (limestone / dolostone / marble) caves and karst. However, it is also likely to include entries on: evaporite caves and karst, lava caves, pseudokarst, sea caves, silicate caves and karst, tectonic caves, glacier caves and talus caves. There will be eight major themes that will form a basis for seeking the c.450 individual A-Z entries, although some entries will be included in more than one 'theme'. Seven of the themes concern different aspects of science and the arts as they relate to caves and karst, whereas the eighth theme is geographical. They are: Archaeology and rock art; Biology/bioscience; Conservation/ management; Documentation; Geosciences; History; Resources; and World cave and karst regions / famous caves. By the time that this issue of *Cave and Karst Science* is published further details of the Encyclopedia, and an invitation to offer to write particular articles, should be available on the project web site:

http://www.fitzroydearborn.com/london/cave_fs.htm

For the publishers this is a commercial exercise and they are obviously keen to sell as many copies as possible. However, the project will also, in a sense, represent a 'coming of age' for the scientific study of caves and karst landscapes. This will be the first time that the subject has been considered sufficiently important to warrant its own encyclopedia, rather than a series of entries in many other subject-specific encylopediae. Those whose interest in caves and karst is more sporting than "scientific" may not regard this as being of any great significance, yet the current omission reflects an overall lack of understanding of caving in its broader sense by the wider community. Another, more prosaic, indicator, that will perhaps be felt more keenly by those trying to obtain financial support for our sport, is the fact that a diary recently sent to one of us contained, amongst various other useful (?) information, the names and addresses of the National contact for virtually every imaginable British sporting body, except, of course, for a body representing caving. These pages are probably not the place for comment on the current debate surrounding the type of body that should represent British caving, but there is clearly a need for a single National body to improve our image and wider visibility. We would like to think that the knowledge contained in the new Encyclopedia, and in past, present and future issues of *Cave and Karst Science,* might also contribute to an increased understanding of, and respect for, cavers in the wider community.

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The relationship between Carboniferous Limestone insoluble residues and soils on limestone pavements in North Wales

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Abstract: Seven limestone pavements across North Wales were selected for geochemical analysis. The pavements represented a wide variety of locations and cover. At each location a limestone clint and soil from an adjacent gryke were sampled for analysis. Limestone insoluble residue and gryke infilling were analysed for seven elements, Cu, Zn, Pb, Mn, Ni, Sr and Mg, using atomic absorption spectroscopy. The absence of certain elements in the immediate limestone bedrock seems to confirm the claim by some authors that the majority of the insoluble residue in grykes is introduced from outside the area. Glaciation or periglacial aeolian transport/deposition is often cited as the mechanism. Whereas that cannot be ruled out in these areas, an additional source is postulated. Heavy metal smelting began in earnest in North Wales during the late 16th century, and airborne contaminants were released from this process. The levels of heavy metals in the soil samples suggest that this may have been an additional source.

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INTRODUCTION

It is still a matter of general debate as to whether all limestone pavements are developed as a result of glacial scouring (Goldie, 1994). North Wales lay inside the maximum limit of the main Devensian Glaciation and both Welsh and Irish Sea till can be found interdigitating in many localities in the borders and on the north coast of Wales and Anglesey (Campbell and Bowen, 1989; Thomas, 1989). Glacial till should be found within the grykes if the limestone pavements were exposed as a result of glaciation. Certain trace elements are shown to have a natural affinity with limestone (Burek, 1978, 1985; Burek and Cubitt, 1979, 1991) and in the past this has proved useful in analysing till and insoluble residue samples over the Carboniferous Limestones of Derbyshire. However, certain heavy metals are not usually associated with tills, unless they are close to or in the vicinity of actual mineral veins. Away from the veins the influence tails off (Ineson,1969; Burek and Cubitt, 1979) and heavy metals are more likely to be related to anthropogenic sources. If such trace elements are present in the gryke soils, the material must post-date glaciation. In order to test the influence of such outside factors on limestone pavement development and to introduce a possible relative dating technique, it was decided to analyse the insoluble residue of limestone clints and adjacent soils at seven sites across North Wales. Subsequently the results of this study have been linked to the smelting history of the region.

Geology and mineralization in North Wales

Areas of limestone pavement have developed on the Dinantian limestones, specifically the Middle White/Loggerheads Limestone of North Wales, as identified and explained by Appleton (1989) and Somerville (1979). The limestones themselves have been folded and faulted by two of the three major earth movement episodes that have affected North Wales. Those of the Hercynian/Variscan orogeny were the most important in determining the structure of the Carboniferous Limestone of North Wales, and these rocks now dip generally towards the northeast or north.

Three main fault directions in the area are associated with the Hercynian/Variscan movements (Warren *et al.*, 1984). They are north–south, northeast–southwest and east–west. These trends are reflected in joint alignments and subsequently in the orientations of grykes within the limestone pavements. Palaeogene and Neogene ("Tertiary") earth movements tended to reactivate previously formed structures.

There has also been widespread mineralization in North Wales. Whereas the main metalliferous ores were those of lead, zinc and copper, perhaps the best known is the gold of the Dolgellau goldbelt. Silver also occurs locally as a minor component. Mineralization has affected rocks of various ages, including Cambrian, Ordovician and Silurian, but is particularly common in the Carboniferous Limestone, where it tends to form veins or flats beneath impervious shale layers. Much of the mineralization is associated with Variscan/Hercynian to Permian reactivation (Warren *et al.*, 1984), when maximum pressure from the south – as Gondwanaland moved northwards to collide with Eurasia – influenced the direction of joint and fault formation. Mineralization clearly occurred after the structural features formed, but before deposition of the overlying Triassic rocks, as detrital galena has been found in rocks of the Sherwood Sandstone Group in the Shropshire-Cheshire Basin (George, 1961). Deposits of galena and other ore minerals are associated with all three main fault directions.

The most productive zone for the mining of lead, zinc and, to a lesser extent, copper ores from the Carboniferous Limestone forms a semicircle from Talargoch near Prestatyn in the northwest to Minera in the southeast (Williams, 1980), (Fig.1).

Mining in North Wales

Lead and copper mining have been active at least since the Bronze Age (Timberlake, 1994). The Romans established a smelting site at Pentre near Flint (Bennett, 1995) but after their departure in the 2nd Century only small-scale lead working took place until the early 17th Century. It was only after the Restoration in 1660 that large-scale mining recommenced. However, there had been a more general revival of metalliferous mining in Britain in the mid 16th Century.

Until the 16th Century lead ore was smelted in 'boles' or 'bailles', the forerunner of the furnace, in which heat was generated using wood and/or peat, and small amounts of ore were partially smelted (Raistrick and Jennings, 1989). This was a seasonal activity and evidence of these smelting areas is preserved in North Wales place names such as Pen-y-ball above Holywell and Plas yn Balls near Flint. As smelting techniques improved, William Ratcliffe, a haberdasher of London but

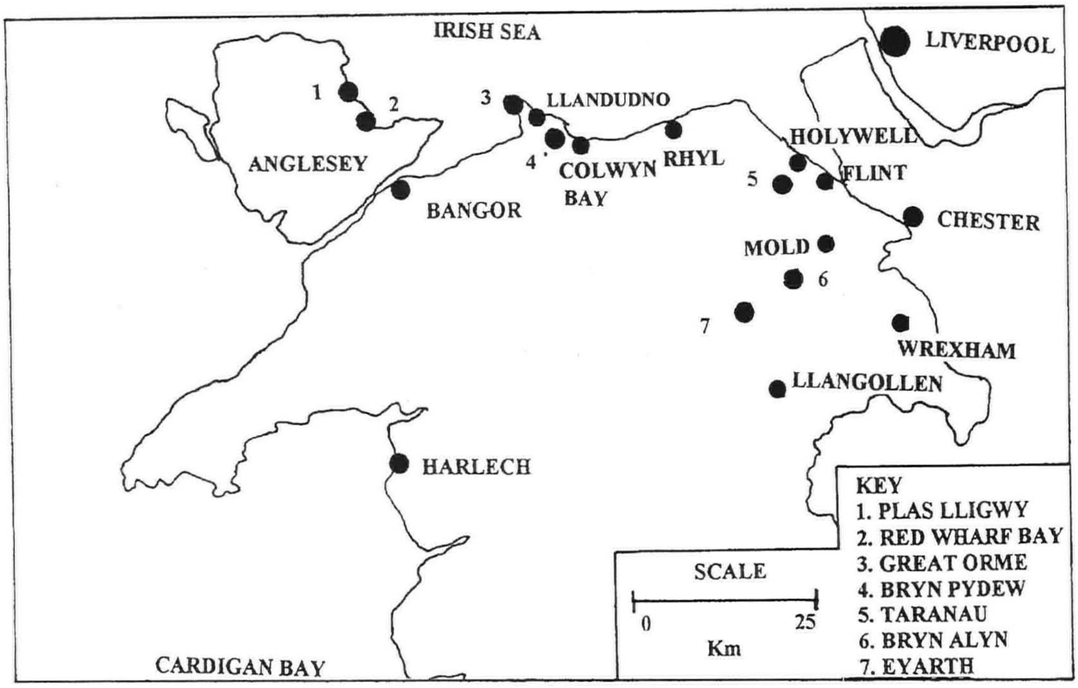

Figure 1. Mineralization and main metal mining areas in North Wales (adapted from Williams, 1980).

owning a mine in Holywell, asked leave of Elizabeth I to build a smelter after the lines of William Humfrey, using a water-driven bellows in a blast furnace. This was illustrated by Agricola in 1556 (Fig.2). The smelter, built on the Holywell stream in Holywell in 1590, was destroyed by local residents in 1591, after an outcry against new techniques by William Mostyn JP and his sons (Rhodes, 1971). This shows that it was an innovation in the area. Another lead-smelting mill was built in 1597 in Mold, by Ratcliffe and Chaloner of London. In 1601 this was sold to a certain Richard Grosvenor of Eaton Hall, an ancestor of the present Duke of Westminster. This mill worked up until 1690, and lead was brought from Llanferres, Llanarmon and Cilcain to be smelted in the Mold area. It is interesting that lead was sold to Chirk Castle and Erddig, for repairs, in 1671. The effect on lead prices of the war with Holland in 1672-1674 is also of interest; after an initial rise the prices went down. This resulted in cessation of smelting at Mold in October 1682, but smelting continued on Deeside. By 1703 all the former lead smelters in the Mold area had been converted to corn mills.

Smelting continued on the Dee between Flint and Whitford, and coal-fired reverberatory furnaces were developed and introduced into Flint in 1696, allowing continuous smelting to take place. The 19th Century saw numerous swings in the price of lead ore, and production fell into decline after 1850 in Flintshire and after 1871 in Denbighshire (Table 1).

Zinc ore from Minera was exhausted by 1914 and all metalliferous ore mining in Northeast Wales ceased in 1987 (Bennett, 1995). Thus, the major mining period in North Wales was from the late 17th Century to the early 19th Century (Williams, 1980). However, official statistics, first kept in the mid-1840s, show that between 1845 and 1913 over 381,138 tons of lead ore was extracted from Flintshire, representing 8.65% of the total UK production. Denbighshire produced 169,247 tons of lead ore, or just less than 4% of the UK total.

MATERIALS AND METHODS

Seven limestone pavement sites were selected from a variety of locations across North Wales (Fig.3). Limestone samples from the clints and soil samples from the gryke bottoms immediately adjacent to (below) the rock sample sites were taken. Insoluble residue was isolated by dissolution of rock samples in 20% HCl, following the methods of Ireland (1971) and Molnia (1974), and the percentage carbonate calculated. Soil Organic Matter was determined by the Walkley-Black method. Soil samples were ashed (450°C overnight) to destroy the organic matter. Residues of both sample types were then digested in a mixture of concentrated nitric acid, hydrochloric acid and 30% hydrogen peroxide. Lead, nickel, copper, zinc, strontium, manganese and magnesium trace metal composition were then determined by Flame Atomic Absorption spectroscopy (Corbelli, 1998).

GEOCHEMICAL RESULTS

Limestone pavements in North Wales are normally developed on pure and massive Dinantian (Lower Carboniferous) limestones. The rocks at all pavement sites contain more than 97% carbonate, except at Plas Lligwy (94%) (Table 2).

The amount of insoluble residue available to form soil is therefore likely to be only a very small percentage of the parent rock, (Harrison *et al.*, 1983, 1991; Corbelli, 1998).

Elemental levels in limestone insoluble residues

Magnesium
Magnesium is the eighth most abundant element in the Earth's crust. It can replace calcium in calcium carbonate to form the mineral dolomite (a calcium magnesium carbonate, $[Mg,Ca]CO_3$). It is a major

Year	UK Ore Tons	Flintshire	% UK Total	Denbighshire	% UK Total
1846	74,551	7460	10.01	26	0.03
1850	92,958	11,475	12.34	-	-
1864	94,463	5,419	5.74	9,694	10.26
1871	93,965	3579	3.81	5,460	5.81
1894	40,600	5,435	13.39	784	1.93
1904	26,374	6,609	25.06	223	0.85

Table 1. Flintshire and Denbighshire lead ore production based on official mineral statistics from the Mining Record Office of the Geological Survey and Museums, (Burt et al., 1992).

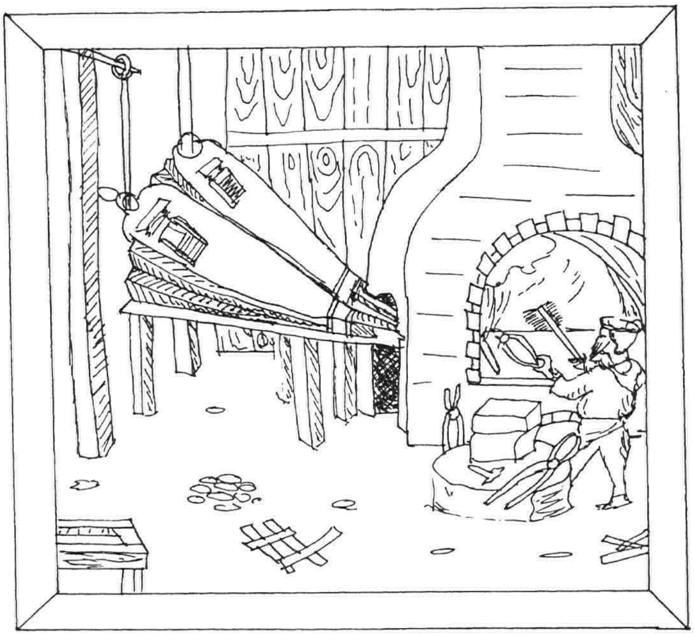

Figure 2. Agricola's bellow blast furnace, 1556.

Site Name	$CaCO_3$ %
Plas Lligwy	94
Red Wharf Bay	97.24
Great Orme	98.58
Bryn Pydew	98.62
Taranau	97.9
Bryn Alyn	97.65
Eyarth Rocks	98.04
Mean	97.39

Table 2. $CaCO_3$ content of North Wales limestone pavements.

constituent of many silicate minerals, and is found in association with clay minerals, due to their cation exchange properties.

This is by far the most abundant of the elements analysed in the insoluble residue samples from every site. Its concentration ranges from 1,840 ppm at Plas Lligwy to 3,535 ppm at Taranau (Table 3). Concentrations are similar in the soils. Its source in the insoluble residue is difficult to determine, but it is not likely to reflect earlier dolomitization, because the carbonate-removing process also dissolves dolomite.

Strontium and Nickel

Strontium has a high affinity with calcium and can reach up to 610 ppm in pure limestone, (Burek, 1978). This is consistent at all sites but at much lower levels, ranging from 27ppm at Eyarth to 60ppm at the Great Orme. Nickel is the twenty-third most abundant element in the Earth's crust, with an average level of 80ppm, though its concentration in limestone is lower, averaging 20ppm. Nickel has a siderphile affinity and can substitute for iron and magnesium (Day, 1963; Yaalon, 1974). It is concentrated in shales and in the organic fraction of marine shells. Nickel is present in all the samples, ranging from 11ppm at Bryn Alyn to 60ppm at the Great Orme, with a mean value of 35ppm, (Table 3). Nickel is commonly associated with iron in laterites, and this may account for a higher than normal concentration here, as the depositional cycles of these limestones included periods of subtropical terrestrial sedimentation. There is a strong similarity between limestone insoluble residue and soil concentrations of strontium and nickel, although both are low.

Manganese

Manganese is ubiquitous in the rocks of the Earth's crust, the twelfth most abundant element, and is usually associated with iron, which it resembles closely in chemistry. However, it is more mobile than iron and more soluble under acid conditions. The average concentration in the crust as a whole is 1,000ppm, in limestones slightly lower at 620ppm. Manganese atoms are similar in size to those of magnesium and calcium, enabling it to substitute within various silicate minerals. Manganese is the most common trace element in the soil (Table 3). It is also present in all the limestone samples but at remarkably lower concentrations than expected, given its range of minerals. Concentrations range from only 11ppm at Red Wharf Bay to 32ppm at the Great Orme (Table 3).

Copper

Copper is ranked 26th among the elements in crustal abundance, ranging from 24 to 55ppm, though its average concentration in limestones is 6ppm (range 0.6 to 13ppm). Copper mineralization (either as the primary sulphide mineral chalcopyrite or secondary minerals such as malachite and azurite) is common in the rocks of North Wales, including within the limestones of Anglesey, the Great

SITE NAME	Cu	Zn	Pb	Mn	Ni	Sr	Mg
INSOLUBLE RESIDUE - *LIMESTONE*							
Plas Lligwy	12	18	15	16	23	34	1840
Red Wharf	2	32	34	11	42	42	2540
Great Orme	8	27	<0.1	32	60	60	3500
Bryn Pydew	<0.1	19	<0.1	28	32	36	2485
Taranau	4	24	<0.1	19	11	28	3535
Bryn Alyn	12	18	<0.1	19	11	40	2975
Eyarth	13	38	39	18	44	27	2440
SOIL							
Plas Lligwy	42	103	66	1927	47	13	2120
Red Wharf	15	35	38	400	20	22	2210
Great Orme	95	252	39	5645	58	14	3850
Bryn Pydew	25	126	51	3645	34	20	2555
Taranau	29	258	236	1245	40	16	3045
Bryn Alyn	54	372	330	2345	31	16	2065
Eyarth	33	139	210	2124	31	30	2160
INSOLUBLE RESIDUE - *TILL*							
Red Wharf	25	59	33	516	42	22	2360

Table 3. Concentration of elements analysed at each site (in ppm).

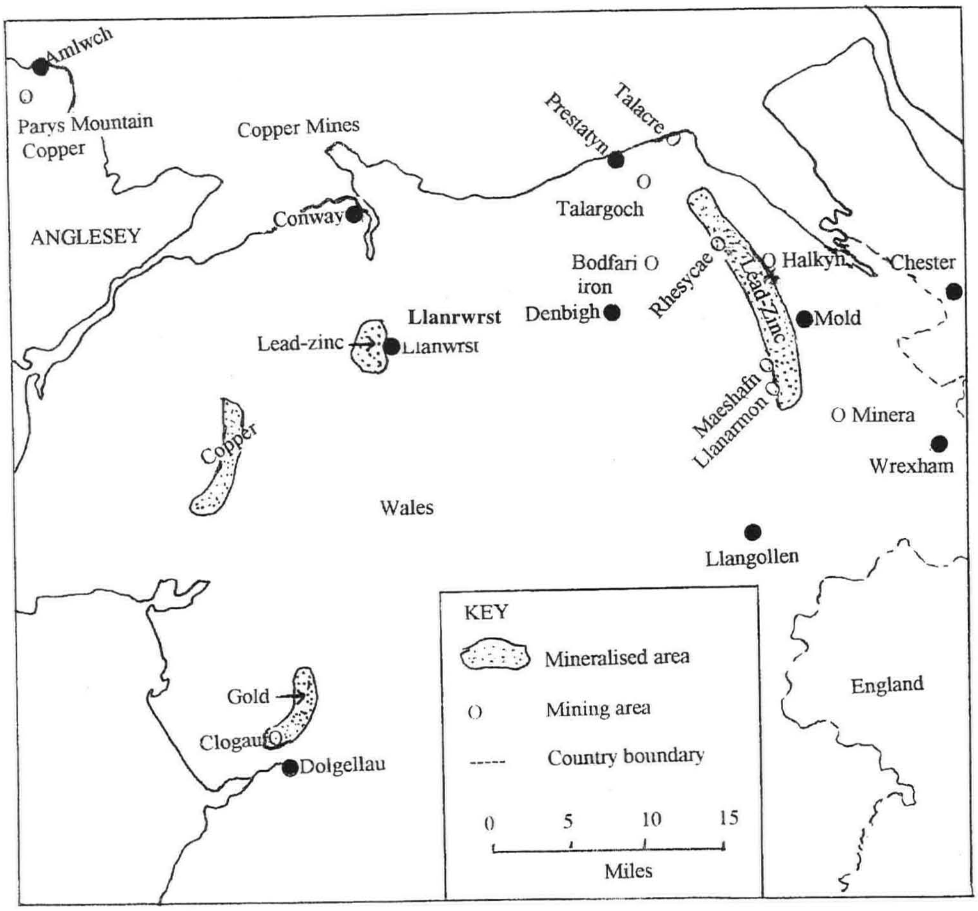

Figure 3. Location of limestone pavement sites in North Wales, sampled for geochemical analysis of insoluble residue and gryke soils.

Orme and Halkyn Mountain. Within the samples copper was present only in low concentrations, generally within the normal range, except at Bryn Pydew, where it was below detection limits. Mineralization does not appear to have affected the pavement sites.

Zinc
Zinc is the 24th most abundant element in the Earth's crust, with an average concentration of 70ppm, but only an average of 20ppm (range 1 to 180ppm) in limestones. Like copper, it can be concentrated in the insoluble residue of limestone in some mineralized areas. The primary ore mineral is sphalerite (zinc sulphide, ZnS). Zinc is also present in a number of silicate minerals. Zinc was present in all the samples, ranging from 18ppm at Plas Lligwy and Bryn Alyn to 32ppm at Red Wharf Bay, all well within the normal range for limestones.

Lead
Lead is the most abundant of the heavy metals in the Earth's crust, averaging 13 to 16ppm overall, but only 9ppm in limestones. There are many lead-containing minerals, but these are usually confined to mineralized areas. Lead can substitute in some silicate minerals, notably feldspar, but is really only raised above average values in rocks such as coal and black shales that contain organic material.

High lead concentrations are to be expected in many parts of North Wales because of mineralization in the Carboniferous limestone, as mentioned above. For example, there has been extensive mining activity at Halkyn and Minera in the past. It is therefore surprising that there were such negligible levels in the Northeast Wales limestone pavement sites samples. Lead was below detection limits in 4 of the samples, and was present only in low concentrations at Plas Lligwy (15ppm), Red Wharf Bay (34ppm) and Eyarth Rocks (39ppm). These concentrations are above the expected range of values, but none can be considered to represent mineralization.

It has been shown elsewhere (Burek, 1978, 1985; Burek and Cubitt, 1991; Ineson, 1969) that lead values in superficial deposits such as tills and in limestone fall away rapidly within a short distance of mineral veins.

Elemental levels in soils

Magnesium
Magnesium has very high concentrations in all the soil samples, ranging from 2,065ppm to 3,850ppm (Table 3), and appears to have a direct relationship with the magnesium levels in the insoluble residue of the clint limestone.

Copper
Copper is an essential nutrient for both plants and animals, and averages 20 to 30ppm in soils (range 15 to 95ppm). Copper is adsorbed strongly by organic matter in soils, and is one of the least mobile trace elements. Where it is being released from the rock by weathering, it is unlikely to be leached if the soil contains organic matter or has a high pH. Both of these conditions are present on limestone pavements.

Copper values vary from 15ppm at Red Wharf Bay to 95ppm at the Great Orme. Copper mining has taken place in the immediate vicinity of the Great Orme site. The data therefore display quite a range of values across the sites sampled, although all site values are within a normal range. Soil concentrations are greater than insoluble residue concentrations, reflecting the nature of the soil properties.

Zinc
Zinc averages 77ppm (range 5 to 816ppm) in UK soils (Archer, 1980), although values in most soils fall within the range 40 to 99ppm. Zinc is present in all the samples analysed, with a median value around 250ppm but with very low values at Red Wharf Bay (35ppm in the soil and 59ppm in the till) and high values at Bryn Alyn (372ppm), which also has the highest concentration for the insoluble residue samples.

Zinc levels in all the samples fall within the range quoted for soils, but most are significantly higher than average, with only the Red Wharf Bay samples being near normal. Zinc, like copper, is adsorbed strongly by organic matter in soil, and co-precipitates with calcium carbonate. It is also insoluble at high pH. These conditions all apply to the pavement soils sampled here, and would explain the retention of

	Cu	Zn	Pb	Mn	Ni	Sr	Mg
Plas Lligwy	3.5	5.7	4.4	120.4	2	0.4	1.2
Red Wharf Bay	7.5	1.1	1.1	36.4	0.5	0.5	0.9
Great Orme	11.9	9.3	39	176.4	1	0.2	1.1
Bryn Pydew	25	6.6	51	130.2	1.1	0.6	1
Taranau	7.3	10.8	236	65.5	3.6	0.6	0.9
Bryn Alyn	4.5	20.7	330	123.4	2.8	0.4	0.7
Eyarth Rocks	2.5	3.7	5.4	118	0.7	1.1	0.9
Mean	8.8	8.3	95.3	110	1.6	0.6	0.9

Table 4. Concentration Factors (soil/insoluble rock residue).

any zinc released by weathering. However, all the soil samples have higher concentrations than their respective insoluble residue samples. The extra zinc must be accounted for by some external source, the most likely being atmospheric deposition, presumably from an anthropogenic source. There has been considerable mining and smelting activity throughout North Wales, involving various metals, most, if not all, of which would have carried zinc as an impurity. For the Northeast Wales sites, lead and zinc mining has been carried out at various localities (Fig.1).

Lead

Lead is present in most soils at very low concentrations, reflecting the general range of values in rocks, namely 10-20ppm, although organic-rich soils tend to have much higher values, ranging up to three times the equivalent mineral soil. Reaves and Berrow (1984), reporting on values from 3,944 Scottish soils, quote a mean of 14ppm (range 2-85ppm) for mineral samples and 30ppm for organic soils. Davies (1983) suggested that concentrations in excess of 110ppm should not occur naturally.

Lead is present in the soil samples, ranging from 33ppm in the Red Wharf Bay till to 330ppm at Bryn Alyn. Parys Mountain contains both lead and zinc, in addition to copper, but the Anglesey pavements are upwind of the mine. At the Great Orme the secondary ore, malachite, was smelted on site, and the primary ore, chalcopyrite, was exported to Swansea for smelting. Only very small quantities of lead were sold from the Llandudno mines, (Aris, 1996). Hence there is no source of airborne lead in the vicinity to have provided anthropogenic contamination. In Northeast Wales, however, there has been extensive lead mining and smelting activity in close proximity to the pavement sites. Most of the lead in the soils is therefore probably related to this external source, as there is very little lead in the insoluble residue (see Table 3).

Manganese

Manganese concentration in soils varies considerable with soil type, as the element is very mobile in certain conditions, and can be accumulated by organic matter. Values quoted range from 500 to 4,000ppm (Berrow and Reaves, 1984). Manganese within this normal range is present in the soil samples, but the values do not reflect those found in the insoluble residues, which have very low manganese levels (mean 19ppm).

Nickel

Bradley *et al.*, (1978) report a mean nickel value of 29ppm for surface soil horizons in Wales and 33ppm for subsoils. In this study nickel varies from 20ppm at Red Wharf Bay to 58ppm at the Great Orme, with a mean concentration of about 37ppm. These values are within the expected range for soils, and broadly comparable with those in the insoluble residue samples.

Strontium

Strontium concentrations range between 13ppm at Plas Lligwy and 30ppm at Eyarth, and they are generally lower in the soils than in the insoluble residues.

DISCUSSION

Several studies have suggested that soil material in limestone areas is not exclusively a residue of limestone breakdown but includes aeolian dust, mixed with the residue through the full soil profile by cryoturbation under periglacial conditions (Piggott, 1962; Bullock, 1971; Burek, 1977, 1978, 1991, 1996; Carroll, 1986). In North Wales much of the limestone is covered by drift deposits, with brown earths and argillic brown earths. In areas on the limestone platform in Clwyd, for example between Minera and Llangollen, joints are filled with a stoneless yellowish-brown clay, buried by till and thought to be pre-glacial (Thompson, 1978). These could resemble earlier interglacial or periglacial deposits described by Burek (1991) in the Peak District. Soils analysed in the grykes were all shallow soils, with a high organic content. This suggests that the accumulation of organic matter from on-site vegetation development, and therefore the surrounding vegetation plays an important role in the development of soil within the grykes.

The influence that the individual elements have on soil development is varied (Table 4). Magnesium concentrations in the insoluble residue are equivalent to those in the soil, as are nickel and strontium. Manganese could be expected to be broadly similar in both soil and insoluble residue but the values found here in the residue are surprisingly low. Copper, zinc and lead all show very high concentration factors 8.8, 8.3, 95.3 respectively) indicating that there has been considerable addition.

One of the possible mechanisms of trace element introduction into the area could have been transport by ice travelling over material that became incorporated and was subsequently deposited within till. The analysis of the Red Irish Sea till (Campbell and Bowen, 1989) at Red Wharf Bay (Trwyn Dwlban), however, showed that this could not have introduced the amount of copper, zinc and lead required. Thus the influence of till or aeolian drift on the soil formation must be limited (Fig.4).

The presence of trace metals in the soils of grykes alongside pure limestone clints with very little contamination has been demonstrated. The distribution of copper, zinc and lead discussed above has certain implications for the introduction of these heavy metals into the soil profiles down the grikes. Of the three main mined and refined metals, zinc shows a reasonable correlation between insoluble residue and soil, suggesting a nation-wide contamination, whereas the scatter for copper is greater, indicating more localized contamination. The data for lead are difficult to interpret, because so many insoluble residue samples contained no detectable lead values. If an average value for limestone is substituted for the measured values, it still indicates contamination.

There are three possibilities. Firstly, this material was introduced naturally via aeolian transport after the limestone had been stripped bare and after the widening of the joints to form grykes by dissolving the calcium carbonate. The erosion rate was calculated as 41mm/1,000 years in Yorkshire by Sweeting (1966). The wind direction in this area is generally westerly or northwesterly. Secondly, it has been

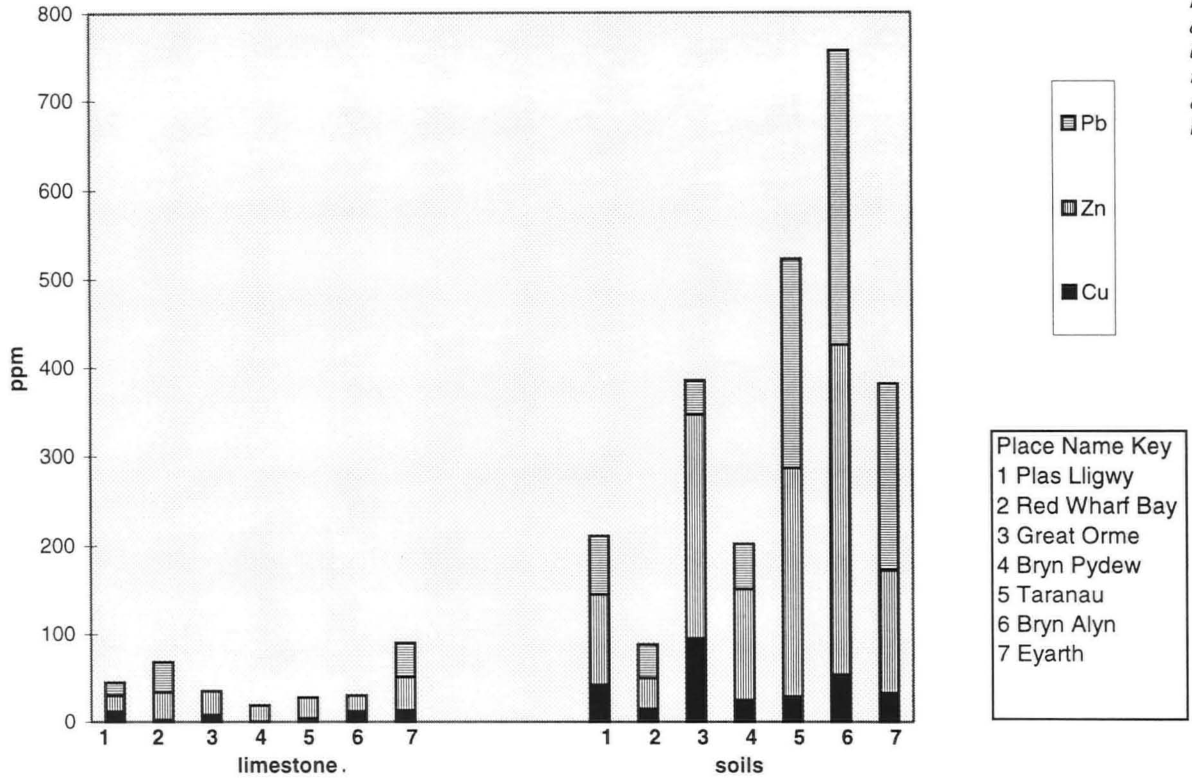

Figure 4. A comparison of copper, lead and zinc levels in the insoluble residue of clint limestone on limestone pavements in North Wales.

introduced anthropogenically. The presence of mineralization and the consequent mining and smelting of these ores has only taken place comparatively recently and for a relative short time period. The third possibility is that the till has been deposited within the grykes and subsequently removed. From the limited amount of data presented here it seems unlikely that this last possibility is valid.

This also indicates that the limestone pavements could not have developed under previous interglacial conditions, unless the proceeding glacial both moved and redeposited mineral debris that had already been exposed and was available for glacial transport. The inclusion of this level of heavy metal material therefore has a further implication beyond whether the material was introduced by man or not. It could help to establish a relative limestone pavement age.

CONCLUSIONS

Evidence presented here suggests that the addition of certain heavy metal trace elements to the soil was not from drift- or aeolian-derived material, but from an anthropogenic source. This is suggested as being mining or industrial activity, and was most probably related to the smelting of heavy metal ores.

The limited amount of time, from a geological or geomorphological point of view, that smelting has been taking place can, in theory, help to put a relative age on the limestone pavements. Further research on the detailed analysis of gryke soil profiles is required and more details of heavy metal levels must be obtained. This would then have the potential for putting a time constraint on soil development, so long as movements of the trace elements both up and down the profile were taken into account. From the preliminary results obtained and reported here, it does seem possible to link trace element geochemistry to a greater understanding of archaeology, glacial geomorphology and an endangered habitat. Ultimately this can only help in understanding the development of limestone pavements and their relationship to glacial limits.

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An assessment of protected karst landscapes in Southeast Asia

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Abstract: Southeast Asia constitutes one of the World's premier carbonate karst landscapes, with a total karst area, including southern China, of about 800,000km^2. The IUCN World Commission on Protected Areas has recognised karst landscapes as being critical targets for designation as protected areas, and this study is an initial inventory of the karst conservation situation in Southeast Asia, excluding China. The karstlands exhibit considerable topographic diversity, including "cockpit" and "tower" styles, together with extensive dry valleys, cave systems and springs. The karst has a long and distinguished history of scientific study. The Gunung Sewu of Java, the Chocolate Hills of Bohol, the pinnacles and caves of Gunong Mulu and the karst towers of Vietnam and peninsular Malaysia are "classic" tropical carbonate karst landscapes. The karst also has archaeological, historical, cultural, biological, aesthetic and recreational significance, but human impacts have been considerable. Probably less than 10% of the karst retains its natural vegetation. Regional protected areas and conservation legislation is highly variable in nature and effectiveness. In practice, the protection of designated areas is problematic. Local patterns are highly variable, but about 12% of the regional karst landscape has been afforded nominal protection through designation as a protected area. Levels of protection in different countries are uneven, reflecting population, economic and political variations. There are significant protected karst areas in Indonesia, Malaysia, the Philippines and Thailand. Karst conservation in Burma (Myanmar), Cambodia and Papua New Guinea is minimal, but there remains the potential to designate additional protected karst areas here, in Vietnam and in Laos (Lao PDR). Overall, however, the future of the region's karst landscapes remains uncertain.

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INTRODUCTION

Southeast Asia is one of the premier karst regions in the world, with a limestone area, including China, of some 800,000km^2. Excluding China, karst covers almost 460,000km^2 - about 10% of the total land area of the region. In 1997 the IUCN World Commission on Protected Areas (WCPA) recognised karst landscapes as in significant need of protection (Watson *et al.,* 1997) and those in Southeast Asia are no exception. In 1998 the Karst Waters Institute (KWI) listed the Ha Tien-Hon Chong Karst in Vietnam as among the ten most endangered karst ecosystems in the World (Mylroie and Tronvig, 1998). At the same time regional concern about protecting the environment and establishing protected areas is gaining support through both government and non-government efforts. In 1985, for example, the Association of Southeast Asian Nations (ASEAN) Agreement on the Conservation of Nature and Natural Resources identified the establishment of protected areas as one of its principal objectives (ASEAN, 1985).

The World Conservation Monitoring Centre (WCMC) has compiled a database of protected areas in Southeast Asia, but it does not identify protected karst areas in its database. Moreover, Gillieson (1996, p.290) calls for the establishment of databases that detail the protection and conservation efforts in karst landscapes, and there have been proposals for the conservation both of individual karst areas (e.g. Aw, 1978) and regional karst terrain (Vermuelen and Whitten, 1999). This study then is an assessment of protected karst areas in Southeast Asia, and is part of a larger study assessing protected karst areas throughout the World. It represents a parallel to studies assessing the conservation of regional forest and wildlife resources (e.g. Collins *et al.*, 1991; Davis *et al.*, 1992; MacKinnon, 1997).

METHODOLOGY

Southeast Asia is defined in this study as including the islands of Indonesia, the Philippines and New Guinea, plus Malaysia, Burma (Myanmar), Thailand, Cambodia, Laos and Vietnam. This definition is based on practical rather than strict geographical parameters, and excludes consideration of China and Taiwan, which will be the subjects of other studies. Broadly, it encompasses the islands of the Malay Archipelago, or the Malesian floristic zone, plus the tropical fringe of the Asian mainland, or the Indo-Chinese floristic region, and the most westerly extent of the Australo-Pacific region (Collins *et al.*, 1991; MacKinnon, 1997) (Fig.1).

The primary objective of the study is to assess the extent to which the regional Southeast Asian karst landscape is afforded protection by its designation as protected areas. To this end, it is necessary to gather data both about extent of the regional karst landscapes and about the location and extent of regional protected areas. Information about the extent of carbonate karstlands within the region is available from a number of diverse sources, including geological maps, atlases, previous research and personal experience. For a summary of this information, which is of highly variable reliability, see the list of references, particularly Middleton and Waltham (1986) and Uhlig (1980) and Appendix. Although many of these karst landscapes are dramatic and well documented, others are more subdued and little-known. To ensure consistency, we assume that all expanses of carbonate rocks indicated in geological sources do in fact represent karst landscapes. Even this liberal interpretation may produce underestimates however. For example, the 1:500,000 Geological Map of Vietnam (Luong and Bao, 1988) depicts some 20,000km^2 of limestones nationwide, whereas Tau (1991) and Do (1998) maintain

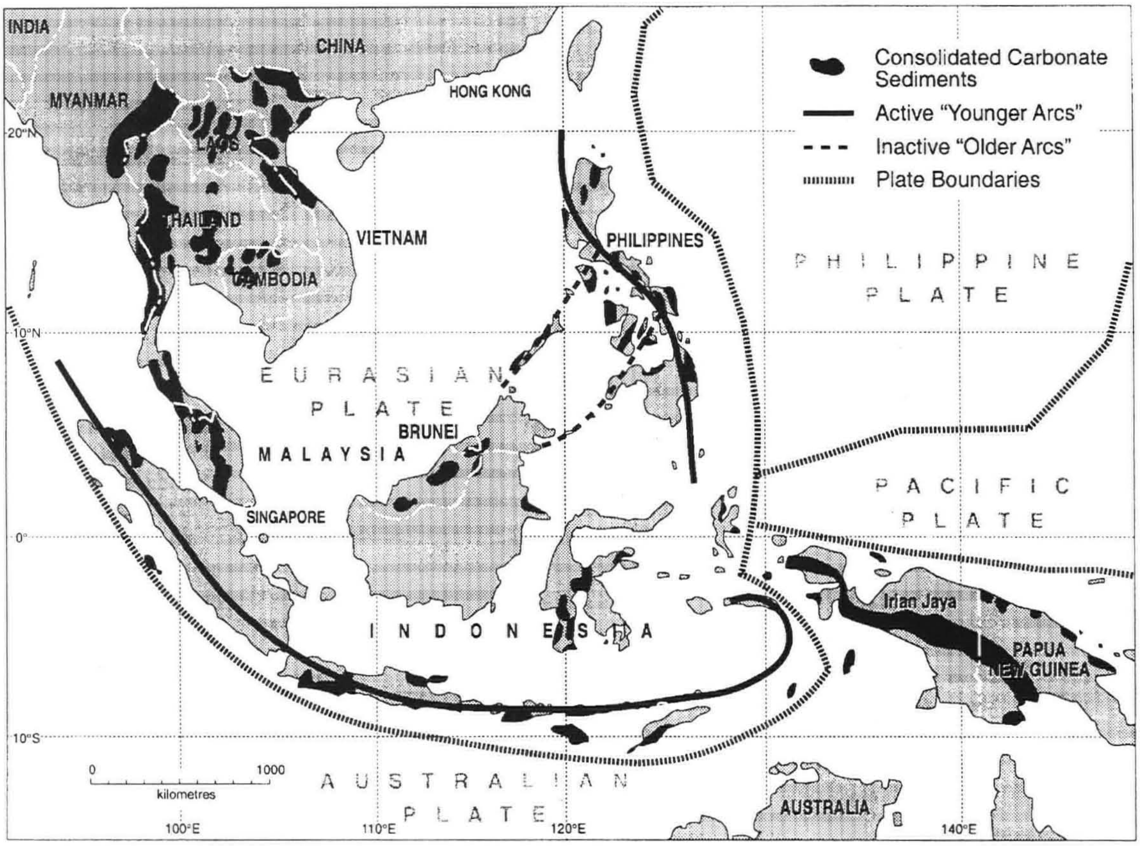

Figure 1. Karst areas of Southeast Asia.

that karst landscape occupies between 50,000km^2 and 60,000km^2 of the country. To the contrary, over 50,000km^2 of limestone occurs in Papua New Guinea, but only about 27,000km^2, or 53% of this is classified as karst by Bellamy and McAlpine (1995). Where conflicting evidence exists we have adopted the larger number, which may ultimately result in a conservative calculation of the proportion of karst designated as protected areas. Because of the differing quality of the data sources employed in this study, all numbers for karst areas should be regarded as approximate.

Reliable information about protected areas is more difficult to acquire, particularly given the wide array of protected area legislation, variations in terminology and size, and the difficulties of verification. The primary source of information is the United Nations List of Protected Areas, maintained and updated by the World Conservation Monitoring Centre (WCMC). This data source was supplemented by information about additional protected areas that do not conform to UN recognition criteria, obtained from individual government sources and other studies, particularly that by Collins *et al.* (1991). We adopt here a liberal approach to the vexed issues of protected areas criteria and terminology, recognising as a protected area any unit of land, regardless of size or legal status, that is managed with primary concern for conservation. As such, protected areas herein incorporate such entities as national, state and private parks and forests, wildlife, forest and archaeological reserves, without regard to issues of effective protection or future status. Proposed, as opposed to existing, protected areas are not considered.

KARST AREAS OF SOUTHEAST ASIA

The carbonate rocks of Southeast Asia range in age from Cambrian to Quaternary, representing the products of discontinuous carbonate deposition over more than 500 million years (Table 1). Dissolution of these carbonate rocks has produced a range of karst landscapes

Country	Cambrian	Ordovician	Silurian	Devonian	Carboniferous	Permian	Triassic	Jurassic	Cretaceous	Tertiary	Quaternary
Burma					Y	Y	Y		Y		
Cambodia				Y	Y	Y					
Indonesia			Y		Y	Y	Y	Y	Y	Y	Y
Laos	Y			Y	Y	Y					
Malaysia		Y	Y	Y	Y	Y			Y	Y	Y
PNG							Y	Y	Y	Y	Y
Philippines					Y	Y		Y		Y	Y
Thailand		Y		Y	Y	Y					
Vietnam	Y	Y	Y	Y	Y	Y	Y			Y	Y

Table 1. Geological Systems that include karstic rocks in Southeast Asia.

Country	Pinnacles	Towers	Conical	Dolines/ Dry valleys	Marine
Burma	?	Y	Y	Y	Y
Cambodia			Y	Y	
Indonesia		Y	Y	Y	Y
Laos			Y	Y	
Malaysia	Y	Y	Y	Y	Y
PNG	Y		Y	Y	Y
Philippines	Y	Y	Y	Y	Y
Thailand		Y	Y	Y	Y
Vietnam		Y	Y	Y	Y

Table 2. Karst landscape styles represented in Southeast Asia.

including dry valleys, enclosed depressions, residual towers, and extensive cave systems (Table 2, Plates 1-5). Karst landscapes in Southeast Asia have been and still are influenced by tectonic, eustatic, and climatic changes (Swan, 1979; Letouzey *et al.*, 1988), and have also undergone significant alterations as the result of human activity (Uhlig, 1980; Vermeulen and Whitten, 1999).

Karst is widespread throughout Southeast Asia (Fig.1), with significant contiguous karst areas of over 5,000km^2 occurring on the Asian mainland and New Guinea. Smaller patches, typically no more than 2,000 to 3,000km^2, occur on the carbonate islands of the Sunda and Sahul platforms and adjacent to the region's volcanic island arcs (Swan, 1979; Letouzey *et al.*, 1988).

The geological framework of the Southeast Asian karst is complex as a result of the juxtaposition of four tectonic plates: the Eurasian, Indo-Australian, Philippine and Pacific (Fig.1). Swan (1979) distinguishes between an older, more stable region, incorporating the Asian mainland and Borneo, and a younger, unstable region associated with contemporary tectonism and the folding of Tertiary deposits. Within the area considered here, Letouzey *et al.* (1988) recognise seven geological sub-regions on the basis of Cenozoic sedimentary basins and their structural framework: the Indochina Peninsula, Borneo, Palawan, the Sulu Island Arc, the Philippine Mobile Belt, the South China Sea, and the West Philippine Basin.

The limestones of the Indochina Peninsula are dominantly Paleozoic in age, although some are Mesozoic, and are associated with geologic structures of the Eurasian Plate (Table 1). The greatest extent of karst is in southeastern Burma and western Thailand, with other significant areas in northern Vietnam, northwestern Cambodia, central Thailand, northern Laos and in peninsular Malaya. The most widespread limestones are Devonian, Carboniferous and Permian in age, with some Cambrian carbonates in Laos and northern Vietnam (Table 1).

Karst development is limited on Borneo, where the small carbonate outcrops range from blocks of Cretaceous platforms in northern Kalimantan and southeastern Sabah, through lenses and limestone blocks in the melanges of the Tertiary Crocker Group in northwestern Borneo to Miocene reef limestones along the northwestern coast. The most extensive carbonates are the thick, shallow-water Eocene to early Miocene limestones of northern Sarawak.

In the Philippines, Palawan incorporates two structural units - the Borneo-Palawan allochthonous belt, and the North Palawan continental block, a remnant of a former margin of China, that crops out also in Mindoro, in the western Philippines. Small blocks of late Triassic to early Jurassic limestones occur in northern Palawan; elsewhere Tertiary limestones dominate, with late Oligocene to early Miocene lagoon and reef limestones in the St Paul area of central Palawan representing the onshore part of a more extensive offshore carbonate platform. On Mindoro Tertiary limestones again dominate, although there are some Permian limestone blocks in melanges, Jurassic carbonates, and Tertiary marbles (Table 1).

The Philippine Mobile Belt, running from northern Luzon to southern Mindanao, represents tectonic blocks accreted to a volcanic arc terrain associated with the Philippine-Eurasian Plate boundary (Fig.1). The Cretaceous basement complex contains limestones and marbles; the extensive Tertiary limestones represent part of an intravolcanic arc or forearc basinal depositional sequence, with discontinuous karst landscapes developed on highly variable carbonates. Throughout the region, Quaternary reef limestones (Table 1) blanket most of the presently non-active islands and atolls.

The South China Sea and the West Philippine Basin are respectively the largest and oldest marginal basins of the western Pacific, but few carbonates are exposed and karstified. The North Palawan block represents a palaeo-forearc area; elsewhere, extensive carbonate banks are remnants of a Tertiary regional carbonate platform.

The Sunda and Banda volcanic arcs form the structural basis for the karst on most of the islands of Indonesia, which are associated with the Eurasian-Indo-Australian Plate boundary (Fig.1). The limestones in this chain are Mesozoic and Tertiary, and the karst is discontinuous. Sulawesi, located on the Celebes Plate, presents a distinct geological evolution, with karst formed on the Tertiary limestones of the central and southwestern portions of the island (Table 1).

The karstlands of Irian Jaya (West Papua) and Papua New Guinea are among the most impressive in the region (Gillieson and Spate, 1998). Associated with the Cordillera of the Pacific-Indo-Australian Plate boundary, karst occurs on Tertiary limestones at elevations up to 4,000m, with karst constituting a large proportion of the central plateau. New Guinea has the most extensive karst in insular Southeast Asia, covering in total nearly 120,000km^2. The island territory of Indonesia, including Irian Jaya, encompasses some 145,000km^2 of karst (Table 1).

Considerable topographic variation characterizes the karst of the region as a whole, with terrain styles including subdued valleys and hollows, distinct, steep-sided, enclosed depressions, some surrounded by discrete conical hills, and striking, vertical-sided towers and dramatic pinnacles (Table 2, Plates 1-5). Dry valleys and subdued depressions are present throughout the region, particularly at lower elevations, but have received little scientific attention. Intermediate

Plate 1. Conical karst, Gunung Sewu, Java, Indonesia.

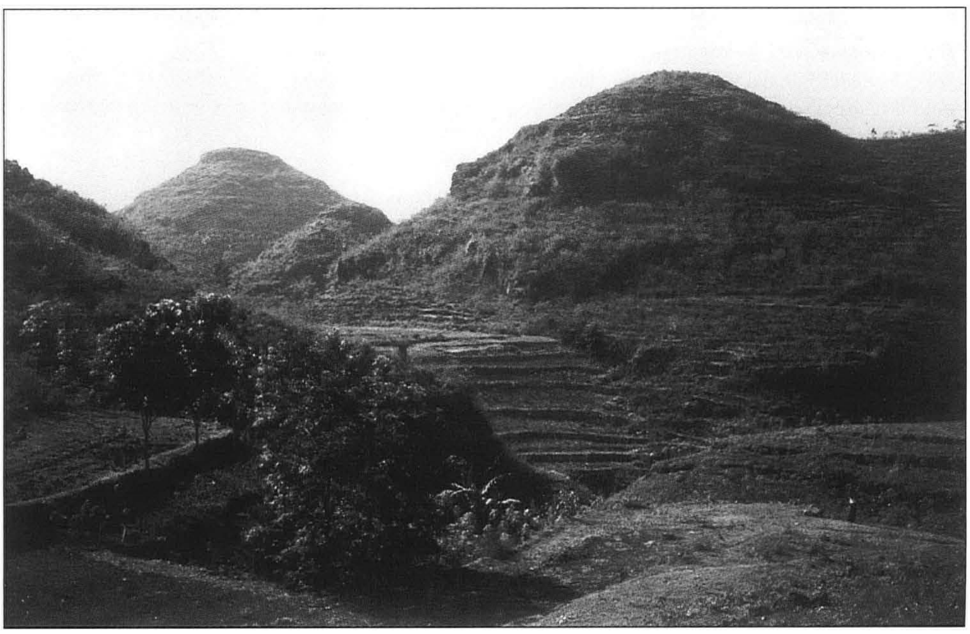

Plate 2. Cone karst, Bohol, the Philippines.

"cockpit" and cone karst is also widespread and is characterized by enclosed depressions and residual hills, which may attain roughly equal prominence (Plates 1 and 2). The residual hills form ridges that act as interfluves between the circular or linear depressions. The dramatic tower karst style is characterized by isolated residual hills separated by a near planar surface (Plate 3). Vietnam, Thailand, peninsular Malaysia and Sulawesi have fine examples of tropical tower karst. Pinnacle karst occurs particularly in the Gunong Mulu area of Sarawak (Waltham, 1995, Plate 4), in Papua New Guinea (Jennings and Bik, 1962; Williams, 1971, 1972, 1978) and in Palawan (Longman and Brownlee, 1980). Variations of these karst types occur throughout the region and are not restricted to the areas described above. Caves, formed by the underground dissolution of carbonate rock, are also abundant throughout the karstlands of the region (Middleton and Waltham, 1986; Gillieson, 1996).

The Southeast Asian karst has a long and distinguished history of academic research, including many classic studies of "type examples", which are central both to mainstream terminology and to contemporary investigation. "Classic" cases include the Gunung Sewu (Thousand Hills) of Java (Lehmann, 1936), the Chocolate Hills of Bohol (Voss, 1970), the towers of Sulawesi (Lehmann, 1936) and Malaysia (Verstappen, 1960) and the pinnacles and caves of Mulu (Waltham and Brook, 1980; Waltham, 1995) and Papua New Guinea (Jennings and Bik, 1962; Williams, 1971, 1972, 1978).

KARST ENVIRONMENTS

The Southeast Asian karstlands are far from homogeneous with respect to geological and geomorphic factors. Moreover, climate, soils and biota are also highly variable, leading to a wide range of specific karst environments.

The karst rocks themselves range from pure, dense, hard, fractured, crystalline limestones, some much altered from their original state, to impure, powdery, soft, porous, amorphous carbonates. Some are covered by volcanic ash, others folded and faulted by tectonic forces. Karst landscape elevations range from sea level up to 4,000m; some are mountainous, others planar; some are isolated hydrologically, others receive allogenic surface drainage from higher, adjacent non-karst terrains (Plate 5).

Climate varies too, being continental in extent though fragmented in form, and with a basic distinction between the mainland and insular components (Sien, 1979). Mean annual precipitation ranges from less than 1,000 to over 4,000mm. Rainfall generally decreases and becomes increasingly seasonal with increasing latitude; it also increases with elevation, and leeward locations, particularly on the mainland, may experience less precipitation seasonally than karst areas to the windward (Sien, 1979). In monsoonal areas there are distinct wet and dry periods of differing intensity and duration. Generally, the Northeast Monsoon prevails from about mid-October to March and the Southwest Monsoon from mid-May until September. Convection storms result in spatially uneven rainfall distribution, and typhoons and tropical depressions can cause severe flooding in normally dry karst areas. Typhoons can develop at any time of year but are most frequent between June and November, with a peak in August/September (Sien,

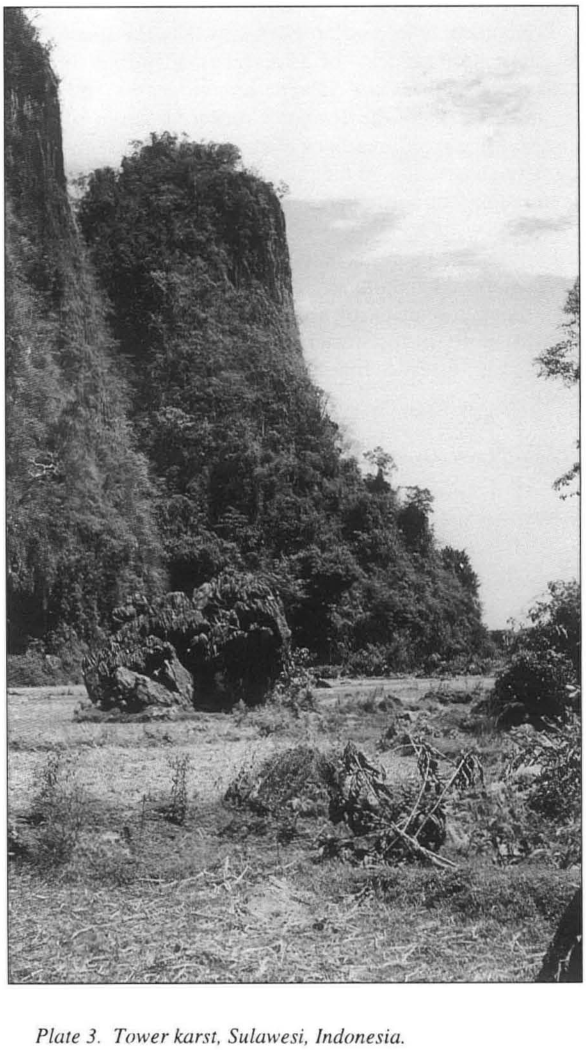

Plate 3. Tower karst, Sulawesi, Indonesia.

Plate 4. Pinnacle karst, Gunung Mulu National Park, Sarawak, Malaysia.

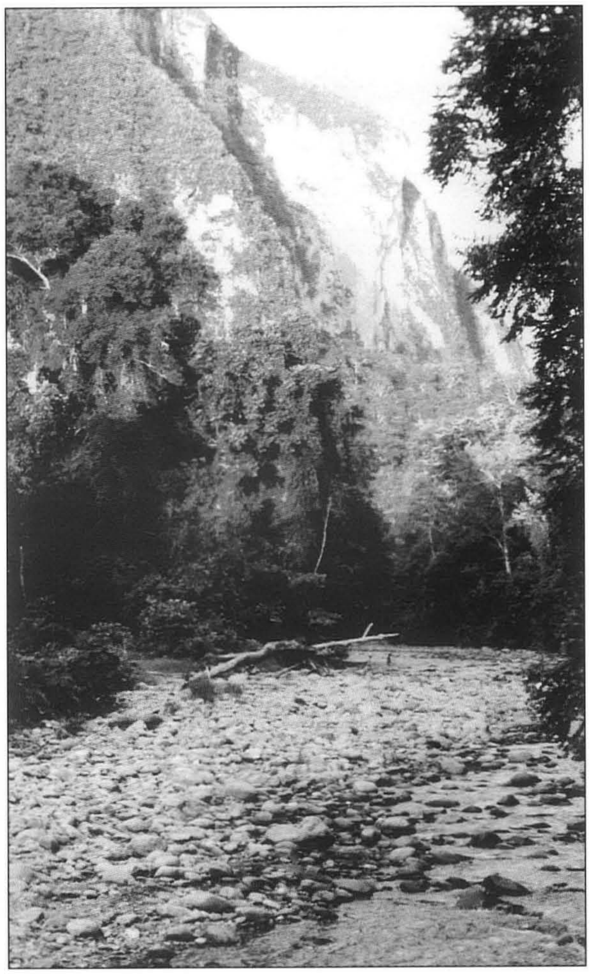

Plate 5. The Melinau River Gorge, Gunung Mulu National Park, Sarawak, Malaysia. The Melinau River is allogenic, rising on adjacent non-carbonate rocks.

1979). Uniform mean annual temperatures of around 26°C prevail over much of the insular and mainland coastal areas, with mainland winter temperatures decreasing northward and away from the coast (Sien, 1979).

Karst soils are also extremely variable, but are dominated by mollisols or rendzinas, which are commonly clay-rich, heavily leached, patchy and thin. Steep slopes tend to be devoid of soils, which are thicker in depression and valley bases; in such locations they offer excellent agricultural potential (Sanchez, 1981). Calcareous clays may give rise to vertisols, and alfisols are developed over limestones in some areas (Swan, 1979). Although the majority of soils are derived from the weathering of the parent carbonate rocks, locally they may be influenced by inputs of fluvial or aeolian sediments.

Natural vegetation consists of both aseasonal tropical rain forest and seasonal (monsoon) forest, with seasonality increasing into the mainland (Hill, 1979; Collins *et al.*, 1991). Southeast Asian forests include both deciduous and semi-evergreen trees, although much of the seasonal forest has been cleared, with only fragments remaining in remote karst areas. Regionally, karst areas have an edaphic vegetation, tolerant of wide variations in soil moisture and higher pH than in non-karst soils (Hill, 1979). Low, tangled, dense forest with many *Ficus* species and Euphorbias is characteristic, and on the mainland teak *(Tectona grandis)* is associated particularly with karst areas (Collins *et al.*, 1991). Wildlife is heterogeneous, with marked divergence between the Sunda and Sahul continental shelves of Asia and Australia respectively. Rates of endemism are highly variable, and detrimental human influence is considerable (Collins *et al.*, 1991; Vermeulen and Whitten, 1999). Specifics of karst area surface flora and fauna have seldom been studied in detail, although see Crowther (1982), Chin (1977) and Vermeulen and Whitten (1999). In the karst of peninsular Malaysia, Chin recorded 1,216 species of vascular plants belonging to 582 genera and 124 families. Of these, 129 species are endemic and are confined to the karst.

Human impacts on Southeast Asian karst landscapes have been long-term and severe (Uhlig, 1980; Collins *et al.*, 1991; Vermeulen and Whitten, 1999), in particular through forest clearing, species introduction, agriculture, utilisation of water resources, and industrial activities, including mining. Reforestation is a contemporary thrust in some regional karst areas, but this is not without its own problems (Urich and Reeder, 1999). Important archeological sites, both surface and subterranean, and forest-dwelling tribal populations are both significant aspects of karst areas throughout Southeast Asia (e.g. Peacock, 1965; Vermeulen and Whitten, 1999).

PROTECTION OF KARST LANDSCAPES

With a total land area of about 5,000,000km^2 and a population approaching 555 million people (CIA, 1999), pressures on Southeast Asia's natural resources are severe, although most nations now recognise the importance of resource protection for environmental, economic and social reasons. Throughout the region efforts to conserve natural resources have involved the establishment of protected areas, in which human activities and impacts are restricted.

The importance of karst landscape protection was highlighted in 1997 by the International Union for the Conservation of Nature and Natural Resources (IUCN) Working Group on Cave and Karst Protection, which published guidelines for the design and maintenance of protected karst areas (Watson *et al.*, 1997). Significant rationales for the protection of karst landscapes include the following:

- as habitats for endangered species of flora and fauna;
- as areas possessing rare minerals and/or unique landscape features;
- as important historic and prehistoric areas with cultural importance;
- as important areas for scientific study across a variety of disciplines;
- as religious and spiritual areas;
- as areas of specialised agriculture and industry;
- as important areas to the understanding of regional hydrology;
- and as recreation and tourism areas with important economic and aesthetic value.

PROTECTED AREAS LEGISLATION

At the Fourth World Congress on National Parks and Protected Areas (held in Caracas, Venezuela in 1992) a protected area was defined as: *"An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means."* (World Conservation Monitoring Centre, 1997). Protected areas make important contributions to the conservation of natural and cultural resources and *"...provide an opportunity for rural development and rational use of marginal lands, for research and monitoring, for conservation education, and for recreation and tourism. As a result, most countries have developed systems of protected areas."* (WCMC, 1997).

A wide range of protected area designations and definitions are implemented because protected area systems vary from one country to another depending upon the countries' needs and priorities, laws regarding natural areas and resources, and financial and institutional support. The 1997 UN List of Protected Areas attempts to consolidate the World's protected areas that meet certain requirements. *"IUCN's Commission on National Parks and Protected Areas (CNPPA) is the leading international scientific and technical body concerned with the selection, establishment and management of national parks and other protected areas"* and serves *"...to promote the establishment of a world-wide network of effectively managed terrestrial and marine protected areas."* (WCMC, 1997).

Three minimum requirements for inclusion in the UN List are set by the World Conservation Monitoring Centre (1997):

1. In general, only protected areas of over 1,000 hectares ($10km^2$) are included, with the exception of offshore or oceanic islands;
2. Management objectives must be defined and accomplished according to IUCN/CNPPA parameters;
3. Sites must be managed by the *"highest competent authority"*, either a state or federal agency.

Country	MAB	World Heritage	Legislation effectiveness*	Government agencies involved[1]	Significant National legislation[2]
Burma	Y	Y		W, F, E	F 1995
Cambodia	Y	Y	0	F, A	E 1996
Indonesia	Y	Y	1.5	F, E	NR 1990, E 1997, F 1985, B 1995
Laos		Y	0	W, F, E, A	
Malaysia	Y	Y	2	W, NP, F, E	NP 1980, W 1972, F 1984, PA 1982, E 1974, NR 1949
PNG	Y	Y	1	E	W 1996, F 1991, PA 1978, NP 1982, E 1978, NR
Philippines	Y	Y	1.5	PA, W, E	PA 1992
Thailand	Y	Y	1.5	NP, W, F, E	F 1985, NP 1961, W 1960, E 1975
Vietnam	Y	Y	1	F, A, WR	B 1994

Table 3. National Protected Areas Legislation [see below for details of abbreviations].

*Braatz *et al.*, 1992
(0 = non-existent, 1 = weak, 2 = moderate, 3 = comprehensive)

[1] F Forestry or equivalent
E Environment, Natural Resources, Conservation Ministry or equivalent
W Wildlife Bureau or equivalent
A Agricultural Ministry or equivalent
NP National Park Division or equivalent
PA Protected Area Bureau or equivalent
WR Water Resources Division or equivalent

[2] NR Natural Resources Act or equivalent
E Environmental Law or equivalent
F Forestry Act or equivalent
PA Protected Area Act or equivalent
NP National Parks Act or equivalent
W Wildlife Protection Act or equivalent
B Biodiversity Act or equivalent

The WCMC database currently includes over 37,000 sites of which only 9,832 qualify for inclusion in the UN List. Many of the excluded sites fall short of the 1,000-hectare minimum area requirement, hence the absence of a country from the list does not necessarily indicate that country has no protected areas. This is particularly relevant to small countries where landscapes are of restricted expanse. Many smaller protected karst areas in Southeast Asia cover areas less than 1,000 hectares, hence they are not included on the UN List.

REGIONAL PROTECTED AREAS LEGISLATION

Protected areas legislation throughout the Southeast Asian region is highly variable as a result of the multiplicity of sovereign nations, government agencies and non-government organisations. The Association of Southeast Asian Nations (ASEAN) Environment Program acts as a regional arbiter of conservation strategies, but the levels of participation of the countries considered here are highly variable. The UN Convention for the Protection of World Natural and Cultural Heritage has been adopted by all the countries considered, and the UNESCO Man and the Biosphere Programme (MAB) has been adopted by all except Laos. Here we are concerned only with summarising national legislation and regional programmes that are of immediate relevance in the context of terrestrial karst landscapes. Some of the more relevant legislation is summarised in Table 3, and fuller details are provided by the World Conservation Monitoring Centre (1992), by McNeely and Miller (1984) and by MacKinnon (1997).

In some Southeast Asian countries protection of wildlife has a long tradition, associated particularly with Buddhist religious sites (Collins *et al.*, 1991). Other countries inherited colonial legislation that restricted certain activities in designated areas, although this was largely intended to protect economic rather than environmental interests, particularly those in timber production and mining. For example, the 1916 Nature Monuments Ordinance in Java led to the establishment by 1929 of 55 nature reserves totalling 1,300km^2. Likewise, the existing protected areas of Indonesia, Thailand and Malaysia have evolved from forest reserves, originally designed to ensure continued timber production, although incidentally limiting forest clearance, protecting wildlife and safeguarding soil and water resources (Collins *et al.*, 1991).

Most regional protected areas legislation is of more recent, systematic, post-independence vintage, with the majority of Southeast Asian countries adopting late twentieth century constitutional provision for the designation of protected areas (Table 3). Throughout the region significant karst landscapes are variously encompassed within national parks (e.g. the Mulu National Park in Sarawak, the Taman Negara National Park in Malaysia and Ao Phangnga National Park in Thailand), forest reserves (e.g. the Ulu Muda and Gunung Jerai Forest Reserves in Malaysia), wildlife reserves, refuges and sanctuaries (e.g. the Phu Luang Wildlife Sanctuary and Chiang Dao Wildlife Reserve in Thailand) and other conservation areas (e.g. the Batu Caves and the Danum Valley Conservation Area in Malaysia). The Puerto Princessa (St. Paul Subterranean River) National Park, in Palawan, the Philippines, the Lorentz National Park, Irian Jaya, Indonesia, Gunung Mulu National Park, Sarawak, Malaysia, and Halong Bay, Vietnam, each of which contains significant karst, have been proposed as UN Natural World Heritage Sites.

Regionally, the pattern of protected areas legislation is uneven, with levels of protection reflecting population, economic, and political pressures. There is significant legislation protecting karst areas in Thailand, Vietnam, Malaysia, Indonesia and the Philippines, but, by contrast, effective protective legislation is minimal in Burma, Cambodia and Laos. Regionally, there is considerable scope for the continued development and implementation of effective protected areas legislation, management policy and enforcement (Margules and Pressey, 2000).

International non-governmental and inter-governmental organisations also play an important role in the proposal, identification, establishment and management of protected areas. Organisations involved nationally and regionally include the Food and Agriculture Organisation (FAO) of the United Nations, the UN Development Programme (UNDP), the Japanese International Cooperative Agency (JICA), the International Union for the Conservation of Nature (IUCN), the World Wide Fund for nature (WWF), Wildlife Conservation International (WCI), Conservation International (CI), the Nature Conservancy (TNC) and the International Council for Bird Preservation (ICBP).

PROTECTED KARST AREAS: THE REGIONAL SITUATION

Almost 10% of the Southeast Asian land area, a total of about 458,000km^2, is karst landscape. Karst protected area totals for individual Southeast Asian countries and the region as a whole are shown in Table 4. Regionally, there are 154 protected karst areas, collectively encompassing 51,150km^2, approximately 12% of the entire regional karst total. Considering individual countries, the greatest number of protected karst areas (44) and the largest total area of protected karst (22,000km^2) are in Indonesia, where approximately 15% of the total karst is protected.

Comparatively, Malaysia affords protection to a lesser area of karst (8,000km^2) but the 28 protected karst areas represent 45% of the total karst area. Of other countries, Thailand affords protection to 41 karst areas, representing 25% of the total karst, the Philippines protect 29% of their total karst landscape (Table 4). Karst protected areas in Burma, Laos and Vietnam are comparatively small, both in terms of absolute area and proportion of the total; Cambodia and Papua New Guinea have yet to designate any karst areas as protected. However, differences in land tenure systems, especially in the latter, mean that effective protection may be provided through private land ownership rather than through government agencies.

This situation, although specific to the karst, also reflects the overall designation of protected areas within the region according to the United Nations and the World Conservation Monitoring Centre (Table 5). Note that the UN/WCMC data are constrained by criteria of size and legal status, meaning that protected areas totals in Tables 4 and 5 reflect different datasets and are not directly comparable. Regionally, there is also a relationship, although not always straightforward, between conservation of forest resources and designation of protected areas within the karst. For example, MacKinnon and MacKinnon (1986) identify *"Forest on Limestone"* as a distinct vegetation category, assessing the areas and percentages protected by country as follows: Thailand, 200km^2, 100%; the Philippines, 20km^2, 11.1%; Malaysia, 240km^2, 9.7%; Indonesia, 3,700km^2, 3.3%; Vietnam, 210km^2, 2.1%; and Laos, 0km^2, 0%.

Country	Karst Area (km^2)	Protected Karst Area (km^2)	Karst Protected (%)	n
Burma	80,000	650	1	2
Cambodia	20,000	0	0	0
Indonesia	145,000	22,000	15	44
Laos	30,000	3,000	10	10
Malaysia	18,000	8,000	45	28
PNG	50,000	0	0	0
Philippines	35,000	10,000	29	14
Thailand	20,000	5,000	25	41
Vietnam	60,000	4,000	7	15
Total	458,000	53,150	12	154

Table 4. Protected karst areas, Southeast Asia, 2000.

PROTECTED KARST AREAS: SELECTED EXAMPLES

Although only 12% of Southeast Asia's karst landscape is afforded protected area status, this total includes some individual karst areas that are extensive and significant in terms of scientific, cultural and recreational criteria. Whereas the majority of the 154 protected karst areas are so designated because of their specific biological, archaeological or recreational significance, a few are recognised on the basis of stricter geomorphic criteria, acknowledging the intrinsic value of karst landscapes themselves.

Indonesia, by far the largest country in the region, with a land area of nearly 2,000,000km^2, protects the largest number of karst areas (44) and the largest area of karst (22,000km^2), although only 15% of the total karst area. Much of the protected karst is in Irian Jaya, for example in the Lorentz National Park and in the Misool Selatan and Pulau Waigeo Nature Reserves. Relatively little karst is protected in Java, Kalimantan and Sumatra but there are numerous small protected karst areas in the Moluccas and the Lesser Sunda Islands. Many more protected areas are proposed (Collins *et al.*, 1991; MacKinnon, 1997).

Karst is protected within 21 of Thailand's National Parks, with notably large areas in Erawan, Kaeng Krachan, Khao Lunag, Khao Sok, Khao Yai and Sai Yok National Parks. Three National Marine Parks - Tarutao, Phi Phi-Hat Nopparat Thara and Koh Surin – also encompass extensive karst. The Ao Phangnga National Park includes impressive marine tower karst (Uhlig, 1994). Karst is also protected within the Thungyai-Huai Kha Khaeng Wildlife Sanctuaries, which constitute a UN World Natural Heritage Site and represent the largest conservation area in mainland Southeast Asia, covering some 6,000km^2. Numerous caves are also conserved as archaeological, religious and tourist sites (Dunkley, 1995; Vermeulen and Whitten, 1999).

The intrinsic and diverse value of karst landscapes is recognised particularly in Malaysia, where approximately 8,000km^2 are protected in national parks, forest reserves, wildlife reserves and sanctuaries, and other conservation areas. It is not coincidental that Malaysia has the greatest proportion of protected karst in the region (Table 4). Caves and karst are important culturally, economically and aesthetically, and more than a dozen important caves are conserved for archaeological, religious and tourism purposes, including the caves at Niah and Mulu. Elsewhere, karst is conserved in Kenong Rimba Park and at Gomantong and Gunung Jerai.

Vietnam's first national park, Cuc Phuong was established in 1962 and a national system of protected areas has been established since 1980. Seven of Vietnam's nine national parks, including Cuc Phuong, encompass karst landscape, and karst constitutes about 65% of the total national park area. Additionally, karst covers about 30% of Vietnam's nature reserves (Chuyen, 1995). Some 100km^2 of karst are protected in Cat Ba National Park, which is within the Halong Bay UNESCO World Heritage Site, which encompasses some 1,500km^2 of classic tower karst. Many caves are protected as natural heritage sites, for example in Ben En National Park, or, as in Con Dao National Park, for the conservation of the Cave Swift, *Colocalia francina*, whose nests are highly prized as the primary ingredient of birds' nest soup. Scenic cone and tower karst is also protected in Phong Nha Nature Reserve, in the Son Tra Protected Area and in Bach Ma, Ba Vi and Ba Be National Parks. Even so, accepting Do's (1998) estimate of the total karst landscape (60,000km^2), Vietnam affords protected area status to less than 10% of its karst.

Country	Protected Area (km^2)	Number of areas protected	Percentage protected
Burma	1,733	2	0.26
Cambodia	29,978	20	16.56
Indonesia	185,653	175	9.67
Laos	24,400	17	10.3
Malaysia	14,848	54	4.46
PNG	820	5	0.18
Philippines	6,059	27	2.02
Thailand	70,203	111	13.66
Vietnam	13,298	59	4.03

Table 5. National Protected Areas summary statistics (WCMC, 1996).

Burma (Myanmar) contains the second largest area (80,000km^2) of karst in Southeast Asia, but less than 1% is incorporated into two designated protected areas, the Shwe u Daung and Shwesettaw Game Reserves and in the vicinity of Pindaya Cave. Some 3,000km^2 of karst are conserved in the protected areas of Laos, notably in the Khammoune National Park, the Hin Namno Karst Reserve and the Xe Bang Fai and Vang Vieng Nature Reserves. Numerous caves are protected, at least nominally, but only about 10% of the total karst in Laos is afforded protection.

The situation in the Philippines is in some respects the most confusing, both because the legal basis for protected areas is complex and because administrative responsibility is vested in a multitude of management units. 55% of the Philippines is "Public Land" (Kummer, 1992), but its conservation status is often questionable. It is even unclear exactly how many national parks exist, or what their precise boundaries are (WCMC, 1992). Significant karst is protected within the Puerto Princessa (formerly St Paul Subterranean River) National Park on Palawan, within the Central Cebu National Park and in Rajah Sikatuna National Park in Bohol. On the last named island, much of the Chocolate Hills area is protected as a Natural Monument (Urich and Day, in prep.). Quaternary coastal limestones are conserved within the Tubbataha Reefs National Marine Park. In 1992 the Philippines adopted a Strategic Environmental Plan for Palawan, *"A comprehensive framework for the sustainable development of Palawan compatible with protecting and enhancing the natural resources and endangered environment of the province..."* (Government of the Philippines, 1992, p.4). In total, about 29% of the Philippines karst is designated as protected areas.

SUMMARY AND CONCLUSIONS

A modest 12% of Southeast Asia's karst landscape is afforded at least nominal protection under the auspices of protected area status. The 154 protected karst areas total about 51,000km^2, with the largest area, 22,000km^2 (52%) in Indonesia. There are also extensive protected karst areas in Malaysia, the Philippines, Thailand and Vietnam, and small areas in Burma and Laos. Cambodia and Papua New Guinea have yet to designate any karst landscapes as protected areas. Overall, the total area of karst and the proportion designated as protected areas is minimal.

We accept that some of the data sources upon which this conclusion is based are not as reliable as we would wish, but we regard them as the best sources available at the regional scale. More detailed field surveys of individual countries and protected areas are warranted, and clearly would provide greater accuracy. Such detailed studies are however constrained by both geographical and political limitations.

Most of the karst areas that are designated as protected areas are so recognised not for their intrinsic value as karst landscapes but for their significance in other, not unrelated contexts, such as their biological diversity, timber resources, hydrological potential, archaeological interest and recreational value. With few exceptions, notably at Mulu, in Sarawak, the scientific merit of karstlands is not a central focus of government and education.

Conferral of protected area status does not, of course necessarily result in effective protection from such threats as forest clearance, agricultural incursion, water contamination, and the looting of archaeological materials. Management and policing of Southeast Asia's protected karst areas is of variable effectiveness and in some instances is non-existent. Some of the largest and most significant of the reserves are the most vulnerable.

It is difficult to assess the Southeast Asian situation by comparison with other parts of the World because few comparable studies have been undertaken. Belize has conferred protected area status upon some 68% of its karstlands, but this is probably anomalous and reflective of low population densities, historical land use directives and a strong recent focus upon eco-tourism (Day, 1996). Elsewhere, an ongoing parallel study of protected karst areas in Central America and the Caribbean (Kueny and Day, 1998 and in press; Kueny, 2000) suggests that approximately 14% of the karst there is designated as protected areas. Proportions elsewhere, notably in North America, Europe, Africa and Australia, may be very different, warranting further study.

In the broader conservation context, the protected karst area percentage approximates to a figure of 10-12%, sometimes suggested as the near-term land area protection target for nations and ecosystems (Noss, 1996). The value of such low numerical targets is, however, questionable (Soule and Sanjayan, 1998).

The protected areas situation in Southeast Asia is extremely volatile, with reserves being created and disestablished on a regular basis. Even within the time span of this study (1998-99) the numbers, sizes and status of many countries' protected karst areas have changed, in some cases dramatically. The numbers presented here will almost certainly be outdated by the time of publication. The contemporary regional attitude towards conservation is not always encouraging, and it will be interesting to follow the future trend in the status of the protected karst areas. The current modest levels of protection may increase in terms of area, proportion and efficacy, or they may decrease as other pressures on natural resources increase. The situation remains fluid.

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APPENDIX

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The travertine flora of Juizhaigou and Munigou, China, and its relationship with calcium carbonate deposition

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Abstract: The flora of two large travertine deposits in Sichuan Province is described. Travertine compositions were similar to those of Europe, averaging 95% $CaCO_3$ (low Mg-calcite). Travertines were covered in algae (mainly cyanobacteria and diatoms) and bryophytes. The most frequent cyanobacteria (N=15 species) were *Calothrix* and *Dichothrix*, and *Achnanthes* and *Cymbella* were most common among the diatoms (N=21). 68% of the algae have been reported from European travertines. Among the bryophytes (13 mosses, 3 liverworts), *Cratoneuron, Fissidens* and *Gymnostomum* were the most abundant, but only 50% of the species are known from European sites. Among the algae, close spatial relationship with the deposited calcite could be established only for *Oocardium*. In the mosses *Bryum, Fissidens* and *Gymnostomum,* parallels were established between the distribution of carbonate and leaf morphology, reminiscent of the intercellular calcification model for marine algae. The implications are discussed with reference to travertine formation on dams and cascades.

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INTRODUCTION

China contains the Earth's largest area of limestone karst, with altitudes ranging from sea-level to 8,700m, and climates ranging from subtropical to extreme alpine (Li and Luo, 1983). Most karst groundwaters are rich in calcium and bicarbonate ions due to the dissolution of limestone, and in mountainous districts, where emerging springwaters are turbulent, excess groundwater carbon dioxide is rapidly expelled into the atmosphere, leading to the precipitation of calcium carbonate on the stream bed (equation 1).

$$Ca^{2+} + 2HCO_3^- \Rightarrow CaCO_3\,(\text{travertine}) + CO_2 + H_2O \qquad (1)$$

The resulting deposits are termed travertine, and they are particularly well developed on waterfalls (Julia, 1983). Some of the largest and most imposing travertine cascades occur in China, where they are becoming developed for tourism (e.g. Huangguoshu, in Guizhou Province, and Huanglong, in Sichuan Province).

Algae and bryophytes growing on the travertine surface aid the precipitation of carbonate. They assist travertine formation by removing carbon dioxide from the water during photosynthesis and by providing a framework for carbonate deposition, allowing the deposits to stabilise in turbulent water. Studies to date have shown that photosynthesis only becomes significant under low flow regimes at some distance from the source, otherwise it is of minor significance when compared with carbon dioxide evasion to the atmosphere (Dandurand *et al.,* 1982; Spiro and Pentecost, 1991). In most cases, plants play a more important role by providing a large and continuously renewable surface upon which the travertine precipitates. For example, UK travertine bryophytes provide a surface area at least five times greater than that of the bare stream bed (Pentecost, 1991).

In recent years the bryophytes of the Guizhou Province travertines have been investigated in detail, and the flora shown to be both rich and unique (Zhang Zhaohui, 1996; Zhang Zhaohui and Pentecost, 2000). Some bryophytes attain their greatest development on travertines, and several appear to be confined to them. There are also freshwater algae known only from active travertines. Actively-building travertine is a comparatively rare substratum and conservation issues are important. In Europe this is recognised under EC Directive 92/43 Annex 1.

This paper investigates the travertines of Jiuzhaigou and Munigou in Sichuan Province. Both are National Nature Reserves, and Juizhaigou is a World Heritage Site. Neither has been investigated previously for its travertine flora, though background biological and hydrochemical data are available (Chou, 1987; Guo, 1988; Zhu *et al.,* 1989; Zhang Jie, 1993; Zhao, 1996). The aims of the investigation are twofold: firstly to compare the travertine flora with those of other Chinese and Western European sites in terms of species composition and richness; secondly to investigate in detail the morphology of bryophyte leaves and their relationship with travertine deposition.

METHODS

Fresh travertine samples were obtained from 41 sites during April 1999 (Figs 1b and 1c). Some were air-dried immediately for algal and bryophyte identification, whereas others were preserved in 20% aqueous ethanol and 1% glutaraldehyde for electron microscopy. Algae and bryophytes were identified using standard floras, to species level where possible. Diatoms were identified after acid cleaning (Round *et al.,* 1990), and their relative abundance determined at Juizhaigou and Munigou from counts of 500 cells. Nomenclature for cyanobacteria, diatoms and bryophytes follows Geitler (1932), Krammer and Lange-Bertalot (1986) and Gao Chien (1996) respectively.

Small air-dried samples of bryophytes and surface travertine were fixed to aluminium stubs, sputter-coated with Au-Pd, then examined in an EM 501B Scanning Electron Microscope operating at 15kV at magnifications of 80 to 600. Samples of glutaraldehyde-fixed material were dehydrated in ethanol series, then critical-point dried using carbon dioxide, and coated as above to preserve organic structures.

For chemical analysis, samples were dried at 105°C, finely ground and weighed. The powders were dissolved in a slight excess of 4N HCl, left for 4 hours at room temperature, and filtered. The filtrates were analysed for Mg, Fe, Mn, Zn and Pb, using atomic absorbtion spectrophotometry. Residues were weighed and combusted at 550°C to determine the $CaCO_3$, organic matter and acid-insoluble components.

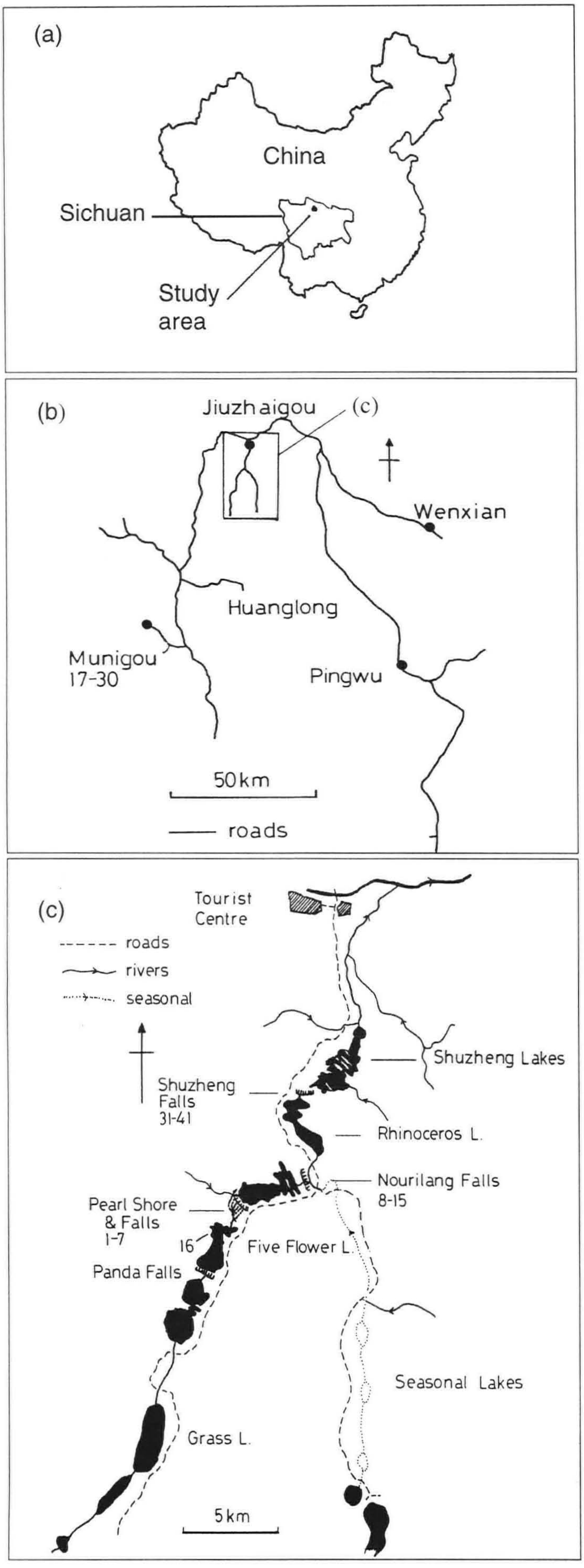

Figure 1. Location of sampling sites: (a) site locations within Sichuan; China, (b) connecting routes between Jiuzhaigou, Munigou and Huanglong; (c) map of Jiuzhaigou Valley National Nature Reserve showing main lakes, waterfalls and numbered collection sites. Location in (b) shown by rectangle.

SITES

Jiuzhaigou Valley National Nature Reserve

This area lies in a deep N-S valley in the Minshan Mountains of northern Sichuan, close to the Tibetan border (103.54°E, 33.00°N; Fig.1). It is a region of alpine and subalpine boreal karst forest at an altitude of 2,000 to 4,300m. The main valley contains a large series of travertine-dammed lakes in its lower section, extending for a distance of about 20km from Panda Lake to Shuzeng Lakes along the Beishui River (Fig.1c). The lakes are up to 4km long, 1km wide and 10m or more in depth. The major travertine dams, situated at the lower ends of the lakes, have migrated considerable distances downstream and currently form a series of large waterfalls, 15m or more in height. They include Panda Falls, Pearl Falls and Shore (Fig.2a), Nourilang Falls and Shuzeng Falls (Figs 2b and 2c). Shuzeng Lake possesses a complex series of narrow and breached/drowned dams over much of its length. Pearl Falls are noteworthy for their extensive gently sloping travertine apron about 300m in length and 300m in width immediately above the falls. The apron, called Pearl Shore, is irrigated with water and is an extension of the dam lip. The entire Juizhaigou sequence provides one of the largest series of travertine-dammed lakes in the world. The Beishui River joins the Jiulingiang River near Juizhaigou Village, and eventually meets the Yangtze River flowing to the China Sea.

Munigou Scenic Area

This site is situated about 75km SSW of Jiuzhaigou (103.30°E, 32.26° N; Fig.1b) along the Pei River. The area is at a similar altitude to Jiuzhaigou (2,800 to 4,070m) and contains a small SW-NE trending river, rising in boreal karst forest, that descends a large travertine cascade, Zhaga Waterfall. The cascade spreads into a braided area of travertine under woodland called the Water Forest (Fig.2d). Below the Water Forest is a series of ancient degraded dams and smaller active cascades extending to Munigou Village, about 5km downstream.

RESULTS AND DISCUSSION

Travertine morphology and gross composition

The $CaCO_3$ content of the travertines averaged 95% (Table 1), similar to that of German cascade- and stream crust travertines (mean 96.2%, Irion and Mueller, 1968) and the UK (mean 94.2 %, Pentecost. 1993). Organic matter content ranged from 0.1 to 9.8% in the Chinese samples, with the highest value coming from a moss travertine at Munigo, which contained numerous bryophyte stems. The algal travertines were lower in organic matter (0.1 to 2.3% dry weight) and comparable with those of the UK. Organic matter consisted of both allochthonous and autochthonous components, as evidenced by pollen grains, though these fractions were not quantified. Acid-insoluble fractions in the Chinese samples averaged 1.48%, close to the mean UK value for active travertines (Pentecost, 1993).

The Mg content varied considerably and tended to be higher in the Juizhaigou samples. These differences may reflect groundwater chemistry, since Mg^{2+} is partitioned into calcite according to its groundwater concentration (Dickson, 1990). Similar mean values are reported from the UK and Germany (1,140 and 460ppm respectively). Chinese Mg values are sufficiently low to classify the main mineral as low magnesian calcite. The mean soluble Fe content is significantly higher than that reported for most European travertines, and probably originates from detrital iron oxides and carbonates (Cidu *et al.,* 1988). At Munigo the travertines were commonly stained orange, and they differed geochemically from those of Jiuzhaigou. There was a positive correlation between the Fe content and the acid insoluble residue, as observed in some German travertines (Irion and Mueller, 1968). The provenance of this iron is unknown; some may be present within the calcite lattice, though it is likely to be largely of detrital origin.

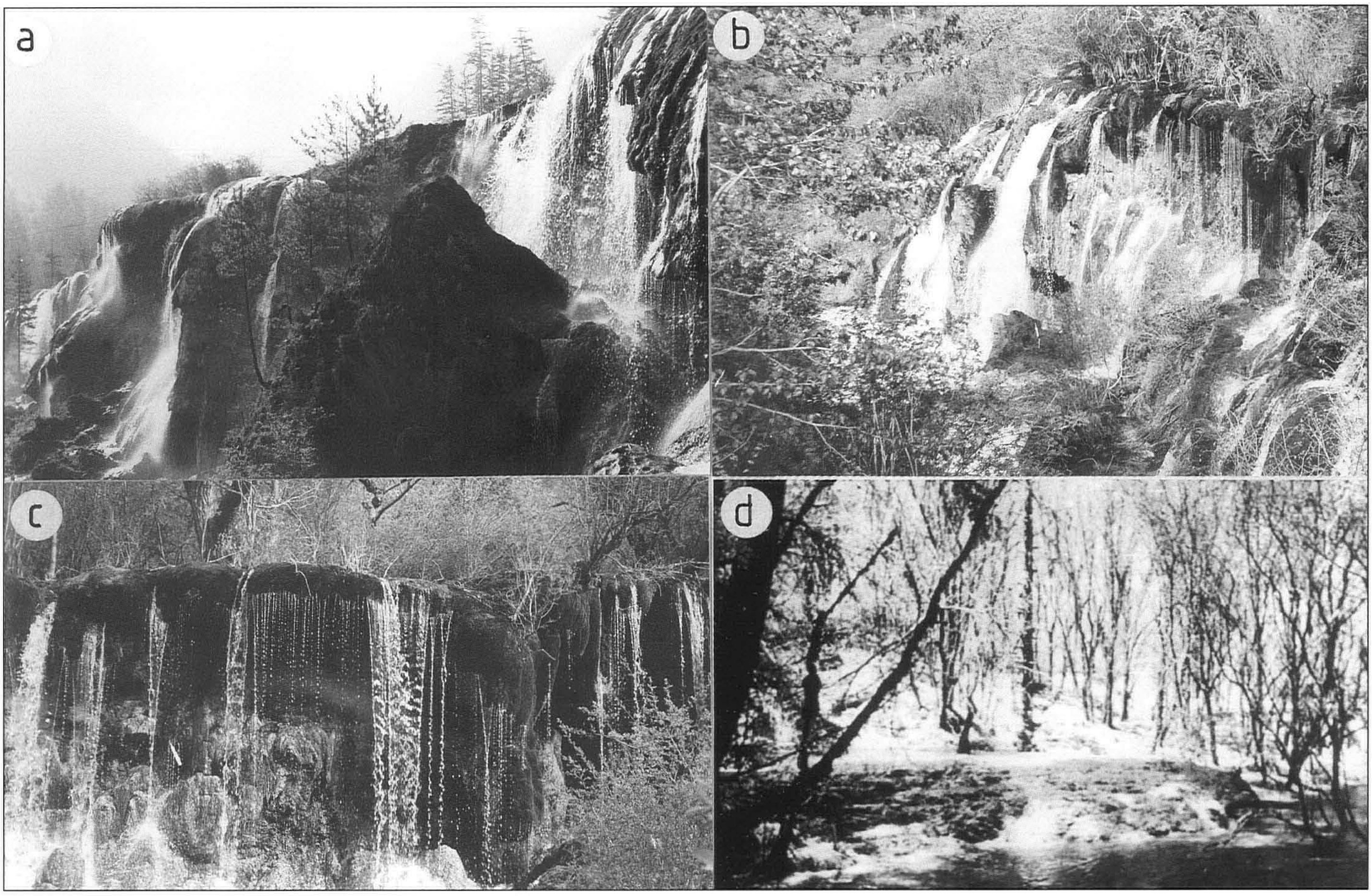

Figure 2. Some travertine sampling locations in Sichuan.:

a) Pearl Falls, Juizhaigou looking NW across the dam front, which is c.200m long and 25m high. Bryophytes can be seen colonising travertine at far left, with large fallen block right of centre. Pearl Shore is situated immediately above the falls.
b) Shuzeng Falls, Juizhaigou. One of a series of small cascades at the upper end of the Shuzeng Lakes, showing areas of torrential flow (left) where algae predominate, and trickling flow (right) where bryophytes dominate.
c) Shuzeng Falls showing in more detail the bryophyte-rich area shown in Fig.2b. The travertine cliff is about 12m high and is covered in large cushions of Barbula dixoniana, Fissidens grandifrons and Gymnostomum subrigidulum. Note growth of mosses at the cascade lip.
d) The Water Forest, Munigou. A large area of active travertine rimstones, colonised by diatoms develops within a dense deciduous forest below Zhaga Waterfall.

Manganese, a minor constituent, was closely correlated with Fe. Data on Pb and Zn in travertines are sparse, but Savelli and Wedepohl (1969) reported higher values of Zn (to 680ppm) in some German samples.

Waters from these sites were not analysed during this study, but previous work by Chou (1987) gave total dissolved inorganic carbon values of 1.8 to 4.2mM/l, and dissolved Ca of 0.85 to 1.65mM/l. These concentrations are characteristic of autogenic karst waters. According to a hydrochemical classification of travertine by Pentecost and Viles (1994), these travertines are probably meteogene (parent limestone dissolved by CO_2 that is derived from the atmosphere and soil zone only). However, the site is at high altitude, and the possibility of a thermal source cannot be discounted entirely.

Flora

Algae

Cyanobacteria (blue-green algae) and diatoms dominated the travertine algal flora. The more common of the fifteen species of cyanobacteria were *Calothrix parietina, Dichothrix baueriana* and *Schizothrix*

Site	$CaCO^3$%	Acid insol. %	Organic %	Mg ppm	Fe ppm	Mn ppm	Pb ppm	Zn ppm
Jiuzhaigou – Nourilang Falls (moss)	92.9	1.1	5.8	2420	375	35	<2	19
Jiuzhaigou – Pearl Falls	97.4	<0.2	2.3	1610	150	10	<2	15
Juizhaigou – Shuzeng Falls	97.9	0.7	0.1	382	2430	107	2	32
Munigou – Upper Falls (moss)	84.6	4.9	9.8	750	5210	320	5	23
Munigou- middle Falls	96.5	2.2	1.1	635	1690	135	<2	38
Munigou- Water Forest	98.4	<0.2	1.3	338	2500	110	2	29
MEAN	94.6	1.48	3.4	1022	2059	120	1.5	26

Table 1. Gross composition of Sichuan travertines from a range of algae- and moss-dominated sites.

Table 2. Flora of the Jiuzhaigou and Munigou travertines.

	Jiuzhaigou	Munigou	W. Europe
Algae			
Cyanobacteria			
Calothrix parietina	X		X
Dichothrix baueriana	X		
Gloeocapsa dermochroa		X	X
G. kuetzingiana	X		X
G. punctata		X	X
Microchaete calothrichoides		X	
Phormidium incrustatum		X	X
P. 'intermedium'		X	X
Plectonema radiosum	X		
Schizothrix pulvinata	X		X
S. vaginata	X		X
Scytonema bewsii	X		
S. bohneri	X		
S. cookei	X		
S. myochrous	X		X
Chlorophyta			
Mougeotia sp.	X		X
Oocardium stratum	X		X
Bacillariophyta			
Achnanthes laevis	X	X	
A. minutissima	X	X	X
Anomoeoneis vitrea	X		X
Cocconeis placentula	X	X	X
Cymbella affinis	X		X
C. cistula	X	X	X
C. delicatula	X	X	X
C. leptoceros		X	X
Bacillariophyta (continued)			
C. minuta f. latens		X	X
C. sp.	X		
Denticula elegans	X	X	X
Didymosphenia geminata	X		X
Eunotia arcus	X	X	X
Fragilaria construens	X		
F. exigua	X	X	
F. tenera	X		
F. ulna	X		X
Gomphonema angustum	X	X	X
G. olivaceum var. calcareum	X		X
G. sp.	X		
Nitzschia sinuata	X		X
Bryophytes			
B. setchwanicum	X		
B. truncorum	X		
B. pseudotriquetrum	X	X	X
Cratoneuron commutatum	X	X	X
C. filicinum	X	X	X
Fissidens grandifrons	X	X	
Gymnostomum aurantiacum	X	X	
G. subrigidulum	X		
Hymenostylium recurvirostrum	X		X
Hepaticae			
Aneura pinguis		X	X
Leiocolea turbinata		X	X
Solenostoma clavellata	X		

pulvinata, but none of these cyanobacteria were found at both Juizhaigou and Munigou (Table 2). Well-defined cyanobacterial mats were uncommon and occurred only where the flow was restricted and probably seasonal. The mats were composed of ubiquitous travertine algae such as *Gloeocapsa kuetzingiana* and *Scytonema myochrous*, with the more unusual and rarely recorded species *Plectonema radiosum* (common and conspicuous at Juizhaigou), *Scytonema bewsii, S. bohneri* and *S. cookei.* Cyanobacteria were generally less common on the travertine at Munigou, with sporadic filaments of *Phormidium incrustatum*, a common European species (Kann, 1988) and the rarely recorded *Microchaete calothrichoides.* Overall, the cyanobacterium flora of the travertines was atypical, when compared with the travertine floras of Western Europe, although the species-richness was similar. *Dichothrix baueriana, Microchaete calothricoides, Plectonema radiosum, Scytonema bewsii* and *S. bohnii* have not been recorded previously from travertine, but are known from Europe on limestone and in calcareous watercourses (Geitler, 1932).

Diatoms were numerically more abundant than cyanobacteria in most of the samples and 21 species were observed on two or more occasions (Table 2). Mainly they were attached forms, either embedded in the carbonate matrix or fixed to the surface by mucilage stalks. A few, such as *Denticula elegans* and *Nitzschia sinuata*, are motile and probably creep over the travertine surface. The relative abundance of diatoms at the two locations is shown in Table 3. The most abundant at both sites was *Cymbella delicatula*, followed closely by *Achnanthes minutissima* (Figs 3a and 3b). The former has been recorded from two European travertines. In England it was a minor component of the Waterfall Beck travertine, an upland site in North Yorkshire, where it was present throughout the year (Pentecost, 1991). In Belgium it was numerically abundant on spring-deposited travertines associated with cyanobacteria and bryophytes (Iserentant, 1988). The species is widely distributed in the calcareous streams and lakes of Europe, ascending to the alpine zone, and not always associated with travertine (Krammer and Lange-Bertalot, 1986). At Peacock Lake, Jiuzhaigou, this species was the major component of large travertine 'bioherms' in shallow water. *Achnanthes minutissima* is more widely distributed on active travertines and is frequently the

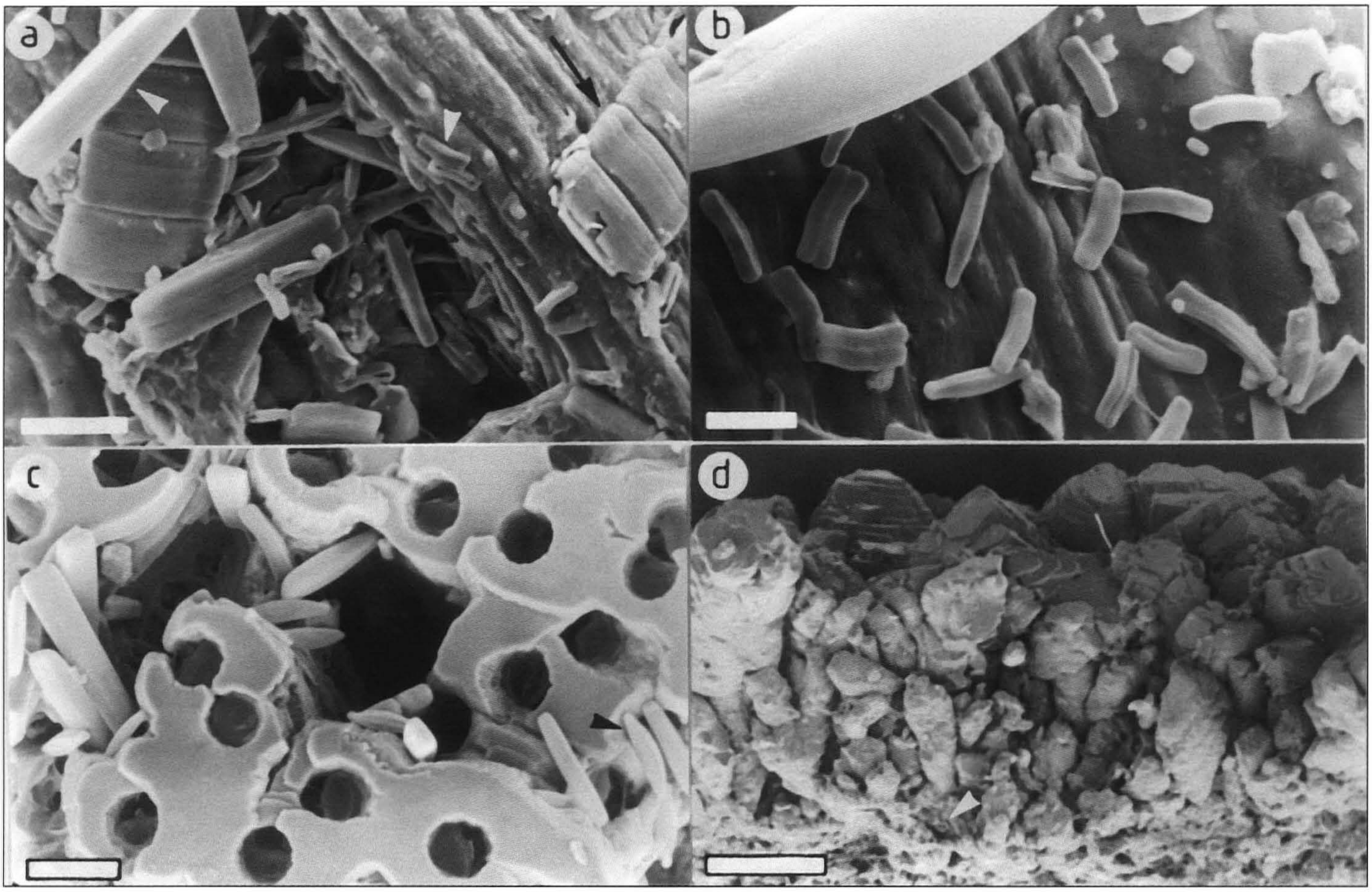

Figure 3. Scanning electron micrographs of bryophyte and travertine surfaces, all critical point dried and Au/Pd coated.

a) Diatoms attached to Gymnostomum subrigidulum c.1mm below the stem apex, Shuzeng, Juizhaigou. On the right (arrow) chains of the oligotrophic diatom Eunotia arcus occur, with small frustules of Achnanthes minutissima (centre arrow) and Gomphonema sp. (left arrow). Small mineral particles, probably of calcite, can be seen associated with some of the diatoms. Bar = 20µm.

b) Detail of Gymnostomum subrigidulum leaf surface 2mm below stem apex from Shuzeng Falls. Scattered frustules of the small diatom Achnanthes minutissima can be seen with a large frustule of Gomphonema sp. (top left). A few particles of calcite are scattered on the leaf surface. Bar = 10µm.

c) Surface of a colony of the calcified desmid Oocardium stratum from fast-flowing water of Pearl Shore, Juizhaigou. The cells are embedded in large crystals of calcite exhibiting plane faces perpendicular to the direction of Oocardium growth. The cells occupied the circular perforations but have been lost, possibly during fixation. Within perforations small discs of mucilage that attached the cells to a long mucilaginous stalk can be seen. The diatoms Achnanthes, Cymbella delicatula (arrow) and Gomphonema are scattered among the perforations. Bar = 20µm.

d) Cross section through an active travertine from a turbulent region of the Zhaga Waterfall, Munigo. The travertine surface (near top) consists of large stepped calcite crystals. A rhombohedron can be seen left of centre. Below, the crystals become progressively smaller and associated with small tubes (arrow) probably filamentous cyanobacteria belonging to Phormidium. Reduction in crystal size is probably the result of biomicritization by cyanobacteria. Bar 200µm.

dominant diatom. It is one of the commonest epilithic species of limestone, and has been found on more than 20 European travertines and on several in the United States (Pentecost, 1990). *Denticula tenuis* was found in small numbers at both of the Chinese sites, and is widely distributed on travertines elsewhere (Hevisi, 1970; Winsborough and Golubic, 1987). *Didymosphenia geminata*, found in abundance on parts of Pearl Shore, Juizhaigou, is noteworthy for its boreal distribution (Krammer and Lange-Bertalot, 1986). In England, it is seasonal and occurs on the travertines of North Yorkshire in the spring. *Gomphonema olivaceum* var. *calcareum* has been described in detail from a European travertine by Winsborough and Golubic (1987), where the mucilaginous stalks become calcified and incorporated into the deposit, but it was not common in the Sichuan travertines. Of the diatoms recorded from the Chinese sites, *Achnanthes laevis, Fragilaria construens, F. exigua* and *F. tenera* have not previously been recorded from travertine. Diatom species found only once are omitted from Table 1, as they are probably casuals and ecologically unimportant (Round, 1981).

Infertile mats of the green alga *Mougeotia* were common on the upper sections of travertine dams at Juizhaigou. Of more interest was the calcite-encrusted desmid *Oocardium stratum*, well known in Europe and the United States for its association with travertine (Pentecost, 1990; Golubic *et al.*, 1993). This species influences the growth of calcite crystals surrounding the cells, providing a regular sequence of crystal faces surrounding the colony (Fig.3c). The ecological requirements of *Oocardium* are unknown. It occurs in fast-flowing alpine and subtropical streams and may be indifferent to water temperature.

Bryophytes

Thirteen moss and three liverwort species were recorded from the travertines (Table 2). Bryophytes were visually more abundant at Juizhaigou, growing on cascades and dams where the flow of water was diminished. Only 50% of these species are known from European travertines, compared with 68% of the algae. Mosses were dominant, common species being *Bryum setchwanicum, Cratoneuron (Palustriella) commutatum* var. *commutatum* and *Fissidens grandifrons* (Fig.2c). These species formed large cushions in moderately flowing water on all slopes and aspects, and were heavily encrusted with travertine. Additional species, particularly *Didymodon (Barbula) tophaceus, Brachythecium rivulare, Bryum*

Figure 3. Scanning electron micrographs of bryophyte and travertine surfaces, all critical point dried and Au/Pd coated.

e) Leaf surfaces of the moss Fissidens grandifroms 1mm below the stem apex from Rhinoceros Lake, Juizhaigou. Impressions of leaf cells are seen clearly in places. Diatoms are frequent and include loose colonies of Fragilaria (arrow, left) and large numbers of Achnanthes minutissima and Cymbella delicatula. Note large crystals of calcite growing in the space between the overlapping leaves. Bar 200µm.

f) Leaves of F. grandifrons 6cm below stem apex. Leaves are densely colonised by diatoms (Achnanthes, Cymbella, Gomphonema) associated with irregular grains of micrite. Bar 200µm.

g) Part of inrolled leaf apex of Gymnostomum subrigidulum 1mm below stem apex from Shuzeng Falls, Juizhaigou. Note micrite within the inrolled margin and absence of algae. Bar 50µm.

h) Three leaves of Bryum setchwanicum 1cm below the stem apex, from Shuzeng Falls, Juizhaigou. This species has its convex leaves closely appressed to the stem. One leaf (bottom, centre) has been removed to reveal micrite deposited in the cavity below it. Note the sharp edge of the calcite deposit where the leaf has been removed and lack of calcite and algae on the exposed leaf surfaces. Bar 200µm.

pseudotriquetrum and *Cratoneuron filicinum*, occurred on the dam rims and cascade lips. In travertine see pages and hollows, a distinct community of *Gymnostomum aurantiacum, G. subrigidulum* and *Hymenostylium* (*Gymnostomum*) *recurvirostrum* was associated with the liverwort *Aneura pinguis.* All of these bryophytes are known associated with travertine in other parts of China (Zhang Zhaohui, 1996) but a boreal influence can be detected through the presence of *Bryum pseudotriquetrum* and *Hymenostylium recurvirostrum.* In Western Europe, the commonest bryophyte associated with travertine formation is *Cratoneuron* (*Palustriella*) *commutatum* var. *commutatum*, which occurs from sea-level to an altitude of at least 1,900m in the French Alps (*authors, unpublished*). Several important European species were absent, notably *Eucladium verticillatum, Conocephalum conicum, Pellia endiviifolia* and *Rhynnchostegium riparioides.* The species richness of the sites is comparable with that of sites in Europe, though the relative paucity of bryophytes at Munigou is noteworthy, and attributable to highly turbulent water.

Plants and travertine formation

Algae and bryophytes have both been implicated in travertine formation (Magdefrau, 1956; Ford and Pedley, 1996) and two processes can be recognised. First, the deposition of calcium carbonate can be established and stabilised by the plant surfaces acting as sites for nucleation and crystal growth. Second, the process of photosynthesis removes carbon dioxide from the water, favouring carbonate precipitation. There is a fair amount of evidence for both processes (Herman and Lorah, 1987; Pedley, 2000) but site characteristics are important, and the extent to which plants are significant varies widely from place to place. Generally, where plant productivity is high and the rate of water flow is low, the biotic component can be expected to be significant. In the area investigated, the mean annual temperature is close to 8°C with a 'growing season' (mean air temperature above 6°C) of about seven months. This is comparable with Waterfall Beck in England, where detailed investigations show that photosynthesis accounts for 5-20% of carbonate precipitation (Pentecost, 1978; Pentecost and Spiro, 1990). A similar 'biotic' component might exist at Munigou, but at Juizhaigou the travertine dams are interrupted by large lakes. The long residence time of karst water in lakes could reduce aqueous CO_2 substantially, by atmospheric gas exchange and phytoplankton photosynthesis. Though there have been a number of 'in lake' studies of CO_2 exchange, photosynthesis and carbonate precipitation (eg. Kempe and Emeis, 1985; McConnaughey *et al.*, 1994), there has been no detailed work in

Species	Juizhaigou	Munigou
Achnanthes minutissima	34.0	14.5
Cocconeis placentula	1.0	+
Cymbella delicatula	42.3	77.6
C. leptoceros	-	3.8
Denticula elegans	2.5	1.2
Didymosphenia geminata	2.3	-
Fragilaria tenera	4.0	-
Gomphonema angustum	2.5	+
G. olivaceum var. calcareum	1.1	-
G. sp.	1.1	-
Total number of frustules counted	520	504

Table 3. Relative % abundance of diatom species at Juizhaigou and Munigou.

relation to travertine dam formation. Nevertheless, the presence of lakes would be expected to increase travertine formation, and it is suspected that the biotic component at Juizhaigou is greater than that reported from Waterfall Beck.

Whereas large-scale chemical budgets provide useful information on the dynamics of travertine-depositing systems, further insights can be obtained from the structural relationship between the associated plants and the deposited carbonate. In common with other active travertines, cyanobacteria were widespread and often intimately associated with carbonate deposits (Merz-Preiss and Riding, 1999). The most interesting observation, however, relates to their distribution in relation to water flow. Under the pounding water of the high cascades, the only plants found in large numbers were endolithic cyanobacteria (Fig.3d). Endoliths have been recorded from other travertines (e.g. Pentecost, 1991; Pentecost *et al.,* 1997), and in some sites have been found to alter the crystal fabric through biomicritization. In the Chinese sites, the association of endoliths with high shear stress suggests that these are the only algae able to colonise the travertine in an otherwise inhospitable high-energy environment.

Calcite particles were seen attached to diatoms growing upon the surface of travertine and on bryophyte leaves (Fig.3b). Although no quantitative measurements were made, there was no obvious relationship between the presence of diatoms and mineralization, and the majority of diatoms were not associated with calcite. Similar observations were reported from a UK travertine but in that case, one species was positively associated with calcite (Pentecost, 1999). However, the species involved, *Rhopalodia gibba*, was not found at the sites in China.

In contrast, the pattern of deposition on bryophyte leaves was more interesting and the progression of travertine deposition could be followed clearly. Since bryophytes grow apically, leaves at the tips of the stems are the youngest, becoming progressively older down the stem. Examination of leaves showed that although there is a progressive increase in travertine deposition with age, it is far from uniform. On the most recently formed leaves little deposition was apparent on *Gymnostomum* or *Fissidens* (Figs 3a and 3e) though diatoms were abundant on the latter. However, this pattern of mineralization became less apparent down-stem, where more general deposition occurred over the entire leaf surface (Fig.3f). Calcite was also deposited preferentially within the inrolled leaf apices of *Gymnostomum* (Fig.3g). The initial confinement of travertine to semi-enclosed spaces was particularly evident in the moss *Bryum setchwanicum.* Here, deposition began beneath the convex leaf surfaces where small volumes of water would be enclosed by the closely overlapping leaves (Fig.3h), whereas deposition was virtually absent on the exposed leaf surface. The occurrence of calcite in these locations recalls the ICS (intercellular space) calcification mechanism found in some marine algae (Borowitzka, 1982) exemplified by *Halimeda* (Borowitzka and Larkum, 1977) and *Padina* (Okazaki *et al.,* 1986).

In *Halimeda* the cortical utricular cells (Fig.4a) provide a series of intercellular spaces in contact with the external medium. There is a significant diffusion barrier for solute molecules and ions passing from the external medium to the ICS, which is in close contact with photosynthesising cells. Photosynthesis removes CO_2 from the ICS leading to a large increase in pH. Diffusion prevents the rapid replenishment of CO_2 from the external medium and the pH rise results in calcium carbonate precipitation. The result is a heavily calcified cortex controlled by the plant's anatomy. There are similarities between the cortical anatomy of *Halimeda* and the leaf morphology of both *Bryum* (Fig.4b) and *Fissidens* (Fig.4c). The leaf structure of the latter is complicated by an infolding of the leaf tissue which further increases the diffusion barrier.

Calcification occurs within the inrolled margin of the brown alga *Padina* but here the process is less controlled and may be an indirect result of the plant's growth mechanism (Fig.4d). However, a parallel can be seen with the strongly inrolled leaf margin of mosses such as *Gymnostomum* (Fig.4e). Bryophyte leaves are unlikely to be designed to induce calcification, although there might be benefits through increased stabilisation, resistance to grazing and protection from high insolation. Other species of *Bryum* and *Fissidens* with similar leaf structures occur in a wide range of habitats where mineralization could not occur, so it is unlikely to be an adaptation to a depositing environment. However, the process may be important in the provision of additional nucleation sites for calcite, eventually resulting in complete burial within a carbonate matrix.

The significance of bryophyte growth on travertine dams was recognised in Burma many years ago (La Touche, 1913). Here it was hypothesised that mosses filtered out calcite particles, leading to

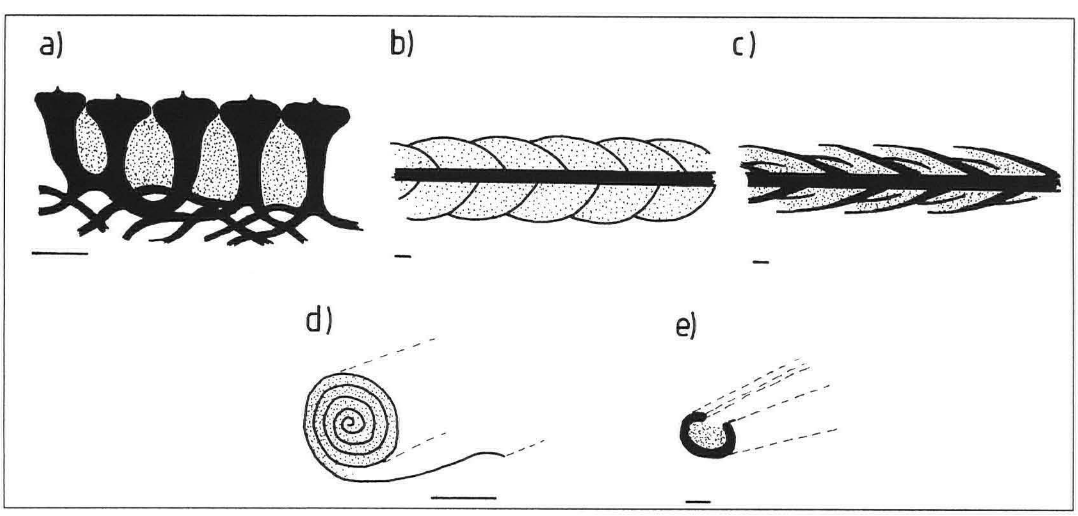

Figure 4. Diagram illustrating structural similarities between two marine calcified algae and two bryophyte genera. Plant tissue black, intercellular space (ICS) stippled. Bar 50m.

a) Section through cortex of the marine alga Halimeda
b) Diagram of stem and leaf form in Bryum setchwanicum
c) Diagram of stem and leaves in Fissidens grandifrons
d) Section through thallus margin of the marine alga Padina
e) Leaf tip of Gymnostomum subrigidulum.

consolidation and dam growth. No evidence of filtration was found on the bryophytes of the Jiuzhaigou dams, though it may occur. There was however a progressive decrease in calcium carbonate deposition toward the growing bryophyte apices. Initially calcite is deposited on specific areas of the leaf, later covering them entirely. It is clear that bryophyte leaf structure influences the early stages of travertine deposition and, thus, dam formation. The calcite saturation index (Ω) of the waters was not measured, but Zhang Jie (1993) found values of 4.07 to 6.31 along the Jiuzhaigou valley. Values exceeding unity demonstrate that calcite precipitation is thermodynamically favourable, providing suitable nuclei are present. It is argued here that such nuclei could be initiated by bryophyte photosynthesis, perhaps aided by evaporation. More general deposition follows, stabilising the bryophyte cushions and leading to dam formation.

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Actively growing subaqueous stalagmites

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Abstract: In this study, stalagmites have been observed to be forming underwater. The stalagmites are found within a flooded horizontal mine adit, where the poolwater is supersaturated with calcite. Pool and drip water chemistry and hydrology were analysed over an annual field cycle. Stalagmite formation was observed to be from drip waters both undersaturated and supersaturated with calcite. Stalagmites were composed of calcite, and were poorly consolidated: all samples were compact on the side faces but several were unconsolidated underneath the splash impact point. Stalagmite morphology varied with drip fall height and overlying water depth. SEM and XRD analyses demonstrate that the stalagmites comprise calcite crystals of 50-200μm, and show no evidence of biogenic particles or binding. Subaqueous stalagmite formation can be postulated to be caused by the disturbance of the impacting drip of surface calcite rafts formed due to degassing and/or evaporative processes, as well as possible calcite precipitation from the mixing of waters at the drip impact point. The stalagmites form by the slow accumulation of calcite crystals, with occasional collapses until a stable structure is formed, which can ultimately be preserved in the rock record. The stalagmites observed in this study can be considered to be an example of the chemogenic precipitation of calcite by a combination of chemical and physical processes. Such evidence has been rarely reported before in either freshwater or marine environments, and should be preserved in palaeokarst environments.

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INTRODUCTION

Stalagmite deposition is generally reported not to occur in subaqueous conditions. It is accepted that conventional calcite stalagmite formation is subaerial and from the degassing of drip waters that contain elevated carbon dioxide concentrations (Holland *et al.*, 1964; Hill and Forti, 1986; Ford and Williams, 1989). Recently, Davis *et al.* (1990) argued that subaqueous helictites (sinuous growths of calcite 0.2 to 2.0mm in diameter and up to 100mm in length) are actively forming in Lechuguilla Cave, New Mexico. The proposed mechanism was chemogenic (the common-ion effect), where calcite-saturated water comes into contact with gypsum blocks, which dissolve and cause the water to come rapidly to calcite supersaturation. This water forms helictites where it enters a pool as a discreet flow. A similar formation process could apply to subaqueous stalagmite formation, where the drip waters have a different geochemical source, causing calcite supersaturation. Alternatively, the formation process may be more complex than simply a chemical reaction, with physical processes such as the displacement of surface calcite films by the impact of drips or the turbulent mixing of water by drip impacts being important. Either process may form more massive calcite precipitates that are likely to be lithified and thus preserved in the geological record. This report describes an example of calcite deposition that is primarily due to chemogenic and physical processes, forming subaqueous stalagmites within calcite-supersaturated mine waters in SW England.

RESEARCH SITE

Subaqueous stalagmites were first observed by the authors at Sharkham Point Iron Mine, South Devon, England (Grid Reference: SX 737546). The geology at Sharkham Point comprises a sequence of Mid Devonian shales, tuffs and limestones, extensively affected by Hercynian folding and thrust faulting (Smythe, 1973). Iron mineralization occurs within the limestone on the north side of the headland. The ore comprises haematite, with abundant barite and lesser amounts of calcite, dolomite and quartz, infilling irregular dissolution cavities in the limestone. The wall rock adjacent to these

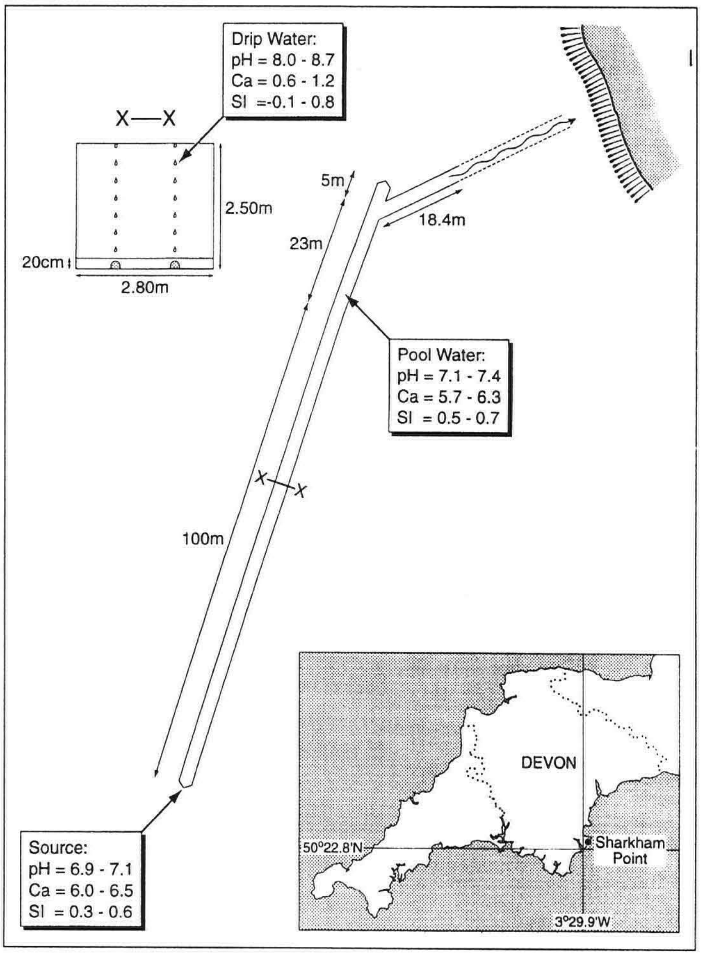

Figure 1. Survey of Sharkham Point Mine. Water geochemical data are shown in terms of pH, calcium concentration in mmol l^{-1}, and saturation index with respect to calcite. Minewater discharges through the mine entrance and flows over a rocky beach into the English Channel.

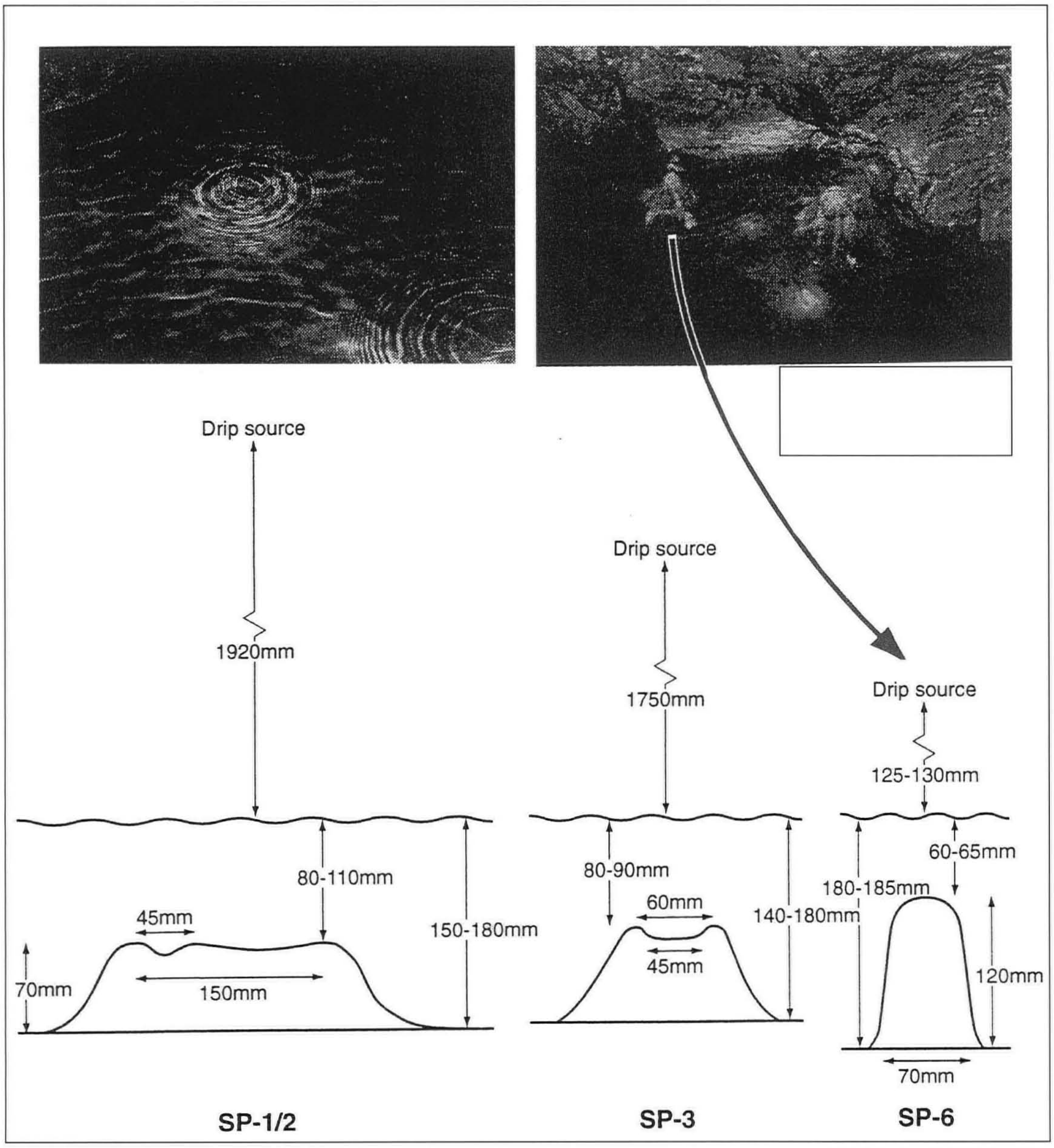

Figure 2. (a) Left: impact of drips with a 2m fall height into the calcite supersaturated pool, subaqueous stalagmites are visible at the base of the pool. Right: subaqueous stalagmites SP-6 and SP-7. (b) Stalagmite morphology of three typical subaqueous stalagmites: SP-1/2 with a double, c.2m fall height drip source, SP-3, with a single, c.2m fall height drip source, and SP-6, with a single, <20cm fall height drip source.

1875 the ore was worked from surface excavations and from adits dug from the coast on the north of the head (Burt *et al.,* 1984). The research site is a horizontal drainage adit (Fig.1) that is approximately 2.2 to 3.0m wide and 1.5 to 2.5m high, containing pooled water 30 to 40cm deep. The pool waters are held back by a tufa-cemented boulder dam near the entrance. Drainage from collapsed old mine workings at the enclosed-end of the adit provides the water supply, and overflow occurs at the adit entrance during the winter months. Calcite rafts form on the pool surface, predominantly at the outward end, and additional flowstone deposition occurs at the enclosed end, whereas tufa is deposited where the overflow water cascades over rocks at the mine exit.

Floor sediments, overlain by the pool water, include stalagmitic deposits. More than 40 such deposits occur; all associated with active drips from the roof of the mine (Figs.1 and 2). Visual inspection of the drip sources demonstrates the absence of stalactites in most cases. The stalagmites are poorly consolidated in their centre, and several have a splash cup on their upper surface. Stalagmite morphology is illustrated in Fig. 2b for stalagmites SP-1/2, SP-3 and SP-6. Significant variation in stalagmite morphology is observed between samples. SP-6 and SP-7 have no drip cup, a smaller diameter and a better consolidation than SP-1/2 and SP-3, which have a greater (2m) fall height (see Figs. 2a and 2b). The stalagmites are also highly friable; stalagmites with splash cups are unconsolidated within the cups to a depth of 2 to 3cm, whereas the remainder of the stalagmite is bound weakly. Those with no splash cup are bound weakly throughout.

SCIENTIFIC METHOD

Three discrete sets of observations were undertaken to confirm that the stalagmites are being deposited subaqueously:

1. The hydrological characteristics of both the pool water and drip waters feeding the stalagmites were observed over both an annual climatic cycle and over a period of several years to confirm subaqueous deposition;

2. The geochemistry of the pool water and drip sources was measured to determine geochemical controls on the deposition of the stalagmites;

3. Subsamples of stalagmite were taken to determine the depositional process and chemical constituency.

The hydrological characteristics of the pool waters were monitored at intervals of 4 to 6 weeks during the 1994 to 1995 period, with additional point samples taken over the period 1994 to 1997. Drip water sources that had associated stalagmites were also monitored for six sites reflecting a range of discharges and calcite saturation. Water samples for geochemical analysis (Ca^{2+}, Mg^{2+}, Na^{+}, SO_4^{2-}, Cl^{-}, K^{+}) were taken from four of the samples (drip sources SP-1/2 and SP-4 and flow sources SP-5 and SP-8) at 3-monthly intervals over the period 1994 to 1995, and analysed using standard MS techniques.

		SP-1 l s^{-1} x10^{-5}	SP-2 l s^{-1} x10^{-5}	SP-3 l s^{-1} x10^{-5}	SP-4 l s^{-1} x10^{-5}	SP-5 l s^{-1} x10^{-5}	SP-6 l s^{-1} x10^{-5}	Pool Depth cm
19/08/94		5.2	1.9	3.1	0.4			
09/09/94		4.2	0.9	2.0	0.4	60	2.1	17.0
14/10/94		4.1	4.1	1.5	0.3	28	2.1	
11/11/94		31	33	1.7	1.7	1700	1.9	18.0
14/12/94		330	230	3.0	2.0	1100	2.0	
13/01/95		28	22	5.3	1.9	>10,000	2	18.0
17/02/95		38	15	15	2.9	>10,000	2	
16/03/95		26	26	8.8	1.6	>10,000	1.7	17.0
27/04/95		7.8	6.8	0.8	7.9	>10,000	1.8	
14/06/95		2.9	5.8	3.8	0.5	>10,000	1.8	15.0
06/08/95		1.7	3.7	0.1	0.4	63	2.0	
mean		45.5	31.7	4.1	1.8	>492	1.9	17.0
stdev		95.9	66.6	4.3	2.2		0.1	1.3

Table 1. Hydrological data for Sharkham Point Mine. SP-1 to 4 and SP-6 are drip sources, site SP-5 is a flowstone. Drip sources SP-1 and SP-2 are separated by 5cm, and feed one stalagmite (SP1/2). Drip rates are calculated from the time between consecutive drips and assume a constant drop volume of 0.15cm^3.

Further samples for total ion chemistry (additional measurements of pH and HCO_3^-) were taken during 1994 to 1997. Total ion balances and saturation indices were calculated using PC WatEq (Rollins, 1987).

One stalagmite (that associated with the drip SP-1/2) was chosen for geochemical analysis, and removed from the mine. A subsample was taken for XRD analysis, the remainder cut and prepared for SEM analysis.

RESULTS

Observations of the pool water during the study period demonstrated that a mean depth of 15 to 25cm was maintained at all times, although a seasonal variation was discernible with a slight (<5cm) lowering in summer. This coincided with the decrease in inlet water discharge, overflow at the entrance of the mine ceased, and evaporation may have occurred. Maximum winter outflow was 0.01m^3s^{-1}; with an estimated total pool water volume in the mine of 60m^3, flow within the mine is laminar during winter overflow, and stagnant during most of the year. Drip water was monitored from six sites, and the results are presented in Table 1. All of them demonstrated variability typical of drip waters in the unsaturated zone (Smart and Friedrich, 1981), and exhibit active discharge at all sites during the study period.

Geochemical results are presented in Table 2. The pool water is highly supersaturated with calcite. The supersaturation is higher than typical in karst waters due to the high sulphate concentrations, probably derived from nearby mineral deposits. Both the pool waters and the drip waters have a high Na-Cl content, approximately 2% of the seawater mean (Wigley and Plummer, 1976), the source of which is sea-spray from the nearby English Channel. Geochemical results demonstrate that some degassing occurs between source and overflow site, with the poolwater remaining supersaturated at all times. Conversely, drip water samples are supersaturated (SP-5) and undersaturated (SP-1/2, SP-3 and SP-8) with calcite, and these correspond perfectly to whether active subaerial stalactite and

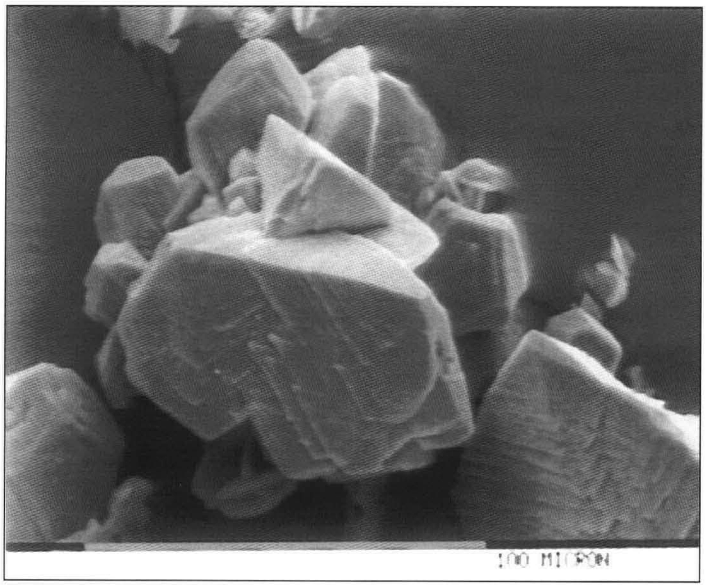

Figure 3. (a) Cross section of stalagmite SP-1/2 under SEM. Calcite crystals demonstrate no preferred orientation and are poorly consolidated, and show no evidence of bacterial action during crystal coalescence.

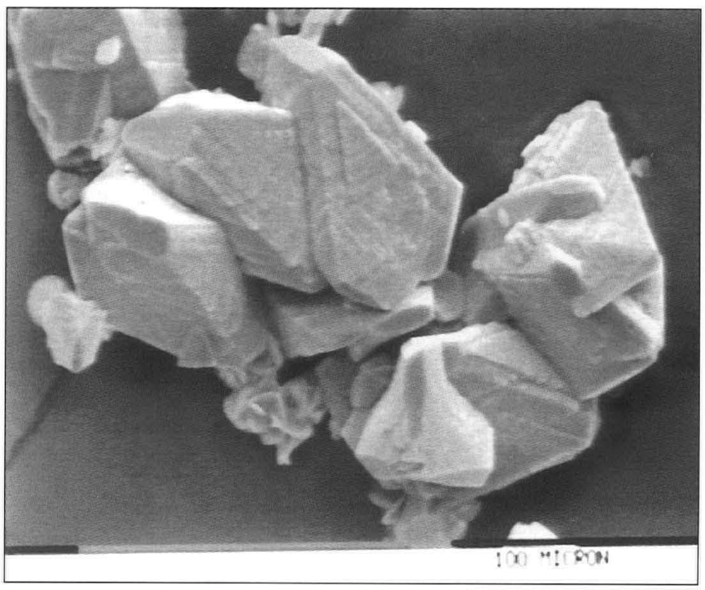

Figure 3. (b) Sample of calcite raft from the same site; note the similarity of form of crystal to that observed in the stalagmite, with the exception of an additional <10µm fraction.

Site		Conductivity µS	pH	Ca^{2+} Mmol l^{-1}	Mg^{2+} Mmol l^{-1}	Ca/Mg	Cl^- Mmol l^{-1}	Na^+ Mmol l^{-1}	Na/Cl	K^+ Mmol l^{-1}	SO_4^{2-} Mmol l^{-1}	HCO_3^- Mmol l^{-1}	Ion balance %	Saturation Index calcite	Saturation Index dolomite
SP-1	mean	1794	8.12	0.69	0.59	1.18	9.06	12.22	1.35	0.11	0.90	2.47	0.76	-0.17	-0.50
	sd	177	0.27	0.07	0.07	0.18	0.69	1.65	0.18	0.01	0.26	0.31	0.38	0.16	0.44
SP-4	mean	2322	8.13	0.85	0.84	0.92	12.5	15.10	1.20	0.17	0.92	2.60	4.95	-0.12	-0.26
	sd	32	0.14	0.19	0.07	0.15	0.82	1.62	0.29	0.01	0.62	0.28	2.81	0.05	0.02
SP-5	mean	1068	8.34	0.99	0.64	1.79	5.38	7.25	1.37	0.09	0.63	3.10	4.50	0.44	0.65
	sd	145	0.28	0.16	0.15	0.52	0.51	0.46	0.12	0.06	0.28	0.14	0.30	0.50	0.89
SP-8	mean	908	8.11	1.39	0.57	1.94	5.18	6.43	1.54	0.06	1.37	2.30	11.45	-0.02	-0.34
	sd	406	0.43	0.42	0.03	0.06	2.59	3.06	0.90	0.01	1.18	0.42	9.83	0.18	0.49
Pool	mean	2427	7.34	5.64	2.27	2.54	5.75	8.03	1.59	0.72	1.99	8.40	5.31	0.62	0.80
	sd	317	0.17	0.98	0.55	0.31	3.77	2.93	0.56	0.10	0.29	0.35	4.17	0.09	0.18

Table 2. Mean and standard deviation geochemical data for typical drip waters and pool water for Sharkham Point Mine. SP-1 is one of two drip sources with no associated stalactite formation supplying stalagmite SP1/2; SP-4 similarly has no associated stalactite from its drip source.

flowstone deposition are present. However, several sources that are undersaturated with calcite (particularly SP-1/2 and SP-3) still have associated subaqueous stalagmite deposits.

XRD analysis on a powdered subsample of SP-1/2 confirmed the stalagmite mineralogy to be calcite. Stalagmite morphology observed over the seasonal cycle was seen to remain fairly constant throughout, although the number and size of the splash cups on SP-1/2 did vary with changing drip discharge. This is shown in Fig.3. SEM examination of the samples demonstrates that the stalagmites consist of small (50-200µm) crystals of calcite, which are randomly orientated and show no interrelation to one another or to the height within the sample. The samples display a growth structure distinctly different from that of subaerial stalagmites (Kendall and Broughton, 1978), and biogenic binding of calcite particles is not present.

DISCUSSION

The stalagmites have been demonstrated to have been underwater throughout the 1994 to 1997 period, and the nature of the outlet from the mine suggests that pooling has probably been maintained since a roof collapse and tufa deposition near the entrance dammed the original outflow route. Drip waters feeding the stalagmites have also been monitored throughout the study period. Hence, it is most probable that stalagmite formation is subaqueous. Stalagmites are associated with drip sources that are both undersaturated and supersaturated with calcite, and hence calcite supersaturation of the drip water is not a prerequisite. Both the stalagmite morphology and crystallography attest to a formation process associated with the drip waters impacting upon the calcite-saturated water. One possibility is that calcite rafts form on the surface of the pool, held *in-situ* by surface tension effects, and formed through evaporation and/or degassing of pool water. Upon drip impact, the disturbance of the water overcomes the surface tension effect and the raft material falls to the bed of the pool, where it slowly accumulates to form a stalagmite. Figure 3b, which presents calcite raft material under SEM, demonstrates a remarkable similarity between this calcite and that found in the subaqueous stalagmites. This confirms that the subaqueous stalagmites are at least in part formed from sunken raft calcite, although the <10µm fraction of raft material appears to remain held on the pool surface by surface tension effects rather than become displaced by the falling drips. The terminal velocities of the falling drips can also explain the stalagmite morphology. The velocity of the falling drips is $6ms^{-1}$ for a 2m fall height, but less than $1ms^{-1}$ for a 10cm fall height. If the drips can be considered as a point source for raft disturbance, then the energy available to displace the raft per unit time would increase with respect to • v. Hence the observation that wider stalagmites are associated with drips with a greater fall height can be explained by drip impact energies. Localised mixing caused by turbulent flow around the drip impact point may also be significant as a factor increasing calcite precipitation. In particular it must be noted that the lithification of the stalagmites must be caused by a process that is not simply the physical displacement of raft material, and is probably due to calcite precipitation binding the crystals together, with the former raft material providing nuclei for precipitation. SEM analysis of the calcite structure attests to a slow accumulation of settling crystals in a stagnant pool, as no sedimentary structures or preferred orientations are observed. Visual inspection of stalagmites *in-situ* demonstrates that collapses occur, similar to micro-scale screes on the stalagmite sides, until a stable structure is formed. Continual agitation of the upper surface of the stalagmite by the drip impacts maintains an erosive cup in quasi-equilibrium with the depositional process.

From the age of Sharkham Point Mine, the accumulation rate of these stalagmites can be determined to be a minimum of 0.5mm yr^{-1}. Subaqueous stalagmite preservation is not commonly observed, as an increase in pool water flow will prevent the continuation of deposition, or at high discharges, destroy the samples altogether. Similarly, disturbance by humans may also destroy these structures before they can be lithified. The authors have sought similar stalagmites at other cave and mine locations, and to date have found only three other subaqueous stalagmite sites: one in a 0.3 x 0.4m stagnant pool within a 160 year-old freestone mine in Jurassic limestone (Brown's Folly

Mine, Wiltshire), one in a pool of similar size and of Holocene age within a cave in Cambro-Ordovician dolomites (Uamh an Tartair, Assynt) and one in a pool of c.1m x 1m and of Holocene age in Carboniferous limestone (Carrigmurrish Cave, Ireland; Fig.4). All three sites are only visited occasionally, and this might support the argument that the deposits may be destroyed by human activity in caves. Further observations are needed to see if similar material is being deposited in other cave and mine sites. Of interest is the observation that stalagmites have only been observed in sites of 10^2 to 10^3 years antiquity. This could suggest that subaqueous calcite is deposited as the first stage of speleothem deposition where there is a pool of stagnant water, before the pool becomes completely filled with calcite and subaerial stalagmites form. If true, then deposits may be observed in the palaeokarst record.

Figure 4. Subaqueous stalagmite in Carrigmurrish Cave, Co Waterford, Eire.

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Vein cavities in the Castleton caves: further information

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INTRODUCTION

Trevor Ford's recent paper (Ford, 2000) on vein cavities in the Peak Cavern and adjacent cave systems in the Derbyshire Peak District is a valuable contribution to our understanding of speleogenesis in this area. The notes that follow are based both upon the author's extensive personal knowledge of many of the sites that Ford (2000) describes, and upon a wider range of literature than that referenced by Ford. It is intended that the information provided below will supplement that in Ford's discussion, and these notes should be read in conjunction with his paper in order fully to understand their significance. For ease of comparison the sites described here are presented in the same order as was adopted by Ford (2000).

Many of the new explorations that prompted Ford's (2000) study are described in great detail in the relevant caving literature. As well as the last decade's issues of *Caves and Caving* referred to, interested readers would be well advised to consult:

- Cave Diving Group newsletters from 1980 to the present;
- Technical Speleological Group journals 11 to 16;
- Derbyshire Caving Association newsletters, from early 1980s onwards;
- *Caves of the Peak District* (1991).

Readers should also refer to Ford's (2000) Figure 2 for a location map of many of the sites discussed below.

Jackpot (P8): The chamber that contains the final pitch and Sump 10 may represent a small vein cavity (Cordingley and Carter, 1997).

Giant's Hole: Ford describes the East Canal vein cavity as extending *"... deep below the water table..."* and refers to the above-water section as *"... about 30m high..."*. Recent exploration has provided more precise dimensions. The submerged part is 25.5m deep (in "normal" water conditions, i.e. when the water is level with the floor of the approach passage from the foot of Geology Pot), where a floor of boulders prevents further descent. A survey and description are available (Cordingley, 1996b). Overhead the rift has been climbed to a total height of 40m (Wright, 1993) and was found to terminate in a "major roof choke". Thus, the East Canal chamber extends for well over 65m vertically. Also, the nearby Maginn's Rift is 25m high (Wright, 1993), not 30m.

Nettle Pot: Exploration by the Derbyshire Caving Club approximately ten years ago (O'Neill, 2000) led to the discovery of another large, elongate cavity forming part of the Red River Series. The "final depth" of the Nettle Pot system is 180m (Gill and Beck, 1991).

Mountbatten Pot: This immature shaft does not seem to have the characteristics of the more typical vein cavities in this district. It is seldom visited, but a detailed description is available (Elliott, 1975). This reference includes an elevation and a photograph of the main part of the shaft. It is described as a *"... natural waterworn fissure..."* that is *"...extremely narrow in places..."*, which makes ladder climbing *"very awkward"*. This fairly detailed source makes no reference to any mineral vein, and the site may simply represent a vadose, joint-guided shaft rather than a true vein cavity.

Winnats Head Cave: The impressive Fox Chamber appears to meet the criteria for inclusion in a list of major north Derbyshire cavities but is not included in Ford (2000).

Longcliff Mine: The most helpful description of the vein cavity herein is provided by Ford (1962), and includes a useful area map and underground survey. The investigations detailed by Ford were actually carried out in 1943 to 1944. Note that collapses that occurred in the early 1980s now prevent access to part of this mine and cavern.

Bottomless Pit (Speedwell Cavern): The floor of the 8m-deep lake is composed of thick silt, as opposed to "boulders" (Cordingley, 2000).

Halfway House Caverns (Speedwell Cavern): Recent exploration has revealed that the height of the large rift chamber is much greater than *"around 30m"*. The large aven rising above The Balcony in Justification Chamber and Royse Hall (Marsden, 1991) has been climbed (and radio-located) to a point some 12m from the surface on the south side of the Winnats Pass (Ball, 2000). Also, the submerged base of this large rift ("Stemple Sump") has been explored underwater to a final depth of 16m (Cordingley, 1994, 1996a). The best minimum estimate of the overall vertical range of this classic vein cavity is therefore 117m.

Pit Props Extension (Speedwell Cavern): A significant mineral vein cavity not described by Ford (2000) lies on the south side of the Speedwell streamway, just upstream of The Bung Hole waterfall. This is possibly formed within the same vein as Block Hall.

Whirlpool Rising (Speedwell Cavern): A significant vein cavity is encountered in the underwater passage here, 122m upstream of the dive base. The main flow of water rises up this from a choke of large boulders at approximately 11m depth (Nasse, 1996). It is possible to see down at least a further 5m between the boulders, but divers have been unable to descend further. This vein cavity is almost certainly formed within Faucet Rake (Westlake 1983; Murphy, 2000).

The Assault Course (Speedwell Cavern): Ford (2000) describes the aven on Faucet Rake as having been *"... climbed to about 60m..."*. This important vein cavity is now known to have a vertical range of 97m, and also includes a fine example of a mineral *"flat"* between the 3rd and 4th pitches (Nixon, 2000). The extensive calcite, barite, galena and fluorite mineralisation here represents an important "type locality", as the area was never entered by the former lead miners and is therefore undamaged.

Leviathan (James Hall's Over Engine Mine): The intersection of New Rake with the (highly cavernous) Stemple Highway Vein accounts, at least in part, for the scale of this large void, along with other important vein cavities associated with J H Mine. Some of these latter cavities have suffered at the hands of the former miners but one chamber is notable for still containing a fine display of large green scalenohedral calcite crystals (Nixon, 2000). The history of mineralisation and speleogenesis of this area of the Peak Cavern system is complex and, whereas the Leviathan shaft is undoubtedly significant, it should not be considered in isolation.

Bathing Pool (Speedwell Cavern): The aven above this large sump pool has been climbed to reach a flowstone blockage at a height of 12m (Cordingley, 1989a). The explored depth of the sump is 26.3m (Murphy, 1994), to a point where a localised restriction prevented exploration of the descending continuation. Thus, the large cavity here has a vertical range of at least 40m.

Russet Well: The maximum accessible depth of the submerged passages here is only 25m (Cordingley, 1987).

The Schoolroom Aven (Peak Cavern): The "Schoolroom" airbell, 12m from the downstream dive base of the Resurgence Sump, contains an aven. This has been climbed for approximately 20m to where further exploration was prevented by a hanging boulder choke (Smith, 1981). Although this reference is brief (and does not include any geological notes), it appears that the aven is similar in form to some of the other vein cavities listed in Ford (2000).

Roger Rains House (Peak Cavern): According to Cordingley (1988) this vein cavity is actually over 40m high, and lies within the easterly continuation of Faucet Rake rather than New Rake. The vein on which Roger Rains House is developed has an obvious surface outcrop in Cavedale above.

The Vestibule (Peak Cavern): Ford (2000) makes the valid point that there is *"... clear evidence of dissolution along fractures under phreatic conditions..."*. Indeed, some of these fractures have large roof passages, clearly of considerable age, developed within them. These passages include The Krypton Series (Cordingley, 1985) and The Mendip Beer Monster's Secret Tap Room (Cordingley, 1993). The latter is a large, phreatically-enlarged passage, with a vertical range of 60m. It may have fed an early vauclusian-type spring (now truncated, choked and obscured by surface deposits) that predates the "main" vauclusian resurgence from The Vestibule at the head of what is now the Peak Cavern gorge.

Buxton Water Aven (Peak Cavern): This towering aven (entered partway through Buxton Water Sump) is not mentioned in Ford's (2000) description. It is probably developed within the same fault as the nearby Victoria Aven. The cavity was first entered more than 50 years ago - shortly before the Cave Diving Group oxygen divers made the breakthrough into the main part of Peak Cavern - when it was referred to simply as the "Forward Halt 1". The aven is about 80m high (Wright, 1992) and is shown on the most recent divers' survey of Buxton Water Sump (Carter and Cordingley, 1994). It has been climbed for 55m (Wright, 1993), to where further upward exploration was prevented by loose fault breccia.

The White River Series (Peak Cavern): Ford (2000) describes this as *"An ancient high-level vadose system...".* The main part of this series consists of a major abandoned trunk route (Nixon, 1991, 1992) known as "The Kingdom" (see Plate 1). Although vadose shafts convey underfit streams down towards the level of the Peak Cavern main streamway, The Kingdom has many classic phreatic features, including a sub-tubular cross section with fine rock pendants and roof half tubes. Vadose modification has played a notable role in its formation (Beck, 2000) but the major developmental factor was dissolution under phreatic conditions. The only true vein cavity in this part of Peak Cavern is "Vug Inlet Aven" (Nixon, 2000), which lies on the south side of The Kingdom, where the latter crosses New Rake. Interestingly, the vein appears to have played little or no role in the inception of the main phreatic trunk route, which has preferentially followed a single bedding plane straight through New Rake.

Galena Rift and EMT Aven (Peak Cavern): These two recently-explored sections of cave (Sullivan, 1998) contain a large and impressive vein cavity (note the reference to lead ore in the name), but are not mentioned in Ford's (2000) paper. They are close to Peak Cavern's Galena Chamber, which is itself a possible vein cavity of the type described by Ford (2000).

Far Sump Extension (Peak Cavern): This is listed incorrectly as "Far Peak Extension" in Ford's (2000) text and as "Far Peak" in a the caption of his Plate 4; there are no such places. The complex of

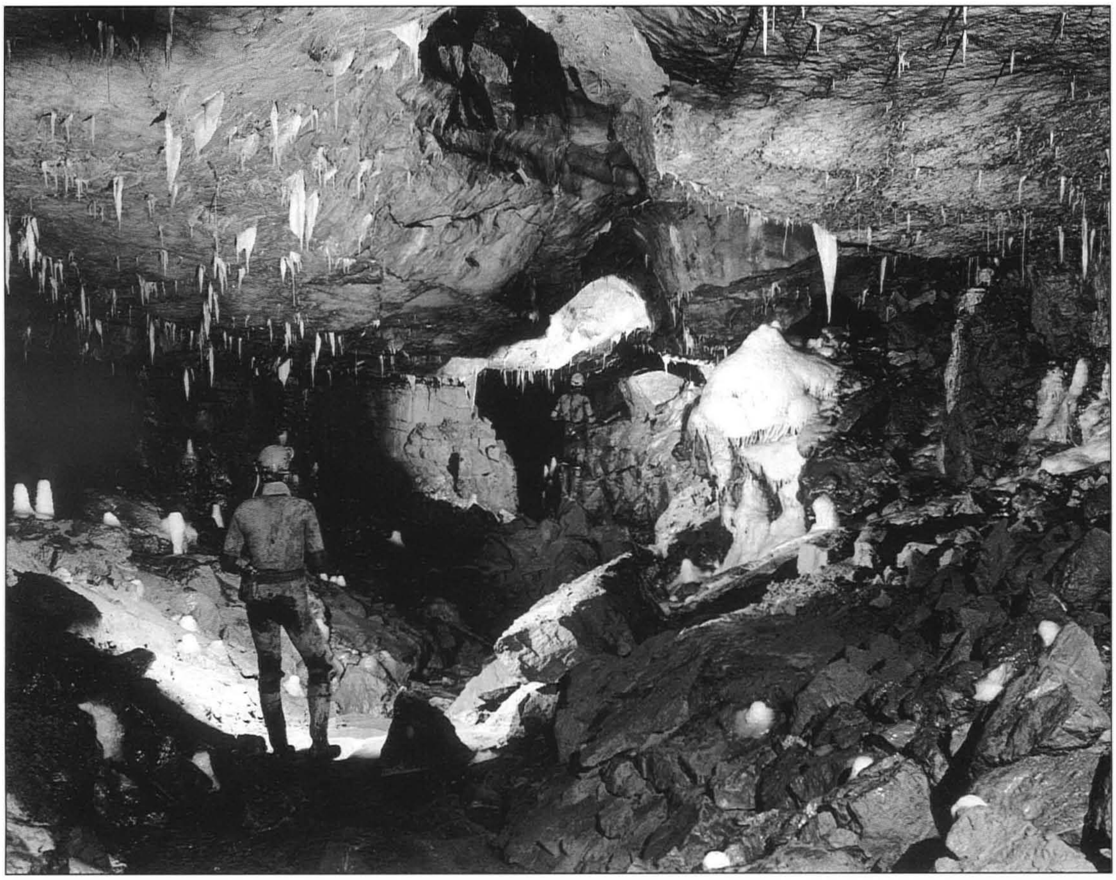

Plate 1. Part of The Kingdom, White River Series, Peak Cavern. The well-developed half-tube visible in the ceiling suggests an early phase of "phreatic" development (Photo by Clive Westlake).

passages here includes some of the finest and most extensive vein cavities in the United Kingdom. A total of more than 600m of vertical shafts is contained within a relatively small plan area. Ford mentioned most of these cavities but readers may find some additional notes helpful:

Stemple Highway, Balcombe's Way and Salmon's Cavern (Peak Cavern): This large complex of vein cavities has a vertical range of approximately 105m. Its highest development is limited by a prominent clay bed (wayboard), which has also guided the formation of an extensive but low phreatic bedding plane passage known as The Total Perspective Vortex. The wayboard is probably the same as that which limited the upward development of the high-level passages above Speedwell's Cliff Cavern nearby (Cordingley, 1989). It is also believed to have had a similar upwardly limiting control in the Leviathan shaft entered from James Hall's Over Engine Mine (where it crops out in the roof of the First Miner's Workshop). The most impressive vein is situated in Calcite Aven, where a vertical sheet of calcite more than 5m wide includes house brick-size calcite rhombs (Plate 2). A chamber formed completely within this massive calcite deposit was entered after a difficult free climb (Plate 3) from partway up Calcite Aven. The only belay from which to effect the descent was a natural bridge of vein material spanning the chamber (Cordingley, 1992).

Major Sump: Ford (2000) describes the large choked vertical submerged shaft terminating the western end of the Far Sump Extension as *"...having "minimal mineralisation..."*. However, a large and obvious vein, seen only by divers, is exposed below water level. The location of the submerged vein, which is up to 0.5m in thickness, was marked on an elevation by Cordingley (1997). Major Sump represents the top of an abandoned (but once substantial) rising, similar to the presently active Main Rising in Speedwell Cavern.

Titan: Britain's biggest natural shaft is on a scale more usually found in continental caves. However, the 160m height of the vein cavity quoted by Ford (2000) is an underestimate. Access to this magnificent aven from Far Sump Extension is by climbing upwards through extensive chokes of boulders that obscure the lower 30m of the cavity. Also, the presence of vein material (Cordingley, 2001) at a depth of 3m directly below Titan in a recently explored submerged passage in Far Sump (where the sump surface is at 214m ASL) probably indicates development associated with the vein/fracture that guided the formation of the Titan shaft. Furthermore, the surface dig at 430m ASL (that will eventually penetrate the choke at the "top" of Titan) is in a large choked shaft formed within the same vein. Therefore, the true vertical range of the Titan is probably at least 219m. Although the mineralisation is not particularly impressive at the shaft base, it is very significant in the upper parts of the cavity. A comment by one of the explorers (Nixon, 2000) illustrates the point: *"At the top of Titan, where the rope is belayed, you are surrounded by massive rhombs of calcite forming large rosettes, very similar to those in Calcite Aven."* (see notes on Calcite Aven above).

Long Rake Mine: Ford (2000) states that the natural part of this system does not appear *"... to be related to younger vadose cave*

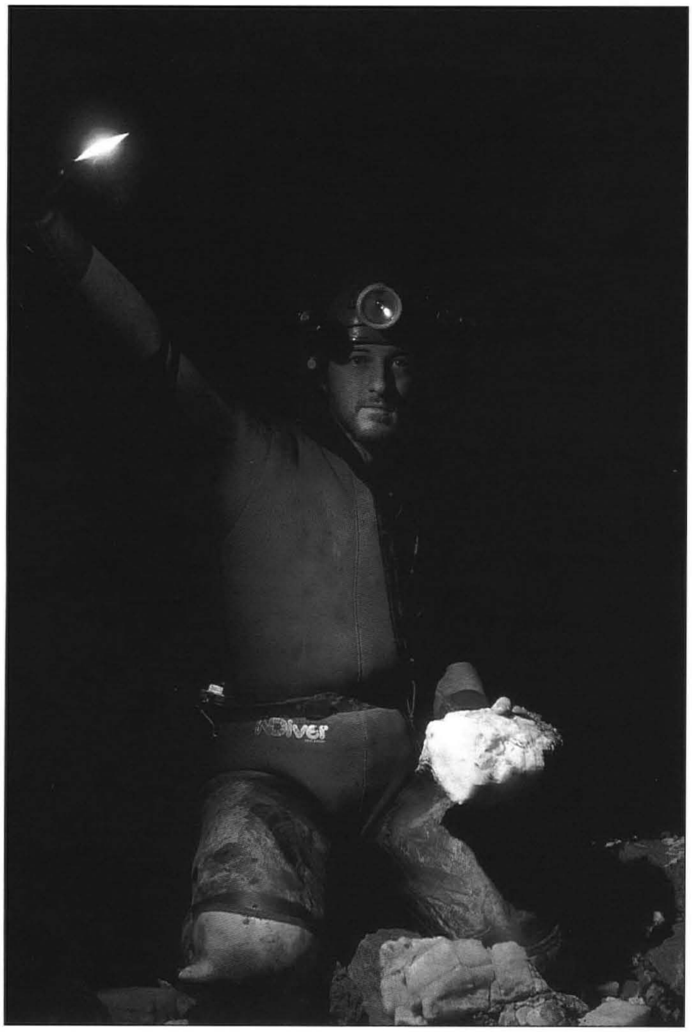

Plate 2. Large fragments of fallen vein material litter the floor of Calcite Aven, Far Sump Extension, Peak Cavern (Photo by John Cordingley).

Plate 3. The first ascent of Calcite Aven (Far Sump Extension, Peak Cavern) in 1998. The Aven is so named due to the presence of the 5m-thick vein visible to the left of the climber (Photo by John Cordingley).

networks...". However, one of the main exploration references (Lord and Worthington, 1969) mentions a substantial stream seen in the lower part of this impressive vein cavity. The flow is at least between 1 and 2 litres per second (Worthington, 2000).

New Venture Mine: Ford (2000) refers to a single vein cavity extending to a depth of 66m. Though the natural development seen in this mine is undoubtedly significant, Wright and Worthington (1971) do not mention that it is formed within a vein.

An additional point worthy of comment is Ford's (2000) view of: *"... the restriction of the known vein cavities to the top 200m or so of the limestone...".* The Titan cavity probably extends (via the choked shaft currently being dug) virtually to the surface at Hurdlow. Furthermore, the nearby (deeply submerged) "New Leviathan" shaft in Speedwell's Main Rising sump is known to extend beyond a depth of 70m. A better estimate of the extent of vein cavity formation would therefore be at least the uppermost 285m of the limestone. Indeed, there are reasons to believe that the submerged passages of Main Rising may well extend to far greater depth (Beck, 1995; Ford, 1995). Thus, the vertical range of "known" vein cavity development in the north Derbyshire limestone is probably more than 300m. Furthermore, the existence of warm springs in the region (Worthington and Ford, 1995), from which some water of meteoric origin resurges, suggests that primary vein cavities may exist at depths in the order of a kilometre or so (Beck, 2000; Worthington, 2000).

In conclusion the author would like to endorse Trevor Ford's comment: *"As exploration continues, more vein cavities will undoubtedly be found".* Those cave explorers who have expressed the view that Derbyshire is "played out" should take note of this assertion.

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Bivalves (Pisidiidae) in English caves

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Abstract: Four new records of Pisidiidae are reported for English caves. Bivalves may form a largely ignored component of some subterranean aquatic invertebrate communities. In view of the poor dispersal ability of this family of bivalves, the viability of cave populations is considered, and potential modes of colonisation explored.

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REPORT

Few bivalve specimens have been recorded from British caves, although cavernicolous species of *Pisidium* (Pisidiidae) and *Congeria* (Dreissenidae) are known in Europe and Japan (Chapman, 1993). Historically, two species of Pisidiidae commonly associated with surface waters (*Pisidium personatum* and *P. obtusale*) were recorded relatively frequently in Irish caves, commonly under muddy conditions too foul for other species (Hazelton, 1974a). Both of these species were recorded in Fisher Street Pot, within the Doolin cave system (Co. Clare), where they are likely to have been carried into the cave by tributaries of the Aille river (Hazelton, 1974b).

Other subterranean records for *Pisidium* in the British Isles include: *Pisidium nitidum* in Pen Park Hole, Bristol (Hazelton, 1975); immature specimens of *Pisidium* in Skoska Cave, West Yorkshire (Hazelton, 1963); and *Pisidium casertanum* in Jeannie Barries, Carlops (Peebleshire) (Hazelton, 1978). This last species has also been found in the Sanctuary Well at St. Mawnan (West Cornwall), a well in a stone-built shelter, consisting of a 1.25m-deep pool fed by a spring (Hazelton, 1970). *P. casertanum* is a highly successful and widespread species, occurring in many different habitats, including those prone to desiccation (Ellis 1978; Kerney, 1999).

Cave biology has been something of a minority interest in the British Isles since the late 1970s and there have been relatively few records of cave fauna reported in British academic literature during this period. However, in the past few years this has begun to change (e.g. Wood and Sadler, 1997; Moseley, 1997; Knight, 1999; Gunn *et al.*, 2000). As part of this renewed interest, four new records of *Pisidium* spp. are reported here, from Devon and from the Derbyshire Peak District. These records are significant because they raise questions regarding the mode of colonisation and viability of subterranean bivalve populations. In each reported instance, only representative specimens have been removed from the caves for detailed examination and identification, to avoid excessive disturbance to populations and the geo-ecosystem in general.

The first of these records is from Fairy Hall Quarry Cave, near Buckfastleigh (Devon) (NGR: SX 743 666). During January 2000, a relatively large population of the pea mussel *Pisidium personatum* (Plate 1) was recorded in a pool near excavation works at the end of the cave. The pool, fed by seepage water, is approximately 0.75m in diameter and up to 0.5m deep. These dimensions are likely to fluctuate with water levels within the surrounding karst. The pool substrate consisted of glutinous mud, rich in organic matter, with a layer of coarser detritus on top. A large number (probably more than 100) of fragmented valves and live specimens of *Pisidium personatum* were observed. Three adult *Niphargus aquilex* (Crustacea: Amphipoda) were also observed in the pool, and a single juvenile was seen in a smaller puddle nearby. Other fauna in the cave consisted of several specimens of Collembola observed on the surfaces of pools throughout the dark zone of the cave.

The other records are all in the Derbyshire Peak District, and consist of a population of *Pisidium nitidum*, recorded at Lumbago Pool in Peak Cavern, Castleton (NGR: SK 1486 8249) over a three-year period (Gunn *et al.*, 2000). No individuals were recorded on the surface of the substratum, probably due to predation by the freshwater shrimp *Gammarus pulex* (Crustacea: Amphipoda), which is common at the site. In addition, *P. personatum* have been recorded from the main streamway in the adjacent cave, Speedwell Cavern (NGR SK 1390 8205), under a wide range of different flow conditions. The valves of the individuals recorded were in some cases heavily encrusted and stained orange/brown, due to burial in the substratum.

The final record comes from farther south in the Peak District, in Lathkill Dale, close to the Garden Path entrance (NGR SK 165 660) of Lathkill Head Cave. About 50 live individuals of *P. personatum* were counted on the surface of the substratum of a small pool approximately 0.5m in diameter. A wide range of sizes (from small juveniles to

Plate 1. Pisidium personatum *from Fairy Hall Quarry Cave (Devon). The valve is c.3mm across at its widest point.*

individuals >3mm in size) was observed, suggesting that adults are able to reproduce successfully at the site. In addition, a number of Tubificid worms (Oligochaeta) and Copepoda (Crustacea) were observed in the pool.

The primary question raised by the discovery of *Pisidium* in caves is:- *Do the populations recorded form viable cavernicolous populations?* A large population of *P. personatum* has been recorded in relatively favourable conditions in a subterranean environment in the Morecambe Bay area (Moseley, 1970), and large numbers of *P. personatum* and *Gammarus pulex* were reported in the sump pool in Hazel Grove Main Cave (Cumbria). The pool was fed by seepage water and lined with deep, rich mud, which contained a high proportion of organic matter. Microscopic examination of the water revealed numerous ciliates, feeding on the bacteria breaking down the organic matter within the mud. In turn the Pisidium and Gammarus probably fed upon these ciliates. As the population of *Pisidium* formed an isolated group, surrounded by an apparently adequate food supply, it is likely that they formed part of a viable cavernicolous population (Chapman, 1995). However, Moseley (1970, p.48) stated that:

> *"... a small isolated population such as this tends to be unstable and to show random fluctuations in numbers, which at any time may decrease to zero without any outside influence (e.g. the food supply may become insufficient). Such a population is at best an impermanent member of the cave fauna."*

Further study of the Morecambe Bay and Fairy Hall populations would be required to examine any fluctuations in numbers. However, the range of sizes of individual recorded at the sites in the new records suggests that as long as the site does not experience prolonged desiccation, and food resources remain available, the population would probably be viable.

The presence of isolated bivalve populations, such as those reported above, leads to a second question:- *How do Pisidiidae get into the cave(s) in the first place?* In Speedwell Cavern it is known that a number of sinking streams form the primary input of water (Gunn, 1991). Juvenile and adult pisids have been recorded in these streams (Gunn *et al.*, 2000) and so may have been carried into the caves under high flow conditions. However, seepage water feeds the pool in Fairy Hall Quarry Cave (Devon) and there are no permanent waterbodies or watercourses on the land above the quarry. Similarly, Lumbago Pool in Peak Cavern (Derbyshire) is fed primarily by percolation water, although a stream sinking in Cave Dale also contributes some water (Gunn, 1991). At present details of the internal hydrology of the pool in Lathkill Head Cave are imperfectly understood, and they require further investigation.

P. personatum can tolerate a wide range of environmental conditions and have been recorded in stagnant water, puddles and temporary pools (Ellis, 1978), commonly in places that dry up during the summer months. Occasionally they have been found away from standing water, for example under ground-litter in marshy woodland (Kerney, 1999). It is therefore possible that this species could be carried into the caves from marshy areas in the catchment above. Due to the relatively small size of these bivalves it may be possible for resilient taxa such as *P. personatum* to live in water-filled mesocavernous spaces within the karst surrounding cave systems. Other organisms such as *Niphargus* have been observed to retreat into these spaces when fluctuating ground water levels lead to the pools they inhabit drying up (Knight, 1999). In addition, the high moisture content of the air in many caves means that the sharp division between the terrestrial and aquatic habitats on the surface is not so clear cut beneath the ground, and many aquatic organisms have been observed moving over a thin film of water on rocks (Knight, 1999). *Pisidium* can crawl upside down, suspended from the surface film of water, by secreting a film of mucus and advancing along it by ciliary action, supported by surface tension (Ellis, 1978). This form of locomotion means that *Pisidium* might be capable of moving along thin films of water on rock surfaces within air-filled mesocavernous spaces. However, one final alternative for the presence of bivalves in some caves is that, due to their small size, individuals may have been carried underground on the clothing and, more likely, footware of cavers. Clearly, further work is required to examine the different modes of colonisation and the presence of Pisidiidae in other cave systems.

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Forum

Readers are invited to offer thesis abstracts, review articles, scientific notes, comments on previously published papers and discussions of general interest for publication in the Forum of Cave and Karst Science.

All views expressed are those of the individual authors and do not necessarily represent the views of the Association unless this is expressly stated. Contributions to the Cave and Karst Science Forum are not subject to the normal refereeing process, but the Editors reserve the right to revise or shorten text. Such changes will only be shown to the authors if they affect scientific content. Opinions expressed by authors are their responsibility and will not be edited, although remarks that are considered derogatory or libellous will be removed, at the Editors' discretion.

CORRESPONDENCE

Comments on the paper "Carbon monoxide poisoning: a potential hazard to speleologists ?" by E R Bregani, T Ceraldi, A Rovellini and C Camerini, (*Cave and Karst Science*, Vol.26, 3) December 1999

Dear Editors,
Having been a member of Gruppo Grotte Milano for more than half a century, I feel rather embarrassed to criticize a paper written by young colleagues in the same Group. On the other hand, having also been a member of the BCRA (and its predecessor) since 1954, I feel obliged to be honest with regard to the contents of our journal.

First of all, I have never found any indication of CO poisoning in caves during my own caving career. Therefore, as such poisoning appears to be relatively uncommon, it would have been preferable to start from an evaluation of the maximum release of CO from acetylene lamps under the worst possible operating conditions. Then, an evaluation of the maximum potential concentration to be expected in a closed cave environment should have been performed. At this point, if - and only if - a possibility of generating CO concentrations of concern from the health point of view had been recognised, the study reported by Bregani *et al.* could have been carried out.

Unfortunately, such a study as was performed appears something of a nonsense, because the results listed in Table 1, with standard deviations of around 25% for COHb and 50% for MetHb, are of a little practical value.

My conclusions are that this "study" was performed without any sound theoretical basis and that its experimental procedures were inadequate. I regret having to say this but, in my opinion, the "study" would be best forgotten.

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Reply from the authors, Dr Angelo Rovellini, M D and Dr Tiziana Ceraldi, M D

Dear Editors,

We are grateful for the chance of answering the comments by Mr Cigna.

The first criticism on our paper seems to be that no theoretical basis supports our hypothesis of CO poisoning in cave exploration with acetylene lamps. We agree with Mr Cigna that our work does not show any direct evidence of CO production by acetylene lamps. However, previous studies have demonstrated that incomplete combustion of hydrocarbon fuels, such as acetylene, results in CO production (1–3).

We appreciate that Mr Cigna never found any indication of CO poisoning during his own long history of caving activity. Nevertheless, anyone exercising medical practice knows that CO poisoning is a protean syndrome, characterised by heterogeneous symptoms, ranging from mild and equivocal disturbances (fatigue, headache, dizziness, nausea, dyspnea, tachycardia, tachypnea) to coma (1, 4). Moreover, in spite of Mr Cigna's opinion, it is not true that CO-poisoning is uncommon, provided that it is investigated, as shown by a large series of previous studies (1, 2, 4).

Mr Cigna suggests that it would have been preferable to start from an evaluation of the maximum CO potential concentration in a cave environment in order to support the hypothesis of CO poisoning in cave exploration. We must remember that symptoms of CO poisoning and blood CO concentration have been demonstrated to be only in part dependent on CO environmental concentration (1-2). Many cases of CO poisoning occur for local causes rather than for environmental ones (2). This is mainly due to the extremely high affinity of CO to haemoglobin (200-250 times higher than O_2).

We underline that our work aimed to evaluate whether acetylene lamps produce any CO-related effects on speleologists during cave exploration. Therefore, whereas elevated environmental or in vitro CO values should support the hypothesis of CO poisoning, low environmental CO values should not exclude this effect.

The comments of Mr Cigna on the standard deviations (SDs) of our data may be viewed as "nonsense". Our SDs for COHb and MetHb were respectively 0.29 vs 0.217 and 0.237 vs 0.192 (24% vs 23%, and 81% vs 48% of mean values). These results should not surprise anyone with experience in biomedical statistics. Many biological variables in the international medical literature show similar SDs: see for instance recent articles in the *Lancet* or in the *British Medical Journal* (5-6). In addition, mean and individual values of COHb and MetHb in our study had no clinical relevance, with the results all lying in the normal range. These very data led us to conclude that CO is absent or at minimal, non-toxic, levels in cave exploration.

Thus we find no substantial reasons for the criticisms by Mr Cigna, though we firmly believe that comments must always be welcome. Obviously, everybody is free to "forget our work".

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Bell holes

I read with interest the *Cave and Karst Science*, Vol.25(3) paper by Tarhule-Lips and Ford on bell holes in the entrance areas of caves in the Cayman Islands. Their conclusion that bell holes are formed by condensation corrosion seems likely, though the role of microbiological activity is less certain. Biofilms would certainly assist the early development of a roof cavity, but as the bell hole deepens, so the reflected daylight dims. Their suggestion that the strict verticality of bell holes is due to the gravitational fall of part-corroded bedrock grains is not convincing. I don't dispute that grains do fall in this way but, if this were the dominant process, one would expect vertical upwards development to be a common feature in the condensation corrosion environment. The strict verticality of bell holes is their most interesting feature, and seems particularly suitable for characteristic symmetry analysis. A personal knowledge of bell holes is not necessary, as the published paper contains such good observational data.

Bell holes are vertical corrosion features in the roofs of cave passages, found near cave entrances in the humid tropics. They are circular in cross-section and normally have a gradual outward taper from top to bottom. Their most striking feature is that they are always vertical, whatever the inclination of the roof or the dip of the strata. As stated by Pierre Curie (1894), *"There is no effect without cause."* The symmetry aspects of this relationship can be expressed as: *"The characteristic symmetry (or the dissymmetry) of an object or medium must be found in the causes that generated that object or medium".* (This form of words is simpler than Curie's very precise definition; it was formulated in Russian and first published in English (Stepanov, 1997) under the title *"The Curie Universal Symmetry Principle"*).

In the case of bell holes, there is a clearly expressed vertical dissymmetry. (Note: dissymmetry can be thought of as the set of symmetry elements that are missing. This is not the same as asymmetry, which is a general lack of symmetry.) We must therefore look for vertical dissymmetry in the cause of bell holes. The two most common causes of vertical dissymmetry in caves are (1) gravitation and (2) the geothermal gradient.

If we consider gravitation first, we should note that condensation is not the exclusive preserve of cave ceilings. In this capillary film environment, condensation occurs in substrate hollows (whether on ceilings or walls) and evaporation takes place from substrate protrusions. Where there is significant evaporation, corallites or crystallictites will form. There are no such speleothems mentioned by Tarhule-Lips and Ford. The material dissolved within the bell hole has been removed by the capillary film and the only possible direction is downwards. There is no grooving within the bell hole, so this is still a capillary film environment, but there is a gravitational component in the direction of movement of the thin film. The bell hole is circular and smooth-sided because condensation takes place uniformly on all surfaces. This is because the warm humid air that is trapped there each morning remains motionless and allows random diffusion of water molecules towards the substrate (i.e. there is spherical symmetry of supply). The shallow taper of most bell holes is explained adequately by Tarhule-Lips and Ford as the weakening of the chemical aggressiveness of the lower parts of the capillary film by admixture of saturated water from above.

The origin of bell pits follows directly from these observations. The capillary film from the bell holes either migrates across the cave roof or falls to the floor as gravitational drips. This explains why bell pits are usually, though not always, located beneath bell holes. From this it can be seen that the origin of both bell holes and bell pits can be explained by the gravitational migration of a thin capillary film. The gravitational fall of part-corroded bedrock grains is not excluded from this analysis, but it is not a necessary component.

If we now consider the geothermal gradient, we would expect its effect to be evenly distributed across the roof of the cave (unlike gravitation, which only affects local areas of condensation). We can discount this factor from the origin of bell holes. However, vertical corrosion of the whole roof does occur in ore karst (isolated cavities with no surface connection, found in mineralised limestones). When intersected during mining, such caves often prove to have migrated upwards through the bedrock. The processes at work are an evaporation/condensation cycle fuelled by the geothermal gradient, with corrosion of the entire roof of the cavity, plus crystallization (and breakdown) products accumulating at floor level as a result of the gravitational movement of the capillary film.

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SCIENTIFIC NOTE

CAVE INCEPTION HORIZONS IN BECK HEAD STREAM CAVE, CLAPHAM, NORTH YORKSHIRE, UK

Four caves, each with its own entrance, make up the Ingleborough Cave System (Jarman and Nolan undated, ?1966; Glover, 1974). These are Ingleborough Cave itself, the mainly submerged Clapham Beck Head, Beck Head Stream Cave (Fig.1) and Foxholes. The entrance to Beck Head Stream Cave (NGR SD 754711) is located approximately 90m up the Clapdale Valley from the well-known Ingleborough Cave. It contains some 450m of known passages conveying Clapham Beck *en route* from Lake Pluto (in Ingleborough Cave) to the Clapham Beck Head resurgence. The farthest upstream section is a 201m-long phreatic loop (Cordingley, 1994), which is accessible only to divers.

In the 1970s, before the exploration of its phreatic section had been completed, the late Dick Glover made a commendable attempt to correlate the bedding planes in the upstream sump of Beck Head Stream Cave (Glover, 1976). Dick was able to visit only a small section of the cave and he did not have the benefit of modern digital gauges for accurate depth recording underwater. More recent observations (Cordingley, 1994, 2000) have revealed that Dick's interpretation is in need of amendment, and the accompanying sketch elevation (Fig.2) should be used in preference to the 1976 drawing (Glover, 1976). Hopefully the following notes provide a useful record of some recent observations in the system, bearing in mind that the underwater section of Beck Head Stream Cave is visited very rarely, and then only by experienced cave divers.

The inception horizons (Lowe, 1992, 2000) guiding Beck Head Stream Cave consist of just two bedding planes, locally linked by four vertical joints. For convenience the lower of the two bedding planes is referred to as BP1 and the upper one as BP2. A third, stratigraphically higher, bedding plane (BP3) has guided the low wet passages below Ingleborough Cave's Giants Hall. The joints in Beck Head Stream Cave include that guiding lakes Avernus and Pluto (J1), the Lake Lethe and Black Hole shaft joint (J2), the joint at the downstream end of the Beck Head Stream Cave sump (J3) and the joint in which the Broadbent Falls are formed (J4).

The Ingleborough Cave Stream (i.e. Clapham Beck) descends from BP3 along J1 to enter the first (shallow) part of the Beck Head Stream

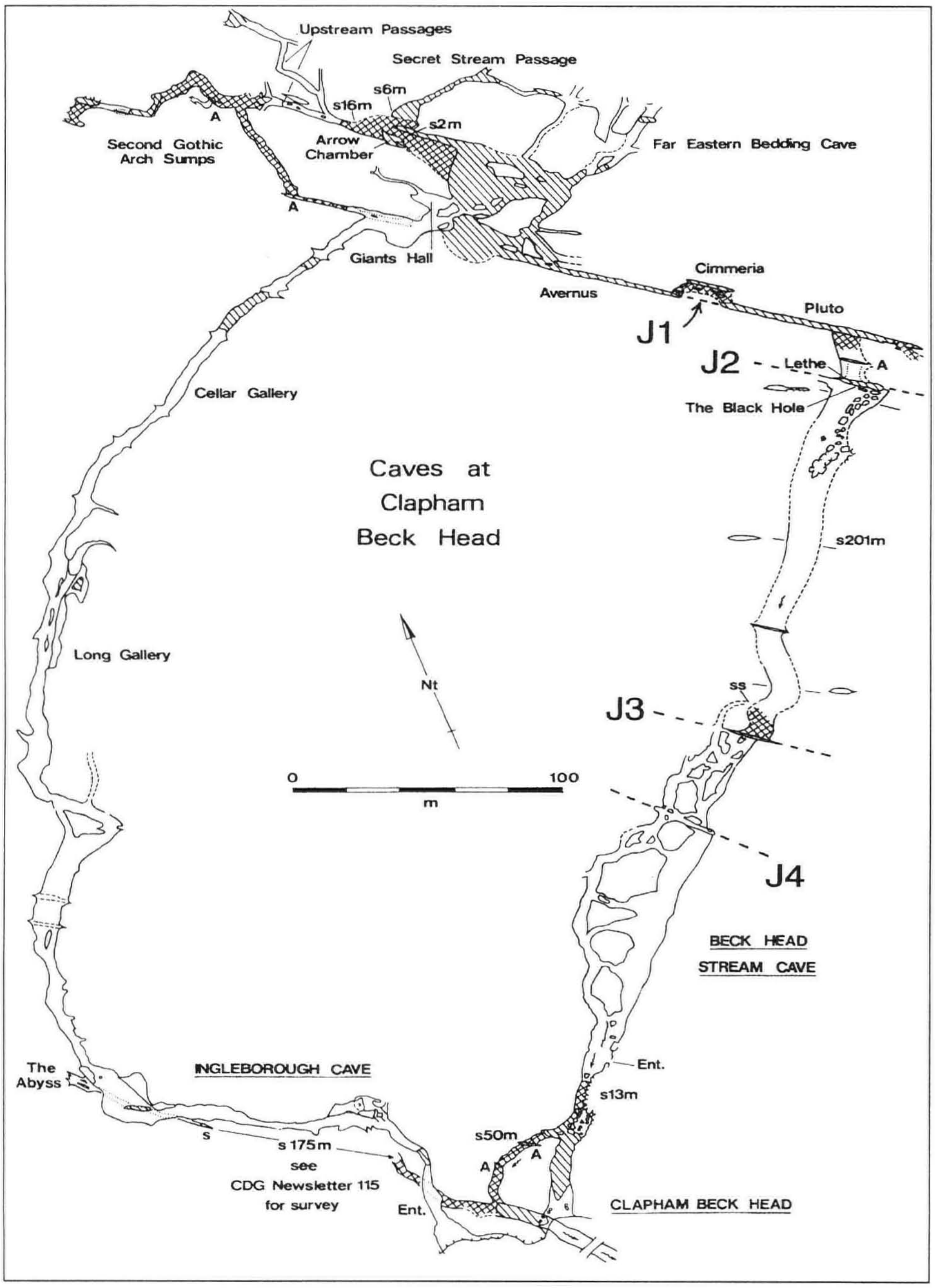

Figure 1. Plan of part of the cave system behind Clapham Beck Head, showing the four joints that contributed to the guidance of cave inception at Beck Head Stream Cave (based, with permission, on Cave Diving Group surveys compiled by Paul Monico).

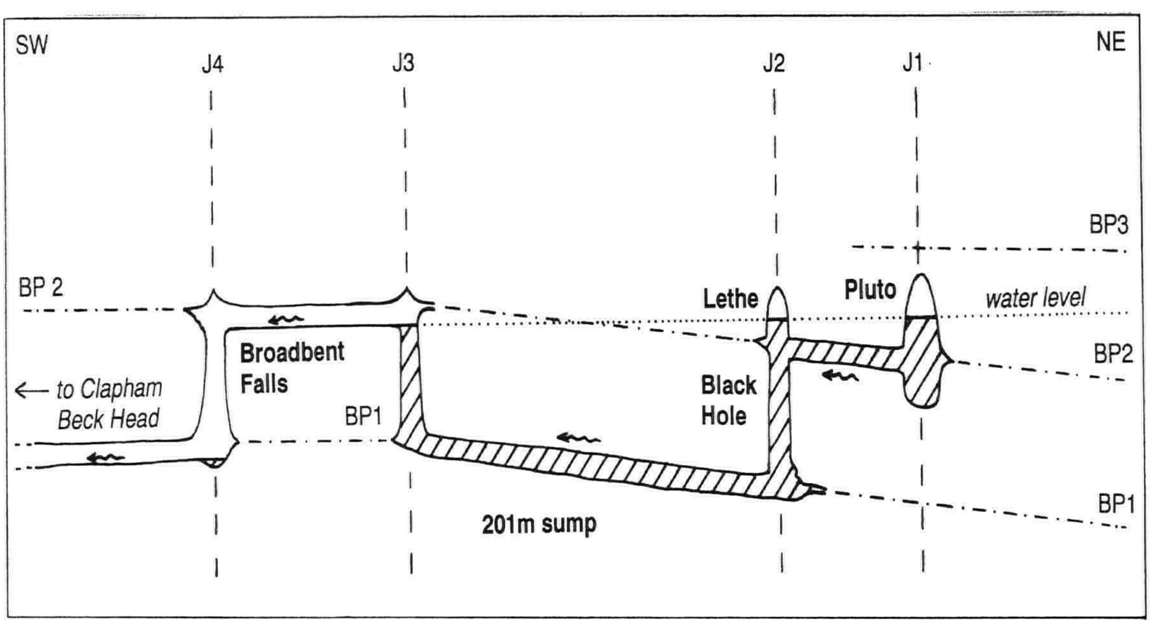

Figure 2. Diagrammatic section showing the relationship of parts of the Ingleborough and Beck Head Stream caves to the inception horizons and joints that have guided their development (not to scale).

via the Broadbent Falls (J4). The remainder of the cave, together with the whole of Clapham Beck Head (see note below), is guided by BP1. The only other possible exposure of BP1 elsewhere in Ingleborough Cave is the passage at the base of the 15m-deep flooded shaft in the "Upstream Passages" (accessed from the Second Gothic Arch).

This interpretation is based on direct observations made during several visits, when visibility was uncharacteristically good. Of particular note is the occurrence of a highly fossiliferous horizon in the uppermost part of the limestone bed immediately below BP2. This exposes fine etched-out brachiopods, together with coiled molluscs that superficially resemble goniatites, but these need more detailed study and identification.The best specimens are underwater, in the shallow part of the phreatic loop between Lake Pluto and Lake Lethe. However, good examples are also exposed downstream of the sump, as far as the top of Broadbent Falls. This fossil-rich horizon provides evidence that there is no significant vertical displacement along the four joints described above - i.e. these are not faults.

Future workers studying inception horizons in the better-known parts of Ingleborough Cave might also like to note the published description and, particularly, the survey of Clapham Beck Head (Cordingley, 1995). Part of this cave consists of a 175m-long undrained phreatic section that connects the "Abyss" passage in Ingleborough Cave with the main resurgence at Clapham Beck Head. The whole of this submerged route has developed within BP1, which (at the upstream end) crops out at 2m depth in the flooded fissure sump at the downstream end of the Abyss passage. Presumably BP2 is exposed along the dry part of the Abyss passage, but at the time of writing there has been no opportunity to confirm this.

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BOOK REVIEWS

Shaw, Trevor, 2000. *Foreign Travellers in the Slovene Karst 1537-1900.* Založba ZRC, 244pp, 145 figs., Ljubljana, 2000. A4-format, paperback, with coloured reproduction of a XIX Century drawing of Postojnska jama on the cover.

The book offers a very informative survey of recorded foreign visits to the Slovene karst and caves in the given period. The kernel of the book (pp.52-219) is a systematic review of the documentation relating to 93 visits. Before quoting (fragments of) the actual documents, the author introduces each traveller in a few short lines. Besides full name and the time of the visit, the circumstances of the visit and details of the source documents are listed. Generally, there follows a short comment about the text itself, stressing the most important or interesting details. The bulk of each "contribution" consists of a reprint, or even a reproduction (facsimile), of the original text. In some cases a facsimile of original handwriting is added to the reprint. Texts that were originally in English are dominant, whereas the others have been translated into English. Some of the texts had been printed previously - for public or for private use - but several of them had never appeared in print, and it must have taken great effort by the author to find the originals and obtain permission to reproduce them.

Most of the source texts were not originally intended to describe the caves and other karst phenomena specifically, and the author has worked hard to improve them, by removing irrelevant detail. In some cases, the introductory lines include remarks about what was omitted. Many of the illustrations are contemporary pictures of the authors of the related blocks of text. However, many reproductions of cave drawings are included too, together with some views of the landscape. The reviewer's impression is that the "cropping" of originals, and selection of the figures overall, have been very well done, and that the author hit just the right balance. The information encompassed by the title of the book is compiled and arranged in the best possible way.

Such a collection of text, though perhaps interesting simply as a compilation of historical texts, would hardly attract readers lacking a wider knowledge of the underlying circumstances. The introductory chapters effectively fill this knowledge-gap. *Acknowledgements* take nearly a whole page, and when reading them one gets some impression of what an effort must have gone into just searching for and compiling the material. In the *Introduction,* generalities about the karst of Slovenia are followed by a short outline of the history of its research. A phrase from this section must be reproduced in its entirety, as it is of fundamental importance to the comprehension of the whole book (p.9): *"It is necessary here to say what sort of visitors to the karst have been regarded as 'travellers' in this book."* One might wonder why 48 visitors were British, 17 came from USA, 13 from Germany, 5 from France, 4 from Italy and one each from the Czech Republic, Croatia, Hungary, Romania, Sweden, Russia and (modern) Austria. The author gives a very convincing reason: most were from maritime nations, and at that time, Trieste was an almost inevitable stop if approaching Europe from this side, or leaving it for the East. Many of the visits took place during stopovers of just a few days. The chapter ends with additional information about the literature, covering details that might be useful to readers with a deeper interest.

The next chapter, *Travelling in the Slovene lands,* gives a quite exhaustive framework to the "action" that is the central interest. It covers the occupations of the travellers, and the purposes of their visits, their sources of information, routes and roads, dangers and fears, language problems, accommodation, organisation of the visits, locations of interest, and the visitors' behaviour (catching *protei*, breaking stalactites etc.). The following chapter, *Caves and other karst sites*, is no less useful. It gives systematic information about 12 caves and 4 surface sites. Among them, Postojnska jama was the most visited, and the information about it is the most comprehensive, covering various aspects of the visits, from fees and visitors' book, through the extent of the tour, the *"Grottenfest"* and the lighting of the cave, to details of the cave railway.

This is followed by the essential core of the book, entitled *The travellers' descriptions*. At the end there are two (very useful) appendices, covering *Equivalent place-names* (which were only rarely written down correctly) and *Units of measurements* (conversion factors). These are followed by a comprehensive list of notes and references, a Slovene summary, and the Index.

The research and compilation have been very well executed, and one can hardly imagine that such a heterogeneous mass of source material, not all originally intended for public consumption, could be presented in a better way. However, the reader must remain aware of "filtering": the compilation of texts covers a very sharply defined group of people who actually visited the area. Keeping this in mind, one is not surprised that these visits did not contribute significantly to the scientific knowledge about the Karst as an area, or about karst in general. However, the author has compiled valuable source material and, when appropriate statistical work has been done, this will offer profound insights into several areas of interest. It will help explain how "lay" people acquired contemporary scientific ideas (a time-lag is obvious), how footpaths equipped for tourists grew (especially in Postojnska jama), how tourism developed in general, which "fairy tales" were told to visitors, how interest in Cerkniško polje gradually declined and instead became focused upon Postojnska jama, etc.

Even without deeper study, three significant observations must be recorded. Firstly, outstanding exceptions among the texts are those by the trained geologists, Hamilton and Strickland. Though bringing no really new ideas, these reflect a comprehension of the karst, as a natural phenomenon, that does not differ essentially from current understanding. Secondly, in Postojnska jama the time-lag between actual knowledge of the cave and the information given to the visitors, was at least two dozen years. Finally, those readers who hope to find authentic testimony about how the Karst (which was then attracting the curiosity of the scientific world) looked at that time, will find a comprehensive choice of very tangible and colourful descriptions.

The book by Trevor Shaw is a well executed and valuable publication, which does not contribute directly to the knowledge of the history of karst science, but sheds interesting light upon the wider circumstances of its early development in the Slovene karst.

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Korpás, László, 1998. *Palaeokarst studies in Hungary*. Budapest: Geological Institute of Hungary. 138pp + map fold-outs.

Potential "foreign" readers of this A4-size softback publication should not be misled or diverted by the National epithet in the title. Whereas the final one hundred pages or so of the volume <u>do</u> examine a plethora of palaeokarst occurrences in Hungary in considerable detail, the preceding pages deal with more general and cosmopolitan aspects of the core subject and related issues. Such a brief overview cannot hope to be as comprehensive as are the broader, classic texts on the topic of palaeokarst, such as those of Bosák *et al.* (1989) and James and Choquette (1988). However, it might be considered to dwell more deeply upon "applied" aspects of palaeokarst, while dealing practically and efficiently with "pure" theoretical ideas. It succeeds well in highlighting a number of significant, if not crucial, issues, and in presenting exceedingly tight précis of a variety of case studies from around the world.

It has long been recognised that penecontemporaneous as well as subsequent karst processes have led to the burial and preservation of karstic features within many parts of the rock succession. Examples are commonly referred to in text books such as those mentioned above. Many relate to significant observations made by cave or karst scientists (eg Ford, 1952, describing evidence of mid-Carboniferous karstification in the English Peak District, and Osborne, 1995, describing late-Palaeozoic karstification in southeastern Australia). Other valuable examples were first mentioned in publications deriving from studies outside the general framework of karst science, such as those of Young (1979) and Palmer *et al.* (1980), both relating to karstification features recorded within the Lower Palaeozoic Durness carbonate sequence of northern Scotland.

Arguably the existence of ancient karst forms and their possible involvement in later processes was mentioned in passing by various early cave scientists, most notably W M Davis (1930). Only relatively recently, however, has significant stress been laid upon the importance of such features as potential influences upon later cave development (and other processes), and this importance accepted by a broad spectrum of earth scientists. Obvious corollaries are that cave development equates with increased porosity and permeability, and that these in turn relate to such high-profile issues as water supply (and pollution potential), hydrocarbon migration and storage, and various forms of mineralization. Concern about the potential vulnerability of palaeokarstic aquifer systems to the effects of over-exploitation, and the side-effects of exploiting other palaeokarst-hosted resources, was the underlying reason for many of the studies described in the book.

All of the above aspects are touched upon by the author in an informative and attention-grabbing one-page general *Introduction*. This is followed by the first chapter proper, dealing with *Palaeokarst systems and geological models*. In a little over thirteen sides of text, tables and drawings, the author describes the basic notion of palaeokarst and the [then] current state of knowledge. Many well-known texts are referenced, and a number of equally well-known illustrations reproduced. The chapter ends with a succinct appraisal of exploration strategies and potential methods of study.

Chapter 2 is also wide-reaching, though in context a lack of depth is inevitable. The results of previously published studies of palaeokarst from geologically distinct settings in the Bahamas, the Caribbean, England, various parts of Spain, and Greece are examined in only twelve sides of mixed text and figures. A number of striking and informative colour photographs are presented in a separate section towards the end of the book. Whereas the considerations differ somewhat in approach, depth and emphasis, overall the author succeeds in identifying the essence of each study and presents his own overview interpretation alongside useful distillates of the original writers' wisdom.

In the two-page Chapter 3, the author briefly reconsiders aspects of the examples from Chapter 2, before introducing a model of carbonate platform evolution and related karst development, both of which are in turn related to aspects of geological cyclicity. After describing the model (p.35), the author presents five broad conclusions. Interestingly, or perhaps surprisingly (depending upon the reader's indoctrination), conclusion 5 attributes a greater role in palaeokarst level formation to mechanical abrasion (related to submarine earth tidal pumping) than to mixture corrosion.

The remaining chapters (4 to 6) deal in much greater details with *"Palaeokarst systems in Hungary"* (on an area by area basis, covering about 65 pages), *"The 3D model of the composite karst system, Buda Hills"* (5 pages) and *"The palaeokarst potential of Hungary"* (7 pages). This reviewer has neither the inclination nor the detailed local knowledge to dissect and criticise these chapters. However, an admittedly superficial reading left an undoubted impression not only of impeccably carried-out research, but also of in-depth and up-to-date appraisal of the evidence deriving from that research. Many interesting and provoking ideas and explanations are presented though, inevitably, in some cases, one can see possible alternative ways that aspects of the observational evidence could be interpreted.

Summing up: for me this publication provides an extremely valuable overview and rationalization of palaeokarst and its crucial importance to a variety of environmental/economic considerations. This extends far beyond the limits of the detailed examples from a single country – interesting enough in their own right – that are examined in the major part of the text.

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THESIS ABSTRACT

WHITEHEAD, R, 2000

Water tracing experiments in the Peak District: A study of the drainage of the Bradwell-Eyam-Stoney Middleton area, Derbyshire, UK.

Unpublished MSc (Surface and Groundwater Resources) dissertation, Geographical Sciences, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK.

This project describes the current knowledge of the drainage in an area in the northeast of the English Peak District ranging from Bradwell in the north to Stoney Middleton in the east. Previous work is summarised and the natural and artificial drainage of the area are considered. A series of water tracing experiments were conducted using fluorescent dyes with the aim of determining the direction, speed and nature of drainage from four previously untraced stream sinks. These sinks were thought to be situated close to the basin margins, which separate drainage to the Bradwell catchment in the north from easterly drainage to Stoney Middleton and southerly drainage towards the Wye Valley. The dye tracing experiments added to knowledge of the locations of these boundaries and highlighted the complexity of the drainage in the area. The results are interpreted with reference to previous work, and information on the geology, climate and hydrology of the area is used to put the results in context.

RESEARCH FUNDS AND GRANTS

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The British Cave Research Association has established the BCRA Research Fund to promote research into all aspects of speleology in Britain and abroad. Initially, a total of £500 per year will be made available. The aims of the scheme are primarily:

a) To assist in the purchase of consumable items such as water-tracing dyes, sample holders or chemical reagents without which it would be impossible to carry out or complete a research project.
b) To provide funds for travel in association with fieldwork or to visit laboratories that could provide essential facilities.
c) To provide financial support for the preparation of scientific reports. This could cover, for example, the costs of photographic processing, cartographic materials or computing time.
d) To stimulate new research that the BCRA Research Committee considers could contribute significantly to emerging areas of speleology.

The award scheme will not support the salaries of the research worker(s) or assistants, attendance at conferences in Britain or abroad, nor the purchase of personal caving clothing, equipment or vehicles. The applicant must be the principal investigator, and must be a member of the BCRA in order to qualify. Grants may be made to individuals or groups (including BCRA Special Interest Groups), who need not be employed in universities or research establishments. Information about the Fund and application forms Research Awards are available are available from the Honorary Secretary (address at foot of page).

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Editors: Dr. D J Lowe, c/o British Geological Survey, Keyworth, Notts., NG12 5GG, UK and Professor J Gunn, Limestone Research Group, Dept. of Geographical and Environmental Sciences, University of Huddersfield, Huddersfield, HD1 3DH, UK.

CAVES AND CAVING - quarterly news magazine of current events in caving, with brief reports or latest explorations and expeditions, news of new techniques and equipment, Association personalia etc.
Editor: Hugh St Lawrence, 5 Mayfield Rd., Bentham, Lancaster, LA2 7LP, UK.

CAVE STUDIES SERIES - occasional series of booklets on various speleological or karst subjects.
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No. 2 *An Introduction to Cave Surveying;* by Bryan Ellis, 1988. Reprinted 1993.
No. 3 *Caves and Karst of the Peak District*; by Trevor Ford and John Gunn, 1990. Reprinted with corrections 1992.
No. 4 *An Introduction to Cave Photography;* by Sheena Stoddard, 1994.
No. 5 *An Introduction to British Limestone Karst Environments;* edited by John Gunn, 1994.
No. 6 *A Dictionary of Karst and Caves*; compiled by Dave Lowe and Tony Waltham, 1995.
No. 7 *Caves and Karst of the Brecon Beacons National Park;* by Mike Simms, 1998.
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Hydrology Group organises meetings around the country for the demonstration and discussion of water-tracing techniques, and organises programmes of tracer insertion, sampling, monitoring and so on. The group publishes an occasional newsletter.

Speleohistory Group publishes an occasional newsletter on matters related to historical records of caves; documentary, photographic, biographical and so on.

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