Cave and Karst Science

The Transactions of the British Cave Research Association

BCRA

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Sources of pollen in stalactite drip water in two French caves
Macroinvertebrates in limestone springs in the Wye valley, Derbyshire, UK
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Cave and Karst Science

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Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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Cover photo:

Wormhill Spring is the largest of over 20 limestone springs that supplement the flow of the River Wye, the only river to maintain a perennial flow across the northern 'White Peak' district of Derbyshire. The springs have a diverse aquatic ecology, as discussed in the article by Smith *et al.* in this Issue.
Photo by John Gunn.

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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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D T P by Rebecca Talbot

EDITORIAL

David Lowe and John Gunn

In previous editorials we have discussed the use of scientific terminology by cave and karst scientists and in issues 23(2) and 24(2) of the journal there was a fulsome discussion of what does or does not constitute 'pseudokarst'. This, of course, presupposes that we are confident in our understanding of what is actually meant by the term 'karst'. Here in the UK, and probably in many other parts of the world, most cave and karst scientists, and many others, think they know, even though half of the answers given actually beg the question. Are we really asking and answering the question of what karst is, or are we asking about the origin of the word itself ?

Argument continues over the niceties of a widely acceptable definition of karst, and how much we dare 'limit' such a definition, but fundamentally the detail doesn't get in the way of what most people perceive karst to be. In spite of all the nit-picking controversy and the disagreements between the pedantic and the less pedantic and between the 'splitters' and the 'lumpers', there does seem to be a level of general agreement about the *'what'* of karst.

But as for the word karst itself, are the usual glib statements as well founded as most of us like to assume? Are we really aware of the *'how'* and the *'why'* of the word 'karst', which trips off the (English) tongue as the favourite shorthand for describing the subject area to which it is applied? Probably very few of us ever bothered to look further than the more readily available explanations in the better known geomorphology or hydrology text books and dictionaries. A derivation from the Slovene "kras", via the German "Karst" seems readily acceptable, but how many people have asked *"Did the word really start there?"*. On this basis it was something of a surprise when (in November 2000) we received a draft manuscript of a paper examining this very question – *"...whence the name?"*. Now, more than 12 months later, we have published the revised manuscript in this Issue, and the nature of the publication and the events leading up to it require some degree of explanation.

Our well-known editorial policy is that all 'papers' and 'reports' must be reviewed, generally by existing members of our editorial panel network, sometimes by newly approached individuals with a particular expertise, and sometimes (particularly with reports) by ourselves. Occasionally we have great difficulty identifying appropriate referees or in persuading them to take on the task. Sometimes we don't even receive responses to enquiries and, rarely, manuscripts sent out simply disappear. Yes, it really does happen! In the case in question one of our regular team was asked to comment, and did so within a very short time, making several helpful suggestions, but also pointing out that ideally the text should be examined by a reputable etymologist. We made enquiries, including asking advice from the author of the manuscript, but then spent several fruitless months trying, without success, to find a willing referee.

As by this time one of us had invested significant effort into "smoothing" the English of the original draft we were disinclined to abandon its eventual publication. E-mail dialogue with the author eventually brokered a compromise on publication. Despite its length, complexity and potential significance, we agreed that the article could be treated as a report, rather than as a paper. Even then our normal policy on peer review would have to be relaxed. After some further discussion we decided that such a relaxation was justified. The article should be published, both as a contribution to knowledge and in the hope that its appearance might prompt some level of subsequent comment and discussion, conceivably even by those same etymologists that we had failed to find when searching for a referee.

Having made the decision to publish the manuscript (and to provide this contractual Editorial justification of the decision), we thought that the hard part was over. Not so. We simply did not imagine the technical problems that would have to be faced. It was obvious from the receipt of the first draft that the manuscript was peppered with a staggering variety of diacritical marks (broadly ‘accented characters’), inherent in the many languages being discussed. The author also used other expedients to indicate linguistic nuances that are difficult to convey via the written word. During the editing process, involving several corrupted e-mailed texts, reference hard copies, floppy disks and severe eye-strain, most of these were tracked down, reinserted and validated, using PC-based word processing software. Trial prints looked fine, and we sighed with relief. Unfortunately, the next step to publication involved moving from PC to Mac-based computing. Maybe some expertise was lacking here, or there was a failure to use the best available approach, but all the hard-won diacritical marks "evaporated" (some to be replaced by rogue symbols), and Greek characters turned to garbage. Weeks later, after much research and even more eye-strain, Becky Talbot managed to assemble a text that – we hope – looks something like the original. However, despite our best efforts, we suspect that some of the subtlety and precision of the original may have been lost. For this we apologise both to readers and – perhaps more so – to the author. We hope that despite any minor introduced warts and wens, the story as a whole remains of interest, and we look forward to any comment or discussion of the author’s ideas that emerges.

At the recent BCRA AGM in Buxton there was some comment to the effect that it is ‘too difficult’ for the ‘average caver’ to prepare an article to the high standard expected by *Cave and Karst Science* referees. We hope that the above account might serve as a demonstration of the Editors’ commitment and desire, both to maintain high standards and to assist contributors in achieving them.

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Pre-Devensian dolines above Crummackdale, northwest Yorkshire, UK

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Abstract: This paper reports a preliminary study of large Pre-Devensian dolines above Crummackdale Head. The distribution of these dolines has been plotted on 1:10,000 scale base maps, and selected dolines have been measured. All these large dolines have acted as sediment depositories. Most contain fine sandy silt, yellow in the aerobic zone and grey below. This is interpreted as loess. These sediments pass upwards into peat or remnant peat that is shown to date from 9,000 B.P.140

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INTRODUCTION

In view of the volume of karst research carried out in the Yorkshire Dales (Craven District of northwest Yorkshire) over the years, it is perhaps surprising that the large dolines that are thought to pre-date the Devensian glaciation of the area have merited mention (Clayton, 1966, 1981; Sweeting, 1974; Waltham, 1997) but have attracted little detailed research. Very little is known of their precise distribution, nor have the sediments within these large dolines been examined. Given their size, and apparent age, it is reasonable to assume that the dolines must have acted as depositories during the Late Quaternary to Holocene period. As such, they should contain sequences of sediments capable of yielding a surrogate climatic record for the period, which could be linked to the Dales cave sediment and incision record (Gascoyne *et al.*, 1983). Their importance as a facet of the Holocene record should also be recognised. For these reasons the authors began an investigation at a single location, the limestone pavement area above Crummackdale and east of the Ingleborough massif, where the existence of such dolines has previously been noted (Fig. 1) (Waltham, 1997).

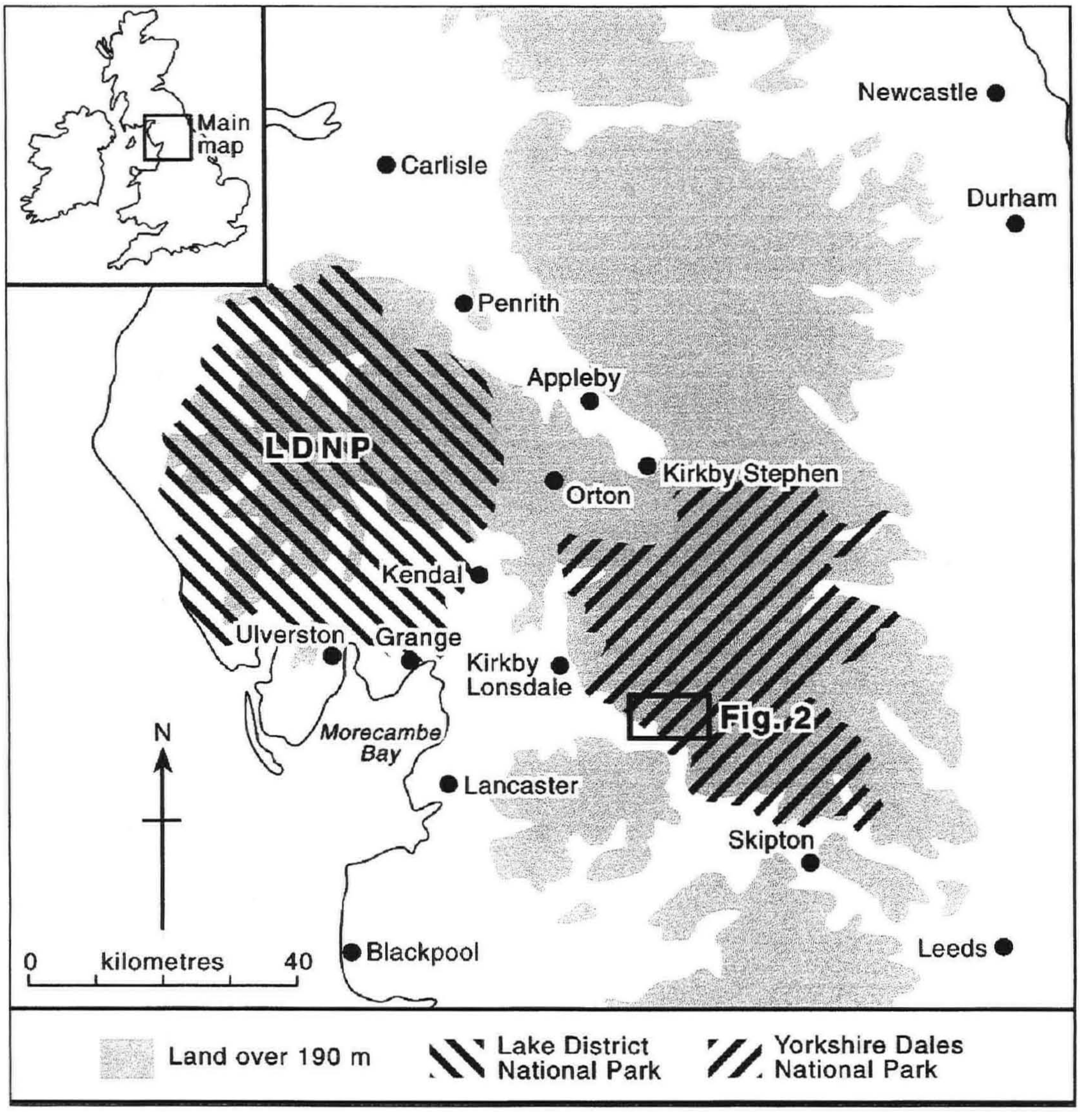

Figure 1. Location map to show the position of the site within the British Isles

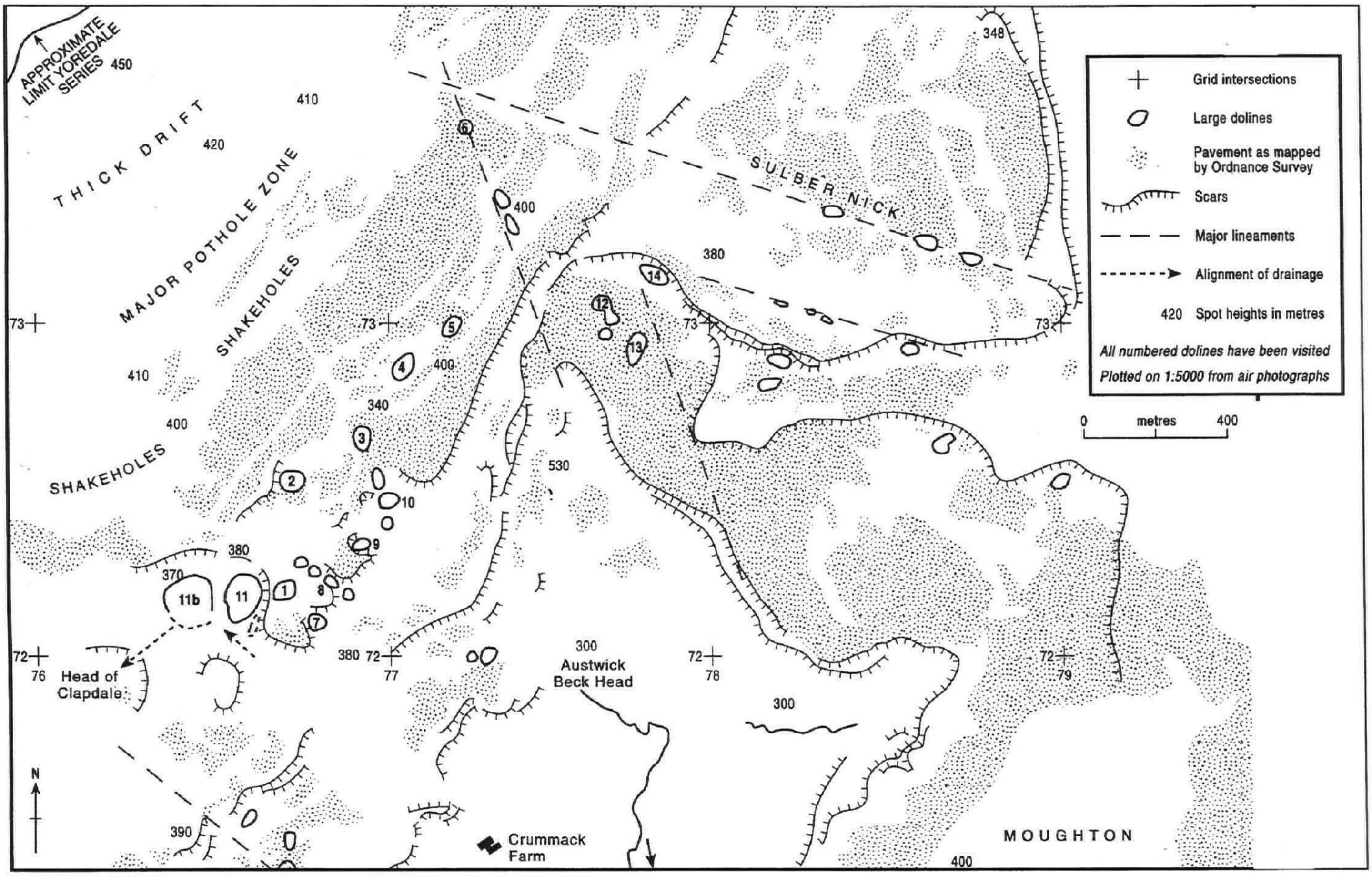

Figure 2. Pre-Devensian doline distribution above the head of Crummackdale. (Plotted from air photographs onto 1:10 000 map sheets after ground truthing.) (Numbers within dolines refer to surveyed dolines; numbers associated with intersections are grid references. All other numbers are altitudes in metres).

Doline	Diam.(m)	Alt.(m)	1	2	3	4	5	6	7
1	48	385		x				x	
2	40	390+						x	
3	30	<390		x	x		x	x	
4	40	400+				x			
5	30	400+				x			
6	30	390		x	x			x	x
7	25	370+	x					x	
8	25	385	x				x		
9	20	385	x						
10	40	385					x		
11	80	365	x			x			
11b	80	360	x			x			
12	44	370		x	x	(2 coalesced)			
13	84	370		x	x				
14	45	<360	x					x	x

Table 1a. Doline characteristics and morphology: data from numbered dolines. 1 = in embayent; 2 = scar rim present; 3 = within pavement; 4 = indeterminate limit; 5 = part of series; 6 = shakehole in floor; 7 = peat present N.B. Altitudes are of the surface in which the doline is set, i.e. its rim.

Site	Number	Mean	Range
Western area surveyed dolines	36	42.7m	20 – 84m
Others		23m	10 – 35m
Moughton		47.5	25 – 75m

Table 1b. Doline characteristics and morphology: mean and range of doline diameter

The authors have based their work on the hypothesis that loess deposits can be expected to overlie till or drift beneath a palaeosol. This hypothesis is derived from the views of Vincent (1995) that loess was deposited over all areas of the Great Scar Limestone Group outcrop during the retreat phase of the Devensian glaciation, and that limestone pavements developed beneath this cover, which has since been eroded.

Those dolines that are developed in Devensian drift deposits, and hence post-date the glaciation of the area are generally known as 'shakeholes'. They are relatively small, tend to be funnel shaped, are usually less than 10m in diameter and rarely exceed 2-5m in depth. They are in marked contrast with the larger dolines, thought to pre-date the Devensian. These larger dolines may be up to 750m in diameter and 50m deep, although most are shallower, having been truncated by Devensian glacial scour.

METHODS

This research is based on field methods supported by laboratory analyses. A preliminary visit made to the head of Crummackdale in 1997 found large dolines below Sulber Scar at altitudes between 360m

Altitude	Total dolines	Numbered	Other	Moughton
400 – 409m	3	2		1
390 – 399m	2	1		1
380 – 389m	12	6	5	1
370 – 379m	7	3	1	3
360 – 369m	9	3	6	
350 – 359m	2		2	
340 – 349m	1		1	

Table 2. Doline altitude distribution

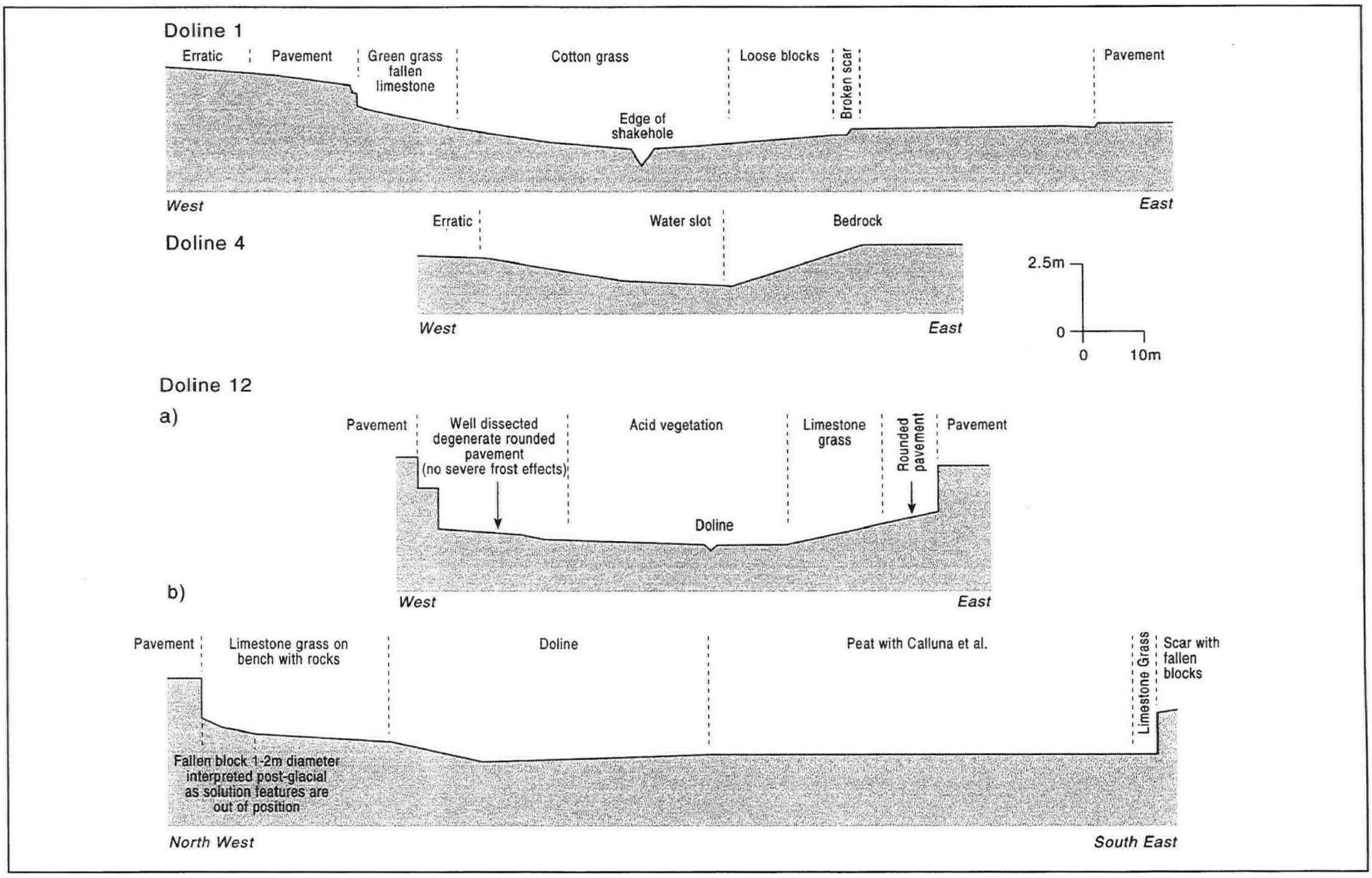

Figure 3. Cross sections of dolines 1, 4 and 12 (for further detail refer to Table 1a).

and 370m. Some auger coring was carried out. Making use of air photo coverage the survey was extended to the entire area above Crummackdale Head. Further fieldwork in 1998 and 1999, concentrated on the ground-truthing of all large dolines recognised on air photos. One constraint was that the topography of individual dolines determines the accuracy of their location by air photographs. Where shallow dolines exist within drift-covered areas, they do not show clearly on the photographs, because the acid vegetation within the dolines is no different from that growing on the surrounding till. The most clearly defined large dolines are those within pavement areas, with a scar rim, or within areas of limestone turf.

Although diameter can be determined from the air photo analysis when the locations have been plotted onto topographic maps, depths cannot be so determined. Hence, the morphometry of selected dolines was measured in the field, using tape, clinometer and staff. The results were plotted as profiles from which the measurements were derived. An auger was used to obtain sediment cores, and laboratory analyses were carried out on selected samples of the various sediments encountered. These analyses included sedimentary texture, weight loss on ignition and iron content. As many doline sediments are capped by peat or remnant peat degraded by oxidation, samples of peat were collected. Pollen analysis was undertaken on samples from two dolines, using standard methods (Innes, pers. comm.).

RESULTS

Ground-truthing demonstrated the accuracy of the air photo interpretation but confirmed that shallow dolines, or those with uniform vegetation, can be overlooked. The distribution of dolines was plotted onto a 1:10,000 base map, part of which is shown as Figure 2. The large-diameter, shallow dolines are quite distinct from the Post-Devensian 'shakeholes', some of which are developed in the floors of the older, larger dolines.

Most of the dolines west and northwest of Crummack were visited. Their morphology was investigated and many were measured. Selected cross-sections are provided (Fig.3). All of the numbered dolines (Fig.2; Table 1) have been investigated in detail. Some general statistical information has been recorded (Tables 1a and 1b; Table 2) and initial sedimentary investigation has been undertaken (Fig.4 and summarised in Table 3). A preliminary pollen count of the basal 5cm of the overlying peat from Dolines 6 and 14 has been made (Table 4). The interest in the basal 5cm of the peat was occasioned by a need to date the underlying sediments.

On the limestone surface above the head of Crummackdale, 36 dolines were mapped from aerial photos onto maps at a scale of 1:10,000 (Fig.2). Of these, 24 were checked in the field and 15 were either measured or sampled. The remainder, of which 6 occur on Moughton Scar, east of Crummackdale, have received no ground-truthing. All of these dolines occur at altitudes between 360m and just over 400m (Table 2), and the modal altitude of the surface into which the dolines have been let down lies between 380m and 389m. Doline diameter ranges from 20 to 80m, averaging 42.7m (Table 1b) and most are shallow, between 5 and 10m in depth, but this is usually due to the fill material that has accumulated within the doline. Rarely rock may be exposed at the base of 'shakeholes' that have developed in the floors of some larger dolines. A few, such as Dolines 6 and 14, become waterlogged and contain bogs (Table 1a). However, the presence of remnant oxidised peat in many suggests that wet conditions were previously much more significant. The artificial drainage of the peat covered glacial drift to improve sheep grazing may well account for this.

The dolines occur preferentially either in angles (embayments) in low scars (Dolines 7, 9 and 11) or within areas of pavement (Dolines 3, 6, 12 and 13). They may form a stepped series along major lineaments (Dolines in line with 8, or 10 to 3) each above a small break of slope

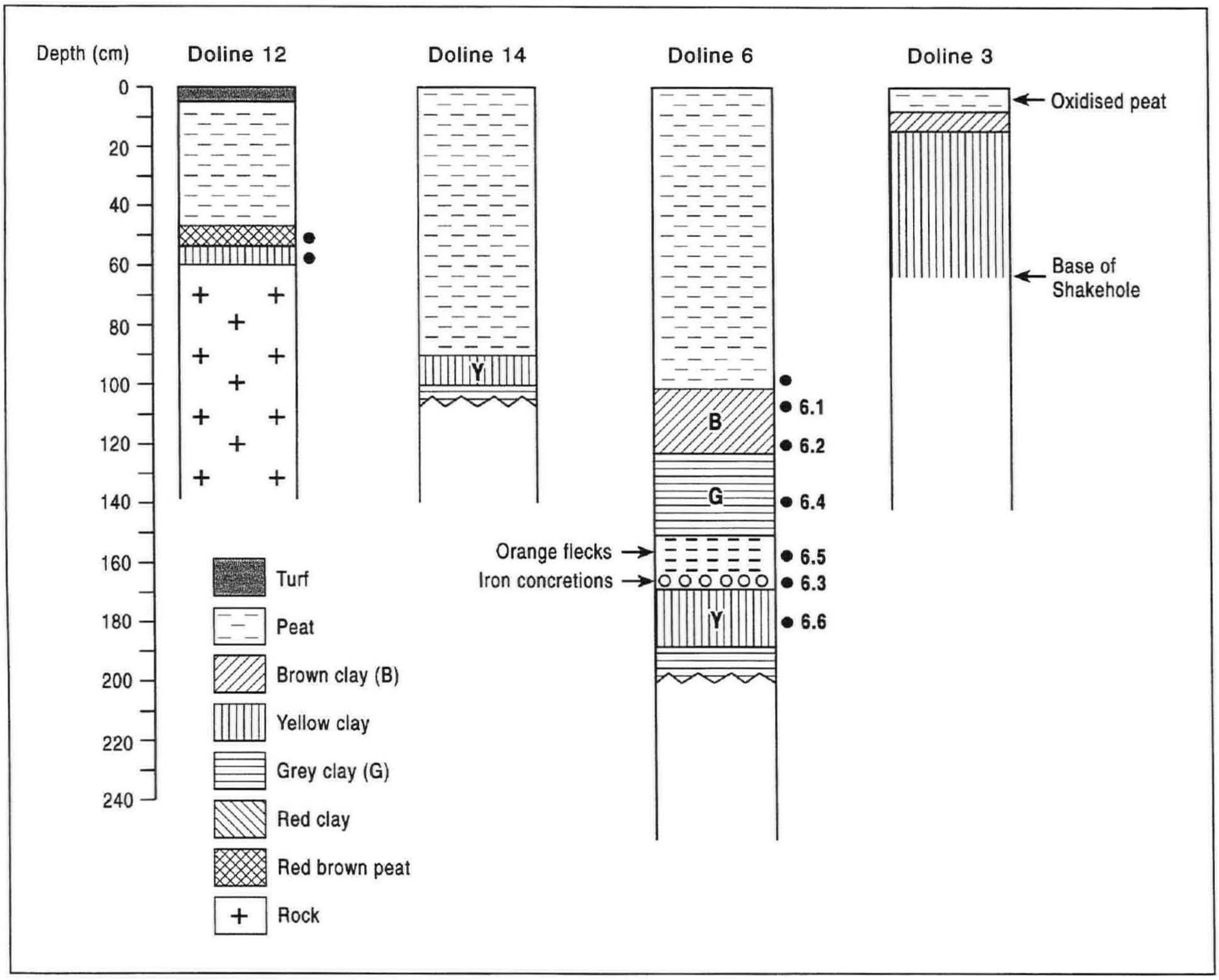

Figure 4: Sediment profiles from dolines 3, 6, 12 and 14.

caused by a low scar. A surprising number are circular and bounded by shallow scar outcrops (Dolines 1, 3 and 6) (Table 1a; Figs 3 and 4).

Coring, to a depth of about 1m, has shown that peat or peaty rendzina soil almost everywhere overlies yellow silty clay, which becomes grey at depth where it is in an anaerobic position. Iron staining, mottling or the presence of small iron concretions may separate yellow from grey silty clays (Fig.4). This iron accretion zone is always at or near the base of the yellow silty clays and above the grey silty clay layer. Virtually every hollow shows a similar sequence. In some, the silty clay overlies gritty glacial drift deposits. In most, the presence of glacial drift was recognised either by the presence of adjacent erratics or of erratic pebbles brought to the surface by rabbit activity. Selected profiles have been reproduced (Fig.4) and grain-size characteristics were determined by laboratory analyses (Table 3). Loss on ignition and tests for the presence of iron were also carried out on sediments from Doline 6 (Table 3). A sample collected from the basal 5cm of the thick peat in a raised bog in contact with organic stained clay overlying yellow clay in Thieves Moss (Doline 14) was subjected to pollen analysis. Preliminary results indicate that it developed from about 9,000 B.P., which accords with the Holocene warming following the Loch Lomond (Younger Dryas) stadial (Innes, pers.comm). It seems as though peat at altitudes of about 400m, developed only after the Loch Lomond (Younger Dryas) cold phase, dated from 11ka to 10ka. The dominant tree, grassland and aquatic species are listed in Table 4.

Doline 6	Clay	Silt	Sand			Ignition loss	Iron present
			Fine	Medium	Coarse		
6.1	27.3	25.6	47.1	-	-	8.5	7.4
6.2	17.9	38	34.6	9.5	-	11.4	5
6.4	22.3	42.3	15.4	-	-	6.6	3.6
6.5	15.3	44.3	19.4	2.2	7	11.6	10.7
6.3	19.3	43.2	24.5	5.7	7.3	7	3.6
6.6	18.3	52.8	27.4	1.5	-	9.8	8.5
6.3 (Fe concretions)						8.7	9.3
Doline 4	49.2	27.8	23	-	-		
Doline 10	5.3	57.6	31.8	5.2	-		
Doline 11	4.1	53.3	28.5	5.5	8.6		

Table 3. Preliminary sedimentary analysis (all figures as %)
**See Figure 4 for positions of samples 6.1 to 6.6*

Figure 5a. Photograph of doline 1.

Figure 5b. Photograph of doline 6, with raised bog.

DISCUSSION

The survey of a limited area above Crummackdale Head has shown that dolines of moderate dimensions, are widespread and occupy specific topographic sites. These dolines are thought to pre-date the Devensian glaciation and differ markedly from the smaller post-glacial 'shakeholes'. It was expected that modern soils or palaeosols would overlie scree (clitter) formed and mobilised during the Loch Lomond stadial, when periglacial conditions must have affected these areas (Roberts, 1989). However, to date no scree has been found in a doline sequence and nor have palaeosols been identified. Peat or oxidised former peat is the surface material except in very well-drained sites. The preliminary palynological results indicate that peat formation occurred subsequent to the Loch Lomond stadial. Although scree formed at that time, periglacial movement appears to have been insufficient to displace the material from the scar foot into the dolines.

However, to date all coring has been restricted in depth. The presence of stony drift at depth, which inhibits auguring, suggests a full sequence will require a pit to be excavated in the base of one of these dolines. The dolines certainly contain sedimentary sequences (Fig.4). In the field the yellow and grey stoneless sediments appear to be silty clays. However, laboratory analyses of these materials shows clearly that silt and fine sand fractions are dominant (Table 3). Silty clay sediments from Doline 6 with the floating bog (samples 6.4 and 6.5) and from samples from dolines 4, 10 and 11, give an average for the yellow or grey silty clay materials as follows: Clay 19.2%, Silt 45.1%, Fine Sand 23.6% , Medium Sand 2.6% and Coarse Sand 3.2%. The 'clays'' are 67% silt and fine sand. Thus the preliminary analyses suggest that this fine textured sediment may indeed be loess, as proposed by Vincent (1995). Further comparative work is still required and many more samples will be needed from dolines. We suspect that the proportions are strongly affected by the fine fraction component of the local glacial drift.

A preliminary experimental survey of five large dolines has been attempted by Gullen (1999) using resistivity and similar techniques. It is thought that four of the five dolines coincide with those reported in this paper (Dolines 1, 7 10 and 11), but the map included in Gullen's dissertation is insufficiently detailed to be certain. Gullen interpreted her results as showing that weathered limestone or till may occur to a depth of 20m. She therefore concluded that sediment occurs only in small quantities in these dolines. We consider that any sediment depth in excess of 4m is sufficient to provide some sequential information. In any case, a depth of up to 20m is not an insignificant amount. Further work is clearly necessary to establish the causes of changes in resistivity.

Evidence of glacial drift has been recorded in terms of large erratics, usually of sandstone and large rounded blocks of limestone, which probably derive from the glacial till, lying on the surrounding pavement. Pebble size drift material occurs below the silty clays in many dolines. It is often brought up by rabbit activity. This material may have been mobilised from adjacent till deposits during the Loch Lomond stadial. The evidence suggests that these large dolines and the pavements have been exposed from glacial drift by erosion. No palaeosols have been recognised and most dolines have peat as the overlying material. Much of this former ubiquitous peat cover is now undergoing oxidation. The Thieves Moss site (Doline 14) has acted as a depository and has minor karst windows suggesting that it too is related to the larger, probably pre-Devensian dolines. This is in contrast to Waltham *et al.* (1997 p.50) who consider the Thieves Moss area to be merely structural in origin.

TREE Sp. = 50%		GRASSLAND = 45%		AQUATIC + SPORES = 5%	
Hazel	23%	Sedge	31%	Fern	2.50%
Birch	19%	Grass	10%	Algae	1.60%
Pine	6%	Heather	2%	Lesser bullrush	0.30%
				Equisetum	0.30%

Table 4. Summary of pollen count: Thieves Moss (pollen taken from basal 5cm of raised bog)
N.B. only dominant species listed (after J.Innes)

CONCLUSIONS

Large dolines thought to be pre-Devensian in age are common, but spatially clustered, in the area above Crummackdale Head. Many are shallow, or partially masked in glacial drift giving a uniform vegetation cover, and in consequence they have not previously been noted or recorded. It was expected that modern soils would overlie scree materials and that palaeosols would be present below. However, this does not appear to be the case and the soils have formed on ubiquitous yellow or grey stoneless silty sands that appear to be loess that has been stripped from surrounding limestone pavements. Scree, which is presumed to be the product of periglacial weathering during the Loch Lomond stadial, is widespread but does not appear to have moved far from the scars from which it is derived, as none has been found in any of the dolines. Furthermore, the tentative conclusion from the Thieves Moss (Doline 14) peat suggests that peat growth began after the Loch Lomond (Younger Dryas) readvance. No palaeosols have been identified. However, it must be realised that coring has been restricted in depth.

The intention is now to extend the research to obtain much longer sedimentary sequences, either by coring or the digging of soil pits, to provide a past climatic record, to record the evidence for pre-Devensian landforms as inherited landforms, both dolines and pavement types, and to map the distribution of these relict areas. Ground truthing will take place at sites identified by air photo analysis. As for the Crummackdale Head dolines, reference had been made to the location of such sites but almost no detailed work has been carried out. The importance of the sedimentary sequences as surrogate climatic change data that could have a bearing on studies of global warming, makes further research highly significant.

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REFERENCES

Clayton, K M, 1966. The origin of the landforms of the Malham area. *Field Studies*, Vol.2, 359-384.

Clayton, K M, 1981. Explanatory description of the landforms of the Malham area. *Field Studies*, Vol.5, 389-423.

Gascoyne, M and Ford, D C, 1984. Uranium Series dating of Speleothems II: Results from the Yorkshire Dales: Implications for cave development and Quaternary climate. *Cave Science*, Vol.11, 65-85.

Gullen, T, 1999. Non-invasive investigation of polygonal karst features: Yorkshire Dales National Park. Thesis Abstract, *Cave and Karst Science*, Vol.26(2), 96.

Sweeting, M M, 1974. Karst Geomorphology in North-West England. 46-78 in Waltham, A C [Ed.] *Limestone and Caves of North-West England*. [David and Charles.]

Roberts, N, 1989 *The Holocene*. [Blackwell.]

Vincent, P, 1995. Limestone pavements in the British Isles: A review. *Geographical Journal*, Vol.161, 265-274.

Waltham, A C, Simms, M J, Farrant, A R and Goldie, H S, 1997. *Caves and Karst of Great Britain*. Geological Review Series. Joint Nature Conservation Committee. [Chapman and Hall.]

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Sources of pollen in stalactite drip water in two caves in southwest France

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Abstract: Pollen filters were placed under active stalactites in the Villars and La Faurie caves (southwest France) for one year, to see whether pollen grains were brought in by seepage water and to quantify the pollen fluxes. In the Villars Cave, filters that were protected from the cave atmosphere did not collect any pollen, whereas those that were open collected a few grains, demonstrating that, here at least, pollen was carried by cave air and not by seepage water. In La Faurie Cave, two protected filters collected a few pollen grains, partially representative of the local vegetation, which show that some pollen arrives in the cave with seepage water. Pollen grains extracted from three stalagmites from Villars Cave show that only stalagmite that includes detrital layers contains a significant amount of pollen. As well as pollen, different kinds of plant and animal micro-debris were found in the filters and in the stalagmites, providing complementary information about the sources of the pollen.

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INTRODUCTION

Speleothems are among the most readily datable continental deposits, by means of U/Th and ^{14}C radiometric methods). This makes them a valuable data source for palaeoenvironmental reconstruction (Harmon *et al.*, 1975; Atkinson *et al.*, 1978; Li *et al.*, 1989; Quinif, 1989). The observation of annual growth laminae, visible or luminescent, gives some stalagmites a very high resolution chronology, which permits the investigation of seasonal and annual signals and thus increases the interest of speleothem for palaeoenvironment studies (Shopov and Dermendjiev, 1990; Baker, 1993; Genty and Quinif, 1996). Although they have been studied for more than 30 years (Duplessy, 1967; Duplessy *et al.*, 1970), their palaeoclimate signals are still difficult to interpret. This is principally because their chemical signals (trace elements, stable isotopes) are not reproducible outside a small sampling area (Fantidis and Ehhalt, 1970; Fornaca-Rinaldi *et al.*, 1968; Lauritzen, 1995; Bar-Mattew and Ayalon, 1997; Roberts *et al.*, 1996). Consequently, speleothem pollen content might be a useful aid to the interpretation of those signals.

The first speleothem pollen analyses were made on flowstones from prehistoric cave sites and shelters: La Vache Cave (Ariège, southern France: Leroi-Gourhan, 1967), Remouchamp Cave (Belgium: Damblon, 1974), La Chaise Cave (Charente, southwest France: Paquereau, 1976; etc). These first studies showed that pure calcite horizons did not contain pollen, and only flowstones that are contaminated with detrital sediments contain pollen (Diot, 1988). At some sites it was also demonstrated that pollen grains were trapped, along with atmospheric particles, when the cave was open to the atmosphere (Renault-Miskovsky and Texier, 1980). During the late Nineteen-seventies a specific methodology was developed especially for speleothems (Bastin, 1978). Despite low concentrations (generally less than 5 pollen grains per gram of calcite), pollen can provide useful information about past environments around caves, that cannot be provided by other measurements. It has been demonstrated that the history of vegetation changes reconstructed from several Holocene stalagmites in Belgium were consistent with records from lake sediments and peats (Bastin, 1990; Bastin and Quinif, 1993).

However, the sources of pollen in caves are not well known. Is pollen brought into caves by seepage water, by air or by animals? Are the fluxes into caves seasonal, and at what concentration? Are they representative of the local vegetation, or is there a mixture of pollen grains deposited at different intervals? Several recent studies have addressed these questions (Coles *et al.*, 1990; McGarry *et al.*, 2000). *In situ* experimentation is rare. One of the first, made in the Foissac Cave (southern France), showed that pollens were carried by seepage water

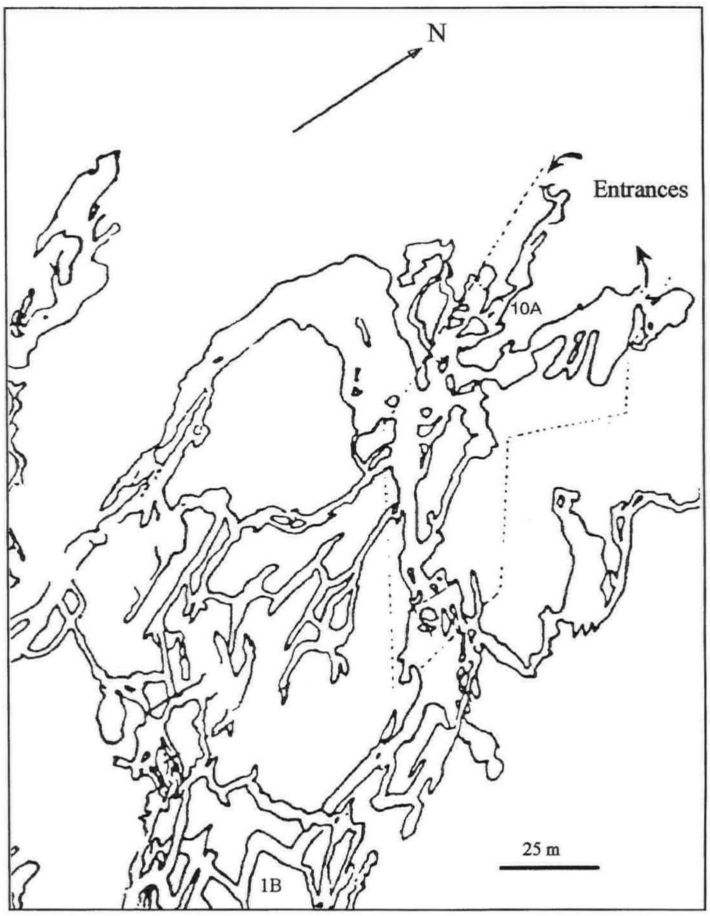

Figure 1a: Location of sampling sites: (A) Villars Cave, stations #10A and #1B, arrows indicate cave entrances, the dotted line indicates the tourist path (from Vidal and Baritaud, Périgueux Speleo Club)

Taxons	Mosses above the cave (%)	Mosses near the river (%)
Pinus	16.3	37.3
Abies	0.6	4.9
Picea		0.7
Juniperus	4.6	1.6
Carpinus	39	7.2
Corylus	6.1	7.8
Quercus ped.	4.1	0.1
Quercus ilex		1.3
Acer	0.3	
Alnus	1.7	0.3
Betula	0.3	2.3
Castanea		0.7
Fraxinus	0.6	0.3
Juglans	0.6	0.3
Salix	0.6	0.3
Tilia	0.3	
Ulmus	0.6	
Buxus	0.3	
Hedera	0.9	
Poaceae	10.2	14.2
Cerealia	0.3	0.7
Artemisia	1.2	0.3
Asteroïdeae	1.2	0.7
Brassicaceae	2	0.3
Caryophyllaceae	1.2	
Centaurea jacea	0.9	0.3
Chenopodiaceae	0.6	0.3
Cichorioïdeae	0.3	0.3
Ericaceae		0.3
Leguminosae	0.6	1.4
Plantaginaceae	0.9	1.5
Polygonaceae	0.6	
Ranunculaceae	1.5	0.3
Rosaceae	0.6	1.3
Rumex	0.3	0.3
Scrophulariaceae	0.3	0.3
Urticaceae	0.3	0.3
Cyperaceae	0.3	1.4
Hydrocharidaceae		0.3
Typhaceae	0.6	0.3
Monolete spores	0.3	
Trilete spores		0.7
Arboreal Pollen/Total	76.7	74.2
Total	344	306
Number of taxa	36	34
Unidentified pollens	3.8	3.6
Soft water Algae	0.3	
Fungus Spores	10	120

Table 1. – Villars moss pollen. All are percentages except fungal spores (row numbers).

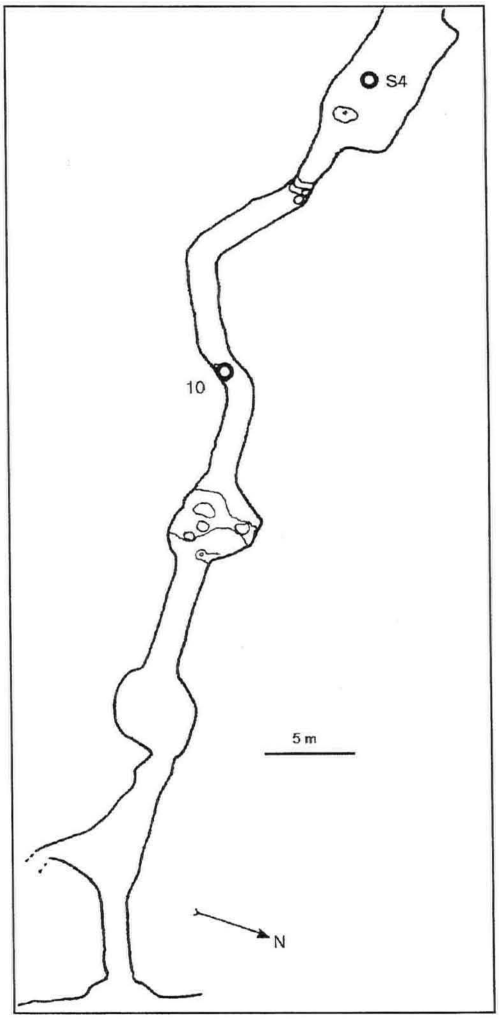

Figure 1b. La Faurie Cave, stations #S4 and #10.

beneath stalactites, and that the collected pollen were representative of the pollen rain of the previous month (Bui-Thi Mai and Girard, 1988). Another *in situ* study was undertaken in two shallow caves in New York State (Burney and Burney, 1993). Using several pollen traps, for air and seepage water, the authors showed that pollen entered the caves by way of the atmosphere, and that spectra from inside the caves are identical to spectra from the outside.

The main objective of the present study was to ascertain, in two shallow caves, whether pollen is brought by seepage water and/or by cave air, and if the assemblages are representative of the local vegetation. The first year was dedicated to the construction of an efficient pollen filter, which could remain in position for a full year without being filled by precipitated calcite. Analyses of the pollen content of mosses near one of the caves, and of modern and Holocene stalagmites, were compared with the filter contents.

SITE DESCRIPTION

Villars Cave (southwest France: 45°30′N, 0°50′E, 175m; Fig.1A) has developed in oolitic limestone of Bajocian age, and is 13km long. Most of the surrounding area is covered by deciduous forest composed of oaks and hornbeams, which are typical of this region (Lavergne, 1969). A small pine forest covering the area above the northern part of the cave was planted some thirty years ago, when the cave was fitted out for tourism. There is grassland above the southern part of the cave, which is called the "Trou qui Fume". The three studied drip stations (#10B, #1B and #7) are situated beneath the deciduous forest. They were chosen because they were monitored for a full year (drip rate and chemistry; Genty, unpublished; Baker *et al.*, 1997). Station #10B is 30m from the entrance, in a small chamber near the tourist path, between 10 and 15m below the surface. Station #1B is located in the lower part of the cave in the bed of the seasonal river, 30 to 35m beneath the surface and 200m from the entrance. Station #7 is at the extremity of the tourist path, under an active flowstone (Fig.1A).

La Faurie Cave (southwest France: 45°08′, 1°11′, 225m) forms a horizontal gallery in limestone of Bajocian age. The cave comprises a succession of small chambers linked together by narrow passages (Fig.1B). Its narrow entrance (<0.4m high; 0.8m wide) limits the air exchange between the cave and the exterior. Station #S4 is situated 50m

	VILLARS				LA FAURIE	
Taxons	Station 7	Station 97-1 b	Station 98-1 b	Station 10B	10	S4
Pinus	25	4			1	2
Juniperus	1					
Corylus					1	1
Quercus	2	2				4
Alnus	1					
Fraxinus	1					
Poaceae	6	3			6	1
Artemisia		1				
Brassicaceae	1			1		3
Chenopodiaceae				1		
Cichorioïdeae	1					
Leguminosae					3	
Rumex		1				
Monolete spores		1				
Trilete spores	1					
Total	39	12	0	2	13	8
Number of taxa	9	6	0	2	4	4
Unidentified pollens	12	1	0	0	2	0

Table 2. – Pollen grains collected on filters placed under stalactites of Villars and La Faurie caves.

from the entrance and about 20m beneath the surface. Station #10 is 30m from the entrance and 10m deep. Most of the land above the cave is covered with grassland, with a small forest of oak and hornbeam near the entrance.

METHODS

The first objective was to analyse the pollen content of cave seepage water under stalactites. After a period of trials, a pollen trap was constructed that could filter dripping water for at least one year without being filled by precipitated calcite. Then two filters were placed under stalactites for several months, without protection around the funnel (#7 and #1B in Villars Cave). During the next years, four filters, protected from the cave atmosphere by an aluminium sheet, were installed under two stalactites in the two caves whose overlying vegetation is different (deciduous forest and grassland), in order to compare the pollen taxa collected. Because the stations studied have been monitored, it has been possible to calculate the pollen fluxes (with the starting hypothesis that pollen grains are carried by seepage water). Drip rates were calculated with monthly drip counts for stations #1B and #7 (Villars), #S4 and #10 (La Faurie), and with an automatic counting apparatus for #10B (every 10 minutes; Villars).

In addition to the filters, other analyses for the Villars Cave were the pollen content of (1) mosses above the cave, whose pollen content is characteristic of the local vegetation (Heim, 1970); (2) a modern stalagmite, which has grown exactly at station #1B during the last 50 years, and two Holocene stalagmites.

All materials were processed for pollen analysis, and microdebris was also extracted from filters and stalagmites, to provide useful information about pollen sources (Diot, 1991).

Moss treatment

Two samples of moss polsters were analysed: the first was from the forest above the cave, the second from near the river a few metres down from the cave entrance. The mosses were placed in a 10% potassium hydroxide solution for 15 minutes.

Filter treatment

5µm nylon filters were used, permitting collection of pollen and spores as well as microdebris. Each filter was placed in a circular plexiglass box 10cm in diameter (Fig.2). Two small holes (0.5cm) above and under the box allow the passage of seepage water. After the first $CaCO_3$ precipitation such a system maintains a high pCO_2 inside the box, preventing further calcite precipitation and blocking of the filter. On removal from cave, the nylon filter was first washed with distilled water, centrifuged and then acetolysed in order to remove the lipid and protein layer that covers the exine, so that the pollen ornamentation can be seen and characterised. Samples containing abundant siliceous minerals were reacted with HF (40%), followed by HCl, in order to remove any fluorosilicates that were present.

Stalagmite treatment

Bastin's (1978) method was used in a slightly simplified form. Several tests made on speleothems from different places in Europe demonstrated that such simplification did not affect the efficiency of the method significantly (Plassart, 1999). Stages are:

1) HCl attack and centrifuging;
2) HF attack for 12 hours and centrifuging;
3) Three times: 10 minutes of HCl attack followed by centrifuging;
4) Washing;
5) Basic fuchsine colouration in an alcoholic solution in order to detect any contamination by modern pollen.

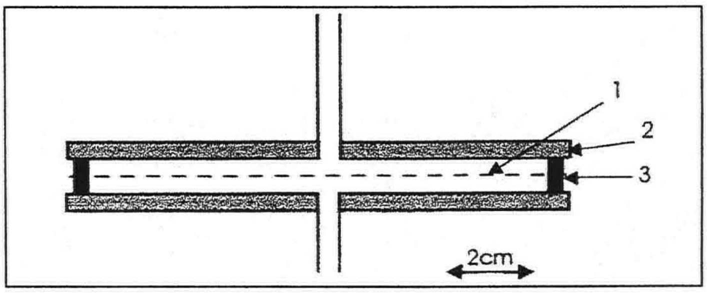

Figure 2a. Seepage water pollen filter. The filter (1) is maintained by rubber joins (3) in a plexiglass box (2) that maintains a high CO_2 partial pressure and avoids $CaCO_3$ precipitation.

		VILLARS				LA FAURIE	
		97-1B	98-1B	10	7	10	S4
Plant microdebris:							
	brown	7	4		60	8	19
	yellow	0	4	8	3	1	4
	translucent	15	18		16	41	73
	brownish	7	2		13	5	6
	cells	18		7	4	7	6
Micro-charcoal		19	12	14	24	15	7
Fungus spores		1	2	1	1	6	21
Plant bristles		30	25	8	12	10	20
Insects:							
	hairs	12	10		3	10	12
	tissue with hairs	10	7			4	8
	legs			1		33	1
	wings	1					
	pieces of acariens					11	
	entire acariens					3	
Algae:							
	unidentified	2	3	3	0	11	1
	Spirogyra					13	
Pollen		12	0	2	39	13	8
Total		133	87	43	175	191	186

Table 3 – Microdebris collected on filters placed under stalactites of Villars and La Faurie caves.

Three stalagmites from the Villars cave were analysed. The first one (Vil-stm#1B) grew at station #1B, where the filters were placed, and must have started to grow after 1953 AD, because it sealed a caver footprint that was made after the date of the cave discovery (1953 AD). Vil-stm#1B is situated near the riverbed, which flows only when precipitation is very high, generally during wet winters. The other two stalagmites are: (1) a Holocene stalagmite (Vil-stm6) collected south of the tourist path, which was divided into three pieces for pollen analysis; (2) a broken stalagmite of unknown age (Vil3) found in the embankment of the path.

RESULTS AND DISCUSSION

Pollen deposited in moss polsters

Pollen are named in accordance with the Coste Flora Nomenclature (1985). Villars mosses show a high percentage of tree pollen: 77% for the moss above the cave and 74% for the moss near the river (Table 1). The large number of taxa (34 and 36) is representative of the local vegetation: ferns are rare (less than 1%), hornbeam (*Carpinus*) pollen grains are more numerous in the forest moss sample than in the river one (39% against 7.2%). The latter sample is situated at the edge of the pine wood and trapped more pine pollen (37.3% against 16.3%). Grass pollen, mostly Graminaceae (Poaceae), dominates (10.2% and 14.2%) the herbs. Both moss samples contain some unidentified and corroded pollen grains (3.8% and 3.6%) and saprophyte fungal spores (Table 1). No mosses have been analysed at the La Faurie site, but here too, it is assumed that pollen arriving at the soil surface above the cave is representative of the local vegetation.

Pollen brought by seepage water

Villars – the pollen concentration was low for all the filters, with some being sterile: 0 to 39 grains for 10 to 12 recording months (Table 2). For station #1B, and a period of one year, 12 grains were found when the filter was open to the cave atmosphere, whereas none were recorded when the filter was protected from the atmosphere by an aluminium sheet. Station 10B, which was not protected and which is close to the tourist path, gathered 39 pollen grains in 10 months (Station 7; Table 2). These results demonstrate that pollen grains arrive by cave air and not by water, at least at this site. The great number of tourists (>50,000/year) might be the principal cause of pollen influx in this cave. The sealed filter at station #10B collected only two grains during a full year of dripping (during which 373 litres of water passed through the filter), despite the fact that it was placed on the tourist path. These two pollen grains (Poaceae) possibly represent contamination.

The number of pollen types in these samples is very low when compared with those from the mosses: a maximum of 9 types (#7), whereas more than 30 were found in the mosses. However, pollen of pine (*Pinus*), oak (*Quercus pedunculata*), hornbeam and Graminaceae (Poaceae) dominate, as with the mosses. Other types, not abundant in the mosses, are found in the filters (tables 1 and 2). The larger number of pollen grains found in the #7 filter is possibly due to: (1) the fact that it was not protected and is near the tourist path and/or (2) the fact that it is a straw stalactite under a flowstone floor that drains a large surface.

We note that even where few or no pollen grains were collected, microdebris fragments were numerous (Table 3). They comprise organic matter particles larger than 5µm and unidentified plant tissue remains less than 100µm long. Under the microscope, small opaque particles (less than 20µm long) were observed. These are micro-charcoals and/or inert organic matter (inertinite). Plant bristles and insect hairs are abundant. A wing (125µm long) and an insect leg were found. Fresh water algae were found in 3 of the 4 filters (Table 3). In Villars Cave protected filters collected 2 to 4 times less microdebris than did the non-protected ones. This indicates that the cave air brought in at least part of the microdebris.

La Faurie – The two protected filters collected 8 and 13 pollen grains, which, for a comparable time duration, is more than in Villars (Table 2). Poaceae were the most abundant at station #10, whereas tree pollen was dominant at station #S4. These pollen taxa are also found in the local vegetation. Microdebris were numerous: 186 and 191 for #S4 and #10 respectively. As in Villars Cave, plant bristles and insect hairs were most common. An entire acarian, 220µm long, was also found.

The larger quantity of pollen and microdebris found in the protected filter of La Faurie Cave (compare to Villars Cave) could be due to various causes: (1) wider supply conduits that allow the transport of

Stations	date of sampling beginning	date of sampling end	duration days	quantity of water litres	number of pollens	pollen concentration pollens per 1,000 litre
Villars #1B	6/2/97	26/3/98	413	1299.4	12	9
Villars #1B (protected)	18/2/98	29/1/99	345	1080	0	0
Villars #7	26/4/96	6/2/97	286	736	39	53
Villars #10B (protected)	18/2/98	29/1/99	345	373.5	2	5
La Faurie #S4 (protected)	25/8/97	29/1/99	522	813.7	8	10
La Faurie #10 (protected)	23/1/98	29/1/99	371	44	13	295

Table 4. – Pollen flux calculations.

bigger particles; (2) position and dimension of the drainage surface of each stalactite; (3) contamination due to the very great pollen and microdebris content in the La Faurie cave air, which went through the filter protection. Badgers living in the cave might be the main cause of such contamination. Despite the observation of hairs and prints of animals in the first part of the cave, it seems unlikely that badgers contaminated the filters because of the screen protection around them, and also because the latter were put deeper in the cave.

Pollen influx calculations

Pollen influx has been calculated with the hypothesis that all pollen comes from the seepage water – which is probably not likely everywhere, as already discussed. However, the calculation is useful, to see whether pollen fluxes are coherent with pollen concentrations found in stalagmites. Pollen fluxes vary from 0 to 295 pollen/1,000 litres of seepage water (Table 4). Only two stations have a significant flux: Villars station #7 (52 pollen grains/1,000 litres) and La Faurie station #10 (295 pollen grains/1,000 litres). As seen above, pollen grains at station #7 are likely to be from the cave air, but the La Faurie #10 filter was protected, and thus it is likely that these pollen were brought by the water. The average HCO_3 concentration of these stations is 382 mg/l, which will potentially produce 27.6g of calcite during the time duration of filtering (actually, only a fraction of HCO_3 is used for $CaCO_3$ precipitation, but this does not significantly change the concentration results). This leads to a theoretical concentration of 1.6 pollen grains per gram of calcite (44 grains were found). This value is in broad agreement with former work on cave stalagmites, where the maximum pollen concentration found was about 5 pollen grains per gram (Bastin, personal communication).

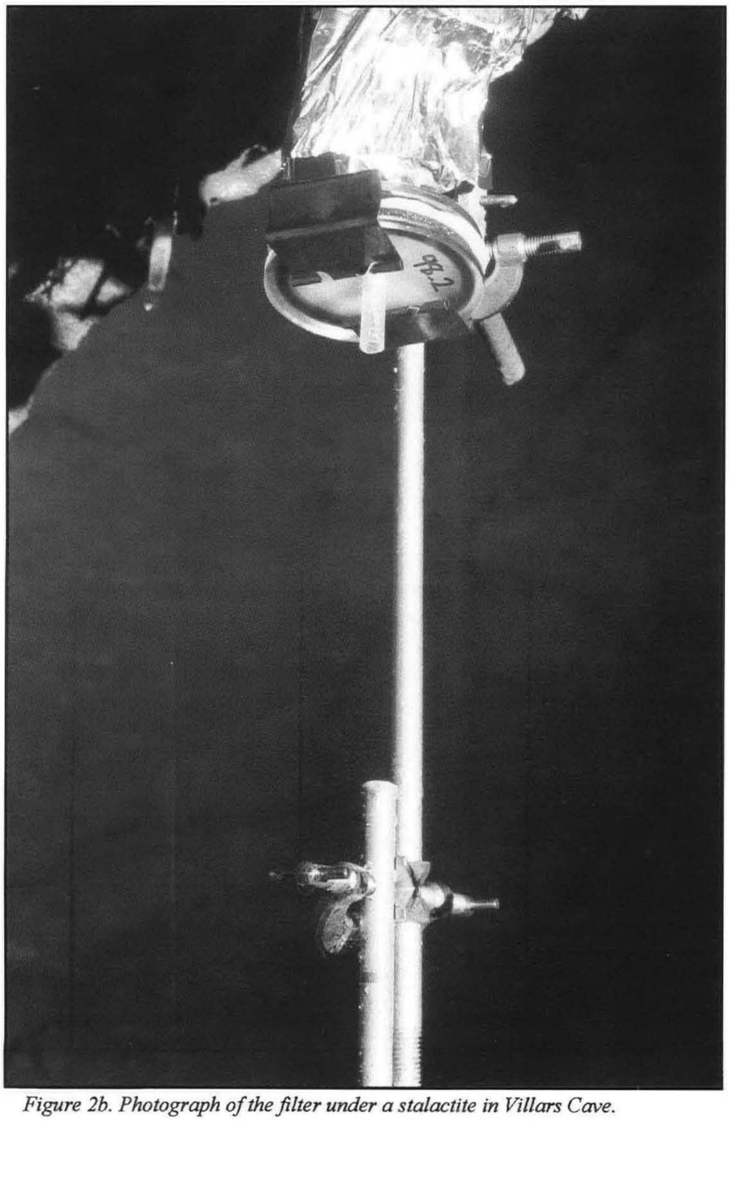

Figure 2b. Photograph of the filter under a stalactite in Villars Cave.

All the pollen fluxes observed in Villars Cave and La Faurie Cave are much lower than those observed in the Foissac Cave in southern-France (59 to 157 pollen grains per litre, which is 59,000 to 157,000 pollen grains per 1,000 litres; Bui-Thi Mai and Girard, 1988). This great difference could be due to: (1) a significant level of air contamination if the Foissac Cave filters were not protected; (2) a very large seepage water conduit allowing the transport of a lot of particles. The latter is consistent with the high content of detrital particles that were found in that case and with the period when the study was made (high pollen production at Spring time).

Pollen incorporated in stalagmite (Villars)

Only the modern stalagmite Vil-stm#1B has a significant pollen record (2.52 pollen grains per gram of $CaCO_3$) and a larger number of taxa (32), comparable to the mosses (Table 5). The pollen content of other stalagmites is so low (concentrations, Table 4) that any environmental interpretation is unviable.

The pollen content of Vil-stm#1B shows differences compared with moss spectra: alder (*Alnus*) and chestnut tree (*Castanea*) abound in the stalagmite, whereas hornbeam (*Carpinus*) is very common in the mosses (Fig.3). This could be due to:

1) a different nearby vegetation during the last 50 years of stalagmite growth, with more chestnut trees and less pines than today;
2) pollen recycling through the soil and cave and mixing with pollen from the local vegetation during a relatively long time period;
3) pollen trapped in the stalagmite has a more distant origin.

Unlike the two other stalagmites, Vil-stm#1B includes evidence of several hiatuses, which are well marked by detrital layers on polished sections. These are due to river floodings, which occur occasionally during wet winters. The river goes into the cave 3km from station #1B, so it is likely that it brings pollen from different areas, and also older pollen that has been deposited in the river bed during earlier floodings. This complicates interpretation of the Vil-stm#1B pollen content.

The two other stalagmites have between 0.035 and 0.082 pollen grains per gram, which is negligible. These samples are composed of pure compact calcite without any visible detrital layer, which confirms that it is likely that the pollen content of Vil-stm#1B has been brought by detrital contamination.

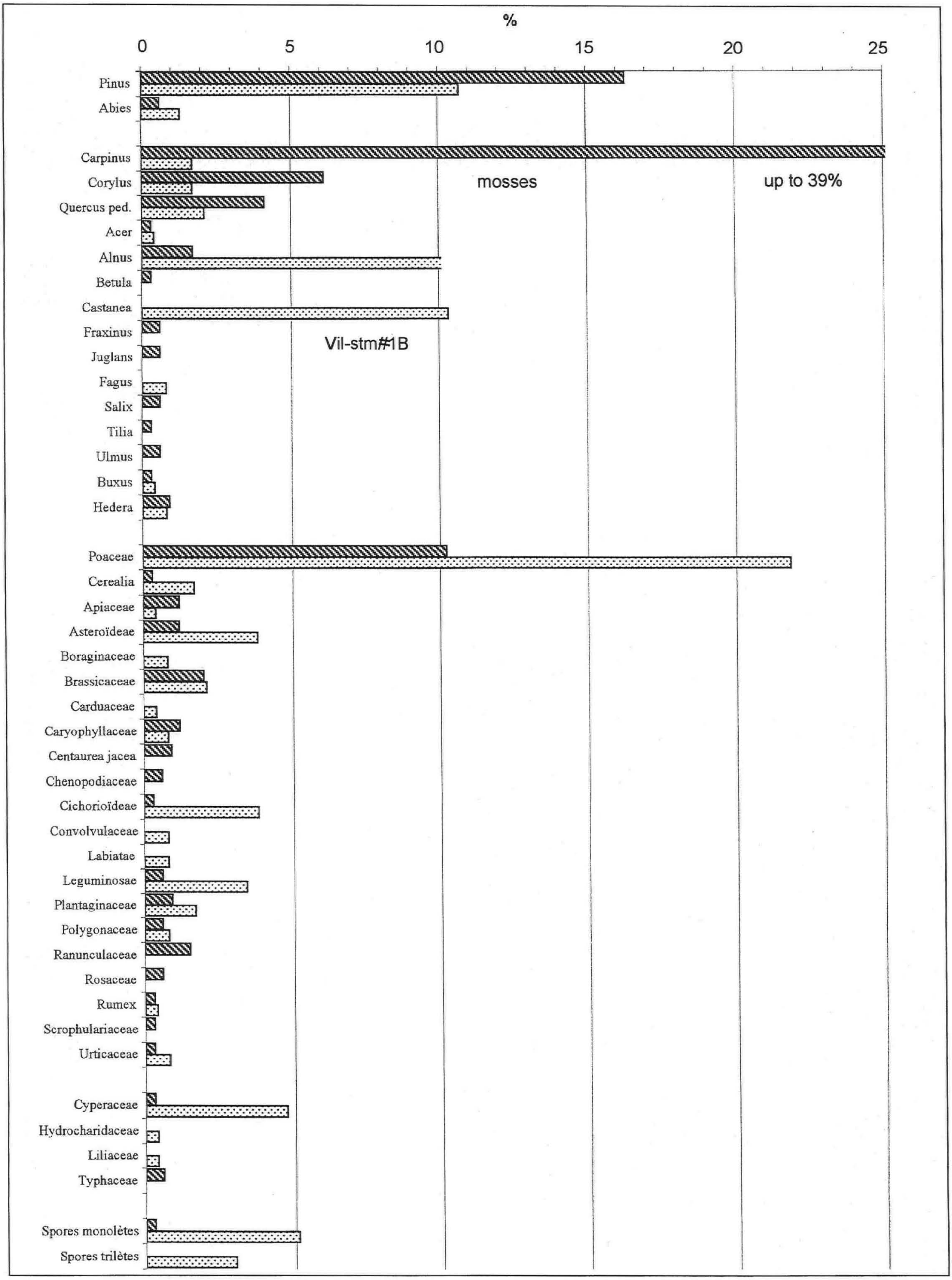

Figure 3. Comparison between the pollen content of the mosses found near Villars Cave and the modern stalagmite Vil-stm#1B.

Taxa	stalagmite Vil-stm#1B (%)	stalagmite Vil-stm6			stalagmite Vil 3
		A	B	C	
Pinus	10.7			1	1
Abies	1.3				
	0				
Carpinus	1.7				
Corylus	1.7				
Quercus ped.	2.1				
Acer	0.4				
Alnus	10.7	1			
Castanea	10.3				
Fagus	0.8				
Salix	0	4			
Tilia	0			1	
Buxus	0.4				
Hedera	0.8				
Poaceae	21.8	3		1	
Cerealia	1.7				
Apiaceae	0.4				
Asteroïdeae	3.8				
Boraginaceae	0.8				
Brassicaceae	2.1				
Carduaceae	0.4				
Caryophyllaceae	0.8				
Cichorioïdeae	3.8			1	
Convolvulaceae	0.8				
Labiatae	0.8				
Leguminosae	3.4	3			
Plantaginaceae	1.7				
Polygonaceae	0.8				
Rumex	0.4			2	
Urticaceae	0.8				
Cyperaceae	4.7				
Hydrocharidaceae	0.4				
Liliaceae	0.4				
Monolete spores	5.1		1		
Trilete spores	3		1	2	
AP/T	40.9				
Total	234	11	2	8	1
Weight g	93	141	114	97	295
Concentration pollen/g	2.5161	0.078	0.0175	0.0825	0.0034
Number of taxa	32	4	2	6	1
Unidentified pollen	9.4	5	1	2	1
Soft water algae	3				
Fungus spores				3	

Table 5. – Pollen extracted from three stalagmites in Villars Cave.

MICRODEBRIS		Vil-stm#1B	Vil-stm6			Vil3
			A	B	C	
		abundance				
Plant microdebris:						
	brown	very abundant	very few	very few	few	very few
	yellow	abundant	very few			
	translucent	few				
	brownish	few	very few	few		
	cells	rare				
Microcharcoals		abundant	very few	few	very few	very few
Moss spores			very few	very few		very few
Mushroom spores:		abundant				
	Sporotheca	few				
	Diporotheca	few				
Leaf hairs		few	few	very few	very few	very few
Insects:		very few				
	bristle		very few	very few	-	very few
	legs					
	tissue with bristle					
	wings					rare
Algae:		few				
	Spirogyra	very few				
	Zygnema	very few				
	Concentricystes	few				
Microfossils:						
	type 119	very few				
Intestin parasites:						
	Trichuris	very few				
Yellow globules					few	
Total		very abundant	< 100	< 50	< 50	< 50

Table 6. – Microdebris extracted from three stalagmites in Villars Cave.

It is the same for the microdebris: Vil-stm#1B has so much debris that a precise count is impossible (it covers 7 small thin sections), whereas they are rare on Vil-stm6 and Vil3 (Table 6). Plant tissues and cells are found in all the stalagmites but they are numerous only in Vil-stm#1B. Micro-charcoal is abundant. Insect fragments (bristles, legs and a piece of an acarien) are found in several stalagmites. Vil-stm#1B is characterised by abundant fungal spores and by algae. Type 119 (Pals *et al.*, 1980) indicates an aquatic origin, others indicate stagnant waters (Type 62 and 314; Van Geel, 1976; Lopez *et al.*, 1998). Some saprophytic fungi species, filament forms of two to several lodges, are difficult to characterise; others have been identified - *Diporotheca* or type 143 (Van Geel *et al.*, 1986), which belongs to a tree parasite fungus, and *Chaetomium* or type 7A (Van Geel, 1978). Both indicate a forest environment.

The large abundance of pollen and microdebris found in the Vil-stm#1B stalagmite and the presence of algae demonstrate that the main source of these particles is temporary flooding of the river. Filter content has also demonstrated that a little pollen and microdebris is also brought by the cave air, at least since the caves have been visited by tourists. The fact that the other stalagmites that are far from the river and which do not have any detrital layers contain little pollen, is in favour of the hypothesis that, here at least, pollen grains and microdebris are not brought in by the seepage water.

CONCLUSIONS

This study demonstrates the following:

1) pollen from the mosses collected above one of the caves is representative of the local vegetation, which demonstrates that the pollen arriving at the cave is local;

2) filters that were put under stalactites and protected from the cave air did not collect any pollen in the Villars Cave, while unprotected filters (among them one at the same place as the protected filter but during another year) have collected some. This demonstrates that, in this cave, pollen is not brought in by the seepage water (at least during the studied year) but by the cave atmosphere and probably due to the tourist visits;

3) in the La Faurie Cave, the two protected filters collected a few pollen grains, which suggests that, at this site, some pollen is brought by the seepage water, but more experimentation is necessary to measure the cave-air pollen content;

4) pollen taxa collected on filters are similar to the local vegetation, but not all types are found;

5) in the Villars Cave stalagmites, only the sample that was contaminated by detrital particles by temporary flooding possesses a significant number of pollen grains and microdebris. Its pollen spectrum is similar to that of the mosses but with differences in the tree taxons indicating a possible change of vegetation and/or contamination by older or distant pollen. The other stalagmites, which are composed of pure compact calcite, have a negligible quantity of pollen and very little microdebris;

6) microdebris fragments have been studied in stalagmites and filters. They are mainly composed of plant residues (tissues, plant hairs), micro-charcoals, insect bristles and fragments, algae and spores. They provide useful information about the origin of the pollen.

These results confirm the great heterogeneity found in speleothem feed waters. It has already been shown that drip rates of two stalactites can have a very different response to:

1) rainfall and water excess, even if they are a few centimeters from each other (Genty and Deflandre, 1998; Borsato, 1997);
2) chemistry (Roberts *et al.*, 1996).

It is shown here that the pollen content is also very variable. In the Villars Cave it is likely that pollen grains are brought by the air, and locally by the river. In the La Faurie Cave, it is probable that little pollen is brought in by the seepage water, but in this latter cave, more experiments are needed to check whether contamination is possible due to the very high pollen content in the cave air. Consequently, pollens found in stalagmites or flowstones must be interpreted with caution when used for paleoenvironmental reconstruction, especially if they are found in portions where detrital layers occur, because contamination by floods carrying recycled and far-travelled pollen grains might have taken place.

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REFERENCES

Atkinson, T C, Harmon, R S, Smart, P L and Waltham, A C, 1978. Paleoclimatic and geomorphic implications of 230Th/234U on speleothems from Britain. *Nature*, Vol.272, 24-28.

Baker, A, Smart, P L, Edwards, R L and Richards, D A, 1993. Annual growth bandings in a cave stalagmite. *Nature*, Vol.364, 518-520.

Baker, A, Genty, D, Dreybrodt, W, Barnes, W, Mockler, N and Grapes, J, 1997. Testing theoretically predicted stalagmite growth rate with Recent annually laminated samples: implications for past stalagmite deposition. *Geochimica et Cosmochimica Acta*, Vol.62, 393-404.

Bar-Mattews, M and Ayalon, A, 1997. Late Quaternary Paleoclimate in the Eastern Mediterraneen Region from Stable Isotope Analysis of Speleothems at Soreq Cave, Israel. *Quaternary Research*, Vol.47, 155-168.

Bastin, B, and Schneider, A M, 1984. Palynologie en milieux karstiques. *Kölner Geog. Arb.*, Vol.45, Koln 84, 87-93.

Bastin, B, 1978. L'analyse pollinique des stalagmites: une nouvelle possibilité d'approche des fluctuations climatiques du Quaternaire. *Annales de la Société Géologique de Belgique*, Vol.101, 13-19.

Bastin, B, 1982. Premier bilan de l'analyse pollinique de stalagmites holocènes en provenance de grottes belges. *Revue belge de géographie*, 106ème année, 87-97.

Bastin, B, 1990. L'analyse pollinique des concrétions stalagmitiques: méthodologie et résultats en provenance des grottes belges. *Karstologia Mémoires*, Vol.2, 3-10.

Bastin, B, Cordy, J-M, Gewelt, M and Otte, M, 1986. Fluctuations climatiques enregistrées depuis 125 000 ans dans les couches de remplissage de la grotte Scladina (province de Namur, Belgique). *Bulletin Association Française de l'Etude du Quaternaire*, Vol.1-2, 168-177.

Bastin, B and Quinif, Y, 1993. Une fin d'interglaciaire: le plancher stalagmitique de Feluy. La transition entre les stades isotopiques 5 et 4. *Speleochronos*, Vol.5, 19-23.

Bastin, B, Quinif, Y, Dupuis C and Gascoyne, M, 1988. La séquence sédimentaire de la grotte de Bohon (Belgique). *Annales de la Société Géologique de Belgique*, Vol.111, 51-60.

Borsato, A, 1997. Dripwater monitoring at Grotta di Ernesto (NE-Italy): a contribution to the understanding of karst hydrology and the kinetics of carbonate dissolution, 6th Conference on Limestone Hydrology and Fissured Media. *Proceedings of the 12th International Congress of Speleology*, Vol.2, 57-60.

Bui Thi, M and Girard M, 1988. Apports actuels et anciens de pollens dans la grotte de Foissac (Aveyron, France). *In* Publication de l'Institut français de Pondichéry (Ed.), (Vol.25, pp.43-53).

Burney, D A and Burney, L P, 1993. Modern pollen deposition in cave sites: experimental results from New York State, *New Phytologist*, Vol.124, 523-535.

Coles, G M, Gilbertson, D D, Hunt, C O and Jenkinson, R D, 1990. Pollen taphonomy in caves. Cave Science, Vol.16, 83-89.Coste, H, 1985, Flore descriptive et illustrée de la France, de la Corse et des contrées limitrophes. Ed. E.A. Blanchard, Paris.

Damblon, F, 1974. Observations palynologiques dans la grotte de Remouchamps. *Bull. Société Royale Belge d'Anthropologie Préhistorique*, Vol.85, 131-155.

Diot, M F, 1988. Etudes palynologiques du remplissage de la grotte Vaufrey. In *La grotte Vaufrey à Cénac et Saint-Julien (Dordogne). Paléo-environnements, chronologie et activités humaines.* Paris SPF (Ed.). *Mémoires de la Société Préhistorique française.* (Vol.19, 75-88).

Diot, M F, 1991. Le palynofaciès en archéologie: intérêt de son étude. *Revue d'Archéométrie*, Vol.15, 54-62.

Duplessy, J C, 1967. Etude isotopique du concrétionnement de l'Aven d'Orgnac – Application à la paléoclimatologie de la région Sud-Ardéchoise, Thèse de 3e cycle, Paris, 45p.

Duplessy, J C, Labeyrie, J, Lalou, C L and Nguyen, H V, 1970. Continental climatic variations between 130,000 and 90,000 years BP. *Nature*, Vol.226, 631-632.

Fantidis, J, and Ehhalt, D H, 1970. Variations of the carbon and oxygen isotopic composition in stalagmites and stalactites: evidence of non-equilibrium isotopic fractionation. *Earth and Planetary Science Letters*, Vol.10, 136-144.

Fornaca-Rinaldi, G, Panichi, C and Tongiorgi, E, 1968. Some causes of the variation of the isotopic composition of carbon and oxygen in cave concretions. *Earth and Planetary Science Letters*, Vol.4, 321-324.

Genty, D, and Quinif, Y, 1996. Annually laminated sequences in the internal structure of some Belgian stalagmites - Importance for paleoclimatology. *Journal of Sedimentary Research*, Vol.66, 275-288.

Genty, D and Deflandre, G, 1998. Drip flow variations under a stalactite of the Père Noël Cave (Belgium). Evidence of seasonal variations and air pressure constraints. *Journal of Hydrology*, Vol.211, 208-232.

Harmon, R S, Thompson, P, Schwarcz, H P. and Ford, D C, 1975. Uranium-series dating of speleothems. *National Speleological Society Bulletin*, Vol.37, 21-33.

Heim, J, 1970. Les relations entre les spectres polliniques récents et la végétation actuelle en Europe occidentale. Univ. de Louvain, Lab. de Palyn., de Phytosociologie, University Thesis, 181pp.

Lauritzen, S-E, 1995. High-Resolution Paleotemperature Proxy Record for the Last Interglaciation Based on Norwegian Speleothems. *Quaternary Research*, Vol.43, 133-146.

Lavergne, D, 1969. Carte de la végétation, Bergerac, n 57. CNRS (Ed.), Toulouse, Service de la carte de la végétation de la France.

Leroi-Gourhan, A, 1967. Pollens et datation de la grotte de La Vache (Ariège). *Bulletin de la Société Préhistorique de l'Ariège*, Vol.22, 115-127.

Li, W X, Lundberg, J, Dickin, A P, Ford, D C, Schwarcz, H P, McNutt, R and Williams, D, 1989. High-precision mass-spectrometric uranium-series dating of cave deposits and implications for palaeoclimate studies. *Nature*, Vol.339, 534-536.

Lopez-Saez, J A, Van Geel, B, Farbos-Texier, S and Diot, M-F, 1998. Remarques paléoécologiques à propos de quelques palynomorphes non polliniques provenant de sédiments quaternaires en France. *Revue de Paléobiologie*, Vol.17, 445-459.

McGarry, S F, Baker A, Caseldin, C J, Hawkesworth, C J, 2000. A multyproxy study of speleothems, in Climate Changes – The Karst Record II Abstract, Krakow, Poland, p.79.

Pals, J-P, Van Geel, B, and Delfos, A, 1980. Palaeoecological studies in the Klokkeweel bog near Hoogkarspel (Prov. of Noord-Holland). *Revue de Palaebotanique et de Palynologie*, Vol.30, 371-418.

Paquereau, M M, 1976. Flores des deux derniers interglaciaires dans le Sud-Ouest de la France. *L'Anthropologie*, Vol.80, 201-227.

Plassart, F, 1999. Mise au point d'une méthode d'extraction des pollens à partir des speleothèmes. Rapport de Maîtrise de Préhistoire, Université de Bordeaux 1, 43pp.

Quinif, Y, 1989. La datation uranium-thorium. *Spéléochronos*, Vol.1, 3-22.

Renault-Miskovsky, J, Texier, P-J, 1980. Intérêt de l'analyse pollinique détaillée dans les concrétions de grotte : applications à l'Abri Pré-Lombard (Tourettes-sur-Loup, Alpes Maritimes). *Bulletin AFEQ*, Vol.3, 129-134.

Roberts, M S, Smart, P L, Perkins, W T, Pearce, N J G and Hawkesworth, C J, 1996. Trace elements in Holocene speleothems. In Karst Water Institute, University of Bergen Norway (Ed.). (Special Publication Vol.2, 138-139).

Shopov, Y Y and Dermendjiev, V, 1990. Microzonality of luminescence of cave flowstones as a new indirect index of solar activity. *Comptes Rendus de l' Académie Bulgare des Sciences*, Vol.43, 9-12.

Van Geel, B., 1976. Fossil spores of Zygnemataceae in ditches of a pre-historic settlement in Hoogkarspel (The Netherlands). *Revue de Paleobotanique et de Palynologie*, Vol.22, 337-374.

Van Geel, B, 1978. A palaeoecological study of Holocene peat bog sections in Germany and The Netherlands. *Revue de Paleobotanique et de Palynologie*, Vol.25, 1-120.

Van Geel, B, Klink, A G, Pals, J-P and Wieger J, 1986. An Upper Eemian lake deposit from Twente, eastern Netherlands. *Revue de Paleobotanique et de Palynologie*, Vol.47, 31-61.

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The macroinvertebrate communities of limestone springs in the Wye Valley, Derbyshire Peak District, UK

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Abstract: This paper presents the results of a study of the spring-dwelling macroinvertebrates of 18 springs in the Wye Valley, Derbyshire. The fauna found within the springs is a mix of species exhibiting ubiquitous, crenobiontic and crenophilic ecological valence, with the relative contribution that these groups make varying between sites. Multivariate analysis indicates that water chemistry is not a major influence on the benthic communities, and that the major environmental determinant at a broad-scale of analysis is related to flow regime. Some taxa are characteristic of springs with a permanent or an intermittent flow regime, although the majority of the fauna occur in both habitat types. The mechanisms through which recolonisation of the intermittent springs occur are also examined. The conservation and protection of these unique and little-studied habitats is discussed, and suggestions are made as to how to achieve this in the Wye Valley.

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INTRODUCTION

Freshwater springs have been neglected as a specific area of groundwater research by aquatic ecologists. This situation has been attributed to the fact that studies have often revealed that species richness within springs is lower than in downstream areas (Erman and Erman, 1995). However, high species richness within springs has been found by some ecologists (e.g. Morse and Barr, 1990; Ferrington *et al.*, 1995; Webb *et al.*, 1995), and certain species of macroinvertebrates have been discovered to occur mainly in, or are endemic to, spring habitats (Erman and Erman, 1995). It is now becoming increasingly recognised that such habitats make an important contribution to biological diversity, both locally and at a larger scale. Permanent spring ecotopes possess features that may aid in the advancement of community ecology. Spring communities may demonstrate most of the structural and functional properties seen in other aquatic communities, yet are naturally less complex than those found in alternative lotic habitats (Williams and Williams, 1998). Stern and Stern (1969) considered small, constant-temperature springbrooks to be as near perfect systems for the study of lotic communities as occur in nature.

At present no British statutory agency maintains a national or regional inventory of freshwater springs. Official data regarding the faunal integrity of springs does not exist for the Peak National Park, or nationally. Springs do not appear to be specifically protected in any region of Britain, although they may receive indirect protection if they lie within areas designated as SSSIs or sites with other sensitive area status. In the Peak District there are 10 cave/karst SSSIs, but in none of these is there any mention of aquatic macroinvertebrates as a feature of interest. Some karst features have been included in regional biodiversity plans because they are of international importance for bats, of at least county importance for other wildlife, and of international importance for cave structures and minerals. However, even where karst has been identified as a significant component of an area's biodiversity, caves and mines remain the focal point of research and protection, and springs are generally mentioned only casually.

Three case studies have been carried out in the Wye Valley, Derbyshire to further the understanding of the structure, function and distribution of macroinvertebrates in limestone springs. This paper describes the first of these studies, in which the main aim was to investigate whether macroinvertebrate assemblages differ significantly between 18 limestone springs within the Wye Valley, and to examine which physico-chemical factors influence macroinvertebrate distribution and richness within the springs.

THE ECOLOGY OF SPRINGS

The area around a spring's source, known as the eucrenal (or crenal) zone, has been variously described according to its thermal characteristics. The boundary of this zone has been defined as the point where the annual variation in water temperature does not exceed 5°C (Illies, 1952) or 2°C (Erman and Erman, 1995). Downstream of this boundary, the hypocrenal zone (or springbrook) occurs. Illies (1952) considered that the eucrenal zone is delimited from downstream areas more distinctly than any other lotic segments as a result of the limitation to (crenobiontic), or preference for (crenophilic), the area around the spring source shown by some macroinvertebrate fauna. The eucrenal zone is a major freshwater habitat type that is now recognised worldwide, as is the branch of aquatic ecology that deals with its study (*Crenobiology*: Illies and Botosaneanu, 1963).

Danks and Williams (1991) comment that spring habitats contain a limited number of macroinvertebrate species of diverse origins, and that there is a substantial number of spring-specialist species, many of which are in distinctive genera. Springs are also habitats where, protected from large oscillations in climate, relict species have endured in many areas of the world (Hynes, 1970). Late glacial cold-stenothermic (psychrophilic) relicts are thought to have immigrated to springs shortly after the last glacial epoch where this habitat type may have provided a refuge from the increasing temperatures. Postglacial, thermophilic relicts may also occur in springs alongside late glacial cold-stenotherms. Postglacial relicts remain from a fauna living at warmer times than present, and European springs provide shelter from low winter temperatures for such species (Thorup and Lindegaard, 1977).

Like cave and hypogean waters, many springs exhibit thermal stability throughout the year, (van der Kamp, 1995). This is a biologically important feature, and these springs may represent a highly stable ecological environment (Williams, 1991a). However, such constant conditions are not present in all spring systems, and the temperature, chemical composition, suspended-solid content, and discharge of springs can also exhibit both gradual (seasonal) and sudden (incidental; storm-related) variations (van Everdingen, 1991). Persistence of spring discharge may also be a highly significant factor from a biological perspective. Variability of flow is closely related to persistence (Danks and Williams, 1991), and if this is associated with changes in temperature and water quality it may be of particular importance

THE WYE VALLEY SPRINGS

Although rainfall infiltrates through the soil and enters the limestone directly in the majority of the White Peak, streams of aggressive water flow off the Millstone Grit Group uplands and sink into swallets at the limestone/shale margin before supplying water to the springs that form the River Wye headwaters. Wye Head (SK 0499 7304) is generally held to be the source of the River Wye. However, an equally large quantity of water is discharged from Otter Hole Resurgence (SK 0460 7330), some 400m to the northwest, which drains the same area. A bed of lava between Millers Dale and Monsal Dale helps to maintain the Wye on the surface, and as the river passes through the White Peak, a series of springs augment and help to maintain the flow.

All of the springs (Fig.1) arise from the Carboniferous limestone outcrop and feed the River Wye either directly or via trout breeding ponds. Although a total of 57 springs were found rising adjacent to the river, 18 sites were chosen on the basis of areal extent and ease of access. All springs selected were located east of the town of Buxton, Derbyshire. The immediate setting of the 18 sites varies considerably. Table 1 provides a general description of the 18 spring sites, including their geographical position and characteristics of their surroundings.

MATERIALS AND METHODS

Each spring was sampled four times at approximately three-monthly intervals from February 10th until November 27th 1998. Surber sampling was employed to gather the macroinvertebrate data from the spring habitats. A standard Surber sample was taken directly at the point of groundwater emergence and another within the centre of the springbrook at a point midway between the spring's source and its confluence with the River Wye. Surbur sampling causes minimal disturbance to the habitat relative to other biological sampling techniques. Identification was taken down to species level for most of the major macroinvertebrate orders, with the exception of first and second instar larvae and certain taxonomically demanding groups such as the Diptera and Oligochaeta. The source and springbrook biological data were analysed both separately and in combination. The latter enables a comprehensive taxon signature to be determined for each spring.

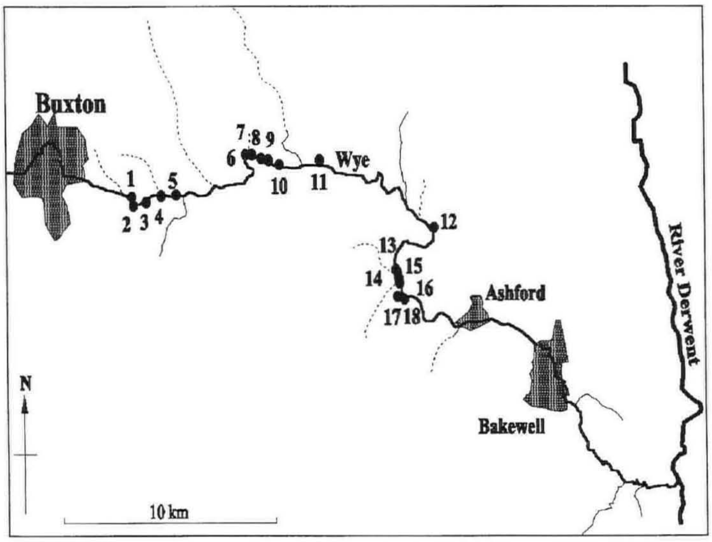

Figure 1. Location of the 18 Wye Valley springs

Conductivity, pH, dissolved oxygen, bicarbonate concentration and temperature were determined on each sampling occasion at spring source. Substrate composition was recorded according to the Wentworth Scale (Wentworth, 1922). The aspect (direction of spring source orientation), spatial dimensions, vegetative cover and diversity of in-spring microhabitats were also recorded at each of the sampling sites. Discharge was measured at spring source using the standard velocity-area (incremental) technique. Percentage variation in spring discharge was calculated using the following formula:

$$\left(\frac{\max Q - \min Q}{\max Q}\right) \times 100$$

An alternative measure of permanence was provided by deriving a relative index of permanence (RIoP). This was calculated by ranking each spring according to mean discharge and minimum discharge at summer baseflow. The separate ranks were then summed to provide the RIoP for each spring site (adapted from Feminella, 1996). Both indices were used as variables within the multivariate analyses. Obviously, without continuous monitoring of spring discharge through use of a weir or flume, these types of discharge measurement must be regarded only as approximations. However, they do allow the relative variation in discharge between the spring sites to be established. Water samples for laboratory analysis were taken at source on each sampling occasion.

The bulky raw data that are generated in studies of community ecology can be summarised, noise and redundancy reduced, and broad patterns detected for comparisons with abiotic variables by the use of 'multivariate analyses' (Gauch, 1982; Ludwig and Reynolds, 1988). Species dependent multivariate methods are more sensitive than species independent (univariate and graphical/distributional) methods when discriminating both temporally and spatially, and when detecting the responses of benthic communities to environmental change.

It is often recommended that 'rare' species should be eliminated from a dataset before any multivariate techniques are applied as they may not be true representatives of a community, and their inclusion in the analysis may add 'noise' (Gauch, 1982; Norris, 1995). However, a species that is rare in a small sample may be consistently present in a larger sample, thus rarity is relative. Adding a cut-off line to the rarity spectrum may therefore add a subjective element to the analysis. Rare species also constitute much of the species diversity of ecological communities (Abel, 1989; Faith and Norris, 1989; Fore and Karr, 1996). All 'rare' species were left in all datasets for the multivariate analyses presented within this consideration, and the species data transformed using $\ln(x + 1)$ before ordination in order to give more weight to community composition and less weight to the most dominant species. All environmental variables were standardised to zero mean and unit variance. Canonical Correspondence Analysis (CCA) was used to correlate the species data to the environmental variables, with the significance of individual environmental variables tested using 1,000 permutations (Monte Carlo permutation test) in the forward selection procedure. The data from each sampling occasion was analysed independently before aggregation and analysis of the whole dataset.

RESULTS

A total of 12 water chemistry variables were measured at the 18 springs. The 18 springs exhibit a broadly similar chemistry, with the springwater characterised by its high Ca and HCO_3 concentrations. The mean annual concentrations of major ions are presented in Table 2. The mean annual temperature at 17 of the 18 springs was within 1.0°C (range 7.9 – 8.9°C)

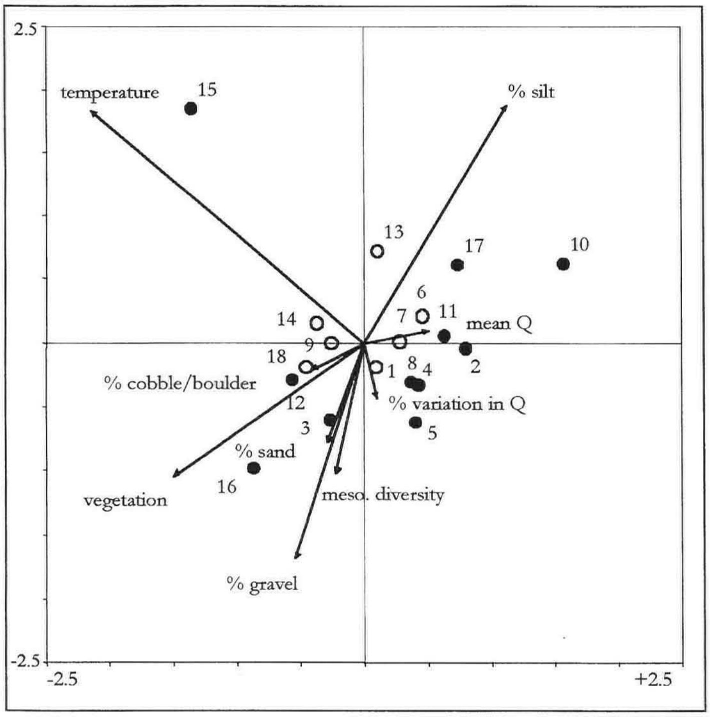

Figure 2. CCA ordination biplot of 18 spring sites in relation to environmental variables, (open circles = permanent springs, filled circles = intermittent springs).

of each other, and within 1.0°C of the mean annual air temperature for the locality (8.0°C). Site 15 is anomalous, exhibiting a mean annual temperature of 11.8°C (range 11.1 - 13.5°C).

At the broadest scale of analysis, the sites can be divided on the basis of their hydrological conditions into permanent and intermittent springs. Seven springs were permanent and 11 were intermittent during the period of this study. The springs that continued to flow year-round exhibited discharge fluctuations of between 36% and 59%, with sites 1, 9, 13 and 18 exhibiting the most stable flow regime over the year. A wide range of substrate sizes are present within the springs, from silty/muddy substrate in springs 2, 10, 15 and 17, to large cobble-boulder sized in areas of sites 3, 6 and 9. An important source of organic substrate within many of the springs was allochthonous detritus (particulate organic matter, >0.5mm), chiefly in the form of tree leaves (predominantly *Fraxinus excelsior* and *Corylus avellana*). Submerged macrophytes, in particularly *Nasturtium officinale* and *Apium nodiflorum*, occurred in both intermittent and permanent springs, but were more common in the latter. The physical habitat data is presented in Table 3.

SUMMARY OF BIOLOGICAL RESULTS

Sixty-four macroinvertebrate taxa belonging to 45 families were quantified from a total of 132 samples taken from the springs. The combined biological results from the four sampling occasions are shown in Table 4. Of these taxa, 52 (81.3%) were insect and 12 (18.7%) were non-insect. The number of taxa (S) found at an individual spring over the study period ranged from just 10 at site 4 (intermittent) to 32 taxa at sites 16 and 18 (permanent). The mean number of taxa found per spring was 18.0. Total macroinvertebrate abundance (N) over the study period ranged from 111 at site 11 (intermittent) to 2,273 at site 18 (permanent)

Twenty-two of the taxa were found at only one spring site during 1998. Nineteen of the taxa are considered rare in the spring samples, occurring in only one out of the 132 samples obtained over the study period. These taxa are marked with an asterisk in Table 5. Chironomidae was the taxon collected most frequently, occurring at all of the 18 sites and in 116 (87.9%) of the 132 samples taken. The second most frequently collected taxon was *Gammarus pulex*, which occurred in all of the springs and in 105 (73%) of the samples. The planarian *Crenobia alpina* was found at all 18 springs and in 72 samples (54.5%).

The species diversity (calculated from the annual aggregated source and springbrook data) varies widely between the 18 spring sites. Table 6 presents the species richness (S), abundance (N), diversity (H), EPT richness, equitability (J) and dominance (d) values for the 18 springs. A simple correlation analysis was carried out to investigate whether any relationship existed between species richness, diversity and abundance and any of the measured physico-chemical variables. Although a modest (negative) correlation was established between total macroinvertebrate abundance (N) and RIoP ($r = -0.432$) this was not significant at $P = 0.05$ (critical value of r at 16df = 0.468). All other indices showed a very weak correlation when tested separately with the environmental data.

Environmental influences on macroinvertebrate community structure
A preliminary CCA of the water chemistry data produced no significant variables in respect to macroinvertebrate community structure. Analysis of the physical habitat data revealed that one variable, percentage variation in discharge, was significant at the 95% level. However, the

Site	Name	Flow regime	Bank	Grid Reference	Elevation (m)	Aspect (°)	Mean width (m)	Length (m)	Surrounding vegetation
1	*Cowdale Spring*	permanent	R	SK 0886 7229	252	110	1	30	sparse woodland
2	*Kidtor Spring*	intermittent	R	SK 0869 7219	251	110	0.5	15	sparse woodland
3	*Ashwood Dale Resurgence*	intermittent	R	SK 0895 7222	254	0	1.5	75	sparse woodland
4	*Woolow*	intermittent	R	SK 0947 7242	248	60	0.5	10	sparse woodland
5	*Topley Pike*	intermittent	R	SK 1004 7251	250	20	1	25	sparse woodland
6	*Wormhill Springs (W)*	permanent	L	SK 1221 7351	225	110	10	60	dense woodland
7	*Wormhill Springs (E)*	permanent	L	SK 1246 7342	225	110	3	70	dense woodland
8	*Cheedale (W)*	intermittent	L	SK 1273 7343	218	18	0.25	10	sparse woodland
9	*Cheedale (E)*	permanent	L	SK 1300 7340	218	170	3	15	sparse woodland
10	*Cheedale Bridge Resurgence*	intermittent	L	SK 1288 7340	210	170	0.25	30	sparse woodland
11	*Litton Mill*	intermittent	L	SK 1652 7306	203	220	2.5	30	sparse woodland
12	*White Cliff Spring*	intermittent	L	SK 1821 7179	165	182	4	5	grazed pasture
13	*Lees Bottom 1*	permanent	R	SK 1712 7074	158	90	0.5	180	dense woodland
14	*Lees Bottom 2*	permanent	R	SK 1724 7073	154	90	3.5	30	sparse woodland
15	*Lower Dimindale 1*	intermittent	R	SK 1713 7059	153	110	1	60	grazed pasture
16	*Lower Dimindale 2*	intermittent	R	SK 1718 7035	147	120	5	60	open grassland
17	*Great Shacklow 1*	intermittent	R	SK 1768 6987	148	110	5	100	grazed pasture
18	*Great Shacklow 2*	permanent	R	SK 1789 7073	145	120	6	60	grazed pasture

Table 1. General characteristics of the 18 limestone springs.

Site	Name	pH	Cond. (µS)	HCO3 (mg/L)	O2 (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	NO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	Fe (mg/L)
1	*Cowdale (Rockhead) Spring*	7.41	545	225	12.5	95.7	8	10	1.1	13.2	29.7	25.4	0.37
2	*Kidtor Spring*	7.3	788	302	4	117.2	6.2	23.8	3.6	35.7	35.8	46.2	0.23
3	*Ashwood Dale Resurgence*	7.16	579	222	10.5	102.7	6.1	14	0.9	19.4	33.3	33.1	0.64
4	*Woolow*	7.22	659	221	11.2	97.2	7.6	18.1	0.7	26.8	31.7	34.5	0.48
5	*Topley Pike*	7.32	591	212	9.4	94.5	8.2	15.3	2.1	20.3	41	27.9	0.59
6	*Wormhill Springs (W)*	7.19	606	202	9.1	89.7	6.7	21.7	3.7	20.3	57.5	39	0.45
7	*Wormhill Springs (E)*	7.2	619	199	9.4	92.9	6.8	17.8	3.5	21.4	57.9	36.9	0.29
8	*Cheedale (W)*	7.19	579	204	12.2	91.7	6.4	15	2.2	20.9	47.7	28.1	0.34
9	*Cheedale (E)*	7.2	548	221	11.9	96.6	6.5	13.2	1.2	19.7	43	23.5	0.19
10	*Cheedale Bridge Resurgence*	7.38	442	219	12.9	86.1	3.8	9.5	0.6	20.5	35.6	14.5	0.24
11	*Litton Mill*	6.71	515	196	12.3	84.4	4.4	10.9	0.7	23.5	32.5	32.1	0.39
12	*White Cliff Spring*	7.11	494	207	11.9	88	5.6	12.7	0.8	27.8	40.1	29	0.25
13	*Lees Bottom 1*	7.57	598	219	9.8	96.4	6.3	15.5	1	29.1	43.5	30.3	0.31
14	*Lees Bottom 2*	7.8	521	214	9.5	92.3	6.8	14.8	1.5	20.7	46.4	29.5	0.23
15	*Lower Dimindale 1*	7.95	472	222	6.5	92.6	18.5	13.1	0.7	9.9	51.5	24.4	0.26
16	*Lower Dimindale 2*	7.82	492	227	8.2	89	8.2	14	1.5	23	40.1	20.5	0.3
17	*Great Shacklow 1*	7.3	563	208	9.7	96.9	6.5	10.8	1.3	22.4	41.1	22.7	0.22
18	*Great Shacklow 2*	7.36	532	217	9.8	94.3	6.6	10.6	1	17.4	40.5	22.7	0.46

Table 2. Mean values of chemical parameters in 18 limestone springs.

CCA ordination (Figure 2), shows no clear separation of the two major spring types on axis 1 or 2, and none of the canonical axes proved to be significant. Axes 1 and 2 explain only 34.1% of the total species-environment variance (see Table 7), although a high species-environment correlation was achieved for the canonical axes (0.96 and 0.97 for the first two axes respectively). Separate CCA analysis of the macroinvertebrate data collected from the spring sources and spring-brooks produced differing significant environmental variables (see Table 8). Variation in spring discharge was significant in both habitats, with variation in temperature also significant at the spring sources. In the springbrooks, mean annual water temperature and percentage composition of silt substrate were also significant.

The spring sites in which mats of emergent vegetation such as *Nasturtium officinale* occurred exhibited inflated macroinvertebrate biomass relative to the other springs. However, site 13 also exhibited high macroinvertebrate abundance year-round (in terms of individuals) despite a lack of emergent vegetation to provide in-stream habitat for the fauna. A possible factor influencing biomass at the site may be the large amounts of tufa present in the spring. The surface roughness of the substrate at site 13 is thus much greater than in other springs in the Wye Valley, a factor that has previously been reported to influence macroinvertebrate species richness and abundance (Erman and Erman, 1984).

The biological health of a stream is generally adversely affected when the physical habitat is in poor condition (Resh *et al.*, 1995). The input of sediment resulting from the regular sloughing of the stream banks may negatively impact sensitive macroinvertebrates, resulting in a change in species composition to those more tolerant of sedimentation. An excess of silt may smother a biotope and has long been known drastically to reduce numbers of Coleoptera, Ephemeroptera and Plecoptera (e.g. Cordone and Kelley, 1961). Sites 12, 15, 17 and 18 in the Wye Valley are subject to puddling by livestock. However, although the diversity of ephemeropterans and plecopterans was low in these springs, coleopterans such as Scirtidae and *Helophorus brevipalpis* are relatively abundant at the sites. Other taxa, such as the Sphaeriidae and Oligochaeta, are frequently associated with finer sediments (Armitage *et al.*, 1995), and some Chironomidae taxa utilise fine sediments in the construction of tubes and cases. The percentage of silt substrate appears to be a significant determinant of community structure within the springbrook channels (see Table 8), although no correlation could be established between the percentage of silt substrate and species richness (or any of the suite of biological indices).

Site	Name	Mean annual T (°C)	Dominant substrate	Habitat Diversity [1]	% veg. cover [2]	Mean annual Q (L/s)	RioP [3]	% variation in Q [4]
1	*Cowdale (Rockhead) Spring*	8.7	gravel	5	20	15.8	14	39.3
2	*Kidtor Spring*	8.3	silt	4	0	4.9	19	100
3	*Ashwood Dale Resurgence*	8.2	gravel	5	20	29.3	12	100
4	*Woolow*	7.9	sand	4	40	1.7	26	100
5	*Topley Pike*	8	sand	5	30	8.2	18	100
6	*Wormhill Springs (W)*	8.4	boulders	6	10	197.6	2	54.7
7	*Wormhill Springs (E)*	8.4	gravel	2	80	182.8	4	53.7
8	*Cheedale (W)*	8.5	gravel	3	30	4.3	21	100
9	*Cheedale (E)*	8.6	cobbles	5	20	35.9	6	44.1
10	*Cheedale Bridge Resurgence*	8.1	silt	3	0	2.2	24	100
11	*Litton Mill*	8.2	gravel	4	20	9.4	17	100
12	*White Cliff Spring*	8.6	sand	3	70	4.2	22	100
13	*Lees Bottom 1*	8.4	cobbles	4	0	15.7	14	40.3
14	*Lees Bottom 2*	8.6	gravel	4	50	26.6	10	59.2
15	*Lower Dimindale 1*	11.8	silt	3	10	3.2	23	100
16	*Lower Dimindale 2*	8.8	cobbles	4	80	4.5	20	100
17	*Great Shacklow 1*	8.5	silt	3	30	2.2	24	100
18	*Great Shacklow 2*	8.9	gravel	5	70	20.2	10	36.1

Table 3. Annual physical habitat parameters for the 18 springs

1. *Physical habitat types within the spring, including leaf packs, rock substrate, vegetation, woody debris, etc.*
2. *Figures represent maximum macrophyte cover during the summer months.*
3. *Summed ranks of mean Q and minimum Q at summer baseflow.*
4. *(Maximum Q- MinimumQ) / Maximum Q x 100*

The difference between the faunal communities of the permanent and intermittent springs was investigated using the biological indices given in Table 6. F_{max} tests were executed in order to confirm that the variances of the samples were homogenous, and a two-tailed t-test carried out on the indices. The permanent and intermittent sites showed no significant difference with regard to any of the suite of biological indices. However, examination of the raw faunal data does reveal that site 11, the spring with the longest dry period, did exhibit a very low diversity and abundance of macroinvertebrates. SIMPER (similarity percentage analysis) was run on the annual macroinvertebrate data in order to discover which macroinvertebrate taxa were the most discriminatory between the permanent and intermittent springs. *Nemurella picteti* was revealed to be the most discriminating species for the spring sources (11.17%), springbrooks (8.16%), and springs (13.0%), and was more strongly associated with a permanent flow regime.

DISCUSSION

Characteristics of the spring fauna

Two categories of macroinvertebrates comprise the faunal communities within the Wye Valley springs: i) species which may occur in a variety of permanent waters throughout the locality; and, ii) a unique limestone spring fauna, unable to exploit larger lotic habitats, or exhibiting specific adaptations to a temporary flow regime. These findings agree with those of Danks and Williams (1991) who suggested that spring fauna comprised of two broad classes - specialist macroinvertebrate species that live exclusively in springs and the more generalist aquatic species that inhabit a variety of habitats, including springs.

According to Fischer (1996) natural freshwater springs in Europe contain an average of 47.6% crenobiontic and crenophilic species, although this contains a number of unidentifiable Diptera larvae. In this case study 23.4% of the spring-dwelling taxa were not found in the trunk stream. This is probably due in part to the connectivity of all the springs to the trunk stream. However, only two of these species (3.1% in terms of species richness) are thought to be obligate crenobionts/crenophiles. The remaining taxa are facultative crenophiles in the Wye Valley, as a result of suitable habitat characteristics (e.g. temporary water content, or a hygropetric environment) being present within the spring sites. This situation corresponds with that reported by

	SPRING SITE																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ARTHROPODA																		
INSECTA																		
PLECOPTERA																		
Nemouridae																		
Nemurella picteti	106	1	16		73	1675	942	60	22				167	1		10		666
Nemoura erratica	154		48	9	84		1	109	1	8			137	4	1	16	9	45
Nemoura cambrica	4		145		193				1		5		14	1		36		
Nemoura cinerea			33			2			1					11				1
Leuctridae																		
Leuctra geniculata																		1
Caenidae																		
EPHEMEROPTERA																		
Caenis rivulorum																1		
Baetidae																		
Baetis rhodani	4	13		1		4	7	1			1		16	8	8	17		6
Ephemeridae																		
Ephemera danica																2		1
Ephemerellidae																		
Ephemerella ignita		1														5		
Heptageniidae																		
Ecdyonurus torrentis																1		
TRICHOPTERA																		
Ryacophilidae																		
Rhyacophila dorsalis															1			
Limnephilidae																		
Limnephilidae spp.	1		5		2		1	1		2		6			2	1	3	16
Limnephilus centralis												2						
Limnephilus lunatus			26									23			1	3		1
Limnephilus rhombicus															1			
Halesus radiatus								2										
Halesus digitatus																		
Drusus annulatus	3		5				1				1		17		1	50		2
Microptema lateralis										2	3	1						
Micropterna sequax			15		16		7	5		1	3		22	1				
Potamophylax cingulatus	7	2	1			1				3						1		2
Potamophylax latipennis	1	5	6	7	5		4					2				3		
Melampophylax mucoreus		2																1
Chaetopteryx villosa																		2
Stenophylax permistus														1				
Glossosomatidae																		
Agapetus fuscipes	2				137		19						5	2	9	44		203
Leptoceridae																		
Leptoceridae spp.										1								
Oecestis testacea												2						
Goeridae																		
Silo pallipes															2			
Psychomyiidae																		
Psychomyiidae spp.													3					
Beraeidae																		
Beraeodes minutus																1		
Beraea maurus																		1
Polycentropodidae																		
Plectrocnemia conspersa								2			1		4		5			16
Polycentropus flavomaculatus												1				5		
Lepidostomatidae																		
Lepidostoma hirtum								1										
MEGALOPTERA																		
Sialidae																		
Sialis lutaria												1						
HEMIPTERA																		
Veliidae																		
Velia sp.													2					
COLEOPTERA																		
Elmidae																		

Table 4 (continued over page)

Elmis aenea	111					5	2						2		1	1		
Elmis aenea (larvae)	12			2		5	8		4						3			
Esolus parallelepipedus										1								
Hydroporinae																		
Hydroporus incognitus																	1	
Dytiscidae																		
Dytiscidae (larvae)						27	3	3	2	1			1	1		1		1
Agabus bipunstulatus														1				
Agabus guttatus						7	2		1									
Scirtidae																		
Scirtidae (larvae)	1		2					13	2	3			19	4	38	37	10	27
Hydrophilidae																		
Helophorus brevipalpis													1	9	13	86		21
DIPTERA																		
Tipulidae	9	7		12	38	3	12	3	8	6	8	5	25	1	2	8	22	5
Chironomidae	178	156	237	116	124	210	141	29	168	15	67	19	113	13	16	124	228	11
Chironomidae (pupae)	5	3		1		1	4	1		1	1				1	11	5	
Ceratopogonidae	1						1			1								
Ceratopogonidae (pupae)			3														1	
Simuliidae						1							594	16	9		4	
Psychodidae	2	1	2		4	34	58	3	170	2	3	4	33	21	3	9		72
Psychodidae (pupae)														2				
Muscidae																		
Limnophora riparia (pupae)																	2	
Trichoceridae																	4	
Dixidae			1				20						1	7		1		4
Ptychopteridae												5			10			
Stratiomyidae							1						5					42
Diptera puparia ind.								2									1	
ARACHNIDA																		
ACARI																		
Hydracarina										1				1				
CRUSTACEA																		
AMPHIPODA																		
Gammaridae																		
Gammarus pulex	91	1433	160	378	909	10	637	350	49	572	10	727	454	380	317	794	121	1024
ISOPODA																		
Asellidae																		
Asellus aquaticus	37	8	13	6	42							24				4		3
ANNELIDA																		
OLIGOCHAETA	19	110	2	383	68	1	15	26	26	8	4	2	8	1	2	10	197	1
HIRUDINEA																		
RHYNCHOBDELLAE																		
Glossiphoniidae																		
Glossiphonia complanata		6			2													1
Helobdella stagnalis			1													1		
Piscicolidae																		
Piscicola geometra																1		1
PHARYNGOBDELLAE																		
Erpobdellidae																		
Erpobdella octoculata	1											1				1		
MOLLUSCA																		
GASTROPODA																		
PULMONATA																		
Ancylidae																		
Ancylus fluviatilis							1	1								1		5
Lymnaeidae																		
Lymnaea peregra	26	1	1													1		3
PROSOBRANCHIA																		
Hydrobiidae																		
Potamopyrgus jenkinsi		7																1
BIVALVIA																		
CYRENODONTA																		
Sphaeriidae		1													5			1
PLATYHELMINTHES																		
TURBELLARIA																		
Planariidae	9	69	109	85	259	38	117	56	11	18	4	4	570	274	5	30	1	85

Table 4. (continued) Aggregated annual macroinvertebrate data from the 18 limestone springs.

Species	Site	Flow regime
Agabus bipunstulatus *	14	linear/permanent
Beraea maurus *	18	permanent
Beraeodes minutus *	16	linear/intermittent
Caenis rivulorum *	16	linear/intermittent
Chaetopteryx villosa *	18	permanent
Ecdyonurus torrentis *	16	linear/intermittent
Esolus parallelepipedus *	10	intermittent
Halesus radiatus *	8	intermittent
Hydroporus incognitus *	17	intermittent
Lepidostoma hirtum *	8	intermittent
Leuctra geniculata *	18	permanent
Limnephilus centralis *	12	intermittent
Limnephilus rhombicus *	15	linear/intermittent
Limnophora riparia *	17	intermittent
Oecestis testacea *	12	intermittent
Rhyacophila dorsalis	15	linear/intermittent
Sialis lutaria	12	intermittent
Silo pallipes *	15	linear/intermittent
Stenophylax permistus *	14	linear/permanent
Tinodes unicolor *	13	permanent
Trichoceridae *	17	intermittent
Velia caprai	13	permanent

Table 5. Taxa found at only one spring site during the 1998 case study
** taxa found in one out of 132 samples obtained over the study period.*

Lindegaard *et al.* (1998) for Danish springs, in which the faunal communities were dominated by species that are found in a variety of alternative aquatic habitats.

Of the Trichoptera found within the current study, *Limnephilus centralis, Melampophylax mucoreus*, and *Micropterna lateralis* were also reported to be associated with German springs by Robert (1998), although all were also found in downstream rhithral habitats. Trichoptera species richness is high in some of the springs considering the small effective size of the habitat.

The variety of life history patterns seen in lotic macroinvertebrates is very wide. However, the life cycles of macroinvertebrates can be divided into two major types: i) **non-seasonal** - where the life cycle spans either more, or much less than one year with overlapping generations, and in which all stages of development are present at all times; and, ii) **seasonal** - which is subdivisible into slow or fast seasonal, but where a distinct mean body-size change can be observed over time in the members of a cohort (Hynes, 1970). Although it has been suggested that many insect and non-insect taxa show non-seasonal life cycles in freshwater springs (e.g. Stern and Stern, 1969; Williams and Hogg, 1988; Gooch and Glazier, 1991), the greatest abundance of macroinvertebrates was found in the Wye Valley springs in November. Many seasonal species attain their largest populations at this time, when the breeding season has terminated.

Specialist spring fauna

The source areas of some of the Wye Valley springs are obviously important as egg-deposition sites for nemourid plecopterans, especially *Nemurella picteti*, which is strongly associated with the eucrenal zone. Gerecke *et al.* (1998) noted that spring mouths were important deposition sites for stream-dwelling plecopterans, when they discovered enormous amounts of early instar larvae in their study of Bavarian springs. However, the family is not strictly considered as crenobiontic/crenophilic. The trichopteran Beraea maurus has been reported to be crenobiontic in Germany by Fischer *et al.* (1998) and Robert (1998). In Denmark, Beraea maurus is also considered to be crenobiontic (Lindegaard *et al.*, 1998). No obligate hypogean fauna was found in the 18 springs. This finding corresponds with the results of biospeleological studies conducted in other areas of the White Peak (Gunn *et al.*, 2000).

Factors influencing the spring fauna

The ionic composition of the springwaters was found to be generally similar, and appears not to exert a significant influence on macroinvertebrate community structure within the springs. However, pulses of highly differing water quality may occur at springs in karst systems with a short residence time, particularly those from cavernous formations (van der Kamp, 1995). It is possible that these pulses may escape detection, and yet still exert a significant effect on the biota of the spring.

The water temperature of the permanent springs generally remains constant within a spring throughout the annual cycle. Williams (1991b)

Site	Species Richness (S)	Total Abundance (N)	Shannon-Wiener diversity (H)	Simpson's diversity	Margalef's diversity	Equitability (J)	Berger-Parker dominance (d)	EPT richness
1	20	784	1.53	3.98	1.16	0.3	0.36	8
2	17	1826	0.16	1.05	1.1	0.03	0.97	6
3	20	831	1.45	3.47	1.16	0.29	0.38	9
4	10	1000	0.2	1.09	0.5	0.04	0.96	3
5	14	1956	0.99	1.94	0.7	0.2	0.7	6
6	13	2024	0.06	1.02	0.4	0.01	0.99	4
7	19	2204	0.71	1.95	0.54	0.14	0.59	7
8	17	668	0.87	1.97	0.64	0.17	0.67	7
9	13	466	0.81	1.92	0.93	0.16	0.66	4
10	16	646	0.07	1.03	0.16	0.01	0.99	5
11	12	111	0.83	2.18	0.72	0.17	0.63	6
12	16	829	0.15	1.07	0.3	0.03	0.97	6
13	23	2213	1.1	2.46	0.6	0.22	0.58	9
14	20	760	0.31	1.13	0.83	0.06	0.94	8
15	21	456	0.23	1.1	0.69	0.05	0.95	9
16	32	1317	0.55	1.26	2.06	0.11	0.89	15
17	13	609	0.25	1.15	0.21	0.05	0.93	2
18	32	2272	0.86	2.07	1.74	0.17	0.58	14

Table 6. Diversity, richness, dominance and equitability values for 18 springs, 1998 (all indices calculated from aggregated annual data).

CCA	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	0.182	0.173	0.167	0.132
Species environment correlation	0.964	0.97	0.921	0.945
Cumulative % variance				
of species data explained	9.5	18.5	27.1	34
of species-environment relation	17.4	34.1	50.1	62.7
	F ratio	P value		
Significance of first canonical axis	0.835	0.875	N/S	
Significance of all canonical axes	1.051	0.305	N/S	
Inter-set correlation of environmental variables with species axes				
Temperature	-0.668	0.582	-0.061	0.291
% silt	0.353	0.596	-0.386	0.496
% sand	-0.089	-0.245	-0.608	-0.383
% gravel/pebble	-0.17	-0.536	0.068	0.029
% cobble/boulder	-0.129	-0.064	0.718	-0.283
Habitat diversity	-0.072	-0.323	0.419	-0.047
% variation in Q	0.03	-0.139	-0.808	0.159
Mean Q	0.155	0.03	0.569	-0.217
% vegetation cover	-0.469	-0.331	0.139	-0.072
Significant environmental variables	F ratio	P value		
% variation in Q	1.46	0.020*		
*P=0.05				

Table 7. Results of CCA on the annual macroinvertebrate data from 18 springs, in conjunction with environmental variables, 1998.

suggests that springs with narrow annual temperature ranges may contain more species of macroinvertebrate than those with wider annual ranges. Variation in temperature was found to be a significant determinant of community structure in the Wye Valley springs, although no significant correlation could be found between the annual variation in temperature and species richness (or any other of the suite of biological indices). Mean annual temperature was revealed as a significant determinant of community structure within the springbrook channels at the broad-scale of analysis presented in this case study, although again this was not correlated with species richness.

Substrate composition is now considered to be one of the primary determinants of benthic species distribution in all lotic environments, with greater substrate heterogeneity associated with a more diverse benthic fauna (Richards *et al.*, 1993; Armitage *et al.*, 1995). The physical habitat within a spring is thought to be necessarily important to macroinvertebrates, most notably substrate and the amount of aquatic/emergent vegetation present (Williams and Williams, 1999). Removal of watercress (*Nasturtium officinale*) and disturbance of the substrate in a Pennsylvanian spring was followed by a decrease in numbers of Gammarus and an increase in the abundance of plecopterans, ephemeropterans and dipterans (Gooch and Glazier, 1991). The spring fauna shifted in composition toward that of insect-dominated stream communities as a result of this 'simulated scouring' of a kind naturally found in stream habitats. A loss of *Gammarus* was also reported after removal of a watercress mat in a Virginian spring (Miller and Buikema, 1977). However, within the present study multivariate analyses did not reveal substrate or vegetative cover to be a major determinant of community structure at a broad-scale analysis. A significant correlation could not be established between the abundance of *Gammarus pulex* within the 18 springs, and the percentage cover of vegetation (r = 0.183; critical value of r at 16df = 0.468).

CCA: Spring source	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	0.276	0.255	0.232	0.182
Species environment correlation	0.984	0.971	0.949	0.968
Cumulative % variance				
of species data explained	11.2	21.6	31	38.4
of species-environment relation	16.7	32.1	46.1	57.1
	F ratio	P value		
Significance of first canonical axis	0.757	0.695	N/S	
Significance of all canonical axes	1.117	0.185	N/S	
Significant environmental variables	F ratio	P value		
% variation in Q	1.5	0.015*		
Variation in temperature	1.48	0.040*		

CCA: Springbrook	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	0.242	0.194	0.188	0.163
Species environment correlation	0.98	0.947	0.969	0.977
Cumulative % variance				
of species data explained	11.5	20.7	29.7	37.5
of species-environment relation	18.3	33	47.2	59.6
	F ratio	P value		
Significance of first canonical axis	0.911	0.095	N/S	
Significance of all canonical axes	1.185	0.11	N/S	
Significant environmental variables	F ratio	P value		
% variation in Q	1.39	0.050*		
Mean temperature	1.82	0.005**		
% silt	1.71	0.010**		
*P=0.05 **P=0.01				

Table 8. CCA output results of source and springbrook data from 18 springs, 1998.

Lindegaard *et al.* (1998) concluded that the fauna in their study of Danish springs was not influenced strongly by measured environmental factors, probably as a result of the high heterogeneity of the substrates within the springs. This agrees with the findings of the Wye Valley case study, with only flow regime proving a significant determinant of biology at the broadest scale of analysis.

Effects of flow regime on spring macroinvertebrate communities

It is widely recognised that hydrological variability within aquatic ecosystems is one of the primary factors controlling the distribution of fauna (Townsend *et al.*, 1987). Benthic communities within temporary aquatic systems have been found to differ from those within nearby permanent systems (Wiggins *et al.*, 1980; Williams, 1996). However, Feminella (1996) found that despite large differences in flow permanence among study streams, the macroinvertebrate communities present in permanent and intermittent sites differed only slightly, with 75% of species ubiquitous between the habitat types and displaying no pattern with respect to flow permanence. Many of the diversity and richness measures employed in Feminella's study were found to be correlated with flow permanence. In the winter and spring months the faunal composition within the intermittent springs of the Wye Valley closely resembles that of the permanent springs, but the faunal similarity recorded between intermittent and permanent springs was found to be much lower than that recorded by Feminella (1996).

Regularly occurring dry periods can eliminate: i) bi- or multivoltine macroinvertebrates such as *Baetis* spp. and *Caenis* spp.; ii) animals with life cycles of two or more years, e.g. *Crunoecia irrorata* and *Ephemera danica*; and, iii) animals with their major growth period in the summer, e.g. *Ephemerella* spp. and *Ecdyonurus* spp. Species with these types of life histories were generally more common in the permanent springs, with ephemeropterans absent from the majority of springs, and found at very low abundance in others. The ephemeropterans present in the springs were a subset of those occurring in the trunk stream. The exception was at site 16, where five species of Ephemeroptera were found during the study period. Site 16, along with site 2, rises very close to the bank of the trunk stream, and is subject to frequent backflooding. The overall community composition of these springs was the most similar to that of the trunk stream stations. Although taxa such as Ephemeroptera do not contribute significantly to the biological diversity and abundance within the springs, some of the sites may offer refugia for these taxa when extreme conditions (e.g. flood) prevail in the River Wye.

Temporary waters may have communities comprising taxa whose aquatic life-spans are brief enough to be completed while flow is present in the water body. Williams (1996) considered Ephemeroptera, Coleoptera, Trichoptera, and simuliid, tipulid and chironomid Diptera to be particularly well represented in temporary freshwaters. Dipteran taxa were common at the source of the intermittent springs of the Wye Valley, especially at sites 11 and 17. However, the order made up only 12.8% of the faunal abundance (in terms of individuals) in the intermittent springs, compared to 18.9% in the permanent sites. This finding contradicts that of Glazier and Gooch (1987) who found dipterans to be more abundant in a shallow intermittent freshwater spring, as opposed to a nearby permanent spring with almost identical water chemistry.

CHANGES TO:	SOURCE OF IMPACT
WATER QUALITY	Fertilisers Agrochemicals Slurry/silage leaks* Septic tank leaks* Illegal release of sewage, silage and slurry into cave entrances, dolines, stream sinks and in disused quarries* Agricultural tipping Digested sewage sludge application* Concentrate from cattle rendering* Afforestation practices Highways runoff* (e.g. hydrocarbons from petroleum; chloride ions from de-icing) Runoff from landfill* Mineral extraction (pollution by oil, accidental spillage)*
WATER QUANTITY	Land drainage Increasing groundwater abstraction and development De-watering of quarries* Spring source capture* Afforestation practices Global warming
SEDIMENT LOADS	Livestock grazing* Land drainage Construction (roads, buildings) Mineral extraction (increased fine sediment concentrations)*
ORGANIC INPUT	Coppicing and other woodland management Riparian habitat management

*Table 9. Potential threats to the biology of springs * are considered significant threats in the White Peak of Derbyshire*

Most of the species found in the intermittent sites are not specifically adapted to a temporary aquatic environment, with perhaps the exception of *Limnephilus centralis*, *Micropterna lateralis*, *Helophorus brevipalpis* and *Stenophylax permistus*. The organisms are able to survive as a result of favourable aspects of their life cycles, such as a long summer flight period e.g. *Limnephilus lunatus*, *Micropterna sequax* and *Plectrocnemia conspersa*, or a very brief life span e.g. Chironomidae. Clifford (1966) commented that most macroinvertebrates found in intermittent streams can be considered to be 'pre-adapted' - not adapted *per se* - to the adverse conditions of a temporary aquatic habitat.

Williams and Hynes (1977) compared the communities of a temporary and a permanent stream that were physically connected (facilitating easy faunal transfer between the two habitats), and found very little faunal overlap. The coexistence of closely related species was also noted in the temporary aquatic habitats. It was suggested that this may have been due to a plentiful available food supply (allowing potential competitors to coexist), and/or instability in the habitat, meaning that there is only a short time for selective pressures to operate. In the present study, examination of the raw faunal data revealed that 56.3% of the taxa (36 of 64) in the Wye Valley springs were found at both permanent and intermittent sites, and showed no pattern with regard to spring permanence. Previous ecological studies have indicated that permanent and intermittent springs within some regions may share the same taxa, although species dominance may differ (Williams and Williams, 1999). Despite the majority of the fauna being ubiquitous between the two habitat types, some differences in species composition are evident in the data from the springs. For example, the Plecoptera (most notably *Nemurella picteti*) were found in abundance at the source of the permanent springs, but were absent from the source of the intermittent sites, except for one individual collected at site 2 in May, and two individuals at site 16 in August. The Nemouridae are considered to be particularly vulnerable to conditions of habitat instability (Erman and Erman, 1995).

Recolonisation dynamics within intermittent springs

In previous ecological studies, some aquatic macroinvertebrates have been found to over-summer in small isolated pools in the bed of intermittent streams (Larimore *et al.*, 1959; Williams and Hynes, 1976; Boulton, 1989). However, in the Wye Valley study, all spring sites classed as intermittent dried completely, and no water was present in the springbrook channel in the late summer. Recolonisation of the intermittent springs on resumption of flow must occur through other means than in-spring survival in remnant pools. All substrate samples collected from the intermittent spring sites in summer also revealed an absence of macroinvertebrate fauna.

Examination of the seasonal data from the intermittent sites allows some general observations regarding the recolonisation of temporary springwaters to be made. The ability of insects to disperse aerially makes them more rapid colonisers than oligochaetes, molluscs, crustaceans and triclads (Williams, 1991b). Molluscs are frequently the last taxon to recover following disturbances as a result of poor dispersal mechanisms (Wallace, 1990). It is generally assumed that insects can colonise an empty spring biotope more easily than non-insect taxa, and that the length of the springbrook is significant with regard to the time to recolonisation of source areas by non-vagile organisms. However, of 11 intermittent spring sources, six were dominated by *Gammarus pulex* by November 1998, two by *Crenobia alpina*, two by Oligochaeta and one by vagile Chironomidae. Gammaridae and Planariidae were found by Stehr and Wendell Branson (1938) to reappear in all parts of an intermittent stream in the autumn when precipitation resumed flow. In the Wye Valley, the springs in which *Gammarus pulex* did not assume dominance on resumption of flow were characterised by a lack of in-stream vegetation and a fine grained substrate. Gammaridae, although omnivorous, have been found primarily to consume plant material such as *Nasturtium* spp. in springs (Minckley, 1963).

Gammarus spp. are known to colonise adjacent empty habitats by upstream migration (Williams and Williams, 1993), and the upstream movement of *Gammarus pulex* has been demonstrated by many researchers (e.g. Macan and Mackereth, 1957; Hultin, 1971). Most stream macroinvertebrates exhibit a marked positive rheotaxis, and it is known that many are capable of compensating for their downstream drift by movement upstream (Hughes, 1970). Although upstream and downstream movement of macroinvertebrates in spring systems has been reported to be significantly lower than in other lotic habitats (e.g. Butler and Hobbs, 1982), Zollhöfer (1999) found that *Gammarus fossarum* dominated the migration pathways within a restored springbrook system. *Gammarus fossarum* first reached the spring source – which was 380m from the trunk stream – just 17 days after restoration, and after 30 days the species made up 64% of individuals.

Asellus aquaticus was found at three intermittent spring sources in November 1998, all located in woodland areas of the valley. If temporary waters have a well-developed litter of vegetation on their bed, aquatic isopods such as *Asellus* may find refuge for short periods (Wiggins *et al.*, 1980). Iversen *et al.* (1978) commented that *Asellus aquaticus* is well suited to life in an intermittent aquatic environment, as it can move into the substrate to avoid desiccation. Lindegaard *et al.* (1998) found *Asellus aquaticus* in suitable habitats in Danish springs, but considered that the species would not normally be found in these biotopes. Zollhöfer (1999) did not collect *Asellus aquaticus* until day 90 after resumption of flow in a restored Swiss spring.

A series of dynamic colonisation phases was found to occur by Zollhöfer (1999) in freshwater springs. The colonising macroinvertebrate taxa were separated into fast, intermediate and slow colonisers. Fast colonisers included Chironomidae, Simuliidae, *Baetis rhodani* and *Gammarus fossarum*. Intermediate colonisers (1 month – 1 year) included flatworms, bivalves, tipulids and two species of Trichoptera. Slow colonisers (more than 1 year) were Plecoptera (including *Nemurella*) and crenophilic/crenobiontic Coleoptera. Chironomidae and *Gammarus fossarum* were found to be the dominant taxa with the highest relative abundances at all sampling sites in the restored spring over the entire sampling period. The findings of the Wye Valley case study contradict those of Zollhöfer to some extent. The Nemouridae, Chironomidae and limnephilid Trichoptera found at the intermittent sites in November were first or second instar larvae, often found in large numbers. The dominant recolonisation mechanism is unlikely to be drift or migration in these taxa and it is suggested that oviposition has occurred directly at the source of the springs.

It is not only the quality of habitat, but also the pool of species in surrounding aquatic sites that determines the biotic and abiotic organisation of stream communities (Wevers and Warren, 1986). Therefore, explanations of the faunal composition within the Wye Valley springs need to consider the available pool of potential colonists (Ricklefs, 1987). In a comparative survey, *Gammarus pulex* was also found to be the dominant species of macroinvertebrate within the River Wye

(34.3% of total organisms collected), and its dominance in the intermittent springs on resumption of flow is therefore unsurprising.

Brooks and Boulton (1991) found that six weeks after flow resumed in an Australian temporary stream, the greatest densities of taxa and individuals were found on coarse gravel-sized substrates. It was thought that there may be little incentive for animals other than filter-feeders to recolonise cobble-sized substrates, due to fast interstitial currents and a lack of organic matter. Conversely, in the present study, sampling of the intermittent spring sources on resumption of flow revealed that the greatest densities of organisms were generally exhibited by springs dominated by a sand substrate (e.g. sites 4, 5 and 12) due to high abundances of *Gammarus pulex*. Site 16 - the cobble-dominated intermittent spring - had a greater abundance of organisms than some of the gravel-dominated sites (e.g. sites 11 and 16). The springs with a silt substrate (sites 2, 15 and 17) exhibited a relatively low abundance of organisms on resumption of flow.

Conservation of spring ecotopes

The limestone springs of the Wye Valley are important not just ecologically, but also hydrologically. The springs feed public water supply indirectly and contribute to the surface flow of the River Wye, a river widely used for angling and leisure pursuits. The Limestone Research Group at the University of Huddersfield, UK has recently compiled an inventory of springs in the White Peak, including their geographical position, elevation, and details of flow routes, as part of an unpublished hydrogeological report compiled for the Environment Agency (Gunn, 1998). However, no biological data were available for inclusion within the database.

A comprehensive effort is required in order to compile a baseline data inventory of spring-associated fauna throughout Britain. Springs and seepages are mentioned in The New Rivers and Wildlife Handbook (RSPB, NRA, RSCA, 1994) as special edge habitats that merit separate conservation consideration. However, no specific policies with regard to crenobiology exist within any public body or NGO at present.

When harsh conditions (e.g. floods) prevail in the River Wye, the permanent spring habitats in the valley may be important in that they offer relatively constant environments as refugia for certain taxa. It has also been suggested that in spring-fed fluvial systems, spring habitats may provide a macroinvertebrate refuge when areas of the trunk stream itself are impacted by contaminants. The springs may then later contribute to the recovery of macroinvertebrate communities within the river (Williams *et al.*, 1997). The recolonisation of affected areas of rivers by macroinvertebrates from tributaries has been previously recognised (Armitage and Petts, 1992).

Freshwater springs have previously been reported to harbour biological communities that are distinct to some extent from those found in surface streams within the same geographical area (McCabe, 1998). Although a particular spring may exhibit low species richness or diversity, it may contribute significantly to the overall biological diversity within a geographical area as a result of containing rare species. The nationally rare aquatic beetle *Hydroporus obsoletus* was discovered on just one sampling occasion, at the source of site 17, Great Shacklow 1. It could be considered, from a habitat management stance, that such springs require greater protection than those in which the species present occur in alternative aquatic ecotopes within the area. Bick (1982) even suggests that a spring habitat may be 'devalued' if there is a large number of ubiquitous species present, particularly if this is due to a lack of competition with stenotopic spring species. However, Erman (1998) recommends that prudent and conservative land management should assume that *all* freshwater springs need protection to conserve their macroinvertebrate populations, even in the absence of specific ecological studies.

The generally small spatial extent of springs makes them extremely vulnerable to impacts caused by humans, animals or climatic changes. Table 9 summarises the main threats to the biology of spring habitats. Williams (1991a) stressed the importance of drawing up guidelines for the conservation and protection of springs from urban, agricultural and industrial pressure. Permanent springs may be particularly vulnerable because of their potential for water-bottling sites and livestock watering holes. Such activities may result in the type localities for organisms being destroyed.

The major land use within the allogenic and autogenic catchment of the Wye Valley is grassland-dominant agricultural grazing. Some of the springs in the valley are susceptible to puddling by cattle, which leads to the addition of fine sediment to the spring channel. The deleterious influence of sediment for macroinvertebrates has been well documented by many researchers (e.g. Rosenberg and Wiens, 1978; Wagner, 1989; Wood and Armitage, 1997). Roughley and Larson (1991) consider that livestock access poses a severe threat to some of the rarest and most endangered coleopterans in Canada, including *Hydroporus carri*, which occurs only in springs and seepages in the Rocky Mountain foothills and the Cypress Hills.

In the Wye Valley, local impacts from cattle grazing should be offset by protecting the immediate source area of sensitive sites, thus restricting watering to the lower springbrook area, where macroinvertebrate species are more likely to be ubiquitous in habit. This should be considered at sites 12, 14, 15 and 18. However, at site 17, it is possible that the disturbance by cattle may be a contributory factor to the presence of certain species of macroinvertebrate that prefer a finer grained or muddy substrate, e.g. *Hydroporus incognitus* and *Limnephilus vittatus*. Gerecke *et al.* (1998) suggested that disturbance by hydraulic intervention and/or livestock may have been responsible for the unusual composition of the macroinvertebrate fauna in one of 19 Bavarian springs sampled. Zollhöfer (1999) found that specialist crenobiontic beetles such as *Hydroporus ferrugineus* may even occur in the small waterbodies created by the trampling of cattle.

Human-induced global warming has the potential to exert a profound effect on the communities of freshwater ecosystems, including the cold stenotherms of springs (Carpenter *et al.*, 1992). These effects include: a decrease in macroinvertebrate densities, promotion of precocial breeding (in amphipods) and emergence (in insects), and alteration of growth rates, sex ratios and size at maturity (Hogg and Williams, 1996). Williams and Williams (1999) comment that it is the rapidity with which human-induced changes occur, and whether or not organisms will adapt to them, rather than the absolute changes per se which make this a serious concern. A steadily warming climate will result in drier and longer summers, and the seasonal replenishment of aquifers may be affected (Downing, 1998). This may in turn result in the increased desiccation of springs, which would necessarily have severe implications for some crenobiontic and crenophilic fauna.

Increasing groundwater abstraction has the potential to induce similar impacts on spring-dwelling fauna. Some of the macroinvertebrates of the Wye Valley springs are adapted to a periodic loss or decline of flow (e.g. *Limnephilus centralis*, *Micropterna sequax* and *Micropterna lateralis*). However, populations in permanent springs, unaccustomed to intermittent conditions, may lack mechanisms that allow them to survive a temporary loss of habitat. Although many of these species are ubiquitous in habit, some crenobionts/crenophiles may be under serious threat from increased drought, e.g. *Agabus guttatus*, *Beraeodes minutus* and *Beraea maurus*, although Sommerhäuser *et al.* (1996) found the latter species in temporary streams in Germany. The results of the Wye Valley study highlight the need for further information on the hydrologic requirements of spring-dwelling fauna. As hydrological regime has been revealed to be a major determinant of crenobiological patterns, the endangering of groundwater in the Wye sub-basin requires preventative measures to guarantee both water quality and flow if spring communities are to be protected. In Britain research in the field of groundwater ecology is helping to develop flow policies and criteria for the allocation of groundwater resources for human versus natural system needs (e.g. Elliot *et al.*, 1999; Petts *et al.*, 1999). It is suggested that in karstic areas such as the White Peak, crenobiological issues should be a consideration within any such policies. Van der Kamp (1995; p.15) challenged biologists and hydrogeologists to "*put their heads together in the selection, description and study of springs*". The results of this research project have reinforced the absolute importance of this suggested approach.

The maintenance of natural biogeochemical conditions in a karstic aquifer depends on the maintenance of essentially natural vegetation within its catchment. Land-managers, ecologists and hydrogeologists are important to this end, and consultation between the various disciplines is essential. For example, all woodland management executed along the Wye Valley (e.g. coppicing or felling), should bear in mind the subsequent effect on the biota of the springs. The woodland provides typical environmental conditions (in terms of allochthonous input and shading) for many springs in the locality, and habitat intervention in the immediate vicinity of the woodland springs should therefore be minimised as far as is practicably possible. Some of the trichopterans collected from the intermittent springs (e.g. *Stenophylax permistus* and *Limnephilus lunatus*) will spend the summer months as diapausing adults in the adjacent woodland environment. Such woodland areas provide humidity, shade and shelter, and the destruction of such structures may threaten species with specific life cycle adaptations to these habitats (Sommerhäuser *et al.*, 1996).

Land-use practices can be managed in order to protect the quality of groundwaters only when the catchment area has been defined correctly. Effort is needed to define the areas feeding the limestone springs, and ongoing research in the White Peak is seeking to determine the groundwater flow paths more precisely through the use of water tracing experiments. In the Wye Valley, the north (left) bank springs have been shown by such experiments to receive recharge from the block of Carboniferous limestone to the north that includes the Waterswallows, Tunstead and Dove Holes quarries. The catchment area for the springs rising on the south (right) bank of the River Wye is uncertain, but is likely to drain an extensive area extending up to the topographic divide with the River Dove catchment, an area that also includes many limestone quarries (Gunn, 1998). The extractive industry is a significant land use in the area, and quarrying represents a potential threat to the groundwater quality and balance in the Wye catchment. Groundwater quality in some springs is commonly affected by quarrying, both through accidental spillage and the increase in fine sediment concentrations. Water pumping from quarries also has the potential to affect the groundwater balance, altering the amount and direction of conduit flow.

Unfortunately, special conservation problems do arise in the White Peak as a result of the inherent nature of the karst hydrology and geomorphology. The area likely to be influenced by any future water pollution incidents may be extremely difficult to predict due to the frequent lack of concordance of surface topographic watersheds with underlying groundwater divides (Price, 1996). In some karst areas, naturally occurring depressions (dolines/sinkholes) are used as convenient places to dump dead stock or domestic refuse, although this is fortunately not common in the White Peak. Such incidents, along with agricultural operations, in the allogenic catchment may impact on the fauna of springs a considerable distance away. This research project has revealed that nitrate levels are low in the springs of the Wye Valley, and there was no indication of groundwater pollution from agricultural organic sources during the study period. However, isolated incidents of this type have been reported from the study area in the past (J. Gunn; D. Percival; T. Richardson; *pers. comm.*).

The establishment of a British species inventory of springs is recommended. This would enable the identification of national, regional and local patterns regarding faunal abundance and diversity, and identify any springs containing endemic or rare fauna. It has previously been claimed that the biota of springs is very similar world-wide (Ward and Dufford, 1979). However, Williams (1983) expects that regional differences in spring fauna may occur based on geological, climatic and vegetational differences. One of the authors has also undertaken limited biological sampling of limestone springs in County Fermanagh, Northern Ireland, an area exhibiting broadly similar geology, climate, and in-spring physico-chemical and vegetational characteristics to the White Peak. This has revealed that the springs contained different faunal communities to those of the Wye Valley, suggesting that biogeographical factors account for community variation within such ecotopes (Smith, unpublished data).

REFERENCES

Armitage, P D, Pardo, I and Brown, A, 1995. Temporal constancy in 'mesohabitats' – Application to management. *Archiv für Hydrobiologie*, Vol.133, 367-387.

Armitage, P D and Petts, G E, 1992. Biotic score and prediction to assess the effects of water abstraction on river macroinvertebrates for conservation purposes. *Aquatic Conservation: Marine and Freshwater Ecosystems*, Vol.2(1), 1-17.

Bick, H, 1982. Bioindikatoren und umweltschutz. *Decheniana – Beihefte*, Vol.26, 2-5.

Boulton, A J, 1989. Over-summering refuges of aquatic macroinvertebrates in two intermittent streams in Central Victoria. *Transactions of the Royal Society of Southern Australia*, Vol.113, 23-34.

Brooks S S and Boulton, A J, 1991. Recolonisation dynamics of benthic macroinvertebrates after artificial and natural disturbances in an Australian temporary stream. *Australian Journal of Marine and Freshwater Research*, Vol.42, 295-308.

Butler, M J and Hobbs, H H, 1982. Drift and upstream movement of invertebrates in a springbrook community ecosystem. *Hydrobiologia*, Vol.89, 153-159.

Carpenter, S R, Fisher, S G, Grimm, N B, and Kitchell, J F, 1992. Global change and freshwater ecosystems. *Annual Review of Ecology and Systematics*, Vol.23, 119-139.

Clifford, H F, 1966. The ecology of invertebrates in an intermittent stream. *Investigations of Indiana Lakes and Streams*, Vol.7, 57-98.

Cordone, A J and Kelley, D W, 1961. The influence of inorganic sediment on the aquatic life of streams. *California Department of Fish and Game*, Vol.47, 189-228.

Danks, H V and Williams, D D, 1991. Arthropods of springs, with particular reference to Canada: synthesis and needs for research. *Memoirs of the Entomological Society of Canada*, Vol.155, 203-17.

Downing, R A, 1998. *Groundwater: our hidden asset*. British Geological Survey, Nottingham. 59pp.

Elliott, C R N, Dunbar, M J, Gowing, I and Acreman M C, 1999. A habitat assessment approach to the management of groundwater dominated rivers. *Hydrological Processes*, Vol.13(3), 459-475.

Erman, D C and Erman, N A, 1984. The response of stream macroinvertebrates to substrate size and heterogeneity. *Hydrobiologia*, Vol.108, 75-82.

Erman, N A, 1998. Invertebrate richness and Trichoptera phenology in Sierra Nevada (California, USA) cold springs: sources of variation. 95-108 in Botosaneanu, L (ed.), *Studies in Crenobiology: The biology of springs and springbrooks*. [Leiden: Backhuys Publishers.]

Erman, N A and Erman, D C, 1995. Spring Permanence, Trichoptera Species Richness, and the Role of Drought. *Journal of the Kansas Entomological Society*, Vol.68(2), 50-64.

Feminella, J W, 1996. Comparison of benthic macroinvertebrate assemblages in small streams along a gradient of flow permanence. *Journal of the North American Benthological Society*, Vol.15(4), 651-669.

Ferrington, L C Jr, Kavanaugh, R G, Schmidt, F J and Kavanaugh, J L, 1995. Habitat separation among Chironomidae (Diptera) in Big Springs. *Journal of the Kansas Entomological Society*, Vol.68(2), 152-165.

Fischer, J, 1996. Bewertungsverfahren zur Quellfauna. *Crunoecia*, Vol.5, 227-240.

Fischer, J, Fischer, F, Schnabel, S, Wagner, R and Bohle, H W, 1998. Die Quellfauna der hessischen Mittelgebirgsregion. Besiedelungsstruktur, Anpassungsmechanismen, und Habitatbindung der Makroinvertebraten am Beispiel von Quellen aus dem Rheinischen Schiefergebirge und der osthessischen Buntsandsteinlandschaft. 183-199 *in* Botosaneanu, L (ed.), *Studies in Crenobiology: The biology of springs and springbrooks.* [Leiden: Backhuys Publishers.]

Gerecke, R, Meische, C, Stoch, F, Acri, F and Franz, H, 1998. Eucrenon/Hypocrenon ecotone and spring typology in the Alps of Berchtesgaden (Upper Bavaria, Germany). A study of microcrustacea (Crustacea: Copepoda, Ostracoda) and water mites (Acari: Halacaridae, Hydrachnellae). 167-182 *in* Botosaneanu, L (ed.), *Studies in Crenobiology: The biology of springs and springbrooks.* [Leiden: Backhuys Publishers.]

Glazier, D S and Gooch, J L, 1987. Macroinvertebrate assemblages in Pennsylvania (USA) springs. *Hydrobiologia,* Vol.150, 33-43.

Gooch, J L and Glazier, D S, 1991. Temporal and spatial patterns in mid-Appalachian springs. *Memoirs of the Entomological Society of Canada,* Vol.155, 29-49.

Gunn, J, 1998. *The hydrogeology of the Carboniferous Limestone in the Derwent Catchment.* Unpublished report for the Environment Agency. LRG Report 98/13, 37pp.

Gunn, J, Hardwick, P and Wood, P J, 2000. The invertebrate community of the Peak-Speedwell cave system, Derbyshire, England – pressures and considerations for conservation management. *Aquatic Conservation: Marine and Freshwater Ecosystems,* Vol.10, 535-369.

Hogg, I D and Williams, D D, 1996. Responses of stream invertebrates to a global warming thermal regime: an ecosystem-level manipulation. *Ecology,* Vol.77, 395-407.

Hughes, D A, 1970. Some factors affecting drift and upstream movements of Gammarus pulex. Ecology, Vol.51, 301-305.

Hultin, L, 1971. Upstream movements of *Gammarus pulex pulex* (Amphipoda) in a South Swedish stream. Oikos, Vol.22, 329-347.

Hynes, H B N, 1970. *The Ecology of Running Waters.* [Toronto University of Toronto Press], 555pp.

Illies, J, 1952. Die Mölle. Faunistische-ökologische Untersuchungen an einem Forellenbach im Lipper Bergland. Ein Beitrag zur Limnologie der Mittelgebirgbäche. *Archiv für Hydrobiologie,* Vol.46, 424-612.

Illies, J and Botosaneanu, L, 1963. Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considérées surtout du point de vue faunistique. Verhandlungen der Internationale *Vereinigung für Theoretische und Angwandte Limnologie,* Vol.12, 1-57.

Iversen, T M, Wiberg-Larson, P, Hansen, S B and Hansen, F S, 1978. The effect of partial and total drought on the macroinvertebrate communities of three small Danish streams. *Hydrobiologia,* Vol.60(3), 235-242.

Larimore, R W, Childers, W F and Heckrotte, C, 1959. Destruction and re-establishment of stream fish and invertebrates affected by drought. *Transactions of the American Fisheries Society,* Vol.88, 261-285.

Lindegaard, C, Brodersen, K P, Wiberg-Larsen, P and Skriver, J, 1998. Multivariate analyses of macrofaunal communities in Danish springs and springbrooks. 201-210 *in* Botosaneanu, L (ed.), *Studies in Crenobiology: The biology of springs and springbrooks.* [Leiden: Backhuys Publishers.]

Macan, T T and Mackereth, J C, 1957. Notes on *Gammarus pulex* in the English Lake District. *Hydrobiologia,* Vol.9, 1-12.

McCabe, D J, 1998. Biological communities in springbrooks. 221-228 *in* Botosaneanu, L (ed.), *Studies in Crenobiology: The biology of springs and springbrooks.* [Leiden: Backhuys Publishers.]

Miller, J D and Buikema, A L Jr, 1977. The effect of substrate on the distribution of the spring form (Form III) of *Gammarus minus* Say. *Crustaceana,* Vol.4, suppl., 153-163.

Minckley, W L, 1963. The ecology of a spring stream Doe Run, Meade County, Kentucky. *Wildlife Monographs,* Vol.11, 1-24.

Morse, J C and Barr, C B, 1990. Unusual caddisfly (Trichoptera) fauna of schoolhouse springs, Louisiana, with description of a new species of Diplectrona (Hydropsychidae). *Proceedings of the Entomological Society of Washington,* Vol.92, 58-65.

Petts, G E, Bickerton, M A, Crawford, C, Lerner, D N and Evans, D, 1999. Flow management to sustain groundwater-dominated stream ecosystems. *Hydrological Processes,* Vol.13(3) Special Issue: Groundwater Dominated Rivers, 497-513.

Price, M, 1996. *Introducing Groundwater.* [London: Chapman and Hall], 278 pp.

Resh, V H, Norris, R H and Barbour, M T, 1995. Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology,* Vol.20, 108-121.

Richards, C, Host, G H and Arthur, J W, 1993. Identification of predominant environmental factors structuring stream macroinvertebrate communities within a large agricultural catchment. *Freshwater Biology,* Vol.29, 285-294.

Ricklefs, R E, 1987. Community diversity: relative roles of local and regional processes. *Science,* Vol.235, 167-171.

Robert, B, 1998. Quelltypische Köcherfliegen (Insecta: Trichoptera) in Nordrhein-Westfalen (Deutschland) – Ein Überblick. 109-123 *in* Botosaneanu, L (ed.), *Studies in Crenobiology: The biology of springs and springbrooks.* [Leiden: Backhuys Publishers].

Rosenberg, D M and Wiens, A P, 1978. Effects of sediment addition on macrobenthic invertebrates in a northern Canadian river. *Water Research,* Vol.12, 753-63.

Roughley, R E and Larson, D J, 1991. Aquatic Coleoptera of springs in Canada. *Memoirs of the Entomological Society of Canada,* Vol.155, 125-140.

RSPB, NRA and RSNC, 1994. *The New Rivers and Wildlife Handbook.* [Sandy RSPB], 426pp.

Sommerhäuser, M, Robert, B and Schuhmacher, H, 1996. *Flight periods and life strategies of caddisflies in temporary and permanent woodland brooks in the Lower Rhine Area (Germany).* Proceedings of the eighth international symposium on Trichoptera, Minneapolis/St Paul, July 1995, 425-433.

Stehr, W C and Wendell Branson, J, 1938. An ecological study of an intermittent stream. *Ecology,* Vol.19, 294-310.

Stern, M S and Stern, D H, 1969. A Limnological Study of a Tennessee Cold Springbrook. *The American Midland Naturalist,* Vol.82, 62-82.

Thorup, J and Lindegaard, C, 1977. Studies on Danish springs. *Folia Limnologica Scandinavia,* Vol.17, 7-15.

Townsend, C R, Hildrew, A G and Schofield, K, 1987. Persistence of stream communities in relation to environmental variability. *Journal of Animal Ecology,* Vol.56, 597-613.

van der Kamp, G, 1995. The Hydrogeology of Springs in Relation to the Biodiversity of Spring fauna: A Review. *Journal of the Kansas Entomological Society,* Vol.68,(2) suppl., 4-17.

van Everdingen, R O, 1991. Physical, Chemical and Distributional Aspects of Canadian Springs. *Memoirs of the Entomological Society of Canada,* Vol.155, 7-28.

Wagner, R, 1989. The influence of artificial stream bottom siltation on Ephemeroptera in emergence traps. *Archiv für Hydrobiologie,* Vol.115(1), 71-80.

Wallace, J B, 1990. Recovery of lotic macroinvertebrate communities from disturbance. *Environmental Management,* Vol.14, 605-620.

Ward, J V and Dufford, R G, 1979. Longitudinal and seasonal distribution of macroinvertebrates and epilithic algae in a Colorado springbrook-pond system. *Archiv für Hydrobiologie,* Vol.86(3), 284-321.

Webb, D W, Wetzel, M J, Reed, P C, Phillippe, L R and Harris, M A, 1995. Aquatic Biodiversity in Illinois Springs. *Journal of the Kansas Entomological Society,* Vol.68(2) suppl., 93-107.

Wentworth, C K, 1922. A scale of grade and class terms for classic sediments. *Journal of Geology,* Vol.30, 377-392.

Wevers, M J and Warren, C E, 1986. A perspective on stream community organisation, structure and development. *Archiv für Hydrobiologie,* Vol.108, 213-233.

Wiggins, G B, Mackay, R J and Smith I M, 1980. Evolutionary and ecological strategies of animals in annual temporary pools. *Archiv für Hydrobiologie,* Vol.58, suppl., 97-206.

Williams, D D, 1983. National survey of freshwater springs. *Bulletin of the Entomological Society of Canada,* Vol.15, 30-34.

Williams, D D, 1991a. The spring as an interface between groundwater and lotic faunas and as a tool in assessing groundwater quality. *Verhandlungen der Internationale Vereinigung für Theoretische und Angwandte Limnologie,* Vol.24, 1621-1624.

Williams, D D, 1991b. Life history traits of aquatic arthropods in springs. *Memoirs of the Entomological Society of Canada,* Vol.155, 63-87.

Williams, D D, 1996. Environmental constraints in temporary fresh waters and their consequences for the insect fauna. *Journal of the North American Benthological Society,* Vol.15, 634-650.

Williams, D D and Hogg, I D, 1988. Ecology and production of invertebrates in a Canadian coldwater spring - springbrook system. *Holarctic Ecology,* Vol.11, 41-54.

Williams, D D and Hynes H B N, 1976. The ecology of temporary streams I. The fauna of two Canadian streams. *Internationale Revue der Gesamten Hydrobiologie,* Vol.61, 761-787.

Williams, D D and Hynes H B N, 1977. The ecology of temporary streams II. General remarks on temporary streams. *Internationale Revue der Gesamten Hydrobiologie,* Vol.62, 53-61.

Williams, D D and Williams, N E, 1993. The upstream-downstream paradox of lotic invertebrates: quantitative evidence from a Welsh mountain stream. *Freshwater Biology,* Vol.30, 199-218.

Williams, D D and Williams, N E, 1998. Invertebrate communities from freshwater springs: what can they contribute to pure and applied ecology? 251-261 *in* Botosaneanu, L (ed.), *Studies in Crenobiology: The biology of springs and springbrooks.* [Leiden: Backhuys Publishers.]

Williams, D D and Williams, N E, 1999. Canadian Springs: postglacial development of the invertebrate fauna. 447-467 in Batzer, D P, Rader R and Wissinger S A, (eds.), *Invertebrates in freshwater wetlands of North America: ecology and management.* [New York: John Wiley and Sons.]

Williams, D D, Williams, N E and Cao, Y, 1997. Spatial differences in macroinvertebrate community structure in southeastern Ontario in relation to their chemical and physical environments. *Canadian Journal of Zoology,* Vol.75, 1404-14.

Wood P J and Armitage, P D, 1997. Biological Effects of Fine Sediment in the Lotic Environment. *Environmental Management,* Vol.21(2), 203-17.

Zollhöfer, J M, 1999. *Spring biotopes in Northern Switzerland: Habitat Heterogeneity, Zoobenthic Communities and Colonization Dynamics.* PhD Thesis, Swiss Federal Institute of Science and Technology, Zürich.

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Karst, Kras or *Karaśattu*: whence the name?

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Abstract: The cavernous region of modern Slovenia, which gave its name to the science of karstology, is called Karst in Germanic and Kras in Sloven (Slavic) languages, but the meaning of this name is still unknown. This article attempts to find the hidden meaning and finds it not in the sphere of geology but in the realm of the human troglodytes. Their ancient Dravidian name Karaśattu is found to be the source of the name Karst and Kras. Corroboration of this finding comes from the karsts of Slovenia and of France. Religious use of the caves is found to be the main reason for the appearance of this name. Latin records and the surviving toponymy of the Karst are the principal sources of the revealing discovery. These include numerous names, such as Rekka, Timavo, Wetterloch, Žegnana jama, Karavanke Mountains, Adriatic, and other corroborating terms, which, when properly understood, shed a new light on the distant history of the Slovene Kras. Interestingly enough, it is the Chinese way of describing the process of karstification that has presented us with the key to the mystery of the oronym Rekka. Its parallel has been found in India.

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INTRODUCTION

Much has been written about the origin, the meaning, and the application of the names Kras, Karst and their variants, which describe a cavernous region north of Trieste Bay at the northern head of the Adriatic Sea. They are used today to describe geologically similar regions elsewhere in Europe and beyond, yet it appears that understanding of the names is still lacking.

It is said that the words *kras* and *karst*, currently used in Sloven (commonly though erroneously called Slavic)[1] and German languages respectively, derive from the Celtic word *karra* for 'stone'[2] , which is still used in the Irish Gaelic (carraig = stone). However, it is also said that both terms are of *"pre-Indoeuropean [sic.] origin"*[3] . Nobody explains why they are not Indo-European. Their classical forms, preserved in a variety of historical sources, are *Carusadus, Carusadius, Karusad Mons, Carusad, Carsus, Carso,* etc. Ptolemy uses the form τω Καρουσαδιω ορει (Karusadio Mountains)[4] . None of them has a known and understood meaning. The earliest Sloven form is "Garst", which is found on the charter of 1177[5] . The forms Kras and Karst are explained as a result of the *"early Slovene metathesis 'kar-' into 'kra-'"*[6] . At the same time, Germans are said to have transformed the original Slovene Kras into Karst. If *"... it is certain that in the year 804 Slavic tribes, the predecessors of the modern Slovene, settled in Istria,"* then the claim that the name Kras or Karst is Slovene cannot be true. The name was there already in early Roman times, when Kras or Karst formed a part of the Roman Empire under the name "Regio X - Venetia et Histria".[7] The form *kras* is also used by the Slovaks (Slovenský kras)[8] , Poles (kras), Czechs (Český kras, since 1922)[9] and Moravians (Moravský kras), as well as by some Croats. Presently, Croats are switching to their own form Krš with the same application [10]. None of these nations comprehends the meaning of this name, even though in each of their languages the root kras suggests 'beauty'. Slavic etymologists suggest an Illyrian (implying non-Sloven [non-Slavic]) origin of the word kras, but no historical record substantiates the claim [11].

Beauty or *krása* (in Slovak) is not among the meanings usually attributed to the name Kras and Karst, except in Slovakia. Instead, drawing etymology from the Celtic *kar* for 'stone', it is often said that *"... the original popular meaning of the word 'kras'... [was] the barren ground"*.[12] Writing in 1894, E A Martel argued that "Karst (Kras in Croatian, Gaberk in Slovenian, Carso in Italian)" derived from "the Celtic word which means a stony landscape," and some argue that it is applicable to any stony land surface[13]. This is claimed with reference to Strabo's description of Istria, but all this Greek-writing Roman geographer has to say about the subject is, that it is a "mountainous country" (ὀρεινή)[14] inhabited by the "Carni" (Κάρνοι)[15] . He refers to the inhabitants, not to the country they inhabit. Thus, from the earliest times, the name *Karnoi* and its variants refers to the people of this particular country and not to the country itself. So it appears on the map of W Lazius and A Ortelius, dated 1561 and 1573, where the ethnonyms Karstii ("Kárst") and "Carniolae" appear alongside the ethnic names of other human groups in the frontier countries of Istria and Slovenia ("Histriae et Windorium Marchae"), namely Goritiae ("Goercz") and Chazeolae ("Kaczeola")[16] . The claim made in *The Encyclopedia of Geomorphology* (1968, p.582), that the Slovenian names Krš and Kras, and the German Karst, were variants of the regional name *"for the territory made of compact limestones to the north and to the south of the port of Rijeka in Yugoslavia"* is thought by some to be *"erroneous"*[17] , though it may prove to be only a partial mistake. By now it seems to be clear that the use of the name Kras and Karst in a territorial sense is secondary. Furthermore, should the name Karst ~ Kras be derived from the Celtic *kar* for stone, it would in no special way relate to either the Kras or the Carniola region, but it could be applied to any stony area anywhere in Europe and beyond. However, Karst and Kras are special names, applied long ago to a very special piece of land in Slovenia. Besides this, *kal* rather than kar, appears to have been the oldest known local name for 'stone', as we see it applied in the name Črni Kal, where the oldest human artefact, a stone scraper attributed to the Neanderthal man, was found[18]. No less than 35 names of mountains, hills and summits, such as Kal, Kalce, Kalec, Kali, Kalič, Kaliče, Kaliči, Kališče, Kališe, can be found in the *Atlas Slovenije*, while 31 settlements and 13 other toponyms are based on the same root *kal*[19] . *Kal* is a Tamil (Dravidian Indian) word for 'stone' and a certain source of the Celtic *kar*[20] . The Slovene (Slovenian) and Sloven (Slovak) word for rock, *skala*, derives from the same Tamil root.

THE LAND CALLED KARST ~ KRAS

In an attempt to find our way to the understanding of the meaning of the ancient names whose language affinity has not yet been ascertained, we must identify the main characteristics of the object and territory they describe. In Slovenia, karst – kras allegedly has *"the original popular* *meaning" of "the barren ground"* which happens to *"coincide with areas built of Cretaceous limestone"*, wrote Gams *et al.* in 1973 [21]. Even the wind storm (*"burja"* or *"bora"*) has been invoked to sustain this interpretation of Karst [22]. Hacquet (1778) is cited as having *"used the word Karst as a synonim* [sic.] *for a barren land similar to Arabia"*[23] . The same meaning is ascribed to the name Kras, even though it was coined as a regional name only in 1874 by F Jesenko [24]. The second part of this definition is also applicable to the Kras area of Slovakia, Moravia and Česko (the Czech Republic), but it is not true to say, that these three kras areas are areas of barren ground. In fact, they are beautiful and productive areas. Barrenness is therefore not a feature common to all kras areas. Nevertheless, the Karst above Trieste Bay impressed the early travellers as mostly bare and rocky, lacking soil and possessing irregular surface features in the form of closed depressions, locally known as *"doline" (singular dolina)*[25]. These *"huge funnel-shaped or crater-like depressions...* [gave] *the landscape such an unspeakably desert-like character"*, according to A Von Morlot in 1848[26]. In 1858, Schmidl described the "doline" as *"funnel-shaped abysses ('trichterförmige Abgründe')... called foiba in Istria"* . In the Austrian literature *dolina* means the same feature but *"... with steep or collapsed walls"*[28] . These *doline* were translated into English as "swallow holes", but the most expressive of all names for them is the Serb *vrtača*. Cvijić (1895) used the latter name to describe not only the funnel-shaped *doline*, but also *"... karst lakes, collapsed dolines, pitches, including those that end in a cave at the bottom (e.g. Črna jama and Pivka jama)"* [29]. The same "swallow-holes" occur also in Slovakia (e.g. Glatz in Slovak Paradise), where they are called *závrty* (singular *závrt*), with the meaning 'screw-holes'. These *závrty* conduct rainwater into underground caves [30].

Indeed, more important than any other characteristic of the Karst ~ Kras is the presence within it of numerous caves [31]. Karst regions are made of water-soluble (mainly carbonate) limestone, which lends itself to water erosion and to the formation of caves. This led the prominent French speleologist E A Martel to use descriptive terminology, such as the *"phenomènes calciers"* (limestone phenomena), *"paysages calcaires"* (limestone landscapes), etc., to describe the karst's features, and to avoid the name Karst, which he did not understand [32]. Others were more daring, and today the word karst is used as a technical term for cavernous limestone landscapes. Was it just a matter of pedantry? Perhaps not! It is today recognised by karstology that *"the karst underground is the essential part of a karst landscape"*, and this is studied within the science of speleology. Curiously enough, both karstologists and speleologists use the term karst, which they do not fully comprehend [33]. This is a situation quite unique in the field of the natural sciences, and it calls for a closer examination of the term karst ~ kras.

CAVES AND TROGLODYTES

"Caves are the karst features best known to the lay people", writes the prolific Slovene writer-karstologist Andrej Kranjc [34]. Caves have attracted people, men and women, since the greatest antiquity, and we hear about the cave-dwelling troglodytes from the earliest historical writers. Herodotus (BC 484?-425?) writes about *"... the Ethiopian hole-men, or troglodytes"* in the 5th century BC [35]. Plinius Gaius Secundus (The Elder) (23-79) writes about the *"Troglodytes"* in Africa, whose Indian ancestors sailed on rafts (*ratibus*) across the Erythraean Sea (Indian Ocean) to trade and traffic in East Africa, where they intermarried with the local women. Some of their mixed progeny opted to live like troglodytes in secluded caves, but they continued to act as trade intermediaries [36]. They were recluses, described in their native Tamil (Dravidian language of ancient India and Mesopotamia) as *tura-kollai-ditar*, wherefrom emerged the corrupted Greek name *Tróglodýtés* (Τρογλοδυτης) [37]. The original Indian *tura-kollai-ditar*, meaning *"one who is well established in forest region to renounce"*, were, as their name indicates, forest-dwelling recluses, and even the corrupted Greek word *Tróglodýtés* bears no reference to cave(s), which the Greeks called *speeleon (σπήλαιον)*. For this reason, modern scientists and amateurs who study the caves, call themselves speleologists rather than troglodytes.

Even our modern dictionaries recognise this fact when they define troglodyte as *"... a person living in seclusion, one unacquainted with affairs of the world"*. But as more and more of the forest recluses opted for caves,[38] they became known to the Greeks and, later, to the Romans as 'cave men' or 'cave dwellers' and, consequently, some dictionaries translate the Greek *Tróglodý tés* and Latin *Tróglodyta* as *"one who creeps into holes"* [39]. Today, even Tamil dictionaries translate *Troglodyte* as 'cave man', but the real Dravidian word for a cave man is *kugaivási*, which is based on the words *kugai* for 'a cave' and *vási* 'to dwell, to reside', 'a residence'[40] , though its primary meaning is 'a recluse'[41] . This Tamil-Indian word went to Africa on sea-going rafts with the early Indian *kugaivási* in the pre-Christ period, probably as far back as the Bronze Age. It survived among their Quena (Hottentot) descendants in South Africa until recent colonial times in the form of a tribal name !Khugeiqua ("Hoengeiqua"), meaning 'Cave People' in their own Quena language, in the Eastern Cape [42].

Back in Europe, we find evidence that Dravidian-Indian cave-dwelling recluses reached the Karst area of Slovenia as well. We find them hidden in caves under the name *"Carni"* (Κάρνοι), who inhabited the *"mountainous country"* (όρεινή) between Pannonia and the northern recesses of the Adriatic, as we are informed by Strabo (c.63 BC-AD 21)[43]. *The Oxford Classical Dictionary* (2nd ed., 1970) is unable to explain the origin and identity of the Carnoi (Carni in English translations) [44], or "Carnos", as they are called by Pliny (c.23-97 AD) [45] , but their name betrays their origin. It consists of the *Tamil Kara*, meaning 'to hide', which was the main outward goal of the ancient and modern hermits. Thus the Greek *Karnoi* are 'those who hide (in caves)' i.e. the Cave-dwellers [46]. In early times (perhaps as far back as the Bronze Age in the 3rd to mid-1st millennium BC), many of the cave-dwelling recluses would have been – as a result of intensive Indo-European trade in tin, amber and gold – of Dravidian origin. This means that they would have been of dark complexion, and this is preserved in the old Sloven (Slovak) dialects in Slovakia, in the name *karan* for a *"person of dark complexion"* [47]. Ancient gold-washing in the karst area is reported by Strabo (63 BC to AD 21) [48]. That ordinary people also lived in the caves of the Slovenian Karst since the earliest times is well known. The name Karnoi would have described them adequately.

Andrej Kranjc argues that *"karst"* derived from "Kras", therefore that Kras is older than *karst* and Karst [49]. However, the chronology of this, or vice-versa transition is not clear. The earliest known writer/explorer to use the name Kras in the form of *"karoš"* was the Frenchman Balthazar Hacquet in his work *Oryctographia carniolica* in 1784 [50]. He appears to have picked up the word *"karoš"* in 18th century Carniola, where it must have been used, still in its pre-metathesized form *karos*, by the common people, as if the metathesized form *kras* had not yet been in use or existence. This argues for a reverse derivation of *kras* and *Kras* from *Karst*. However, Münster's use of both *"Kars"* and *"Carnia Ober Crain"* in 1550 [51], and Hacquet's use of the form "Krain" in the title of his book, call for caution, even though the final *-s* in *kras* almost certainly originates from the final *-st* in *Karst*. And *Karst* had already been recorded in the form of "Grast" in 1177 [52] . On this name is based the Sloven *"Kraševec"* (singular) *"Kraševci"* (plural) for the inhabitants of the Kras, [53] as well as the Slovenized name Kranjska for the Latin Carniola [54], which is located just north of Karst [55]. The original meaning of the Dravidian word *kara* 'to hide' survives in the Sloven (Slovak) and other Sloven (Slavic) words 'kradmo', 'kradmý ', 'prikradnuša', all of which convey the idea of 'hiding' or 'hidden', and are translated into English by the word *stealth* [56].

Religion goes underground

The most important thing to notice is the fact that more often than not, the caves of the Karst provided dwellings, holy shrines and sanctuaries for religious recluses. It is known, for instance, that the martyr Saint Socerb (Servulus or Servus) lived in the cave Sveta Jama (Holy Hole) near Socerb [57], and when he was killed on 24th May 284 AD, an altar was built inside, and the cave became a destination of regular religious pilgrimage [58]. Holy mass was said in Sveta Jama from the 3rd or 4th century AD onwards. The cave church at Landar was mentioned in 888[59]. Several caves known under the name of "Wetterloch" (translated as "Weather Hole," or "Diera počasia") attracted religious processions every year, usually on Pentecost (Whitsun) Sunday or on Ascension Day. On such occasions, priests blessed the entrances to the caves. The purpose of these blessing was to remove fear from the people – particularly fear of the dark and unknown underground.

Of course, the custom of visiting or staying in the Karst caves for religious purposes did not begin with the arrival of Christianity. This is indicated by names like Lintvern or "Lindwurm", which means 'dragon', and describes the intermittent karst spring at Notranjska cave; or a cave called *"Žegnana jama"* (Blessed Cave) [60]. In 1748 the Austrian Emperor Franz I Stephan sent J A Nagel, who had been working in the salt mines in Solivar near Preöov, Slovakia ("Soovar" in "Oberungarn"), to Carniola (Kranjska) to investigate the Karst caves [61]. He visited several "Wetterloch" caves, including the one called Coprniöka jama, where *coprnica* means 'a witch' and implies that witches (*bosorky*) lived in such caves, located on the summit of the Slivnica Mountain near Cerkniöko jezero (lake). In this hole he found *"the vessel with pitch (bitumen) thrown into serving as a food for the devil"*. With this sacrifice, the people of the region, whose pagan superstition made them fear the caves, *"tried to prevent the thunderstorm and hail coming out of the cave, provoked by witches and devil"* [62].

To counteract their superstitions, Nagel showed two invited priests that a stone thrown into the cave caused no evil, and that there was nothing to fear [63]. The Tamil word for 'fear' is *vetirppu*, and *vetir* means 'to tremble (with fear)'[64]. *Vetir* is a homonym of the Sloven (Slavic) *veter~vietor* for 'the wind', and is the obvious source of the German misnomer *Wetter*. This makes no sense when applied in the form of Wetterloch (weather hole) to the dark holes in the karst (e.g. Ĉrna jama), regardless of the fact that some of them may have been draughty (e.g. Vetrovna luknja).[65] No weather ever came out of these holes, but the rural folk 'feared' them and, using the term of the ancient Dravidian dwellers in the karst holes, called them *vetir*-holes or *veter*-holes, meaning 'the holes of fear' (*diery strachu* in Sloven/Slovak). To appease the fears of the folk, these perceived holes of fear were exorcised by the priest's imprecations. This is expressed by the Sloven word *zažehnaný*, which led to the name "žegnana jama" (Blessed Cave) being given to one of these holes of fear. The most likely Tamil form of the compound 'hole of fear' was *vetir-valai*,[67] the second word most probably being the source of the Slovene term polje (*valai > balai > palej > polje*) for the karst depressions known as *'karst polje'* (e.g. Loš ke polje, Planinske polje) [68], among which the largest and best known is Cerkniško karst polje (Church karst depression) [69].

Fears and superstitions inspired by the karstic holes of fear (*vetir-valai*) were not new in the 18th century, and certainly not new even in the 1st century AD. They hailed from distant pagan times, when the God Triglav, remembered in the name "Triglav Lakes", ruled over this Karst and Kranjska land [70], from the highest mountain of the Slovene land, also called Triglav (2,863m), as far back as the Bronze Age, if not Palaeolithic times [71]. It is not a coincidence that some of the richest finds of early human artefacts and decorations, including those made of copper, came from a cave below Mala Triglavca. Mala Triglavca also produced ceramics from Roman times [72].

The great antiquity of these fears and superstitions is indicated by the ancient Dravidian name for the cave dwellers, which is known from Latin sources. "Carusadus", the name in question, is used in classical sources to designate the Karst region of Kranjska (Carniola)[73]. The name in fact does not refer to the Karst land but, once again, to the people of the land, and Martel was justified in being reluctant to speak about "karstic limestones" (Karstkalk) and Karst Land [74]. Carusadus is an almost surprisingly faithful reproduction of the Tamil *Karaś attu*, which consists of the Dravidian words *kara* 'to hide' and *aśattu* for 'a person who hides down below'; in other words, *'a person who hides in a cave'*.

Such a person, called *aś attu*, could be there in search of a 'non-existent thing' i.e., in search of eternity, or of an illusion called 'the first time', which so heavily preoccupied the minds of the ancient Egyptians[75]. The *Karaśattu* spent their lives in the darkness of the caves searching for the light of the ultimate truth. But, to those outside, the dweller in a deep cave may have appeared to be "a low kind of person", even "a mean person", whom the Christian inhabitants of Karasattu land came to call a witch or even a devil [76]. The custom of using pitch or bitumen to keep the devil down in the deep harks all the way back to Sumerian Mesopotamia. Dravidian languages were spoken here, and bitumen (smola) was used profusely in Úr and elsewhere in the construction of houses and palaces [77], in order to protect them against the same evil that terrified the ordinary Kraševci people of Karst and Kranjska.

The custom of giving pitch to the cave-dwelling *Karaśattu* arose from their practice of mummifying dead bodies. This is preserved in the Sloven (Slovak) word *smola* (*smů la* in Czech) for the pitch, which derives from the Sanskrit prefix *sa-* meaning 'with' or 'together' and the Tamil *muli* for 'dryness' [78]. Thus formed, *smola* is 'what keeps the dryness' (in a boat or in a mummy). Of course, not all hermits always lived underground, and some didn't live underground at all. Some lived in open shelters or in small mortarless stone huts, some of them corbelled, which can be described in Tamil as *kiř-kai*. This is the most likely source and prototype of the oval stone dwellings found in the Kras area, called *"hiška"*.[79] Similar oval huts were built in South Africa by the Quena and Sotho hermits called *BaDulanoš i*, who had Indian blood in their ancestry.

The asattu hermits in France

Quite obviously, questions that may arise in connection with the early history and chronology of the Slovens (Slovaks) and Slovens (Slavs) cannot be discussed here. They are dealt with in great detail in the somewhat heftier manuscript of my book, *Sloveni a Slovensko: Velebníci Vlasatého Boha na Horizonte Histórie (c.3200 pr. Kr. – 907 po Kr.)*. Martin: Matica slovenská. MS 1998 *[Sloveni and Slovakia: The Worshippers of Hairy God on the Horizon of History (c.3200 BC - 907 AD]*. Meanwhile, a confirmation of the correctness of these linguistic deductions comes from non-Sloven (non-Slavic) France. The *Karaśattu*, or 'the men who hide in caves', were cultured and educated people and they made a cultural and religious use of the caves. This is implied by the term *aśattu* and by the name Karassatu. A similar, if not identical, meaning must have clung to the Latin form of the term, *usadus*, and to the name Carusadus.

Surmising the guiding potential of this term *aśattu* (Tamil) ~ *usadus* (Latin), attention was turned to the French locality Ussat, where E A Martel practised the art of speleology between 1894 and 1930[80]. Dr S Craven and his extensive speleological library aided location of Ussat in the important French karst region of Ariège, on the river Ariège, just southeast of Tarascon-sur-Ariège in the foothills of the Pyrenees. In the vicinity of Ussat village there is a hot bath called Ussat-les-Bains and two important karstic caves with very suggestive names: the Grotte de L'Eremite (or L'hermite) – the Cave of the Hermit – and the Grotte des Églises – the Cave of Churches. Another two large caves, called the Grotte de Lombrive and the Grotte de Niaux, are located on the western side of the river Ariège.

The cultural content of the first two caves consists largely of rock paintings and some engravings, both appropriate for the underground dwelling and a temple of the Bronze Age hermits. The Grotte de

L'Eremite contains a *"Bronze Age figure, a schematic drawing of a female figure in yellow ochre about 15 inches high, resembling the paintings of the Spanish Levant (S.E. Spain)"*. The nearby Grotte des Églises has a religiously symbolic pebbled floor and several paintings of the sacred ibexes, of a horse and an ox. Most importantly *"... a number of small paintings in red outline"* are *"... associated with some irregularly placed red spots"* [81]. Such red spots are most typical in the cave and other dwellings of the Indian Kara-aśattu, for they symbolise their submission to the Triglav of ancient India, the triune trimurti of God Śiva, who is himself a Cave Dweller, bearing the name of Bilávása (One residing in a hollow) [82]. These red spots, painted on rock with fingers, are also very common in the caves painted by the Quena (Indo-Kung or Indo-Bushman) priests and hermits, who were the chief rock painters of South Africa, as for instance in the Finger Cave (*'Kai-//u*) on the Geelbek river at Laingsburg in the Karoo [83]. These religious rock painting priests were known to the Quena by the name *suri*, derived from the Dravidian word suri for the same category of men in India. Many other terms they used, such as *Karoo* (dry land), *'kai* (finger), *//u* (cave), etc., were of Dravidian origin [84].

Throughout the ages, the caves of Ussat in Ariège were used as 'hiding' places by the hermits, and religious heretics (as for instance the Albigenses in the 12-13th centuries, who practised a cult that combined the Dualism of Manes with Priscillinism, Oriental and Gnostic beliefs and the Gothic Arianism) and were known in post-mediaeval times as *"gleizetos"*, or *"petites eglises"* (small churches) [85]. The name Ussat refers to the more ancient times and reflects the name of their ancient religious dwellers – the *Karaśattu*, that is 'the men who hid and dwelt in caves'. Karaśattu appears to have been the name that Ptolemaeus (AD 150) found translated by the name "Cauari Καίρυοι", meaning 'Cave dwellers', and this may have been equally well applied to both the inhabitants of the caves in the karstic south of France and to the cave-dwellers of the Slovene Karst.[86] This evidence places the derivation of the Roman Carusadus and of the Sloven Kras and Karst from the Tamil *Kara-aśattu* on very firm foundations. Perhaps, it is also not by mere coincidence that the highest concentration of ancient cave dwelling, apart from India and Sulawesi, focuses on the river Garonne and its tributaries, whose name also seems to rest on the Dravidian root *kara (gara)* for 'hiding'[87]. Thus the Dravidian *Kara-aśattu*, in its various Europeanised forms (Karst, Kras, Gar-, Carniola, Carusadus, etc.) appears to have been applied to the regions of inhabited cavernous limestone in many parts of Europe, not only in the Karst area of Slovenia. Its present-day scientific application to the cavernous limestone regions all over the world is therefore not unprecedented.

The hiding mountains and rivers

Another corroboration of the Dravidian origin of the name Karst comes from the alternative name "Karavanke Mountains", historically first recorded as Καρουάγκας ὄρος [88] (*Carvancas mons*) by Ptolemy in the middle of the 2nd Century AD [89]. Kranjc mentions this name twice, but leaves it unexplained, while implying that it may mean the same as Karst or Kras, which he thinks derive from the "pre-indoeuropean root 'ka(r)a/ga(r)a' – stone"[90]. In reality Karavankas (Karavanke), which today designates the mountain range between the upper Drava and upper Sava rivers, has a different derivation. It shares its first part Kara-, derived from the same Tamil word *kara* 'to hide', with Karst, but its second component *-vanka-s* derives from another Tamil word vangku, which means 'cave'[91], and which corresponds very closely with the Greek ουάγκας[92]. Thus, the Dravidian name *Karavangku*, made into Greek *"Karuankas" (Καρουάγκασ)* and Slovene-ized into Karavanke Mountains (German *Karavanken*), addresses itself directly to the hiding caves - of which there are several hundreds, some of them inhabited since the Palaeolithic[93]. It describes the Karst area literally, both in general and in specific reference to the karstic part of the present Karavanke [94], as 'the Mountains of the Hiding Caves', which is indeed what they are. The Slovene oronym *Gaberk*, first recorded in its Latin form *"Mons Gaberk"* by Valvasor in 1689, has a similar meaning and a somewhat more complex origin [95]. It is based on the Tamil word *kara* 'to hide', abbreviated into *Ga-*, and on the Germanic *Berg* for 'mountain', Slovene-ized into *berk*. Thus composed, Gaberk describes the Karst region as 'Hiding Mountain' (cf. Slovak *Harbek* in the karst area of Slovak Paradise).

Interestingly enough, hermits and other people with troglodytic inclinations were not the only interested parties who used to hide in the caves. Rivers also hide in the karstic caves, in fact, without them the Karst would not be the spectacular geological feature that it is. And it was precisely this hiding characteristic of the Karst's main river that made the region famous and noticed by ancient authors since before the time of Christ [96]. The best known among the hiding or underground rivers is the Reka river, spelt "Recca" on the oldest maps [97]. This name is peculiar, because *reka, rieka, rijeka, _eka* and other Sloven (Slavic) variants of this word mean the same, namely 'river'. Thus the Reka river would literally seem to mean the 'River river' (rieka Reka, in Slovene and Slovak, řeka Reka, in Czech, etc.). This is indeed puzzling. A possible solution for the above puzzle can be won from Wolfgang Lazius's 1573 map of *Goritiae, Karstii, Chaczeolae, Carniolae, Histriae, et Windorum Marchae Descrip.*, which is a revised version of the original map published in the atlas *Typi Chorographici Prouin: Austriæ* ... in 1561. On this map we find a mixture of Slovene, Latin and German names, e.g. Iabloniz, (Slovene), Recca flu. (Slovene-Latin), Albia flu. (Latin), Výpach flu. (German), etc. This map recognises the underground connection between the Recca river ("Recca flu") and the Timava river ("Timauus flu.") by having an explanatory note at the place where the Recca river disappears in the äkocjanska jama, saying: *"S. Rasan, vbi Recca flu. absorbetur, & in Timaui fontibus erumpit"* ("S. Rasan, where the Recca river is absorbed [in the ground], & in the sources of the Timava breaks out [on surface]." On this map, the main feeder of the very short Recca river is a large stream called by the Latin name "Albia flu", meaning White river[98]. This name most probably referred to the fact that, in this upper portion of its course, the river ran in the light ("s svetlega") i.e., on the surface,[99] as opposed to the lower, dark underground portion of its course. Here it was the River of Light. That the size or length of this river and its connecting with other rivers may be a result of the cartographer's confusion or fiction, as pointed out by Shaw and MacQueen, is of no consequence as far as our understanding of the Recca – Timava connection is concerned .[100]

Similarly, the arbitrary elevation of the ancient toponym Rasan into "S. Rasan" (Saint Rasan), as well as the emergence of "St Canzian" [101], "Scazan"[102], "S. Kazan"[103], and eventually "St. Kanzian" an Škocjan"[104], and whose name fails to appear even in the most exhaustive list of Christian saints[105], is irrelevant to the task before us. The real patron saint of the local church appears to have been Saint John, reflected in the name *"ecclesiam sancti Johannis de Timavo"* (1077-1084), who also was the patron of this most typical karst river: *"in flumine Sancti Joanis de Carsto"* (1289)[106]. St. Kanzian may in fact be a corruption of the old Italian San Giano through the later "San Canziano Timavo"[107]. However, the transition from *San Giano* to sv. Kanzian is not easy to demonstrate.

Meanwhile, it has come to my attention belatedly that a survey of 15 localities named or connected with the name Škocjan found them situated in karstic areas and in a close proximity of the "disappearing waters" (*"ponikalnih vodah"*) and appearing waters (*"izviri"*), and near other karstic features. This association would explain the appearance of the devotion to St John (the Baptist; San Giano), on the Timavo river.[108] However, the oldest form of the name appears to be "Kancijan" and a man with this name is said to have died in Imola, Italy, in the 3rd century AD[109]. This would certainly pre-date the appearance of the cult of St John the Baptist in these parts of the world. The form "Kancijan" points to a different, pre-Christian period and culture, to the time when the pagan Karasattu dwelt in the local caves. The name Kancijan consists of the Tamil words *kañćam* meaning 'water' and *iyan* meaning 'to extoll, to glorify, to worship'[110]. The resulting *kañća-iyam* or *kañć iyam* would mean 'water extolling', 'water worship' or 'water glorification', whereas the personalised form *Kañč iyan* (Slovene Kancijan) would describe a Water-worshipper. Certainly, the extraordinary behaviour of the karstic waters was responsible for the emergence of the local water cult – as reflected in the numerous shrines dedicated to Kancijan. Apparently, the ancient Dravidian and Sloven cave-dwelling Karasattu cultivated and worshipped this cult long before it entered the Bible, and most probably therein lies the very origin of the water cult of St John the Baptist. His cult was definitely pre-Christian. He baptised people before even Jesus was born. It is highly doubtful that the Catholic Church ever beatified Slovene Kancijan. He is the saint of the karst's underground waters alone.

This revelation obliges us to look again at the *"ponikalnica"* or the place called "Rasan, where the Recca river is absorbed in the ground", and we soon discover that it is ancient. The name "Rasan", as recorded by Lazius, appears to be coeval with Kancijan, and most probably derives from the Tamil *áru* 'river' and *śá* 'to die', making the name *Áṛu-śa-n* and *Rasan*. This means the place where 'the River Dies'[111] in the underground, an exquisitely appropriate description of the deep abyss under the village of Škocjan in Karasattu [112].

Already in the 1st to 2nd Century BC Poseidonius of Apameia (c.135 to c.51-50 BC) knew that this White river falls into the dark underground of the karstic caverns and after running underground for about a hundred and thirty stadia comes out of the mountains and makes its exit near the sea under a new name Timava ("Τίμαυον - Timavon" and its later variants Timavo, Timauus, etc.)[113]. All of these forms of the name Timava recall the Sloven (Slavic) word 'tmavá' for 'dark', making it a 'Tmavá rieka' or 'Dark river' – dark either because its waters are dark – which seems to be the case[114] – or, because it emerges from the darkness of the underground. Significantly, while submerged, the Recca river passes under the mountains called by Kircher in 1665 "Timavus Mons"[115] . This means Dark Mountains (*Tmavé hory*), which interpretation seems to be confirmed by Lazius's map of 1573, where in the same place appears "*Schwartzneck*" i.e. Black Neck [116]. Sometime in the Middle Ages a castle called *Schwartzneck* was build on these black hills [117]. An interchange in 1289 of the name *"Carsto"* in the dedicatory name of the local church, *"flumine Sancti Joannis de Carsto"*, for the earlier *"Timavo"*, both of which names refer to the darkness of the hiding cave, fully supports the reading of *Timavo~Timava* as *'tmava'*, that is, 'Dark river'[118] in Sloven (Slavic) languages. Ampelius's reference to this river as *"Timavus in Illyriko"* further affirms the Sloven origin of this name. A major factor that may have contributed towards the obfuscation of the name Timava might be the relatively recent extension of its application to the so-called "Škocjansko Reko" above Škocjanska jama, otherwise known simply as "Reka"[119] .

The interplay of the names Light or White (*Albia*) for the upper, surface course, versus Dark (*Tmava or Timava*) for the lower, underground course, finds an interesting outcome in the statement made by Polybius in the 2nd Century BC. According to Polybius, when this river (*Albia*) emerges from the underground through its seven sources, one of which is salty, it is called by the natives "the Source, but also the Mother of *Thalattes*." Not having the real understanding of the name, translators of the Greek *πηγήν καί μητέρα θαλάττησ* (peeyeen ke meetera Thalattees) read *θαλάττησ* as *θαλασση* (thalasse) meaning 'the sea', and translated the whole descriptive hydronym as "the source and mother of the sea"[120], which does not make much sense. Either Polybius did not get it right or by his time the name was no longer understood. This name in fact pre-dated Polybius by centuries, if not millennia, and in its original form referred to the essence of this unusual river. In its Dravido-Sanskritic form it must have read: *kuṇḍa mátar taḷḷá tésu*, meaning 'the Spring or Birth Mother of the (River of) Light'[121], which described very appropriately the source of re-emergence of the lost River of Light from the darkness of the karstic underground. The Sanskrit word *kuṇḍa*, translated into Greek as 'the source' (*πηγήν*), is still used in many Sloven (Slavic) languages to describe the female organs of giving birth, which are the source of children.

This understanding of Timavo, i.e. that it stands for the dark underground course of the Rekka river, is corroborated by the related mythology that has been recorded by various classical authors. First of all, Strabon links the Timavo area with ancient gold-washing, which, as already pointed out, attracted ancient Dravidian Indian prospectors and traders to Karasattu, and they left behind numerous toponyms based on words from their languages.

One of their ancient towns had a Dravidian name *Ur*, meaning 'the Town', later latinised into "Urium"[122]. Another one, closer to the Timavo, was called "Atria", meaning either 'the Horse' or 'the Mountain' (from Ta. *attiri*)[123], both of which are relevant to the question of Timavo. "Atria" was once an illustrious city, and the Adriatic Gulf got its name therefrom[124]. Was it a Mountain Sea or a Horse Sea? The oldest name that we know for the indigenous Sloven Illyrians (i.e. *Horali* or Highlanders)[125] in this area was "Daunii", which, being derived from the Tamil word *dávu* 'to disappear'[126], described them as those 'who disappear (in the caves or mines)'. This name was not used any more in Strabo's time (63 BC - AD 21), though it was known from the mythological legends[127]. The early Daunii worshipped the Dravidian god of the dark underground called *Dio-med-* (+ varying suffix), which Strabo's Greek sources Hellenised into *"Diomedes"* [128]. His female counterpart was *Medea*, daughter of the King of the golden region at Colchi, who was kidnapped by the Argonaut Jason while he was searching for the "golden fleece" [129]. Medea was the "earth-goddess", modelled on the pattern of Śiva's consort Sítá, the Indian 'Mother-Earth', known as *Bhúmi-já* or 'Earth-born' [130]. Sítá, the heroine of the great Indian epic work *Rámáyana* [131], was born from the dark recesses of the Earth through a furrow or canal, ploughed out by her godly consort Śiva, in the same manner as the Timavo river emerges from the dark aquifer of the Karasattu.

This myth is reflected in the local Dauni tradition (preserved by the neighbouring "Heneti" i.e. Venetians), which says that "Diomedes even tried to cut a canal [apparently from the 'Dark Springs' or *"Timavi Fons"* of the "Timavon River") as far as the sea" [132]. Not surprisingly, the ancient Daunii ('Disappearers') built in the Timavo river's vicinity "a sanctuary of Diomedes", called "the Timavon" (*ἱερόν του Διομήδους... τό Τίμαυον*), in other words, 'a sanctuary of the Dark One' [133]. His Illyrian name Timavon, which stresses the darkness of the underground, is a Sloven (old Slavic) translation of his ancient Dravidian name *Máyón*, the 'Black One' [134]. Its Dravidian augmentative suffix *-on*, is still used in Sloven (Slovak) words like *blázon* (the fool), *mudroň* (the clever), etc. His Greek name Diomedes stresses his "home" in the dark underground [135], and it harks back to the Dravidian god of the underground, named *Dio-med- or Mêdini-iś vara*[136]. The country of the Disappearing Daunii and of their 'Dark Underground' hero god Timavon was characterised by "the plains [that] lie in hollows," which almost certainly refers to the *kale* and *doline* (plural of *kal* and *dolina*) of the karstic Karasattu. One of the local mythical accounts tells that in one of these doline, though Strabon's sources place the incident on the nearby "Islands of Diomedes", the Black Underground hero Timavo eventually "disappeared", and by these means he acquired his *apotheosis* (*ἀποθέωσιν*) or deification[137] .

Once deified, God Timavon, the ruler of the Black Underground came to be worshipped and propitiated by appropriate sacrifices, namely "the white horse," and this sacrifice continued at least to the beginning of the Christian Era [138]. The choice of the white horse, once again, harks back to the Dravidian Indian origin of Timavon's earliest devotees. Timavon's main gift to his devotees was water, hence the white horse, which in Indian historical mythology was a "product from water"[139] that emerged from *"the Churning of the Ocean by the Gods and Asuras"* [140], was the most appropriate choice. Obviously, the early Sloven Illyrians were familiar with this Indian myth, which they must have learned from their mixed Sloveno-Dravidian ancestors, from the 'Disappearing' Daunii. The white horse of the dark underground God Timavon purified the waters and the souls of his Sloven devotees in Karasattu. He also had the power to foretell the coming of Doomsday by means of his re-emerging from the underground darkness through the chasm in the mountain [141]. Their Sloven (Slavic) and Slovene (Slovenian) descendants trusted the powers of the white horse and used him as the main medium of prophecy and divination [142].

Timavo, the god of the Dark Underground, was obviously bisexual: the white horse represented his male nature, the mountain chasm of the Timava river stood for his female nature. But as is usual in the Indian iconography of God Śiva, the two sexes are but two aspects of one God. This is reflected in the name *Attiri* (Lat. *Atria*, later Adria), given to the noble city where his Timavo temple stood at one time, which acknowledges his bisexuality by describing it as a male Horse city and at the same time as a female Mountain city. The female mountain chasm was the Birth Mother of the river of Light, mentioned by Strabon. This river fed the Sea, which thus also got the name Adriatic. The name Adriatic Sea attests to the great and far reaching importance of the Timavo Sanctuary on the re-emerged River Rekka.

An unanswered question is, what is the meaning of "Recca", because it obviously is not the Slovene rijeka or Sloven (Slovak) *rieka*, meaning 'a river'. The river in question, for as yet unknown but certainly historically justifiable reasons, is not called *rijeka Rijeka*, but always *rijeka Reka* or *Rekka*. Slovene Karst has a number of rivers, but none of them on the surface. All of its rivers worked themselves through dolines into the karstic underground, forming there a huge "karst aquifer" [143]. Here we are helped by the Chinese way of expressing the process of karstification, in which the underground rivers play a major role. The Chinese expression for karstification means *"to gnaw at the stone"*, which is what the underground rivers are doing [144].

To gnaw at the stone means 'to remove it little by little' or to 'gnaw it away', and this meaning is conveyed by the Tamil word *ari*, while *kam* is a Tamil word for 'water' [145]. Thus, *Ari-kkam* is a 'Gnawing river' or 'Karstifying river'. In the process of Europeanisation of this Tamil term, the initial *A-* was taken for a prefix and was dropped, together with the nominal suffix *–m*. This left behind the Sloven (Slavic)-looking form Rikka. Under the influence of the Sloven (Slovak) *rieka* for 'river', this assumed the form Rekka, which was Latinised into *Recca* and corrupted into Reka in recent times. Similarly formed is the 'Gold-Gnawing river' called "Suvarnarekha" in the gold-bearing region of Chota Nagpur in the Indian states of Bihar and Orissa [146]. Thus Rekka rijeka (and the faulty form Reka) in the Slovene Karasattu does not mean 'River river', as may have been thought so far. It is a 'Karstifying river'. This understanding of the hydronym Rekka rijeka also justifies and explains why the city of Rijeka (Fiume), on the western coast of Istria, can be so called, even though it lies on no major river or stream. Its short stream, called Rijecina, bursts straight out from the karst spring nearby [147]. It also seems very likely that this ancient and historical understanding of the name Rekka may be recognised in the German name "Reka Höhle" ('Karst Cave'), which used to be applied to Škocjanska jama [148], where this extraordinary river begins its karstifying action. This Karstifying river or Rekka rijeka is the absolutely central feature of the entire Slovene Karasattu or Karst region.

It is of course possible that the name Rekka for the karstifying underground river is the ultimate source of the pan-Sloven (pan-Slavic) word *rieka ~ řeka ~ rijeka ~ reka*, etc. for 'a river'. Dravidian hermits, who in the Bronze Age or in subsequent ancient times, dwelt with their Sloven brothers in the karstic caves of Central Europe, which frequently contained underground rivers, may have called these rivers *"rekka"*. The monastic underground term gradually made its way to the light of the world above, where it assumed the meaning of any river. Of course, the same process had most probably occurred already in India, where we see the term *irékai* or *réka* in Dravidian languages[149] and the form *rekhá* in Sanskritic languages [150]. The origin of the pan-Sloven term 'reka' is otherwise etymologically unexplained. If the etymology of the Sloven (Slavic) *reka* presented here is correct, Karstology would have made a major contribution towards the better understanding of the linguistic make-up of the Sloven (Slavic) nations.

SUMMARY

The sum of the results of this investigation is as follows. The names Kras (Sloven i.e. ancient Slovak, later rendered as Slavic) and Karst (German), applied today to the cavernous limestone area of Slovenia, as well as to geologically similar regions elsewhere in Slavic Europe and beyond, have a common root in the Dravidian word kara, meaning 'to hide'. As such, their primary reference is not to the caves themselves but to the cave dwellers, after whom the cavernous area of Slovenia was called Kras ~ Kranjska. Hence the Greek name *Karnoi* (Κάρνοι) and the Latin name *Carnos*, both describe the people who dwelt in caves. The derivation of the Sloven nominal form Kras from the Tamil verbal form *kara*, 'to hide', most probably occurred via the Sloven verbal form *kara-ti*, which transition is known in the historical dynamics of the Sloven (Slavic) phonology [152].

The form Karst, which took hold in the Germanic languages, derives from the Tamil *Kara-aśattu*, where the Dravidian word *aśattu*, for 'a person who hides down below', has been added to the already explained Tamil verb *kara*, 'to hide'. Consequently, the toponyms Kras and Karst describe the cavernous limestone areas as regions where, in ancient times, religious recluses hid in caves. The names Kras and Karst are therefore ethnic and cultural, not geological. This, however, should not preclude their application to the geological formations of the cavernous limestones. They can be read as describing the 'Hide-out region(s) of the hermits who dwelt in caves'. Their applicability transcends the boundaries of the Slovene cavernous limestone. This was first recognised, though without any understanding of the names Karst and Kras, by F Grafen von Hohenwart in 1830, and since then the form karst has become a general scientific term for areas of cavernous limestone[153] and other soluble rocks.

In vino veritas!

Recent Karst poetry reaches all the way to the ancient pagan hermits, exalting the *Teran* wine, which was already famous in Roman times[154]. Most probably the ancient hermits introduced it into Kras, calling it *teral (>teran)* 'pure toddy, clear juice' (in Tamil)[155]. The *Refoök* grapes that produce the excellent red *Teran* wine grow on the red soil (*terra rossa*) that covers the karstic rocks, reaching the greatest depth on the bottoms of *dolines* [156], right above the heads of the Karasattu hermits. Undoubtedly they were the first wine makers and the first cultivators of the red soil of the doline, calling it in Tamil *jér-ovvu-cej*, meaning 'a ploughed-like-ground'[157], whence came the Sloven *jer-ovica* or *jerovica* for the red ploughing soil[158]. An alternative term introduced by the Karasattu may have been jér-tarai, describing it as 'ploughing soil' [159], which in time produced the general Latin term *terra* for 'the soil', as in the Italian *terra rossa* for *jerovica*. Of all the soils of Karst, *Jerovica* was and still is "most often cultivated"[160], and may in fact have been the very first ploughed soil in the Balkans, if not in Europe.

Da, kraški svet, res si krasan in zemlja tvoja čudotvorna, ker ona vam daje teran, čeravno sama je uborna.	Glorious you are, my Kras world, and your land truly amazing, giving us Teran your wine, Although you yourself are destitute.
Pa na bo Turek, Žid, kristjan, al stare še poganske vere, vsak že pohvalil je teran, ko sa navžil ga je-do mere.	The Turk, Jew, or Christian, or older yet, of Pagan faith, giving us Teran your wine, Whenever glasses full were raised.

(M Kodrič) [161]

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FOOTNOTES AND BIBLIOGRAPHY

1 Hromnik, C A, 1998. Sloveni: Unde orti estis? Slováci, kde sú vaše korene? *Slavia Antiqua*, Vol.39, pp.283-292.

2 Jennings, J N, 1971. Karst. p.1. [Canberra: Australian National University Press.]

3 Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. Slovenska kraš ka terminologija - Slovene Karst terminology. p.45. [Ljubljana: Zveza geografskich institucij Jugoslavije.]

4 Ramovš,F, 1936. Kratka zgodovina slovenskega jezika. Ljubljana, p.246. Cit. in: Kranjc, A, 1998. Kras (the Classical Karst) and the development of Karst science. Kras (klasični Kras) in razvoj znanosti o Krasu. Acta Carsologica - Krasoslovni zbornik, 27(1,9), p.154; "Carusadio Χαρονσα διομ mõte" in: Ptolemaeus, C. 150/1966. Geographia. Strassburg 1513. Introduced by R A Skelton. Facs. reprint p.19v. [Amsterdam: Theatrum Orbis Terrarum.]

5 Kos, F, 1915. *Gradivo za zgodovino Slovencev v srednjem veku*, 4. Ljubljana. Cit. in: Kranjc, A, 1998. Kras (the Classical Karst) and the development of Karst science. Kras (klasièni Kras) in razvoj znanosti o Krasu. *Acta Carsologica - Krasoslovni zbornik*, 27(1,9), p.154.

6 Ramovş 1936. *Kratka zgodovina*, p.246, cit. in: Kranjc, A, 1998. Kras (the Classical Karst), p.154.

7 Kranjc, A. 1998. Kras (the Classical Karst) and the development of Karst science. Kras (klasični Kras) in razvoj znanosti o Krasu. *Acta Carsologica - Krasoslovni zbornik*, 27(1,9), p.154.

8 Kukačka, M 1988. *Svet slovenských hÔr*. Martin: Vydavateľstvo Osveta, 4/9, 5/3.

9 Kuklík, K 1988. *Chráněná krajinná oblast Český kras*. [Praha: Vydavatelství ČTK Pressfoto.]

10 Kranjc, A 1998. Kras (the Classical Karst) and the development of Karst science. Kras (klasični Kras) in razvoj znanosti o Krasu. *Acta Carsologica - Krasoslovni zbornik*, 27(1,9), p.154.

11 Holub, J and Lyer, S, 1967. *Stručný etymologický slovník jazyka českého se zvláš tním zř etelem k Slovů m kulturním a cizím*. p.266. [Praha: Státní pedagogické nakladatelství.]

12 Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. *Slovenska kraška*, p.45; Kranjc, A 1994. About the name and the history of the region Kras. O imenu in zgodovini pokrajine Kras. *Acta Carsologica*, 23(6), p.84.

13 Martel, E A, 1894. *Les Abîmes*. Paris. Cit. in: Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. *Slovenska kraöka terminologija - Slovene Karst terminology*. p.49. [Ljubljana: Zveza geografskich institucij Jugoslavije.]

14 Strabo, c.63 B.C.-A.D. 21/1983. *The Geography of Strabo*. v.III, p.56: lib.7.5.3. [London: William Heinemann.]

15 Strabo, 1919. *The Geography*, v. II, p.282-285: lib. 4.6.9.

16 Kranjc, A, 1994. About the name, 23(6), p.85.

17 Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. Slovenska kraöka, p.49.

18 Kranjc, A, (ed.), 1997. *Kras: Slovene Classical Karst*. p.137. [Ljubljana: ZRC SAZU.]; Kranjc, A, 1998. Kras (the Classical Karst), p.156. The Slovene kal for 'a pan of water, pool, puddle' derives from the Tamil word *kaluř*, meaning 'a pool, puddle, dirty water, stream, excess of water' (Slovak *kaluž* and *kaluž a*; Czech *kaluž e*, with similar meanings. Burrow,T and Emeneau, M B, *A Dravidian Etymological Dictionary*, s.93; *The Lifco Tamil-Tamil-English Dictionary*. 1978. p.184. [Tirucci: Ti Viddil Plavar Kambeni.]; Linking of Črni Kal with the watery kal appears to be mistaken. Titl, J. 1998. *Geografska Imena v Severozahodni Istri*. p.42. [Koper: Knjižnica Annales.]

19 Information supplied by Andrej Kranjc, e-mail 20 April 2001 and 15 May 2001.

20 *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.181.

21 Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F,. 1973. Slovenska kraška, p.46, 50.

22 Kranjc, A, (ed.) 1997. Kras..., p.51-53.

23 Hacquet, B, 1778-89. *Oryctographia carniolica oder physikalische Eredbeschreibung des Herzoghtums Krain*. Leipzig, p.64-65. Cit. in: Gams, I. (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šuš terš ič, F, 1973. *Slovenska kraš ka terminologija - Slovene Karst terminology*. p. 50. [Ljubljana: Zveza geografskich institucij Jugoslavije.]

24 Kranjc, A, 1998. Kras (the Classical Karst), p.158.

25 Kranjc, A, 1998. Kras (the Classical Karst), p.155.

26 Morlot, A von, 1848. Über die geologischen Verhältnisse von Istrien. Naturw. Abh., H. 2, Wien, p. 308. Cit. in: Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. *Slovenska kraška terminologija - Slovene Karst terminology*. p.51. [*Ljubljana: Zveza geografskich institucij Jugoslavije.*]

27 Schmidl, A, 1858. Wegweiser in die Adelsberger Grotte un die benachbarten Höhlen des Karstes. Wien. Cit. in: Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. *Slovenska kraška terminologija - Slovene Karst terminology*. p.51. [Ljubljana: Zveza geografskich institucij Jugoslavije.]

28 Gams I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. *Slovenska kraška*, p.51.

29 Cvijić, J. 1895. Karst. *Geografska monografija*. Beograd. Cit. in: Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šuš terš ič, F, 1973. *Slovenska kraš ka terminologija - Slovene Karst terminology*. p.52. [Ljubljana: Zveza geografskich institucij Jugoslavije.]

30 Hromník, C A. Personal experience 1950-1968.

31 Kranjc, A, 1999. Mission of J A Nagel to Carniola in 1748. *SlovenskýKras (Acta Carsologica Slovaca)*, 37, p.131-138.

32 Martel 1894. Les AbÔmes, Paris. Cit. in: Kranjc, A, 1997. Karstology and speleology in Slovenia (from the history of Karst and cave science to their perspectives). O krasoslovju in speleologiji v Sloveniji (o zgodovini vede o krasu in jamah ter o njunih perspektivah). *Annales: Anali za istrske in mediteranske študije*, 11, p.95.

33 Kranjc, A, 1997. Karstology and speleology in Slovenia (from the history of Karst and cave science to their perspectives). O krasoslovju in speleologiji v Sloveniji (o zgodovini vede o krasu in jamah ter o njunih perspektivah). *Annales: Anali za istrske in mediteranske študije*, 11, p.95-102.

34 Kranjc 1997. *Karstology*, p.96.

35 Herodotus, BC 430/1972. *The Histories*. Translated by Aubrey de Sélincourt, revised by A R Burn. p.332: bk 4, 183-84. [Harmondsworth: Penguin Books.]

36 Plinius Gaius Secundus (The Elder), 23-79/1945. *Natural History*. Transl. by H. Rackham. v. IV, p.62-65: lib.12.87-88. [London: William Heinemann, Cambridge, Mass.: Harvard University Press.]

37 The *Lifco Tamil-Tamil-English Dictionary*, 1978, p.373, 248, 353.

[38] *Ramayana*. c.850-200 BC/1951/1990. Retold by C Rajagopalachari. p.144. [Bombay: Bharatiya Vidya Bhavan.]

[39] *The American College Dictionary*. 1953. Ed. by Clarence L Barnhart. p.1299. [New York: Random House.]

[40] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.214, 595.

[41] *The Great LIFCO Dictionary [English-English-Tamil]*, 11th ed., 1981. p.1345. [Madras: The Little Flower Co.]

[42] Haupt, C A, Journaal gehouden door den Adsistend Carel Albregt Haupt...1752. In: Godeé Molsbergen, E C, 1922. *Reizen in Zuid-Afrika in de Hollandse Tijd* 'S-Gravenhage: Martinus Nijhoff, v. III, p.288, 292; Hromník, C A, 1999. The Ethnonym Quena: the True Name of the Hottentots. Paper read at the XX Congreso Internacional de Ciencias Onomásticas en Santiago de Compostela (20-25 Sept. 1999).

[43] Strabo, 1919, 1983. *The Geography*, v. II, p.282-285: lib. 4.6.9; v. III, p.256: lib. 7.5.3.

[44] *The Oxford Classical Dictionary*. 2nd ed., 1970. Ed. by N G L Hammond and H H Scullard. [Oxford: Clarendon Press.]

[45] Plinius, 1945. *Natural History*, v. II, p.98-99: bk 3.133.

[46] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.176.

[47] Ripka, I, Buffa, F, Ferenčíková, A and Nižnanský, J (eds), 1994. *Slovník slovensk_ch náreèí* (A-K). v.I, p.750. [Bratislava: Veda, vydavateľstvo Slovenskej akadémie vied.]

[48] Strabo, 1919. *The Geography*, v. II, 1919, p.318-319: lib. 5.1.8.

[49] Kranjc, A, 1998. Kras (the Classical Karst), p.156-158.

[50] Hacquet, B, 1784. *Oryctographia carniolica oder physikalische Eredbeschreibung des Herzoghtums Krain, Istrien, un zum Theil derbenacht - barten Länder*. - I. Th., I-XVI, p.162. Leipzig. Cit. in: Kranjc, A, 1998. Kras (the Classical Karst) and the development of Karst science. Kras (klasièni Kras) in razvoj znanosti o Krasu. *Acta Carsologica* - Krasoslovni zbornik, Vol.27(1,9), p.157-158.

[51] Map: Münster, S, 1550. [Karnia, Kars, Histria]. In: *Cosmiographiae universalis*... Basel, p.693. Reprod. in: Shaw, T R and MacQueen, J G, 1998. Did the Argonauts of Greek myth go underground in the Slovene Karst? Ali sa Argonavti iz grškega mita prečkali Slovenski Kras pod zemljo? *Acta Carsologica*, Vol.27(1), p.383.

[52] Kos 1915. *Gradivo za zgodovino*, 4. Cit. in: Kranjc 1994, About the name, p.83.

[53] Kranjc, A (ed.), 1997. *Kras*, p.145.

[54] Kranjc, A 1997. Brief account of the development of speleology in Slovenia (to 1914). Kratek pregled razvoja speleologije na Slovenskem (do 1914). *Acta Carsologica*, Vol.24(2.11), p.100-104.

[55] Map: Lazius, Wolfgang. [1573] *Goritiae, Karstii, Chaczeolae, Carniolae, Histriae, et Windorum Marchae Descrip*. Engraved map, reprod. in: Shaw, T R and MacQueen, J G, 1998. Did the Argonauts of Greek myth go underground in the Slovene Karst? Ali sa Argonavti iz grškega mita prečkali Slovenski Kras pod zemljo? *Acta Carsologica*, Vol.27(1), p.376.

[56] Stealthy in Polish is 'tajemny, skryty' which means 'mysterious, hidden'. Grzebieniowski, T, *Langenscheidt's Pocket English Dictionary: English-Polish, Polish-English*. p.352. [Warsaw: Langenscheidt.]

[57] Kranjc, A, 1994. About the name, p.83.

[58] Kranjc, A, 1997. Brief account..., p.100.

[59] Kranjc, A, 1997. Karstology, p.96.

[60] Kranjc, A, 1999. Mission of J A Nagel, p.132.

[61] Nagel, J A, 1748. *Beschreibung deren auf allerhochsten Befehl Ihro Rom. Kaiserlich k'niglichen Maytt. Francisci I. untersuchten, in dem Herzogthume Crain befindlichen Seltenheiten der Natur. National -bibliothek, Handschrift* Nr. 7854, Wien. Cit. in: Kranjc, A, 1999. Mission of J A Nagel to Carniola in 1748. *Slovensk_ Kras* (*Acta Carsologica Slovaca*), Vol.37, p.131, 136.

[62] Kranjc, A, 1999. Mission of J A Nagel..., p.131.

[63] Kranjc, A, 1999. Mission of J A Nagel..., p.132.

[64] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.657.

[65] Anelli, F. 1941-1944. Osservazioni di meteorologia ipogea nelle Grotte di Castel Lueghi presso Postumia (N.17 V.G.). - Le Grotte d'Italia, ser. 2a, vol. 5, p.5-34, Postumia. Cit. in: Kranjc, A, 1999. Mission of J A Nagel to Carniola in 1748. *Slovenský Kras (Acta Carsologica Slovaca)*, Vol.37, p.132.

[66] Kranjc, A, 1999. Mission of J A Nagel..., p.132.

[67] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.615.

[68] Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. Slovenska kraš ka, p.51. The form polje may have developed under the influence of the pan-Sloven pole for 'field', which derives from the Tamil *pulam* for 'field'. *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.490.

[69] Kranjc, A, 1999. Mission of J A Nagel..., p.131.

[70] Mlinar, C, 1990. *Savici pod kožo*. *Proteus* 57, p.1, 13-18. Cit. in: Kranjc, A. 1999. Mission of J.A. Nagel to Carniola in 1748. Slovenský Kras (*Acta Carsologica Slovaca*), Vol.37, p.134.

[71] Kranjc, A, 1997. Brief account..., p.100.

[72] Kranjc, A (ed.), 1997. *Kras*, p.137-139, 141.

[73] Kranjc, A, 1994. O imenu in zgodovini pokrajine Kras. *Annales. Anali Koprskega primorja in bližnjih pokrajin*, v.4, p.131.

[74] Martel, E A, 1894. *Les Abîmes*, cit. in: Kranjc, A, 1997. *Karstology*, p.95.

[75] Hancock, G and Faiia, S 1998. *Heaven's Mirror: Quest for the Lost Civilization*. [London: Michael Joseph.] passim.

[76] Kranjc, A, 1999. Mission of J A Nagel..., p.137.

[77] Sitchin, Z, 1976/1977. *The 12th Planet*. p.32-33 [New York: Avon Books.] Woolley, L, 1936. *Abraham: Recent discoveries and Hebrew Origins*. p.61. [London: Faber and Faber.]

[78] Chaturvedi, M and Tiwari, B N (eds), 1970. A Practical Hindi-English Dictionary. p.674 [Delhi: National Publishing House.]; *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.257, 570.

[79] Kranjc, A (ed.), 1997. Kras, p.175-176; *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.213, 240. The initial *k-* in Tamil is very often pronounced as h.

[80] Choppy, J, 1997. Les deux faces de la pensée de E A Martel. *International Journal of Speleology. Physical Speleology*, Vol.26(3-4), p.10.

[81] Sieveking, A and Sieveking, G, 1962. *The Caves of France and Northern Spain: a guide*. p.158-159. [London: Vista Books.]

[82] *The Linga-Purána*. 5th ?C. AD/1973. Translated by a Board of Scholars. Part I, ch.65, p.269. [Delhi: Motilal Banarsidas.]

[83] Hromník, CA, 2000. Geelbek – research notes and slides.

[84] Hromník, CA, 2000. The Karoo of the Quena. *The Graaff Reinet Advertiser*, 25 August 2000, p.11; Hromník, C.A. The art of design in the ancient South African litaku (ruins). In: *Making Art – Making Meaning. Proceedings of the 13th Annual Conference of the Association of Art Historians in Stellenbosch*, 12th Sept. 1997. pp.52-56. [Johannesburg: University of the Witwatersrand.]

[85] Baring-Gould, S, 1911. *Cliff Castles and Cave Dwellings of Europe*. p.77,

113-114, 279. [London: Seeley.]

[86] Ptolemaeus 150/1966. *Geographia.* Strassburg 1513, p.17.2.

[87] Kempe, D 1988. *Living Underground: A History of Cave and Cliff Dwelling.* p.52. [London: The Herbert Press.]

[88] Kranjc, A (ed.), 1997. Kras, p.154; Ptolemaeus, C. 150. *Geographia,* II 14,1, cit. in: Bezlaj, F 1982. *Etimološki Slovar Slovenskega Jezika. Etymological Vocabulary of Slovene Language,* K-0. [Ljubljana: Slovenska Akademija Znanosti in Umetnosti. Inštitut za Slovenski Jezik.] Brought to my attention by A Kranjc.in an e-mail to C A Hromník, 25 December 2000.

[89] Ptolemaeus, C. 150/1478. *Cosmografia.* Quinta Europe Tabula. Roma: 1478. Facs. Reprint, introduced by R A Skelton. [Amsterdam: Teatrum Orbis Terrarum.], 1966.

[90] Rostaing, C, 1974. *Les noms de lieux.* Paris. Cit. in: Kranjc, A 1994. About the name and the history of the region Kras. O imenu in zgodovini pokrajine Kras. *Acta Carsologica,* Vol.23(6), p.83.

[91] *The Lifco Tamil-Tamil-English Dictionary,* 1978, p.176, 596.

[92] Ptolemaeus 150/1966. *Geographia. Qvinta Evropae Tabvla.* Strassburg 1513, p.18v.

[93] Information supplied by Dr. Andrej Kranjc, e-mail 15 May 2001.

[94] Middleton, J and Waltham, T, 1986. *The Underground Atlas: A gazetteer of the world's cave regions.* p.224. [London: Robert Hale.]

[95] Valvasor, J W, 1689. *Die Ehre des Hertzgothums Crain.* Laybach. Cit. in: Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Šušteršič, F, 1973. *Slovenska kraš ka terminologija - Slovene Karst terminology.* p.46, 48. [Ljubljana: Zveza geografskich institucij Jugoslavije.]

[96] Kranjc 1994. O imenu in zgodovini, p.131.

[97] Map: Lazius [1573] *Goritiae, Karstii,...* In: Shaw T R and MacQueen, J G, 1998. Did the Argonauts..., p.376-377.

[98] Map: Lazius [1573] *Goritiae, Karstii,...* In: Shaw, T R and MacQueen, J G, 1998. Did the Argonauts..., p.376-377.

[99] Kranjc, A, 1994. Prispevek k imenoslovju Škocjanskih jam. *Annales. Anali Koprskega primorja in bližnjih pokrajin,* v.4, p.188.

[100] Shaw, T R and MacQueen, J G, 1998. Did the Argonauts of Greek myth go underground in the Slovene Karst? Ali sa Argonavti iz grškega mita preèkali Slovenski Kras pod zemljo? *Acta Carsologica,* Vol.27(1), p.376.

[101] Habe, F, 1988. *Jame Grotte Š kocian.* [Sež ana: TOP Portorož TOZD Gostinstvo Sežana.]

[102] Map: Mercator. 1642. [Includes "Karst"]. Amsterdam, (Karst Research Institute Collection). In: Kranjc, A 1998. Kras (the Classical Karst) and the development of Karst science. Kras (klasič ni Kras) in razvoj znanosti o Krasu. *Acta Carsologica - Krasoslovni zbornik,* Vol.27(1,9), p.163.

[103] Shaw T R and MacQueen, J G, 1998. Did the Argonauts..., p.379.

[104] Kranjc, A (ed.), 1997. *Kras,* p.83.

[105] Baring-Gould, S 1872-1877. *The Lives of the Saints.* [London: Hodges.] 12 vols.

[106] Bezlaj, F 1961. *Slovenska vodna imena.* II. Del (M-Ž). p.260. [Ljubljana Slovenska Akademija Znanosti in Umetnosti. Inštitut za Slovenski Jezik.]

[107] Shaw, T R, 1992. *History of Cave Science: The exploration and study of limestone caves, to 1900.* 2nd ed. p.264. [Sydney: Sydney Speleological Society.]

[108] Novak, D. 1981/82. Škocjan in Slovenia. *Naše jame (Ljubljana),* 23-24, p.49-53.

[109] Življenjepisi svetnikov. Cit. in: Novak, D. 1981/82. Škocjan in Slovenia. Naše jame (Ljubljana), 23-24, p.49.

[110] *The Lifco Tamil-Tamil-English Dictionary,* 1978, p.158, 90.

[111] *The Lifco Tamil-Tamil-English Dictionary,* 1978, p.80, 276.

[112] Kranjc, A (ed.), 1997. *Kras,* p.82-83.

[113] Poseidonius of Apameia, c.135 to c.51-50 BC. Cit. in: Strabo. c.63BC-AD21/1919. *The Geography of Strabo.* v.II, p.318-319: lib. 5.1.8. [London: William Heinemann.]. Also cit. in: Kranjc, A (ed.) 1997. *Kras: Slovene Classical Karst.* p.56. [Ljubljana: ZRC SAZU.]. His translated text reads: "...a river, the Timavus, runs out of the mountains, falls down into a chasm, and then, after running underground about a hundred and thirty stadia, makes its exit near the sea". This version needs to be reconciled with other translations, where the short river Timava "...comes out of a mountain...", as rendered in: Czörnig, K, 1891. *Die gefürstete Grafschaft Görz und Gradisca.* Gorica. Cit. in: Gams, I (ed.), Habe, F, Leben, A, Novak, D, Osole, F and Š uš terš ič , F, 1973. *Slovenska kraš ka terminologija - Slovene Karst terminology.* [Ljubljana: Zveza geografskich institucij Jugoslavije.] p.47.

[114] Kranjc, A (ed.), 1997. *Kras,* p.54, 71, 74-75.

[115] Kircher, A, 1678. *Mundus subterraneus, in XII libros digestus,* 2nd ed. [Amstelodami: Jo. Janssonium.] Liber V. Miracula aquarum, p.507. Quot. in: Kranjc, A (ed.), 1997. *Kras: Slovene Classical Karst.* p.15. [Ljubljana: ZRC SAZU.]

[116] Map: Lazius, Wolfgang. [1573] *Goritiae, Karstii, Chaczeolae, Carniolae, Histriae, et Windorum Marchae Descrip.* Engraved map, reprod. in: Kranjc, A. 1994. About the name and the history of the region Kras. O imenu in zgodovini pokrajine Kras. *Acta Carsologica,* Vol.23(6), p.85.

[117] Kranjc, A (ed.), 1997. *Kras,* p.237.

[118] Bezlaj, F, 1961. *Slovenska vodna imena.* II, p.260.

[119] Ampelius, L.2nd or 3rd century AD. *Ampelii liber memorialis,* VI 10, cit. in: Bezlaj, F, 1961. *Slovenska vodna imena.* II, p.259-260.

[120] Polybius. c.205 - c.123BC. Cit. in: Strabo. c.63BC-AD21/1919. *The Geography of Strabo.* v.II, p.318-319: bk.5.1.8. [London: William Heinemann.]

[121] *Burrow and Emeneau, A Dravidian Etymological Dictionary,* s.115; Zimmer, HR, 1946. *Myths and symbols in Indian art and civilization.* Bollingen Series VI, 1974). p.203. [Princeton, N.J.: Princeton University Press.]; *The Lifco Tamil-Tamil-English Dictionary,* 1978, s.548, 340, 382.

[122] Strabo, 1983. *The Geography...,* v.III, p.130-131: lib.6.3.9.

[123] *The Lifco Tamil-Tamil-English Dictionary,* 1978, s.21.

[124] Strabo, 1919. *The Geography...,* v.II, p.316-317: lib.5.1.8.

[125] Hromnik, C A, 1998. *Sloveni a Slovensko: Velebníci VlasatÈho Boha na Horizonte Histórie* (ca. 3200 pr. Kr. – 907 po Kr.). MS 2000, presently considered for publication by: Matica slovenská, Martin.

[126] *The Lifco Tamil-Tamil-English Dictionary,* 1978, s.348-349.

[127] Strabo, 1983. *The Geography...,* v.III, p.126-127: lib.6.3.8.

[128] Strabo 1919. *The Geography...,* v.II, p.318-319: lib.5.1.8.

[129] *The Oxford Classical Dictionary,* 2nd ed., 1970, s.105.

[130] Walker, B, 1968. *Hindu World.* [London: George Allen and Unwin.], Vol.2, p.404, 406.

[131] Graves, R, 1955. *The Greek Myths.* [Harmondsworth: Penguin Books.], Vol.II, p.253.

[132] Strabo, 1983. *The Geography...,* v.III, p.130-131: lib.6.3.9.

[133] Strabo 1919. *The Geography*..., v.II, p.318-319: lib.5.1.8.

[134] Subrahmanian, N, 1980. *San?gam Polity: The Administration and Social Life of the Sangam Tamils.* p.366. [Madurai: Ennes Publications.]

[135] Strabo, 1983. *The Geography*..., v.III, p.130-131: lib.6.3.9.

[136] Kittel, F, 1894/1982. *A Kannada-English Dictionary.* p.1296 [Mangalore: Basel Mission Book and Tract Depository.]; *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.581.

[137] Strabo, 1983. *The Geography*..., v.III, p.130-131: lib.6.3.9.

[138] Strabo 1919. *The Geography*..., v.II, p.320-321: lib.5.1.9.

[139] Stutley, M and Stutley, J, 1977. *A Dictionary of Hinduism: Its Mythology, Folklore and Development* 1500 B.C.-A.D. 1500. p.23. [London: Routledge and Kegan Paul.]

[140] Varma, R and Varma, S, 1985. *Ascent to the Divine: The Himalaya, Kailasa-Manasarovar: In Scripture, Art and Thought.* p.110 and picture 67. [Neuchâtel: Lotus Books.]

[141] Knappert, J1991. *Indian Mythology: An Encyclopedia of Myth and Legend.* p.135. [London: The Aquarian Press.]

[142] KrižŽko, P, 1868. Starobylé nápisy na kremnickom pohorí. *Letopisy Matice slovenskej* 5(2), s.92.

[143] Kranjc, A (ed.)) 1997. *Kras*, p.55.

[144] Kranjc, A, 1994. About the name..., 23(6), p.87.

[145] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.41, 173.

[146] Map: *Indian subcontinent: India, Pakistan, Bangladesh, Sri Lanka. Scale 1:4 000 000.* [Edinburgh: John Bartholomew] 1977; Spelt "Suvarnariksha" in: Cunningham, A, 1871/1990. *The Ancient Geography of India.* I. The Buddhist Period, including the campaigns of Alexander, and the travels of Hwen-Thsang. p.431. [Delhi: Low Price Publications.]; "Subarnarekha" in: Map: Bartholomew, J, 1936. *The Oxford Advanced Atlas*, 5th ed. p.61. [London: Oxford University Press.]

[147] Andrej Kranjc e-mail to Cyril Hromník, 28 December 2000.

[148] Kranjc, A, 1994. Prispevek k imenoslovju Škocjanskih jam, p.191.

[149] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.95.

[150] Chaturvedi and Tiwari (eds), 1970. *A Practical Hindi-English Dictionary*, p.552.

[151] Holub and Lyer, 1967. *Struèný etymologický slovník jazyka èeského*, p.428.

[152] Slawski, F et al., 1976. *Slownik praslowiański. tom* II (C-D), p.31. [Wroccaw, Warszawa, etc.: Wydawnictwo Polskiej Akademii Nauk.]

[153] Von Hohenwart, F G, 1830. *Wegweiser für die Wanderer in der Berühmten Adelsberger und Kronprinz Ferdinands-Grotte bey Adelsberg in Krain.* [Laibach: Ignaz Aloys Edlen.]. Cit. in: Kranjc, A (ed), 1997. Kras: Slovene Classical Karst. p.16. [Ljubljana: ZRC SAZU.]

[154] Kranjc, A, 1998. *Kras* (the Classical Karst), p.155.

[155] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.384.

[156] Kranjc, (ed.), 1997. *Kras,* p.105, 155.

[157] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.141, 150, 310.

[158] The Slavic etymology of the suffix -ica is inadequate. See: Slawski *et al.*, 1976. *Slownik praslowianski,* tom I, p.98.

[159] *The Lifco Tamil-Tamil-English Dictionary*, 1978, p.335

[160] Kranjc, A (ed.), 1997. *Kras*, p.105-106.

[161] Kranjc, A (ed.), 1997. *Kras*, p.189.

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Alona quadrangularis (O F Muller) (Chydoridae: Cladocera): first record from a Derbyshire (UK) cave.

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Abstract: The first record of Cladocera (*Alona quadrangularis*: Chydoridae) for Derbyshire caves is reported. *Alona quadrangularis* was common in a number of benthic samples from Speedwell Cavern. Some possible reasons for the under recording of this and other meiofauna in subterranean environments are examined.

(Received 17 October 2001; accepted 31 October 2001)

Historically, ecological research on subterranean ecosystems has concentrated on relatively large 'macro' organisms (>1mm). This has meant that those organisms that can easily be observed with the naked eye, and usually those that occupy positions at the top of food-chains in cave ecosystems, have been studied (Sket, 1997). However, recent research on riverine gravels, alluvial aquifers (Ward *et al.*, 2000) and cave ecosystems (Hobbs, 2000) has indicated that meiofauna (organisms <1mm but retained on a 63mm mesh) are significantly more abundant than was originally assumed, and are commonly the dominant faunal groups in subterranean aquatic environments. The term '*meiofauna*' includes a large variety of faunal groups (Crustacea, water mites, rotifers and worms), some of which spend their entire life history as part of this microscopic world, whereas others may only be temporarily considered part of it (e.g. insect larvae) (Roberston *et al.*, 2000).

During the processing of an invertebrate sample collected from Speedwell Cavern (15/8/00), using a $0.05m^2$ cylinder sampler with a 90mm mesh net, fine organic debris was observed floating on the surface of the sorting tray. Preliminary inspection of this material without the aid of a microscope suggested that it was composed primarily of small plant seeds. However, detailed examination under a compound microscope indicated that the majority of the material was in fact a cladoceran, *Alona quadrangularis* (Chydoridae) (Figure 1).

Cladocera are small (typically <1mm in size) Crustacea that inhabit most freshwater ecosystems and some saline habitats. Cladocera commonly form an important part of the meiofauna community. The majority of taxa are usually found in stagnant / still water bodies (ponds and ditches) although substantial numbers have been recorded in flowing water. They are widely used in ecotoxicological research, since they are relatively easy to culture in the laboratory (Knops *et al.*, 2001). Around 450 species are known globally, of which 94 species and sub-species have been recorded from subterranean waters, although only 12 are considered to be troglobites / stygobites (Dumont and Negrea, 1996).

Alona quadrangularis is relatively widely distributed in the Holartic, Afrotropical, Oriental and Neotropical biogeographical regions. It is found extensively in still waters and slow flowing streams with a silt or sand substratum, and sometimes in areas of rich vegetation (Dumont and Negrea, 1996). It is a benthic organism that crawls on the surface of the substratum (bedrock, gravel, sand, silt) (Fryer, 1993) and vegetation (Dumont and Negrea, 1996). In the UK, it is widely distributed, with records from the English Lake District (Scourfield and Harding, 1966) and throughout Yorkshire (Fryer, 1993), and from a wide range of habitats. There is a single record of Cladocera from Welsh caves – *Daphnia obtusa* (Jefferson, 1989) – and one from Irish caves – *Alona*

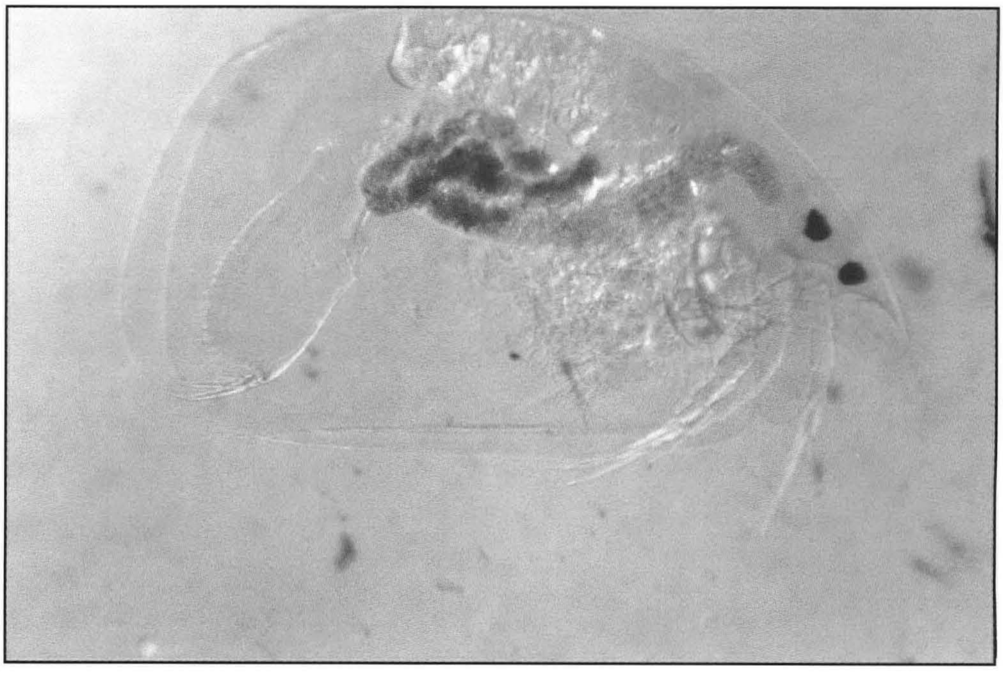

Figure 1. Alona quadrangularis (O F Muller) (Chydoridae: Cladocera) – size (length) is approximately 0.6mm.

the genus *Alona* (Dumont and Negrea, 1996). The population recorded in Speedwell Cavern is almost certainly derived from an epigean population carried into subterranean passages by sinking streams. The abundance of individuals was in excess of 1000 per m^2 in some samples collected from sandy, slow flowing sections of the main streamway and backwater areas. Given the wide distribution in both epigean and hypogean waters, the population from Speedwell Cavern is probably troglophilic in nature.

It is possible that Cladocera, and in this instance *Alona quadrangularis*, have been under recorded in historical samples for several reasons. First, their relatively small size (<0.5-0.7mm) means that they are not retained on the sieves typically used for processing macro-invertebrate samples. Second, the carapace, the outer protective 'shell' that covers the softer body of the organism, may be covered with silt particles making detection difficult. Third, air bubbles may become trapped in the carapace so that the organism floats on the surface film of the water in a sorting tray. As a result Cladocera may be overlooked or misidentified in samples from subterranean habitats.

The study of meiofauna in cave environments has largely been ignored in Britain, as was the case for many hypogean habitats until the last decade. Further biological research in caves will undoubtedly increase the known biodiversity of individual caves, and the abundance of meiofauna (>50 from a $0.05m^2$ sample) is such that potentially large numbers of individuals can be retrieved with relatively little impact on cave environments. However, the taxonomy of meiofaunal groups is particularly demanding and requires many hours of detailed study with a microscope. In addition, the unnecessary disturbance and removal of organisms from caves should be avoided where possible. Even so, further research regarding meiofauna, to provide a greater understanding of subterranean foodwebs, is clearly required and justified.

ACKNOWLEDGEMENTS

We thank Geoffrey Fryer for confirming the identification of *Alona quadrangularis* and for his advice regarding the work. PJW gratefully acknowledges the support of a NERC Small Research Grant for New Investigators (NER/M/S/1999/00152) to undertake the project. Thanks to Graham Proudlove and Lee Knight for their help in tracking down the records of Cladocera recorded from hypogean environments, Professor John Gunn for help in planning and undertaking the work, and to John Harrison for providing access to the sites.

REFERENCES

Dumont, H J and Negrea, S, 1996. A conspectus of the Cladocera of the subterranean waters of the world. *Hydrobiologia*, Vol.325, 1-30.

Fryer, G, 1993. *The Freshwater Crustacea of Yorkshire: A faunistic and ecological survey*. 312pp. [Yorkshire Naturalists' Union.]

Gunn, J, Hardwick, P and Wood, P J, 2000. The invertebrate community of the Peak-Speedwell cave system, Derbyshire, England – pressures and considerations for conservation management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, Vol.10, 353-369.

Hazelton, M, 1963. *Biological Records Cave Research Group of Great Britain Part VIII*. 41pp. [The Cave Research Group of Great Britain.]

Hazelton, M, 1974. Irish vice county records of fauna collected from the hypogean and related zone. *Transactions of the Cave Research Group of Great Britain*, Vol.15, 203-215.

Hazelton, M, 1977. Life underground – biospleology. 231-261 in Ford, T D (Ed.) *Limestones and Caves of the Peak District*. [Norwich: Geo Books.]

Hobbs III, H H, Crustacea. 95-107 in Wilkens, H, Culver, D C and Humphreys, W F (Eds) *Ecosystems of the World 30: Subterranean Ecosystems*. [Amsterdam: Elsevier.]

Jefferson, G T, 1989. Cave biology in South Wales. 56-69 in: Ford, T D (Ed.) *Limestones and Caves of Wales*. [Cambridge: Cambridge University Press.]

Knops, M, Altenburger, R and Segner, H, 2001. Alteration of physiological, growth and reproduction of Daphnia magna under toxicant stress. *Aquatic Toxicology*, Vol.53, 79-90.

Robertson, A L, Rundle, S D and Schmid-Araya, J M, 2000. An introduction to a special issue on lotic meiofauna. *Freshwater Biology*, Vol.44, 1-3.

Scourfield, D J and Harding, J P, 1966. *A Key to the British Species of Freshwater Cladocera*. Scientific Publication No. 5, 55pp. [Ambleside, Cumbria: Freshwater Biological Association.]

Sket, B, 1997. Distribution of Proteus (Amphibia: Urodela: Proteidae) and its possible explanation. *Journal of Biogeography*, Vol.24, 263-280.

Ward, J V, Malard, F, Stanford, J A and Gonser, T, 2000. Interstitial aquatic fauna of shallow unconsolidated sediments, particularly hyporheic biotopes. 41-58 in Wilkens, H, Culver, D C and Humphreys, W F, (Eds.) *Ecosystems of the World 30: Subterranean Ecosystems*. [Amsterdam: Elsevier.]

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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.

SCIENTIFIC NOTE

SYN-GLACIATION HYDROLOGY RECORDED IN RE-USED, PRE-EXISTING CAVE SYSTEMS.

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Whereas the potential for subglacial karstification is limited, due to the depleted aggressiveness of glacial melt water (Smart, 1984), the use of pre-existing cave systems by subglacial waters has been recorded from a number of areas (Lauritzen, 1983, 1984; Smart, 1983; Murphy, Smallshire and Midgley, 2001). The use of pre-existing cave systems by subglacial meltwaters is consistent with both theory and observation, suggesting that temperate alpine glacier plumbing is commonly karstic in form (Shreve, 1972).

Two fundamental types of subglacial channel are recognised. N-channels (or Nye channels) are cut down into the glacier bed, and R-channels (or Rothlisberger channels) are incised upwards into the ice (Fig.1). The presence of N-channels implies that water flow is focussed consistently on the same route and these are areas of erosion rather than deposition. After deglaciation they are preserved as incised river channels. R-channels, however, are much more variable spatially, and after deglaciation they are preserved as steep-crested sinuous ridges of sediment, called eskers. An understanding of whether cave conduits utilised by subglacial meltwaters acted as N-channels or R-channels is of considerable value when carrying out sediment studies in such cave systems.

Lauritzen (1983, 1984) recognised a period of reversed phreatic flow in the history of Storbekkgrotta and Kalkrastgrotta in central Glomdal, Norway. The reversed phreatic flow episode resulted in the development of paragenetic half tubes and rock pendants. As the paragenetic features are superimposed upon vadose features the reversed flow must have occurred after base-level lowering. This reversed phreatic flow is explained as a result of subglacial water flow, when a temperate soled ice field over-rode the local topography and provided an uphill directed englacial hydraulic gradient (Fig.2).

Lauritzen interpreted the pre-existing karst conduits as having been extremely stable N- (or Nye) channels (Nye, 1973) in a glacio-hydrological context. No sediments deposited by the subglacial waters are described by Lauritzen, the sediments in the cave systems being a product of an earlier phase in the caves' development, and this is consistent with the N-channel interpretation.

The Dale Barn Cave system in North Yorkshire is a remarkable linear system, orientated approximately southeast–northwest beneath Scales Moor, through the southwesterly nose of Whernside, from Chapel-le-Dale to Kingsdale (Fig.3). Today the active cave passages carry streamways from both the Chapel-le-Dale and Kingsdale ends of the cave to a confluence almost directly beneath the topographic divide, before draining to the Dry Gill resurgence in Chapel-le-Dale. A series of abandoned passages lies above the active levels. As in the central Glomdal caves described by Lauritzen, the presence of phreatic scallops (in this case indicating a northwesterly palaeo-flow direction) superimposed on large speleothem deposits in the relict passages indicates that a second phreatic episode occurred in the system's history. The sediments in the relict conduits beneath the eastern flank of Kingsdale originated in Chapel-le-Dale, as indicated by the orientation of sedimentary structures and the occurrence of a small (<10%) component of fine-grained chloritized metasediment clasts within the passage fill. This rock type only crops out up-valley of the Dale Barn Cave system in Chapel-le-Dale.

The sediments in Dale Barn Cave's Vandals Passage consist of diamicton alternating with sand and gravel. The unit boundaries are very sharp and locally undulose, with sporadic units of pale grey clays, which are less extensive laterally than the other units. The Vandals Passage sedimentary succession is very similar to that described from the eskers of the Laurentide ice sheet in Canada (Brennand, 1994, 2000), which are inferred to be casts of R-type subglacial channels (Rothlisberger, 1972). Considering the similarity of the Vandals Passage sediment fill to that of the Laurentide eskers described by Brennand (2000), the role of the pre-existing karst conduit being utilised by subglacial meltwaters in the case of Dale Barn Cave is more like that of an R-channel than an N-channel.

The sedimentary record provided by esker deposits on the land surface is biased towards the retreat stage of subglacial hydrology, as

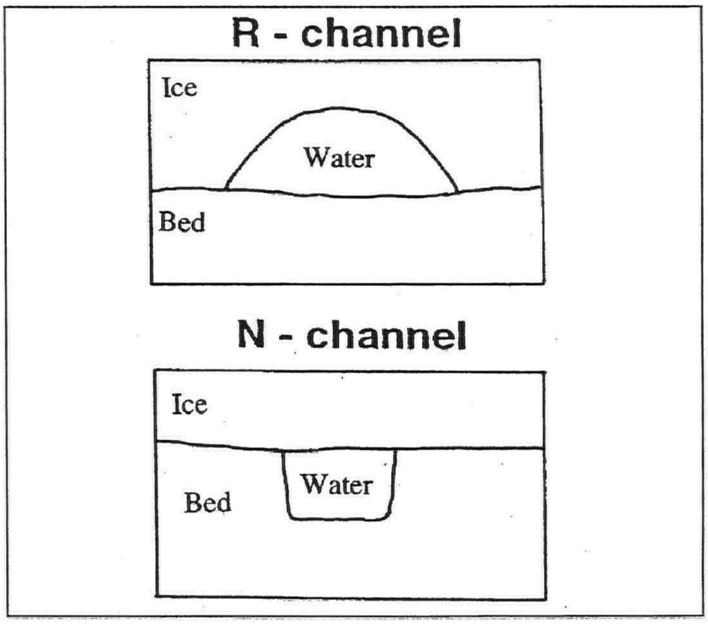

Figure 1. Subglacial meltwater channels types. Reproduced from Brennand (2000).

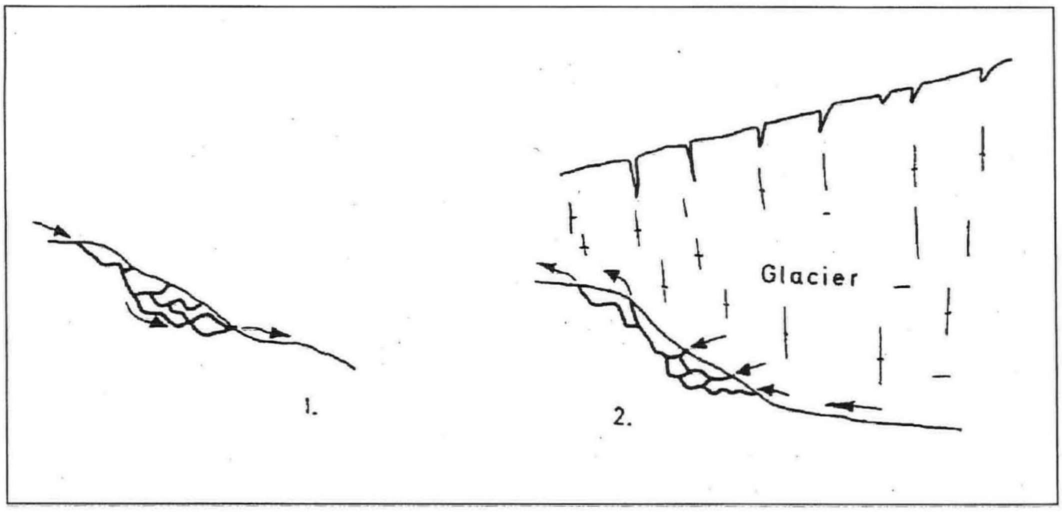

Figure 2. Subglacial reversal of karst drainage as illustrated in Storbekkgrotta and Kalkrastgrotta, Norway.
1. *'Normal' downhill drainage; interglacial situation.*
2. *Reversal flow beneath a glacier sloping in opposite direction of the landscape.*

Reproduce from Lauritzen (1984) with permission.

earlier deposits are unlikely to be preserved. Esker systems therefore represent a 'deglacial snapshot' of ice sheet hydrology (Brennand, 2000). Due to the spatial and temporal variability of glacier plumbing, any connection with a pre-existing karst conduit at the sole of the glacier is likely to be short lived. Perhaps, therefore, cave fill deposits such as those from Vandals Passage in Dale Barn Cave will provide a record of the subglacial drainage system from other stages of the glacial cycle.

REFERENCES

Brennand,T A, 1994. Macroforms, large bed forms and rhythmic sedimentary sequences in subglacial eskers, south-central Ontario: implications for esker genesis and meltwater regime. *Sedimentary Geology*, Vol.91, 9-55.

Brennand, T A, 2000. Deglacial meltwater drainage and glaciodynamics: inferences from Laurentide eskers, Canada. *Geomorphology*, Vol.32, 263-293.

Lauritzen, S-E, 1984. Evidence of subglacial karstification in Glomdal, Svartisen. Norsk *Geografisk Tidsskrift*, Vol.38, 169-170.

Lauritzen, S-E, 1983. *Arctic and Alpine Karst Symposium. Program and Field Guide.*
University of Oslo.

Murphy, P J, Smallshire, R and Midgley, C, 2001. The sediments of Illusion Pot, Kingsdale, UK: Evidence for sub-glacial utilisation of a karst conduit in the Yorkshire Dales? *Cave and Karst Science*, Vol.28, No.1, 29-34.

Nye, J F, 1973. Water at the bed of a glacier. Symposium on the hydrology of glaciers, *International Association for Scientific Hydrology publication*, Cambridge, 95, 189-194.

Rothlisberger, H, 1972. Water pressure in intra- and subglacial channels. *Journal of Glaciology*, Vol.11, 177-203

Shreve, R L, 1972. Movement of water in glaciers. *Journal of Glaciology*, Vol.11, 205-214.

Smart, C, 1984. Glacier hydrology and the potential for subglacial karstification. *Norsk Geografisk Tidsskrift*, Vol. 38, 169-170.

Waltham, A C, Simms, M J, Farrant, A R, and Goldie, H S, 1997. Karst and Caves of Great Britain. *Geological Conservation Review series No.12.* [London: Chapman and Hall.]

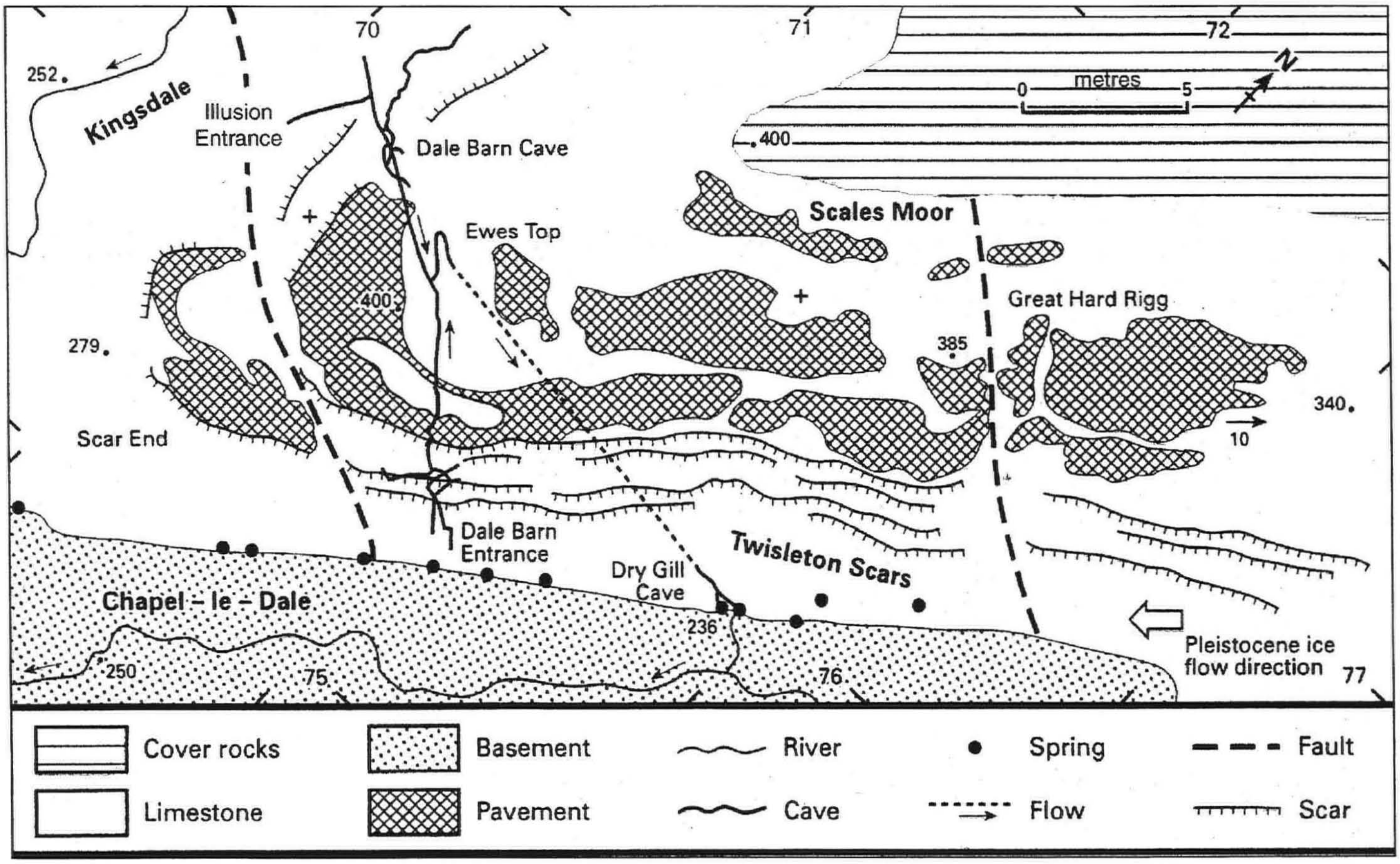

Figure 3. Geological map of Scales Moor. Reproduced from Waltham et al. with permission

BOOK REVIEW

Mike Simms, 2001. Exploring the Limestone Landscapes of the Burren and the Gort Lowlands.
Burrenkarst.com, Eden House, Belfast BT8 8JY.
ISBN 0-9540892-0-0.
Price £5.99, copies available from Landscapes@burrenKarst.com.

This 64 page booklet has much in common with the *"Caves and Karst of..."* booklets in the BCRA Cave Studies Series, including Number 7, on the Brecon Beacons National Park, which was also written by Mike Simms. However, it is aimed at 'the ordinary visitor' and is a guide for walkers, cyclists and motorists rather than being specifically for cavers. The structure comprises a 16-page introduction to the geology and geomorphology of the area under the headings: *"The rocks and their story"*; *"The Surface landscape"*; and *"Beneath the surface"*, followed by details of seven *"Excursions"*. The scientific section is well written, with excellent photographs and clear diagrams, and the level of explanation is appropriate for a general readership. Technical terms are highlighted in colour with an explanation in the text where they first occur, and there is a brief *"Index of Technical terms"* at the back of the booklet. This is particularly useful, as it can be used to cross-reference back to the first use of a term.

The routes of the excursions are shown on four sketch maps, and the author recommends that the booklet be used in conjunction with the Ordnance Survey Discovery Series 1:50,000 sheets 51 and 52. I feel that this is a much more sensible approach than trying to reproduce small sections of the published maps within the text. Six of the seven excursions relate to the Burren and the seventh to the Gort Lowlands. All have been thought out carefully, and the stops are annotated with an appropriate level of scientific information, together with detail on parking and safety. I especially like the warning that: *"Only experienced cavers or climbers should attempt to descend into Hell"* (for the context buy the booklet and see page 35). The notes are also linked back to examples discussed in the first part of the book. As someone who knows the Burren moderately well, I could not think of any site that I would have expected to be included but which isn't. However, there are certainly some sites that I was not aware of, and which I intend to visit next time I am in the area. This is particularly the case with the Gort Lowlands Excursion, where there is clearly much more to see than I had realised.

At £5.99 the booklet is excellent value, not least because of the high standard of production and the large number of colour photographs and diagrams. However, I wish Mike had had the courage to stop the absurd trend of pricing almost everything one penny less than a whole number of pounds! Putting that aside, overall I am very impressed with this booklet, and would advise any reader who intends to visit the Burren to purchase a copy. For those whose purpose is primarily caving, it will provide the context for exploration and point to sites that are well worth a visit en-route to the cave or on the 'day off'. If the group includes non-cavers, then the booklet provides a perfect answer to the question: *"... what am I/we supposed to do while you are underground?"* I would also strongly recommend the booklet to anyone intending to lead a field trip to the Burren, as there is information of relevence to groups at all levels, from GCSE to undergraduate.

Reviewed by John Gunn, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK.

BOOK REVIEW

Bogdan P Onac, 2000, Geologia regiunilor carstice [Geology of karst terrains]. 400pp. Bucuresti, Editura Didactica si Pedagogica,

This book is a welcome addition to the literature on caves and karst. Although it is written primarily in Romanian, extensive English summaries at the end of each chapter have gained it a wider readership than the classic Romanian work in karst, Marcian Bleahu's Relieful carstic. Onac's English summaries account for about 25% of the book length, and an even greater percentage of the text length, since the figures are contained within the Romanian sections and have bilingual captions. The English sections are very clear and idiomatic, thanks to the author's fluency in that language and to polishing by an American reviewer. The bilingual approach is not as cumbersome as it might seem, and it combines the virtues of making the book accessible both to the author's university students and to the international karst community.

This book gives an up-to-date view of the subject that integrates many recent advances in the field. It is accurate as well as clear enough to be accessible to readers with little scientific background. In contrast with the several other books available in the field, this one focuses mainly on the ways in which cave studies can help to reveal past climatic and hydrological conditions. Early chapters provide a concise discussion of karst geology, chemistry, hydrology, geomorphology, and speleogenesis. The last half of the book contains extensive coverage of cave sediments and minerals and the various methods for analyzing and interpreting them. These are the author's speciality and the topics that make the book most valuable to karst specialists. Of special note are chapters on speleothem mineralogy and crystallography, interpretation of Quaternary history from cave deposits, cave climatology, morpho-climatic systems, cyclic karst evolution and palaeokarst. The final chapter rounds out the subject by examining the volatile issue of management and protection of karst.

Extensive references at the end of each chapter are not only up-to-date but also highly international in scope. There is also a glossary (in Romanian) and an appendix of useful sites on the Internet. The book is attractively printed and illustrated with many clear diagrams, although some of its photos suffer from excessive contrast (a fault of the printer, not the author).

I recommend this book highly to those with a general interest in karst, and most specifically to those who wish to apply karst studies to paleoclimatology and regional interpretation. It is a welcome and important addition to the literature in these fields.

Reviewed by Arthur N Palmer, Department of Earth Sciences, State University of New York, Oneonta, NY 13820-4015, USA.

THESIS ABSTRACT

PRESSDEE, C, 2001

Engineering Impacts of Karst: A review of some engineering aspects of limestone weathering with case studies from Devon and Ireland.

MSc Thesis, Engineering Geology and Geomaterials, School of Earth and Environmental Sciences, The University of Greenwich, Medway University Campus, Pembroke, Chatham Maritime, Kent ME4 4TB, UK.

The thesis aims to review the nature of karstic limestone terrains and the implications for engineering practices as a result of the uniquely difficult ground conditions they present. Case studies are included to highlight two very different, yet apparently common, engineering problems on karst. This abstract deals only with Linhay Hill Quarry in Ashburton, Devon where pinnacled rockhead and clay infilled dissolution pipes present problems in the extraction and processing of the limestone for use as aggregate.

The quarry has been in existence for over a hundred years and the current owners are drilling and blasting the Devonian limestone and processing it for a variety of purposes; namely aggregates for concrete, macadam and unbound applications. In the quarry, the rock is fairly evenly bedded and dipping towards the east. Near the ground surface it is extensively solution weathered to form a karst surface, which is now buried by more recent deposits. The extensive karst topography gives considerable problems, currently on the north side, where the intimate mixture of solution weathered limestone and later infilling clays and sandy sediments makes drilling and blasting difficult and contaminates the limestone material.

On the basis of the work carried out, the following summary of findings is presented:

- Using published engineering classification schemes; the Chercombe Bridge Limestone in and around Linhay Hill Quarry has been classified as Class III to IV Karst ('Mature' to 'Complex' Karst, Waltham, 1999).
- The origin of the karst is proposed to be the result of a combination of sub-tropical climate and localised valley conditions in the early Tertiary. Weathering and erosion of the Dartmoor granite and adjacent Cretaceous rocks provided fluvial sediment to subsequently infill the solution channels and cavities in the limestone.
- The physical effects of weathering have been shown to reduce the strength and density of the limestone whilst increasing the water absorption. This has implications for the quality of aggregate produced in the quarry.
- The chemical effects of dolomitisation and solutional weathering have been shown to produce a highly variable material in the quarry.
  Residual insoluble minerals were found to be randomly distributed and exhibited typically high densities, high absorptions and high clay and iron oxide/hydroxide contents.
- The nature of the infilled karst together with the effects of weathering mentioned above has significantly affected the workings of the quarry with considerable cost implications. They are listed (in no particular order) as follows:

1. Overburden stripping extremely time consuming and costly.
2. Increased drilling times through clay infilled fissures/cavities.
3. Enforced blast hole surveying techniques due to variable ground.
4. Enforced blast charge restriction resulting in reduced primary fragmentation.
5. Induced dolines in the surrounding farmland.
6. Costs of washing/scrubbing of clay coated 'contaminated' rock.
7. Clay materials not always removed resulting in reduced efficiency of processing plant.
8. Quality of aggregates impaired by variable rock properties and presence of clay.
9. Implications for concrete and mortar include potentially reduced workability, strength and durability.

ABSTRACTS FROM *KARSTOLOGIA*, FOR 1997 AND 1998

Karstologia 29 (1997)

The sociological and demographic characteristics of French cavers
François JOVIGNOT
The data come from three main sources: public data, an extract from the computer file of the members of the French Federation of Speleology (FFS) and a survey carried out among 285 FFS members. The importance of independent practice out of the FFS must be stressed as well as the difficulty to keep new members loyal to the federation because of a high "turn-over". France ranks high among nations as regards the numbers of practising people. Like many other federations of natural outdoors activities, FFS cavers are mostly men. The average age is over 30. Like most sportsmen, speleologists are generally well-to-do or belong to the middle class, with a fairly high academic background. The geographical breakdown of speleologists shows contradictory results: today cavers tend to be more numerous in the vicinity of caves ("countryside caving"), but statistics show that cavers are also mostly town-dwellers, like the great majority of sportsmen. It should be noted that, contrary to sportsmen, the increase in the number of FFS members is due to the expansion of rural speleology rather than to urban recruitment. Present day speleology is going through a period of transition. The large urban teams who have promoted speleology so far, are progressively being replaced by small size teams, living close to caves: such a change has been made possible thanks to new technology.

Karsts and paleokarsts of the Mialet Basin (Cevennes, Gard, France): formation and morphological evolution of an ancient karst cut by topographical surface
Laurent BRUXELLES
The Mialet basin is a limestone massif of 62km^2 on the edge of the Cevennes Mountains, made of 400m of limestones and dolomites. Two allochtonous rivers (Gardons) cross and dissect it. Many caves are to be found at each level and their formation cannot be explained with today's topography. Surface karstic features (dolines) are rare but karstic fillings and many speleothems can be observed on the surface. These deposits are former karst (paleokarst) cut by rivers incision. Recent karstic systems are organized differently but new subterranean circulations sometimes flow in old galleries and declog them.

Morphometric interpretation and speleogenesis. Examples of caves in the Provence area, France (gallery orientations, patterns and structural grid)
Jean-Joseph BLANC and Raymond MONTEAU
Successive tectonic phases on limestone massifs are at the origin of a fracturation grid with several pattern dimensions, and linear or organized drain directions. Mechanical reactivations are observed from Oligocene until Plio-Quaternary on a former "pyreneo-provençale" structure (Eocene). Statistical analysis of gallery and fracture directions, cave levels and descent stages (overdeepening) show several erosional stages occurring after the formation of the Antevindobonian erosional surface. The active speleogenesis during Oligocene and Miocene was controlled by tectonics in connection with European rifting and mediterranean opening. In Messinian a short and significant lowering of mediterranean base level (and water table) made drastic erosion and created vertical pits. The horizontal cave level dug during the stabilization phase of Pliocene, now perched over underground rivers, shows a new overdeepening because of glacio-eustatic Quaternary oscillations. Compressive or distensive mechanical reactivations (Upper Miocene, Pliocene, Quaternary) modified the drainage and consequently the cave organization: self-piracy, confluence and diffluence. In the endokarst, the drainage inversion can be detected in late Upper continental Miocene and early Messinian (6,5 Ma), in correlation with the tilting and extension of the continental margin. Five caves in Provence are studied: Sabre, Petit Saint-Cassien, Rampins, Planesselve river, and Tete du Cade networks.

The karstic cut-off of incised meanders
Jean NICOD
Three types of cut-off can be observed: 1) by natural bridge or short tunnel: Pont d'Arc type self-piracy (Ardeche, France); 2) by caves system or hydrogeological network, Lesse type (Ardenne, Belgium); 3) subaerial in karstic environment, the case of Vis in Navacelles (Herault, France). The main processes are debated: anteriority or/and coexistence of the underground drainage, impact of neotectonics, of the load and the screes and of the water chemistry changes.

The Lez spring aquifer: a reservoir of water... and biodiversity (Herault, France)
Florian MALARD, Janine GIBERT and Roger LAURENT
The Lez spring is the main source of drinking water for the inhabitants of the city of Montpellier. This spring has been exploited since the eighteenth century but the amount of groundwater pumped has markedly increased over the last 30 years. This karst harbours an extremely diversified community of groundwater

species (at least 37 species) that is a several million-year-old heritage. Overpumping induces a loss of habitats by lowering the water table during periods of low groundwater recharge. It also results in an artificial fragmentation of mesohabitats by increasing the hydraulic disconnection of different regions in the saturated zone. Thus, overpumping may strongly affect the groundwater fauna but few data are available yet to evaluate the potential loss of biodiversity. There is clearly a need to integrate studies of groundwater fauna within the framework of interdisciplinary groundwater monitoring, management and/or protection programmes.

Karstologia 30 (1997)

Current databases used by speleologists lack a cartographic dimension
Jean-Marc ROBBEZ-MASSON, Olivier HUTTEL, Célia LEVINET, David PLAGNES, Cathy VAQUER, Laurent VILLARET
Geographical Information Systems (GIS) make up for this inadequacy by allowing simultaneous management and spatial query of point, line and polygon entities. It is shown on a limited example in southern France the potential importance of these techniques in the field of karstology.

Karst and pseudo-karst features in quartzite in Burundi
Bernard PEYROT
Central Africa, underground karstic caves are to be found in Precambrian carbonated series, but also in quartzite as in the case of Burundi. The arenisation process, which took place during very wet periods of intense biological activity, may explain the origin of these caves and of karstic landforms such as pavements and pinnacles.

Pseudo-karstic features in plutonic and metamorphic rocks of South Cameroon
Jean-Paul VICAT, Bernard LIPS, André POUCLET, Jean-Marc LEGER and Luc WILLEMS
Plutonic and metamorphic rocks of South Cameroon show numerous surficial and deep pseudo-karstic features. Most surficial landforms are recent. The deep features are fossils and posterior to the Cretaceous peneplain surface. All the studied pseudo-karstic features are related to plagioclase dissolution by acid rainwaters.

Speleogenesis and valleys: the South Larzac (Herault, France)
Hubert CAMUS
The Causses and mediterranean Garrigues present a long continental evolution from late Cretaceous. The karstic network analysis and the dynamic study give geomorphological indicators to reconstruct the paleogeography of this area when the geological indicators are not present. The paleoclimatic action and the tectonic movements make the actual landscape melting a lot of ages and genesis different elements. The endokarst preserves sedimentological and paleoclimatic witnesses and also hollowing shapes that traduce the successive steps of the paleogeographic evolution. The network's levels of the South Larzac are connected with the landscape karstic forms: poljes, canyons, peripheric valleys. The reef limestone of the Seranne and the dolomite of the Monts de St-Guilhem explain this good conservation of the endokarst and of the landscapes.

The Lours nomads of the Kuh-e-garrin limestone massif (Central Zagros, Iran)
Dominique DUMAS
Today many nomadic confederations live in the Zagros range. For a long time, these high mountains have offered these populations both shelter and a large territory which is not as arid as the piedmont plains due to orographic rainfall Whereas the Baxtyari and Qashqaï are well described in the literature, little is known about the Lours nomads. In this paper, observations and investigations on nomadic families (Summers 1994, 1995, 1996) are presented together with the characteristics of their seasonal migrations. The socio-economic dimension of these populations is also studied to explain the reasons that account for the overgrazing clearly visible in all Zagros mountains. Today, these high mountain karsts are subject to a higher anthropogenic pressure than previously, which entails an irreversible disappearance of vegetation and soils.

New iron and manganese minerals in the Wind Cave (Padurea Craiului mountains, Romania)
Gabriel DIACONU and Mariana MORAR
[Short "note" only: no Abstract.]

Karstologia 31 (1998)

Energy dissipation and adaptability in the karst systems
Yves QUINIF
The phenomenon of karstification and even the term "karst" have been studied extensively but the concepts used explain only partially this complex problem. In this paper a global thermodynamic and geological approach to karstification is proposed. The universal thermodynamic concepts - energy dissipation and entropy variation - are first studied. In the second approach the karstic systems are studied in their geological and geomorphological environment.

New approach to speleogenesis: the pseudo-endokarst of Tournai (Belgium)
Anne VERGARI
In the paleokarstic features of the carboniferous limestones (synclinorium of Namur Hainaut, Belgium) new endokarstic forms have been discovered and named "pseudo-endokarsts". From a morphological point of view, the pseudo-endokarst looks like a gallery. But, in fact, it results from an in-situ alteration: the "ghost rocks". The study of the sedimentary cross-section in the "pic-à-glace cave" described in this article offers new understanding of endokarst genesis. Dynamic flows are no longer the only way to initiate karstification.

Speleothem crystallography in the Lithophagus cave system (Padurea Craiului Mountains, Romania)
Lucrecia GHERGARI, Bogdan Petroniu ONAC, Matei VREMIR and Robert STRUSIEVICZ
The Lithophagus cave system hosts interesting mono- and polycrystalline calcite speleothems (stalactites, stalagmites, crystals, helictites, fongites). Our studies allowed us to identify the crystallographic forms that build up these speleothems, the presence of twins and several generations of crystals. The main growth directions were identified for the helictites. The interpretation of the statistical data enables us to highlight the relationships between crystallographic forms that appear on some speleothems, their frequency, and the different cave environments.

Morphological reconstitution of an ancient karst from endorarstic survey. Example of Antre de Vénus (Vercors-France)
Jean-Jacques DELANNOY and Serge CAILLAULT
The whole of the information that can be found in the endokarst gives a better knowledge of the hydrogeologic, geomorphologic, tectonic and climatic evolution of a calcareous mountain mass. However, the study of the cavities is not yet developed or integrated in the karst studies. The objective of the present work is to show the interest of such a process by the study of a cavity in the northern Vercors: "Antre de Vénus". From simple observations of the shapes, the deposits and their relationships, a speleogenetic reconstitution of this cavity and, mainly, of the environment, is proposed.

Genesis of the Julliminden Basin karst (Niger)
Ibrahim BOUZOU MOUSSA and Philippe SCHOENEICH
The carbonated and cuirass areas of the Julliminden basin plateaus show many closed-in, circular or oval depressions. Though noticed early by geologists, they have been described only recently. These depressions are similar to the known karstic forms such as dolines, uvalas and poljes. Some of them, such as valleys with bayonet-shaped lines and karst with residual hillocks, are typical. The lithological differences that characterize these plateaus make it possible to make assumptions on the origin of these pseudo-karstic forms: dissolution of limestones, sandstones (Continental terminal) and weathered rocks of the basement, and withdrawing.

The fortified caves of Sabarthes (Ariège, France)
Florence GUILLOT
Among the fortresses built in the county of Foix in the Middle Ages, some fortified caves were built like castles. These isolated fortifications belonged to the counts of Foix. They are evidence of the dynamic period of castle building in the 12th and 13th centuries in the context of a geopolitical move toward space appropriation by the local counts. Such power tended to become greater than that of the local noblemen. These fortifications belonged to a spectacular defensive system, which remained in place until the end of the 13th century.

New observations on the hydrogeology of the Cruet valley, Haute-Savoie, France
Jean SESIANO
Following a recent dye-tracing experiment the hydrogeological model for the Cruet valley, in the northern French Prealps has had to be modified. Faults, parallel and transverse to the valley, allow a mixing of waters from different origins. There is thus possible contamination by surface pollutants of several Cruet valley springs supplying water for human consumption.

Karstologia 32 (1998)

Chronological and climatic signification of laminated speleothems in North China
Tan MING, Liu TUNGSHENG, Qin XIAOGUANG, Wang XIANFENG
Speleothems from North China show that many of them have very fine

microlayer growth. Most of these layers have bi-optical characters that can be observed under fluorescent and transmitted light. Hydrological analysis and radio-isotopic dating demonstrate that those layers are annually laminated. A Holocene stalagmite from Shihua Cave in Southwest Beijing presents thousands of micro-layers that are very similar to tree rings. Based on the measurements of the thickness of annual layers, short-term climatic changes over the last 1,130 years in the Beijing area are discussed.

Karst and glaciations in the Southern pre-alpine valleys
Alfredo BINI, Paola TOGNINI, Luisa ZUCCOLI
At least 13 glaciations occurred during the last 2.6Ma in the Southern pre-alpine valleys. The glaciers scouring alpine and pre-alpine valleys all had the same feature, being valley temperated glaciers. Their tracks and feeding areas were always the same, just like the petrological contents of their deposits. Contrary to previous assumptions until a few years ago, the origin of these valleys and of the lakes occupying the floor of some of them (Orta, Maggiore, Como, Iseo, Garda lakes) is due to fluvial erosion related to Messinian marine regression. The valley slopes modelling is Messinian in age, too, whereas most caves are older. As a general rule, glaciers worked on valley slopes just as a re-modelling agent, and their effects were greater on valley floors.

The karstic evolution began as soon as the area was lifted above sea level (late Oligocene - early Miocene), in a palaeogeographical environment quite different from the present one, although the main valley floors were already working as a base level. During Messinian time, the excavation of deep canyons along pre-existing valleys caused a dramatic lowering of the base level, followed by a complete re-arrangement of the karstic networks, which got deeper and deeper. The Pliocene marine transgression caused a new re-arrangement, the karst network getting mostly drowned below sea level. During these periods, the climate was hot-wet tropical, characterised by a great amount of water circulating during the wet season. At the same time tectonic uplift was at work, causing break-up of the karst networks and a continuous rearrangement of the underground drainage system. In any case, karstic networks were already well developed long before the beginning of Plio-Quaternary glaciation.

During the glaciations, karst systems in pre-alpine valleys could have been submitted to different drainage conditions, being: a) isolated, without any glacial water flowing; b) flooded, connected to the glacier water-filled zone; c) active, scoured by a stream sinking at glacier sides or in a sub glacial position. The stream could flow to the flooded zone (b), or scour all the unflooded system long down to the resurgence zone, the latter being generally located in a sub glacial position.

The glacier/karst system is a very dynamic one: it could get active, flooded or isolated depending on endo- and sub-glacial drainage variations. Furthermore, glaciers show different influences on karstic networks, thus working with a different effect during their advance, fluctuations, covering and recession phases. Many authors believe, or believed, the development of most surface and underground karst in the Alps is due to glaciations, with the last one held to be mostly responsible for this. Whatever the role of glaciers on karstic systems, in pre-alpine valleys caves, we do not have evidence either of development of new caves or of remarkable changes in their features during glaciations. It is of course possible some pits or galleries could have developed during Plio-Quaternary glaciations, but as a general rule glaciers do not seem to have affected karstic systems in the Southern pre-alpine valleys with any remarkable speleogenetic effects: the glacial effects on them are generally restricted to the transport of great amounts of debris and sediments into caves.

The spotting of boulders and pebbles trapped between roof stalactites shows that several phases of in- and out-filling of galleries occurred with no remarkable change to earlier features, including cave decorations. The presence of suspended karst systems does not prove a glacial origin of the valleys, since most of them pre-date any Plio-Quaternary glaciation, as shown by calcite cave deposits older than 1.5Ma.

The sediments driven into caves might have caused a partial or total occlusion of most galleries, with a remarkable re-arrangement of the underground drainage system. In caves submitted to periglacial conditions through all the glaciations, we can find deposits coming from weathered surface sediments, sharp-edged gelifraction debris and, more rarely, alluvial deposits whose origin is not related to the circulation of the glacial meltwater. In caves lower than or close to the glacial limit we generally find large amounts of glacier-related deposits, commonly partly or totally occluding cave galleries. These sediments may be directly related to glaciers, i.e. carried into caves by glacial meltwaters, resulting from surface glacial deposit erosion.

They generally show 3 dominant facies:
A) lacustrine deposits; B) alluvial deposits and C) debris flow deposit facies. The only way of testing the soundness of the aforementioned hypothesis is to study the main characters and spreading of cave sediments, since they are the only real data on connection of glaciers to endokarst networks.

Blue Lagoon, South Africa, a cave with Permian paleokarstic fillings and aragonite speleothems
J.E.J. MARTINI and H.F.G. MOEN
The authors describe a 7km-ong phreatic maze they discovered and explored during the last decade of the 20th century in South Africa, developed in the late Archean dolostone in the Malmani Subgroup. This cave is of interest mainly for two aspects. Firstly the cave intersects paleokarst channels filled with bleached kaolinic residuals of Permian age. This paleokarst is most likely to have developed relatively shortly after the Gondwana glaciation in a cool, humid climate. Secondly the cave is remarkable for an abundance of aragonite speleothems. Particularly interesting are subaquatic aragonite formations: rafts, cones, volcanoes, sea urchins and pool floor crust. Aragonite rafts are always associated with more or less calcite, which seems to have formed first and was apparently essential in the initial formation of this speleothem. In the pool floor crust, a cyclical calcite-aragonite deposition seems to correspond to alternation of humid and dry periods, calcite representing wet years. The amplitude of this cycle is possibly in the order of a few decades. Phosphate minerals which developed on cave soil, rock and carbonate speleothems in contact with bat guano, have been identified, in particular the rare mineral collinsite

Was the Wallace Line ever crossed by man during the prehistoric period?
Jean-Michel Chazine and Luc-Henri Fage
Before 1992, the Indonesian part of Borneo (Kalimantan) had not been the subject of archaeological research. Five speleological and archaeological research missions discovered numerous sites, first in the centre island (Müller Range, in some isolated parts) and secondly in the huge karst region of Mangkalihat peninsula (NE of Kalimantan) where the first painted caves in Borneo were found in 1994. During the last expedition in September 1998, we discovered two other painted caves: the most beautiful and richest ever found in Borneo, with numerous negative hand stencils and painted figures in a good state of preservation. These discoveries have been made in a very difficult area (pinnacle and cone karst in the rainforest) by a small team - one caver and one archaeologist. The systematic exploration of Borneo caves is essential to answer the question of the role played by the Island in the prehistoric migrations between Asia and Australia.

The travertines of Coly (Dordogne, France): influence of endokarst in valley travertine genesis
Frédéric HOFFMANN
The "Doux de Coly" is a vauclusian spring with a 4km-long phreatic gallery that regulates the carbonated mineralization of water. Because the CO_2 pressure is too high inside the conduit, this artesian spring cannot deposit carbonates. The spring water connects with another river, the Chironde, and creates the Coly River. This mixing of waters induces chemical variations and allows valley travertine deposition by CO_2 degassing and carbonate precipitation. A 2-year-long water chemistry study reveals the influence of the "Doux de Coly" karstic system (phreatic zone) in the formation of travertines.

RESEARCH FUNDS AND GRANTS

THE BCRA RESEARCH FUND

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)

GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a minimum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Farm Barn, Cutler's Lane, Castlemorton. Malvern, Worcestershire, WR13 6LF, UK. Closing dates for applications are: 31August and 31 January.

THE E K TRATMAN AWARD

An annual award, currently £50, made for the most stimulating contribution towards speleological literature published within the United Kingdom during the past 12 months. Suggestions are always welcome to members of the GPF Awards Committee, or its Secretary, David Judson, not later than 31 January each year.

BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

CAVE AND KARST SCIENCE - published three times annually, a scientific journal comprising original research papers, reports, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.
Editors: Dr D J Lowe, c/o British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, and Professor J Gunn, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HDI 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: Clive G Gardener, 23 Landin House, Thomas Road, London, E14 7AN, UK.

CAVE STUDIES SERIES - occasional series of booklets on various speleological or karst subjects.

No. 1 *Caves and Karst of the Yorkshire Dales*; by Tony Waltham and Martin Davies, 1987. Reprinted 1991.
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.
No. 8 *Walks around the Caves and Karst of the Mendip Hills*; by Andy Farrant, 1999.

SPELEOHISTORY SERIES - an occasional series.

No.1 The Ease Gill System – Forty Years of Exploration; by Jim Eyre, 1989.

BCRA SPECIAL INTEREST GROUPS

SPECIAL INTEREST GROUPS are organised groups within the BCRA that issue their own publications and hold symposia, field meetings, etc.
Cave Radio and Electronics Group promotes the theoretical and practical study of cave radio and the uses of electronics in cave-related projects. The Group publishes a quarterly technical journal (c.32pp A4) and organises twice-yearly field meetings. Occasional publications include the *Bibliography of Underground Communications* (2nd edition, 36pp A4).

Explosives Users' Group, provides information to cavers using explosives for cave exploration and rescue, and liaises with relevant authorities. The Group produces a regular newsletter and organises field meetings. Occasional publications include a *Bibliography and Guide to Regulations*, etc.

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.

Cave Surveying Group is a forum for discussion of matters relating to cave surveying, including methods of data recording, data processing, survey standards, instruments, archiving policy, etc. The Group publishes a quarterly newsletter, Compass Points (c.16pp A4), and organises seminars and field meetings.

Copies of BCRA Publications are obtainable from: Ernie Shield, Publication Sales, Village Farm, Great Thirkleby, Thirsk, North Yorkshire, Y07 2AT, UK.

BCRA Research Fund application forms and information about BCRA Special Interest Groups can be obtained from the BCRA Honorary Secretary: John Wilcock, 22 Kingsley Close, Stafford, ST17 9BT, UK.