Cave Science

The Transactions of the British Cave Research Association

BCRA

Volume 16 Number 3 December 1989

Cave archaeology symposium

B.C.R.A. symposium abstracts

Quaternary evolution of the South Pennines

Caves of Irian Jaya

Cave Science

The Transactions of the British Cave Research covers all aspects of speleological science, including geology, geomorphology, hydrology, chemistry, physics, archaeology and biology in their application to caves. It also publishes articles on technical matters such as exploration, equipment, diving, surveying, photography and documentation, as well as expedition reports and historical or biographical studies. Papers may be read at meetings held in various parts of Britain, but they may be submitted for publication without being read. Manuscripts should be sent to the Editor, Dr. T. D. Ford, at 21 Elizabeth Drive, Oadby, Leicester LE2 4RD. Intending authors are welcome to contact either the Editor or the Production Editor who will be pleased to advise in any cases of doubt concerning the preparation of manuscripts.

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Cave Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 16 Number 3 December 1989

Contents

Cover: Some of the caves in the low cliffs of Magnesian Limestone along the north side of Creswell Crags on the Derbyshire-Nottinghamshire border. Though of no great extent, these caves are of immense archaeological importance, and were the venue of a B.C.R.A. meeting which produced most of the papers in this issue of Cave Science. By Tony Waltham.

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Cave Science is published by the British Cave Research Association, and is issued to all paid up members of the Association.
1989 subscription rate for non-members is £16.00.
Membership Secretary: N. Briggs, 127 Bulls Head Lane, Coventry CV3 1FW.

Individual copies and back numbers of Cave Science are obtainable from:
B.C.R.A. Sales, 20 Woodland Avenue, Westonzoyland, Bridgwater, Somerset TA7 0LQ.
The permanent address for B.C.R.A. is: B.C.M.-B.C.R.A., London WC1N 3XX.

ISSN 0263-760X

CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

CAVERS, CAVING AND CAVE ARCHAEOLOGY

Charlotte A. ROBERTS

Abstract: The subject matter of this paper is aimed at cavers in particular and explains the importance of cave archaeology within a sport caving context. Past and present studies of cave archaeology are considered and the future of the discipline are discussed.

"cave deposits are historical documents but (they) have often been treated with scant respect" (Tratman 1975)

This paper is aimed particularly at cavers who may not yet be convinced of the value of cave archaeology as a subject relevant to caving as a sport. Cave archaeology is not an area of interest for many active cavers and the subject often becomes relegated to the fringe areas of a caver's interests and is considered an area to be studied by those who may not be particularly active in the sport. Furthermore, many cavers may feel that cave archaeology is a subject reserved for the rock shelter type caves (e.g. at Creswell Crags) which, after all, are the caves that cavers tend to avoid in favour of more 'sporting' caving trips.

However, in the normal course of events in caving, if anything that appears to be an archaeological deposit is encountered during digging procedures in a particular cave system a dilemma ensues. Should the caver inform an archaeologist, should he/she keep the artefacts that emerge as they continue digging or should they just ignore it all and hope that nobody finds out? The basic fear is that digging into caves potentially measureless to man may be prevented by archaeologists!

It is a very complex problem. Surprisingly, there are very few professional cave archaeologists in this country and those tend to excavate abroad. Even more confusing is the fact that cave archaeology is a multidisciplinary subject requiring lots of specialists to study the different aspects of the cave sediments. But, there are also the dedicated amateur cave archaeologists who are the backbone of British archaeology. They would welcome involvement in cave archaeology. In addition, there are cave scientists specialising in some aspect of cave studies whether it be palynology, palaeomagnetism or paleontology. Many are not cavers. In fact, this is a common problem with cave archaeology because much of the evidence for human or animal use of caves occurs in the entrances to caves, archaeologists do not need to be expert cavers. However, it should be borne in mind that the potential for cave archaeology in the deeper parts of some caves are quite high e.g. nitrate extraction works and defence walls in the caves of south China (Waltham 1986).

Cavers can be helpful in the study of cave archaeology and in an expedition situation this is particularly relevant (Roberts 1986). If there has been no archaeologist on the caving team, some cavers in the past have reported archaeological discoveries to local archaeologists and taken finds to the local museums. It is this kind of co-operation which the British Cave Research Association is hoping to achieve. There is a need for exchange of information and ideas to help cavers understand why cave archaeological work is important for reconstructing past human behaviour. There is also a need for cave archaologists to enter the minds of cavers and to comprehend the need for caving as a sport. Conflicts could then be more easily overcome. To try to remedy this situation a list of archaeological contacts, for cavers in different parts of the country to contact in the event of an archaeological discovery in a cave, was published recently (Roberts 1986). There has indeeed been some use made of this information.

ARCHAEOLOGY IN CAVES: ITS IMPORTANCE

What must be appreciated by cavers is that a cave can provide detailed information on its past history. Caves are efficient sediment traps and these sediments build up in layers, distinguished by features such as colour and texture, making up the stratigraphy of the site. These sediments may record past human activity for thousands of years (Pierpoint 1984:8). The strata may incorporate evidence of past human activity in the form of artefacts, ecofacts and structures and can be used to piece together the cave's past history in reverse order. However, provenance and horizon of finds is as important as the find itself. Finds alone are little use to archaeologists. Fortunately, in a cave, these sediments are generally protected from weathering and erosional processes and remain stable in a changing environment, so extensive and complex depositional sequences can be preserved (Hunt and Gale 1983:324). Once these archaeological deposits are disturbed either by cavers or excavated by archaeologists this evidence is lost forever. In many circumstances cavers may be unaware that they are destroying archaeological evidence in the most subtle ways. Garcia and Rouzaud (1985) illustrate this point in their article on prehistoric footprints in caves in France. To the unwary caver this very delicate and important evidence could be destroyed in one trip into a cave. Altamira Cave in Northern Spain is a site which holds the famous Hall of the Paintings. The presence of visitors to the cave has led to deterioration in the condition of the paintings due to changes in carbon dioxide concentrations (Villar *et. al.* 1986:21). At Joint Mitnor Cave in Devon (Curry 1987:15), concern over the deterioration of the bone section by visitors and the environment of the cave has led to more detailed conservation techniques.

In the case of prehistory we have no written records so reconstruction of past societies relies on archaeology and for some periods of time excavation yields the only evidence. Cave excavations are particularly important evidence for these periods of time when, in some areas of the world, societies were making extensive use of well-sited cave entrances. Studies of cave deposits can not only produce information of the exploitation of that particular cave but in many instances there may well be archaeological evidence which sheds light on a much wider area, e.g. at Franchthi Cave, Greece (Wilson 1975:210).

Archaeological evidence is as important as for example, the biological, hydrological or paleontological information which we can extract from cave environments. The whole picture of a cave's history is what matters, not one particular aspect. This is perhaps why foreign expeditions from Britain are now tending to assemble teams of cavers with particular expertise e.g. China Caves Project (Waltham 1986), Ankarana, Madagascar (Wilson 1987). This way of organising an expedition ensures that the maximum amount of information is generated about all aspects of the caves discovered.

Potential sites: what circumstances?

Caves have always attracted people and animals and these sites are still being used for many purposes today — sport, show caves, scientific work, dumping of refuse, water supply, mineral extraction, habitation, to name a few. Their use obviously varies around the world. We as cavers and archaeologists in this country are drawn to their entrances mainly for sport or science.

There are perhaps two main instances when cavers might come across archaeological deposits, in the 'home' and 'abroad' situation. The former tends to occur in normal digging procedures to extend cave systems already known or in the process of discovering new caves altogether. There have been many instances of bones (both human and animal), pottery etc. being discovered by cavers in Britain and these discoveries are invaluable for archaeologists (Baguley 1987). Some has been reported (see Wilcock 1957:10 and The Times May 9th 1968) but most of the finds have not, and knowledge about them tends to come 'through the grapevine' with a lot of luck. In the archaeological field, failure to publish is a great archaeological crime but in the field of cave archaeology knowledge of finds from caves may not even reach the right people to be published. As King said (1976:538), "Too much has already been sacrificed in the race to bottom the shaft and clear the passage".

The National Trust were concerned very recently that caves of archaeological importance in the Manifold Valley were being disturbed by cavers (Roberts 1987:51) but incidents such as these are fortunately very few. To protect archaeological sites of national importance against damage by people some sites are 'scheduled' as ancient monuments and it then becomes illegal to interfere with the site in any way. The more important cave sites are protected in this way but many are not. It was felt by B.C.R.A. that it would be useful to have information on scheduled cave sites available for interested parties and this was reported in 1985 (Roberts 1985:44). In 1966 the Birkenhead Y.M.C.A. Speleological Group could have used this information before they illegally disturbed deposits in the scheduled site of Pontnewydd Cave in North Wales (Green 1984:19). In the United States, (Middleton 1983), "in most states it is illegal to . . . either remove or disturb historic or prehistoric artifacts or bones . . .". Perhaps Britain has a long way to go with respect to the protection of its archaeological caves.

On expeditions cavers are highly likely to come across archaeology in caves. They are, in many instances, visiting areas which are new and are discovering hitherto unknown caves. The caver is important in many respects for the future of cave archaeology. There are many examples of expeditions to far flung corners of the world revealing hitherto unknown caves with archaeological deposits. It is obvious from some caving expedition reports that an archaeologist or paleontologist e.g. Wilson (1987), or somebody who was capable of recording and reporting finds, had been recruited to the team. This can only be done if the expedition considers it likely that archaeological deposits will be discovered in the cave areas they will be visiting. However, as has already been stressed, there are few experienced cavers with archaeological expertise in this country at least. There are many expeditions, particularly visiting European countries, which have had a sensible approach to the problem but have had difficulty in persuading the archaeologists in the country that they were willing to co-operate, and were not going to destroy every cave archaeological site they discovered wholesale (Time Barter pers. comm.).

Unfortunately, there are also cases when cavers and archaeologists refuse to work together. This is a particularly negative attitude which does not help the cause. It is hoped that the B.C.R.A./Creswell Cave Archaeology Study Weekend has illustrated, particularly to cavers, that with planning and care much useful information can be generated from cave archaeological studies.

PAST STUDIES

Cave archaeology studies has had a long history since the 19th century work of Buckland (1823) and Boyd Dawkins (1874). The first comprehensive work on British cave archaeology was by Buckland. There have been many well known excavations in Britain including sites such as Kent's Cavern, Victoria Cave, Brixham Cave, Wookey Hole and particularly at Creswell Crags. There are not many areas of the world that can produce such a variety of archaeological and paleontological remains that the British Isles so it is surprising that there are so few centres or professional archaeologists undertaking cave archaeological studies. Creswell Crags is in a fortunate position where this type of work can be integrated with tourism, leisure and employment for local people. It has also had a long history of cave excavation (Campbell 1970). The Pengelly Cave Studies Trust is perhaps its southern counterpart based at the Pengelly Cave Studies Centre in Buckfastleigh, Devon.

Early digging of caves tended to be aimed at quantity not quality although there were some exeptions. Some sites were totally dug out and, although finds were kept, their provenance was not recorded (King 1974:183). Sieving of archaeological sediments, for example, to extract more detailed information about the cave's history seems to have been a rare event. Now, on virtually every archaeological site, cave or otherwise, sieving of sediments is carried out as a basic extraction procedure. Excavation techniques have improved beyond belief and the amount of archaeological evidence generated is immense. The processing of that data is another lengthy story.

In the early days of cave excavations, caving was not the popular sport that it is today. There was therefore little threat to the survival of archaeological caves at that time. However, in the 1960s Pill was already pointing out that, "the influx of newcomers to caving, if continued at the present rate, inevitably means heavier traffic and more incidental damage to the contents of caves . . . more vigilance should be exercised whenever new caves or passages are opened up". This is an ever increasing problem today and the situation will worsen if collaboration between cavers and archaeologists is not developed.

PRESENT STUDIES

There are unfortunately few cave excavations seriously being carried out in Britain at the present time and only Pontnewydd and Creswell Crags are actively being investigated. There is, however, much scientific work being undertaken on cave sediments from caves with known archaeological interest (e.g. Joint Mitnor Cave in Devon). There have recently been publications on specific aspects of cave sediments (see Jones and McKeever 1987) and at Creswell Crags methods of excavation have developed so that the maximum amount of information can be extracted with the minimum amount of disturbance of the deposits being excavated (Hunt *et. al.* 1987). Cavers would perhaps see these methods as unacceptably detailed and time-consuming. It is true that methods such as these would considerably hold up exploration in a cave discovery situation but this would be unlikely to occur in the normal processes of excavation. At Creswell Crags money and time is available for a very important study of the cave sites in this unique limestone gorge. In most instances where cavers find archaeological deposits allowance for adequate recording and/or excavation would be an acceptable compromise for most archaeologists and cavers unless, of course, the site proved to be an important 'missing link' in the history of the area.

There are, in fact, many cavers who are currently interested in scientific aspects of caves including archaeology. At present there is little information for their needs except what is communicated through the ages of B.C.R.A. and Pengelly publications. There is a real need for a national publication such as a Newsletter which may go some way to conveying information about cave archaeology to professional archaeologists and lay people alike. There is one major hurdle to overcome, however, and this is the constant secrecy which people have with regard to cave archaeological deposits. As there are so few cave archaeologists it seems strange that there is no established group of all the people involved.

FUTURE OF CAVE ARCHAEOLOGY

Unless there is a major effort in collaboration, co-operation and publication cave archaeology as a subject, particularly in the sporting caver's mind, has a long way to go. It is still in its infancy in many respects and will not mature quickly. There is a need for more communication and meetings such as the one this weekend. Perhaps an increase in archaeologists speaking to cavers at their conferences such as the annual B.C.R.A. meeting, with cavers being given the opportunity to say what they think about archaeology. This may help the cause.

It is hoped that where there are show caves, museums will be established which display cave archaeological information with the rest of the cave's history as at Dan-Yr-Ogof in South Wales (Pengelly Newsletter 52 1987).

Cavers need to be more aware of what to watch out for when archaeology may be suspected and, on expeditions abroad they should be encouraged to include an archaeologist on the team or do a lot of preliminary work so that they are prepared for any archaeological material which they might find (Roberts 1986).

Stressing to cavers that they should collaborate with archaeologists and inform them of finds is essential. Britain by no means has revealed all its archaelogical caves and if archaeologists are to extract vital information from newly discovered caves their needs must be respected by cavers and vice versa. It is hoped that this meeting may help to pave the way for the future of British cave archaeology and that both cavers and archaeologists will go away understanding more about each other's fascination with caves.

REFERENCES

Baguley, F. S. 1987 Report on the meeting held in respect of the archaeological cave sites on National Trust property on south Gower.

Buckland, W. 1823 Reliquiae Diluvianae; or observations on some organic remains contained in caves, fissures and Diluvial gravel, and other geological phenomena attesting to the action of a Universal deluge. John Murray, London.

Campbell, J. 1970 Excavations at Creswell Crags. Derbyshire Archaeological Journal vol. 89; pp 47-157.

Curry, D. 1987 Conservation of bone section in Joint Mitnor Cave. Pengelly Cave Studies Trust Ltd. Newsletter 51, p. 21.

Dawkins, W. B. 1874 Cave Hunting. London.

Department of the Environment 1978 List of ancient monuments in England 3 volumes. London: H.M.S.O.

Garcia, M. and Rouzand, F. 1985 Scene de chasse en ariège. Les dossiers histoire et archaeologie vol. 90, pp. 50-55.

Green, H. S. 1984 Pontnewydd Cave. A lower palaeolithic hominid site in Wales: 1st report. National Museum of Wales, Cardiff.

Hunt, C. and Gale, S. J. 1986 Palynology: a neglected tool in British cave studies. In K. Paterson and M. Sweeting (eds), New Directions in Karst. (Proceedings of the French Karst Symposium) Geobooks, Norwich: pp. 323-332.

Hunt, C., Brooks, I. P., Coles, G. and Jenkinson, R. D. S. 1987 Archaeological cave surveying. Cave Science vol. 14, No. 2, pp. 83-84.

Jones, G. L. and McKeever, M. 1987 The sedimentology and palynology of some postglacial deposits from Marble Arch Cave, County Fermanagh. Cave Science Vol. 14, No. 1, pp. 3-6.

King, A. 1974 A review of archaeological work in the caves of north-west England. In Waltham, A. C., Limestones and caves of north-west England. David and Charles, Newton Abbot, pp. 182-200.

King, A. 1976 Cave palaeontology and archaeology. In Ford, T. D. and Cullingford, C. H. D. (eds), The science of speleology. Routledge and Kegan Paul, London.

Middleton, J. 1983 International News. Caves and Caving, No. 22, p.27.

Pengelly Cave Studies Trust Ltd. Newsletter 1987 Dan-yr-ogof Museum and Cave Conservation Centre. Number 52.

Pierpoint, S. 1984 Cave archaeology in Yorkshire. Studies in Speleology, vol. 5, pp. 7-14.
Pill, A. L. 1966 An introduction to cave excavation. Cave Science (B.S.A. series) vol. 5, pp. 420-477.
Roberts, C. A. 1984 Archaeology. Caves and Caving No. 29, p. 44.
Roberts, C. A. 1984 Archaeological contacts for cavers. Caves and Caving No. 31.
Roberts, C. A. 1986 Expedition archaeology. In D. Willis (ed), Caving Expeditions. Royal Geographical Society, London, and B.C.R.A., pp. 97-103.
Roberts, C. A. 1987 Manifold Valley caves. Caves and Caving No. 35, p. 51.
The Times May 9th 1962 Bones found in cave believed to date from Bronze Age. Page 8.
Tratman, E. K. 1975 The cave archaeology and palaeontology of Mendip. In D. I. Smith (ed), Limestones and caves of the Mendip Hills. David and Charles, Newton Abbot, pp. 352-403.
Villar, E., Fernandez, P. L., Gutierrez, I., Quindos, L. S. and Soto, J. 1986 Influence of visitors on carbon dioxide concentrations in Altamira Cave. Cave Science vol. 13, No. 1, pp. 21-24.
Waltham, A. C., 1986 China Caves '85 Royal Geographical Society, London.
Wilcock, J. D. 1957 Cave explorers and archaeological finds. B.C.R.A. Bulletin No. 4, p. 10.
Wilson, D. 1975 Science and Archaeology. Penguin, London.
Wilson, J. (ed) 1987 The crocodile caves of Ankarana: expedition to Northern Madagascar 1986. Cave Science Vol. 14, No. 3, pp. 107-119.

Received June 1989

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

TAPHONOMY AND THE PALYNOLOGY OF CAVE DEPOSITS

G. M. COLES, D. D. GILBERTSON, C. O. HUNT, and R. D. S. JENKINSON.

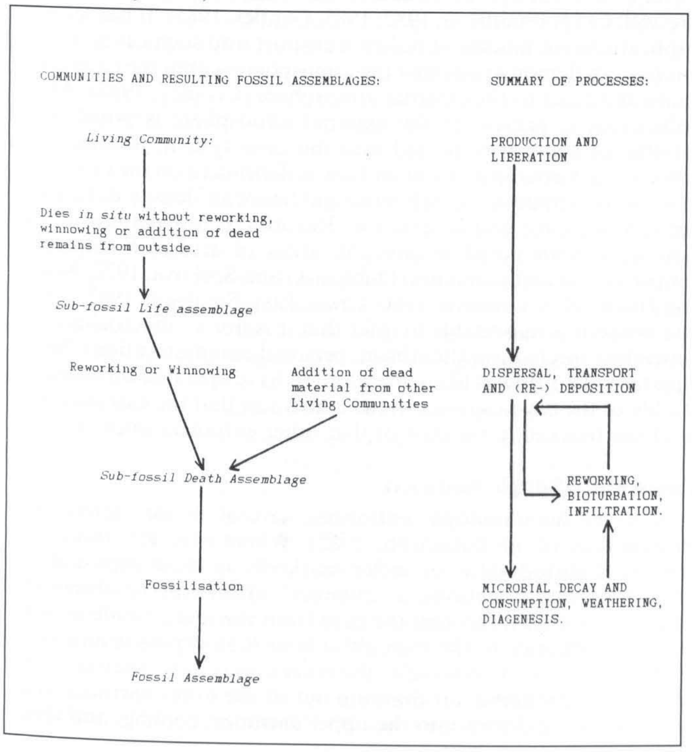
Abstract: The processes governing the formation of pollen and spore assemblages within cave sites are reviewed. An interim model of pollen and spore movement is presented. Areas of present ignorance are highlighted and discussed.

Palynology ("pollen analysis") is a technique that obtains information in the form of "numerical data resulting from the counts of various pollen and spore types present in a stratigraphical series of sediment samples" (Birks, 1973b). In order to interpret such data in terms of past vegetation it is a necessary basic assumption that there is a functional relationship between the number of grains of a given taxon preserved in a sediment body and the number of individuals of that taxon in the former vegetation around the site. Therefore to interpret the fossil record, it is necessary to understand this functional relationship; to do this we must consider the processes by which fossil pollen and spore assemblages are produced.

The study of the production of a fossil assemblage is termed taphonomy, the "science of embedding" (Efremov, 1940); In this paper the term "pollen taphonomy" refers to the study of all the processes governing the production of sub-fossil assemblages of both pollen and spores. Many studies of pollen taphonomy have been carried out in widely differing environments (for reviews see Birks and West, 1973; Birks and Birks, 1980, chapter 9); however, few studies of modern pollen deposition in caves have been reported. This represents a major limitation to the development of cave palynology because it is evident that the models and inferences commonly employed to interpret pollen diagrams from lake sites or mires are inappropriate to the consideration of caves. Clearly the pollen analysis of cave sediments has problems and pitfalls (Turner, 1985).

The processes leading to the production of a fossil assemblage are summarised in figure 1 (after West, 1973). Reference to this figure shows that the processes governing the formation of a palynological assemblage may be viewed in terms of (1) production, (2) dispersal, transport and deposition and (3) post-depositional processes. This paper will consider the taphonomic controls on the production, dispersal, transport and deposition of pollen assemblages in caves. The present, explicitly taphonomic, approach has frequently been used to discuss pollen and spore assemblages from lake and mire sites (see for example papers in Birks and West (eds, 1973)), but it has not previously been applied to cave sites.

Figure 1. The processes leading to the formation of a fossil assemblage (after West, 1973, with modifications).



POLLEN AND SPORE PRODUCTION: THE POLLEN CATCHMENT

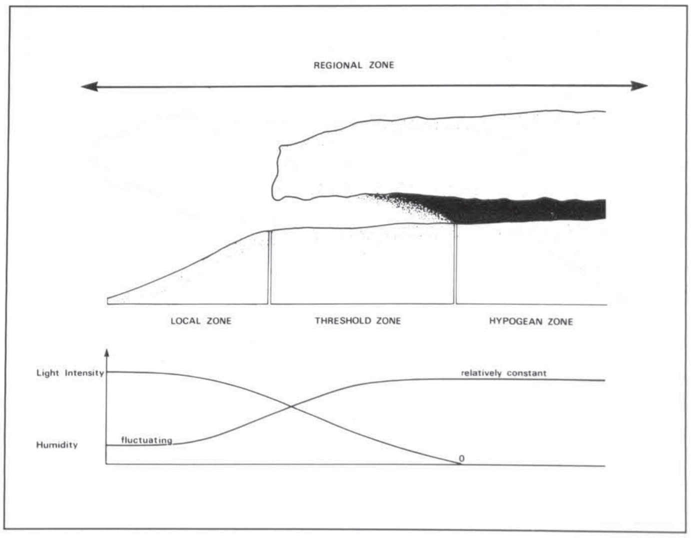
The "pollen catchment" is the area from which pollen and spores reaching the sampling site are derived. Like many other types of palynological sampling location, such as lakes or mires, the physical structure of caves gives rise to a distinctive series of vegetation zones around it. Unless this local zonation of vegetation is taken into account no understanding of pollen assemblages in caves can be made.

The vegetation zones producing pollen and spores and of importance to cave studies can be considered as follows. The zones are described proceeding outward from the "dark zone". The idealised extent of each zone is shown in figure 2.

1. The Hypogean or Dark Zone; the interior of the cave, completely dark and with relatively constant temperature and humidity. The complete absence of light precludes the growth of higher plants and that of the majority of lower plants with the exception of certain saprophytic fungi (Mason-Williams and Benson-Evans, 1958; Mason-Williams, 1965; Cubbon, 1970; 1972; 1976). While the spores of these fungi may eventually provide information of palaeoecological significance, the present understanding of this group as microfossils is limited, and their contribution to the palynological assemblage found within caves will not be considered further here.

2. The Transition or Threshold Zone; the zone is characterised by increasing light intensity and decreasing humidity towards the entrance of the cave. The area of the transition zone is controlled by the physical structure of the cave and its aspect. The chief control for plants growing in this zone is the reduced intensity of light (Dalby, 1966). The assemblage of plants shows a trend towards increasing numbers of taxa and decreasing tolerance of low light intensity, towards the cave entrance. This relationship is illustrated by the studies of Piearce (1975) and Gidman (1975) of the entrance flora of Ingleborough Cave, Yorkshire. Secondary factors apparently controlling plant growth in this zone include the substrate (generally alkaline or circum-neutral), the relatively constant humidity and the reduction of competition from other light demanding species (Cubbon, 1976). These secondary factors may help to explain the often noted dominance of ferns in the vegetation of the cave entrance threshold (Mason-Williams and Benson-Evans, 1958; Cubbon, 1970; Dobat, 1970; Lloyd, 1977). The composition of the assemblage of plants in the transitional zone may be regarded as the result of the existence of the cave. The assemblage would not be present in that form if the cave were absent.

Figure 2. A section through an idealised cave showing the location and extent of the vegetation zones from which pollen and spore components may be derived.



3. The Local Zone; the area immediately surrounding the cave, but not necessarily directly influenced by it. The vegetation in this zone would be present in the area regardless of the presence or absence of the cave, although such vegetation may well reflect a specific microhabitat in its own right, such as gorge sides or talus slopes (Jenkinson and Gilbertson, 1984).

4. The Regional Zone; The regional vegetation as determined by climate, soils and time, and influenced by the activities of biota and man.

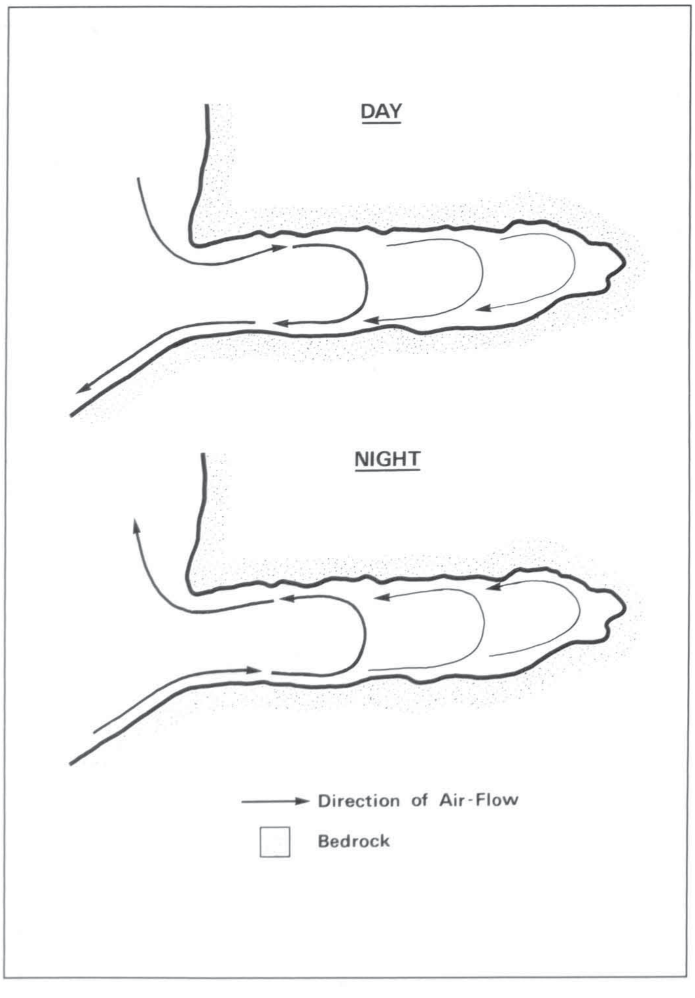
These zones tend to reflect continuous (not discrete) distributions of plants and each zone naturally grades into the succeeding zone. The dimensions of each near cave and cave zone will reflect the physical structure of the cave entrance and its surroundings since immediate topographic factors will provide physical limits on the amount of light, and with respect to aspect, the duration of light, falling on the entrance area.

Pollen and Spore Assemblage Components derived from these Vegetation Zones

Ultimately the assemblage of pollen and spores deposited in a given cave will be derived from these vegetation zones by means of airborne, waterborne and animal/insect-borne dispersal and transport mechanisms, together with grains derived from earlier deposits by reworking.

Each vegetation zone will contribute to the final pollen and spore assemblage a *component* whose composition will reflect the composition of the vegetation within that zone. We may therefore consider the pollen and spore assemblage deposited in the cave as being composed of three *components;* a threshold component (tC), a local component (loC) and a regional component (rC). The pollen and spore assemblage deposited within the cave will be a function of these components. Tauber (1967a) has demonstrated in the external (i.e. non-cave) environment that the contribution of different components to any given sub-fossil assemblage is governed by the transport mechanism responsible for the dispersal and transfer of pollen and spores to that site. Therefore, it appears probable that this also holds true for cave systems. The transport mechanisms responsible for moving pollen into cave systems can be considered as follows.

Figure 3. The pattern of diurnal air flow in a cave with a single entrance (after Smithson, 1982).



TRANSPORT OF POLLEN AND SPORES INTO CAVE SYSTEMS

Evidence from taphonomic studies outside the cave environment indicates that there are three principal modes of terrestrial pollen dispersal and transport: airborne (Tauber, 1965, 1967a), waterborne (Peck, 1973) and animal/insect-borne (Bottema, 1975). Little attention has been paid to these very different modes of pollen transport in previous studies of fossil pollen assemblages from caves. It is evident, however, that some transport pathways are better understood than others.

In addition to the transport pathways moving pollen and spores into cave systems we may also consider transport mechanisms suspected of operating within the cave itself, such as the reworking of sediments by geomorphic processes, bioturbation by cave flora (largely in the entrance zone, but the action of fungal colonies in the dark zone should not be discounted), bioturbation by resident cave fauna and animals with dens in the cave together with human activity. This varied group of processes, which results in the addition of a "reworked component" to the pollen and spore assemblage, is at present very poorly understood (Coles, 1988) and is the subject of experimental investigation. Discussion of reworking in this paper will therefore be largely confined to that which directly affects, or results from, the transport of pollen and spores into a cave system.

MICROCLIMATIC CONTROLS ON AIRBORNE POLLEN TRANSPORT WITHIN CAVES

The microclimate of a cave is the major control on the entry of pollen as airfall into a cave system. Recent studies (Wigley and Brown, 1971, 1976; Smithson, 1982; Gentles, 1985) have distinguished two principal controls on cave microclimates; first, the number of cave entrances and second, the presence or absence of active streamway passages within the cave.

Caves with a Single Entrance

In caves with a single entrance the microclimate appears to be characterised by a diurnal pattern of airflow reversal (Smithson, 1982). During the day the air outside the cave is generally warmer and therefore less dense than the air inside the cave. The cold dense air therefore drains out of the cave into the valley below and warmer, less dense air is drawn into the cave at roof height, where it cools, sinks and drains out of the cave. This pattern of airflow continues throughout the day. However, at night the air inside the cave is generally warmer, and is therefore less dense, than the air outside the cave. Airflow then reverses - with warmer air escaping at roof level while colder air is drawn in at ground level (figure 3).

This pattern of air flow, has been noted at several caves in the mountains of the Crimea, U.S.S.R (Dubljanski and Sockova, 1977), the Sterkfontein Tourist Cave, South Africa (Niven and Hood, 1978), Fox Hole Cave, Derbyshire (Letheren, 1980), Coldwater Cave, U.S.A. (Lewis, 1981) and in the "sack" or "blind" caves at Creswell Crags (Smithson, 1982; 1985; Gentles, 1985). It has several implications for models of pollen transport into such caves. First, this pattern demonstrates that the atmosphere within the cave does relate and react to the external atmosphere (Cropley, 1965). Thus pollen that is present in the external atmosphere is potentially capable of being transported into the cave system. Second, the differential diurnal pattern of air flow is dependent on the existence of a relative temperature difference and hence air density difference between the cave and its exterior. Records of this pattern of air flow have been noted in caves in areas of arid (sub-tropical), temperate and arctic climates (Dubljanski and Sockova, 1977; Niven and Hood, 1978; Letheren, 1980; Lewis, 1981; Smithson, 1982, 1985) and hence it is reasonable to infer that it is not a "macroclimate" dependent mechanism (Smithson, personal communication). Such a pattern of air flow is likely therefore to have operated throughout the life of the cave - subject to the constraint that the entrance has not been blocked in the past or that other entrances once existed.

Caves with Multiple Entrances

In caves with multiple entrances, several factors affect the throughflow of air (Smithson, 1982). Where cave entrances are separated altitudinally, or differ markedly in their exposure to prevailing wind directions, a "chimney" effect may be observed, where air is drawn through the cave from the low altitude or low exposure entrance to the high altitude or high exposure entrance (Atkinson, 1981). Conversely, the reverse may be observed, with cold, relatively dense, air draining out of the lower entrance and warm air being drawn into the upper entrance, cooling, and then flowing out of the lower entrance (Myers, 1962; Wigley and Brown, 1971; 1976). In both cases a substantial throughput of air may be envisaged, the exact volume of air being dependent on the cross-sectional area of the cave, the length of its passages and the degree of altitudinal separation. The effectiveness of these air currents in transporting pollen and spores will depend on the velocity of the draught created.

The air flow patterns in caves which have multiple entrances grouped at one end of a series of interconnected but "blind" passages are more complex. Generally, however, the air flow pattern observed in the deep cave follows that described for single entrance "sack" caves above. The air flow in the entrance area of Robin Hood's Cave, Creswell Crags, Derbyshire, however, appears to be related to the prevailing external wind direction and the extent of interconnection between the entrances (Smithson, 1982; 1985; Gentles, 1985). Air flow may also be influenced by human acitivites, such as the lighting of fires within the cave, although this is unlikely to provide a major pathway it further complicates the consideration of airborne pollen transport (Gentles and Smithson, 1986). Such complexity of air flow should be kept in mind when comparing pollen sequences recovered from entrance and deep cave locations and inhabited and uninhabited caves.

Caves with Active Streamways

The presence of active streamways within the cave will also affect air flow through the cave since boundary layer effects at the air/water interface will drag air along in the direction of water flow (Wigley and Brown, 1976). In caves where the stream sumps or sinks a return air flow at roof level is often noted (Myers, 1962). Where the stream remains vadose throughout its traverse of the cave system return air flows are less commonly observed and it is usual that air flow should follow stream flow direction (Myers, 1962). Little work has been carried out on the exact effects of active streamways on the microclimates of caves. It is probable, however, that stream-modified air flow may well play an important role as a taphonomic pathway for pollen and spores in the caves that have active or intermittently active streamways.

POLLEN AND SPORE INFLUX VIA AIRBORNE TRANSPORT

In all the above cases the efficiency of airborne transport will depend on the velocity of the air current. Smithson (1982) in a study of diurnal air flow in the "sack" caves at Creswell Crags, Derbyshire, reported weak air flows in the order of 0.2 metres/second. Air flows in multi-entranced caves and caves with active streamways often appear to be considerably higher but at present few accurate measurements of air flow velocity within such caves have been taken. Previous work has shown that the terminal velocity of fall of most pollen and spores lies between 0.01 and 0.1 m/second (Raynor and Ogden, 1965), hence even the low velocity air currents reported in caves will be sufficient to transport pollen and spores without undue sorting by grain density taking place.

In order to establish patterns of airborne pollen movement within caves Van Campo and Leroi-Gourhan (1956) exposed slides coated with glycerine jelly at various locations in several caves within the same area. The caves varied in their lengths, cross sections and whether or not a through-draught of air was present. They concluded that pollen coming into a "blind" or "sack" cave with a single entrance could be traced to about 10 metres from the entrance and that pollen and spore concentrations decreased with increased distance into the cave. In caves with multiple entrances where a through draught of air existed, pollen could be traced much further into the cave. Pollen influxes at 10 metres into the study cave were very low, in the approximate order of 500 to 1000 grains per 500mm^2 per year. Exact pollen influxes per area per year were not determined by Van Campo and Leroi-Gourhan because the pollen trapping period was limited to the summer months.

Pollen taphonomic studies in three "sack" caves at Creswell Crags, Derbyshire (Coles, 1988; Coles *et al*, in preparation) suggest that the sampling location with regard to the distance into the caves has minimal effect on the composition of the pollen and spore assemblage recovered. However, as predicted by distance decay models of pollen deposition from a point source (Turner, 1964; Raynor *et al*, 1970) the concentration of pollen and spore deposition decreased with increased distance into the cave system. Annual pollen influx figures of between 2,500 and 800 grains per 500mm^2 were recorded in the entrance zones while between 1500 and 500 grains per 500mm^2 were recorded in the far chambers at distances of between 15 and 18 metres into the caves.

The Relationship between Areas of Vegetation and Airborne Pollen Transport

Few attempts have been made to assess the relationship between airborne pollen deposition and the area from which pollen assemblages are drawn. Although Van Campo and Leroi-Gourhan (1956) in their study made little attempt to relate pollen rain to external vegetation, they concluded that the deposited pollen was most representative of the local vegetation "within the immediate locality" although this area was not defined by them.

Weinstein (1983) attempted to establish the pollen catchment area of two caves in the Nahal Oren, south of Haifa, Israel, through the examination of modern sediments ("dust") trapped on the walls of the caves. The caves occupied similar altitudinal locations but had opposing aspects. The respective valley sides support slightly different vegetation assemblages and Weinstein found that the pollen assemblage in each cave was closely related to the local vegetation surrounding the cave entrance and the slope immediately above it. She concluded that the results indicated the input of representative "local pollen spectra". From examination of the local vegetation records presented by Weinstein (1983) it is possible to suggest that the "local area" lay within 100 metres to 200 metres of the cave entrance. The period of accumulation of the "dust" and the area sampled was not stated. Therefore it is not possible to estimate the total annual pollen influx or the influx per area.

At Creswell Crags (Coles, 1988; Coles *et al*, in preparation) it was found that the pollen assemblage deposited by airborne transport within the caves is dominated by taxa which grow within the adjacent Creswell Gorge. Up to 90% of the pollen and spore assemblage reaching the caves is composed of taxa which are part of the vegetation within 500 metres of the cave entrance. Further, up to 40% of the taxa represented recorded at the sampling stations have representatives growing within 100 metres of the cave entrance and within the cave entrance itself. It may therefore be suggested that pollen deposited by airborne transport is biased towards pollen and spore components drawn from the Threshold and Local vegetation zones (as defined above).

The influence of airflow may also explain the high frequencies of Filicales (Fern) spores recorded in both modern trapping experiments (Coles, 1988; Coles *et al*, in preparation) and in many palynological analyses of cave sites (e.g. Leroi-Gourhan and Girard 1971; Renault-Miskovsky, 1972; Gale and Hunt, 1986). Ferns are a common component of the cave entrance flora and with decreasing light intensity become the dominant vascular plant group (Lloyd, 1977). Most fern species release their spores at night (Page, 1982) when the pattern of air flow into a cave is one of cool air being drawn in at ground level, while warm air escapes at roof level. This would draw into the cave large numbers of the fern spores released at this time by ferns growing in the cave entrance. Because large numbers of fern spores may enter the cave in this way at present, it follows that high numbers of fern spores in a cave deposit does not necessarily indicate that the pollen and spore assemblage has been subject to extensive weathering (see for example, Dimbleby and Evans, 1974; Dimbleby, 1985, 134).

The presence of dense vegetation in the cave entrance may also have a filtering effect on the air flowing through it and hence may further reduce the numbers of pollen and spores found within the caves (Martin, 1973). Nevertheless, cave pollen diagrams tend to show a marked increase in the numbers of pollen and spores recovered per volume of cave sediment during warm phases of the Quaternary (e.g. O'Rourke and Mead, 1985; Coles, 1988). It would therefore appear probable that the filtration effect (if present) does not drastically affect pollen influx or that pollen and spores re-floated in the Autumn (as discussed in Tauber, 1967b) are subsequently deposited within the cave.

WATERBORNE POLLEN TRANSPORT

Two forms of hydraulic transport of pollen and spores into cave systems may be envisaged: (1) transport in water or as sediment by streams entering cave systems through swallets or sinkholes and (2) transport by water which has percolated through bedrock, or in downward percolating water infiltrating through the cave sediment.

Transport by Streams

That waterborne pollen and spores will pass through cave systems has been shown by Zotl (1959) and Atkinson (1968) who used *Lycopodium* spores to trace sink-riser connections and incidentally demonstrated the movement of pollen and spores through phreatic or largely phreatic cave systems. In the largely vadose Flint-Mammoth cave system of Central Kentucky, U.S.A., Peterson

(1976) demonstrated that pollen was transported by streamways into cave passages for a distance of a least 0.8 km (his furthest sampling station from an input point) without notable decline in concentration.

Peterson (1976) found that the pollen and spores occurred with sand, silt and organic matter in passages with a flow regime sufficient to transport sand. The pollen spectra recovered from different points along cave streams below a given input showed little variation and Peterson concluded that there was little evidence for hydraulic sorting of pollen and spores along the passage studied. Whether this holds true for other cave systems is presently unknown. Peterson further noted that pollen-bearing cave sediments in active streamway passages were subjected to continual reworking or sorting. He suggested that the high incidence of degraded grains in the streams resulted from bacterial attack during transport and repeated reworking rather than mechanical abrasion during transport.

Stream Catchment and Pollen Catchment

Several papers have been published on the transport of pollen and spores by streams and rivers; many more have been published on pollen deposition in lakes and ponds. In consequence, the derivation of pollen and spores deposited in lake sediments, and in part in streams, is now relatively well understood (e.g. Davis, 1967, 1968; Peck, 1973; Crowder and Cuddy, 1973; Pennington, 1973; Bonny, 1976). In general it has been found that rivers and streams will carry a pollen load that reflects the vegetation of the hydrological catchment area together with a regional rain-out component (Birks and Birks, 1980, 182). In consequence the greater the area of the hydrological catchment the more "regional" the pollen spectra recorded.

That this is probably also true for streams entering cave systems via swallets was demonstrated in the Flint-Mammoth study of Peterson (1976). He established that the pollen load of streams within the cave system was directly related to the pollen load of streams entering the cave system via swallets. He further noted that the pollen load reflected the vegetation of the hydrological catchment area surrounding and upstream of the point of input.

On the basis of this limited evidence it is suggested that rivers entering a cave system via a swallet carry a pollen load that reflects the vegetation of the river catchment from which the stream originated. Pollen and spores transported by streams would therefore tend to be dominated by regional pollen components and that these would resemble those of a "normal" stream catchment such as that illustrated by Peck (1973) or Crowder and Cuddy (1973). This pollen load could then be incorporated into fluviatile sediments within the cave in a manner similar to that from unenclosed rivers (Brush and Brush, 1972).

Pollen Transport by Percolating Ground-Water

Several workers have noted the presence of downward percolating "ground-waters" entering cave systems. Previous studies of these "drip flows" or "seepages" has taken place in the context of karst process studies (Trudgill, 1985) although several workers have been aware that such flows may potentially transport pollen and spores (e.g. Van Campo and Leroi-Gourhan, 1956; Dimbleby, 1985) no previous experimental investigation of this transport mechanism has come to our attention.

In most caves "drip-flows" are sporadic in distribution, but are present throughout the system. In spite of the notable porosity of some limestones (such as the Magnesian Limestone at Creswell Crags, see Kaldi, 1980), these "drip flows" generally appear to be related to areas of faulting or fissuring of the bedrock. This water is ultimately derived from the ground surface above the caves and in several cases flow rates can be shown to closely relate to surface rainfall (Pitty, 1966). As a result, it is possible that, in rock with areas of high permeability, this water may carry pollen down from the ground surface through fissures to be redeposited in the cave - in this case the pollen spectra represented will probably reflect the local vegetation above the cave together with a small regional component (see for comparison, Andersen, 1974).

Several authors have commented on the possible effects of such seepage. Dimbleby (1985) considered that the results obtained by Damblon (1974) and Bastin (1979, 1982) from the analysis of flowstones and stalagmites were "a clear indication that pollen is being transported by water into the cave system" (Dimbleby, 1985, 128). An alternative hypothesis, however, is that pollen is brought in as airfall and is redeposited by water flowing down the walls of the cave onto the surface of the flowstone or stalagmite into which it is then incorporated by the continued growth of the flowstone. Indeed the spatial pattern of gradual reduction in pollen and spore concentration with increasing distance into the cave noted by Van Campo and Leroi-Gourhan (1956) and the authors (Coles *et al*, in preparation) for airborne pollen and spores is possibly reflected in the results obtained by Bastin (1979). Nevertheless in one case he was able to demonstrate the presence of pollen in stalagmite formations at up to 600 metres from the cave entrance which may indicate local "seepage". Bastin (1979) believed that the assemblages recovered represented "local" pollen spectra although he did not define the area described as "local".

Experimental trapping of downward percolating "groundwater" in C7 Cave, Creswell Crags, Derbyshire (Coles, 1988), has recorded little evidence for pollen transport by this route. It was suggested that this was the negative result of the effective "filtration" of pollen and spores from downward percolating water by the soil and vegetation mat overlying the limestone bedrock. If correct this would imply that the presence/absence of soil and vegetation is the crucial control on the downward movement of pollen and spores. It was acknowledged, however, that percolating water flowing down the cave walls may play a role in moving pollen and spores deposited as airfall on the cave walls into areas of sediment deposition on the cave floor.

With so little experimental evidence available, the case for pollen and spores being brought into the cave via seeping "ground waters" must therefore remain open. The impact of water infiltrating through cave sediments is at present unclear. It forms part of a complex series of pollen/spore movements in cave sediments which are currently under investigation. The preliminary results suggest that in the Creswell Crags cave sediments infiltration-based transport is not important.

ANIMAL AND INSECT-BORNE POLLEN TRANSPORT

The effect of insects, animals and people in bringing pollen into cave systems was discussed by Van Campo and Leroi-Gourhan (1956) who suggested that increased pollen concentrations observed in cave passages and in areas with a high probable density of human or animal occupation resulted from the transport of pollen and spores into the cave system on hands and feet and by animals on their paws and fur.

Five possible animal/insect borne pathways for pollen and spores can be envisaged:

(1) Transport on the exterior of the animal or insect vector concerned: in this case the pollen present will directly reflect the vegetation through which the vector last travelled and which will therefore tend to have bias towards the local vegetation component.

(2) Indirect pollen transport on the exterior of the animal or insect in the form of soil or sediment containing pollen adhering to the animal. In this case the pollen may well be redeposited from completely different contexts.

(3) Pollen transport within the gut. This may be redeposited in the cave either in the form of faeces or as the result of the animal/insect's death and the resultant decomposition of the carcass and incorporation of the animal's gut contents into the cave sediments. In this context it has been observed by Dimbleby (1985, 134) that pollen and spores are remarkably resistant to digestion by animals or insects (Dimbleby, 1978, 114) and thus may be passed along a food chain and eventually voided by the carnivore at the end of that chain.

(4) Pollen transport on bedding or food materials brought into the cave by animals using it as a den (Bright and Davis, 1982; Davis and Anderson, 1987).

(5) The introduction of pollen and spores into cave sediments, actively or passively, by organisms which are bioturbating the cave sediments.

The Vegetation reflected by Insect- and Animal-borne Pollen and Spores

The pollen load of insect vectors such as the Honey Bee has received attention from many authors including Hodges (1952) and Faegri (1961). The effects of insect vectors on the composition of pollen spectra from non-cave terrestrial environments have been considered by Bottema (1966, 1975) who suggested that the pollen load of each insect species will depend on the feeding preference of that species and will convey little information on the overall vegetation composition. Van Zinderen Bakker (1982) suggested that insect vectors may be an important taphonomic pathway for pollen entering the cave system, but no published experimental work has yet been directed at this problem.

Ingram (1969) in his study of the desiccated carcasses of mammals from Thylacine Hole Cave, Western Australia, showed the potential importance of animals for the transport of pollen into cave systems. He studied the gut contents of the desiccated remains of *Megaleia rufa* (red kangaroo), *Trichosorus vupecula* (possum), *Onychogaleae lunata* (crescent-tailed wallaby) and *Canis familiaris* (dingo) and obtained results from the first three specimens. He concluded that the pollen and spore assemblages recovered represented, in large part, the diet of the animal concerned and therefore gave only a "second rank approximation" of the external vegetation at the time of the animal's death. He did not discuss the relationship between the modern diets of living relatives of the animals examined and the diets of the desiccated carcasses.

Analysis of desiccated coprolites found within cave sites has been carried out with the aim of establishing the ancient diet of animals (Martin *et al.*, 1961; Thompson *et al.*, 1980; Bright and Davis, 1982) and man (Schoenwetter, 1974; Bryant, 1974). Studies of cave coprolites have generally been interpreted in terms of palaeo-diet (e.g. Martin *et al.*, 1961; Bright and Davis, 1982); however, comparison between plant cuticle and pollen evidence in Shasta Ground Sloth *(Nothrotheriops shastense)* dung led Thompson *et al* (1980) to conclude that "the pollen spectra contain little dietary information" and they suggest that the "pollen frequencies may reflect the regional pollen rain . . . incidentally ingested as the sloth consumed pollen-dusted leaves and twigs".

Analysis of Packrat *(Neotoma)* middens supports this contention and suggests that animal den deposits will tend to largely reflect local and regional vegetation rather than dietary factors (Davis and Anderson, 1987).

The effectiveness of animal or insect vectors in bringing pollen and spores into the cave is dependent on several factors. These are: first, the availability of a suitable vector, for instance the presence of animals with dens in the caves; second, the type and size of animals using the caves (for instance carnivores or herbivores, mega- or micro-fauna); and third, the length of occupation by the animal or insect vector (for instance was it a single accidental occurrence, or was it a regular seasonal behaviour of that species?). The effect of animal and insect transport is obviously difficult to quantify and to some extent is dependent upon the recognition of the context of material remains (bones, teeth, insect remains, etc) in the sedimentary record. The necessity for multidisciplinary research in caves is underscored by this observation.

Human Influence on the Pollen Record from Caves

Direct human influence on the pollen spectra of caves has been considered by Van Campo and Leroi-Gourhan (1956), Kautz (1980) and Van Zinderen Bakker (1982).

Van Campo and Leroi-Gourhan (1956) in discussing "occupation areas" noted that the pollen spectra from such situations were often dominated by herbs, especially aquatics and plants of the water's edge. High frequencies of ferns were also noted. They suggested that many of the herb species could have been brought in as food and that the high fern frequencies resulted from the practice of using ferns as bedding. A similar conclusion was reached by Van Zinderen Bakker (1982) at Wonderwerk Cave, South Africa, who suggested that very high frequencies of grass pollen may indicate the bringing in of bedding material. However, at Kirkhead Cave, Cumbria, Gale and Hunt (1985) suggested that high frequencies of fern spores did not reflect human activity but recorded the airborne introduction of spores from ferns growing in the cave entrance.

Leroi-Gourhan has suggested that the presence of clusters of pollen may represent the presence of anthers or fallen flowers (Leroi-Gourhan and Girard, 1979). At Shanidar Cave, Iraq, high concentrations of pollen from flowering plants were consistently noted in the sediments surrounding a Mousterian grave, but not in sediments from elsewhere in the cave that were believed to be contemporary with the burial (Leroi-Gourhan, 1968, 1975). It was suggested by Leroi-Gourhan that these high concentrations were the result of the placing of a "floral tribute" in the grave. A similar pattern had been previously reported by Van Campo and Bouchard (1962) at Roc de Marsal, Commune du Bugue (Dordogne), where high frequencies of herbaceous pollen were found in several Mousterian graves. On the basis of the pollen and spore assemblage recovered Van Campo and Bouchard (1962) also suggested the season of burial. However, problems exist in making attributions of this type. In particular, no published consideration was given to the problem of differentiating between pollen entering the grave while the body was being buried and the pollen and spores that may have been already present in the sediments removed and then (presumably) replaced to form the grave fill.

At Guitarrero Cave, Peru, Kautz (1980) interpreted changes in the relatively high frequencies of pollen from possible food plants recorded during periods of human occupation in terms of the "palaeoethnobotany" of the human groups concerned. Kautz inferred that much of the pollen introduced into the cave was introduced directly on the food itself. This would appear to need qualification, given that the majority of plants postulated as being introduced into the cave would have only been of value as food sources many months after their respective flowering seasons.

A SIMPLE MODEL OF POLLEN DERIVATION AND TRANSPORT IN CAVES

An initial model of pollen transport into cave systems derived from the above considerations is proposed and summarised in figure four. This shows four generalised hypothetical pollen and spore transport pathways.

Airborne pollen transport: On the basis of distance decay models (e.g. Turner, 1964) it is suggested that airborne transport will contribute components drawn (with decreasing importance) from the threshold, local and regional vegetation of the area around the cave. Pollen deposition from airborne transport will be dependent upon the specific microclimate of the cave. In sack caves it has been suggested that the density of pollen deposited per given area will decrease in relation to the distance of the sampling location from the entrance. In caves with two or more entrances or flowing water a more complex pattern may be envisaged; however, the presence of regular and constant air currents into the cave suggests that the airborne pollen component will consistently reflect changes in the external vegetation, because this transport mechanism is neither localised or seasonal.

Waterborne pollen transport: Streams entering cave systems via swallets will carry a pollen load that reflects the vegetation and/or soils of the hydrological catchment of the stream. Pollen assemblages contributed by streams will therefore tend to reflect regional and local components. The exact relationship between these components will be determined by the size of the hydrological catchment - increasing catchment size will increase the regional component at the expense of the local one, and the micropalaeontology and erodability of the soils and bedrocks of the area.

It may be expected that pollen brought into the caves through "drip flows" would result in localised concentrations of pollen adjacent to areas of high bedrock permeability. These pathways will tend to be localised and it would be very unlikely that there would be a direct relationship between distance into the caves and pollen deposition density. Pollen and spores entering the cave in this way would reflect the local vegetation and soils directly above the cave.

Human/Animal/Insect-Borne pollen transport: Pollen brought into the caves on animal or insect vectors will probably tend to reflect the local vegetation of that vector's habitat. It was anticipated that deposition by animal/insect vectors would be irregular in spatial distribution and largely reflect that vector's specific use of the cave environment. Human transport of pollen will reflect the introduction of bedding, food and raw materials into the cave and will have little relationship to the composition of the vegetation in the external environment as a whole. Such transport is difficult to quantify and its overall contribution is at present unknown.

Post-Depositional pathways: Sediment reworking and bioturbation remain the most obscure of the pathways under consideration and to which current experimental study is addressed.

Effectiveness of each transport pathway: As noted above it would appear probable that the mechanism of airborne pollen transport into caves is not climate dependant and does introduce pollen and spores representative of the surrounding vegetation. Unlike animal/insect vectors and waterborne transport it would have continued to operate throughout both "warm" and "cold" stages of the Quaternary. This may suggest that the dominant mode of pollen deposition in caves is airborne and that water and animal/insect borne transport are responsible for additional inputs into specific locations, governed by the geomorphology of the cave and the areas of insect, animal and human use or occupation, within the cave under special conditions (presence of free water, presence of suitable animal/insect vector, animal dens, etc.). This may suggest the desirability of examining two parallel lithostratigraphically related sample columns of sediment through a cave deposit in order to reduce the possibility of these localised factors biasing the results.

The model proposed suggests that the composition of the pollen and spore assemblage deposited in the cave environment will be governed by the overall contribution of each transport mechanism to the sediments under investigation.

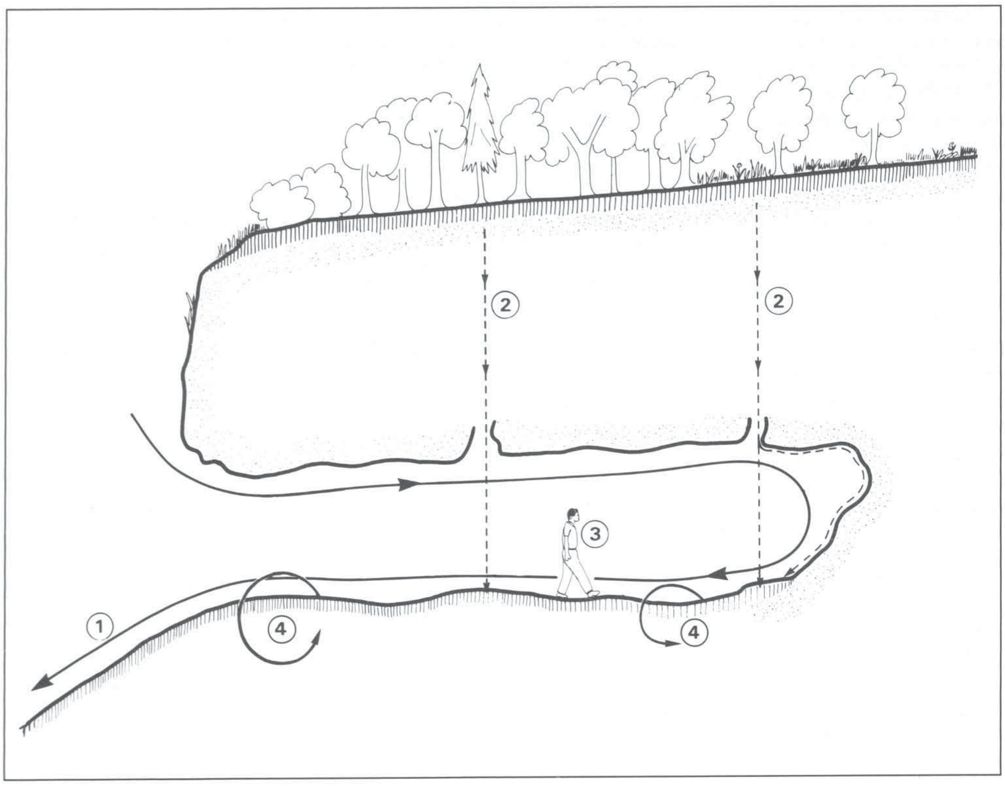


Figure 4. A taphonomic model of pollen and spore deposition in cave systems: A section through an idealised cave showing the possible transport pathways of pollen and spores; (1) Airborne transport (2) Waterborne transport pathway (shown here as downward percolating "ground water"), (3) Animal (including man) and Insect-borne transport, (4) Reworking and Bioturbation.

CONCLUSIONS

A major theoretical critisism of the body of cave palynology undertaken to date has been the lack of consideration of the taphonomy of pollen and spores in cave systems. The interpretation of cave pollen diagrams has therefore, to a great extent, depended upon the intuitive assertion that some sort of relationship must exist between the pollen and spores within a cave and the external vegetation from which it is derived (Dimbleby, 1985). This relationship has not been investigated in the same way as, for example, the mode of pollen transfer in forested areas or the recruitment of pollen into lakes.

This paper has attempted to review the processes by which pollen and spores are transported into caves and the respective areas from which pollen and spores transported by differing agencies may be drawn. A simple model of pollen derivation and transport into cave system has been proposed as a basis for future research. The paper has highlighted our present ignorance of many areas of pollen taphonomy in caves. However, several interim conclusions can be drawn.

1. The area from which pollen and spores are derived will depend on the mechanism by which the pollen and spores are transported.
2. Caves in which the dominant mode of pollen transfer from the external environment is by airborne transport will reflect a local pattern of vegetation and will often be strongly influenced by the composition of the vegetation of the cave threshold zone, where the filtration effects of vegetation may also be important.
3. Conversely caves where the dominant mode of pollen transfer from the external environment is by waterborne transport will reflect a wider catchment and will closely reflect the vegetation and soils (and possibly bedrock) of the hydrological catchment from which the streamway derives its water.
4. It may therefore be suggested that any understanding of palynological assemblages from cave sites must be prefaced by an understanding of the sedimentary depositional environment of the cave sediments being investigated.
5. Further, the influence of animals, insects and man upon the composition of pollen and spore assemblage from cave sites has often been underestimated. Therefore an understanding of pollen accumulation must again be considered in the light of faunal or archaeological evidence for the use of the cave as a den, roost or human occupation site.
6. The post-depositional history of pollen and spores in cave sediments merits further study.

Such factors result in a complex interacting series of taphonomic effects which influence caves and that these processes need to be more fully understood to facilitate the reliable interpretation of pollen diagrams from cave sediments. Failure to understand these processes, and the extent to which they may differ in rate or type from those affecting more familiar palynological study sites, as well as the use of inappropriate models of pollen derivation and transport, may have led many critics to suggest that caves do not produce "reliable" palynological data. Consequently when it can be shown that changing frequencies of pollen and spores in cave sediments result from changes in the composition of the vegetation in the external environment which have been affected by a complex series of taphonomic processes, and do not result from the random reworking or recycling of pollen and spores or the infiltration and modern contamination of the sediment, then the palynological analysis of cave deposits may yet be regarded as a useful palaeoenvironmental and bio-stratigraphic technique.

It may be concluded that if cave palynology is to cease being a "neglected tool in British cave studies" (Hunt and Gale, 1985), then future research should be directed towards the better understanding of the taphonomic processes governing the formation of pollen and spore assemblages in cave sediments.

ACKNOWLEDGEMENTS

G. M. Coles acknowledges a Science and Engineering Research Council CASE award in the Department of Archaeology and Prehistory at the University of Sheffield. The authors wish to thank the SERC, Derbyshire County Council and Nottinghamshire County Council for financial support during this research, as well as Dr. P. A. Smithson of the Department of Geography, University of Sheffield, and the staff and volunteers of the Creswell Crags Visitors Centre for assistance, facilities and access to the Creswell Caves, England, where many of the observations above were formulated.

BIBLIOGRAPHY

Andersen, S. T., 1974. Wind conditions and pollen deposition in a mixed deciduous forest I: Wind conditions and pollen dispersal. *Grana,* Vol. 14, p. 57-63.

Atkinson, T.C., 1968. Tracing swallet waters using *Lycopodium* spores. *Transactions Cave Research Group Great Britain,* Vol. 10, p. 99-106.

Atkinson, T.C., 1981. The climate of Castleguard Cave, Canada. *Proceedings 8th International Speleological Congress,* p. 322-324.

Bastin, B., 1979. Essai de définition d'une terminologie précise applicable au commentaire des diagrammes polliniques se rapportant au Quaternaire. *Bulletin Soc. Royale Botanique Belgique,* Vol. 112, p. 7-12.

Bastin, B., 1982. Premier bilan de l'analyse pollinique de stalagmites Holocènes en provenance de grottes Belges. *Revue Belge de Géographie,* Vol. 106, p. 87-97.

Beaulieu, J. L. de, 1969. Analyse pollinique des sediments du sol de la cabane Acheuléene du Lazaret. In M. de. Lumley *(et al)* Une cabane Acheuléene dans la Grotte du Lazaret (Nice). *Mémoire Soc. Préhistorique Francaise,* Vol. 7, p. 125-126.

Birks, H. J. B., 1973a. *The past and present vegetation of the Isle of Skye: A palaeoecological study.* Cambridge University Press, Cambridge.

Birks, H. J. B., 1973b. Modern pollen rain studies in some Arctic and Alpine environments. *In* Birks, H.J.B. and West, R. G. (eds), 1973. *Quaternary Plant Ecology.* Blackwell Scientific Publications, Oxford, London and Edinburgh, p. 143-168.

Birks, H. J. B. and West, R. G. (eds), 1973. *Quaternary Plant Ecology.* Blackwell Scientific Publications, Oxford, London and Edinburgh.

Birks, H. J. B. and Birks, H. H., 1980. *Quaternary Palaeoecology.* Edward Arnold, London.

Bonny, A. P., 1976. Recruitment of pollen to the seston and sediments of some English Lake District lakes. *J. Ecology,* Vol. 64, p. 859-887.
Bottema, S., 1966. Palynological investigation of a settlement near Kalopsidha (Cyprus). *In* Astrom, P. *et al.* (eds), 1966. Excavations at Kalopsidha and Aylos Iakovos in Cyprus. *Studies in Mediterranean Archaeology,* Vol. 2, p. 133-134.
Bottema, S., 1975. The interpretation of pollen spectra from prehistoric settlements (with special attention to Liguliflorae). *Palaeohistoria,* Vol. 17, p. 17-35.
Bright, R. C. and Davis O. K., 1982. Quaternary palaeoecology of the Idaho National Engineering Laboratory, Snake River Plain, Idaho. *American Midlands Naturalist,* Vol. 108, p. 21-33.
Brush, G. S. and Brush L. M. Jr., 1972. Transport of pollen in a sediment-laden channel: A laboratory study. *American J. Science,* Vol. 272, p. 359-381.
Bryant, V. M., 1974. Pollen analysis of prehistoric human faeces from Mammoth Cave. *In* Watson, P. J. (ed), 1972. *Archaeology of the Mammoth Cave Area.* Academic Press, New York, p. 203-210.
Coles, G. M., 1988. *Aspects of the application of palynology to cave deposits in the Magnesian Limestone region of North Nottinghamshire.* Unpublished Ph.D. Thesis. University of Sheffield.
Coles, G. M., Gilbertson, D. D., Hunt, C. O. and Jenkinson, R. D. S. (In Preparation) Airborne pollen budget of three caves at Creswell Crags, North Nottinghamshire.
Cropley, J. B., 1965. Influence of surface conditions of temperatures in large cave systems. *Bulletin National Speleological Soc. America,* Vol. 27, p. 1-10.
Crowder, A. A. and Cuddy, D. G., 1973. Pollen in a small river basin: Wilton Creek, Ontario. In Birks, H. J. B. and West, R. G. (eds), 1973. *Quaternary Plant Ecology.* Blackwell Scientific Publications, Oxford, London and Edinburgh, p. 61-78.
Cubbon, B. D., 1970. Flora records of the cave research group of Great Britain from 1939 to June 1969. Transactions Cave Research Group of Great Britain, Vol. 12, p. 57-74.
Cubbon, B. D., 1972. Flora Records for 1969-1970. *Transactions Cave Research Group of Great Britain,* Vol. 14, p. 201-203.
Cubbon, B. D., 1976. Cave Flora. In Ford, T. D. and Cullingford, C. H. (eds), 1976. *The Science of Speleology.* Academic Press, London, p. 423-452.
Dalby, D. H., 1966. The growth of plants under reduced light. *Studies in Speleology,* Vol. 1, p. 193-203.
Damblon, F., 1974. Nouvelles recherches à la grotte de Remouchamps. *Bulletin Soc. Royale Belge d'Anthropoligique et de Préhistoire,* Vol. 85, p. 132-155.
Davis, M. B., 1967. Pollen accumulation at Rogers Lake, Connecticut, during Late- and Post-Glacial Time. *Review Palaeobotany Palynology,* Vol. 2, p. 219-230.
Davis, M. B., 1968. Pollen grains in lake sediments; Redeposition caused by seasonal water circulation. *Science,* Vol. 162, p. 796-799.
Davis, O. K. and Anderson, R. S., 1987. Pollen in Packrat *(Neotima)* middens: Pollen transport and the relationship of pollen to vegetation. *Palynology,* Vol. 11, p. 185-198.
Dimbleby, G. W., 1978. *Plants and Archaeology.* (second edition) John Baker, London.
Dimbleby, G. W., 1985. *The Palynology of Archaeological Sites.* Academic Press, London.
Dimbleby, G. W. and Evans J. G., 1974. Pollen and land snail analysis of calcareous soils. *J. Archaeological Science,* Vol. 1, p. 117-133.
Dobat, K., 1970. Considerations sur la vegetation cryptogaminque des grottes du Jura Souabe (sud-ouest de L'Allemagne) *Annales de Speleologie,* Vol. 25, p. 871-907.
Dubljanski, V. N. and Sockova, L. M., 1977. Microclimate of karst cavities of the mountain Crimea. *Proceedings 7th International Speleological Congress,* p. 158-160.
Efremov, I. A., 1940. Taphonomy: A new branch of palaeontology. *Pan-American Geologist,* Vol. 74, p. 81-93.
Faegri, K., 1961. Palynology of a bumble-bee nest. *Veroffentlichungen des Geobotanischen Institutes Rubel in Zurich,* Vol. 37, p. 60-67.
Gale, S. J. and Hunt C. O., 1985. The stratigraphy of Kirkhead Cave an Upper Palaeolithic site in northern England. *Proc. Prehistoric Soc.,* Vol. 51, p. 283-304.
Gentles, D. S., 1985. *Troglodytes and Pyromania: Present and Palaeolithic.* Unpublished B.A. Dissertation, Department of Archaeology and Prehistory, University of Sheffield.
Gentles, D. S. and Smithson, P. A., 1986. Fires in Caves: Effects on Temperature and Airflow. *Proc. Univ. Bristol Speleological Soc.,* Vol. 17, p. 205-217.
Gidman, C., 1975. Biological studies in Ingleborough Cavern. *Transactions British Cave Research Assoc.,* Vol 2, p. 116-122.
Glennie, E. A. and Hazelton, M. H., 1962. Cave Flora and Fauna. In Cullingford, C. H. D. (ed), 1976. *British Caving.* Routledge, London.
Hicks, S. P., 1977. Modern pollen rain in Finnish Lapland investigated by analysis of surface moss samples. *New Phytologist,* Vol. 78, p. 715-734.
Hodges, D., 1952. *The Pollen Loads of the Honey Bee.* Printed Privately, London.
Hunt, C. O. and Gale, S. J., 1985. Palynology: a neglected tool in British Cave Studies. *In* Paterson, K. and Sweeting, M. M. (eds), 1985. *New Directions in Karst Studies.* Geo Books, Norwich, p. 319-328.
Ingram, B. S., 1969. Sporomorphs from the desiccated carcasses of mammals from Thylacine Hole, Western Australia. *Helicite,* Vol. 7, p. 62-66.
Jenkinson, R. D. S. and Gilbertson, D. D., 1984. *In the Shadow of Extinction: The Archaeology and Palaeoecology of the Lake, Fissures and Smaller Caves at Creswell Crags, S.S.S.I,* University of Sheffield Monographs in Prehistory and Archaeology, Sheffield.
Kaldi, J., 1980. *Aspects of the Sedimentology of the Lower Magnesian Limestone (Permian) of Eastern England.* Unpublished Ph.D Thesis. University of Cambridge.
Kautz, R. R., 1980. Pollen analysis and paleoethnobotany. *In Guitarrero Cave - Early man in the Andes.* Academic Press, New York and London, p. 45-63.
Leroi-Gourhan, A., 1966. La Grotte de Prélétang (Commune de Presles, Isère) (II): Analyse pollinique des sédiments. *Gallia Préhistoire,* Vol. 9, p. 85-92.
Leroi-Gourhan, A., 1968. Le Néanderthalien IV de Shanidar. *Bulletin Soc. Préhistorique Francaise,* Vol. 65, p. 79-83.
Leroi-Gourhan, A., 1975. The flowers found with Shanidar IV, a Neanderthal burial in Iraq. *Science,* Vol. 190, p. 562-564.
Leroi-Gourhan, A. and Girard, M., 1971. L'Abri de la Cure à Baulmes (Suisse). Analyse pollinique - avec une introduction de M. Egloff. *Annales Soc. Suisse Préhistoire et d'Archeologie,* Vol. 56, p. 7-15.
Leroi-Gourhan, A. and Girard, M., 1979. Analyses polliniques de la Grotte de Lascaux. Lascaux Inconnu: 12e. Supplément à *Gallia Préhistoire,* p. 75-80.
Letheren, J., 1980. Evidence for thermal air currents in a small cave with a single narrow entrance from an outer chamber. *Transactions British Cave Research Assoc.,* Vol. 7, p. 169-178.
Lewis, W. C., 1981. The breathing of coldwater cave. *Proceedings 8th International Speleological Congress,* p. 89-90.
Lloyd, O. C., 1977. Ferns in Cave entrances. *Proceedings 7th International Speleological Congress,* p. 288.
Martin, H. A., 1973. Palynology and historical ecology of some cave excavations in the Australian Nullarbor. *Australian J. Botany,* Vol. 21, p. 283-316.
Martin, P. S., Sabels, B. E. and Shutler, D., 1961. Rampart cave coprolite and ecology of the Shasta Ground Sloth. *American J. Science,* Vol. 259, p. 102-127.
Mason-Williams, A., 1965. The growth of fungi in caves in Great Britain. *Studies in Speleology,* Vol. 1, p. 96-99.
Mason-Williams, A. and Benson-Evans, K., 1958. *A preliminary investigation into the bacterial and botanical flora of caves in South Wales.* Cave Research Group of Great Britain Publication No.8. Cave Research Group of Great Britain, Berkhampstead.
Myers, J. O., 1962. Cave Physics. *In* Cullingford, C. H. D. (ed), 1962. *British Caving* (Second Edition). Routledge and Kegan Paul, London, p. 226-251.
Niven, F. M. and Hood, G. M., 1978. Diurnal atmospheric characteristics of the Skertfontein tourist cave. *South African J. Science,* Vol. 74, p. 134-136.
O'Rourke, M. K. and Mead, J. I., 1985. Late Pleistocene and Holocene pollen records from two caves the Grand Canyon of Arizona, USA. *Assoc. American Stratigraphic Palynologists Contribution Series,* Vol 16, p. 169-186.
Page, C. N., 1982. *The Ferns of Britain and Ireland.* Cambridge University Press, Cambridge and London.
Peck, R. M., 1973. Pollen budget studies in a small Yorkshire catchment. *In* Birks, H. J. B. and West, R. G. (eds), 1973. *Quaternary Plant Ecology.* Blackwell Scientific Publications, Oxford, London and Edinburgh, p. 43-60.
Pennington, W., 1973. Absolute pollen frequencies in the sediments of lakes of different morphometry. *In* Birks, H. J. B. and West, R. G. (eds), 1973. *Quaternary Plant Ecology.* Blackwell Scientific Publications, Oxford, London and Edinburgh, p. 79-104.
Peterson, G. M., 1976. Pollen analysis and the origin of cave sediments in the central Kentucky karst. *Bulletin National Speleological Soc. America,* Vol. 38, p. 53-58.
Piearce, T. G., 1975. Observations on the fauna and flora of Ingleborough Cavern, Yorkshire. *Transactions British Cave Research Assoc.,* Vol. 2, p. 107-115.
Pitty, A. F., 1966. *An approach to the study of karst water - illustrated by results from Poole's Cavern, Buxton.* Occasional Papers in Geography Number 5, University of Hull.
Raynor, G. S. and Ogden, E. C., 1965. Twenty-four hour dispersion of ragweed pollen from known sources. *Upton, New York, Brookhaven National Laboratory Report Number BNL 957 (T-398).*
Raynor, G. S., Ogden, E. C. and Hayes, J. V., 1970. Dispersion and deposition of Ragweed pollen from experimental sources. J. Applied Meteorology, Vol. 9, p. 885-895.
Renault-Miskovsky, J., 1972. La végétation pendant le Würmien II aux environs de la Grotte de l'Hortus (Valflaunès, Hérault) D'après l'étude des pollens. *Etudes Quaternaires,* Vol. 1, p. 313-324.
Schoenwetter, J., 1974. Pollen analysis of human paleofaeces from Upper Salt Cave. *In* Watson, J. (ed), 1974. *Archaeology of the Mammoth Cave Area.* Academic Press, London and New York, p. 49-58.
Scott, L., 1984. Fossil pollen grains from coprolites as indicators of late Quaternary environments near Taung, South Africa. *In* Utting, J. (ed), *Abstracts Sixth International Palynology Conference (Calgary),* p. 150.
Scott, L., 1987. Pollen analysis of hyaena coprolites and sediments from Equus cave, Taung, Southern Kalahari (South Africa). *Quaternary Research,* Vol. 28, p. 144-156.
Smithson, P. A., 1982. Temperature variations in Creswell Crags Caves (near Worksop). *East Midlands Geographer,* Vol. 8, p. 51-64.
Smithson, P. A., 1985. Cave micro-climates at Creswell Crags. In Briggs, D. J., Gilbertson, D. D. and Jenkinson, R. D. S., 1985. *Peak District and Northern Dukeries Field Guide.* Quaternary Research Association, Cambridge, p. 159-164.
Tauber, H., 1965. Differential pollen dispersion and the interpretation of pollen diagrams. *Danmarks Geologiske Undersøgelse (series II),* Vol. 89, 69p.
Tauber, H., 1967a. Investigations of the mode of pollen transfer in forested areas. *Review Palaeobotany Palynology,* Vol. 3, p. 277-286.
Tauber, H., 1967b. Differential pollen dispersion and filtration. *In* Cushing, E. J. and Wright, E. H. (eds), 1967. *Quaternary Palaeoecology.* Yale University Press, Yale, p. 131-141.
Terrell-Nield, C. E., 1985. Analysis of the invertebrate cave community in Robin Hood's Cave, Creswell Crags. *In* Briggs, D. J., Gilbertson, D. D. and Jenkinson, R. D. S. (eds), 1985. *Peak District and Northern Dukeries Field Guide.* Quaternary Research Association, Cambridge, p. 165-177.
Thompson, R. S., Van Devender, T. R., Martin, P. S., Foppe, T. and Long, A., 1980. Shasta Ground Sloth *(Nothrotheriops shastense)* at Shelter Cave, New Mexico, USA: environment diet and extinction. *Quaternary Research,* Vol. 14, p. 360-376.
Trudgill, S., 1985. *Limestone Geomorphology.* Longman, London.
Turner, C., 1985. Problems and pitfalls with the application of palynology to Pleistocene archaeological sites in Western Europe. *In* Renault-Miskovsky, J., 1985. *Palynologie Archaeologie. Centre de Recherches Archaeologiques Notes et Monographies Techniques,* Vol. 17, p. 347-372.
Turner, J., 1964. Surface sample analysis from Ayrshire Scotland (with appendix by David Nicol). *Pollen et Spores,* Vol. 6, p. 583-592.
Van Campo, M. and Leroi-Gourhan, A., 1956. Note préliminaire à l'étude des pollens fossiles de différents niveaux des grottes D'Arcy-sur-Cure. *Bulletin Muséum Soc. Préhistoire Francais,* Vol. 28, p. 326-330.
Van Campo, M. and Bouchard, J., 1962. Palynologie et paléontologie du Quarternaire. - Flore accompagnant le squelette d'enfant moustérien découvert au Roc de Marsal, Commune du Bugue (Dordogne) et première étude de la faune de gisement. *Séance,* Vol. 254, p. 897-899.
Van Zinderen Bakker, E. M., 1982. Pollen analytical studies of the Wonderwerk Cave, South Africa. *Pollen et Spores,* Vol. 24, p. 235-250.
Weinstein, M., 1983. The influence of slope direction on the pollen spectra. *Pollen et Spores,* Vol. 23, p. 381-387.
West, R. G., 1973. Introduction. *In* Birks, H. J. B. and West, R. G. (eds), 1983, *Quaternary Plant Ecology.* Blackwell Scientific Publications, Oxford, London and Edinburgh, p. 1-6.
Wigley, T. M. L. and Brown, M. C., 1971. Geophysical applications of heat and mass transfer in turbulent pipe flow. *Boundary Layer Meteorology,* Vol. 1, p. 300-320.
Wigley, T. M. L. and Brown M. C., 1976. The physics of caves. *In* Ford, T. D. and Culingford, C. H. (eds), 1976. *The Science of Speleology.* Academic Press, London, p. 329-358.
Zotl, J., 1959. *Steirische Beitrage zur Hydrologie.* Graz: Graz, p. 125-157.

Received August 1989

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

THE ARCHAEOLOGICAL CAVES OF CRESWELL CRAGS

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Creswell Crags are of great international significance, being uniquely important for the study and understanding of human origins in Europe. The caves at Creswell, on the Nottinghamshire-Derbyshire border, represent the most northerly concentration of early prehistoric human occupation that has survived anywhere in the world. Archaeological deposits of the Middle and Late Pleistocene age (from 150,000 to 10,000 years ago) as rich as those at Creswell Crags are an extremely rare resource.

Equally important are the wealth of archaeological finds from the Creswell caves which just post-date the height of the Last Ice Age, 18,000 years ago. These finds are the most important evidence in Northwest Europe for its re-colonisation by man and animals as the ice-sheets waned. They provide an excellent opportunity for understanding how human beings solved the problems of coping with harsh ice age environments in Europe. The engraved bones with images of animals recovered from the caves are well known, and provide unique examples of the origins of Ice Age art in Britain.

Many of the caves containing evidence for early human occupation in Britain were seriously damaged by the explorations of early antiquarians, who could not anticipate modern methods of scientific research. Whilst the caves at Creswell Crags suffered at their hands, research discoveries since 1977 have revealed a rich resource of unexplored sites and the examination of these has shown that they offer enormous potential for further scientific studies.

A number of sites comparable with, but less well known than Creswell Crags, exist within a ten mile radius of this central site, along the ridge of Magnesian Limestone which extends along the Nottinghamshire/Derbyshire border from Mansfield in the south to Worksop and then into South Yorkshire.

In total, 50 individual caves and shelters have been identified, the majority of which contain significant undisturbed archaeological deposits, including 10 sites as yet untouched. Taken together, the sites interlock to provide a regional chain of evidence about men and animals and their environment in prehistoric times — a resource that is unique in Britain and is central to our understanding of Early Man and his setting in this country and in Europe.

• Pin Hole Cave, Creswell

In addition to the archaeological heritage, both Creswell Crags and the similar Magnesian Limestone dales such as Pleasley Vale, Markland and Hollin Hill Grips and Anston Stones Gorge, have important geological, geomorphological and ecological interest, recognised by designation as Sites of Special Scientific Interest.

The leisure and amenity value of these sites has long been recognised by the local population, who have enjoyed them for informal recreation wherever access could be gained. However, the first effective recognition of their value as sites for interpretative, recreational and educational use, was realised in 1977 when Derbyshire and Nottinghamshire County Councils leased the Creswell Crags site from Welbeck Estates and opened a Visitor Centre at the eastern end of the Crags gorge. In 1984 the Visitor Centre was extended in response to rapidly expanding interest and demand, and today caters for a quarter of a million visitors per year, providing exhibitions and information on Early Man and his environment.

As a result of discussions held in March 1985 between representatives of Derbyshire and Nottinghamshire County Councils, a major Seminar was held on 15th and 16th January 1986, sponsored by the Countryside Commission, English Heritage, Bassetlaw and Bolsover District Councils and the two County Councils. Delegates attended from a wide variety of organisations with an interest in the Crags, and at the end of the Seminar a 'Statement on Creswell Crags' was adopted, which identified opportunities and problems and called for the production of a detailed strategy for the future management of the Crags and related resources in the surrounding countryside.

A Members' Steering Committee was set up by the County and District Councils to oversee the preparation and implementation of the strategy. The terms of reference outlined for the production of the strategy document were: first and foremost to provide for the protection of a site of international importance; to show how the opportunities of Creswell Crags and the surrounding countryside can be realised and the problems dealt with; to identify the roles of the national agencies, local authorities and the local community, as well as landowners, the private sector and voluntary bodies in meeting these needs; and to show how resources can be secured to implement its proposals.

Since the archaeological area of importance is in fact much wider than Creswell Crags, embracing much of the Magnesian Limestone outcrop in Nottinghamshire, Derbyshire and South Yorkshire, it was felt appropriate to recognise this wider "Area of Heritage". The recognition of such an area enables many opportunities to be taken up and resources raised that the promotion of Creswell Crags alone would not permit; it also presents far wider opportunities for employment, tourism, leisure, education and research. This document describes the resources and the opportunities presented by the Creswell Crags Heritage Area and outlines a proposed strategy for its future.

THE LANDSCAPE OF CRESWELL — A UNIQUE HERITAGE

The significance of the resource in the Creswell Area lies in the internationally important concentration of Middle Old Stone Age and Late Old Stone Age sites, the internationally important fossil record from the caves, the great diversity of other archaeological sites (with sites from most periods of regional or local importance), the internationally important Westphalian Stratotypes (supported by a wealth of other geological localities), and a number of biological sites of SSSI status. Most of the known sites occur in areas with little agricultural activity and under little pressure from industrial or residential development.

Geology

The rocks of the Heritage Area date from the Carboniferous (360-290 million years old) and Permian (290-250 million years old).

There are good exposures of late Carboniferous (Coal Measures) rocks, which provide at Doe Lea and Long Duckmanton two International Stratotypes for the Westphalian Epoch (stratotypes are places where Geological Time is defined; all correlations of Westphalian time worldwide must therefore be made with rocks of the Heritage Area). The Bolsover District is famous for the fossils found in the Coal Measures. Particularly the Bolsover Dragonfly discovered in Bolsover Colliery, and the exquisitely preserved plant fossils, which range in size from the tiniest spores to whole trees.

The Permian rocks (Magnesian Limestone) are spectacularly exposed in the gorges of the area, which are important as geological localities for the unusual structures — visible in the gorge sides.

Recent findings suggest that the gorges and caves were initiated about 250 million years ago, shortly after the drying-up of the shallow sea in which the Magnesian Limestone was laid down. Some elements of the Creswell landscape are thus of enormous antiquity, and lay buried for many millions of years under younger rocks, before being exhumed during the last few million years.

The Creswell area is of considerable geological importance because unlike much of the Northern and Central Britain, it is doubtful if it was ever covered by actively eroding ice-sheets in the Quaternary Period. The caves of the Heritage Area thus contain a sedimentary record of much of the last million years that is unusual amongst terrestial deposits in Western Europe in its completeness. In addition to the outstanding archaeological material, the cave sediments preserve continuous rich and diverse sequences of fossil plants and animals. The Heritage Area is unique in having the potential to integrate all of these lines of evidence into a detailed cultural and environmental history of the Last Ice Age and much of the last million years.

The Quaternary Significance of Creswell Crags

We are still living in an Ice Age. Glaciers and ice sheets still cover substantial areas of the earth's surface. It was only slightly over 10,000 years ago that the last glaciers in the mountains of the British Isles melted away; and only 6,000 years before that, that half the country was covered by ice sheets. The present period represents an interglacial — a temperate stage between much colder episodes. The history of the last two million years — the Quaternary period — has been characterised by repeated shifts between glacial and interglacial climates, and consequent environmental changes:

- the spread and decline of vast ice sheets;
- substantial falls (over 100m) and recoveries of sea level as ice sheets advanced and retreated;
- radical changes in geography as a result of sea level change and the buckling of the land surface beneath the ice sheets; with the British Isles repeatedly being connected to, then separated from the European mainland;
- enormous changes in the distribution of plants, animals and soils, with temperate woodland being driven out of Western Europe during glacial periods;

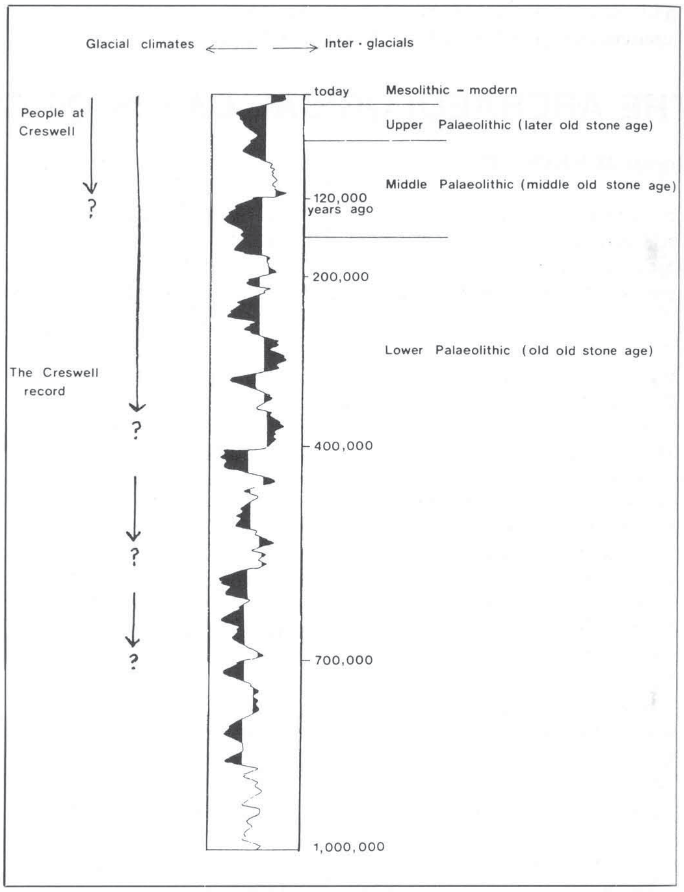


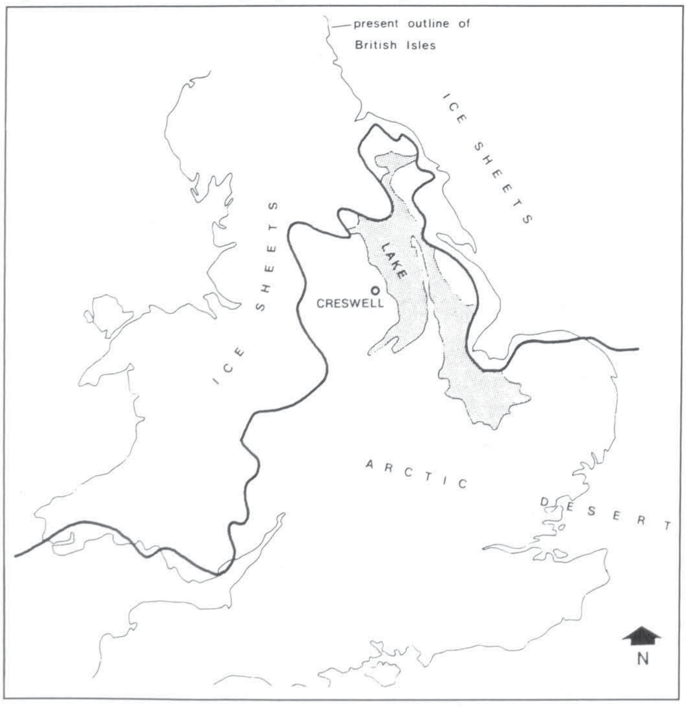
Figure 2. Creswell Crags — The Prehistoric Timetable

- the development of Early Man and the eventual emergence of our own species — *Homo sapiens* — towards the end of the Last Ice Age, probably about 50,000 years ago;
- widespread migrations, colonisations and extinctions of plants and animals in response to all these factors.

A full understanding of these complex events and changes is very difficult, since sequences of deposits representing more than a few thousand years are very rare. At Creswell, however, there is a complete sequence of deposits spanning the last 100,000 years, and partial sequences representing most of the last half million years. These deposits are of particular importance because of the human artefacts and remains, animal and plant fossils and exact dating evidence which they contain.

The public importance of Creswell Crags lies as much in its leisure, amenity and educational potential as in its research significance. Since the initial leasing of the site in 1977, visitor figures have increased each year, to reach a quarter of a million in 1986, reflecting a growing public awareness of and wish for involvement in its heritage.

Figure 1. Creswell at the height of the last Ice Age.



ARCHAEOLOGY

The North Nottinghamshire/North Derbyshire borders have been famous for their prehistoric remains for over a century. The world importance for the area lies in the great concentration of Old Stone Age sites, mostly in caves. There are also nationally and regionally significant sites of younger prehistoric and historic age, which add to the importance of the area. The main archaeological sequences from Creswell can be summarised as follows.

Middle Old Stone Age (150,000-40,000 years ago)

Four archaeological sites at Creswell Crags provide evidence of use during the Middle Palaeolithic. The most important is Pin Hole Cave, which provides evidence that Middle Palaeolithic people visited these islands at least twice, something that cannot be clearly demonstrated elsewhere in Britain. The people were reindeer, horse and possibly mammoth hunters who followed the herds north to their spring feeding grounds in the Creswell area, retreating southward from the cold in winter. The sites at Creswell are the most northerly places in the world known to have been reached by man before 20,000 years ago.

Late Old Stone Age (40,000-10,000 years ago)

The Creswell area contains the larger of only two very dense concentrations of sites of this age known in the British Isles. Ten major localities, together with 46 minor sites, have yielded some of the richest assemblages of stone tools, some very rare bone tools, some of the earliest burials and much of the earliest art known in Britain. Mother Grundy's Parlour, is the Type Site (the international standard of comparison) for the Creswellian stone tool industry. Pin Hole Cave is also of great importance since at least two separate episodes of use during this period time can be demonstrated there, something of great rarity in the British Isles.

Middle Stone Age (10,000-5,500 years ago)

The Creswell area is tremendously rich in material of this age, with ten major cave sites, rock shelters and open sites and a large number of minor sites known. The most important is the rock shelter at Thorpe Common, containing evidence of probably the oldest house structure so far discovered in Britain, and a rich collection of stone tools and the remains of people who hunted in the thick forests that sprang up after the end of the Last Ice Age.

New Stone Age (5,500-4,000 years ago)

Little work has been done on sites of this age, but there is evidence of the use of caves at Creswell, Markland Grips and Whaley, and a spectacular burial site at Ash Tree Cave. Many field scatters are known, particularly from the Elmton, Pleasley and Hardwick areas.

Bronze Age (4,000-3,000 years ago)

There is a concentration of evidence of this period from Scarcliffe, where there was a settlement and a number of burials in barrows. Thirteen other small settlements are known from the Creswell area. Use of caves continued and includes a burial in Pin Hole Cave.

Iron Age (1,000 BC-AD 50)

In the later part of the period, the area was in the territory of the Cortitani. Evidence for this period includes a promontory fort at Markland Grips and two small settlements in Whitwell Wood.

Romano-British (AD 50-AD 410)

Eight small rural farming settlements, two small villas and five cave sites are known in the Creswell area, together with 30 minor sites. The villa site at Mansfield Woodhouse is probably the most important of the local sites.

Medieval (AD 410-AD 1550)

Little has survived from the collapse of the Roman Empire or the Anglian or Danish invasions, except the town defences at Bolsover, some stonework at Ault Hucknall Church and a number of place names with Anglian and Danish roots. Many of the settlements of the area were founded before the Norman Conquest, but the earliest surviving architectural heritage dates from the later part of the Medieval period. From this time we have some interesting and regionally important churches, such as those at Steetley, Sookholme, Ault Hucknall and Teversal, three small castles at Worksop, Cuckney and Bolsover and some moated manor houses such as that at Stainsby. The shrinkage or abandonment of some villages, late in the 14th century, has left traces at Blingsby and Elmton. The pattern of Medieval settlement remains in the street plans of most villages and towns, while the medieval pattern of land management remains in the field patterns of the area and the hunting parks of Scarcliffe and Whitwell Wood.

Post-Medieval and Industrial (1550-present)

From the early part of this period date the major rebuilding of Bolsover Castle and the building of Hardwick Hall. The Industrial period saw the construction of a typical coalfield industrial landscape, with mines, railways, a canal and many new settlements and the expansion of older ones, such as the Model Village at Creswell.

PALAEONTOLOGY

The Creswell area has a unique Quaternary record of fossil, plants and animals, second only to Rancho La Brea in Los Angeles, U.S.A. in terms of the number and diversity of fossils known. Most of the fossil bones date to the end of the last Glacial period, but a significant number predate the last Glacial. The key points of the palaeontological record are:

Penultimate Glacial and Earlier (before 120,000 years ago)

Animal bones of this age, including the dirk-toothed cat *(Homotherium latidens),* which became extinct over a quarter of a million years ago, hippopotamus and leopard have been known from Robin Hood's Cave and Mother Grundy's Parlour for many years. Recent dating evidence from the cave shows that deposits and bone assemblages well over 200,000 years old are still present in the cave. In a recent reassessment of the surviving deposits in the cave, unusual small vertebrate assemblages, including frog, toad, lizard and vole were found in these very old deposits. These are the earliest fossils at Creswell, and date from three early warm periods, probably in the region of 500,000-200,000 years ago. Only six other fossiliferous sites of this broad age have been found in the British Isles; none shows the types of assemblage or the completeness of record of the deposits in Robin Hood's Cave.

Last Interglacial (120,000-100,000 years ago)

Bones of this age, including hippopotamus, steppe rhinoceros, bison, hyaena and mammoth, are known from Robin Hood's Cave and Mother Grundy's Parlour at Creswell and Ash Tree Cave and Steetley Quarry Cave elsewhere in the Creswell area. This represents a considerable proportion of the material of this age known in the British Isles.

Last Glacial (100,000-10,000 years ago)

The fossil record from the last Glacial period, known from 30 caves and a number of open air sites in the Heritage Area, is unique in the number and diversity of fossils so far excavated, with literally millions of bones, of 190 vertebrate species. The record includes many species only known in the British fossil record from Creswell and includes large and small mammals, one of the world's richest collections of fossil birds and unusual groups rarely found as fossils including bats, fish, amphibians and reptiles. The sequence through the deposits in Pinhole Cave is also unique, since the very rich fossil groups there were laid down continuously over the whole span of the Last Glacial, a quality of record unparalleled anywhere.

Present Interglacial (10,000 years ago-today)

After the end of the Last Glacial, material continued to accumulate in the caves. These deposits are exceedingly rich — one cubic metre of sediment containing up to 250,000 bones — including locally extinct animals such as beaver, bear, wolf reindeer and auroch. Similar deposits occur elsewhere in the British Isles, but few are as rich as those of the Creswell area.

Natural History

The Creswell Area contains a number of sites important for their Natural History. Most are botanical sites, including limestone grasslands and woodlands. Also notable are the bat populations of some of the caves.

LATER UPPER PALAEOLITHIC ENGRAVINGS FROM THE CRESWELL CAVES

One unusual aspect of the archaeological information from the Creswell Caves is the occurrence of bonework and in particular the finds of engraved bone.

At four sites: Mother Grundy's Parlour, Robin Hood's Cave, Pin Hole and Church Hole Cave there have been finds of prepared pieces, that is bone fragments polished and prepared for engraving and in addition all these sites have produced examples of engraved bone. Controversy has surrounded these finds since the first discovery of a horse's head engraving (Plate 21) during the 1876 excavations in Robin Hood's Cave (Boyd Dawkins 1876). This piece in particular is now thought to be a genuine in situ discovery though it was previously thought that it was planted into the excavations of the cave (Sollas 1915; Jackson 1962).

Since this discovery many more examples have been found in the Creswell Caves, particularly Pin Hole, which clearly indicate that engraved bone work is a genuine feature of the Upper Palaeolithic use of the caves. Perhaps the most startling piece, found by Armstrong (1929) is the 'Masked Human Figure' (Plate 1). This unusual engraving was produced on the terminus of a highly polished bison rib and represents a rare attempt to portray the human form.

The Creswell evidence represents the earliest evidence of art in Britain, finds of great significance, marred only by the circumstances and controversies associated with their discovery.

REFERENCES

Armstrong, A. L. 1929. Pin Hole Excavations, Creswell Crags, Derbyshire: discovery of an engraved drawing of a Masked Human Figure. Proc. Prehistoric Society, Vol. VI, pp. 27-30.

Dawkins, W. B., 1876. On the Mammalia and Traces of Man in Robin Hood's Cave. Quart J. Geological Society, London. Vol. XXXII, pp. 240-259.

Jackson, J. W., 1962. Archaeology and Palaeontology in British Caving: An introduction to Speleology. Cullingford C. D. H (editor), Routledge and Kegan Paul, London.

Sollas, W. J., 1915. Ancient Hunters and their Modern Representatives. London.

Received August 1989

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

PIN HOLE CAVE, CRESWELL

R. D. S. JENKINSON

Abstract: Pin Hole Cave, excavated by A. L. Armstrong over 30 years, has provided significant evidence of human and animal occupation of Britain during the Quaternary period. A full review of Armstrongs' pioneering work was undertaken during the 1970s and this clearly showed the quality, quantity and diversity of the archaeological and palaeontological remains recovered during his excavations.

Two major drawbacks of Armstrongs' work have been the lack of reliable dating and environmental data which could improve our understanding of this rich sequence. In view of this, new excavations, using micro-excavation techniques and a programme of multi-disciplinary research work commenced. This paper describes the context of the new work.

Few Quaternary cave sequences offer evidence comparable with the quality and quantity of information available from Pin Hole Cave. Unique excavation techniques were designed to cope with the complexity of the cave fill and the multi-disciplinary nature of the investigation. These techniques are described and discussed against a background of earlier investigations. Like the majority of the caves at Creswell, Pin Hole Cave was subjected to investigations in the late 19th century (Mello 1875), work which concentrated on the entrance.

It was not until the 1920s that this cave was investigated extensively by A. L. Armstrong who, as well as introducing improved excavation techniques, published extensive notes and two syntheses of work (Armstrong 1924 and 1949). Armstrong's death in 1959, however, prevented a comprehensive appraisal of the Quaternary sequence in Pin Hole although recently attempts have been made to interpret both the archaelogocial and palaeontological evidence (Kitching 1963; Jackson 1966; Campbell 1969 and 1977). Interpretation of Armstrong's excavation has been controversial mainly due to a misunderstanding concerning his recording techniques, difficulties which have recently been overcome (Jenkinson 1984).

The detailed picture which emerges is of a complex archaeological sequence with two distinct Middle Palaeolithic and two distinct Upper Palaeolithic industries, the last of these industries being associated with human remains, bone engravings and cowrie shells. The extensive faunal assemblage found, details a very wide species diversity.

Notably high incidences of hyena remains occur and evidence exists for the presence of fish, amphibians, birds (including eggs), insectivores, bats and rodents. Although Armstrong was meticulous in the excavation and recording of Pin Hole Cave several factors have inhibited a greater understanding of the cave-fill. These include an undated sequence using absolute techniques and, from recent studies in Robin Hood's Cave, the unsuspected complexity of the cave-fill including the considerable time-span represented over relatively small thickness of sediment. The one foot (0.3 metre) spit interval used by Armstrong therefore bulked together materials of very different antiquity and climatic asssociations. The excavation techniques in use today, were designed to overcome these problems.

The areas presently under investigation lie at the terminus of the Armstrong work approximately 30 metres into the cave. These are an area about 1.5 x 1.0 metres at the top of the sequence, and an area about 1.0 x 0.5 metres investigating much earlier deposits at the base of the sequence.

The excavation was so designed to take into account the complexity of the cave-fill and the multi-disciplinary nature of the investigation. This entailed the need for tight horizontal and vertical control achieved using fixed datum positions over the two excavation areas. Each datum board is strung with plumb-bobs on a 100mm grid. Excavation proceeds by the removal of 10mm spit depths from each 100mm square with each find, artefact, bone, mollusc etc., and sedimentary unit being recorded in three dimensions with the aid of perspex planning frames. Samples are taken for a number of analyses including sedimentology, mineral magnetism, palaeomagnetism and palynology, from each sedimentary unit in each spit. To avoid contamination of any sample, brass excavation tools are used.

The excavation strategy presently in use, while fulfilling the aim of a greater understanding of such a complex Quaternary sequence, does create problem areas as a result of the scale and speed of excavation.

With regard to the micro-scale level of excavation, the excavation of 100mm unit squares creates problems of monitoring changes in stratigraphy. This problem is more acute at the lower excavation area where extremely subtle differences exist between complex vertical and horizontal sedimentary units. In order to monitor these subtle differences and changes in stratigraphy a series of 10cm squares are planned and excavated simultaneously. Thus the anatomy of each square is maintained for recording and sampling, the result being a more accurate and complete record of the entire site.

Additionally, with the approximate rate of two weeks to excavate one 10mm spit depth over the entire upper excavation area, drying out of the sediment results in the boundaries between sedimentary units becoming blurred. Even with frequent spraying using a fine water spray, the difference between a freshly trowelled surface and one not trowelled for two weeks is marked, especially with the present use of quartz halogen lamps for lighting. To avoid any loss of information which may result from the drying out of the excavation, each 100mm square is planned immediately after it is excavated although excavation of the same square takes place some two weeks later.

Although the excavation strategy adopted in Pin Hole is extremely rigid with tight horizontal and vertical control, there is room for flexibility within this framework, a flexibility to cope with problems relating to the complexity of the site and the speed of excavation. Thus, at the end of the day excavation in Pin Hole Cave yields an extremely accurate and micro-scale record of a rich and complete sequence, this along with multi-disciplinary analysis resulting in a detailed picture of the Late Pleistocene at Creswell Crags.

REFERENCES

Armstrong, A. L. 1924. Report of Committee for Archaeological Exploration of Derbyshire Caves, Interim Report 3. Report Brit. Assoc. Adv. Sci., Section H.

Armstrong, A. L. 1949. Exploration of Prehistoric Sites in Derbyshire. Jour. Derbys. Arch. Nat. Hist. Soc., vol. 69, pp.69-73.

Campbell, J. B. 1969. Excavations at Creswell Crags. Derbys. Arch. Jour. vol. 89, pp. 47-58.

Campbell, J. B. 1977. The Upper Paleolithic of Britain. Oxford University Press. 2 vols.

Jackson, J. W. 1966. The Creswell Caves Jour. Brit. Spel. Assoc. vol. 6, pp. 8-23.

Jenkinson, R. D. S. 1984. Creswell Crags: Late Pleistocene Sites in the East Midlands. British Archaeological Reports, Oxford.

Kitching, J. W. 1963. Bone, tooth and horn tools of Paleolithic man: an account of the osteodontokeratic discoveries in the Pin Hole Cave, Derbyshire. Manchester University Press.

Mello, Rev. J. M. 1875. One some bone caves in Creswell Crags. Quart. Jour. Geol. Soc. London, Vol. 31, pp. 679-691.

Received August 1989

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

MOLLUSCS FROM A. L. ARMSTRONG'S EXCAVATIONS IN PIN HOLE CAVE, CRESWELL CRAGS

C. O. HUNT

Abstract: A detailed study is presented of the distribution of some 700 mollusc shells found either by Armstrong or during recent excavations. Preliminary deductions of the ecology of these molluscs are presented.

A. L. Armstrong's excavations in Pin Hole Cave, Creswell Crags, Derbyshire, are famous for recovering the most complete Middle and Upper Palaeolithic archaeological and vertebrate palaeontological sequences yet found in the British Isles (Jenkinson, 1984). These records cannot, however, be placed accurately in a chronological and environmental framework, since many research methods, such as radiocarbon dating and palynology, were not available to Armstrong. To remedy this deficiency, the surviving archaeological and palaeontological finds were comprehensively restudied (Jenkinson, 1984; Jenkinson & Gilbertson, 1984) and fresh excavations were initiated in the cave in 1984.

In addition to the archaeological and vertebrate remains, Armstrong also recovered a considerable number of mollusc shells from Pin Hole. Some of these shells were identified in the 1920s and 1930s by J. W. Jackson, but most were never studied. As part of a large-scale study of past and present mollusc faunas at Creswell Crags, the molluscs from Pin Hole were analysed during 1987.

During his comprehensive re-study of the Pin Hole material in the late 1970s, R. D. S. Jenkinson recorded approximately 718 molluscs from the cave, lodged in the collections of the Manchester Museum (Geology). In 1987, 216 of these specimens could not be relocated for study. Fortunately, Jenkinson had recorded the surviving contextual information for these molluscs. This information is preserved in the archives of the Creswell Crags Visitor Centre and is used in some of the analyses in this paper.

The remaining 502 specimens were identified, and, if possible their locations in the cave fill established from Armstrong's co-ordinate system, using the method of Jenkinson (1984). 228 specimens, however, had lost their associated stratigraphical information and could be located no more accurately than to Pin Hole Cave. The following discussion is thus based largely on the remaining 274 specimens that could be unequivocally located within the cave fill. It must be stressed that this is only 38% of the molluscs known to have been recovered from the cave and, since only large specimens of large species are represented, probably only a small proportion of the original assemblage. Nevertheless, although this study is only a small sample of a biased subsample, its findings are consistent with the results of Jenkinson (1984) and throw some new light on the palaeoecology and biostratigraphy of an uniquely important site.

Table 1. Mollusc distribution by inferred "layer" in Pin Hole Cave.

"LAYER" A	unidentified specimens
"LAYER" B	*Helicigona lapidica*
	Colchlodina laminata
	Cepaea nemoralis
	Cepaea hortensis
	Cepaea spp.
	Oxychilus cellarius
	Oxychilus ?helveticus
	Aegopinella nitidula
	Arianta arbustorum
	Clausilia bidentata
	Lymnaea peregra
HIATUS AND EROSION	
"LAYER" C	*Oxychilus cellarius*
	unidentified specimens
HIATUS	
"LAYER" D	*Oxychilus cellarius*
	Cepaea spp.
	Cochlodina laminata
	Helicigona lapidica

Table 2. List of molluscs from Pin Hole Cave

Cepaea nemoralis	*Discus rotundatus*
Cepaea hortensis	*Cernuella virgata*
Cepaea spp.	*Vallonia costata*
Oxychilus cellarius	*Vitrea contracta*
Oxychilus helveticus	*Helix aspersa*
Helicigona lapidica	*Cochlicopa lubrica*
Cochlodina laminata	*Azeca goodalli*
Aegopinella nitidula	*Clausilia dubia*
Arianta arbustorum	*Lauria cylindracea*
Lymnaea peregra	*Acanthinula aculeata*
Clausilia bidentata	*Ena obscura*
Pomatias elegans	*Pupilla muscorum*
Vallonia excentrica	

Table 3. List of molluscs from surface contexts with no horizontal control (± Late Holocene assemblage)

Cepaea nemoralis	*Aegopinella nitidula*
Oxychilus cellarius	*Oxychilus helveticus*
Cepaea hortensis	*Vallonia costata*
Pomatias elegans	*Discus rotundatus*
Vallonia excentrica	*Vitrea contracta*
Helicigona lapidica	*Cochlicopa lubrica*
Cernuella virgata	*Pupilla muscorum*
Helix aspersa	

Distribution

Ten species of molluscs are demonstrably present in unequivocally located positions within the cave fill (Figs. 1-7) and this information is summarised in Figures 8-10 and Tables 1-3. When plotted in terms of horizontal distance into the cave (Fig. 8) then a general trend of decreasing numbers of specimens with increased distance into the cave can be seen. This trend is broken by relatively high numbers of specimens at the limit of excavation. Certain taxa, particularly *Cochlodina* and to a lesser extent *Helicigona* (Figs. 3-4) are mostly found in the entranceway and passage and are virtually absent from the chamber. In contrast, *Oxychilus* and *Cepaea* seem to have been generally distributed in the cave.

Taphonomy

Most of the specimens studied were whole, undamaged specimens. In an unbiased sample from a terrestrial environment, this would tend to rule out certain predators, such as small mammals and some birds, which give rise to characteristic breakage patterns, and suggest a life assemblage. In Pin Hole, it is very probable that many fragmentary specimens were not recovered by the excacator, so such a suggestion cannot be made with any great conviction. Nevertheless, the presence of strictly vegetarian taxa such as *Helicigona* and *Cochlodina* in substantial numbers only in those parts of the cave that would have received sufficient light for at least some plant growth suggests that for these taxa at least this might be the case. The presence of the carnivorous *Oxychilus* (cf. Evans & Jones, 1973) in substantial numbers in the chamber as well as further forward in the cave can be explained in terms of this taxon's tendency to scavenge carrion. The *Cepaea* spp. are not known to scavenge, yet show a similar distribution to *Oxychilus*. Some specimens of this large taxon may have been carried into the chamber by predators, or they might have been scavenging carrion left by the large predators and people that used this part of the cave. The single specimen of the aquatic *Lymnaea peregra* was almost certainly carried into the cave by a predator (cf. Jenkinson & Gilbertson, 1984, p. 21, Fig. 9).

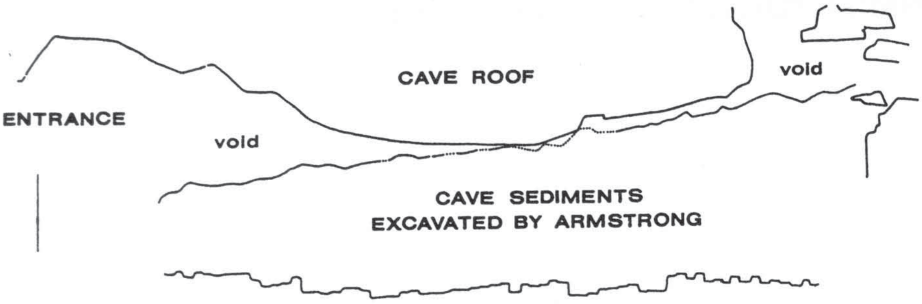


Figure 1. Long section of Pin Hole Cave showing area excavated by Armstrong (data from R. D. S. Jenkinson).

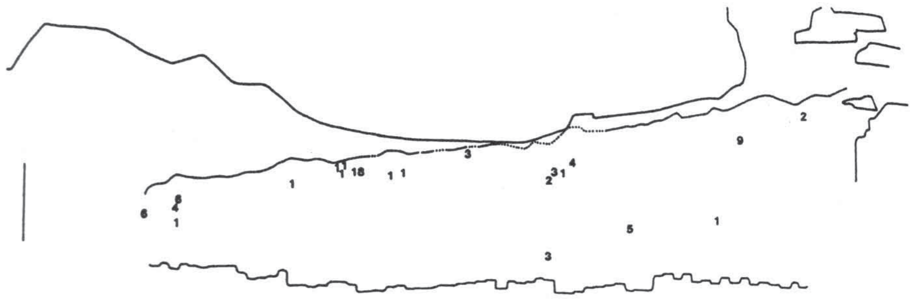


Figure 2. Distribution of Cepaea *spp. in Pin Hole Cave.*

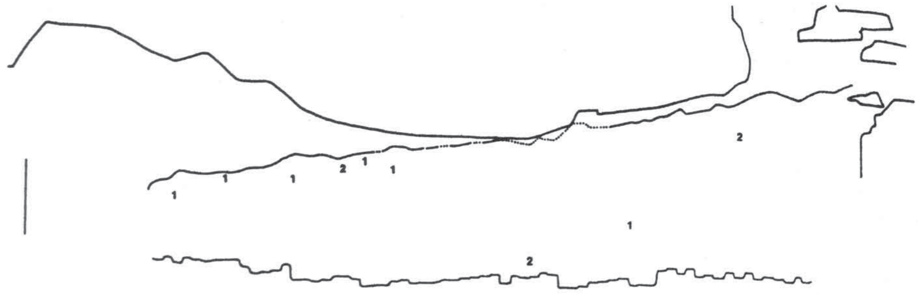


Figure 3. Distribution of Cochlodina laminata *in Pin Hole Cave.*

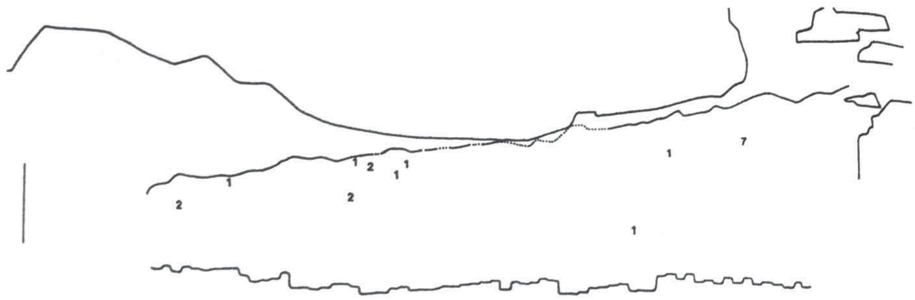


Figure 4. Distribution of Helicigona lapidica *in Pin Hole Cave.*

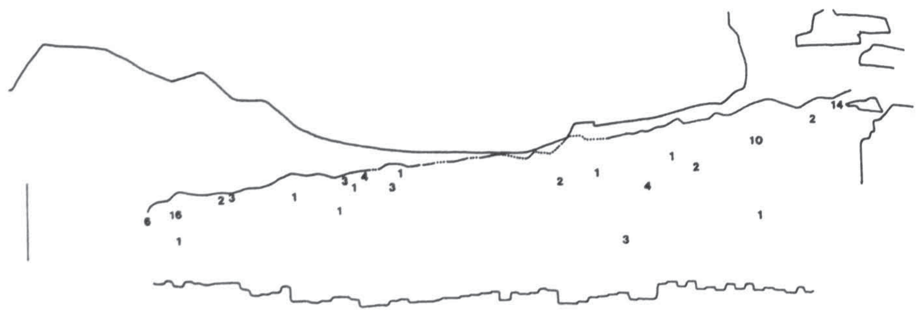


Figure 5. Distribution of Oxychilus *spp. in Pin Hole Cave.*

Figure 6. Distribution of Aegopinella nitidula (triangle), Arianta arbustorum (square), Lymnaea peregra (diamond) and Clausilia bidentata (circle) in Pin Hole Cave.

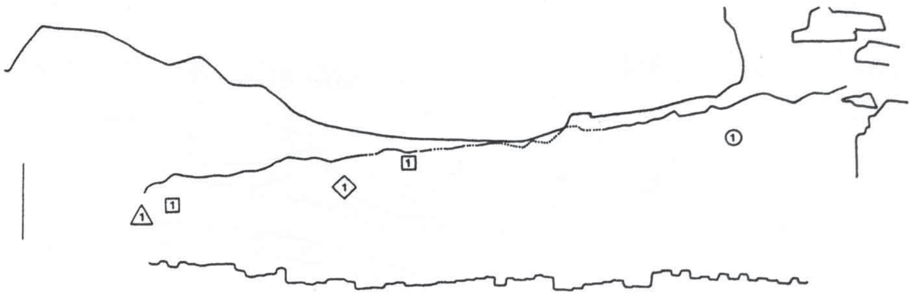
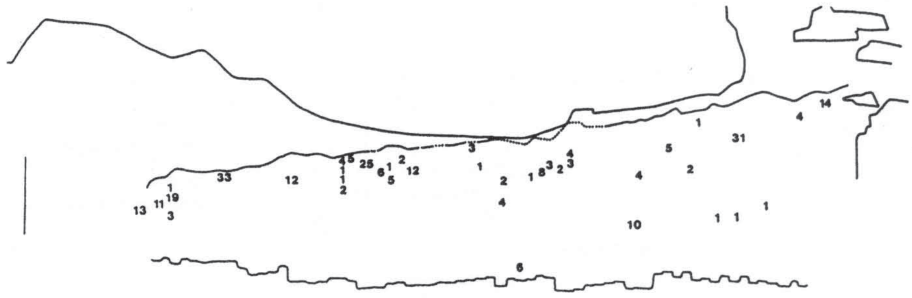


Figure 7. Distribution of all molluscs in Pin Hole Cave.



Figures 1-7 show that most molluscs were found in the top 1.5m of the cave-fill, with large numbers found in the top foot of the extraction, fewer in the second foot, substantial numbers in the third and fourth feet and very few beneath the fourth foot, though there are slight concentrations in the sixth and eleventh feet. This information is summarised in Figure 9.

Stratigraphy

Recent radiocarbon dates from material excavated by Armstrong (Jenkinson, pers. comm.) suggest that the stratification in the cave was not completely uniform or parallel with the surface of the cave fill. The dates and the total distribution of molluscs, with a tentative interpretation of the stratigraphy of Pin Hole are shown in Fig. 10. The mollusc taxa present in each "layer" are listed in Table 1.

In this interpretation, the highest unit ("layer" A), which is virtually barren of molluscs, is attributed to the Late Glacial Stadial (11,000-10,000 BP). The underlying mollusc-rich "layer" B probably accumulated during the Late Glacial Stadial (15,000-11,000 BP). The last glacial maximum (20,000-15,000 BP) was probably a time of erosion in the cave. "Layer" C probably accumulated in a minor interstadial some time before 34,000 BP. The most probable candidate is the Upton Warren Interstadial, but an earlier episode is also possible. "Layer" D probably reflects one or more of the Early Devensian interstadials.

If this interpretation is correct, the results from Pin Hole Cave conflict substantially with the results of molluscan analyses of interstadial and Late Glacial open-air and waterlaid deposits. Taxa such as the *Oxychilus* spp., *Helicigona lapidica, Aegopinella nitidula,* the *Cepaea* spp. and the Clausiliidae are not recorded in British sequences except in deposits of Holocene and interglacial status (Kerney, 1977a, b; Holyoak, 1982; and references therein). Since all of these taxa require relatively mild, moist, sheltered conditions, it may be suggested that they immigrated into suitable niches such as caves as soon as thermal amelioration permitted, but were precluded from entering much of the landscape unless sufficient cover was present — a phenomenon that occurred only during the forest biozones of interglacials and some major interstadials.

Conclusions

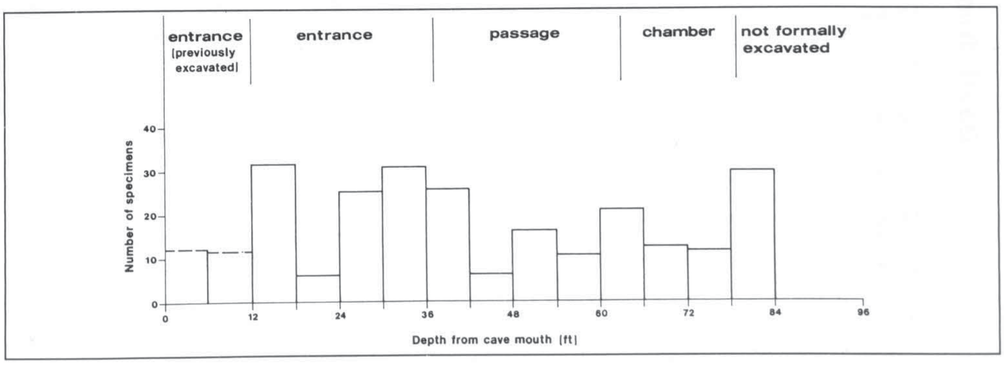
Molluscs recovered by A. L. Armstrong in his excavations of Pin Hole Cave give some indications of the probable distribution of molluscs in the cave fill, though the method of recovery precluded the finding of the smaller taxa. Some indication of the probable richness of this original fauna may be obtained from Table 2, which includes results from a number of (unfortunately now unstratified) sediment samples.

The damp, sheltered environment of the cave probably made it an attractive habitat for most of the molluscs considered in this report, which most likely grazed vegetation growing in the photic zone of the cave. The *Oxychilus* and perhaps the *Cepaea* spp. probably invaded the dark zones at the back of the cave to feed on carrion left by large predators including possibly man. Other molluscs, certainly including the specimen of *Lymnaea peregra* and possibly some of the *Cepaea* spp. were brought into the cave by predators.

The stratigraphical distribution of the molluscs probably reflects a series of climatic oscillations during the last glaciation. Stadial conditions seem to be reflected by sediments barren of molluscs, while interstadials seem to have been marked by the appearance of more or less diverse mollusc assemblages.

These results suggest that mollusc analysis can be a useful tool in cave biostratigraphy and palaeoecology. A separate molluscan biostratigraphy is needed for cave environments, since the biostratigraphic schemes current for open-air and aquatic environments do not appear to be applicable in this very specialised facies. This new scheme should be based on several large-scale, well dated excavations and should account for taphonomic patterns within the caves.

Figure 8. Distribution of molluscs per six-foot excavation block in Pin Hole Cave (horizontal)



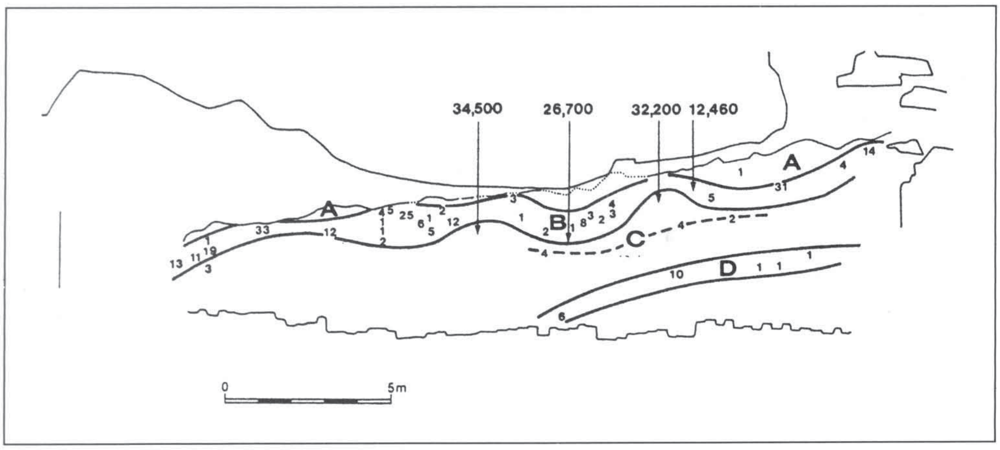


Figure 10. Suggested stratigraphy of Pin Hole Cave, synthesising radiocarbon dates and mollusc distribution.

ACKNOWLEDGEMENTS

This work was carried out with financial assistance from the East Midlands Area Museums Service. I thank Dr. R. D. S. Jenkinson for securing the grant and providing facilities for carrying out the work, and much helpful advice. I thank Dr. R. M. C. Eagar for access to the collections, use of facilities and much kind help at Manchester Museum (Geology), and Dr. R. Jacobi for assistance with finding specimens there and discussions. I thank Ms. S. Skinner for drafting the diagrams.

REFERENCES

Evans, J. G. & Jones, H. 1973 Subfossil and modern land-snail faunas from rock rubble habitats. Journal of Conchology, London, vol. 28, pp.103-130.

Holyoak, D. T. 1982 Non-marine molluscs of the last glacial period (Devensian) in Britain. Malacologia, vol. 22, pp.727-730.

Jenkinson, R. D. S. 1984 Creswell Crags: Late Pleistocene Sites in the East Midlands. Oxford: British Archaeological Reports, British Series, No. 122.

Jenkinson, R. D. S. & Gilbertson, D. D. 1984 In the shadow of extinction: A Quaternary Archaeology and Palaeoecology of the Lake, Fissures and Smaller Caves at Creswell Crags SSSI. Sheffield: University of Sheffield, Department of Prehistory and Archaeology.

Kerney, M. P. 1977a British Quaternary non-marine Mollusca: a brief review, in Shotton, F. W. (ed.) British Quaternary Studies. Oxford: Oxford University Press, pp.31-42.

Kerney, M. P. 1977b A Proposed Zonation Scheme for Late-glacial and Postglacial Deposits Using Land Mollusca. Journal of Archaeological Science, vol. 4, pp.387-390.

Received August 1989

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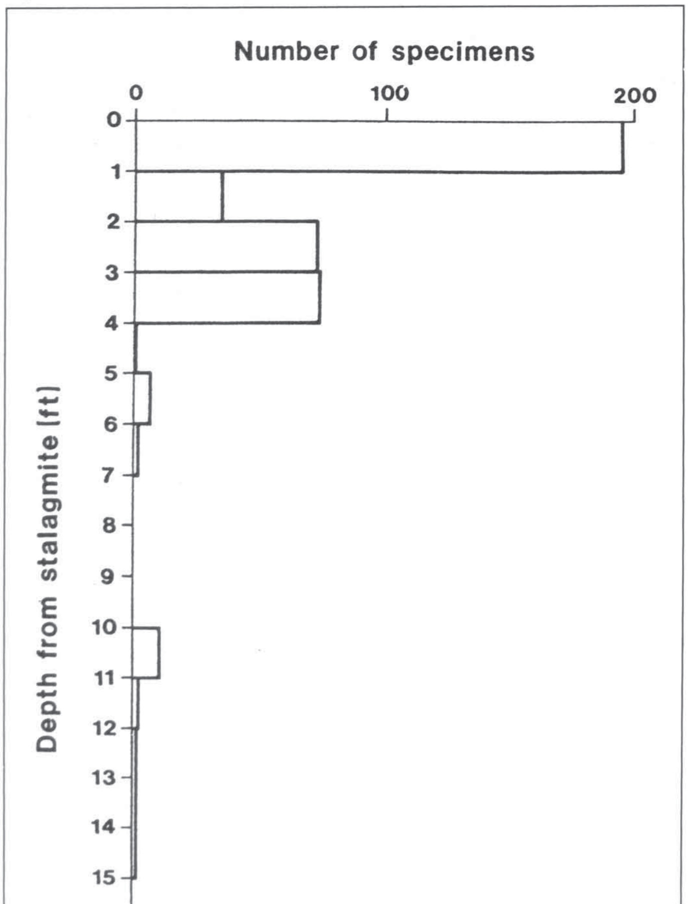
Figure 9. Vertical distribution of molluscs in Pin Hole Cave by one-foot excavation units.



CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

THE SEDIMENTARY SEQUENCE IN ROBIN HOOD'S CAVE, CRESWELL CRAGS

David GILBERTSON

Abstract: All the published information on the nature and stratigraphy of Quaternary deposits in Robin Hood's Cave, Creswell Crags, England is integrated. This aids the correlation of modern work in the cave with the poorly understood excavations of Victorian cave "hunters" who reported spectacular finds from it.

The archaeological significance of Robin Hood's Cave, Creswell Crags is well known. The cave has yielded the oldest known piece of art from Britain — an engraving on bone of a horse's head. It was the site of a major 19th century controversy concerning the possibility of fraudulently planted bone and teeth remains, and has yielded both a notable collection of Palaeolithic handaxes and a large vertebrate fauna. These topics were described in more detail in Briggs *et al* (1985) and Jenkinson (1984). The basic problem in current understanding of the finds and deposits from Robin Hood's Cave centres on uncertainties concerning the antiquity of the materials found within it. Jenkinson (1985, 1978) catalogued and summarised the 19th and early 20th century records and publications which concerned the cave and showed how they need to be treated with circumspection. The more recent work recorded in Campbell (1977) was principally concerned with the area just outside the cave. Without doubt, the Thorium/Uranium Series dating programme of Rowe and Atkinson (1985, and this volume) has provided the most useful advances yet made in our understanding of the nature and significance of the development of the deposits within the cave. Unfortunately, the legacy of 19th and early 20th century excavation is such that it is very difficult to relate these new age determinations on flowstones within the cave to the archaeologically important deposits that have been documented as occurring within it.

The most reliable synthesis of the available stratigraphic evidence is that by Jenkinson (1984). This synthesis is inevitably based upon the accounts of the cave deposits given by Heath (1879, 1880, 1882), Laing (1889), Mello (1876, 1877), and Dawkins and Mello (1879). A number of the units recognised have not been seen since the early 20th century. Jenkinson's (1984) synthesis recognised the following sedimentary units in Robin Hood's Cave. These units are listed in Table 1 and the revised synthesis discussed below is based principally upon them. Only passing reference is made to the excavations at the cave entrance by Campbell (1969, 1977). These data may well prove to be important when seen in the light of the recently available Thorium/Uranium series age estimations provided by Rowe and Atkinson (1985).

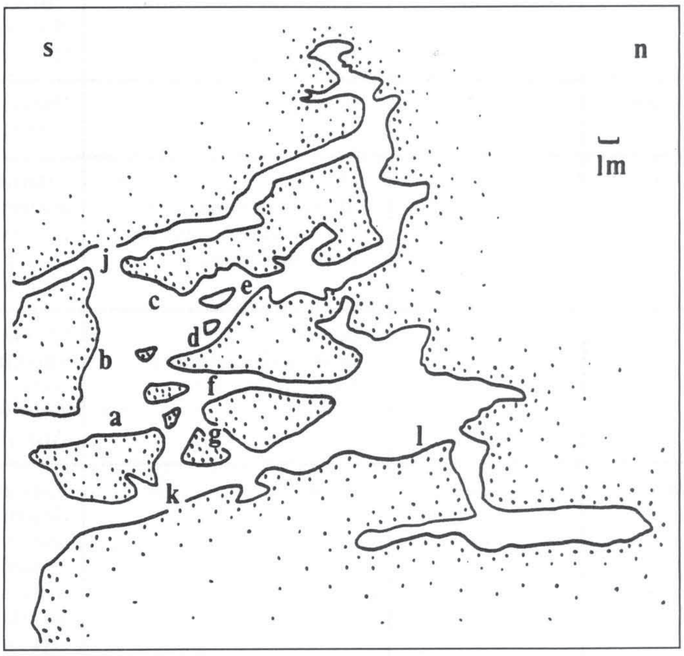


Figure 1. Plan of Robin Hood's Cave, Creswell Crags, on the Nottinghamshire and Derbyshire border. This complex cave opens to the Creswell Crags gorge to the south. Both gorge and cave are eroded into the Lower Magnesian Limestone (Permian). Sites a to l are described in Table 1 and the text, and indicate the locations of important archaeological finds, sections or exposures.

Discussion

At present it is not possible to correlate with reliability the composite sequence presented above to that which is still evident in the cave. However, all is not lost. The important work of Rowe and Atkinson (1985) and Rowe (this volume) has provided a number of Th/U chronological "coat hangers" onto which the present re-investigation of the archaeology and geology of the extant exposures can be fixed. It is also possible to recognise some significant similarities in the extant exposures to those features noted in the 19th century publications. For example, it is possible that Units 7M3 to 10 inclusive, and Unit 5 and 6, in the summary composite sequence are both still detectable, and also have the "correct" stratigraphic relationships, in the modern cave. Part of the problem of interpreting the 19th century accounts lies in the poverty of these written records; in particular the extent to which they ignored the description of the matrix of their finds. Inevitably subtleties, distinctions or crucial features which strike the 20th century archaeologist as most important are not mentioned in the published accounts. The similarities between the present exposures (Fig. 1 and Table 1) and the composite section presented above are sufficient to question whether the flowstone of Unit 6/1 above, might be the same as the two thin adjacent flowstones dated to approximately 165,000 years old in the two Uranium series dates by Rowe and Atkinson (1985: RH-2 UEA 820324-6) and Rowe (this volume). It is not yet possible to match the infill sequence in Robin Hood's Cave to those described in the nearby Pin Hole cave and Mother Grundy's Parlour Cave, as suggested by Armstrong (1931, 1942), and discounted by Briggs and Griffin (1985).

The cave infill sediment sequence is clearly likely to be complicated and there is every reason to suspect from the general character of the older Uranium series dates obtained by Rowe and Atkinson (1985) that the processes of re-working, derivation, partial emptying and partial re-filling have all played a role in the development of this cave sequence. These issues are amongst many being studied in the present research programme at Creswell Crags.

The critical issues concerning the genuineness of the finds of the engraving of the horse's head and the tooth of the *Machairodus* are not resolved. It is possible that the engraved bone was obtained from the cave sediment layer to which it was attributed. The present research programme has also indicated that very old cave sediments are present in Robin Hood's Cave. These may yet prove to be the source from which the tooth was derived and deposited by natural geomorphic processes into the reported provenance layer. Alternatively, as Heath's (1880) argument implies, perhaps the "hands of people" were involved — if it was, it is still impossible to demonstrate whether that hands were ancient or 19th century.

REFERENCES

Briggs, D. J., Gilbertson, D. D. and Jenkinson, R. D. S. (eds) 1985. Peak District and Northern Dukeries: Field Guide. Quaternary Research Association, Cambridge.

Briggs, D. J. and Griffin, C. M. 1985. Sediment Provenances in the Creswell Caves. In Briggs, D. J. *et al* (eds). Peak District and Northern Dukeries. Quaternary Research Association, Cambridge, pp.139-150.

Campbell, J. B. 1969. Excavations at Creswell Crags. Derbyshire Archaeological Journal vol. 89, pp.47-58.

Campbell, J. B. 1977. The Upper Paleolithic of Britain. Clarendon Press, Oxford. 2 volumes.

Dawkins, W. Boyd, 1877. On the Mammal-Fauna of the Caves of Creswell Crags. Quarterly Journal of the Geological Society of London, vol. XXXIII, pp.589-612.

Dawkins, W. Boyd and Mello, J. M. 1879. Further Discoveries in the Creswell Caves. Quarterly Journal of the Geological Society of London, vol. XXXV, pp.724-735.

Heath, T. 1879. An Abstract and Description and History of the Bone Caves of Creswell Crags. Wilkins and Ellis, Derby.

Heath, T. 1880. Creswell Crags v. Professor Boyd Dawkins. Clulow, Derby.

Heath, T. 1882. Pleistocene deposits in Derbyshire and its immediate vicinity. Derbyshire Archaeological and Natural History Journal vol. 1, pp.161-178.

Jenkinson, R. D. S. 1978. The archaeological caves and rock shelters in the Creswell Crags area. Creswell Crags Visitor Centre, Research Report Number 1; Nottinghamshire County Council.

Jenkinson, R. D. S. 1984. Creswell Crags: Late Pleistocene Sites in the East Midlands. British Archaeological Reports No. 122, Oxford.

Table 1. The sedimentary sequence in Robin Hood's Cave, Creswell Crags, on the Nottinghamshire/Derbyshire border, reconstructed from the available published records. In reality many of these layers may need to be subdivided, and the interpretations and correlations above which have been derived from this literature may need revision. The cave locations a-l mentioned in this table are indicated on fig. 1.

UNIT	THICKNESS	RECORDED	DESCRIPTION AND INTERPRETATION SUMMARY AND AGE ESTIMATES
10	?	bone, animal and human; metal and other artefacts	"Surface-soil" — occurs as a layer and in pits/? burials dug through unit 9 — little visible today, except at j. Layer 1 of Heath (1882), recorded by Mello (1876) at a, b, d, e. Late Holocene in age.
9	0.2-0.5	interpretation difficult.	"Stalagmite" — visible today throughout southern part of cave. Layer 2 of Heath (1882). Early Holocene/very late Devensian.
8	0.5-0.2m	abundant bone rhino, bear, horse, hyaena: flint implements	"Breccia" — a thermoclastic deposit, in matrix of calcite from flowstone of Unit 9 — visible today throughout the southern part of the cave. Layer 3 of Heath (1882). Late-Devensian in age.
7M1	0.02-0.07m	none recorded	"Stalagmite" — probably visible today at j, k; layer 4 of Heath (1882). Antiquity unknown, probably Late Devensian.
7M2	0.3m	charcoal, abundant bones, bones, diverse species, flint implements	"Reddish loamy earth" — allochthonous and autochthonous materials, supposed provenance of tooth of *Machairodus* and engraved horses head on rib bone — deposit is visible today at a, b, c, d, e, f, j, k and l. Described by Mello (1875, 1876) and Laing (1889). Antiquity unknown.
7M3	0.3-0.6m	bones: bear, wolf, reindeer, hyaena, quartzite implements	"Lighter earth" — *in situ* weathering and induration by flowstone of allochthonous aeolian and derived soils, waterlain in places; visible today at b and k. Described by Mello (1875, 1876) for a, b, dimensions and nature disputed by Heath (1882). Antiquity unknown — ?early/middle Devensian or Wolstonian?
6/1	0.02-0.03m	none	Stalagmite — possibly visible today at b. Heath's (1882) layer 6 described at a; Wolstonian or ?middle/early Devensian: the critical and unanswered question is whether this deposit can be correlated reliably with the two thin flowstones which are exposed at b and Th/U dated by Rowe and Atkinson (1985) to approximately 165+—8 ka; these flowstones at b are at about the same height and general stratigraphic position as Heath's layer 6.
6	0.3-0.6m	bones: quartzite implements	"Mottled Bed" — autochthonous and allochthonous, aeolian and waterlain materials — possibly visible today at k: Described by Mello (1875, 1876) at f and g; ?early or middle Devensian or pre-Ipswichian?
5	0.7-1.1m	bones, hyaena, quartzite implements	"Red sand", in situ weathering, autochthonous cave material, allochthonous aeolian and soil materials, locally affected by mass-movement, and water, possibly, in part, a hyaena den? — visible today at a, b, c, d, f, g, k, and l; Heath's (1882) layer 7: ?early or middle Devensian or pre-Ipswichian?
4	?	none	"Sandy-clay rolled pebbles" — presumed to be autochthonous with aeolian and waterlain components. Possibly visible today below shaft l and in shaft m. Described by Laing (1889) at l; ?early or middle Devensian or pre-Ipswichian?
3	?	bones: rhino, bison, hyaena	"Stiff red clay" — aeolian, waterlain and mass-movement. Possibly visible today at l: Described by Dawkins (1877), Laing (1889) for a, c, k.
2	0.7m?	none?/or same as Unit 3	"Yellow ferruginous sands" — ?autochthonous deposit, ?in situ weathering and rockfall from cave/fissure sides. Not visible today in cave floor, but present on walls of shaft at k; pre-Ipswichian; described by Mello (1876) and Laing (1889) at a, b and l; pre-Ipswichian in age.
1	0.5-1.0m	none	"White calcareous sand" in pockets — ?autochthonous deposit, in situ weathering of Magnesian Limestone. Not visible today in cave floor, probably visible on the walls of shaft in cave roof at k; pre-Ipswichian in age. Described in Mellow (1876), Laing (1889) at b, d, f, g and l.

Laing, R. 1889. On the bone caves of Creswell and the discovery of an extinct Pleistocene Feline (Felis brevirostris), new to Great Britain. Reports to the British Association for the Advancement of Science (Newcastle), pp.582-584.
Mello, J. M. 1875. On some bone caves in Creswell Crags. Quarterly Journal of the Geological Society of London, vol. XXXI, pp.679-691.
Mello, J. M. 1876. On the bone caves of Creswell. Quarterly Journal of the Geological Society of London, vol. XXXII, pp.240-259.
Mello, J. M. 1877. The bone caves of Creswell Crags. Quarterly Journal of the Geological Society of London, vol. XXXIII, pp.579-588.
Rowe, P. J. and Atkinson, T. 1985. Uranium-Thorium Dating Results from Robin Hood's Cave. In Briggs, D. J. *et al* (eds). Peak District and Nortern Dukeries: Field Guide. Quaternary Research Association, Cambridge, pp.200-207.

Received June 1989

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

THE SEDIMENTS FROM THORPE COMMON ROCKSHELTER

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Abstract: Rockshelter deposits accumulate in specialised niches through the breakdown of the enclosing bedrock, the addition of windblown and fluvial sediment, and in the case of archaeological sites, human habitation debris. Each site is a unique entity within the environment and its sediments will reflect that individuality. The physical and chemical analyses of the sediments of the prehistoric rockshelter at Thorpe Common, South Yorkshire has provided a history of accumulation. Although this data cannot be attributed directly to specific datable climatic occurrences general trends can be seen in the results.

The attraction of rockshelter deposits is that they provide specialised niches of sediment accumulation for materials originating both from within the shelter and also from the outside environment. The record of events that can be extrapolated from these deposits have been one of the main sources of information concerning human habitation in Europe during the past 100,000 years, and are therefore of great significance to both archaeology and environmental science.

The aims of this paper are to provide through the detailed description and analysis of the sediments a sedimentary history for the rockshelter, to reconstruct the physical environment and palaeoclimate prior to and during the occupation of the site, and to relate this information to the regional archaeological evidence.

As each rockshelter is a unique entity, even within a small geographical area with uniform regional climate, the sedimentary ensembles within nearby rockshelters may vary because of bedrock variability, exposure and aspect, local relief, size and shape, and the intensity of human occupation (Farrand 1985). Therefore the determination of a sedimentary sequence for this area will be of significance locally, regionally and even nationally as it will provide a hitherto unknown history. The great majority of sedimentary sequences that exist in this area, are associated to phreatic cave systems, (e.g. Creswell Crags, Markland Grips — Jenkinson 1984; Gilbertson and Jenkinson 1984) rather than semi-exposed sequences such as that provided by the Thorpe Common rockshelter.

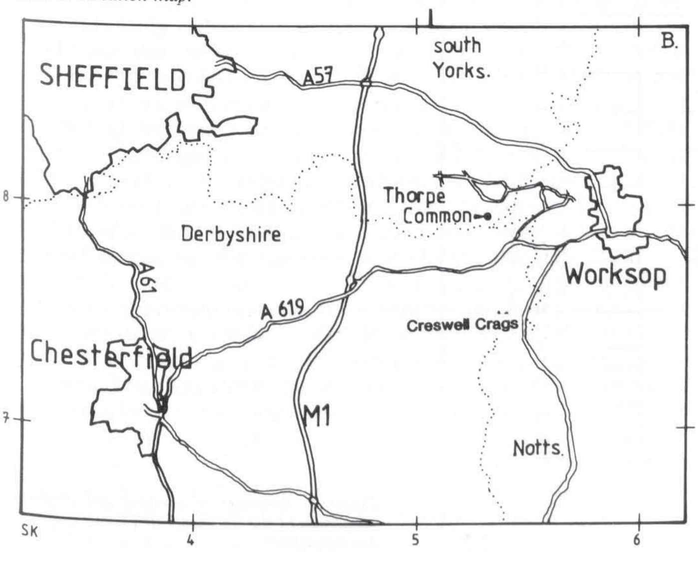
Geology

The rockshelter site of Thorpe Common is located in South Yorkshire at SK 5287 7937 some 5km west of Worksop and a similar distance north of Creswell Crags (Figures 1 & 2). The site is situated on the eastern edge of a steep-sided, presumed glacial drainage channel, eroded into the eastward-dipping Lower Magnesian Limestone (Permian) during the Ipswichian Interglacial. Locally the outcrop of the Magnesian limestone defined by a west facing escarpment (Mitchell, 1947; Reeve 1976).

Laboratory Analysis

The samples numbered in figure 3 were analysed by standard sedimentological methods. Standard particle size analysis was carried out on bulk samples (less than 45mm diameter). Further analyses were carried out on the fine earth fraction (<500µm) to determine the calcium carbonate content, organic carbon, pH, calcium, magnesium, sodium and potassium contents. Assessments of the particle shape were made for two size ranges — medium sand (250µm-425µm) and stones (8mm-32mm) — using the visual comparison chart designed by Powers (1953). This however gives only a qualitative assessmeent of the particle shape.

Figure 1. Location map.



RESULTS

The results of the chemical and physical analyses of the sediments are summarised in figure 4. More detailed analyses of the physical properties are shown in figure 5.

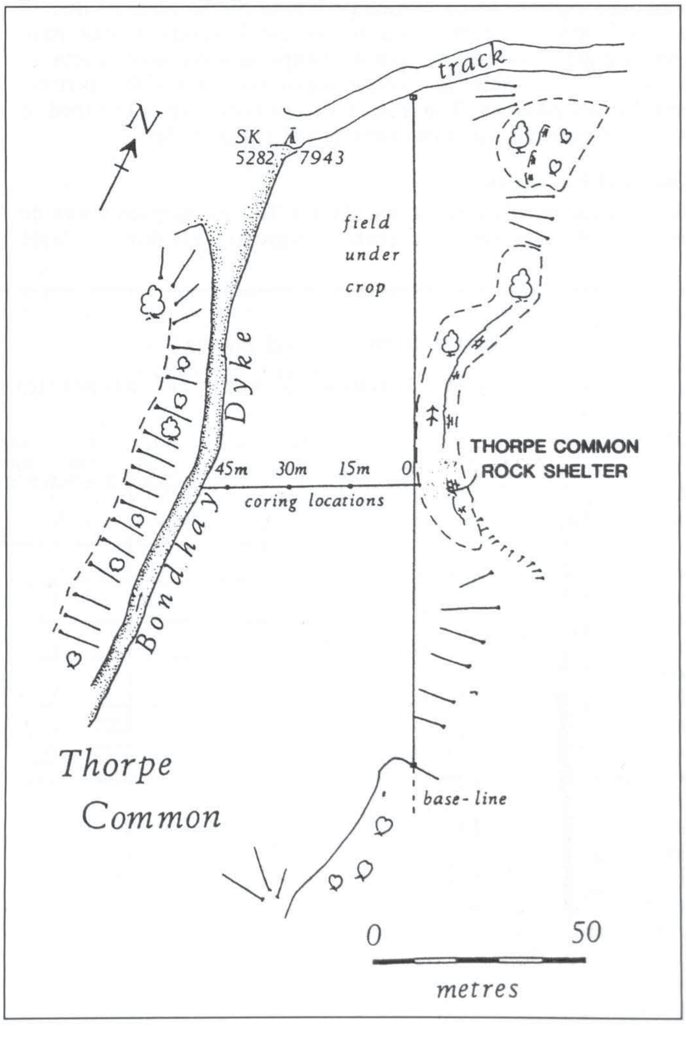
Physical Properties

From figures 4 and 5 it can be seen that silt predominates in over 70% of the samples analysed and the presence of which undoubtedly reflects the physical environment prevailing at the time of deposition.

Consideration of the textural properties in the sequence suggests the following sedimentary units can be recognised;

Unit 1. This comprises the uppermost samples (43, 41 & 5) which all contain a gravel fraction accounting for between 50% and 80% of the total volume.

Figure 2. The surroundings of the Thorpe Common Rockshelter.



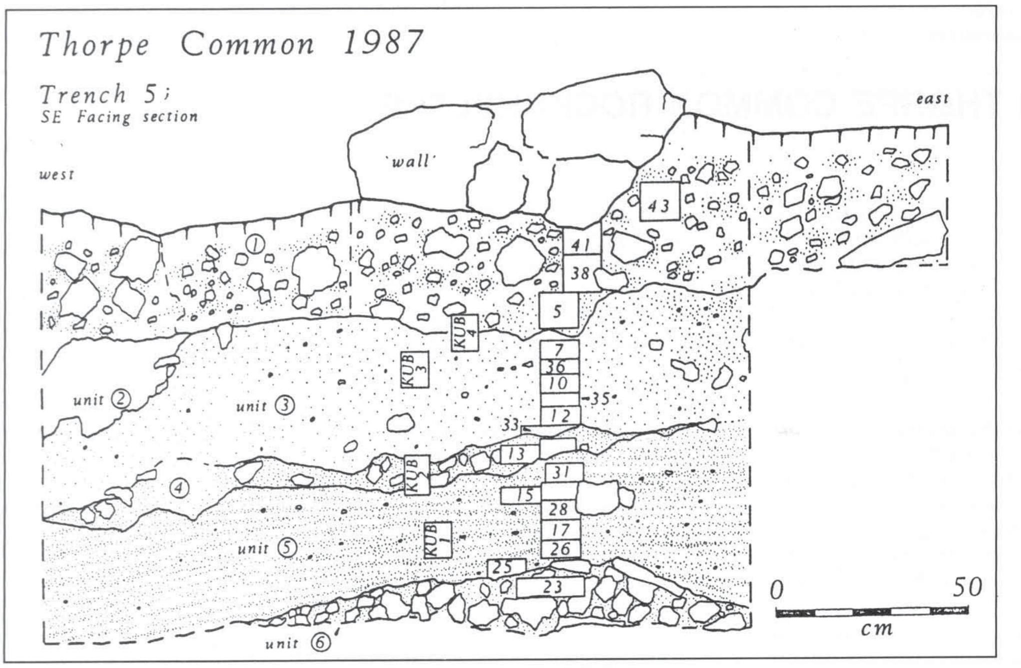


Figure 3. Diagrammatic section of the deposits in Thorpe Common Rockshelter, 1987.

Unit 2. Samples 7, 36, 10, 35, 12 & 33 indicate a mixed deposit with a dominance of medium to fine sand and coarse silt grains. However consistent values for medium and fine silt and clay remain throughout.

Unit 3. This is difficult to attribute as samples 13 and 31 both have identical colour (figure 3) and very similar particle size distributions of sand, silt and clay, yet both reflect the trends of the units above and below them.

Unit 4. Superficially samples 15, 28, 17, 26 and 25 reflect the distributions of unit 2, however closer examination of the distributions and the particles themselves reveals this to be untrue. These samples have a small clay content, not greater than 10% of any sample, a large silt and sand content and no coarse fraction. Examination of the sand fraction reveals that the facies that indicate a high sand content (28, 17 & 26) are comprised of silt sized particles cemented together by carbonate precipitation. Samples 31 and 15 do not contain a high frequency of silt concretions but have approximately 80% quartz grains comprising the sand fraction.

Sample 23 is similar in its distribution to unit 1 with a distinct bimodal distribution. The main focus of rock size is grouped at -3.5ϕ, there is also a small presence of silt particles.

Chemical Properties

Figure 4 summarises the chemical data. In this diagram it can be seen that pH increases with depth, with greatest alkalinity in layer 23 and greatest acidity in the upper layers (7.2, which is the value for soils on Magnesian Limestone (Reeve 1976)). The organic carbon curve is generally the inverse of the pH and this is reflected in the 99% confidence level when the data was subject to Spearmans Rank correlation coefficient.

The total carbonate is at its highest in sample 41, a high value (relative to the rest of the stratigraphy) is maintained until 50cm depth where $CaCO_3$ falls off rapidly to 1%. There is a gradual increase to layer 13 where it peaks before decreasing downwards. These peaks and troughs appear to correspond to deposits with high occurrences of limestone debris.

The phosphate curve also decreases with depth. The high values in the upper layers reflect enrichment of the deposit by phosphorous released from animal bones and vegetable debris associated with human activity. The presence of phosphate, albeit small, in sample 26 is of interest. It may represent leaching of PO_4 but this should also be reflected in the distribution of minerals that P fixes with, such as calcium (Bakkevig 1980). The explanation may be found by reference to the excavation. The trench that this section was part of comprised of unconsolidated backfill. At a depth of ca. 1m and ca. 15cm from the section a concentration of animal bone was located. The phosphate released into the surrounding matrix from this animal may have been responsible for the unexpected enrichment of PO_4 in layer 26. Although little study has been made of the lateral movements of phosphates and their associated

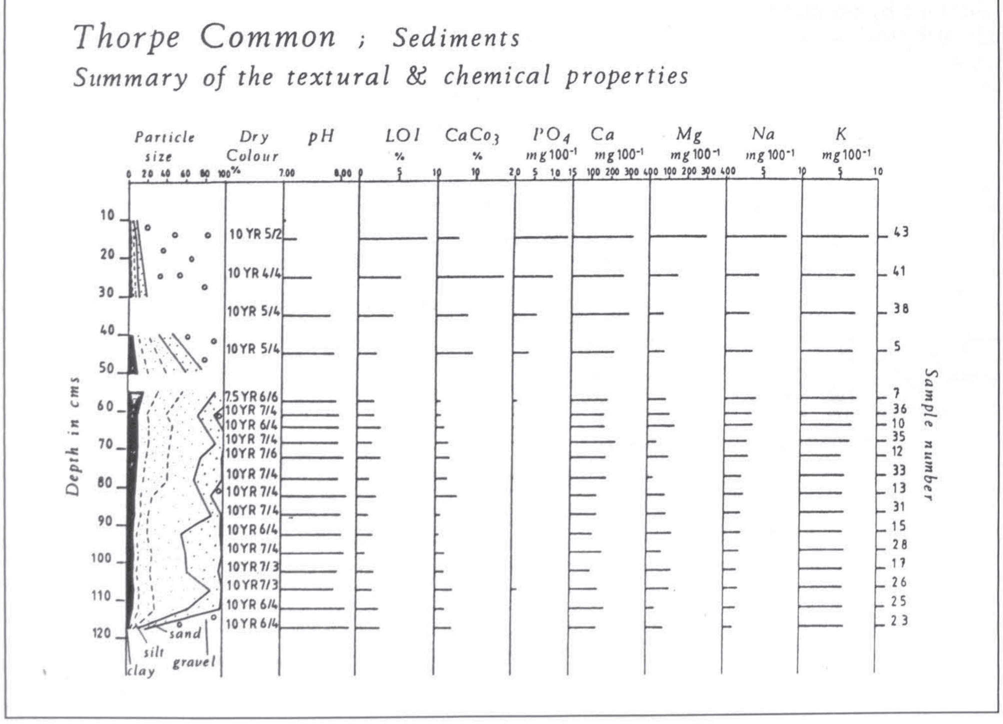
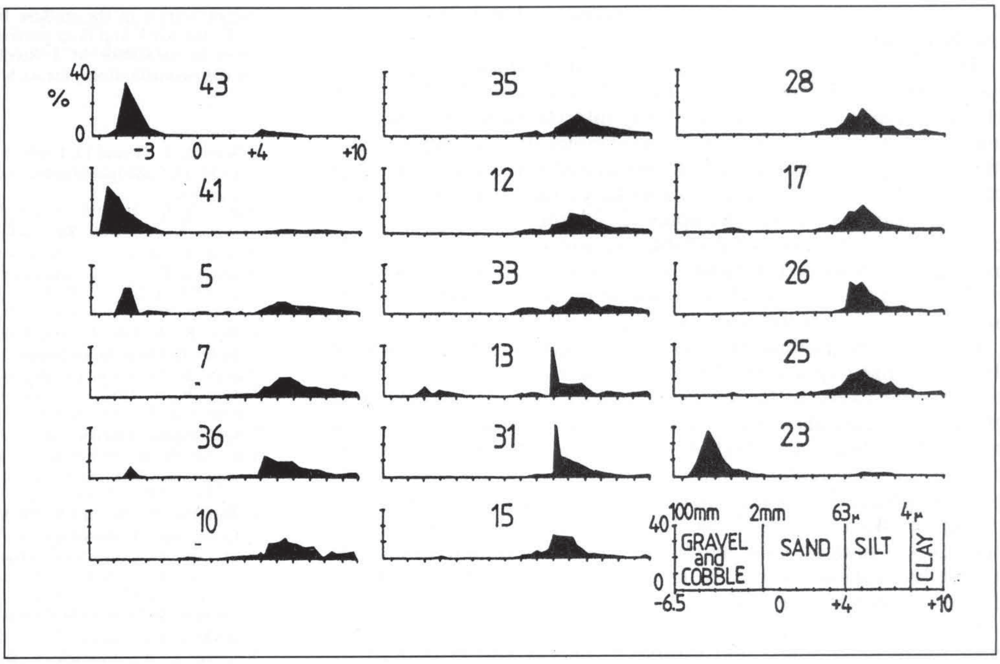


Figure 4. Summary of textural and chemical properties of the sediments in Thorpe Common Rockshelter.

Figure 5. Particle size distribution at different levels in Thorpe Common Rockshelter.



ions of Fe, Ca and A1 it has been noted that lateral variation can be expected (Proudfoot 1976) suggesting that chemical migration here is possible. Alternatively it may represent human activity, but on the basis of the internal evidence so far studied this seems unlikely.

The curves of calcium and potassium show similar trends of decrease with depth. Although both are considered good indicators of human occupation (Butzer 1982; Konrad *et al* 1983) they can only contribute tentatively as indicators of anthrosols, for Ca is a common component of aeolian deposition (Lowe and Walker 1984) and K decreases steadily with depth reflecting its instability in alkaline environments, and this is indicated at Thorpe Common. Magnesium does not correlate with any other mineral present in the sequence. Whilst it is recognised as a good indicator of human activity (Konrad *et al* 1983) it is also a major constituent of this type of limestone as much of the original $CaCO_3$ has been replaced by $MgCO_3$ (Atkinson and Smith 1976, Bradshaw 1973). Its distribution throughout the stratigraphy may be more an indication of weathering processes than of human activity. This can also explain the sodium curve which decreases with depth through unit 2 and then remains consistent through unit 4, tailing off slightly towards the basal layer.

DISCUSSION

Analysis of the results described above suggest the following interpretation of the sedimentary sequence of the rockshelter. The basal material (sample 23) may be regarded as a rockfall deposit, as evidenced by the abundance of angular stones ranging in size from 31.5mm to 5.6mm, which show little indication of surface weathering. They also appear to belong to the lower subdivision of Magnesian Limestone as they are grey and compact. The largest fraction show scant evidence of secondary weathering of their edges, thus indicating either fairly rapid burial or maintenance of the conditions that were responsible for deposition. The latter is attributed to cold phase freeze/thaw activity rather than hydration spalling. However this cannot be considered as conclusive as frost weathering requires a unique balance of available rock moisture and periodic temperature oscillation around freezing point (Butzer 1981). Therefore the presence or absence of rock spall does not necessarily indicate either a cold or a freezing climate. The size of the "eboulis" may be indicative of an environment, not as severe as a full glacial but still rigorous, whereby the frequency of freeze thaw is the controlling factor in fragmentation. Lithology of the face is an important consideration here for the lower subdivision of the limestone, on the basis of evidence from the rockshelter today, has a more blocky and thinner bedding structure than the upper division. Thus any debris produced from this unit is more likely to be smaller in size to begin with, illustrating that the debris from fragmentation is conditioned by the lithology as well as by the temperature and moisture regime. This deposit is accompanied by an interstitial matrix of variable nature which may have resulted from the exfoliation of individual sand and silt grains. On the basis of the sand grain assessment this seems likely. It is evident that some cementation of the deposit has taken place. It is unlikely that this cementation occurred with the deposition of the unit for the larger fragments indicate little evidence of weathering and the finer fraction exhibit a range of particle shapes from very angular to well rounded. In addition to this the concretions that exist on the coarse fragments take the form of rootlets which by inference suggests that this is secondary precipitation of carbonate. Reference to figure 4 shows that $CaCo_3$ increases with depth through the overlying deposit suggesting the translocation of this mineral, which is one of the first components of the sedimentary matrix to be removed by groundwater (Farrand 1985, p.22).

The overlying unit of sediment appears to suggest deposition by a fluid mechanism. This is primarily attributed to aeolian deposition as more than 60% of the sediment is between 6-62µm, indicating a loess (Butzer 1981) and the remainder is between 64µ-2mm, indicating blown sand (Lowe and Walker 1984). However the possibility of alternative modes of deposition should be considered, either in conjunction with aeolian processes or as secondary agents of modification. These may include reworking of loessic deposits by fluvial processes (Smalley 1972) or through the percolation of finer particles through the profile.

On the basis of the internal evidence an aeolian depositionary environment is postulated for the lowest levels of this unit (samples 28, 17, 26 and 25). This is supported by an increase in calcium with depth (figure 4). Many of the sand size particles are cemented silt grains around roots shapes, the cell structure of which is still visible. It is proposed that this occurred *in situ* as a post-depositional modification. The proportion of silt decreases further up the unit and the sand fraction is predominantly quartz grains. This could be indicative of two diverse environmental settings. In the first, the coarsening of the sediment to coarse silts and sands is proposed as being the result of a deterioration in climate and the entrainment and deposition by wind of sand grains. The field descriptions of this laminated unit are similar to those given for the coversands of North Lincolnshire (Buckland 1982) and the particle size distributions are also similar.

One alternative suggestion is that the climate was ameliorating, and while the laminations could not have formed as a direct result of granular disintegration of the rockface they could have been sorted and deposited by increased fluvial activity in the form of snow-melt. Further evidence is needed to fully evaluate this view.

The transition between this unit and the next is only perceptible in the introduction of a coarse fraction in sample 13. The composition of the fine fraction is very similar in sample 13 and the underlying layer, 31 and represents a gradual change. The coarse fraction is subround to rounded in shape and has been subject to secondary weathering indicating a prolonged exposure prior to burial. It is difficult to attribute any climatic interpretation to this units as sediments alone can only give general outlines. There is a predominanace of fine sand in the layer which could have resulted from the reworking of an earlier deposit by fluvial processes which may explain the weathered nature of the rock. Alternatively fragmentation of the rockface occurred as a result of an oscillation in global temperature. More debris may have been deposited but was subsequently removed by the processes that laid down the overlying unit.

The next unit (unit 2) indicates sediments that are still quite silty in composition but increasing in size to coarse silt (45-63μm). However there is no evidence of any internal bedding structures and the deposit appears fairly homogenous. It is unlikely that a monocausal explanation can be postulated for the creation and mode of deposition of this unit, it is likely to represent the interaction of various processes. Samples 12, 35 and 10 indicate a fairly constant composition and distribution and contain a perceptible amount of limestone fragments in the sand range. The deposition of this could have occurred as a result of percolating water through and over the limestone and also as a result of surface water.

In sample 10 molluscan remains were retrieved in the form of *Milax* sp. and *Cepaea* sp.. These indicate a climate similar to the present and likely to be representative of the early to mid post glacial. There are also small mammal remains in this level but these have not yet been identified. Although most of the quartz grains present are subangular in shape, indicating little abrasion, it has been suggested that grain shape is not always a good indicator of transport (Buckland 1982, Willetts *et al* 1982) and the varying degrees of roundness exhibited by the Thorpe Common sand range may reflect various origins rather than a Late Devensian or Flandrian transportational history.

Partial elluviation from unit 1 is proposed as the cause of clay enrichment in sample 7 and sample 5. This is also evidenced by the iron staining of particles in the 500-800μm and smaller range. Evidence of biological activity and soil formation is seen in unit 1. Roots have penetrated through the unit into the underlying deposit and worm activity is abundant. Although high phosphate values appear to indicate increased human activity, the relative amounts of phosphates in different forms will have limited value for archaeology if data for the undisturbed soils are not available (White 1978). It must also be remembered that chemical anomalies in sediments cannot always be viewed in a direct casual relationship with human activity but more as a consequence of several discrete or related factors, one of which was man (Konrad *et al* 1983).

Identifiable mollusc fragments in Unit 1 indicate moist, woodland/grassland and ground litter species that are more cold tolerant than those located in the underlaying strata. These are *Cepaea* sp. *Oxychilus* sp. *Discus rotundatus* and members of the Clausiliidae. Archaeological material in the form of flint artefacts have also been recovered throughout this unit indicating the possibility of disturbance and alteration of the sediments by human activity. The high frequency of coarse gravel and stone fragments is of interest for it appears to correspond to that from the upper division of the Magnesian limestone. It is buff-coloured, massive in structure and exhibits reddish mudstone partings. The latter may explain the source of clay particles throughout the sequence. The fragments are subangular to subrounded and exhibits a surface morphology similar to that of the upper part of the rockface today.

The abundance of debris in the upper unit may be the result of a deliberate concentration of limestone fragments by humans. The fragmentation may have occurred as the result of hydration spalling indicative of alternate wetting and drying of the rock, a process that is believed to play a significant part in the fracturing of limestone (Trudgill 1983).

CONCLUSION

The sedimentological properties observed in the Thorpe Common deposits give indications of the climate and environment under which the sediments were developing. It must be understood that whilst a general description of the processes required to create these deposits is possible, any further more detailed interpretation is not yet justified.

Studies of the sediments in rockshelters should always take account of the fact that each shelter is a unique entity. Its response to external and immediate environmental processes will vary according to the nature of the individual site. As such the determination of a palaeoclimatic history for the site cannot be determined by sedimentary analysis alone.

ACKNOWLEDGEMENTS

Excavation was carried out under the auspices of the Creswell Crags Visitor Centre with assistance provided by Dr. D. Knight and the Community Programme workers from Whitwell. Third year undergraduates from the Department of Archaeology, University of Sheffield, Coralie Mills, Nigel Thew and Dan Barrett provided invaluable help in survey, excavation and coring and I would like to record my indebtedness to them.

I would also like to thank Jill Ulmanis for assistance with laboratory techniques and analysis. Nick Fieller for statistical manipulation of the data. Nigel Thew for indentification of the mollusc fragments.

All the work and data presented in this report is the result of a combined work effort by the author, M. J. Beech and C. de Rouffignac. I would like to thank them for their contributions, for without them this analysis would not have been possible.

REFERENCES

Atkinson, T. C. and D. I. Smith. 1976. The erosion of limestones. in T. D. Ford and C. H. D. Cullingford (eds) The Science of Speleology. pp.151-177. Academic Press, London.

Bakkevig, S. 1980. Phosphate analysis in Archaeology — problems and recent progress. Norw. Arch. Rev. vol. 13, no. 2, pp.73-100.

Bradshaw, M. J. 1973. A New Geology. Hodder and Stoughton, London.

Buckland, P. C. 1982. The cover sands of North Lincolnshire and the Vale of York. in B. H. Adlam, C. R. Fenn and L. Morris (eds) Papers in Earth Studies. Lovatt Lectures — Worcester. pp.143-178. Geo Books, Norwich.

Butzer, K. W. 1981. Cave sediments, Upper Pleistocene stratigraphy and Mousterian facies in Cantabrian Spain. Jrnl. Arch. Sci. vol. 8, pp.133-183.

Butzer, K. W. 1964. Environment and Archaeology. Methuen, London.

Butzer, K. W. 1982. Archaeology as Human Ecology. Cambridge University Press.

Farrand, W. R. 1975. Sediment analysis of a prehistoric rockshelter; The Abri Pataud. Quaternary Research vol. 5, pp.1-26.

Farrand, W. R. 1985. Rockshelter and cave sediments. in J. K. Stein and W. R. Farrand (eds) Archaeological Sediments in Context. pp.21-39. Centre for the Study of Early Man. University of Maine at Orono, Maine.

Gilbertson, D. D. and R. D. S. Jenkinson. 1984. In the shadow of Extinction: A Quaternary Archaeology and Palaeoecology of the Lake, Fissures and Smaller Caves at Creswell Crags SSSI. Dept. Arch & Prehist. Univ. of Sheffild.

Jenkinson, R. D. S. 1978. The archaeological caves and rockshelters in the Creswell Crags area. Creswell Crags Visitor Centre Research Report no. 1

Jenkinson, R. D. S. 1984. Creswell Crags: Late Pleistocene Sites in the East Midlands. BAR British Series 122.

Konrad, V. A., Bonnichsen, R. and V. Clay. 1983. Soil chemical identification of ten thousand years of prehistoric human activity areas at the Munsungen Lake Thoroughfare, Maine. Jrnl. Arch. Sci. vol. 10, pp.13-28.

Lowe, J. J. and M. J. C. Walker. 1984. Reconstructing Quaternary Environments. Longman. London.

Mitchell, G. H., Stephens, J. V., Bromehead, C. E. and Wray, D. A. 1947. Geology of the country around Barnsley. Mem. Geol. Surv. UK.

Powers, M. 1953. A new roundness scale for sedimentary particles. Jrnl. Sed. Petrol. vol. 25, pp.117-9.

Proudfoot, B. 1976. The analysis and interpretation of soil phosphorous in archaeological contexts. in D. A. Davidson and M. L. Shackley (eds) Geoarchaeology. pp.93-113. Duckworth. London.

Reeve, M. J. 1976. Soil Survey Record no. 33. Soils in Nottinghamshire III. Harpenden. Herts.

Smalley, I. J. 1972. The interaction of great rivers and large deposits of primary loess. Trans. New York Aca. Sci. vol. 34, pp.534-542.

Trudgill, S. T. 1983. Sources and Methods in Geography. Weaterhing and Erosion. Butterworths. London.

Received June 1989

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STONE TOOLS AND BLOOD RESIDUES FROM THORPE COMMON ROCKSHELTER

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Others have described the general characteristics of the archaeological deposit at Thorpe Common rockshelter (see Murray, this volume) which consists of a late Mesolithic component dating to about 4000 B.C. My concern with the site is largely limited to the lithic artefacts and the study of organic residues on them. The analysis of organic residues on stone tools is a newly emerging field of study in archaeology and the methods are still very much at an experimental stage. Research involves the development and evaluation of methods for identifying animal species from prehistoric blood residues. By identifying residues, observing their distribution on a tool, and studying their relationship with microwear traces, very precise functional determinations of stone tools can be made. This functional information will allow even more sophisticated behavioural reconstructions than those possible solely on the basis of microwear analysis. The identification of species from blood residues alone will be a significant contribution to archaeology since many sites lack other evidence (i.e. animal bones) of prehistoric subsistence practices. In addition, it has been shown that accurate radiocarbon dates can be run on blood residues using the AMS method so that the residues provide a means of directly dating the use of a tool rather than the age of the layer the tool was found in.

Currently experiments concern the method of haemoglobin crystallisation for species identification. The fact that haemoglobin, the major constituent of red blood cells, will form into crystals under certain conditions was discovered in the mid-nineteenth century and it was demonstrated early this century that haemoglobin crystals have unique characteristics for different species. The haemoglobin crystallisation method was recently adapted for archaelogical purposes by Tom Loy and my work will thoroughly investigate the applicability and usefulness of the method for identifying species from ancient residues. So far I have successfully crystallised haemoglobin from a number of modern control blood samples and also from an experimental tool used to butcher a sheep. I also intend to apply various immunological methods involving anti body-antigen reactions to the indentification of species from prehistoric blood residues.

Stone tools and debitage from Thorpe Common rockshelter are important for my research as they represent a test sample which will allow the independent evaluation of the efficacy of the haemoglobin crystallisation method in an applied situation. The assemblage from Thorpe Common is particularly useful because most of the debitage has not been washed and the tools have generally only been cleaned on one face for the application of a catalogue number. This is important because vigorous washing of stone tools can remove most or all of the residues adhering to them. Ideally, tools subject to residue analysis should not even be touched with bare hands because of the possibility of contamination from sweat, finger grease or secreted blood components.

For the purposes of my research it is not necessary to study the entire assemblage from Thorpe Common; instead, a random sample of artefacts has been selected for analysis. A stratified sampling scheme was employed, partly to facilitate the examination of possible relationships between formal artefact classes and function. Also of interest is the frequency of blood residues in the assemblage, and once identification has taken place, the frequency of different animal species. The debitage will also be sampled to identify tools or tool fragments and items with possible human blood from knapping accidents, and to determine the frequency of blood residues on debitage in the assemblage.

As of this writing, 30 tools have been examined and 16 of these have blood residues present. The residues have been identified as blood by microscopic examination (20 x to 600 x) and comparison of their visual characteristics with control blood residues on experimental tools and by testing with urinalysis test strips sensitive to small amounts of haemoglobin. It is interesting to note that among the 30 items examined so far, 4 out of 5 points and 5 out of 5 retouched flakes test positive for blood, but few items out of the other formal artefact classes have blood residues, most notably 1 out of 5 microliths.

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

ULVA CAVE AND THE EARLY SETTLEMENT OF NORTHERN BRITAIN

C. BONSALL, D. G. SUTHERLAND & T. J. LAWSON

Abstract: The Ulva Cave excavation is part of a multi-disciplinary investigation of the human occupation of Scotland prior to 9000 BP, and of the environmental background to that occupation. To date, work has focused on the most recent deposits within the cave. These are of (?)Lateglacial/Flandrian age and contains artefacts, structural evidence and abundant faunal remains, comprising bird, fish, human and mammalian bones, and marine shells. These deposits have been shown to be underlain by up to 10 metres of Late Pleistocene sediments, the bulk of which probably pre-date the Late Devensian ice advance.

The dating of the first appearance of human groups in Scotland is a fundamental problem in the study of the prehistory of northern Britain. The traditional view is one of very late colonization — the earliest settlement usually attributed to the Mesolithic, between *c.* 8500-8000 BP. In the authors' opinion, however, this interpretation has resulted from inadequate fieldwork and from a poor understanding of the archaeological evidence. Typological evidence suggests that the oldest Mesolithic sites are likely to pre-date 9000 BP. The case for earlier, late Palaeolithic occupation rests on: (i) isolated finds of antler and flint artefacts of probable Lateglacial age from Glenavon, Ballevullin on Tiree and from the bed of the North Sea between Shetland and Norway; and (ii) a deposit containing over 800 shed reindeer antlers in Reindeer Cave, Creag nan Uamh, Assynt, dated to 10,080 +/− 70 yr BP and interpreted as the residue of a raw material cache left by a band of Late Glacial reindeer hunters. From these lines of evidence, Lawson and Bonsall (1986*a*, 1968*b*; Bonsall, 1988) have argued that Scotland was occupied continuously from the Late Glacial onwards. To date, however, there are no securely dated finds of Upper Palaeolithic (or early Mesolithic) artefacts from Scotland, and no settlement sites of Late Glacial or very early Flandrian age have been found.

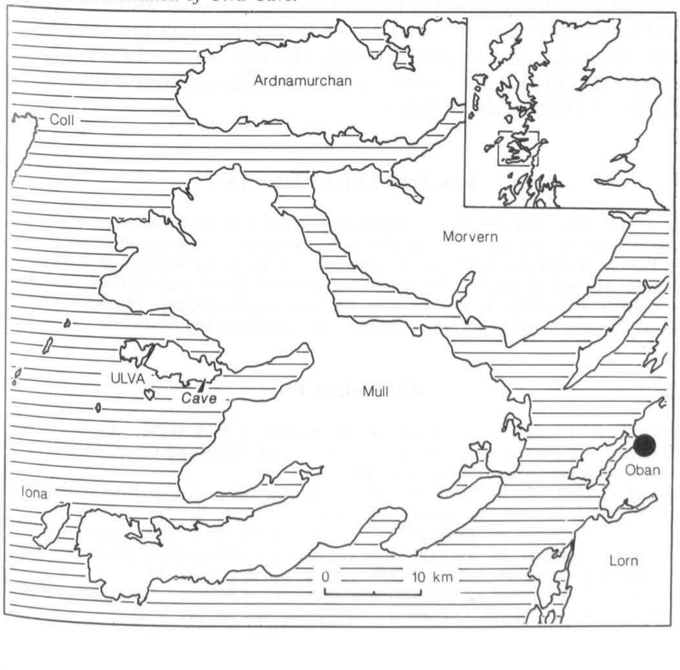
The Ulva Cave excavation is part of a major programme of research into the early settlement of Scotland. The primary objective of this research is the discovery and investigation of sites which preserve evidence of occupation belonging to the period before 9000 BP. Other objectives include the recovery of evidence for climatic, faunal and sea-level changes which would have formed the background to Late Devensian and early Flandrian settlement.

The first season of fieldwork on Ulva was carried out over a 5-week period in July-August 1987, and involved a small team of specialists and volunteer excavators. Grants to support the fieldwork were provided by the Carnegie Trust, Edinburgh University Department of Archaeology Fieldwork and Research Fund, the Royal Archaeological Institute, the Society of Antiquaries of London, and the Society of Antiquaries of Scotland.

ULVA CAVE

Ulva is a small island, roughly 8 x 3 km, off the west coast of Mull from which it is separated by a narrow, shallow sound. Its geology is largely the product of Tertiary volcanic activity, the island consisting of a series of more or less horizontally bedded basalt lavas. The landscape was subsequently modified by Quaternary glaciation.

Figure 1. The location of Ulva Cave.



The Ulva Cave (NM 431384) is situated some 300m south west of the summit of A'Chrannag in the south east of the island, and about 400m from the present shortline (Fig. 1). It consists of a large single chamber which opens out from the base of a basalt cliff, via an entrance which is 10m wide and up to 3m high. The chamber itself is roughly trapezoidal in plan, and is *c.* 17m deep (measured inwards from the drip-line) and *c.* 16m wide. The present floor of the cave is at an average height of 48.5m O.D.

From the cave entrance vegetated scree extends down to a basalt step at an altitude of *c.* 39m O.D. This step may be a marine erosional feature. It is possible, therefore, that the cave was originally formed by the sea at that level. If this interpretation is correct, then the cave can be expected to contain up to 10m of sediments.

Little is known of the recent history of Ulva Cave. It is reported to have been used by David Livingstone's grandparents as a home for several years before they moved onto their croft, and that during the 19th century clearances crofters hid their cattle in the cave (Macintyre 1984: 638). The only record of any previous "excavation" is of a trench dug by geologists from the Geological Survey in the early 1900s (Bailey *et al.* 1924: 390) in order to investigate the nature of the cave infilling.

Features associated with the cave floor

The deposits which form the floor of the cave are very variable (Fig. 2a), occurring beneath a thin layer of animal dung.

The greater part of the floor area is apparently underlain by till-like sediments. These can be divided into a number of stratigraphic units which differ in terms of colour, texture, stone content, and structure. The clast content is variable but always includes a significant proportion of non-local (erratic) lithologies; the matrix varies from clay to sandy loam. These sediments are considered to be of glacial origin, but their mode of deposition within the cave is problematical. In part they may represent a debris flow (or a series of debris flows) derived from material originally deposited within or just outside the entrance area. Provisionally, Late Devensian age is assigned to these sediments.

In places the till-like sediments are overlain by more recent deposits. The cave entrance is partially blocked by angular basalt rubble. Although this probably includes some material that has fallen from the cliff above the opening, it is largely the remains of a substantial dry-stone wall constructed across the entrance — perhaps connected with the use of the cave for sheltering cattle. In the entrance zone, on the inner side of the wall, there is a slightly raised area composed of shell debris and pebble- to cobble-sized angular basalt clasts. The shells include those of *Littorina* sp., *Patella vulgata, Ostrea edulis,* and *Trophon* sp. Also visible on the surface of this "midden" deposit are occasional flint artefacts, rounded pebbles, and fragments of bone. In the western half of the chamber is a substantial area of Flandrian sediments which appear to infill a hollow, or a series of hollows, in the till surface. The north-east corner of the cave contains an area of compacted angular basaltic gravel which similarly overlies the till-like sediments.

There were few signs of recent disturbance within the cave. Evidence was found of at least five previous trenches that had been dug into the cave floor (Fig. 2). The largest and deepest of these is presumed to be that excavated by the Geological Survey, and had been dug to a depth of 1.80 metres. The other four trenches were relatively shallow features ranging from 40 to 120cm deep.

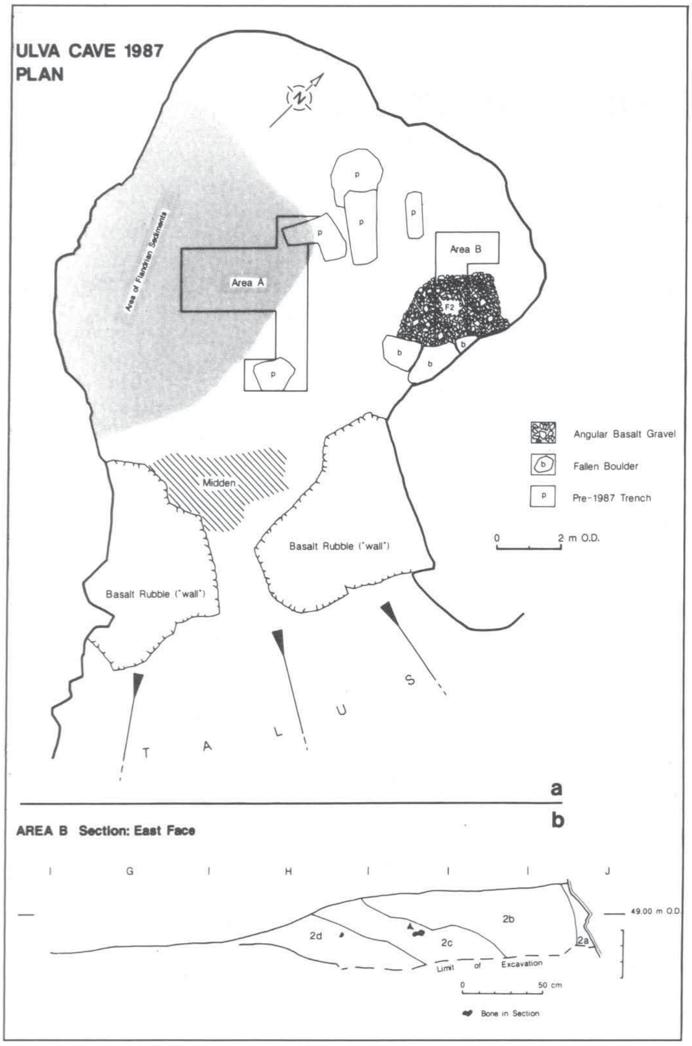


Figure 2. Ulva Cave: a. plan of features associated with the cave floor, and of trenches opened in 1987; b. section — east face of Area B.

CURRENT EXCAVATIONS

The investigation of the cave was approached in three stages. First, a detailed plan of the cave and a counter map of the floor were made. The second stage was to re-excavate the previous trenches and to examine the backfill for artefacts and faunal remains. The Geological Survey's trench was extended to a depth of 3.90m by excavation and hand augering and the section in the east wall of the trench described and sampled. Stage 3 was to begin a controlled excavation of the deposits in the interior of the cave; attention focused on the area of Flandrian sediments (Area A) and on the outcrop of gravel (Area B). For practical reasons, no attempt was made in 1987 to investigate the "midden" or other features in the entrance zone. All the material excavated from Areas A and B was sieved through a 3mm mesh, using a high pressure cold water system.

Area A

The Flandrian sediments were examined to a depth of *c.* 60cm. They consist of a well-stratified series of deposits with organic- and mineral-rich layers. Faunal material was recovered from nearly all the strata, and includes the remains of mammals, fish and shellfish. A small quantity of plant remains were also recovered during wet sieving.

Few artefacts have been found so far, but human occupation is clearly indicated by charcoal-rich layers and lenses, the presence of numerous shellfish remains and fish bones, and an apparently artificial concentration of stones.

The time-range represented by these sediments is uncertain at present, but the excavation has produced ample material for radiocarbon dating. Samples were also taken from flotation and for pedological analysis.

Area B

A trench, one metre wide, was dug to investigate the relationship between the gravel and the surrounding sediments.

The gravel consists of a series of strata dipping towards the south-east wall of the cave (*Fig. 2b:* 2b-2d). The individual layers consist of angular, locally-derived basalt clasts, but differ primarily in terms of colour and the nature of the matrix. There is considerable variation within each layer in terms of the size of the clasts.

The origin and age of the gravel is uncertain at present. It seems improbable that a deposit of this type would have formed inside the cave during the Flandrian; on present evidence a Late Glacial (possibly Loch Lomond Stadial) age is considered more likely.

At the south-east end of the trench the gravel is overlain by a thin layer of clay (2a) and by an organic-rich deposit (F13 — not recorded in the section shown in *Fig. 2b*) containing abundant shell and bone fragments and occasional flint artefacts.

Faunal remains were common throughout the gravel and the overlying deposits. The provisional inventory indicates the presence of bones of amphibians, birds, fish, land mammals (large and small) and seals, and reveals some apparent changes through the sequence (L. Barnetson, pers. comm.). The youngest deposits (F13, 2a) produced the bones of pig and sheep/goat, as well as the remains of a human infant. In contrast, remains of large mammals recovered from the gravel appear to be exclusively those of deer. The presence of Arctic Lemming *(Dicrostonyx torquatus)* amongst the microfauna from the gravel is consistent with a Late Glacial dating. Absent so far from the faunal inventory are the bones of large carnivores, normally well-represented in Pleistocene cave faunas from Britain.

No direct evidence of human occupation in the form of artefacts has been recovered from the gravel so far, but the presence within it of remains of birds, fish and, particularly, seal is of considerable interest.

In the north-west part of Area B the remains of a shallow pit cut into the till-like sediments were found. This feature was only partially excavated in 1987. The character of the infilling, which includes charcoal, shell debris and burnt bone fragments, suggests that the pit was connected with food processing activities. No artefacts have been recovered, but radiocarbon dates will be obtained in due course.

FUTURE PROSPECTS

In northern Britain generally sites which preserve thick depositional sequences of late Quaternary age containing evidence of archaeological and environmental significance are extremely rare. The first season of excavation has established the existence within Ulva Cave of a well-stratified series of Flandrian and Late Glacial? sediments containing artefacts, structural evidence, and/or abundant faunal remains. These deposits have been shown to be underlain by up to 4m (and possibly as much as 10m) of earlier sediments. The site thus has considerable potential for both archaeological and palaeoenvironmental research. The excellent organic preservation and stratification within the upper part of the sequence offers the prospect of establishing the age, subsistence base and seasonality of successive occupations of the cave during the post-glacial period. Moreover, the earliest deposits within the cave are likely to pre-date the Last Glacial maximum, and may include Middle Devensian stadial and interstadial sediments. The recovery of archaeological remains from these deposits would be of enormous significance for the study of early settlement in northern Britain. The palaeonenvironmental potential of a site such as Ulva Cave has been amply demonstrated by the recent investigation of a high-level sea cave in western Norway (Larsen *et al.* 1987) which preserved evidence of climatic and faunal changes over a timescale of tens of thousands of years.

ACKNOWLEDGEMENTS

Many individuals contributed to the success of the first field season on Ulva. In particular, we would like to thank Mrs. J. M. Howard for permission to excavate, Lin Barnetson who provided a provisional report on the faunal remains, Bob Bazeley who acted as site supervisor, the student members of the excavation team, and the inhabitants of the Isle of Ulva for their kindness and hospitality. Thanks are also due to the various grant awarding bodies who supported the fieldwork.

REFERENCES

Bailey, E. B., Clough, C. T., Wright, W. B., Richey, J. E. & Wilson, G. V. (1924) Tertiary and Post-Tertiary Geology of Mull, Loch Aline and Oban. Memoir of the Geological Survey of Scotland, 445 pp.

Bonsall, C. 1988. Morton and Lussa Wood: the case for early Flandrian settlement of Scotland, Scottish Archaelogical Review, vol. 5, pp. 30-33.

Larsen, E., Gulliksen, S., Lauritzen, S., Lie, R., Lovlie, R. & Mangerud, J. (1987) Cave stratigraphy in western Norway: multiple Weichselian glaciation and interstadial vertebrate fauna, Boreas, vol. 16, no. 3, pp. 267-292.

Lawson, T. J. & Bonsall, C. (1986a) Early settlement in Scotland: the evidence from Reindeer Cave, Assynt, Quaternary Newsletter, vol. 49; pp. 1-7.

Lawson, T. J. & Bonsall, C. (1986b) The Palaeolithic of Scotland: a reconsideration of evidence from Reindeer Cave, Assynt, in S.N. Collcutt (ed.), The Palaeolithic of Britain and its Nearest Neighbours: Recent Trends. Sheffield, University of Sheffield Department of Archaeology: pp.85-89.
Macintyre, L. (1984) Ulva — island of memories, The Scots Magazine, September 1984, pp.632-644.

Received June 1989

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

B.C.R.A. Cave Science Symposium, October 1989

Abstracts of papers presented at the meeting

University of Leeds, October 1989

ACTIVE CIRCULATION OF SALINE GROUNDWATERS IN CARBONATE PLATFORMS: EVIDENCE FROM THE GREAT BAHAMA BANK

Fiona Whitaker and Peter Smart, Dept. of Geography, Bristol University.

Large-scale fluid flow in the subsurface of carbonate platforms may be driven by differences in elevation head, density and temperature. In this paper we briefly review these mechanisms and present field evidence demonstrating that significant volumes of sea water beneath North Andros Island in the Bahamas. The processes driving this circulation were investigated using salinity and temperature as natural tracers, measurements of coastal water levels, and budgeting of groundwater discharges from offshore blue holes.

Two water types of near-normal sea water composition circulate beneath North Andros Island. Elevated salinity waters (38-42 ppt) are derived by density reflux from the Great Bahama Bank and flow eastwards beneath the island. These mix with normal salinity cold waters (19-20°C) from deeper than 250m in the adjacent oceans. East to west flow of water from the Straits of Florida may be driven by head differences generated by the Florida Current which impinges on the western margins of the platform. Alternatively, density differences between the reflux and Tongue of the Ocean sea waters may cause more local circulation on the eastern flanks.

These saline groundwater flows have important diagenetic implications, particularly in the explanation of pervasive secondary dolomitization widely reported at shallow depths in the Bahamas.

RADON DAUGHTER CONCENTRATIONS IN BRITISH CAVES: A PROGRESS REPORT

John Gunn and Stan Fletcher, Limestone Research Group, Manchester Polytechnic.
Terry Middleton, Stafford College, Stafford.
David Prime, Radiological Protection Service, Manchester University.

The radioactive gas radon-222 is a decay product of uranium and in turn decays through four short-lived daughters to lead-210. Exposure to high concentrations of radon daughters can give rise to lung cancer and possibly also to other cancers. Since June 1987 we have measured radon daughter concentrations on a sporadic basis in several British caves using both a "Radon Sniffer" (Working Level Meter) and the Kusnetz Method. Radon daughter concentrations vary spatially (from caving area to caving area, from cave to cave within a particular area and from site to site within individual cave systems) and temporally (both seasonally and diurnally).

The highest concentrations (>24 WL) occur in Giant's Hole in the Castleton area of the Peak District where regular cavers may receive a radiation dose well in excess of that received by classified workers in the nuclear industry. Air flow direction was found to be a dominant factor affecting both temporal and spatial patterns within this and several other caves. This in turn is related on a seasonal and diurnal basis to the temperature gradient between air outside and inside the cave. Some of the temporal variation can also be related to changes in atmospheric pressure.

On the basis of very limited spatial sampling, concentrations elsewhere in the country appear to be generally lower ranging from negligible in most caves during winter (outside temperatures less than inside) up to 0.5 WL in Devon, 1.6 WL in the Yorkshire Dales, 2.9 WL in South Wales, and 1.8 WL in the Mendip Hills. The normal annual radiation dose for a member of the public is 15-30 WLH (that is 15-30 hours at 1 WL) and the maximum permitted dose for anyone other than a classified radiation worker is 204 WLH. Hence, it seems likely that the majority of cavers in these areas receive a higher than average radiation dose as a result of their leisure activities and that some may receive more than the permitted dose for non-classified workers. Further information is clearly needed!

The radon daughter concentrations in tourist caves and mines are such that the radiation dose received by a member of the public on a guided tour would be negligible. However, at some sites full-time guides could receive a significant dose and as a result several operators are considering either installing ventilation systems or changing to self-guided tours both of which could result in damage to speleothems.

GEOCHEMISTRY AND ISOTOPE SYSTEMATICS OF SULPHUR IN THE MIXING ZONE OF BAHAMIAN BLUE HOLES

Simon H. Bottsell and Rob Raiswell, Dept. of Earth Sciences, Leeds University.
Peter L. Smart and Fiona Whitaker, Dept. of Geography, Bristol University.

A profile of aqueous sulphur species concentrations and stable isotope compositions is presented for the mixing zone of Cousteau's Blue Hole, North Andros, Bahamas. This and results from two other blue holes show that S^0 and S^{2-} are produced by bacterially mediated sulphate reduction near the base of the mixing zone and that these species are reoxidised at higher levels. Acidity generated by the oxidation reactions can contribute to corrosion of the limestone wallrocks. Estimated rates of corrosion due to these reactions range up to 600mm wallrock recession per 10 ka and are comparable with rates of dissolution caused by inorganic mixing corrosion.

SOME QUANTITATIVE POLLEN EXTRACTION TESTS LEADING TO A MODIFIED TECHNIQUE FOR CAVE SEDIMENTS

D. N. Hale and M. J. Noel, Dept. of Archaeology, University of Durham.

These extraction experiments form part of a larger research project analysing pollen and spores from clastic sediments and speleothems from caves in Derbyshire and Nottinghamshire. The aim is to reconstruct vegetational histories over long timespans with specific reference to the role that humans have played in influencing such changes. Pollen-zonal dating of the sequences is being complemented by palaeomagnetic and uranium series dating and by faunal assemblages.

In order to establish the most suitable pollen extraction method for samples from Robin Hood's Cave, Creswell Crags SSSI, a number of experiments were carried out. The sediments in the cave are generally fine sands and silts and previous work has shown that little pollen remains in them. The low pollen content makes it more important that as many as possible of the grains are extracted from the matrix. A preparation technique was called for which would remove the minerogenic components of the sediment rapidly and safely without dissolving, or otherwise destroying, any organic-walled microfossils (thus including fungi and algae which may be used as environmental indicators). The use of hydrofluoric acid and/or acetolysis was therefore unsuitable.

All the tests involving more standard procedures (HC1, KOH dissolutions, swirling and sieving) showed alarmingly low recoveries of 'marker' *Lycopodium* spores, averaging 9.75%. Tests which involved the use of a heavy liquid separation technique in conjunction with standard procedures almost doubled the recovery rate. The heavy liquid used is zinc chloride, with a relative density of 1.9. Some cave samples that have been processed with this method have yielded 30-35% recoveries.

AGRICULTURAL IMPACTS ON CAVES

Paul Hardwick and John Gunn, Limestone Research Group, Manchester Polytechnic.

There are over 2700 caves in Great Britain, and their value as scientific resources has been recognised by the Nature Conservancy Council's designation of 48 Cave Sites of Special Scientific Interest (SSSI). The 48 sites contain within their boundaries over 32% of known caves and 80% of cave passage.

For each SSSI, a series of Potentially Damaging Operations (PDOs) are set out, and landowners wishing to carry out PDOs are required by law to notify NCC of their intentions. NCC may then object, in which case either a management agreement is sought, or the farmer is offered compensation. PDOs allow the NCC to protect the caves by exerting some control on land-use practices. However, problems have arisen because the impacts of the various PDOs on cave systems have not been fully evaluated.

Consequently, the Limestone Research Group have constructed an impact matrix, which is an initial model of how PDOs may impact on cave geoecosystems, based upon evidence from an extensive literature survey. Where evidence is lacking, impacts have been transposed from studies of agricultural operations on other lithologies. The study has suggested that soil erosion in cavernous limestone catchments has been inadequately investigated and that the impacts of derived sediments may be considerable. An investigation has been commenced in the Castleton karst to determine sediment sources, quantify rates of sediment delivery, and to assess underground impacts.

SEDIMENT DYNAMICS IN THE CASTLETON KARST

Paul Hardwick and John Gunn, Limestone Research Group, Manchester Polytechnic.

Caves form the accessible parts of active and relict limestone drainage systems. The sediments which they contain are often well preserved and their study has revealed much valuable palaeoclimatic, palaeontological and palaeogeomorphological information. However, ongoing research into the impact of agricultural operations on the scientific interest of cave systems has highlighted the lack of information on contemporary sediment accretion or erosion rates in caves and the ways in which these may be affected by agricultural operations in the catchment area. This information is necessary for the development of land-use strategies for surface catchments draining into cave systems. When considering soil erosion and fluvial transport of derived sediments, karst drainage catchments may be viewed either as single or mixed lithology systems. In a single lithology system recharge may be diffuse (directly into bare limestone or through surficial deposits) or concentrated (by closed depressions) whereas in mixed lithology systems a significant component of recharge is via point inputs from surface streams sourced on non-carbonate strata.

Sediment dynamics studies are being undertaken in the Castleton karst research catchment which is a classic example of a mixed lithology karst drainage system. It is the most extensively instrumented catchment of its type in Britain with an automatic weather station, recording rain gauges and recording stage gauges on stream sinks and the three risings. The two main aims of the study are:

1. To quantify sediment transport and storage in a mixed lithology system, particular attention being focused on the role of stream sinks as controls on sediment inputs.
2. To investigate the erosion of soils overlying karstified limestones and the role of diffuse flow in the transportation of derived sediments, nutrients and pollutants to the subcutaneous zone and underlying cave systems.

A QUANTITATIVE EXAMINATION OF CONDUIT FLOW CHARACTERISTICS IN A KARST AQUIFER IN THE MENDIP HILLS

S. L. Hobbs and P. L. Smart, Dept. of Geography, Bristol University.

Hydraulic head/discharge variations in an active phreatic conduit in the maturely karstified Banwell Spring catchment, Mendip Hills, are examined using the Darcy-Wiesbach and Manning-Stickler equations to obtain friction factors, roughness coefficient and Reynolds number for that conduit. The variation of friction factor with discharge (and therefore Reynolds number) suggests that flow is transitional in nature, even though it is always greater than the upper boundary for transition flow. The size of roughness elements are calculated to be greater than the passage dimensions, calling into question the use of theoretical pipe flow equations in karst conduits.

Research from other karst areas, and from the Cheddar catchment in the Mendip Hills, suggests that head loss is not uniformly developed in conduits but occurs as step drops. This may to some extent explain the poor results obtained using theoretical pipe flow equations which are based on uniform head loss.

CARBON DIOXIDE IN SOIL, CAVE AIR AND CAVE WATER

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Carbon dioxide in soil, cave air and water have been measured at a range of sites. Soil air was sampled by emplacing a sealed polythene bag (permeable to CO_2), in an auger hole. After time to equilibrate with the soil air, the polythene bag is removed and the CO_2 content is measured using a hypodermic needle and a Draeger type apparatus. Soil CO_2 is very variable on a single site and 8 to 10 samples are normally averaged. Important causes of inter-site variations include moisture content, soil porosity, organic matter and season. Limestone soils in the British Isles commonly have average soil air contents of 0.7 to 2.0% though site values of over 3.5% have been measured and spot values of nearly 7%. Previous work indicates seasonal variations of soil CO_2 with variations of biotic activity, giving higher values in summer. However, increased wetness seems to lead to higher CO_2 levels and thus, in Britain, soil CO_2 on many sites may be higher in winter.

CO_2 content of cave water was measured using tins to trap pockets of air in contact with moving water. The trapped air can be sampled with a hypodermic needle on a Draeger apparatus, by puncturing a rubber patch cemented over a hole in the tin. It was found that the CO_2 content of the trapped air pocket equilibrates in less than 24 hours. In some cave passages air equivalent CO_2 content of the water was found to be higher than cave air and in other passages lower, with the differences being small in many cases. There is some evidence of seasonal variations of CO_2 in cave air and cave water but this is obscured by short term variations, especially those associated with meteorological and hydrological variations. CO_2 contents of water entering sinks is commonly 3 times that of the average atmosphere. Risings show considerably higher levels of CO_2 content, an extreme example being Rickford Rising, Mendip, with an air equivalent value of nearly 3% CO_2.

FRACTURE CONTROL OF CAVES IN MARBLE IN NORWAY

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A genetic analysis of the guiding fractures in a karst system may help predicting aquifer properties beyond the limits of exploration; as well as providing a model for other non-karstic fracture aquifers. Shear and tension fractures may be distinguished by either observed slip vectors (slickensides) and/or by their angle with the principal axis of stress. Stress axes may be determined from a set of shearplanes where the slip-vectors are known or can be inferred.

In marble karst all primary voids like bedding planes are sealed by metamorphism and karstification is restricted to fractures, except where the bedding provides insoluble barriers. Analysis of several marble caves revealed that both shear and tension fractures are utilized as primary guiding voids for speleogensis. In some cases shearplanes are dominant, suggesting that fracture extension and thereby probability of intersecting other fractures is an important parameter. The 3-dimensional distribution of cave axes trends may also be effectively modelled by beta-analysis (intersection) of fractures and bedding planes.

THE PALEOMAGNETISM AND STRATIGRAPHY OF SEDIMENTS FROM PEAK CAVERN, CASTLETON

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T. D. Ford, Dept. of Geology, Leicester University.

The palaeomagnetic and stratigraphic logging of sixteen sediment sections within Peak Cavern has been carried out in an attempt to provide evidence that will enable the correlation of sequences in the cave, and thus help to establish a picture of the evolution of the system's sedimentary fill. Maypole Inlet, an abandoned high-level tube with 90m of continuously exposed sediments, has proved to be an excellent natural 'laboratory' in which to test these ideas. Sedimentary sequences have also been sampled in other areas of the cave with a view to extending the correlation between passages developed along the Maypole bedding plane, and also to those of the Main Stream Inlet series below. It has not been possible to demonstrate full correlation of palaeomagnetic logs from neighbouring sections. This, however, is consistent with a study of sediment stratigraphy that shows disturbance to be ubiquitous and that rates of deposition can vary widely even between spatially closely related sampling sites. Palaeomagnetic logs have also been used to identify the down-passage continuity of sedimentary features, such as erosional surfaces, that may be diachronous.

THE SANDSTONE CAVES OF NOTTINGHAM

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Beneath Nottingham City is a bed of pebbly sandstone which was deposited by a vast river about 254 million years ago, during the Triassic Period. The sandstone spreads far beyond the city and is recognisable in many parts of the country. Known to the north as the Nottingham Castle Sandstone Formation, it forms the Castle Rock and other smaller cliffs in the city. Normally present beneath this is the somewhat softer Lenton Sandstone Formation.

Within these two sandstones, but particularly the Nottingham Castle Formation, are the hundreds of excavations that comprise Nottingham's caves. The age of the earliest excavations is unknown, but these man-made caves have been present for at least a thousand years. During this time they have been used for such diverse purposes as wells, cess-pits, storerooms for grain, wine, fish and meat, as maltings, breweries and tanneries, dwellings and hideaways, routes of communication, decorative follies, shelters in time of war and as a source of building sand.

The caves are a great source of interest in Nottingham, giving insights into the history and geology of the area. However, they present a major problem in the modern City. Safe redevelopment requires the possible presence of such cavities to be considered and suitable investigations undertaken. The British Geological Survey report, *A Register of Nottingham's Caves,* includes an information sheet for each known cave site and location maps at 1:2500 scale, forming a basis from which developers, planners and future researchers may start more detailed investigations.

WHAT HAPPENS TO ANIMALS WHEN THEY DIE IN CAVES

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Decomposers play a very important role in terrestrial ecosystems, contributing over 95% of total community metabolism, yet they have received relatively little attention. Past investigations relate to carrion exposed on the ground surface, or shallowly buried in soil, although some biospeleologists have used animal baits to attract cavernicolous insects and fungi. However, little information exists on the decomposition processes in caves, where material can be exposed on the surface, yet remain poorly accessible to most animals which normally colonise carrion.

The excavation of animal remains buried in cave sediments has long been important to palaeontology, and more recently to palaeocology. The processes which occur after a carcass has been deposited, during decomposition and subsequent burial in the sediment, are almost unknown, and recent work suggests that these may result in misleading information when the remains are later excavated.

The present work investigates the decomposition of rat carcasses deposited in two caves at Creswell Crags, Worksop, Notts. Results so far emphasise the slow rate of insect colonisation, which is dependent on the distance into the cave carcasses are deposited, and the importance of fungi in the decomposition process. Details of decomposition have been found to vary considerably from one part of the cave to another, and are dependent on the local microclimate. The effects of decomposing material upon cavernicolous invertebrate diversity are being monitored constantly.

The rate of sinkage into the cave sediment, related to sediment depth, and bioperturbation of sediments is also being monitored. It has been observed that carcasses near the cave entrance may be completely buried by beetles of the genus *Necrophorus,* causing considerable disturbance of the sediment. Also, following dipteran infestation of any carcass, larvae burrow into the surrounding sediment to pupate, which results in sediment mixing.

An understanding of such post-depositional processes may be of use to palaeontologists investigating ancient remains, since post-mortal movement and bioperturbation should be taken into account when assessing stratigraphy of cave sediments. It is also hoped that details of the colonisation of the carcasses by both cavernicolous and non-cavernicolous arthropods may be beneficial to certain aspects of forensic science.

HYDRODYNAMICS AND CAVE FORMATION

Keith Plumb, British Cave Research Association.

A firm understanding of hydrodynamics gives a useful insight into many aspects of cave formation and adds to basic information provided by a knowledge of geology and geomorphology. Mathematical models such as Bernoulli's equation help us to understand why meanders form and that vertical meanders are also possible. A study of friction and pressure loss indicate that passages may run full of water for reasons other than geological influences, water table levels and external topography. Passages can carry the maximum flow for a given head when partially full, so increases in discharge can lead to step changes in the flow pattern and shock waves travelling back up the passage. Entrainment of air can have a significant effect on the flow of water and can lead to pulsating flow. Forces such as Magnold forces can keep rocks picked up by the stream from falling back to the floor of the passage. Mechanical damage thus caused could be a significant factor in cave formation.

PHREATIC CAVE THEORY

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This paper presents a theoretical appraisal of phreatic caves. It examines the physical nature of the environment below the surface of the water table in which phreatic cave systems develop. A number of aspects of the environment are considered. A theory of the development of deep phreatic tubes is derived from first principles and is found to reveal the existence of a critical condition which is necessary to the initiation of their development. The development of phreatic ramps is also derived from first principles. These theories are illustrated by considering the initial development of Sleets Gill Cave in Littondale, Yorkshire. Mechanisms for the formation of the deep conduits are then discussed. A model is proposed and a formula is derived which gives the depth of formation of phreatic tubes. The nature of the flow of water in phreatic tubes is considered and the deposition of sediment in these tubes is examined. A method is then proposed for calculating past rates of flow from an analysis of the sediment.

CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

THE QUATERNARY EVOLUTION OF THE SOUTH PENNINES

Peter ROWE, Timothy AUSTIN & Timothy ATKINSON

Abstract: At the southern extremity of the Pennine Range in central England, Carboniferous Limestone is exposed and forms in part an uneven plateau deeply dissected by gorge-like valleys (Dales). Analyses of uranium and thorium isotopes in calcite samples from thick flowstones with a high level relict cave remnant (Elder Bush Cave) indicated that the formations were beyond the range of the uranium-thorium dating technique (350 ka). $^{234}U/^{238}U$ isotope activity ratios approached unity, suggesting that the flowstones may have formed a considerable time before 350 ka. Palaeomagnetic samples taken from cores drilled through the flowstones showed the presence of both normally and reversely magnetised calcite. In some cases reversely magnetised layers overlie normally magnetised layers. This evidence, taken in conjunction with the uranium isotope data, is interpreted as indicating an Olduvai age (1.66-1.87 Ma) for some of the flowstone horizons. It is suggested that the cave became vadose by or soon after 2.0 Ma. The position of the cave near the valley rim enables an estimate to be made of the maximum rate at which the present valley has been excavated. This is calculated to be 5.5 cm/ka. Remnants of old valley floors preserved within the existing valley suggest that downcutting has not been a continuous process. Flowstone from a cave on one of the lower valley floor remnants (Darfur Ridge Cave) has been dated to 284 +34/−27 ka allowing a maximum downcutting rate since that time of 11.2 cm/ka. The proximity of Elder Bush Cave to the valley crest suggests that its abandonment marked the onset of the incision of the present system of dales that characterise the English Peak District, presumably initiated by epeirogenic uplift or tilting.

The antiquity of landscape features has been the subject of much speculation for over a century. As the science of geomorphology has developed, more understanding of form and process has been achieved, but generally techniques for establishing a chronological framework for the observed landforms have been lacking. In Britain during the immediate pre- and post-war years, many "erosion surfaces" were recognised, or at least proposed, (Hollingworth, 1938; Wooldridge, 1950; Sissons, 1954) and some were attributed to sub-aerial erosion, often thought to have occurred during the Tertiary, whilst others were deemed to have a marine origin. In this paper, U-Series and palaeomagnetic techniques are used to establish the chronology of major valley incision into one such "erosion surface".

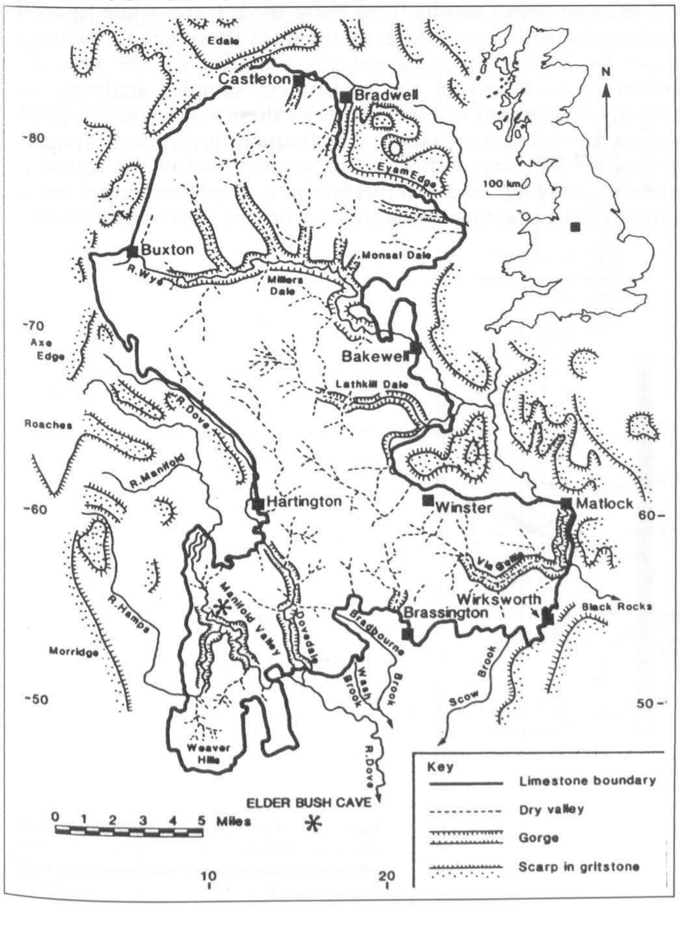
Regional Setting

The English Peak District is an upland area (275-475 metres a.s.l.) situated at the southern end of the Pennine Hills that form a north-south range down the centre of northern England. Here, the Pennine anticline has in part been eroded to reveal limestones belonging to the Dinantian Series of the Lower Carboniferous. To the west, north and east the limestones are unconformably overlain by the impermeable mudstones, sandstones and shales of the Millstone Grit Series of Namurian age.

Much of the limestone, especially in the south, has a gently undulating topography and the term "plateau" has frequently been used to describe the southern part of the limestone outcrop. Many authors have identified a "1000 foot" (330m) erosion surface, not only on the limestone but also on adjacent grits. The age and origin of this feature has been the subject of much speculation (King, 1966; Linton, 1956, 1964). In the north, the plateau is less well defined and summits here rise above 400 metres O.D. The plateau surface is deeply dissected by valleys (Dales) that have been cut by rivers flowing south or south east to the River Trent (fig. 1) and by a complex network of shallower dry valleys.

One of the rivers, the Manifold, has incised a deep valley across the limestone outcrop close to its south-western margin (fig. 1), and gorges have formed where the more resistant reef limestones have been encountered. These reefs contain many dissected fragments of old preatic caves that once carried water to and beneath the River Manifold in former times when it flowed at higher levels than today. An extensive network of phreatic caves exists today beneath the present valley floor and the river frequently disappears underground during the summer months. Remnants of former valley floors can be identified within the existing valley and on the basis of these Warwick (1953) suggested that the valley had been deepened in six successive stages.

Figure 1. Simplified geomorphological map of the White Peak (after Ford, 1977).



Flowstone A, Elder Bush Cave. Stalagmite Boss is right of centre.

The Manifold Valley. View is north from a point near Elder Bush Cave.

METHODS

In order to investigate the chronology of the development of the Manifold Valley, speleothems were collected from twelve fossil cave remnants and dated by the uranium-thorium method. The uranium and thorium isotopes were chemically separated by standard techniques described in Lally (1982) and Rowe (1986), electroplated onto stainless steel planchets and counted by alpha spectrometry. Much of the calcite examined was detritally contaminated or too young to be of significance, but two caves, Elder Bush and Darfur Ridge, contained flowstone of sufficient quality and age to be of use in reconstructing the history of valley incision.

Elder Bush Cave is a truncated high level phreatic tube situated close to the valley rim at 275 metres O.D. Four substantial flowstones., A, B, C and D (of which A and C are about one metre thick), are preserved in this cave (fig. 2) as well as numerous smaller formations. One flowstone (A) has cracked and foundered and a substantial stalagmite boss subsequently grew on its upper surface, after an interval represented by a mud-filled cavity in the stalagmite base. Uranium-thorium dating of hand specimens taken from flowstones A, B and D showed them to be older than the limit of the technique (350 ka) (table 1). $^{234}U/^{238}U$ ratios in samples UEA66 and UEA115 from flowstones A and B were close to unity, suggesting that the samples were probably considerably older than 350 ka. To try and estimate their likely age more closely, a palaeomagnetic investigation was undertaken.

Magnetostratigraphy is a useful tool for correlating and dating Quaternary deposits and Noel *et. al.* (1984) have pointed out its potential for investigating cave sediments. Latham has investigated the palaeomagnetism of speleothems (Latham, 1981; Latham *et al.*, 1979; Latham *et al.*, 1982) and his work has shown that many speleothems have a measurable natural remnant magnetism (NRM).

Oriented core samples were recovered from flowstones A, C and D and the stalagmite boss. The cores were sawn into 2cm sample cubes and their NRM measured on a cryogenic magnetometer after removing any viscous remmant magnetism (VRM) in an alternating field. Pilot studies indicated the presence of a residual, highly stable, primary remanence, and 20mT was chosen as the optimum peak cleaning field. A fuller account of these measurements will be published elsewhere.

RESULTS

Figure 3 is a composite diagram summarising the palaeomagnetic and uranium-series results from Elder Bush Cave, while figure 4 displays detailed sample data obtained for flowstone C. Figure 5 shows the Earth's magnetic polarity timescale for the past five million years. Many of the speleothem samples analysed are reversely magnetised and in some cases these overlie others which possess normal magnetisation. The frequent presence of hiatuses in some of the cores indicates that a great deal of the record is probably missing, and interpretation is therefore rather more complex than a simple comparison with the polarity timescale.

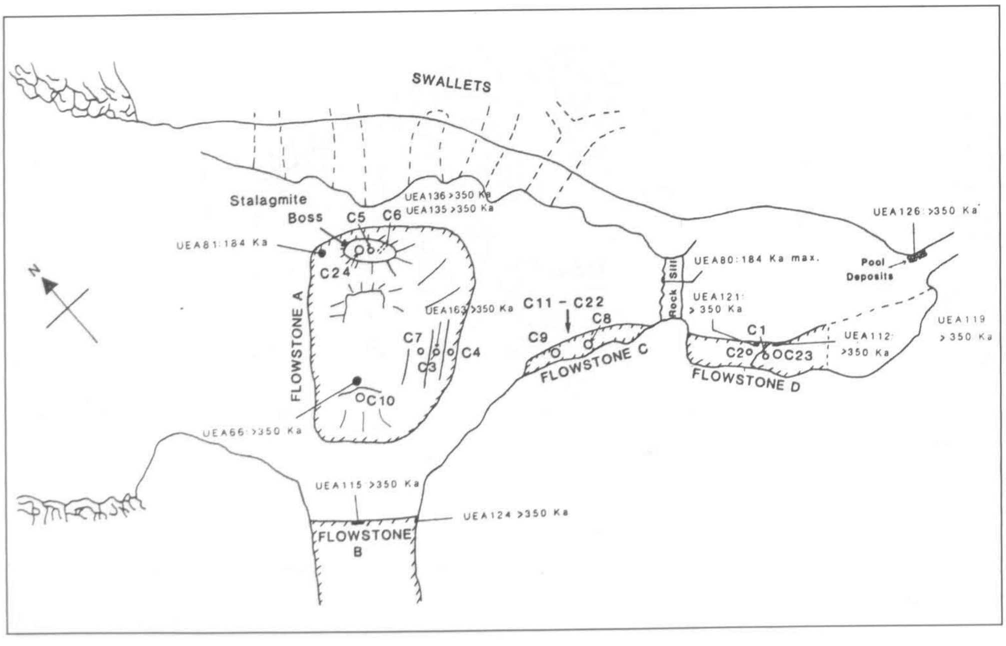


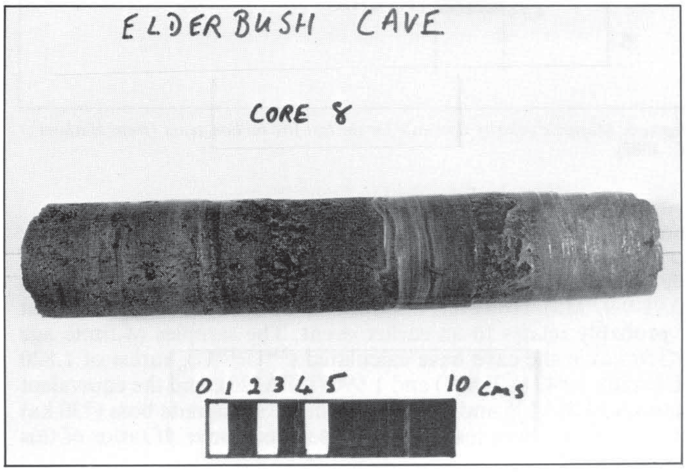
Figure 2. Sketch plan of Elder Bush Cave entrance chamber showing main flowstone formations and locations from which cores and hand specimens were recovered.

View into Elderbush Cave.

Uranium-thorium dating of speleothem samples from Darfur Ridge Cave, situated at shallow depth beneath an old valley floor remnant, showed that one flowstone associated with an old gravel infill possessed an age of 284 +34/−27 ka.

DISCUSSION

$^{234}U/^{238}U$ ratios from the stalagmite boss (UEA135, UEA136, table 1) suggest that the magnetic transition from reversed to normal, seen near the top of the boss represents the Matuyama-Brunhes boundary (0.73 Ma), rather than an older transition such as the lower boundary of the Jaramillo event (0.97 Ma). If the latter were the case, the cave dripwaters would have possessed an initial $^{234}U/^{238}U$ ratio of 2.63. This is considered very unlikely because (i) such high values rarely occur in the literature and (ii) it is six standard deviations higher than the mean initial ratio determined from all well dated speleothems younger than 350 ka in the Manifold Valley (mean = 1.680, 1σ = 0.149, n = 6). An age of 0.73 Ma for this magnetic transition would suggest the much more likely value of 1.57 for the initial $^{234}U/^{238}U$ ratio. The reversely



Typical core from Elderbush cave stalagmite

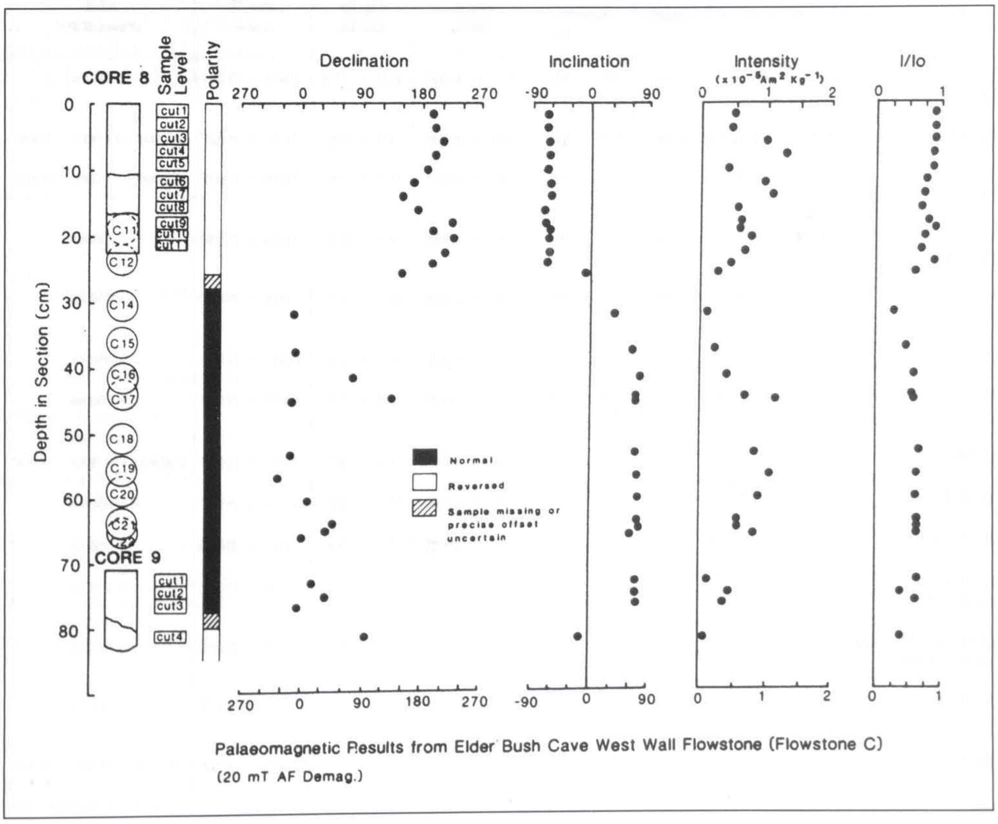


Figure 4. Palaeomagnetic data from flowstone C samples.

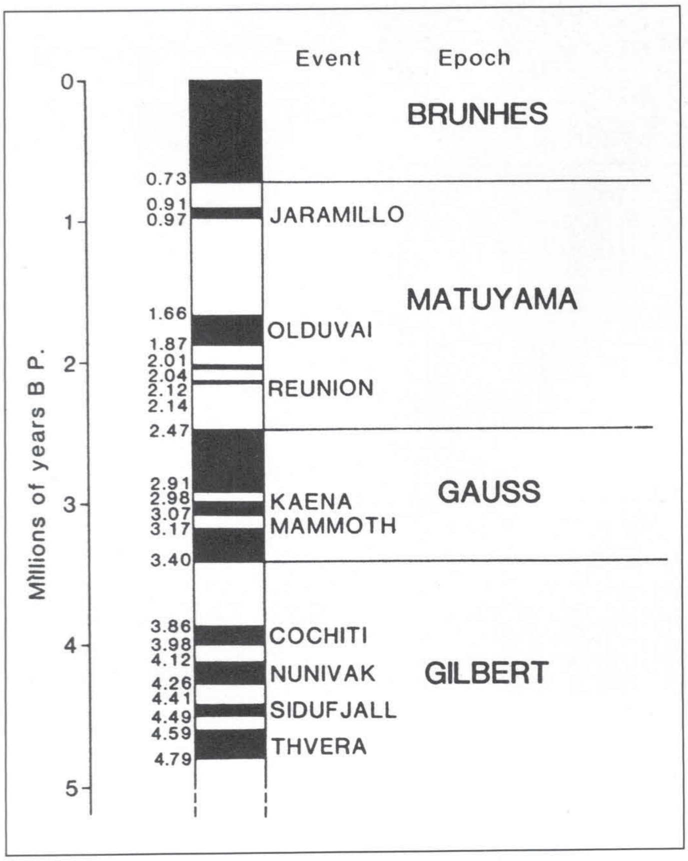


Figure 5. Magnetic polarity timescale for the last five million years (from Harland et al., 1982).

magnetised calcite in the stalagmite boss is therefore most likely to be post-Jaramillo in age and the normal event near the base of the underlying flowstone must be at least as old as the Jaramillo (0.91-0.97 Ma). However, uranium isotopic evidence suggests that it probably relates to an earlier event. The samples of finite age (<350 ka) in the cave have calculated $(^{234}U/^{238}U)_0$ ratios of 1.820 (UEA80), 1.840 (UEA81) and 1.690 (UEA123), and the equivalent ratios for UEA135 and UEA136 from the stalagmite boss (730 ka) could not have been less than 1.57 as stated above. If ratios of this

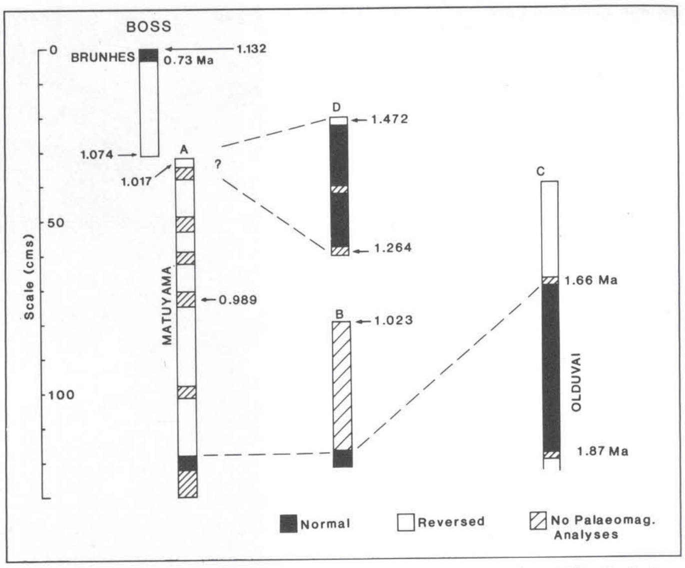


Figure 3. Summary of palaeomagnetic and uranium isotope results from Elder Bush Cave flowstones showing suggested correlations.

order have existed in calcite-forming dripwaters throughout the cave's history, then the proximity of the measured 234-U/238-U to equilibrium in samples UEA66 and UEA163 (see table 1) suggests the reversely magnetised part of the flowstone is much older than the post-Jaramillo part of the Matuyama Epoch (0.91-0.73 Ma). This being so, then the normally magnetised episode observed near its base must related to the Olduvai event (1.66-1.87 Ma). The Jaramillo event is therefore not represented in the sequence (although it may be present in flowstone D). The field relationship between flowstones A and C suggests that they may once have been part of the same formation and it therefore seems probable that the normally magnetised layer observed near the base of flowstone C also relates to the Olduvai event but this has yet to be confirmed by analysis of $^{234}U/^{238}U$ ratios. There is some evidence of reversely magnetised calcite at the base of this formation and if so, its probable age is about 1.87 Ma (fig. 5).

Since speleothem is only able to form in the vadose zone, the evidence suggests that Elder Bush Cave was drained, probably by the downcutting of the Manifold Valley, by or soon after 2.0 Ma. Similarly it is likely that Darfur Ridge Cave was drained by about 300 ka.

CAVE	SAMPLE N°	LAB. N°	U (ppm)	Chemical Yield (%) U	Th	234-U / 238-U	230-Th / 232-Th	230-Th / 234-U	AGE (Years B.P.)
ELDERBUSH (A: TOP)	UEA830109-1	UEA66	0.06	20	45	1.017 ± 0.053	55.6 ± 17.8	0.985 ± 0.051	> 350 ka
ELDERBUSH	UEA831027-6	UEA80	0.08	57	47	1.489 ± 0.036	3.8 ± 0.2	0.876 ± 0.027	184 200 +14 000/−12 600
ELDERBUSH (A: DRAPE)	UEA831027-7	UEA81	0.21	77	15	1.501 ± 0.021	17.1 ± 1.5	0.876 ± 0.022	184 000 +11 300/−10 400
ELDERBUSH (D: BASE)	UEA840524-5	UEA112	0.06	72	76	1.264 ± 0.030	4.4 ± 0.2	1.078 ± 0.033	> 350 ka
ELDERBUSH (B: TOP)	UEA840524-8	UEA115	0.08	53	65	1.023 ± 0.025	30.4 ± 3.3	1.088 ± 0.037	> 350 ka
ELDERBUSH	UEA840524-6	UEA119	0.05	67	81	1.167 ± 0.032	6.7 ± 0.4	1.021 ± 0.034	> 350 ka
ELDERBUSH (D: TOP)	UEA840524-3	UEA121	0.14	70	23	1.472 ± 0.029	6.6 ± 0.3	1.128 ± 0.042	> 350 ka
ELDERBUSH	UEA840524-1	UEA123	0.05	74	57	1.384 ± 0.038	4.6 ± 0.3	0.912 ± 0.033	208 900 +21 800/−18 500
ELDERBUSH	UEA840523-2	UEA124	0.08	71	71	1.044 ± 0.030	12.2 ± 0.8	1.015 ± 0.031	> 350 ka
ELDERBUSH	UEA840524-7	UEA126	0.07	71	59	1.098 ± 0.025	7.5 ± 0.4	1.041 ± 0.033	> 350 ka
ELDERBUSH (BOSS: OUTER)	UEA840905-4	UEA135	0.07	60	74	1.132 ± 0.026	18.9 ± 1.7	1.028 ± 0.026	> 350 ka
ELDERBUSH (BOSS: INNER)	UEA840905-4	UEA136	0.10	58	80	1.074 ± 0.024	27.3 ± 2.2	1.017 ± 0.026	> 350 ka
ELDERBUSH (A: CENTRE)	CORE 3A	UEA163	0.11	55	37	0.989 ± 0.023	91.0 ± 60.1	1.013 ± 0.033	> 350 ka
DARFUR RIDGE	UEA840921-5	UEA137	0.12	63	69	1.305 ± 0.025	17.7 ± 1.4	0.992 ± 0.026	283 700 +34 300/−26 800

Table 1. Uranium-series data for samples from Elder Bush Cave and Darfur Ridge Cave.

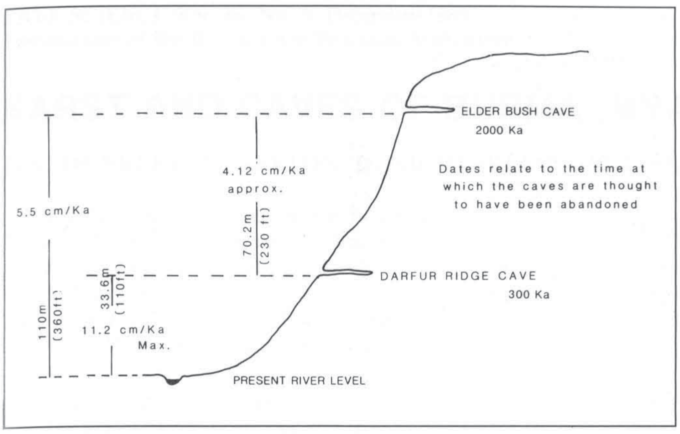


Figure 6. Schematic diagram illustrating the use of palaeomagnetic and uranium-series data in the calculation of the rate of incision of the Manifold Valley.

CONCLUSIONS

Elder Bush Cave stands today about 110 metres above the present river bed and the maximum value for the average rate of valley downcutting over the past two million years can therefore be calculated at 5.5 cm ka^{-1}. If the dated speleothems grew immediately after the drainage of both Elder Bush and Darfur Ridge Caves, the mean valley incision rate between the two would be approximately 4.1 cm ka^{-1}. The maximum average incision rate from Darfur Ridge Cave to the present valley floor was 11.2 cm ka^{-1}. These finding are summarised in figure 6. The incision rates are comparable with cave passage entrenchment rates found by Gascoyne *et al.* (1983) in the northern Pennines (2.2-8.3 cm ka^{-1}) and with valley incision rates in the Magnesian Limestone of the East Midlands (6.6 cm ka^{-1} (Rowe, 1986).

On the western side of the Manifold Valley, opposite Elder Bush Cave, the limestone plateau is well represented. The land surface has little relief and slopes with a gradient of only 1 in 25 upwards from the marked break of slope at the valley rim at about 275 metres O.D. This surface is cut on basinal limestones rather than the resistant reef knolls that dominate much of the Manifold Valley in this locality, and may represent the remains of a land surface that existed at the time Elder Bush Cave was active. Sharp and spectacular breaks of slope occur widely along the rim of the Manifold Valley and that of its tributary, the Hamps, at about 275-290 metres O.D., and also along the nearby Dove Dale, Lathkill Dale and Upper Wye valleys, at 265-300 metres O.D. These breaks of slope appear to mark the commencement of the latest phase of incision into a pre-existing land surface of comparatively low relief. The proximity of Elder Bush Cave to the break in slope together with the chronological data derived from the cave and outlined above, suggest that this phase may have begun around or just prior to 2.0 Ma, probably in response to a falling base level as the southern Pennines experienced renewed uplift.

REFERENCES

Ford T. D., 1977. Limestones and Caves of the Peak District Geo — Abstracts, Norwich.

Gascoyne, M., Ford, D. C. & Schwarcz, H. P., 1983. Rates of cave and landform development in the Yorkshire Dales from speleothem age data. Earth Surf. Landforms, 8: 557-568.

Harland, W. B., Cox, A., Llewellyn, P. G. Pickton C. A. G., Smith, A. G. & Walters, R., 1982. A Geologic time scale, C.U.P. Cambridge.

Hollingworth, S. E., 1938. The recognition and correlation of high level surfaces in Britain: a statistical study. Quat. Jl. Geol. Soc. Lond., 94: 55-84.

King, C. A. M., 1966. Geomorphology. In Edwards, K. C. (ed.), Nottingham and its Region. Br. Assoc. Adv. Sci., Nottingham.

Lally, A. E., 1982. Chemical Procedures. In Ivanovich, M. & Harmon, R. S. (eds.), Uranium Series Disequilibrium: Applications to Environmental Problems. Clarendon Press, Oxford, 79-106.

Latham, A. G., 1981. The Palaeomagnetism Rock Magnetism and U-Th Dating of Speleothem Deposits. Ph. D. Thesis, McMaster University, Hamilton, Ontario, Canada.

Latham, A. G., Schwarcz, H. P., Ford, D. C. & Pearce, G. W., 1979. Palaeomagnetism of stalagmite deposits. Nature, 280: 383-385.

Latham, A. G., Schwarcz, H. P., Ford, D. C. & Pearce, G. W., 1982. The palaeomagnetism and U-Th dating of three Canadian speleothems: evidence for westward drift, 5.4-2.1 ka B.P. Can. J. Earth Sci., 19: 1985-1995.

Linton, D. L., 1956. Geomorphology of the Sheffield Region. In Linton, D.L. (ed.), Sheffield and its Region. Br. Assoc. Ad. Sci., Sheffield.

Linton, D. L., 1964. Tertiary landscape evolution. In Watson, J. W. (ed.), The British Isles. London.

Noel, M., Shaw, R. P. & Ford, T. D., 1984. A palaeomagnetic reversal in Early Quaternary sediments in Masson Hill, Matlock, Derbyshire. Mercian geol., 9(4): 235-242.

Rowe, P. J., 1986. Uranium-Thorius Dating of Cave Sites in the English Midlands. Unpublished Ph. D. Thesis, University of East Anglia, Norwich, U.K.

Sissons, J. B., 1954. The erosion surfaces and drainage system of south-west Yorkshire. Proc. Yorks. Geol. Soc., 29: 305-342.

Wooldridge, S. W., 1950. The upland plains of Britain: their origin and geographical significance. Adv. Sci. Lond., 7: 162-175.

Received June 1989

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CAVE SCIENCE Vol. 16, No. 3, December 1989
Transactions of the British Cave Research Association

KARST AND CAVES OF BURMA (MYANMAR)

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Abstract: In addition to recording the results of the first speleological expedition to Myanmar (formerly Burma) in 1988, this paper collates the available information on karst topography and caves in the country. Limestone is widespread in eastern Myanmar, occurring at intervals throughout the coastal lowlands and ranges bordering Thailand, and the variety of karst topography and caves in Moulmein district and in the southern Shan State is described. Much of that part of the country of speleological interest is presently inaccessible for political and logistical reasons.

There would be few if any countries in the world in which more was known of caves a century ago than is accessible today to either the traveller or to the armchair speleologist. In 1987-88 Burma appeared briefly in world news bulletins as riots accompanied attempts to bring changes to the government which has virtually closed the country for 40 years. Shortly afterwards the country's official anglicised name was altered to the phonetically more accurate Myanmar, its capital Rangoon became Yangon, and Myanmar receded from evening news bulletins and returned to its traditional somnolence. For convenience in reference, the more familiar names have been retained in this paper.

As in neighbouring Thailand, caves in Burma have been known and used for centuries by adherents of Theravada Buddhism, and it was not until the late nineteenth and early twentieth century that Europeans recorded them, during the relatively short period of British occupation. Valuable accounts of limestone geology and associated caves appear in several reports of the Survey of India, which also produced excellent topographic maps highlighting karst terrain.

Since independence in 1948 most of Burma has been off-limits to foreigners and the country became increasingly xenophobic in pursuit of the "Burmese Road to Socialism". Although that policy has officially been abandoned, major difficulties continue to face the free-ranging speleologist, including restrictions on visas and freedom of movement, quirks of currency regulation, rebel control of key karst areas, and considerable logistic difficulties in transportation to areas with cave potential. As an example, Moulmein, near which are tower karst and the best known caves of Burma, has been off-limits for several years. Following civil disorder shortly after our visit in 1988, even tighter restrictions were placed on entry to and travel within the country, and at the time of writing (mid-1989) individual tourist visas were apparently no longer being issued.

One of us (JD) visited Burma in 1976, noting and photographing from a low-flying DC3 the polygonal karst of southern Shan State and the impressive cave entrances on the Kalaw Chaung and Htiswan Chaung, west and south-west of Inle Lake.

In 1987 Tony White made a valiant but successful attempt to check out caves near Ye-ngan, south-east of Mandalay (White, 1987).

In 1986, with the aid of a liaison officer based in Hong Kong and Bangkok who explored the matter with several Ministers of State in Rangoon, John Dunkley and Kevin Kiernan began negotiations with the Government for a speleological expedition. In the meantime, we decided on a small reconnaissance to southern Shan State.

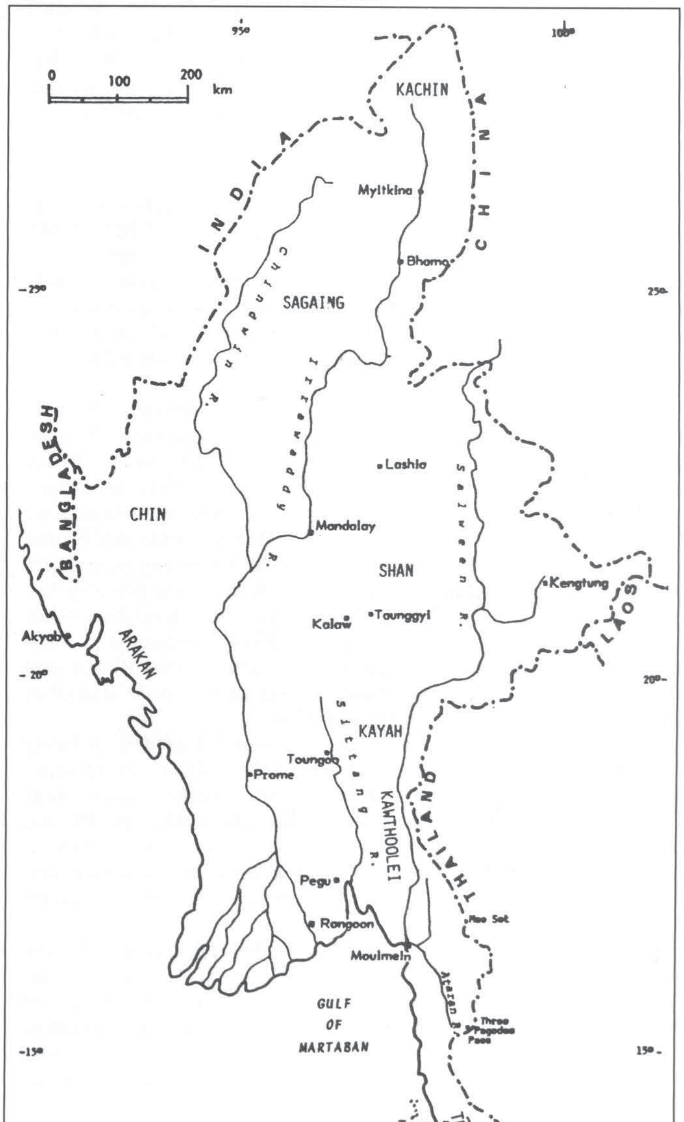
In effect, therefore, this is the first speleological account of a country with massive limestone deposits and a variety of karst terrain with great potential for caves. Accordingly, in addition to recording the results of a five-day reconnaissance by the authors in April 1988, this paper brings together for the first time in over 50 years an accessible outline of the karst and caves of this beautiful country. Particular emphasis is given to southern Shan State and the characteristic tower karst of the Tenasserim coast.

Logistics

There is no denying that this is a difficult country for any kind of serious speleological investigation. When available, visas are rigorously restricted to seven days and exceptions are unlikely to be made for people whose pursuit is widely assumed to be treasure hunting rather than scientific endeavour. While marxist-oriented, Burma pursued, at least until recently its own "Burmese road to Socialism" and at present tourism, speleological esoterica and even foreign aid rank low in priority.

Large areas of limestone with cave potential are off-limits to foreigners or in the control of various insurgent armies or what are still quaintly termed deacoits, including all of southern Shan State to the east of Taunggyi, south of Pinlaung, north of Pindaya and parts of Ye-ngan area. The Mergui archipelago and the magnificent limestone gorge at Gokteik have been closed to foreigners since 1948. Moulmein is currently closed and much of inland Karenni and Kayah States have been in rebel hands for 40 years, being accessible only by smugglers' routes from Thailand. All this means that even government support would be of questionable value;

Figure 1. Location map of Myanmar (Burma).



indeed, given the unpopularity of the government in key areas it may be counter-productive.

As if this is not difficult enough, roads are few, transport is difficult to arrange and the best available may still be carefully preserved World War 2 jeeps, presumably complete with con-rods, exhaust systems and suspensions of bamboo. Officially, Tourism Burma has a monopoly on services to foreigners and charges accordingly, though the determined will discover how to avoid them. Officially, one cannot stay overnight anywhere in the country other than in the few hotels sanctioned by Tourist Burma in Rangoon, Mandalay, Pagan, Kalaw, Taunggyi and Inle Lake. Once again the determined will find alternatives, but they might profit from a reading of Tony White's adventures (White 1988). In relatively busy periods (which may occur at any or all times throughout the year), it may not be possible to get any public transport into or out of Rangoon.

Nevertheless, it is possible to rent vehicles of varying degrees of antiquity for excursions to 'grey' areas of interest to speleologists. Progress will be slow and uncomfortable but you may experience the pleasure, as we did, of meeting people who have not seen foreigners since the British left. Motor traffic is sparse outside Rangoon. If desperate you should be able to rent a buffalo and cart in rural areas, while in Mandalay and Maymyo public transport is still by horse-drawn sulky and stage coach respectively! Fiduciary vagaries of the Burmese kyat make it impossible to estimate costs, but we found most goods and services more expensive, difficult to find, and of noticeably lower quality than in Thailand.

Several foreign tourist guidebooks (e.g. Klein, 1987; Wheeler, 1988) describe how to make the best of a seven-day stay, and anyone contemplating a visit should obtain a wide range of advice.

European accounts of Burmese caves

Only two attempts have been made to give an overview of the caves of Burma, by Annandale *et al.* (1913) and Chhibber (1934). While summarising contemporary knowledge, neither is comprehensive, and it is evident that both relied to a considerable extent on the limited previous published accounts, as does this paper, and very limited field work. A fairly thorough search has not produced any accounts in the speleological literature other than Kusch (1987) referred to below.

The earliest accounts in European literature of caves in this part of the world dealt mainly with caves near Moulmein. Several accounts credited the first published reference to Capt. W. Foley in 1836 (e.g. Annandale *et al.*, 1914; Chhibber, 1934). However, several travellers had earlier remarked on the prominent limestone towers and associated caves. In April 1826 Wilson mentioned P'agat Cave, 26 miles from Moulmein, and in the following year John Crawfurd explored Kogun Cave. In 1833 Low made possibly the first sketch of a Burmese cave (P'agat Cave) and described other limestone towers, caves and associated Buddhist antiquities. In 1835 an American missionary (Malcolm, 1837) also visited P'agat and Kogun Caves and provided the first reference to D'ammabat (Dhammathat) Cave on the Gyaing River.

Foley (1836) mentioned the main caves near Moulmein as being at Yetsey, Tyokhla, Joe-ka-beng, Damatha, Nyown-beng-zeite, Phabia and Dhammathat, along with another cave near Dhammathat which had "been but lately selected by the Phungi for the better concealment of a quantity of manuscripts written in the Thalian or Burmah character, and secreted in the upper part of the Damatha cavern at a time that the country was invaded by the Tschan (Siamese)".

The cave at Nyown-beng-zeite (Nyaungbinzeik) is one of those later referred to as the Kayon or Farm Caves. He also mentioned the cave at Phabowng Thowng, a limestone hill on the banks of the Ataran River near Moulmein with a stream running through it.

The next Burmese cave to be described, and the first elsewhere in Burma was that of Shwe Male, upstream from Mandalay (Yule, 1858, pp. 177-188).

During the period of British occupation Moulmein, near the mouth of the Salween River became a major port and administrative centre. Teak was floated down the Salween from the Shan States and shipped out. Timber traders and others pushed up the Salween and tributaries such as the Gyaing, Ataran and Dondami Rivers, and several caves were described by travellers (Anon., 1872; Annandale *et al.*, 1913; Duroiselle, 1913; Collinge, 1914; Johnston, 1911; Temple, 1894). Close to the town, the "Farm Caves" were popular sites for picnic parties and probably one of the few diversions available in this hot, humid outpost of empire.

The caves of the Ataran River and Thonzoo were referred to by Tickell & Parish (1859), and again by Stolicka (1871). Stolicka did not describe the caves but pointed out how the isolation of the towers containing them admitted of the development of certain persistent peculiarities of their fauna.

Following annexation of Upper Burma in 1886 and the attachment of Burma to the Indian Empire, the Survey of India sponsored several essentially reconnaissance surveys of limestone and other resources of the Shan States. Caves were mentioned in passing in conjunction with mineral, palaeontological or biological reports and researches (e.g. Lydekker, 1886; Collinge, 1914; Choppard, 1924; Pascoe, 1928; Coggin-Brown, 1931, Fermor, 1931).

Descriptions of the karst topography characteristic of Shan State were given by Middlemiss (1900) and by Coggin-Brown (1931). The descriptions given by Middlemiss were reproduced by Chhibber (1934).

In 1987 Heinrich Kusch published the only reference to Burmese caves located in the speleological literature, providing a greatly improved outline of early European exploration of caves near Moulmein. Otherwise, however, he referred only to much older descriptions of the Buddhist statuaries found in some of these caves, and it is evident he did not visit them.

An extensive review of research to that date on cave fauna was provided by Annandale (1913).

Climate and Vegetation

The climate of Burma is controlled by the great monsoon circulation system of South Asia and is influenced in detail by relief-specific peculiarities. The mountain ranges present effective climatic barriers for the SW monsoon in summer and the NE monsoon in winter, so that the central plain of the Irrawaddy and to a lesser degree the Shan Plateau are in rain-shadow.

Burma has a wide range of climate and associated vegetation patterns, varying from tropical monsoon rain forest to alpine tundra; indeed there are glaciers near the border of Tibet. Some 40% of the country is still covered with forest, and Burma remains the world's greatest exporter of teak. However the taunggya (slash-and-burn) agriculture widely practised in upland regions has depleted the forests and soil.

Exposed to the south-west monsoon, the Tenasserim coast is the wettest part of the country, with mean annual precipitation of 4759mm at Moulmein and 5444mm at Tavoy, and mean annual temperatures exceed 25°C. The tropical rain forest in this region produces a large number of valuable hardwood species such as *Dipterocarpus alatus* (Burmese: kanyin). In accessible areas much of the natural vegetation was logged during the colonial era; rubber trees *(Hevea brasiliensis)* are now widespread. In the mountains bordering Thailand, however, there remain vast areas of untouched rain forest.

On the Shan plateau the climate is dry monsoonal, with three distinct seasons: cool and dry (December-March), hot and dry (April-June), and hot and wet (July-November). During the cool season daytime temperatures seldom exceed 25°C, with minima as low as 0°C in January, especially at higher altitudes and in the northern Shan State. Even in the hot season, when day temperatures may exceed 35°C, the elevation reduces humidity and nights are pleasant with minima of 20°C.

The Shan plateau is among the driest parts of Burma with annual precipitation ranging from 600 to 1200mm. In the dry season at least the countryside is reminiscent of the western slopes of New South Wales, or the African savanna. Grassland predominates over wide areas with only scattered woodland mostly on steeper slopes. The vegetation here is characteristically deciduous, the trees losing their leaves shortly after the end of the rainy season. Here one finds *Tectona grandis* (teak), *Xylia dolabriforma* (pyinkado), *Pterocarpus macrocarpus* (padauk or Andaman redwood) and *Terminalis tomentosa* (taukkyan). At higher elevations such as around the old colonial hill-station of Kalaw, mean cool season temperatures fall below 18°C and there are widespread stands of pine.

Limestone

Limestone occurs at intervals along the coastal lowlands and in the ranges and uplands of eastern Burma, usually in long outcrops following the tectonic axis of mountain ranges which extend from the border of Thailand in the far south to Tibet in the north. It is found along the Tenasserim coast, on islands in the Andaman Sea, and in the ranges and uplands east of the Irrawaddy River as far as the borders of Thailand, Laos and China. In the Mergui Archipelago karst towers emerging from the Andaman Sea contain caves and drowned cenotes similar to those near Phangnga, Krabi and Surat Thani in Thailand, and Vung Ha Long in Vietnam.

The best recorded caves in Burma are found near the coast between Amherst and Moulmein, in the tower karst characteristic of this part of the country. Inland from here in Karen State

(Kawthoolei) the limestone is continuous with that on the eastern watershed of the Tenasserim Range, in Thailand.

Further north, karst topography occurs at intervals throughout Karen, Kayah and Shan States, extending into Kachin and across the border into Yunnan Province of China. Limestone is widespread throughout southern Shan State, with a variety of karst topography. In northern Shan State Annandale *et al.* (1913) report that the limestone is crushed to a degree inhibiting cave formation but karst phenomena are widespread.

This paper deals only with that part of Burma lying east of the Irrawaddy River. There are extensive ranges to the west (rising to over 3000m) and in the far north (reaching as high as 5887m on the border of Tibet). Although there is Cretaceous limestone in Arakan State at least, no reference has been located to caves west of the Irrawaddy Basin.

MOULMEIN AND THE TENASSERIM COAST

This region covers the southern part of Mon and Karen (Kawthoolei) States along with Tenasserim State and includes the more than 900 islands of the Mergui Archipelago. The region is a long narrow strip between the sea and the watershed of the Tenasserim Range.

The climate throughout is tropical monsoon with most rainfall occurring between May and October. At Moulmein rainfall averages 4759mm pa, increasing to a maximum at Tavoy (5444mm), then declining to the south where Mergui receives 3926mm and Tenasserim 2821mm. Rainfall also decreases away from the coast. Vegetation of the region falls broadly into four categories: Mangrove forests, tidal forests, tropical evergreen forest and mixed bamboo forest. Although much of the accessible timber close to rivers was cut out during the colonial era, vast areas of virgin forest remain on the slopes of the Tenasserim Range.

Geology and Geomorphology

The most common rocks of the region are of the Carboniferous Mergui Series, composed of argillites, quartzites, greywackes and conglomerates. In the Mergui Archipelago these rocks dominate but have been intruded by granite, various porphyries and in cases overlain by lavas.

The Permian Moulmein Limestone is a continuation of the limestone-dolomite sequence extending from the Shan State south through Kayah and Karen States into Tenasserim. It forms the characteristic towers rising steeply from the alluvial plains of the Salween River. A few islands in the Mergui Archipelago are composed at least partly of this formation e.g. Turret Islands, Domel Island. Outcrops of Permian Limestone also occur in the Tenasserim Range but little is published about these deposits which are continuous with those found in the Khwae Noi and Khwae Yai drainage basin of western Thailand.

In contrast with the thickly forested ranges of the Mergui Series, the limestone hills are craggy, pinnacled and almost bare. Despite their prominence, however, the towers account for less than 1% of the total area even of the coastal plain.

Late Tertiary beds of lacustrine and fluvio-lacustrine origin, consisting of coarse conglomerates with some sandstones and clays cover much of the valley of the Tenasserim River. Running mainly along the regional strike, these were laid down in graben-like depressions associated with the Three Pagodas-Ratcha buri Fault Zone which extends from near Moulmein to the Khwae Noi valley in Thailand.

Quaternary alluvium is widespread especially in the lower reaches of the Salween. Much of this is very swampy and is utilised for paddy fields.

The islands of the Mergui Archipelago appear to lie along several tectonic lines. The highest are King Is. (767m) and Domel Is. (682m); the former is also the largest in the group (440km^2). Except where fringed with mangroves, the island coastlines are generally steep, often with sheer cliffs, and the western side of Tavoy Is. has sheer cliffs 380m high.

Population

It seems likely that Tenasserim, Mergui, Tavoy and perhaps Moulmein were trading towns of some antiquity, flourishing on trade between India and Siam and China. Human activity is at present centred on the lowlands, which are the only parts in control of the central government in Rangoon. For the last forty years there has been a brisk trade in smuggled goods to and from Thailand across several passes in the range, which are controlled by Karen and Wa liberation forces.

Except for a rare opening of Moulmein the region has been closed to foreign travellers for more than 40 years. Entry from Thailand to the rebel-controlled areas is not unduly difficult for the determined, and is safe compared to Shan State.

Caves near Moulmein

Near Moulmein the Martaban coastal range borders a broad swampy coastal and inland floodplain extending to the foothills of the Tenasserim Range. Towers of Permian Moulmein Limestone rise up to 400m above the plain in belts running NW-SE, but account for rather less than 1% of the area. Temple (1893) attributed the origins of the caves to recent marine action but Chhibber (1928) dismissed this.

"Farm Caves"

The first three caves below are referred to in much of the literature of the colonial era. They are located in tower karst up to 160m high in Amherst district, about 13km ENE of Moulmein. Two of the caves are in the eastern side of Kayon hill, 2km SW of the village of Kayon, one on the western side and one in the southern end. According to Chhibber (1928), the caves then received as many as 20,000 visitors a year.

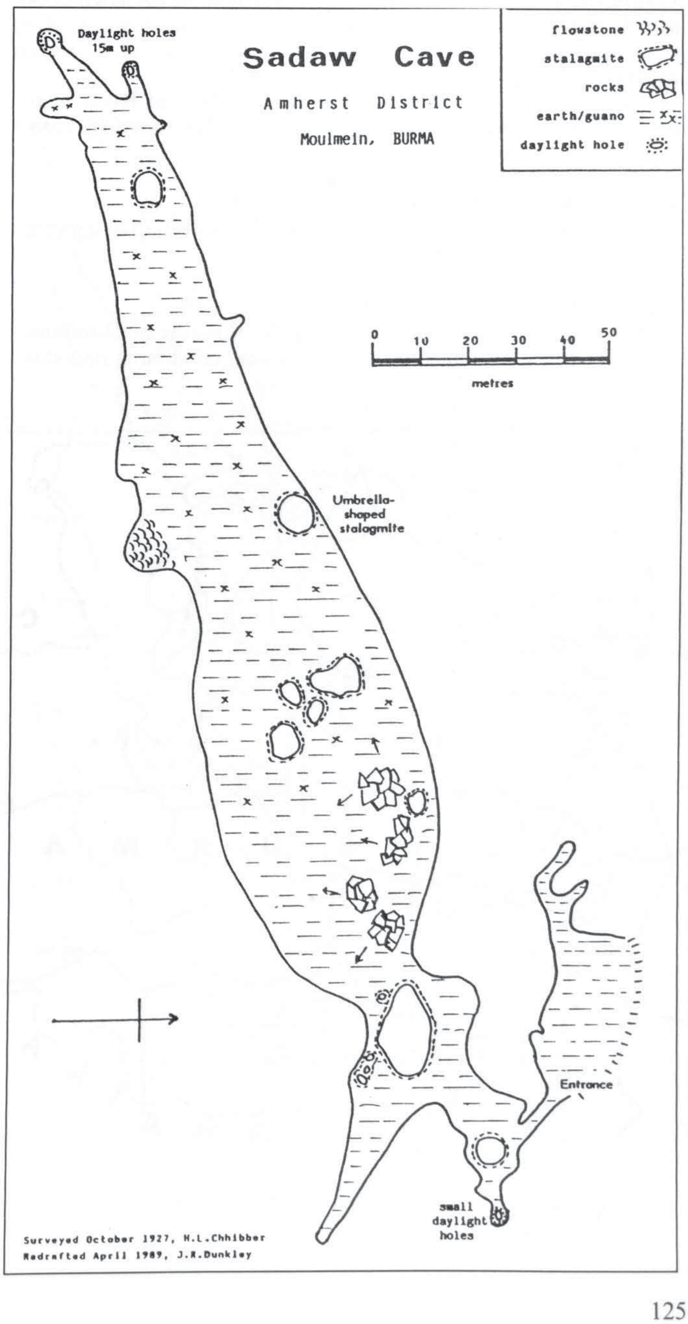
Kayon Cave 97° 43'E, 16° 32'N

Situated almost in the middle of the tower, there are 3 entrances to this cave which has "long tunnel-like halls with long, narrow and fantastic side chambers" (Chhibber 1934). Total length is about 300m.

Sadaw Cave 97° 43'E, 16° 32'N

In the southern end of Kayon hill with an entrance about 20m

Figure 2. Sadaw Cave, Moulmein, Tenasserim State.



above ground level, this is much larger than Kayon Cave but does not contain images. The name derives from a belief that when Buddha assumed the form of an elephant he lived in this cave (Sadaw = Royal Elephant). The 3m wide entrance opens to an enormous hall about 180m long and up to 45m wide, divided into three chambers by large columns measuring up to 30m in circumference. Not far from the entrance a sloping chamber on the left has a daylight hole about 3m across with two smaller adjacent holes. Bats are abundant, with quantities of guano. At the far end of the cave are several more daylight holes. Total length is about 350m.

Ma-saw-ma-ku 97° 43'E, 16° 32'N
A third cave located on the west side of Kayon hill.

Ale-ku 97° 43'E, 16° 30'N
Located in the eastern base of Alekutaung, a precipitous conical tower south of Kayon which resembles a volcanic plug. The cave, devoid of decoration, is at the eastern base of the tower and may contain a metre or so of water during the wet season. There are several small chambers, the largest about 10 x 6 x 7m high.

Nga-ku 97° 43'E, 16° 30'N
At the southern end of Alekutaung, approached through an amphitheatre suggesting a collapsed portion of the cave. One passage leads west, another south-east.

Other Caves in Moulmein District

Foley (1836) mentions caves at Yetsey, Tyokhla, Joe-ka-beng, Damatha, Nyown-beng-zeite, Phabia and Dhammathat, about 29km from Moulmein. The cave at Nyown-beng-zeite (Nyaungbinzeik) is one of those later referred to as the Kayon or Farm Caves.

Cave at Phabaung Thaung 97° 55'E, 16° 16'N
A limestone hill on the north bank of the Atarian River near Moulmein with a stream running through it. Mentioned by Low (1833) and Foley (1836).

Cave in Naungkwe Taung 97° 55'E, 15° 50'N
A small cave near the Ataran River with a bone bed up to a metre deep, excavated by the British Museum.

Bingyi Caves 97° 30'E, 16° 58'N
In a low tower 5km from Binlaing, on the Binlaing or Dondami River, 82km from Moulmein. A large dark cave containing pagodas and many images of the Buddha, attracting numerous devotees and, in past times, European travellers. Historic manuscripts and terracotta votive tablets have been found here (Johnston *et al.*, 1911).

Kogun Cave 97° 35'E. 16° 49'N
About 36km north of Moulmein, about 1km west of the Salween River, 9km WSW of Pa'an. First visited by Europeans in January 1827, by the oriental scholar John Crawfurd. An important site of Buddhist statuaries (Malcolm, 1837; Temple, 1894; Kusch, 1987).

P'agat Cave
Located near Kogun Cave, contains Buddhist statuaries (Low, 1833; Malcolm, 1837; Kusch, 1987).

Parum Cave
Mentioned by Temple (1894), location uncertain but probably near Kogun Cave.

Cave 97° 37'E, 16° 51'N
About 38km north of Moulmein, 5km downstream from Pa'an and on opposite bank of the Salween River. Marked on topographic map, possibly same as Parum Cave or P'agat Cave.

Cave 97° 53'E, 16° 29'N
In Kyauk Taung, 26km east of Moulmein.

Satdan Cave 97° 44'E, 16° 44'N
27km NNE of Moulmein and about 12km east of Salween River.

Underground stream 97° 44'E, 16° 44'N
In the same tower as and a short distance north of Satdan Cave. Apparently an underground passage permitting boats to pass through the tower between two lakes.

Cave 97° 37'E, 17° 14'N
In Webyan Taung, 80km north of Moulmein 1km west of Salween River.

Cave 97° 40'E, 17° 51'N
Near village of Takinloo, about 5.5km east of Salween River.

Mergui Archipelago

Caves are located in a group of six limestone towers known as Elephant Island, off the SE side of Domel Island in the Mergui Archipelago. At the south end of the largest island a sea cave about

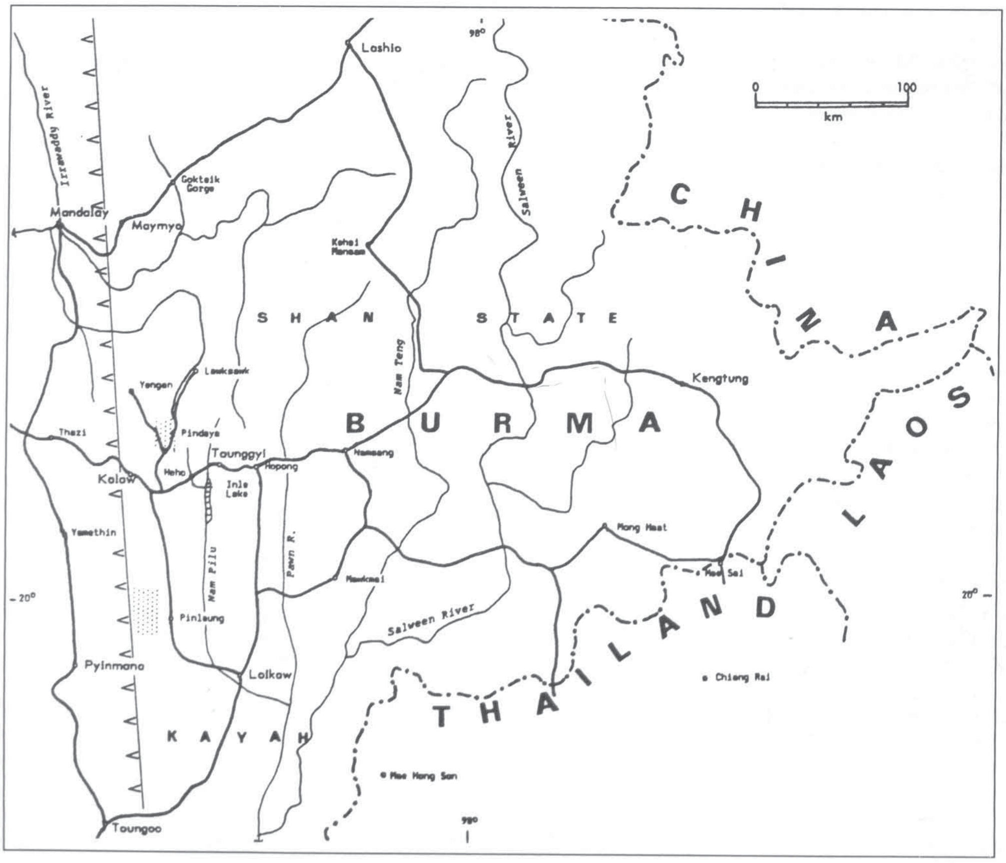


Figure 3. Location map of Shan State, Myanmar (Burma). Shaded areas locate areas detailed in figs. 4 and 5.

80m long runs through the island to a cenote with perpendicular sides, "which gives the impression of the crater of a volcano" (Chhibber, 1934). Birds' nests are exploited in several other caves in the group; as a rule these caves open into the sea with an entrance below high-water mark.

Chhibber (1928, 1934) also reported sea caves in quartzite on the north side of King Island and at Lin Lun in the Mergui Archipelago.

SOUTHERN SHAN STATE

Because of time restrictions, our 1988 reconnaissance was limited to this area where topographic maps indicated great potential for caves in reasonably accessible areas.

Most of southern Shan State has the appearance of a rolling plateau of modest elevation, from 1,000 to 1,500m in elevation, with occasional peaks rising above 2,000m. To the west it presents a sharp scarp (the Shan Scarp) to the valleys and plains of the Sittang and Irrawaddy Rivers in central Burma, and further east it is almost bisected by the deep gorges of the Salween River (fig. 3). The predominantly undulating topography is broken by the Salween and Pawn Rivers, by sharp dip slopes or prominent fault scarps such as those near Heho and Taunggyi, and by prominent upland karst areas.

Among the driest parts of Burma, the Shan Plateau has a dry monsoon climate with mean annual precipitation of 800-1500mm (Kengtung 1300mm, Taunggyi 1518mm). In the upland areas taunggya (slash-and-burn) agriculture is widely practised. Forestry is locally significant and teak is exported. In the insurgent-controlled areas east and north of Taunggyi opium poppy becomes a major crop, increasingly towards the borders of Thailand, Laos and China. The combination of logging, taunggya agriculture, opium poppy cultivation and increasing population pressure in the hills means that there is probably even less remaining monsoon forest than that seen in neighbouring northern Thailand.

Ethnically, Shan State is dominated by the Shans, who are related to the Thais rather than the Burmese, and are also settled in northern Thailand; indeed they call themselves Tai. Like their neighbours they are predominantly lowland farmers and traders. As well there are many ethnic minorities such as Pa-o, Taungyoo, Lahu, Wa and Palaung. Most of these groups still practice at least some slash-and-burn cultivation in upland and less-favoured areas, and little forest cover is evident. The pressure on land is such that wherever there are a few centimetres of soil, most of the larger karst depressions and even the steep rocky stretches of limestone are carefully tilled.

Geology

The geology of the southern Shan State consists of a very thick carbonate sequence of Permian and Mesozoic age that overlies Ordovician and Silurian volcanic and sedimentary rocks. These rocks occur as a series of parallel outcrops with a tolerable uniformity of regional strike very nearly north-south throughout, and with wide local variations of dip.

The main tectonic events were folding in the late Cambrian, late Palaeozoic and late Mesozoic, and block faulting in the late Palaeozoic, late Mesozoic and Tertiary. The key structural elements have a northerly trend. Vertical fault movements exceeded 3,000m.

A narrow Gneissic and Metamorphic Zone is found along the western scarp of the plateau. The dominant feature here is the Panlaung Fault, the western margin of the Nwalabo Fault Complex, which has been active since the Jurassic. Further to the east there is a wide series of Middle to Lower Palaeozoic limestone belts with local beds and inliers of younger shale and sandstone and areas of recent alluvium. The limestones vary in age from Ordovician to Permo-Carboniferous, and the succession has been partly obscured by dolomitisation.

The oldest limestones in the region have been termed the Orthoceras beds of Mawson (Coggin-Brown, 1931) and are of Middle Ordovician age. Next are the Ordovician Pindaya beds, named after the prominent mass between Pindaya and Myinkyado which contains Pindaya Cave.

The Lower Paleozoic strata are overlain by limestone and dolomite several thousand metres thick. Varying from Devonian to Permo-Carboniferous these are the most widespread in the region. They were referred to by La Touche (1913) and later

Figure 4. Polygonal karst near Pindaya, southern Shan State. Dots indicate lowest point in depressions.

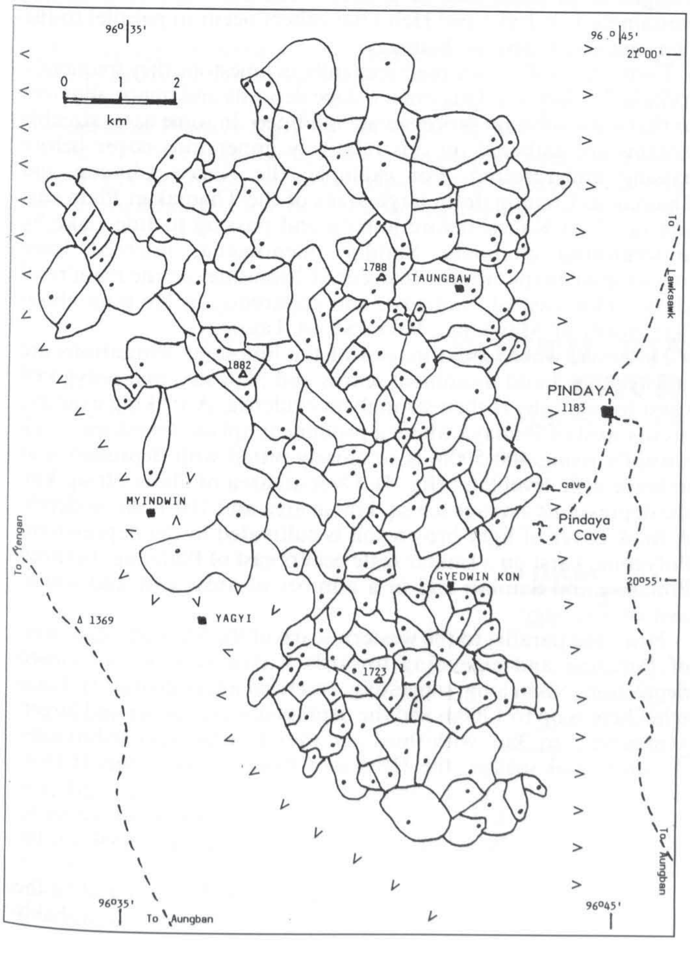
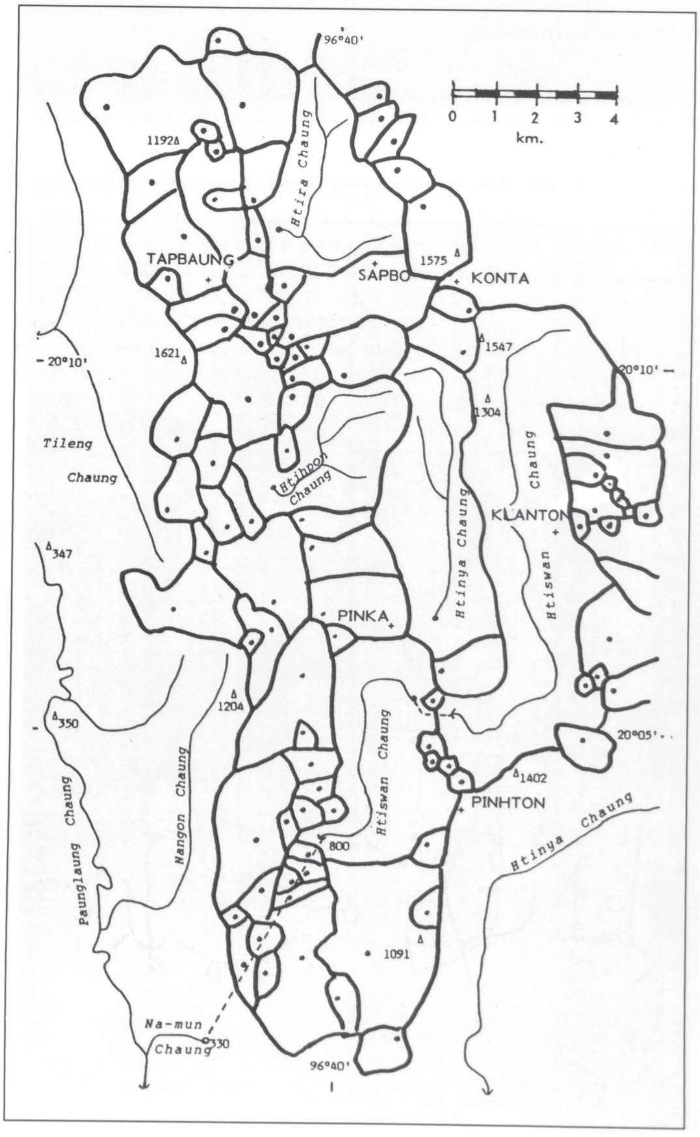


Figure 5. Polygonal karst near Pinlaung, southern Shan State. Dots indicate lowest point in depressions.



Polygonal karst near Pinlaung, southern Shan State, showing contrast between forested slopes and areas affected by taunggya (slash-and-burn agriculture).

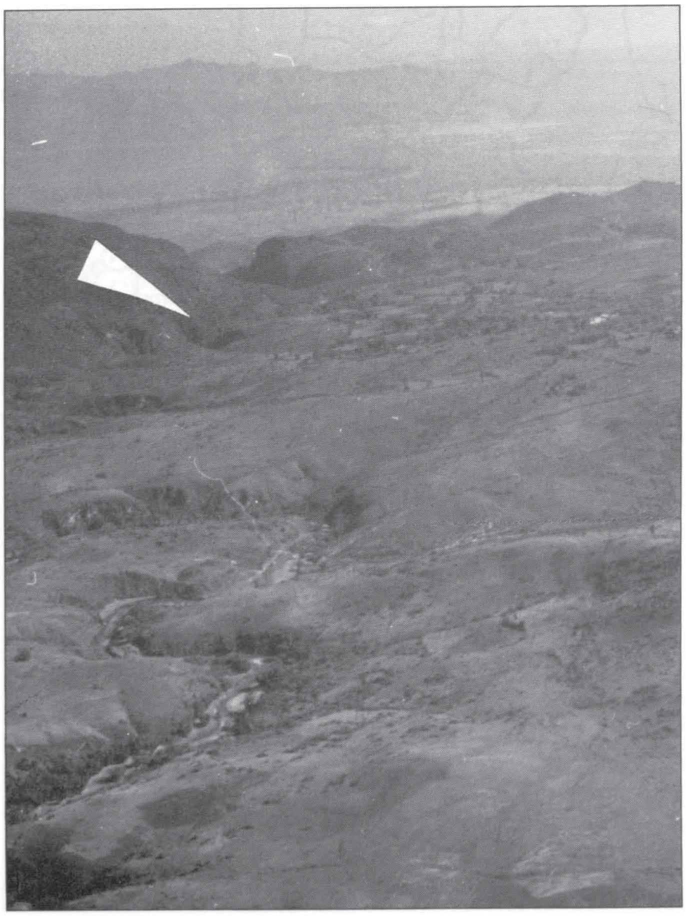
literature as the Plateau Limestone, but new fossil finds modified the scheme and the carbonates are now referred to as the Shan Dolomite Group (Amos, 1975 in Bender, 1983, p.72), including the Thitsipin carbonates. This widespread formation continues towards the south through Kayah and Karenni States, linking with the Moulmein Limestone. It is possibly equivalent to the Ratburi Limestone of southern Thailand.

The chief superficial feature of the plateau is a blanket of terra-rossa soil up to 5m thick. Derived from the limestone, it varies in colour from bright red to brown. Alluvial deposits are of only local significance, being particularly evident in downthrust areas such as the Heho Plain and Lake Inle area.

Karst Geomorphology

Although limitations are obviously imposed by the scale of available maps and the extent of field work, some broad generalisations can be made. In particular, the only detailed geological mapping which could be accessed (Garson *et al.*, 1976) means that inferences have to be drawn over a wide area.

Gorge and sink (indicated by arrow) of Kalaw Chaung, in scarp immediately west of Inle Lake.



The region is predominantly a fluviokarst; integrated valley systems prevail on a regional scale although there are significant areas dominated by polygonal karst with little exposed limestone. Instances are also reported of much more rugged areas of exposed limestone, for example, in the Pinnacle Limestone Formation (Garson *et al.*, 1976, p.35).

The dominant features of the region are the strongly strike-oriented hill ranges running mainly north-south, separated by eroded longitudinal valleys of no great steepness except in the cases of the Salween and Pawn Rivers. Drainage is usually structurally oriented and streams crossing the regional strike usually do so through deep narrow gorges, as in the gorges on the railway and road immediately east of Kalaw. It may be that more detailed examination will show that plunging anticlinal folds also influence drainage patterns, as has been suggested for similar topography in northern Thailand (Kiernan, 1988).

In places longitudinal strike basins lie either in broad synclinal troughs or in what may be grabens. The best known are those containing Inle Lake and Heho but others occur in parallel to the east and south-east of Taunggyi.

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Near and parallel to the western scarp of the Shan Plateau, west of Pinlaung and extending towards Kalaw is a belt of closed depressions 50km long, suggesting structural influence (fig. 5). Local relief here is up to 1200m and the depressions are deeper and larger, averaging 2 sq. km. with third and even fourth order tributaries. A substantial stream, the Htiswan Chaung gathers runoff from about 28 sq. km., passes through a cave (not yet explored) and emerges in to a karst window for a further 6km before being engulfed again. The rising appears to be about 6km SSW on the Na-mun Chaung.

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CAVES IN SOUTHERN SHAN STATE

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Pindaya Cave 96° 40'E, 20° 56'N

Referred to as South Pindaya Cave in local guidebooks, possibly in relation to the next cave listed. Probably now the best-known in Burma, this is the only cave in the country readily accessible to tourists, and is occasionally publicised in tourist literature. It is located about 150m above and a short distance south of the town of Pindaya (fig. 4). A long series of steps leads to a temple (Shwe-ohm-Min Pagoda) at the cave entrance. The entrance chamber is about 30 x 40m and is up to 25m high, and is absolutely packed with Buddhist images of all sizes from a 4m gilt-covered image at the entrance to many about 1-2cm high. Many of these images are stacked "shoulder-to-shoulder" forming a network of walkways and alcoves within the entrance chamber. The cave's other name ("Cave of Ten Thousand Buddhas") is probably not exaggerated. It is quite unlike any Buddhist cave in Thailand.

Beyond the entrance chamber an electrically lit path winds through several large halls. Total length is about 150m and there are no prospects for exploration. A detailed guidebook in Burmese (Thi-la-wa, 1985) is sold at the temple. Locally the cave is said to connect with the great pagodas at Pagan, and other legends connect the history of the cave with Burmese folklore (Thi-la-wa, 1987). As related by Thi-la-wa, this is the same legend recorded by Scott (1900).

The cave appears to be a very old phreatic outflow for drainage from the extensive limestone plateau above.

Cave north of Pindaya Cave 96° 40'E, 20° 56'N

About 2km north along the same scarp another prominent cave temple is marked on topographic maps. A large entrance is clearly visible from Pindaya Cave but local information was that there is no substantial cave.

Gold-plated Buddha images in Pindaya Cave.

Szaten ("Deep Hole") 96° 39'E, 20° 55'N

About 15 minutes walk NW from the Toungyoo village of Gyedwin Kon (marked on topographic map as Nyaunggyingon) (fig. 4), about 5km SW of and 400m higher than Pindaya town, the cave is near the northern lip of a large doline. A dirt-filled depression leads to a small hole. A sizeable chamber leads off from the bottom of a 6m pitch, below which is another pitch about 20m deep which was not explored. Length 50m+.

Although topographic maps indicate many depressions in this area, those seen by the authors took the form of well-cultivated

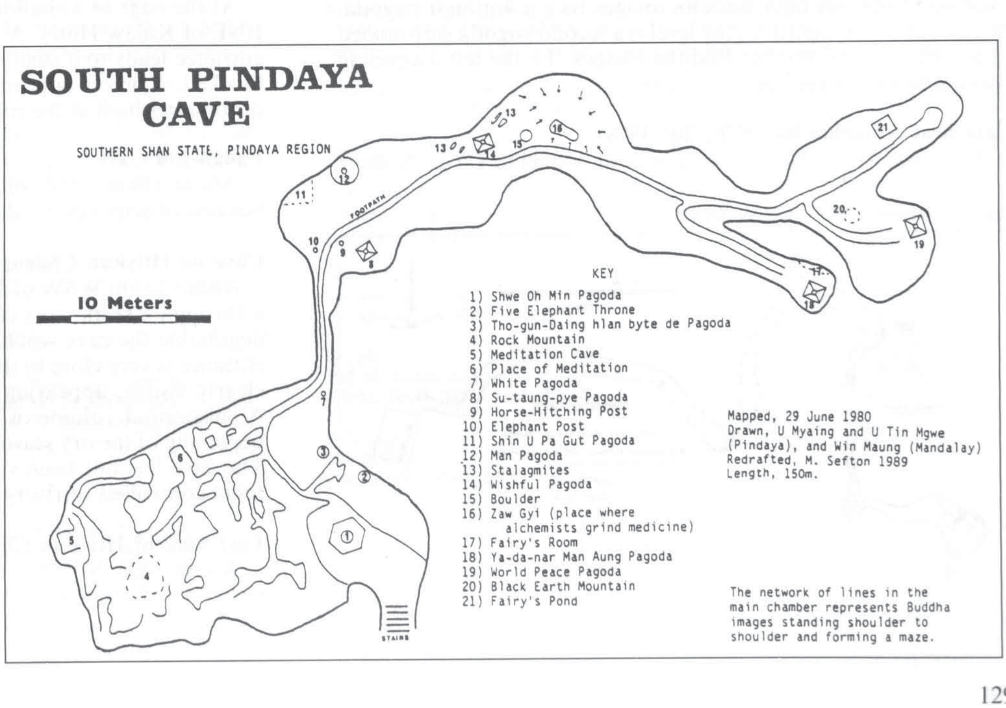


Figure 6. (South) Pindaya Cave, southern Shan State.

Polygonal karst near Pinlaung, southern Shan State, showing contrast between forested slopes and areas affected by taunggya (slash-and-burn agriculture).

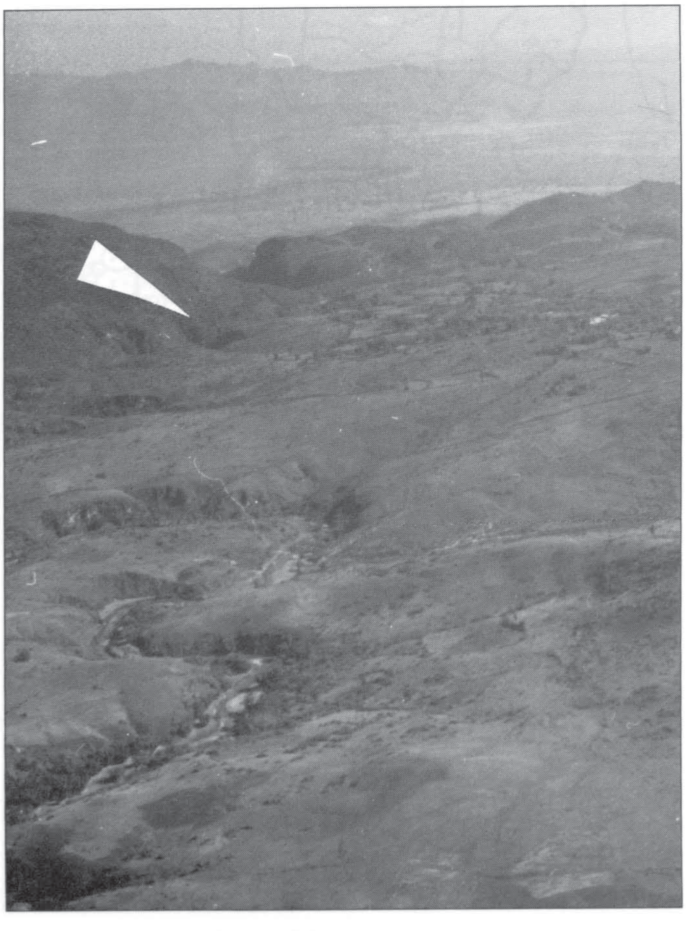
literature as the Plateau Limestone, but new fossil finds modified the scheme and the carbonates are now referred to as the Shan Dolomite Group (Amos, 1975 in Bender, 1983, p.72), including the Thitsipin carbonates. This widespread formation continues towards the south through Kayah and Karenni States, linking with the Moulmein Limestone. It is possibly equivalent to the Ratburi Limestone of southern Thailand.

The chief superficial feature of the plateau is a blanket of terra-rossa soil up to 5m thick. Derived from the limestone, it varies in colour from bright red to brown. Alluvial deposits are of only local significance, being particularly evident in downthrust areas such as the Heho Plain and Lake Inle area.

Karst Geomorphology

Although limitations are obviously imposed by the scale of available maps and the extent of field work, some broad generalisations can be made. In particular, the only detailed geological mapping which could be accessed (Garson *et al.*, 1976) means that inferences have to be drawn over a wide area.

Gorge and sink (indicated by arrow) of Kalaw Chaung, in scarp immediately west of Inle Lake.



The region is predominantly a fluviokarst; integrated valley systems prevail on a regional scale although there are significant areas dominated by polygonal karst with little exposed limestone. Instances are also reported of much more rugged areas of exposed limestone, for example, in the Pinnacle Limestone Formation (Garson *et al.*, 1976, p.35).

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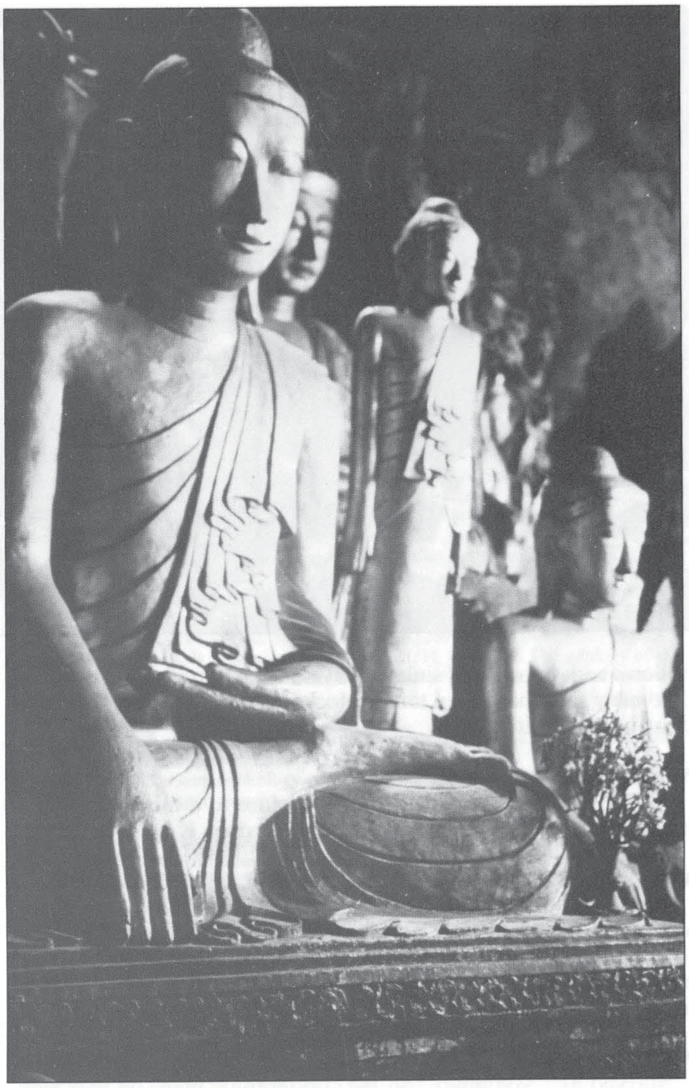

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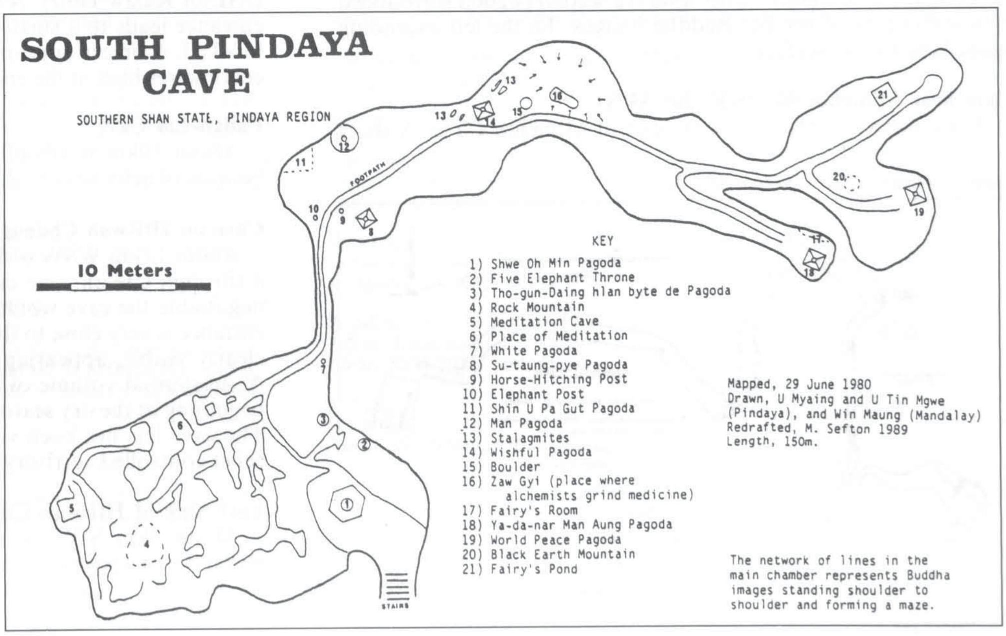


Figure 6. (South) Pindaya Cave, southern Shan State.

above ground level, this is much larger than Kayon Cave but does not contain images. The name derives from a belief that when Buddha assumed the form of an elephant he lived in this cave (Sadaw = Royal Elephant). The 3m wide entrance opens to an enormous hall about 180m long and up to 45m wide, divided into three chambers by large columns measuring up to 30m in circumference. Not far from the entrance a sloping chamber on the left has a daylight hole about 3m across with two smaller adjacent holes. Bats are abundant, with quantities of guano. At the far end of the cave are several more daylight holes. Total length is about 350m.

Ma-saw-ma-ku 97° 43'E, 16° 32'N
A third cave located on the west side of Kayon hill.

Ale-ku 97° 43'E, 16° 30'N
Located in the eastern base of Alekutaung, a precipitous conical tower south of Kayon which resembles a volcanic plug. The cave, devoid of decoration, is at the eastern base of the tower and may contain a metre or so of water during the wet season. There are several small chambers, the largest about 10 x 6 x 7m high.

Nga-ku 97° 43'E, 16° 30'N
At the southern end of Alekutaung, approached through an amphitheatre suggesting a collapsed portion of the cave. One passage leads west, another south-east.

Other Caves in Moulmein District

Foley (1836) mentions caves at Yetsey, Tyokhla, Joe-ka-beng, Damatha, Nyown-beng-zeite, Phabia and Dhammathat, about 29km from Moulmein. The cave at Nyown-beng-zeite (Nyaungbinzeik) is one of those later referred to as the Kayon or Farm Caves.

Cave at Phabaung Thaung 97° 55'E, 16° 16'N
A limestone hill on the north bank of the Atarian River near Moulmein with a stream running through it. Mentioned by Low (1833) and Foley (1836).

Cave in Naungkwe Taung 97° 55'E, 15° 50'N
A small cave near the Ataran River with a bone bed up to a metre deep, excavated by the British Museum.

Bingyi Caves 97° 30'E, 16° 58'N
In a low tower 5km from Binlaing, on the Binlaing or Dondami River, 82km from Moulmein. A large dark cave containing pagodas and many images of the Buddha, attracting numerous devotees and, in past times, European travellers. Historic manuscripts and terracotta votive tablets have been found here (Johnston *et al.*, 1911).

Kogun Cave 97° 35'E. 16° 49'N
About 36km north of Moulmein, about 1km west of the Salween River, 9km WSW of Pa'an. First visited by Europeans in January 1827, by the oriental scholar John Crawfurd. An important site of Buddhist statuaries (Malcolm, 1837; Temple, 1894; Kusch, 1987).

P'agat Cave
Located near Kogun Cave, contains Buddhist statuaries (Low, 1833; Malcolm, 1837; Kusch, 1987).

Parum Cave
Mentioned by Temple (1894), location uncertain but probably near Kogun Cave.

Cave 97° 37'E, 16° 51'N
About 38km north of Moulmein, 5km downstream from Pa'an and on opposite bank of the Salween River. Marked on topographic map, possibly same as Parum Cave or P'agat Cave.

Cave 97° 53'E, 16° 29'N
In Kyauk Taung, 26km east of Moulmein.

Satdan Cave 97° 44'E, 16° 44'N
27km NNE of Moulmein and about 12km east of Salween River.

Underground stream 97° 44'E, 16° 44'N
In the same tower as and a short distance north of Satdan Cave. Apparently an underground passage permitting boats to pass through the tower between two lakes.

Cave 97° 37'E, 17° 14'N
In Webyan Taung, 80km north of Moulmein 1km west of Salween River.

Cave 97° 40'E, 17° 51'N
Near village of Takinloo, about 5.5km east of Salween River.

Mergui Archipelago

Caves are located in a group of six limestone towers known as Elephant Island, off the SE side of Domel Island in the Mergui Archipelago. At the south end of the largest island a sea cave about

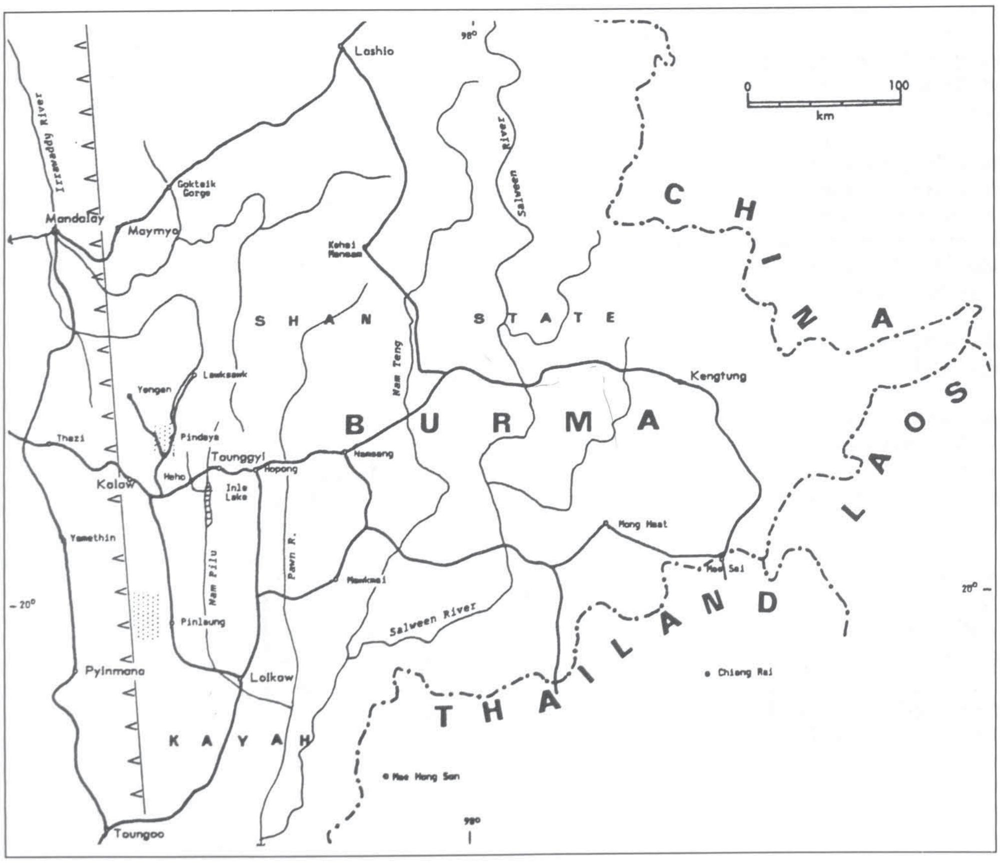


Figure 3. Location map of Shan State, Myanmar (Burma). Shaded areas locate areas detailed in figs. 4 and 5.

80m long runs through the island to a cenote with perpendicular sides, "which gives the impression of the crater of a volcano" (Chhibber, 1934). Birds' nests are exploited in several other caves in the group; as a rule these caves open into the sea with an entrance below high-water mark.

Chhibber (1928, 1934) also reported sea caves in quartzite on the north side of King Island and at Lin Lun in the Mergui Archipelago.

SOUTHERN SHAN STATE

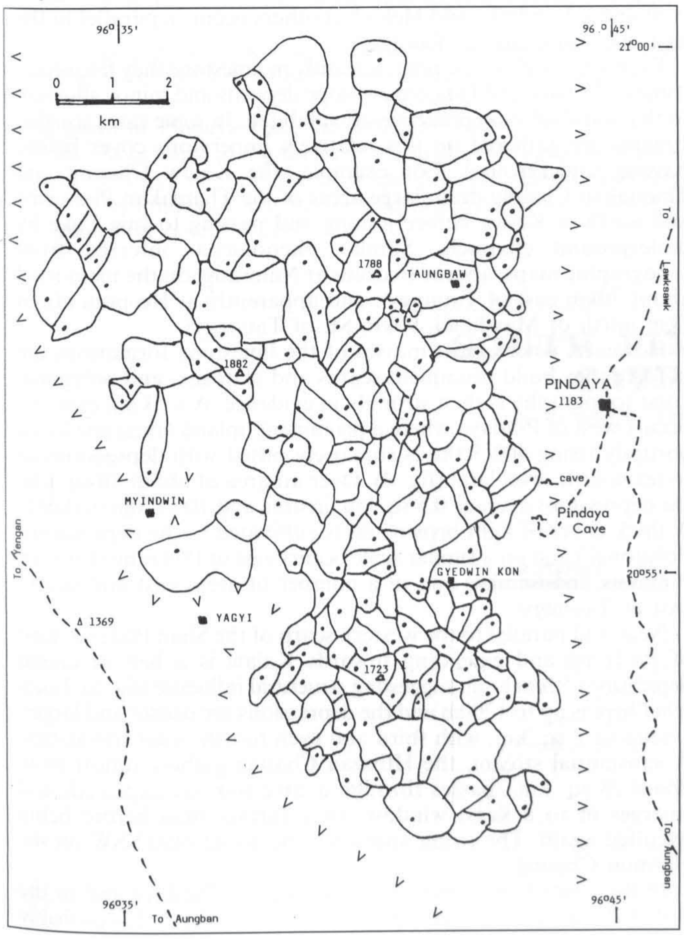
Because of time restrictions, our 1988 reconnaissance was limited to this area where topographic maps indicated great potential for caves in reasonably accessible areas.

Most of southern Shan State has the appearance of a rolling plateau of modest elevation, from 1,000 to 1,500m in elevation, with occasional peaks rising above 2,000m. To the west it presents a sharp scarp (the Shan Scarp) to the valleys and plains of the Sittang and Irrawaddy Rivers in central Burma, and further east it is almost bisected by the deep gorges of the Salween River (fig. 3). The predominantly undulating topography is broken by the Salween and Pawn Rivers, by sharp dip slopes or prominent fault scarps such as those near Heho and Taunggyi, and by prominent upland karst areas.

Among the driest parts of Burma, the Shan Plateau has a dry monsoon climate with mean annual precipitation of 800-1500mm (Kengtung 1300mm, Taunggyi 1518mm). In the upland areas taunggya (slash-and-burn) agriculture is widely practised. Forestry is locally significant and teak is exported. In the insurgent-controlled areas east and north of Taunggyi opium poppy becomes a major crop, increasingly towards the borders of Thailand, Laos and China. The combination of logging, taunggya agriculture, opium poppy cultivation and increasing population pressure in the hills means that there is probably even less remaining monsoon forest than that seen in neighbouring northern Thailand.

Ethnically, Shan State is dominated by the Shans, who are related to the Thais rather than the Burmese, and are also settled in northern Thailand; indeed they call themselves Tai. Like their neighbours they are predominantly lowland farmers and traders. As well there are many ethnic minorities such as Pa-o, Taungyoo, Lahu, Wa and Palaung. Most of these groups still practice at least some slash-and-burn cultivation in upland and less-favoured areas,

Figure 4. Polygonal karst near Pindaya, southern Shan State. Dots indicate lowest point in depressions.



and little forest cover is evident. The pressure on land is such that wherever there are a few centimetres of soil, most of the larger karst depressions and even the steep rocky stretches of limestone are carefully tilled.

Geology

The geology of the southern Shan State consists of a very thick carbonate sequence of Permian and Mesozoic age that overlies Ordovician and Silurian volcanic and sedimentary rocks. These rocks occur as a series of parallel outcrops with a tolerable uniformity of regional strike very nearly north-south throughout, and with wide local variations of dip.

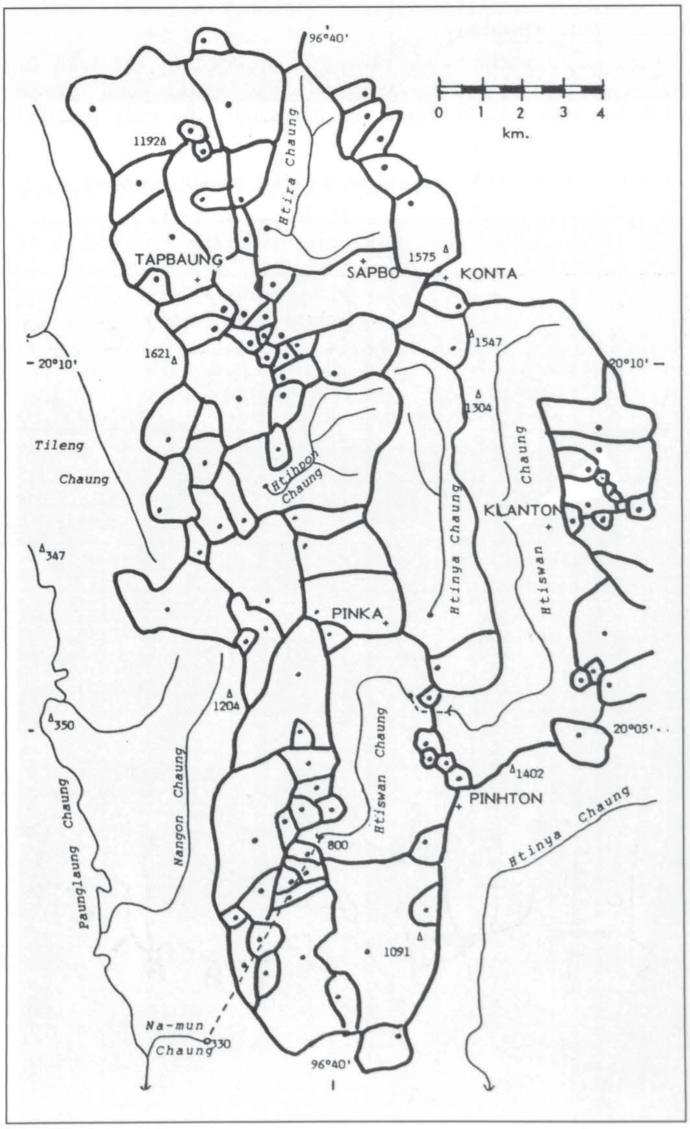
The main tectonic events were folding in the late Cambrian, late Palaeozoic and late Mesozoic, and block faulting in the late Palaeozoic, late Mesozoic and Tertiary. The key structural elements have a northerly trend. Vertical fault movements exceeded 3,000m.

A narrow Gneissic and Metamorphic Zone is found along the western scarp of the plateau. The dominant feature here is the Panlaung Fault, the western margin of the Nwalabo Fault Complex, which has been active since the Jurassic. Further to the east there is a wide series of Middle to Lower Palaeozoic limestone belts with local beds and inliers of younger shale and sandstone and areas of recent alluvium. The limestones vary in age from Ordovician to Permo-Carboniferous, and the succession has been partly obscured by dolomitisation.

The oldest limestones in the region have been termed the Orthoceras beds of Mawson (Coggin-Brown, 1931) and are of Middle Ordovician age. Next are the Ordovician Pindaya beds, named after the prominent mass between Pindaya and Myinkyado which contains Pindaya Cave.

The Lower Paleozoic strata are overlain by limestone and dolomite several thousand metres thick. Varying from Devonian to Permo-Carboniferous these are the most widespread in the region. They were referred to by La Touche (1913) and later

Figure 5. Polygonal karst near Pinlaung, southern Shan State. Dots indicate lowest point in depressions.



State-of-the-art vertical caving (Szaten, near Gyedwin Kon)

hollows with no signs of sinks or caves at the bottom. It is possible that many sinks have been totally blocked as a result of the extensive clearing and cultivation.

Mundewa Cave 96° 40'E, 20° 54'N
About 6km south of Pindaya Cave, close to a monastery on a hill about 1.5km south of the village of Gyedwin Kon. Not visited.

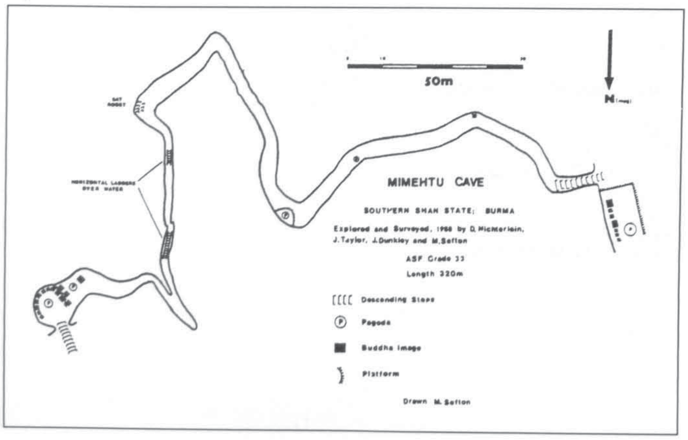
Wagyimya ("Big Bamboo") Cave 96° 40'E, 20° 55'N
200m west of the road, about 6km south of Pindaya on north side of a prominent gorge. This is mainly a rock-shelter but appears to be an old resurgence. There are several smaller caves 20m further east including one with some narrow winding passages about 20m long.

Mimehtu Cave 96° 37'E, 20° 35'N
Marked as "Myinmati" on the topographic map, on east side of road to Pinlaung and Loikaw about 6km south of its junction with the main Kalaw-Taunggyi road. A through stream cave on the south bank of a small tributary of the Kalaw Chaung.

The western entrance is guarded by a raised platform on which sit a number of 1-2m high images of Buddha, and the ubiquitous pagoda. To the right, descending steps in the side of the hill lead to a 4-5m wide streamway, virtually dry during our April visit. Easy walking passage leads past, firstly, a tiny Buddha image on the right, and then two pagodas, the second 3m high, both on the left. After 200m the passage widens a little. A colony of rat-sized bats was observed on a bend just before the passage narrows again. Two horizontal ladders allow pools to be traversed before the passage turns sharply to the right and then gradually opens up into the final chamber. Four 4m high Buddha images face a 4m high pagoda. Beyond, and at a slightly higher level is a second pagoda surrounded by a semi-circle of smaller Buddha images. To the left ascending stairs lead to the surface.

Cave near Mimehtu 96° 35'E, 20° 35'N
A few metres to the east of the exit of Mimehtu Cave. A short climb down at the entrance leads into a chamber 20m long and 10m wide. A narrow stream passage to the left was followed for about 70m before it closed down.

Figure 7. Mimehtu Cave, southern Shan State.



Shwe Ohm-min Cave 96° 33'E, 20° 38'N
Located in a limestone hill about 3km SW of Kalaw. The cave is about 50m long and contains a 3m high Buddha and about 50 smaller ones. Behind the Buddhas is a low, dusty passage with a dig. Towards the end of World War II the Japanese hid in the cave and while trying to flush them out the British dropped an unexploded bomb near the entrance which was only recently dug up and removed. Local legend says that the pagodas at the cave were started by King Manesedhu 10,000 years ago, and that the cave connects with the Makyamuni Pagoda in Mandalay.

Cave near Shwe Ohm-min 96° 33'E, 20° 38'N
Two entrances about 25m north of Shwe Ohm-min Cave connect, and according to local information may be traversed about 100m through the hill to an army barracks on the other side. The lower entrance has a cool breeze.

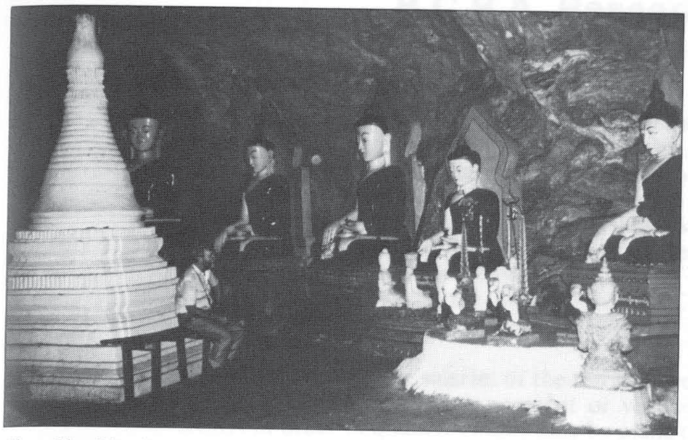
Un-named Cave 96° 35'E, 20° 38'N
On a grassy hill about 1km NE of Kalaw Hotel. A collapsed entrance 5 x 3m can be descended on a tree branch. The main passage descends at a 45° angle to a dig at the bottom. There is much evidence of digging in various places, apparently in search of treasure said to have been abandoned by the Japanese at the end of the war. Length: 25m.

Un-named Cave 96° 35'E, 20° 38'N
At the edge of a shallow depression at ground level about 1km ENE of Kalaw Hotel. A crawl at the bottom of the 2m diameter entrance leads to a small chamber with two short branches, both blocked. A breeze appears to emanate from a low crawl only a few centimetres high at the end of the right hand branch. Length: 20m.

Padah-Lin Cave
About 10km north of Ye-ngan, said to be difficult of access because of activities of "dacoits". An important archaeological site.

Cave on Htiswan Chaung 96° 41'E, 20° 05'N
About 11km WSW of Pinlaung, 60km SSE of Kalaw. Possibly a through stream cave carrying the Htiswan Chaung (fig. 5). If negotiable the cave would be at least 1km long. The downstream entrance is very close to the Rangoon-Heho flight path and is often clearly visible, appearing to be at least 20m high and 10m wide. A substantial volume of water was seen in January, 1976 at the beginning of the dry season, somewhat less on the April, 1988 visit. The cave has not been visited as the area is on the boundary of rebel-controlled territory and is off-limits to foreigners.

Last Sink of Htiswan Chaung 96° 40'E, 20° 04'N
About 3km SW downstream of the last cave above, at an elevation of approximately 800m. The rising is thought to be on the Na-mun Chaung, 5.5km SW at about 550m, so potential exists for an extensive deep cave.



Shwe Ohm-Min Cave, near Kalaw.

According to a local guide at Kalaw, there are three caves near Pinlaung, one barred by a massive iron door.

Caves near Taunggyi 97° 04'E, 20° 47'N

Near a Ngapali village directly over the prominent hill a few kilometres east of Taunggyi. No further details, except the cave was discovered in 1965.

Two other caves are known within walking distance of the town, but no further details are available.

Cave at Ho-pom/Ponglau 97° 44'E, 20° 17'N

Near the villages of Ho-Pom and Ponglau, about 5km north of Mawkmai, 90km SE of Taunggyi. At the foot of an 80m cliff, the cave engulfs the 130km drainage of the Nam Yawng. The entrance is about 45m high and 100m wide, widening inside to some 150m (Chhibber, 1934). Length: about 150m. There are several other large sinking streams in the area west and north of here.

Spring at Ho-Pong 97° 11'E, 20° 48'N

A large resurgence near the main road about 20km east of Taunggyi; there is a painting of the feature hanging in the Shan State Museum in Taunggyi.

Natural Bridge 97° 20'E, 20° 49'N

Marked on topographic map on side of main road about 30km east of Taunggyi; the road appears to pass over the cave.

Cave at Namsang 97° 43'E, 20° 54'N

Near the village of Namsang, on the main road about 70km east of Taunggyi. The flow of Nam Lat or Nam Hawnglat, with a catchment area of over 400km passes underground for about 2km to resurge on the Nam Teng.

CAVES ELSEWHERE IN BURMA MENTIONED IN LITERATURE

Natural Bridges at Gokteik Gorge 96° 53'E, 22° 21'N

Close to the railway viaduct NE of Maymyo, northern Shan State, on the main road to Lashio. These are formed in travertine.

Shwe Male Cave

A large cave near the foot of hills about 13km east of the Irrawaddy at Singu, above Mandalay (Yule, 1858; Chhibber, 1934). The cave is about 100m long and 40m high.

Sankywe Cave

In a limestone hill overlooking the Uyu River near the village of Sankywe, Myitkina District, Kachin State (Chhibber, 1934).

ACKNOWLEDGEMENTS

We are especially grateful to Dr. K. Kiernan for assistance with geological interpretation and other suggestions, to Dr. T. Shaw and Mr. R. Mansfield for several obscure references, and to Mr. J. Davis (Bangkok), Mr. N. Jones (Hong Kong) and U Maung Sein for assistance in Rangoon.

REFERENCES

Anderson, A. R. S., 1899. Bats in Burmese Caves. Natural Science vol. 14 pp. 259-260.
Anon. (?), 1872. Maulmein Caves. Indian Antiquary vol. 1 pp. 160-161.
Anon (?) 1872. (in) Proc. Asiatic Soc. Bengal.
Anon., 1894. Die Skulpturenhohlen bei Maulmein. Globus, Braunschweig 1894, vol. 65 (16) p. 263.
Annandale, N., Coggin-Brown, J. & Gravely, F. H., 1913. The Limestone Caves of Burma and the Malay Peninsula. J. Asiatic Soc. Bengal, vol. 9 (10) pp. 391-423.
Bequaert, J., 1943. Fresh-water shells from cave deposits in the southern Shan States. Trans. American Philosophical Soc., vol. 32 (3) pp. 431-437.
Bender, F., 1983. Geology of Burma. Gebruder Borntraeger, Berlin, 294pp.
Brown, J. C. & Sondh, V. P., 1933. The Geology of the country between Kalaw and Taunggyi, southern Shan States. Rec. Geol. Surv. India vol. 67 pp. 166-248.
Bunopas, S., 1981. Palaeogeographic History of Western Thailand and Adjacent Parts of Southeast Asia — A Plate Tectonics Interpretation. Thai Geological Survey Papers, 810pp.
Burkhill, I. H., 1911. Guano in India. The Agricultural Ledger vol. 1 p. 7.
Carpenter, A., 1868. The Bird's Nest or Elephant Islands, Mergui Archipelago. Rec. Geol. Surv. India vol. 21 pp. 29-30.
Carter, R. R. L., 1930. The Powundaung Caves. Rangoon, 79pp. (not sighted).
Chhibber, H. L., 1928. A short Note on the Limestone Caves in the Neighbourhood of Nyaungbinzeik, Kyaikmaraw Township, Amherst District, Lower Burma. J. Burma Research Soc. vol. 18 pp. 124-131.
Chhibber, H. L., 1934. Geology of Burma. Macmillan, London (esp. Ch. 8, pp. 92-99: Limestone Caves).
Choppard, L., 1924. On some cavernicolous orthoptera and dermaptera from Assam and Burma. Rec. Indian Museum vol. 26 pp. 81-92.
Coggin-Brown, J., 1931. The Geology and Lead-ore Deposits of Mawson, Federated Shan States. Rec. Geol. Surv. India vol. 65 pp. 394-433.
Collinge, W. E., 1914. On a blind woodlouse from Moulmein cave. Rec. Indian Museum vol. 8 p. 466.
Crawfurd, J., 1827. Journal of an Embassy to the Courts of Siam and Cochin China. Reprinted 1967, Oxford University Press, Kuala Lumpur.
Duroiselle, C., 1913. Note on clay tablets from caves near Moulmein. J. Asiatic Soc. Bengal vol. 9 (10) p. 424.
Fea, L., 1888. Viaggio da Moulmein al Mount Mulai, Tenasserim. Bull. Geol. Soc. Italy, series 3, 1 pp. 627-689.
Fermor, L. L., 1931. General Report for 1930. Rec. Geol. Surv. India vol. 65 p. 18.
Foley, Capt. W., 1836. Notes on the Geology etc. of the Country in the Neighbourhood of Moulmeng. J. Asiatic Soc. Bengal vol. 5 pp. 269-281.
Garson, M. S., Amos, B. J., Amos, A. & Mitchell, H. G., 1976. The geology of the country around Neyaungga and Yengan, southern Shan States, Burma. Institute of Geological Science, Overseas Division, Memoir 2, London. 70pp., 10 figs., 1pl., 1 map.
Johnston, H. *et al.*, 1911. The Bingyi Caves, Burma (pp. 119-122 in) The Wonders of the World. Hutchinson, London, 2 vols., 911pp.
Kiernan, K., 1988. Geomorphology of a tropical intermontane basin in the Sino-Burman ranges. Paper presented to 26th International Geographical Congress, Sydney.
Klein, W., 1987. Burma. APA Productions, Singapore, 7th ed., 332pp.
Kusch, H., 1987. Unterirdische Kultstatten des Mon-Volkes in Burma und Thailand. Die Hohle vol. 38 (3) pp. 77-97.
La Touche, T. D., 1900. Preliminary Report on the Geology of the Northern Shan States. Geol. Surv. India, General Report for 1899-1900.
Low, J., 1833. Observations on the geological appearances and general features of portions of the Malayan peninsula. Asiatic Research vol. 18 pp. 128-162 (reprinted in: Miscellaneous Papers on Indo-China vol. 1 pp. 179-201, 1886).
Lydekker, R., 1886. Fauna of the Karnul Caves. Palaeontologica Indica ser. 10, 4 (2).
Malcolm, Rev. H., 1837. Account of the Caves near Moulmein. Asiatic Journal N.S. 24 pt. 2 p.10.
Middlemiss, C. S., 1900. Report on a Geological Reconnaissance in parts of the Southern Shan States and Karenni. Geol. Surv. India, General Report for 1899-1900.
Pascoe, E., 1928. General Report for 1927. Rec. Geol. Surv. India vol. 61 pp. 18 & 106.
Scott, Sir J. G., 1900. Gazeteer of Upper Burma and the Shan States. Rangoon.
Smyth, H. Warrington, 1895. Notes on a Journey to some of the South-western Provinces of Siam. Geogr. J. vol. 6 pp. 401-421, 522-545.
Stolicka, 1871. (in) J. Asiatic Soc. Bengal vol. 40 (2) pp. 143 & 217.
Thaw, A., 1969. Exploring Padah-Lin Caves. Spectrum, April 1969.
Theobald, W., 1873. Geology of Pegu. Mem. Geol. Surv. India vol. 10 p. 139.
Taw-Sein-Ko, 1892. Notes on an archaeological tour through Ramannadesa (The Talaing Country of Burma). Indian Antiquary vol. 21 pp. 377-386.
Temple, R. C., 1893. Notes on Antiquities on Ramannadesa (The Talaing Country of Burma). Indian Antiquary vol. 22 pp. 327-366.
Temple, R. C., 1894. Buddhist Caves in Mergui. Indian Antiquary vol. 23 p. 168.
Thi-La-Wa, 1985. Pindaya Region and History of Shwe Ohm Min Pagoda. Kandawlay, 160pp. (in Burmese).
Thi-La-Wa, 1987. Pindaya Region: Ku Mar Ba Ya and Shin Me Yar History. 96pp. (in Burmese).
Tickell & Parish, 1859. (in) J. Asiatic Soc. Bengal pp. 425 & 465-468.
Wheeler, T., 1988. Burma: A Travel Survival Kit. Lonely Planet, Melbourne, 4th ed., 184pp. ISBN 0 86442 017 X.
White, A., 1988. Zen and the Art of Umbrella Pointing. Caves & Caving No. 40 pp. 14-17.
Yule, Sir Henry, 1858. A Narrative of a Mission to the Court of Ava in 1855. London. (esp. pp. 177-178, 330-331).

Received November 1989

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