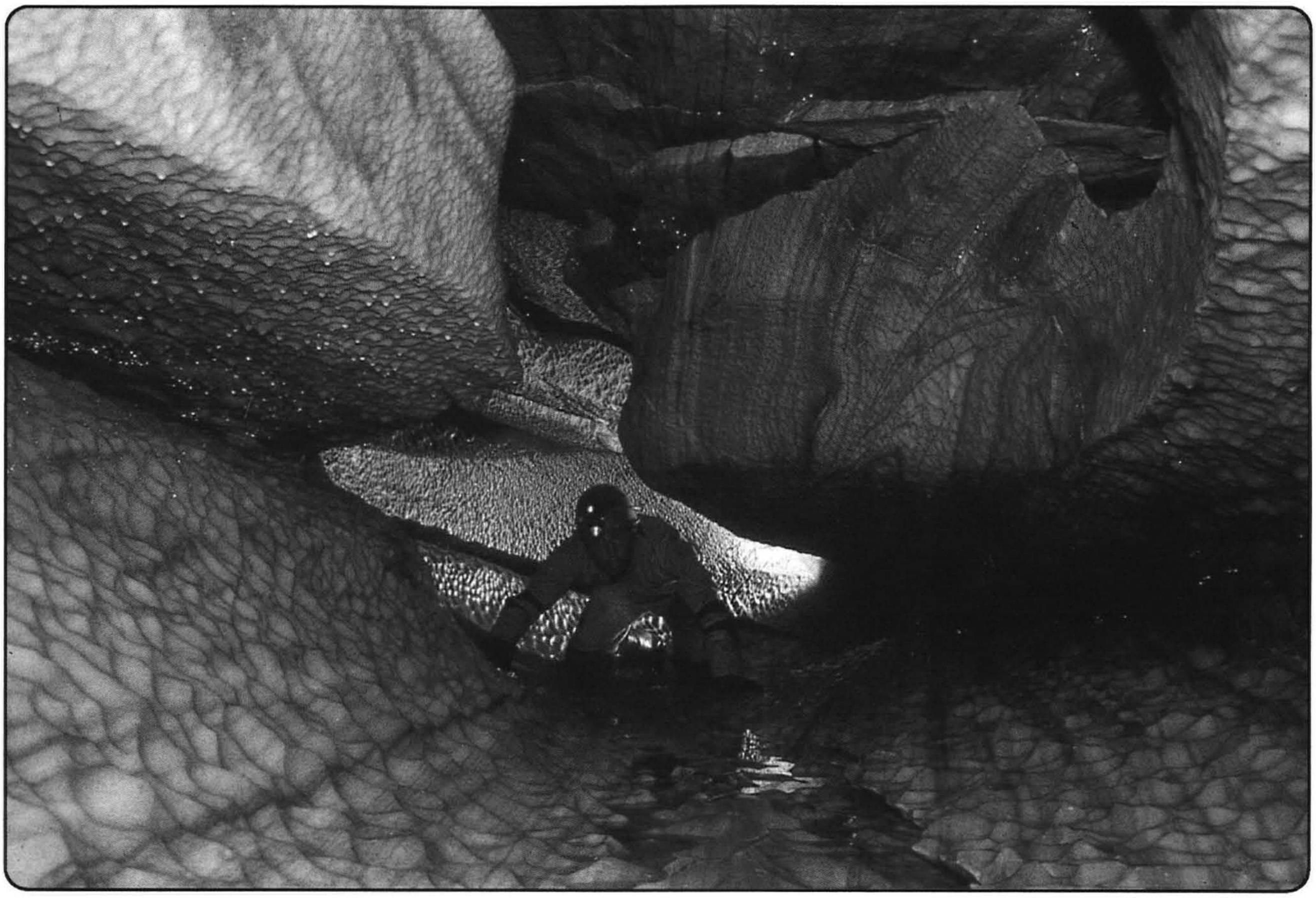
Cave and Karst Science

The Transactions of the British Cave Research Association

BCRA

Volume 22 | Number 1 | August 1995



Late Palaeozoic karstification in south-eastern Australia
Cave sediments in the Assynt area, Scotland
Caves at Vevelstad and Brønnøy, Norway
Pseudokarst in South Africa
Forum

Cave and Karst Science

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

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

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

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

4. Abstracts
Authors (or supervisors) of undergraduate or postgraduate dissertations on cave/karst themes are asked to submit abstracts for publication. Please indicate whether the thesis is available on inter-library loan. Abstracts of papers presented at BCRA and related conferences or symposia will also be published.

Manuscripts may be sent to either of the Editors: Dr. D J Lowe, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, and Professor J Gunn, Limestone Research Group, Department of Geographical and Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK. Intending authors are welcome to contact the Editors, who will be pleased to advise on manuscript preparation.

Notes for Contributors

These notes are intended to help the authors to prepare their material in the most advantageous way so as to expedite publication and to reduce both their own and editorial labour. It saves a lot of time if the rules below are followed.

All material should be presented in a format as close as possible to that of *Cave and Karst Science* since 1994. Text should be typed double-spaced on one side of the paper only. Subheadings within an article should follow the system used in *Cave and Karst Science*; a system of primary, secondary and if necessary, tertiary subheadings should be clearly indicated.

Abstract: All material should be accompanied by an abstract stating the essential results of the investigation for use by abstracting, library and other services. The abstract may also be published in *Caves and Caving*.

References to previously published work should be given in the standard format used in *Cave and Karst Science*. In the text the statement referred to should be followed by the relevant author's name and date (and page number, if appropriate) in brackets. Thus: (Smith, 1969, p.42). All such references cited in the text should be given in full, in alphabetical order, at the end. Thus: Smith, D.E., 1969. The speleogenesis of the Cavern Hole. Bulletin Yorkshire Caving Assoc., Vol. 7. p.1-63. Books should be cited by the author, date, title, publisher and where published. Periodical titles should be abbreviated in standard style, or, where doubt exists, should be written out in full.

Acknowledgements: Anyone who has given a grant or helped with the investigation, or with the preparation of the article, should be acknowledged briefly. Contributors in universities and other institutions are reminded that grants towards the cost of publication may be available and they should make the appropriate enquiries as early as possible. Expedition budgets should include an element to help publication, and the editor should be informed at the time of submission.

Figures: Line diagrams and drawings must be in black ink on either clean white paper or card, or on tracing paper or such materials as Kodatrace. Anaemic grey ink and pencil will not reproduce! Illustrations should be designed to make maximum use of page space. Maps must have bar scales only. If photo-reduction is contemplated all lines and letters must be large and thick enough to allow for their reduction. Letters must be done by stencil, Letraset or similar methods, not handwritten. Diagrams should be numbered in sequences as figures, and referred to in the text, where necessary, by inserting (Fig. 1) etc. in brackets. A full list of figure captions should be submitted on a separate sheet.

Photographic plates are welcome. They must be good clear black and white prints, with sharp focus and not too much contrast; prints about 15 x 10 cm (6 x 4 inches) are best; if in doubt, a selection may be submitted. They should be numbered in sequence but not referred to in the text, except where essential and then after discussion with one of the Editors. A full list of plate captions, with photographer credits where relevant, should be submitted on a separate sheet.

Tables: These should not be included in the text but should be typed, or clearly handwritten, on separate sheets. They should be numbered in sequence, and a list of captions, if necessary, should be submitted on a separate sheet.

Approximate locations for tables, plates and figures should be marked in pencil in the manuscript margins.

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Speleological expeditions have a moral obligation to produce reports (contractual in the case of recipients of awards from the Ghar Parau Foundation). These should be concise and cover the results of the expedition as soon as possible after the return from overseas, so that later expeditions are informed for their planning. Personal anecdotes should be kept to a minimum, but useful advice such as location of food supplies, medical services, etc. may be included, normally as a series of appendices.

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

We prefer articles to be submitted on disk if possible, although paper copy is also acceptable. We can read most PC based word processing packages but if in doubt please consult one of the Editors. Apple Mac disks are accepted as a last resort!

If you have any problems regarding your material, please consult either of the Editors in advance of submission.

Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 22 Number 1 August 1995

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Cover photo:

Martin Smith in dry passage in Bulandsdalgrotta, South Norland, Norway.
This impressive passage, which displays evidence of a complex, multi-stage history of development, cuts through well-banded marble. The banding is locally folded, passage walls and ceiling are well scalloped and impurities within the marble have locally influenced the passage profile and its direction.
Photo by M. Smith (see article by Trevor Faulkner and Geoff Newton).

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EDITORIAL

John Gunn and David Lowe

Both of us have had a busy summer, involving participating in international cave science symposia, presenting lectures, leading field trips and carrying out field work at home and overseas, as well as attempting to produce a new addition to the BCRA Cave Studies Series against a tight deadline. We regret that this has delayed the production of Cave and Karst Science by about two months, and that we were unable to have it ready for the National Caving Conference, as we had initially hoped. Nonetheless, Volume 22, Number 1 is another 48-page edition, including interesting, high quality papers with a wide geographical spread - Europe, Africa and Australasia. This international coverage seems set to continue in future issues as we are receiving a steady and varied flow of articles from all over the world.

If things go according to plan during the remainder of 1995, Volume 22, Number 2 should be completed by Christmas, and will include a report from the 1994 Yangtze Gorges Expedition, compiled by Kevin Senior. Six more papers are currently with referees or have been returned to authors for revision following review. Hence we should be able to complete this Volume early in 1996. Whether we can then get back on schedule and complete the whole of Volume 23 during 1996 depends on a continuing inflow of material and upon the cooperation of our reviewers, without whom we cannot maintain the quality and reputation of the Transactions. Many international journals publish a list of referees and we intend to follow this example in the final issue of this volume.

While the flow of Mainstream Articles and Forum contributions has been very encouraging we are rather disappointed that we have received no abstracts from undergraduate or masters level dissertations. There must be a significant number of cavers who have completed a dissertation dealing with cave and karst related topics during the past few years. You may have lost interest in your research topic and feel that you have nothing else to write, but your abstract has already been written, so why not submit it for publication? Perhaps you don't think its level and quality meet the standards of Cave and Karst Science? Let others be the judge of this, and remember that your work might interest and inspire someone else, or prevent someone else from fruitlessly replicating work that you have already carried out. We are keen to receive dissertation and thesis abstracts from any country, providing only that the abstract is written in English. You may lack the confidence to submit a full paper, but publishing an abstract is a good way to alert other workers about your interests and results.

It is also a little disappointing that we have received very little feedback on the changes that we have introduced since taking over Cave and Karst Science. We thank those readers who have commented positively and encouragingly, and hope that those who have been less complimentary will find this issue more to their liking.

CAVE AND KARST SCIENCE Vol. 22, No. 1, August 1995
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Toerfjellhola and Other Caves at Vevelstad and Brønnøy, Norway

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Abstract: Toerfjell is a 1000m peak situated NE of Tosenfjord in south Nordland, Norway. Drainage to the SW flows beneath a large boulder-strewn dry valley. Underground courses have been entered at Cave of the Cold Wind and Daaaranjueniehola. In Toerfjellhola, a large system carrying a powerful stream, the steeply descending cave passage exhibits fine marble scenery and there are several series of older, higher level passages. The streamway leads to a sump that is 50m above resurgence level. The final roof series leads to a large abandoned trunk passage and a lower entrance, giving a total length to date of 1881m, the 12th longest cave in Norway. The report also includes descriptions of marbles and caves at Visten, Klausmark, Storfjord, Bulandsdal, Storbørja and Storvatn, all in Vevelstad or Brønnøy kommunes. Many of these places are remote sites on the distant sides of fjords that can only be reached by boat crossings.

INTRODUCTION

This is the report of the 1992 Expedition to south Nordland, Norway, supplemented with information from the 1993 Expedition and with details about Klausmark, which was visited in 1986 and 1993. 1992 saw a departure from the earlier South Nordland Expeditions that had completed a comprehensive study of specific areas (Faulkner and Newton, 1990; Newton and Faulkner, 1992). With a large team, the itinerary for 1992 was set much more speculatively and 8 new areas, all previously unvisited by cavers, were targeted. Most of the areas were near the coastal fjord system and the expedition reached them by ferry, by hired dinghy, by hired fishing boat, and, for one member, by canoe. The weather was easily the worst experienced by South Nordland Expeditions to date, with rain falling nearly every day and often for most of the day, sometimes during windy thunderstorms. In such conditions, no mountain camps were established, and we walked in fleece suits and oversuits to prospective sites from the nearest road, often taking 3 hours in each direction. Collectively, expedition members walked more than 1000km and many people made 14 boat crossings. Walking in bad conditions resulted in several minor injuries as people fell on wet hill slopes. Additionally, several people suffered from throat and chest infections at the start and end of the Expedition. Despite all this, the Expedition was a success with 44 new caves, totalling nearly 3km of passage, being explored. The highlight was the exploration of Toerfjellhola to a length of 800m. At 101m deep it is also the deepest system found in south Nordland for over 18 years.

Most Expedition members sailed from Newcastle on Saturday 18 July 1992, returning on 8 August. Members were: Trevor Faulkner and Alan Marshall; Geoff Newton and John Stevens; Wayne Brown, Nigel Graham and Eddy Waters; Ian Gregory and Andy Tyler; Martin Smith and Carole White; and (part time) David St.Pierre and Keith Bryant. During the drive north, Øvre Gaulstadgrotta near Ogndal was extended by 56 m (St.Pierre, 1993).

Meeting at Visthus on Visten fjord, we stopped here 3 nights before returning south to Nevernes on Velfjord to hire a fishing boat to take us to Tettingsdal at the end of a side fjord called Storbørja. Tettingsdal was explored thoroughly over the next 3 days before we returned and drove to Tosbotn to rent camping huts and to dry out sodden clothing. From here, a deep dry valley feature on Durmaalstind was located, and the Toerfjell area visited. The rest of the expedition was based at the 1984/86/88 campsite beside the river Jordbruelv. From there we daily drove back through the Tosen Tunnel to revisit Toerfjell, to take the fishing boat to Bulandsdal or to walk to Mølnvatn, near Storvatn. The last few days were spent returning to Vargskar (Newton and Faulkner, 1992) and prospecting sites near the Gaasvasselv.

The members of the 1986 Expedition who explored the caves at Klausmarkdal were Trevor Faulkner, Pete Hann, Alan Marshall, Geoff Newton and David and Shirley St.Pierre. 11 caves totalling nearly 1km of passage were explored in this valley. (Refer to Faulkner, 1987 for details of the 1986 Expedition).

The 1993 Expedition camped for 6 nights at Toerfjell, surveying and photographing Toerfjellhola whilst adding over 1km to its length, and exploring the new Cave of the Cold Wind. Advantage was taken of the sunny weather to walk farther afield, but limestone outcrops to the north were still snow covered. No features were found on the south side of Grunnvasstind, nor along Godvassdal, despite its long marble outcrop. This 1993 team comprised Geoff Newton and Chris Tomlin; Trevor Faulkner, Simon Abbott and Andy Tyler; Nigel Graham, Wayne Brown and Mike Read; Martin Smith and Carole White; and Keith Bryant. Whilst NG, WB and MR went to Mølnvatn to continue the 1992 explorations and then returned home after 2 weeks, the rest travelled by boat to Bulandsdal for 3 nights. They then travelled on by boat (now with Edgar Johnsen) to Storfjorden for 2 mainly rainy days, to walk to Klausmark for various projects and to search the Storfjorden marble outcrop. The later final activities of this Expedition will be reported elsewhere.

SURVEYS

BCRA Grade 3 surveys were made of the longer caves. Universal Transverse Mercator (UTM) co-ordinates in Grid Zone 33W, square UN or VN, are provided for each referenced cave. In all cave descriptions and surveys A = Altitude, L = Length, D = Depth, VR = Vertical Range; all in metres. BCRA Grade 1 sketches of most shorter caves are available from the authors. Lesser features are listed in the Appendix.

GEOLOGICAL SETTING

The geology of the area is described fully by Stephens, Gustavson and others (1985) and Gustavson (1988). The Norwegian county of Nordland exhibits 4 major flat lying superimposed thrust nappe complexes formed by movement of rocks over relative distances up to 500km westward during Caledonian mountain building periods. Overlying a Precambrian basement of crystalline rocks around 1700 Ma old, the nappes commonly contain schists, gneisses and amphibolites. The more recent, upper nappes contain marbles and marble schists. The thrusts westward have, in general, been accompanied by intense folding and metamorphism. Intrusions of gabbro and granite are also strong features of the region. The four major nappe complexes are referred to as the Lower, Middle, Upper and Uppermost Allochthons. The Upper Allochthon is also subdivided into the Lower (Seve) Nappe and the Upper (Kølli) Nappe.

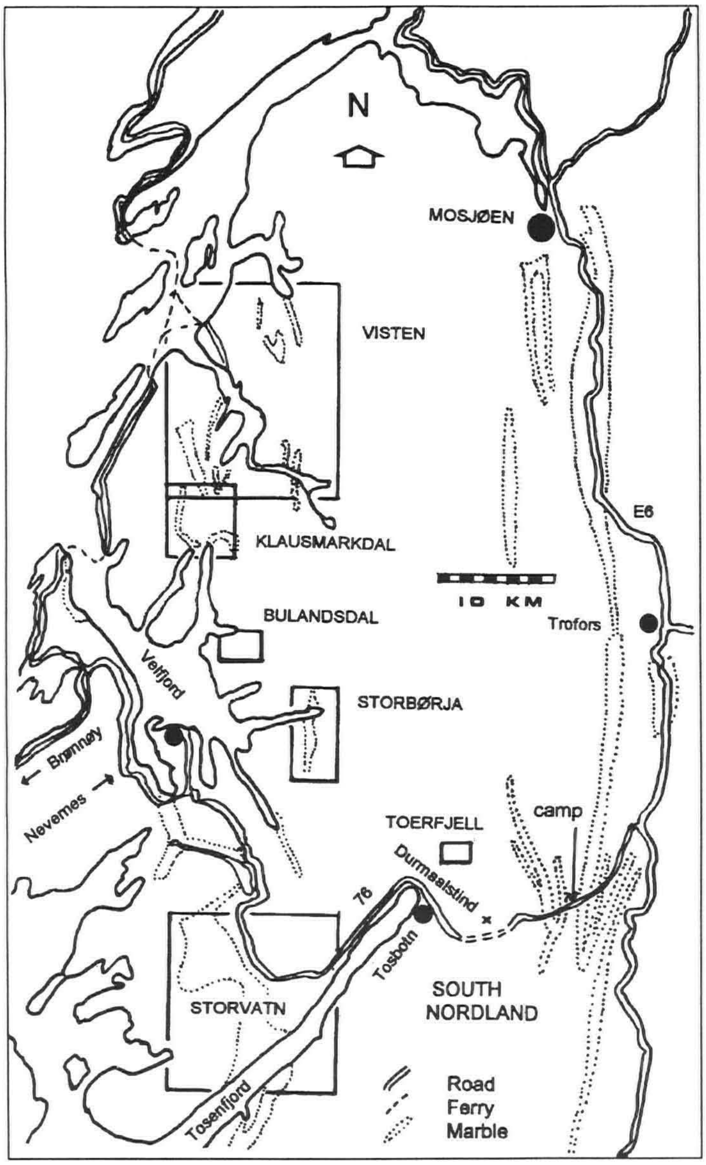


Figure 1. Location of areas in South Nordland, Norway, referred to in the report.

Only two of these allochthons are present in the south Nordland area south of Mosjøen. The bulk of the area (and all of Fig. 1) comprises the Helgeland Nappe Complex that extends as far east as Fiplingdal (Faulkner, 1983) whilst to the NE toward Mo i Rana lies the Rødingsfjell Nappe Complex. Both these nappes are in the Uppermost Allochthon. To the SE, around Børgefjell, lies the Kølli Nappe Series. All the thrust units wedge out to the west near the coast. Limestones in the upper part of the Kølli Nappes were deposited in early Ordovician times (around 442 Ma), followed by four or five episodes of folding and low grade metamorphism of Ordovician and Silurian sedimentary and igneous rocks. The Rødingsfjell Nappe Complex is characterized by early W-E folds, commonly overprinted by later N-S folds. Clearly, the caves in Skinnfjelldal (Faulkner, 1987) lie in a W-E strike of marble along one of the earlier folds. The underground marbles here were seen to be very dark and unattractive, completely different from the beautifully striped marbles commonly found in the Helgeland Nappe Complex (HNC).

In the Uppermost Allochthon, especially in the HNC, thick dolomite and calcite marbles, originally deposited at a continental margin, are characteristic. Some narrow outcrops can be followed for over 100km, with generally a NNE-SSW trend, although in Fig. 1 the trends are closer to N-S. The HNC is related to the Beiarn Nappe Complex in the more popular caving area 200km farther north. This type of marble outcrop is often referred to as "stripe karst". The HNC consists of an original gneissic basement with a "cover" of marbles, iron ores, gneisses, schists and conglomerates. Together they form complex regional polyphase folds generally dating from around 415 Ma (mid Ordovician), with medium grade metamorphism, commonly leaving the "cover" units in tightly pinched synclines, as seen near the E6 in Fig. 1.

Three fold episodes are recognised within in the HNC, with the first perhaps being Precambrian metamorphism of the base rocks. The main HNC westward thrust occurred during the middle episode in mid Ordovician times, with thrusts being active after the peak metamorphism. The third fold episode is characterized by W-E folding.

The evidence collected by many South Nordland Expeditions, particularly to areas west of the E6, amplifies many of the geological statements about stripe karst. Three main types of marble have been observed in the area shown in Fig. 1: a) striped marble with brown/yellow or grey stripes usually a few inches thick separated by narrow bands of dark material, probably organic carbon metamorphosed to graphite; b) pure grey crystalline marble; and c) white marble.

The sequence a) - c) illustrates the varied metamorphic grade within the HNC, with a) preserving most sedimentary history. Good examples of type a) occur in Sirijordgrotta (Faulkner, 1980), Blaafjellgrotta (Newton and Faulkner, 1992) and in Toerfjellhola and Bulandsdalgrotta (this report). Type b) is observed with type a) at Toerfjell and on Elgfjell (Faulkner and Newton, 1990), where caves are found in both types and entrances are common at the junction of the two marbles. The extensive marbles in the Storvatn area are type c), with examples in quarries, in road cuttings and in Mølnvatngrotta (this report). North of road 76 the limestones are generally vertically banded (i.e. dip = 90°) although on Elgfjell the dip is commonly 70°. The white marbles in the Storvatn area are clearly different in form as they appear to occur as extensive sheets with little evidence of banding. Otherwise, the marble outcrops are extremely narrow, with imbricate sequences repeated along W-E planes, for which Elgfjell provides the best example.

Caves in south Nordland seem to form preferentially in the narrower marble bands that cannot be represented on small scale geological maps, even if known to geologists. Any previous estimates of total numbers of caves and passage lengths are likely to be seriously low, and claims to have visited most karstic marbles are surely exaggerated. Indeed, this report gives several fine examples of marble stream caves in outcrops unknown to previous geological mapping. Throughout the area, the influence of gabbro and granite intrusions within the HNC is seen to be very important in the development of probably all caves. Caves at a marble/non carbonate contact or at a grey/striped marble contact are commonly developed along that line of weakness. The interior intrusions, or other contacts between band impurities, commonly form cave walls, waterfalls and sumps, and many examples shown on cave surveys in this Report. All these factors appear to support, perhaps in a simple and extreme manner, an Inception Horizon Hypothesis (cf. Lowe, 1993).

VISTEN

Visten fjord wends its way into the mountains of Vevelstad kommune for 20km. With only small isolated farms along its length it is reputed to be the cleanest fjord in Norway. The local people rely heavily on the plentiful fishing, and several mussel farms can be seen in small bays along the fjord sides. Narrow bands of marble, generally trending N-S, occur north and south of Visten. More very narrow bands of commonly impure marbles exist than are shown on the 1:250000 Geological map (Gustavson, 1988), as at Vistnesodden and in the steep valleys south of the Stokkahatten summit. The shop and small community at Visthus can be reached with vehicles by taking the ferry from Forvik to Stokkasjøen.

Behind Visthus a narrow, deep W-E gorge cuts orthogonally across two major N-S valleys. The gorge was apparently formed by water being diverted west by glacial moraines. At Sørfjorddalen, west of the valley, the marbles form a green ridge that is pockmarked with small shakeholes. Three small caves were found here with maximum sink to resurgence distances of about 150m (VS1, VS2, VS3). The gneiss floor of Sørfjorddal

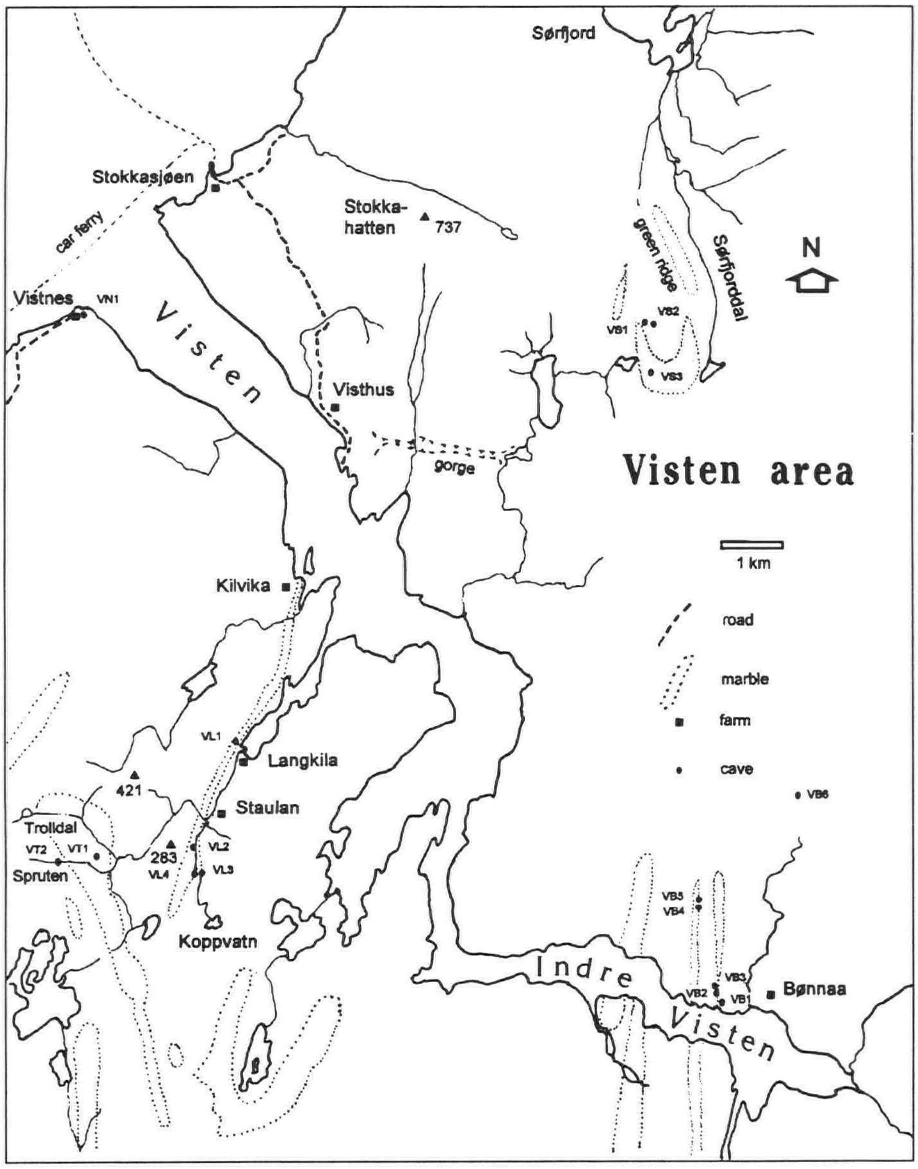
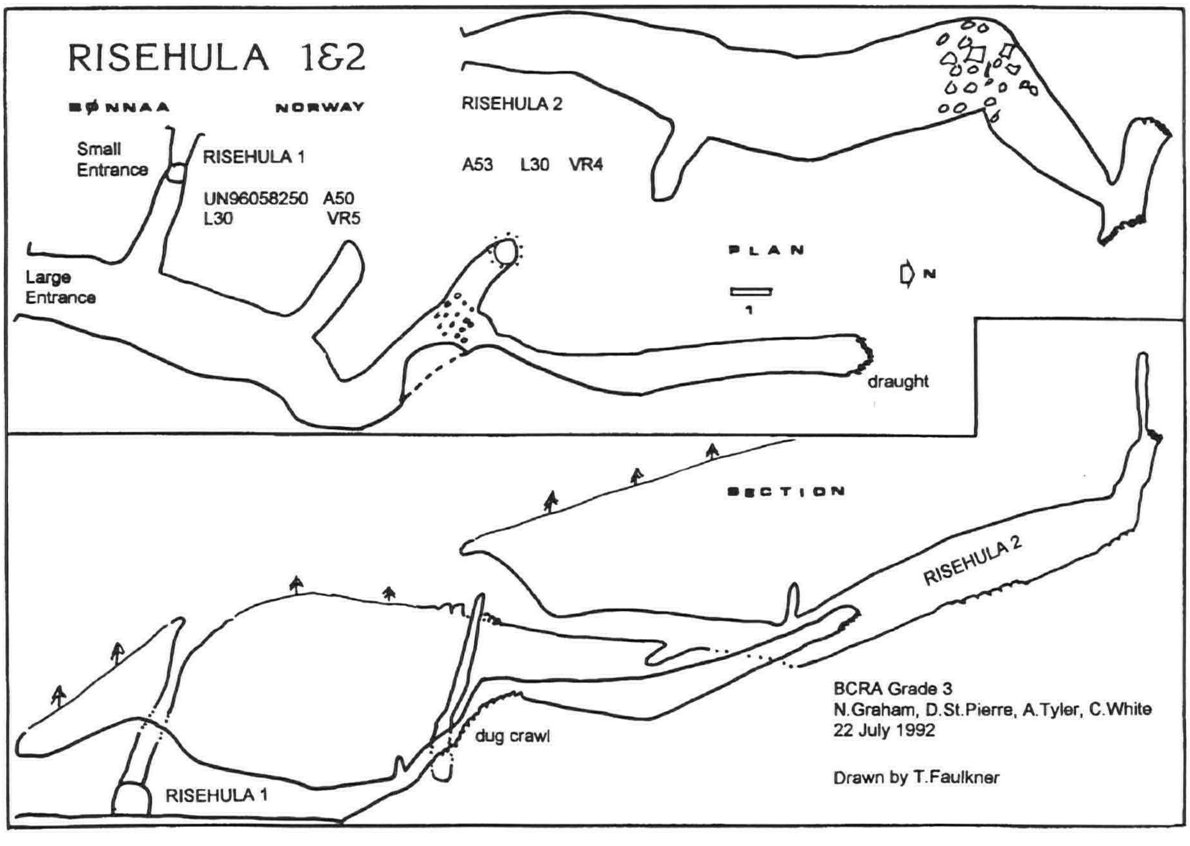


Figure 2. The Visten area, showing cave locations and main marble outcrops.

Figure 3. Survey of Risehula 1 and Risehula 2, South Nordland.



itself was followed from the headwaters lake to near the plain by the fjord without seeing marble or underground drainage. The marble band south of Kilvika was followed for most of its length after reaching Langkila by dinghy from Visthus. Only at VL3 was a significant cave found. Two smaller caves were VL1 and VL2. West of the Langkilelv outcrop, a broad band of marble runs SSE from Trolldalen. Only two features were seen here, VT1 and VT2, although high rivers prevented access south of Spruten. The farm at Bønnaa, near the end of Indre Visten, can be reached by taking the daily ferry from the end of the road south of Visthus. A rowing boat allows access to two narrow marble bands.

RISEHULA 1 AND 2 (VB2/3) UN96058250 A 50 TOTAL L 60 VR 9

These are in a cliff, at the top of a vegetated slope, 500m west of Bønnaa. A 2m high entrance leads after 3m to a passage ascending steeply to a second (smaller) entrance. The fossil passage continues through a dug crawl to a draughting boulder choke. The second cave is a short fossil passage starting near the Risehola 1 upper entrance. It has later been reported that cave paintings were found in one of these caves (Sjøberg, 1994).

DRY WATERFALL CAVE (VL3) UN87958440 A 210 L 60 D 5

The tributary stream flowing from Koppvatn sinks into this cave at the top of a normally dry waterfall above Langkilelvdal. A wet entrance duck leads to a pool and 4m climb down to a very deep canal. A delicate traverse on small ledges on the left wall leads to a linear ascending dry passage and draughting choke. A high, forested wall along the strike separates this cave from a wide resurgence entrance (VL4), near the base of the dry waterfall, which leads to a canal and sump.

KLAUSMARKDAL

Klausmarkelva is a mountain stream draining a series of lakes west of Nilslitind (466m). A marble outcrop runs south for 6km, roughly following the valley line, to reach the sea at the head of Okfjorden, a branch of Velfjord. The surrounding rocks are granite and porphyritic granite. The marble outcrop is distinguished by its capacity to support vegetation, particularly silver birch forest. A geologist's report stated that the limestone at Klausmark *"is so full of caves and potholes that the farmer had to take precautions to prevent the animals from falling into them"* (Rekstad, 1917). The valley is no longer farmed, the large house at Klausmark is now owned by the Norwegian forestry commission. Access is either by a rough footpath from the coast road at Anndalsvaagen (5-8 hours, as in 1986) or by boat to Storfjorden and then a good footpath (1 hour, as in 1993). The footpath from Storfjorden follows a small stream over marble outcrops with no cave features. The continuation of the marble along the valley to Okfjorden was not examined due to the volume of water. Beyond the farm at Storfjorden, the eastward arc of marble was investigated without finding any karst features. Similarly, a marble outcrop on the west side of Storfjorden (reached by canoe) displayed no features.

TRAP CAVE UN86208010 A 180 L 105 D 20(?)

Mostly a crawling passage with three entrances in the scrub, it is on the left bank of the Klausmarkelv a few hundred metres downstream of a waterfall. The entrances have been partly covered with birch logs. A 2m-deep shakehole has two entrances. Downstream starts as a flat-out squeeze to a hands and knees crawl passing a small oxbow on the right where a small stream flows out. The passage continues as a crawl over

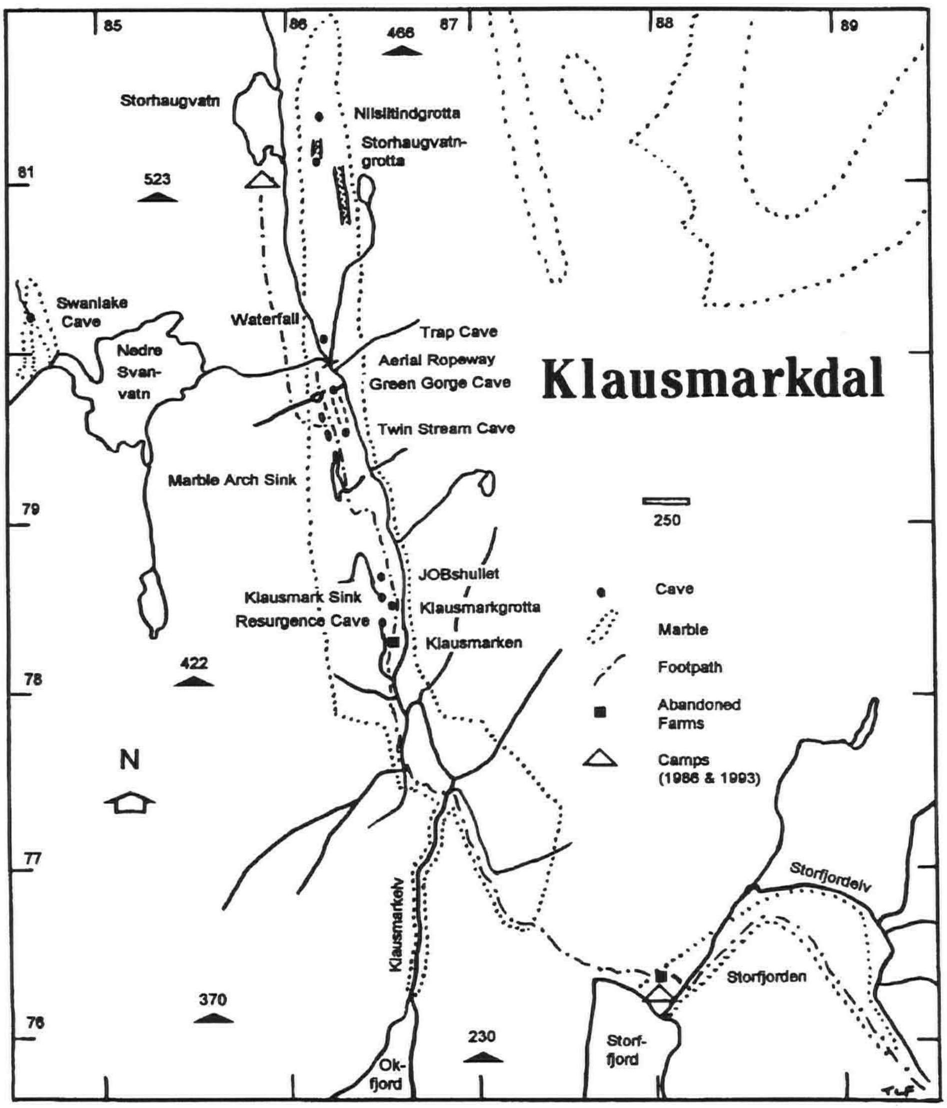


Figure 4. The Klausmarkdal area, showing cave locations and main marble outcrops.

slabs with some moonmilk in the roof to a boulder collapse. A further squeeze gains 8m until becoming too low over boulders and silt. Upstream also starts as a low squeeze to hands and knees crawling past a small alcove on the left to where a small stream sinks in the left hand wall. The passage continues keyhole shaped, 1m in diameter with a 0.2m-deep slot, to a too tight passage in the right hand wall from which the stream flows. There are many small holes in the roof and after a right angle bend the top entrance is reached at a 2m-deep shakehole. Digging here might result in a continuation as the two shakeholes appear to be collapses into an underlying shallow cave system.

GREEN GORGE CAVE UN86257980 **A** 160 **L** 60 **VR** 12

A densely vegetated gorge ascends the valley siden south of where an aerial ropeway crosses the stream below the waterfall. Just before the start of the gorge is a large entrance in the west side of the valley, with a small stream resurging from a sump at the back of the entrance chamber. The cave ascends as a dry passage to a loose boulder choke and 6m-high aven. A 4m drop leads to a wet crawl and another sump. On the cliff above is a sink into a shakehole containing a 7m long, 3m-deep passage.

TWIN STREAM CAVE UN86307955 **A** 180 **L** 106 **D** 12

The green gorge leads south to a broader area with shakeholes, the second of which can be climbed to a rough chamber 6m below. A hole in the floor leads to a tight rift heading east. SW from the chamber eventually reaches a 5m pitch (ladder advisable) into a chamber. From this a tight crawl regains walking passage and streamway. Upstream is too tight, downstream ends in a sump. An overflow passage is partially blocked by silt.

Plate 1. The entrance to Green Gorge Cave, Klausmarkdal (Photo: P. Hann)

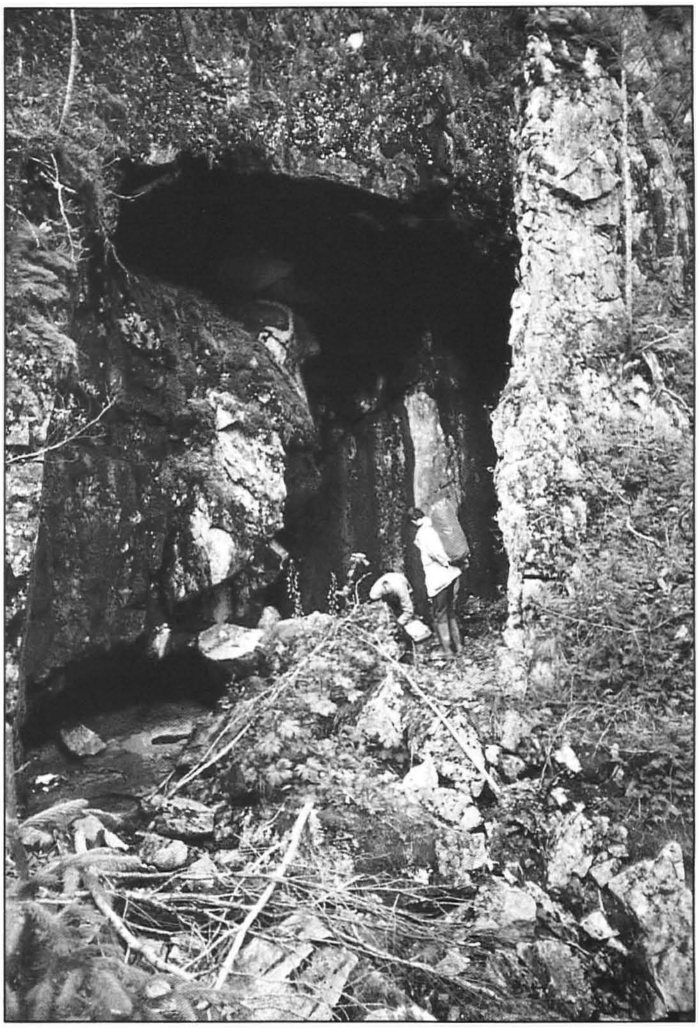
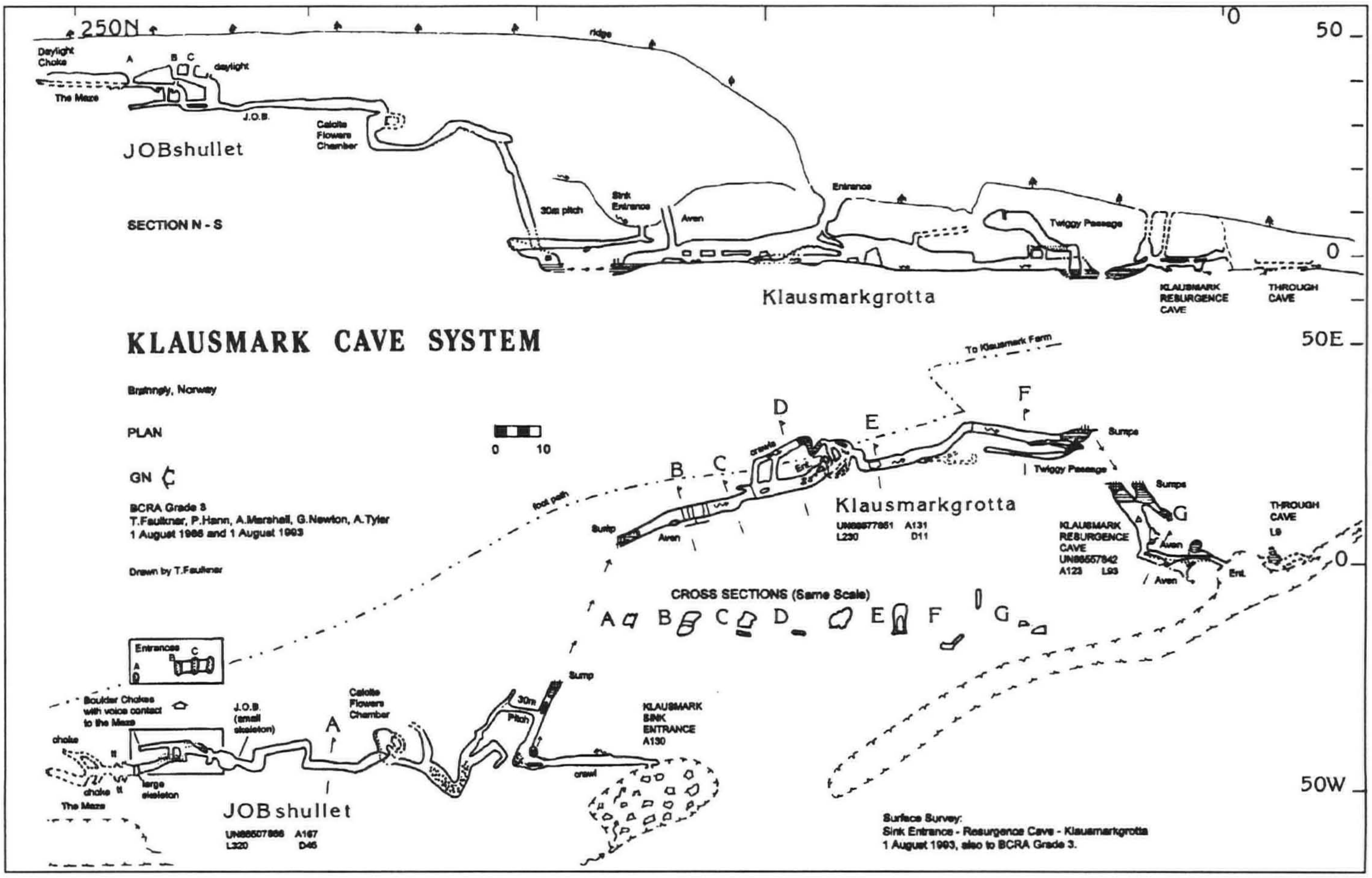


Figure 5. Survey of the caves comprising the Klausmark Cave System, South Nordland.



JOB SHULLET UN86507866 **A** 167 **L** 320 **D** 46

Three pit entrances occur on a 10m-high ridge overlooking a meadow and granite wall to the west. Some entrances are covered by branches. The most northerly has animal bones at its foot. A crawl to the north leads to the Maze. A large passage leads south, downhill to a cross rift, to join a parallel passage and high chamber with a large passage from another entrance entering 5m up. The continuing passage has a complete sheep skeleton where a wooden tag inscribed "J.O.B." was found among the bones. A meandering dry phreatic passage leads to a climb down into Calcite Flowers Chamber. A well decorated side passage occurs beyond here. The main passage slopes up then down to a rift that continues across the top of a 30m pitch, but narrows. The first 8m of the sloping pitch can be free climbed, but it is best to use a 30m ladder that reaches to a sump in a large streamway. Upstream, climbs past a sharp corner to where the water enters the cave below the Klausmark Sink Entrance. This was first opened in 1993 by moving aside large blocks of marble.

KLAUSMARKGROTTA UN86577851 **A** 131 **L** 230 **VR** 11

A steep sided shakehole beside the main valley path, on the other side of the hill to the Klausmark Sink, leads into this large entrance. Downslope to the north reaches the streamway and a sump that has an air surface in very dry conditions. This is some 40m from the sump in JOBshullet. An aven ascends before the sump, but this could not be climbed, even using a 5m birch trunk as a maypole. Downstream can be followed via a low meandering active passage to reach the main passage again, south of the entrance. A roof canyon ascends here to a higher exit. The large stream passage terminates at a deep sump pool. A climb into the roof gains a crawl to a pitch descent into an adjacent pool. It is also possible to use a ladder here to enter the ascending Twiggy Passage which trends back to the north, ending in a calcite choke.

KLAUSMARK RESURGENCE CAVE UN86557842 **A** 123 **L** 93

Below Klausmark Sink the densely vegetated dry valley leads to this cave on the left bank. A large passage on two levels leads to a streamway and large rising sump pool, 10m from Klausmarkgrotta. Two avens lead to higher entrances on the hill side. A short distance down valley is a 10m-long through cave with a pool, and the stream soon reappears to flow past the farm to join the Klausmarkelv.

BULANDSDAL

This valley drains NW into Lislfjord, a side arm to Storfjord. Access is by fishing boat from Nevernes on Velfjord. A track leads up the lower part of the valley along its north side. The stream in the upper part intermittently sinks into cave systems under the boulder strewn valley floor, which follows the strike of a vertical band of marble about 10m wide. Vertical bands of non-carbonate impurity occur within the marbles and these have been a major influence in passage formation, locally forming loose, slippery, dirty walls. On the eastern valley side, several shakeholes lead into older, higher level, caves that are no longer related actively to the main valley systems.

BULANDSDALGROTTA (B2) UN90606720 **A** 340 **L** 326 **D** 11

The entrance is at the first sink of the whole Bulandsdal stream, below a marble cliff 10m wide. A drop leads to a long pool in a wide, 1m-high streamway. A tall clean washed rift passage is soon reached, with the water roaring along its base. Traversing at roof level enables the large Square Chamber to be entered. The water sinks at a pool at the end of the rift and is seen again at a passage leading north from the corner diagonally opposite. This passes under a daylit aven and ends at a boulder choke. The main route continues past Square Chamber as a fine dry passage in nicely banded marble, leading to the very tight Wayne's Exit (B3) near where the stream reappears at the surface from under boulders, only to sink again 50m north at B5. The passage walls commonly display dark layers of impurity marking corners and junctions throughout the cave.

BULANDSELVGROTTA (B7) UN90406765 **A** 260 **L** 176 **VR** 29

The large valley stream cascades from rocks 10m above the valley floor, which is dry above this point. Just above the rising a small hole in the cliff drops into a watery passage with a tight meander leading into the start of a very narrow passage formed between loose slippery walls, probably of mica schist. The cave for the most part is quite straight between acute bends, just over head height and just wide enough to walk along. In several places there are short waterfalls where care is needed, as the walls are slippery and handholds tend to come away. Towards the explored end is a short duck before the passage emerges in a large, 10m-high chamber. A waterfall enters about 7m up, from an apparently small opening, probably quite close to B6. There are no side passages, and near the entrance the cave floods to the roof.

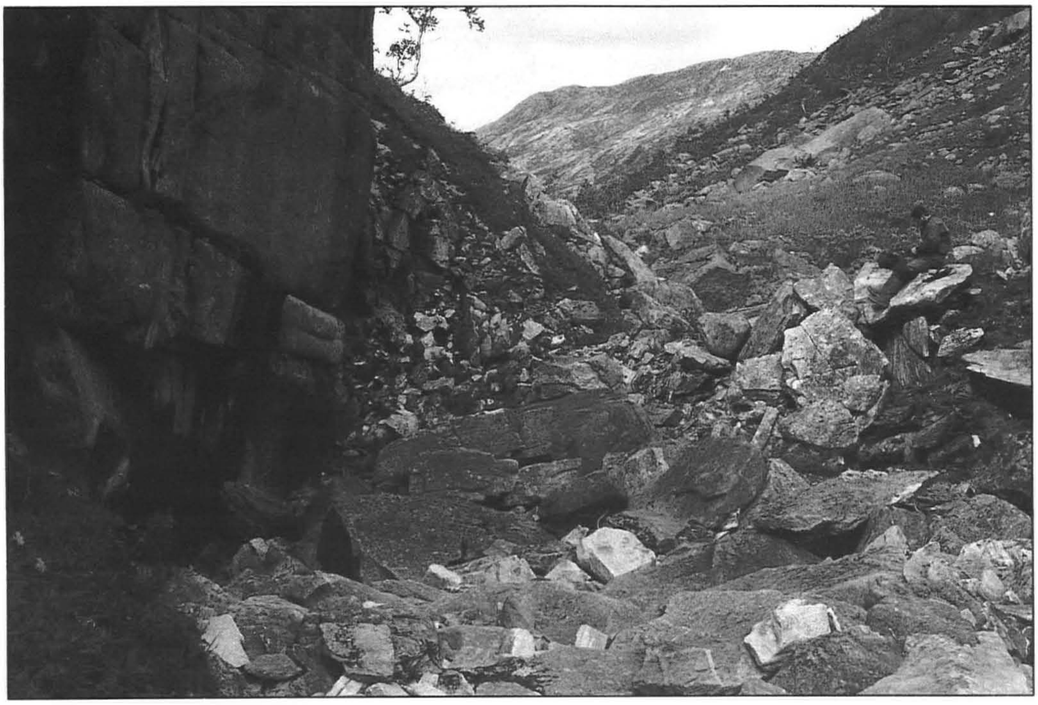


Plate 2. The entrance of Bulandsdalgrotta beneath the marble cliff, with the dry valley continuing beyond (Photo: T. Faulkner)

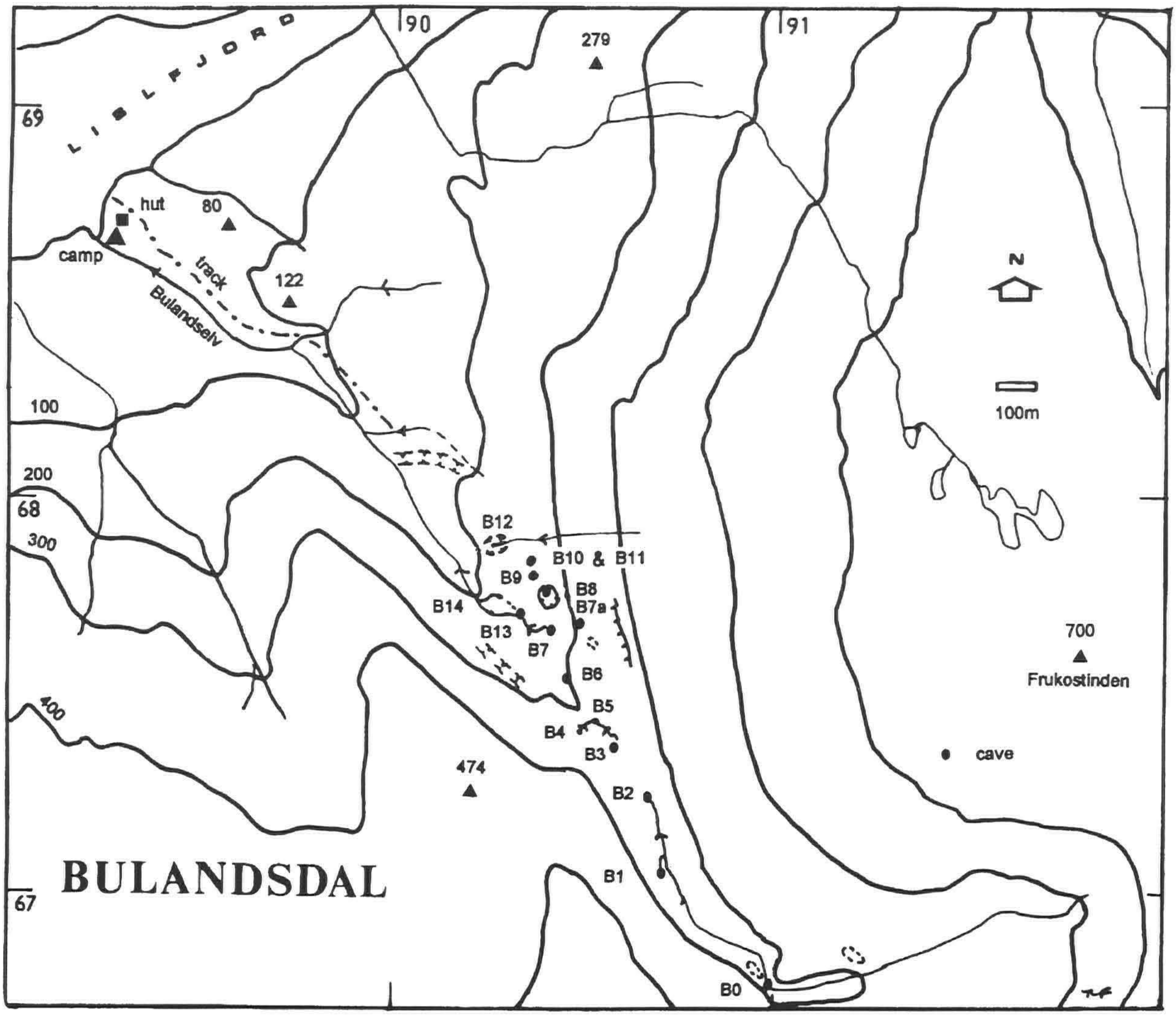
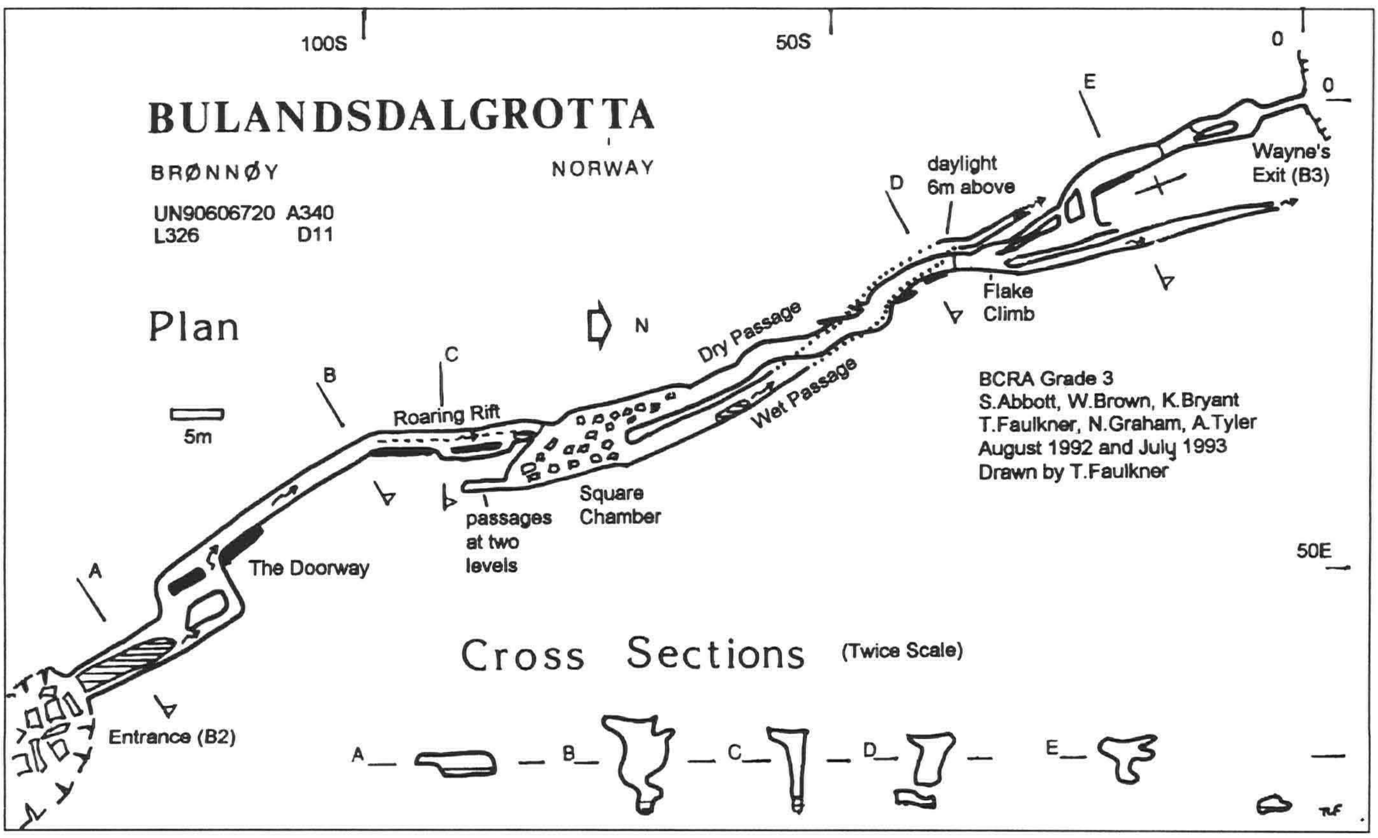


Figure 6. The Bulandsdal area, showing cave locations.

Figure 7. Survey of Bulandsdalgrotta, South Nordland.



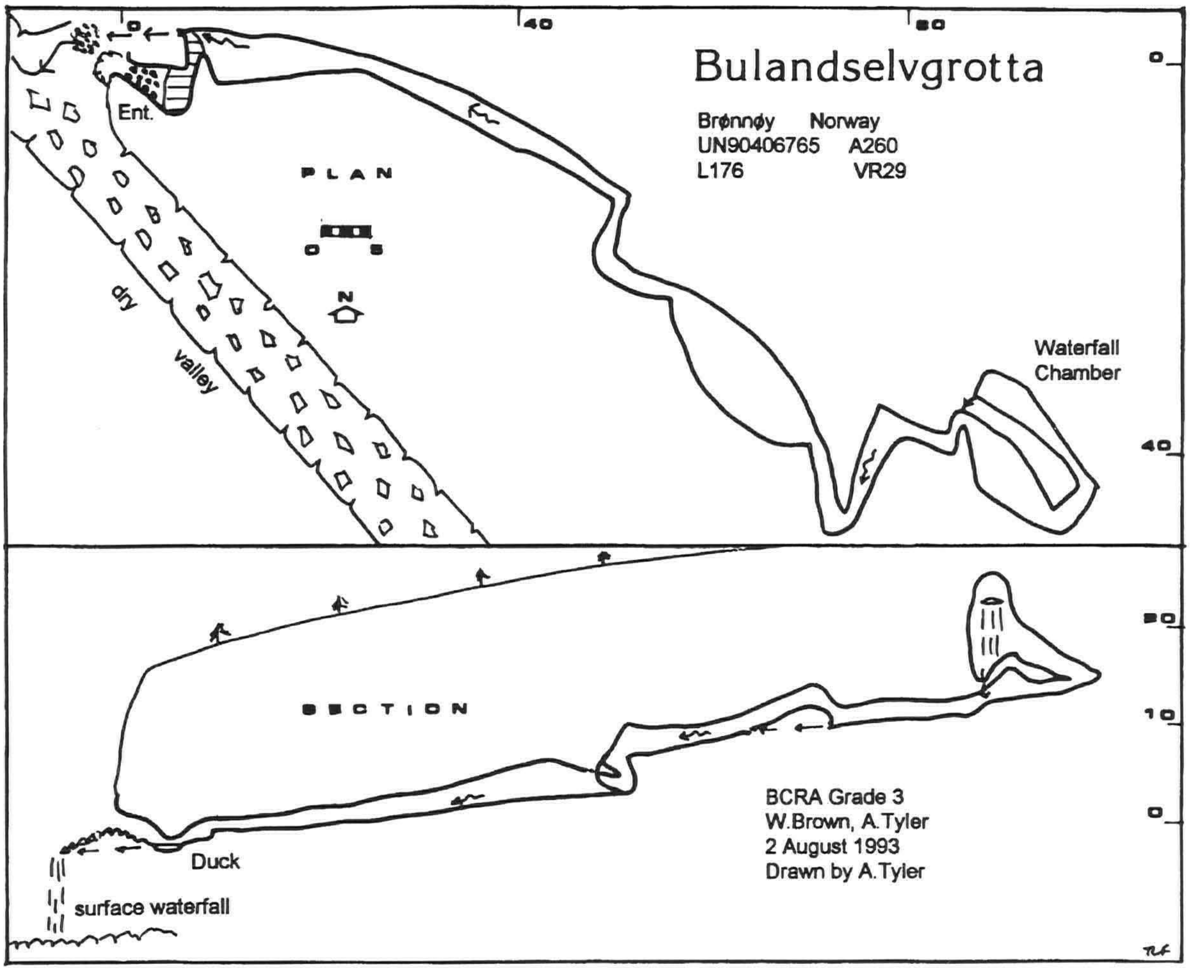


Figure 8. Survey of Bulandselvgrotta, South Nordland.

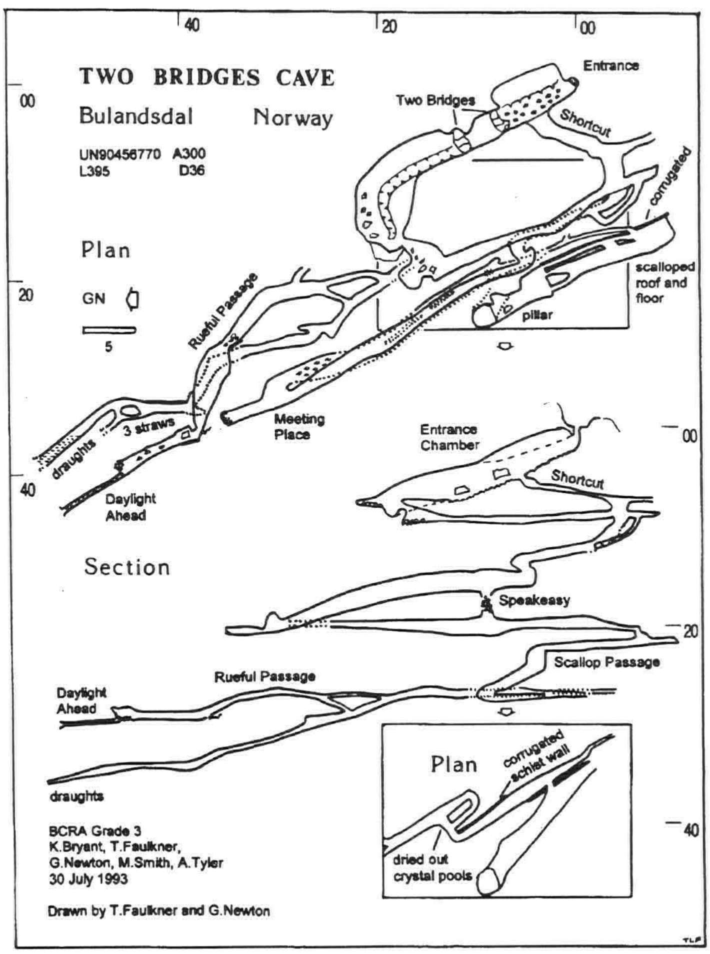
TWO BRIDGES CAVE (B7A) UN90456770 **A** 300 **L** 395 **D** 36

A remarkable cave situated in a ridge above the B7 resurgence, west of a black cliff. The small entrance drops into a large entrance chamber with two rock bridges. At the lower, NW, end of the chamber the route drops down and reverses its direction. This dropping and reversing characteristic is repeated 5 more times until the cave ends at draughting but sedimented crawls. Three of the reversals are to a passage displaced to the west and 3 are displaced to the east so that the route sometimes zigzags down "forwards" and sometimes spirals down underneath itself. The dry phreatic passage varies in size between walking and crawling height, and reversals usually occur where a vertical impervious band of impurity has been breached. In places this band has corrugations with a wavelength of about 5cm. Near the end, a roof passage leads to a low rocky crawl with daylight visible in the distance. It is surmised that this must emerge in the southern side of the large B8 shakehole. From the survey section it is clear that the cave has fed water to northern resurgences at four distinct levels in the past. The section also indicates the possibility of extensions beyond the SE reversals. These may connect to a closed shakehole SE of the present entrance. It seems likely that the cave was formed by the main Bulandsdal stream before the downcutting of the present valley.

SHAKEHOLE CAVE (B8) UN90356775 **A** 270 **L** 100 **D** 20

A large shakehole with craggy sides is located 100m north of the hanging rising, in a parallel dry valley. At its foot the narrow entrance crawl leads via a boulder rift traverse to a bold descent into a large passage. A gentle descent passes a streamway and low exit on the right. After 25m the passage splits into smaller passages that are too tight or choke.

Figure 9. Survey of Two Bridges Cave, South Nordland.



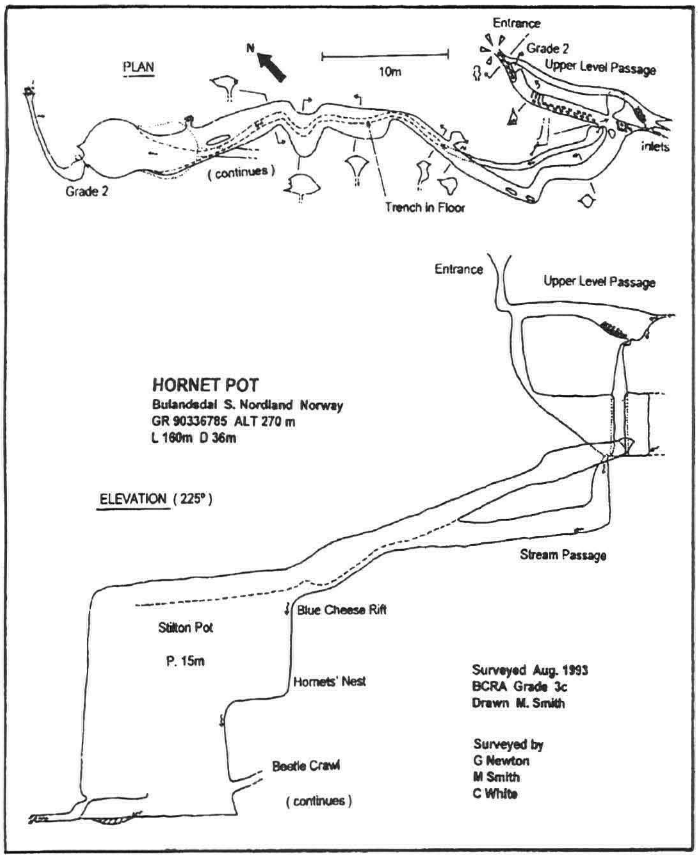


Figure 10. Survey of Hornet Pot, South Nordland.

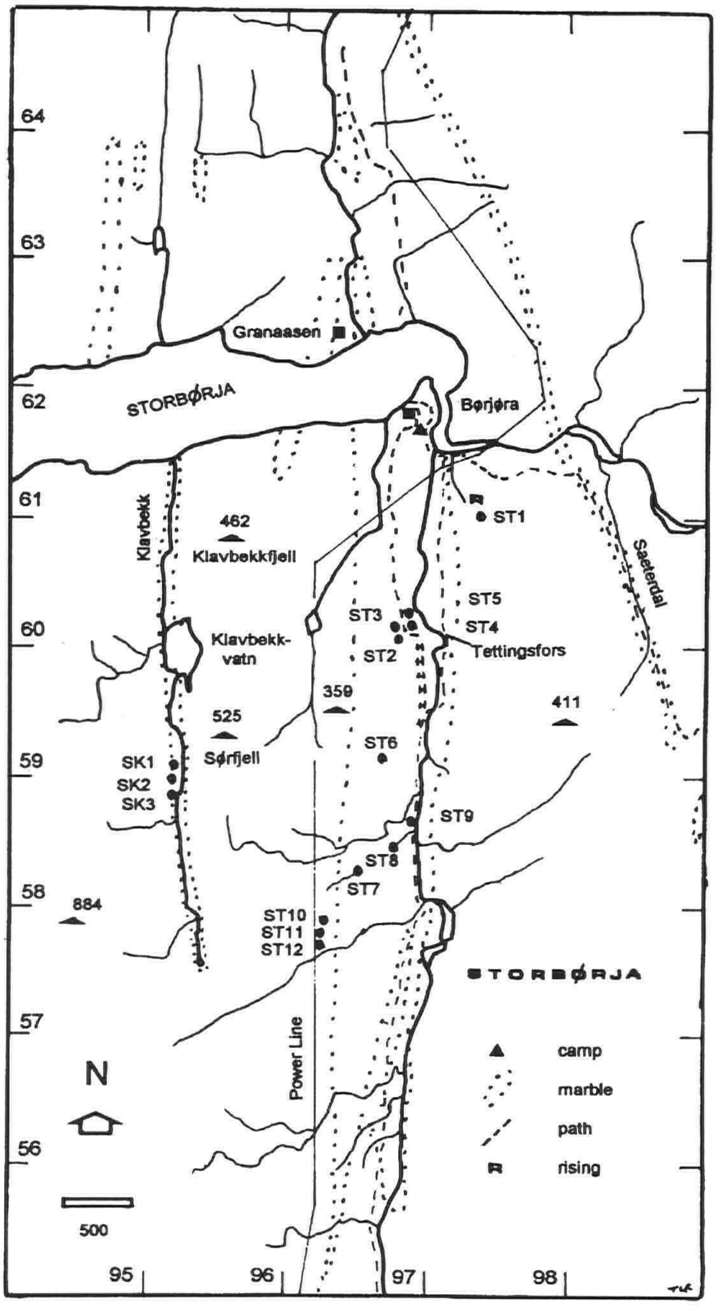
HORNET POT (B10) UN90336785 **A** 270 **L** 160 **D** 36

The entrance is in an obvious shakehole 100m SE of B12. A drop and short squeeze lead to a rift with a tight upper level vadose passage going to a chamber with 3 inlets. The foot of the rift passes to a lower stream passage and Blue Cheese Rift, which is more easily reached via a dry phreatic tunnel. Across this rift a large ledge is the take off for the unbroken 15m deep Stilton Pot ladder pitch, passing the Hornet's Nest ledge half way down. The water flows into a sump with a climb above to an inlet. The probable resurgence is choked a short way downhill from the entrance.

STORBØRJA

Several bands of N-S trending, steeply dipping, marble crop out across the eastern end of Storbørja, a long side fjord reached via an hour's journey by fishing boat from Nevernes on Velfjord. The broadest marble band lies along the west flank of Tettingsdal. However, the marble appears to be impure, commonly contorted, and to occur in narrow layers. At Tettingsfors, the Tettingselv pours over a high waterfall where it meets the limestone, in a manner reminiscent of the Jordbruelv Waterfall (Faulkner, 1987; Faulkner and Newton, 1990). Rather than flow underground, the Tettingselv has cut a narrow inclined gorge, as seen from a footbridge. Several abandoned dry caves were found near Tettingsfors, but dry gorges to the south, parallel to the stream valley, had no cave entrances. South of here the fairly large streams that flow east onto the limestone all stay on the surface to reach the Tettingselv. Only one small stream has an underground course, with an impenetrable sink and a tiny resurgence passage. West of Tettingsdal a deep rift cave was found directly under a power line in a broad upper valley. The next marble band runs along Klavbekk, west of Klavbekkfjell and Sørfjell, and contains a powerful underground stream, which can be partly explored. The footpath through Saeterdal generally follows the crest of a marble ridge with no cave features. The marbles on the north side of Storbørja were explored for about a kilometre without finding cave

Figure 11. The Storbørja area, showing cave locations and main marble outcrops.



features. In 1990, K. Bryant walked 3km north along the Granaaselv, but only observed granite outcrops. However, a possible entrance in the cliffs above Granaasen was observed from the boat. Several old farmhouses at the end of Storbørja that finally abandoned around 1979 but remain in private ownership as summer retreats.

BALCONY CAVE (ST4) UN96806020 **A** 200 **L** 175 **VR** 18

A substantial cliff on the west side of the main Tettingselv valley overlooks Tettingsfors. The "view platform" is directly above the cave. At its base is a narrow ledge above a very steep slope of grass and boulders. The main entrance lies on this ledge facing approximately east. Other holes can be seen in the cliff above. The entrance crawl reaches an interlinking rift. Upwards is a blocked entrance. Climbing up a metre gains Level C with a crawl running back to a daylit boulder choke. Traversing along the rift at this level reaches a second crawl to a similar choke. Ahead is the main way on, but just above it is another, flatout, crawl to an aven. By climbing down the rift a wide crawl (Level D) is passed to a shingle floor. The crawls on Levels C and D meet again in a

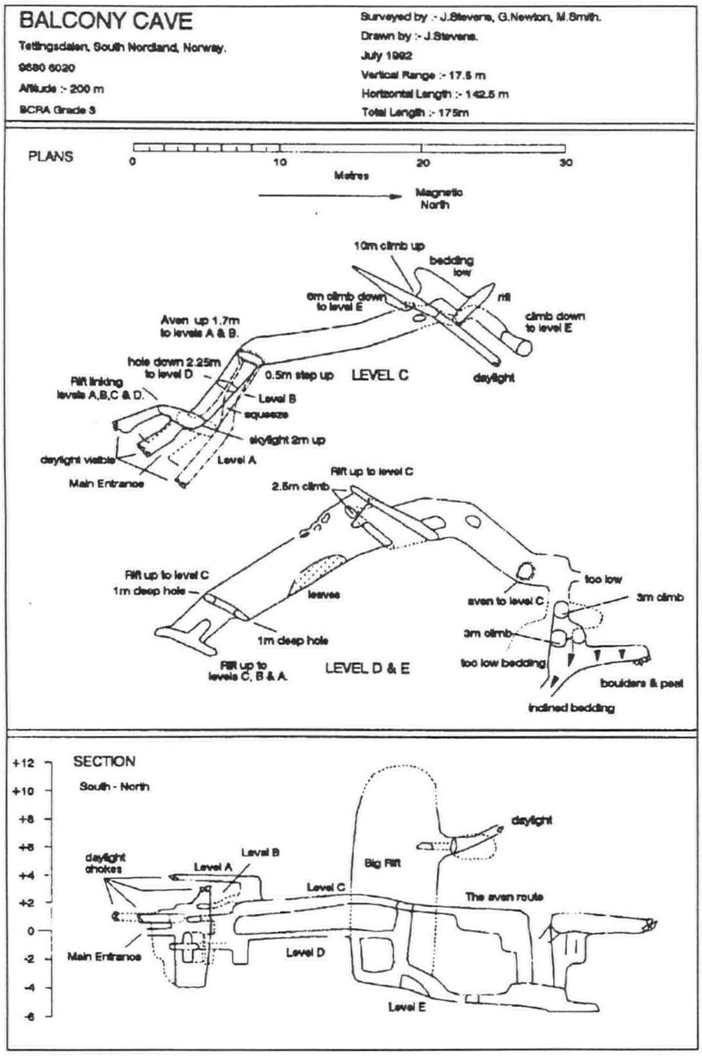


Figure 12. Survey of Balcony Cave, South Nordland.

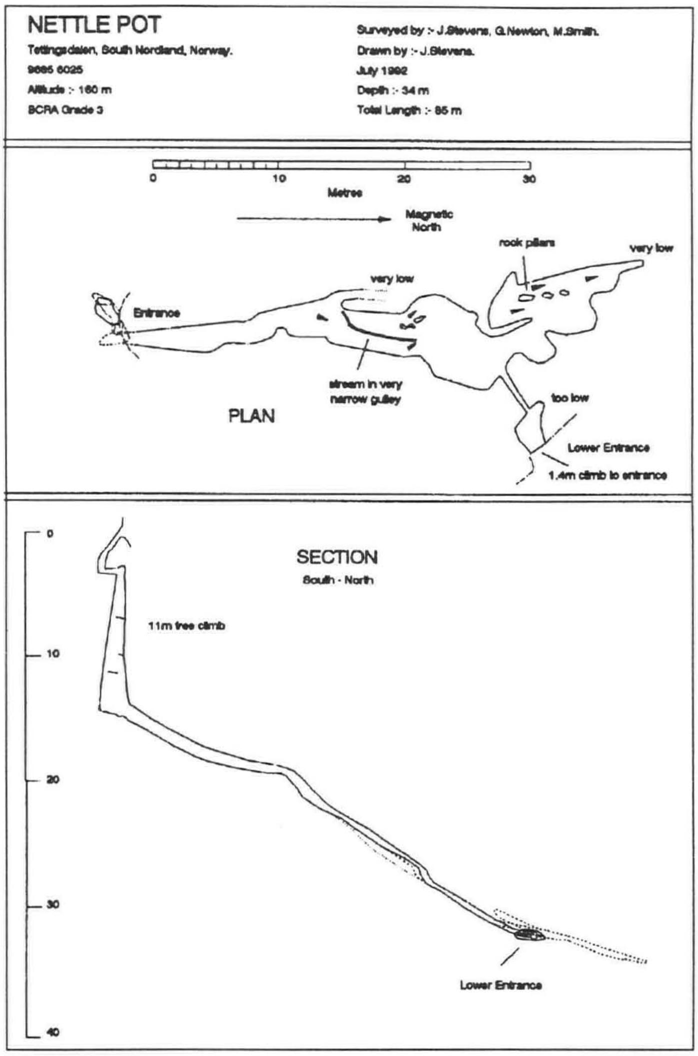


Figure 13. Survey of Nettle Pot, South Nordland.

few metres at a small rift with two blind pots in the floor. Both levels continue, Level D getting wider and more spacious until a floor rift is met. This has been divided into two by a rock pillar, but both ways reach the same point in Level E, 2m from the Big Rift. By crossing the left-hand rift a 2m crawl enters the Big Rift some 4m up. Level C passes an aven almost immediately. This can be climbed to reach a tight crawl (Level B) back to the entrance rift, or at the top, a longer crawl to a daylight choke (Level A). Level C increases in size before becoming flatout. A crawl to the right leads via a couple of easy climbs to reach a dribbling climbable pitch to Level E. By keeping to the left in the flatout section a wriggle emerges some 6m up in the Big Rift, which has several useful ledges. 10m up the Big Rift is a passage that ascends to another daylit blocked entrance, passing a window into a rift. This rift can be accessed by a wide crawl at the same level in the Big Rift. The base of the Big Rift reaches Level E. A comfortable oxbowed passage continues gently down to an aven with a dribble of water. The aven connects back to Level C. Beyond it a bend to the right ends at a low gravel choke. Just past the bend an awkward climb reaches low crawls, one to the left ending at a choke of boulders and peat probably near the surface.

NETTLE POT (ST5) UN96856025 **A** 160 **L** 85 **D** 34

This is situated in the true left bank of the Tettingselv gorge about 100m downstream of the waterfall. The upper entrance is at the foot of a small crag fairly close to the top of the gorge and a large fallen tree leads to the small diagonally sloping opening. A squeeze down leads to a 2m pot and a low crawl to the head of an 11m free climbable pitch. This gives access to a wide low ramp that eventually chokes. At the foot of this is a phreatic tube on the right which leads quickly to the lower entrance. It is possible to see the lower entrance from the opposite side of the gorge.

PYLON CAVE (ST10) UN96205790 **A** 310 **L** 137 **D** 14

This is near pylon 268, at the head of a small dry valley, where a small entrance and 2m climb lead down to a sloping chamber. At its western end is a horizontal passage going south to a fork. Left leads to a daylit blockage. Right is a crawl over granite. Two sloping passages lead west from the horizontal passage and join at another (lower) N-S horizontal passage. A 2.7m climb down reaches the lowest level, a meandering tight vadose passage 2-3m high with many jammed boulders and a small stream running into a small sump at its northern end. Throughout the cave, N-S passages are roughly horizontal, whilst W-E passages "dip" at about 35°.

TOERFJELL

Tosbotn is a small settlement at the head of the long Tosenfjord. 6km to the NE are two peaks: Toerfjell, 1024m, and Rismaalstind, 1030m. Between the peaks is a long deep dry valley floored with large rocks. Large streams flowing from the southern flanks of Toerfjell, from the col between the peaks, and from the northern flanks of Rismaalstind sink in the floor of the upper part of the dry valley or at points along the valley sides. Just beyond where a Toerfjell overground stream reaches the dry valley, all the water reappears at a very large resurgence, the source of the Overengbakk. The marbles in the area are generally difficult to distinguish on the surface, probably due to cover by small birch trees at lower altitudes and due to the effects of glacial moraines. However, the grey and brown striped marbles seen on Elgfjell (6km east) can be recognised. The hydrology is complex and still somewhat uncertain, especially above 500m. Access is by walking from near Granlia along a generally marshy footpath along Tverraadal to the Overengbakk, and then by climbing over the steep ridge of Daaaranjuenie to avoid a waterfall. This takes 3 hours.

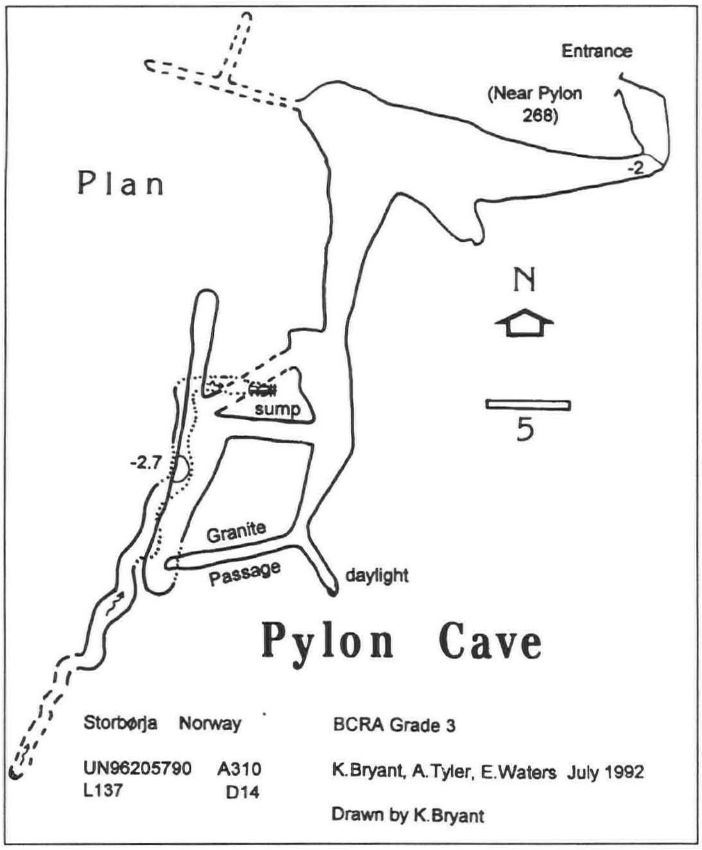


Figure 14. Survey of Pylon Cave, South Nordland.

TOERFJELLHOLA (T6) VN08505002 **A** 485 **L** 1881 **D** 101

Looking from the Daaaranjuenie ridge across a wide flat area, a large stream can be seen to descend the SW side of Toerfjell. The water flows into the deep entrance shakehole of Toerfjellhola, finding its way into underground passages at three separate levels. The route followed by the cave can be observed on the surface at two deep shafts, at the JoKe Exit shakehole, and by following an upper dry valley to the south along a line of small shakeholes. From the foot of the entrance shakehole a large, steeply descending rocky tunnel carries the stream, which forms white water rapids in flood conditions. The flow is supplemented by a powerful 5m waterfall in an 8m daylit shaft. The top of this waterfall can also be reached by crawling along The Wet Way, which starts near the top of the entrance shakehole. At the foot of the waterfall is a passage on the left ending at a boulder choke with daylight visible from the main entrance. Beyond a dry 12m daylit aven on the right the roof lowers, an oxbow leads via an ascending side passage to an easy dig, and the cave appears to terminate where the stream runs under boulders in a breakdown chamber. Ahead, a 3m aven can be climbed to enter the First Roof Series, whence crawls and squeezes lead to the excavated JoKe Exit (T5) at the base of a large shakehole. A small hole in the floor to the right in the breakdown chamber drops 2m to rejoin the water in a small stream passage. A passage on the right has not been pushed, but the stream can be followed to a small chamber. To the right a winding passage leads to a junction with a long rift passage carrying a tributary stream. Upstream the rift is blocked by rocks at all three explorable levels. At the small chamber it is necessary to enter a small hole in the left wall and then drop feet first into the continuing streamway. The water from the tributary stream must enter near here. A fine stream-washed passage in vertically banded marble leads via a short fall to a thundering 3m-deep sloping waterfall, best bypassed above; roof passages at two levels reach two chimneys with free-climbable descents back to the stream. More fine passage leads to a narrowing streamway, where the noise of the water can become almost overpowering before the stream runs under the floor. A dry continuation leads to two dry 6m pitches, both of which regain the main stream passage. Downstream, the way on soon appears impossible at a frightening waterfall. However, by traversing above, it is just possible to reach across the top of the waterfall to enter a low crawl, The Bold Grovel. This exercise is even more difficult to reverse. At the previous first chimney, the upper roof passage crosses into the Second Roof Series which starts as a low crawl to a tall chamber. A vadose overspill meander (oxbowed by the JoMi Crawl) ends at two crawls, one above the other, both leading to the upper reaches of a deep shaft. The shaft does not need to be tackled, as another crawl looping around to the descending Narrow Rift enables the foot of the shaft to be reached. From here the reverberating Bold Grovel waterfall can be observed from above. The way on leads to the sloping 8m Bold Grovel Bypass Pitch that drops into the end of the Bold Grovel crawl itself, at the start of the Third Roof Series. Various interconnecting passages and avens in this area may not be fully explored.

From the foot of the Bypass Pitch, an easy crawl reaches two holes in the floor. A 2m climb down either hole reaches a steeply sloping exposed ledge. At the far side is another climb down to a second ledge. By climbing all the way down to the water, a route upstream emerges at the base of the Bold Grovel waterfall; downstream the route becomes too

Plate 3. The 'limestone' bench at Toerfjell, showing the camp, the upper dry valley and the Overengbakk flowing towards Tosenfjord (Photo: T. Faulkner)

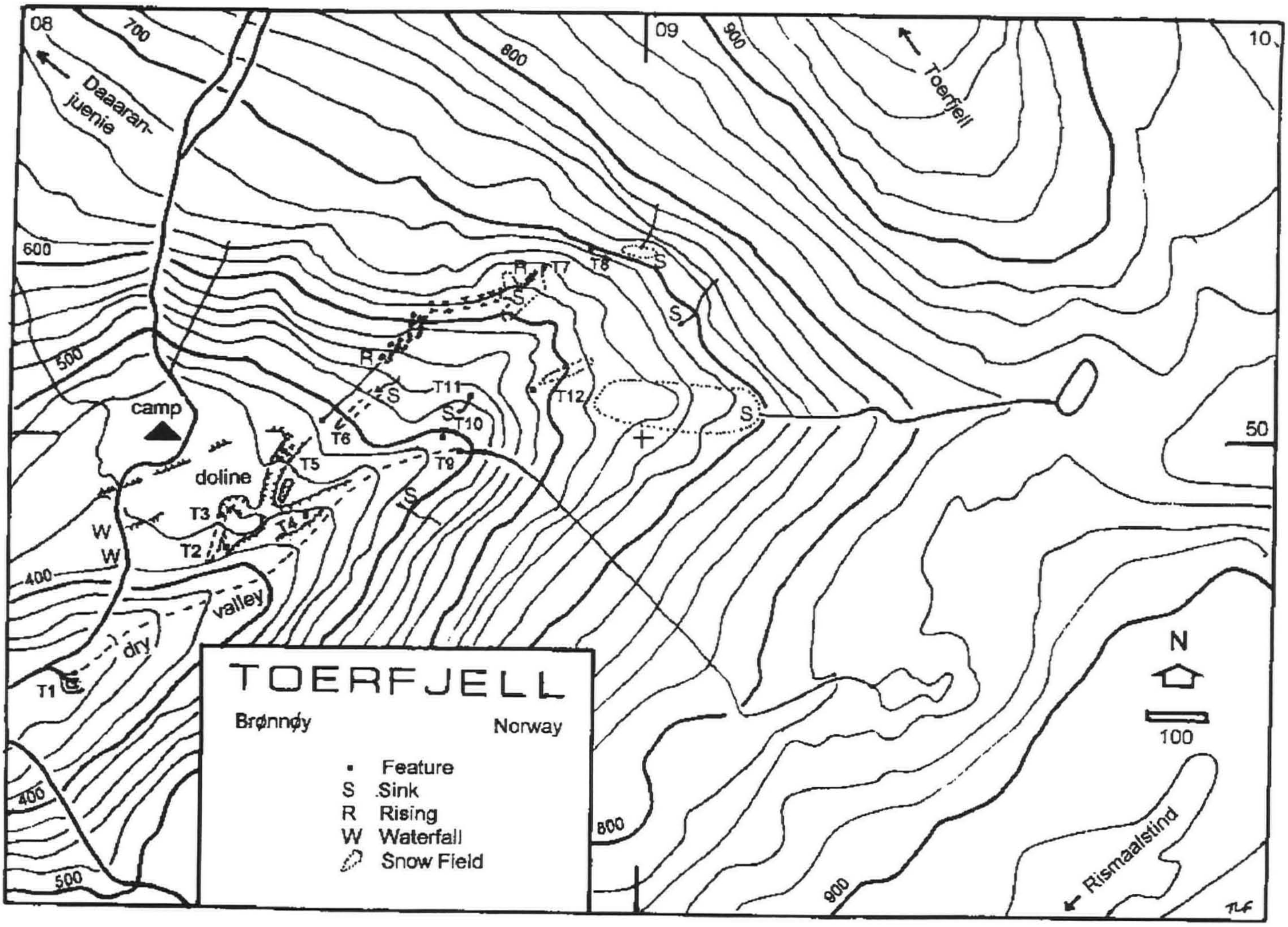


Figure 15. The Toerfjell area, showing cave locations.

small. The bottom crawl from the second ledge is the normal route through to Step Over Rift, a major junction in Toerfjellhola. A 5m free climb reaches its base, with a dry unentered crawl leading back.

By avoiding the two floor holes after the Bypass Pitch and carefully climbing down a complex series of shafts, a higher corner at the end of Step Over Rift can also be gained. From here a back and foot climb down also reaches the base. This route is probably less tiring when returning to the entrance. At least 3 interconnecting passages link the two routes in the complex area between the exposed ledge and Step Over Rift. A small drop from the Rift gains the water. Upstream becomes a too tight rift and downstream also flows into a tight rift, but a crawl to the right rejoins the flow.

Downstream the walking sized route begins to increase in size. On the left an area of boulders is passed, containing the start of an oxbow that leads to The Hall. Some stream flow is lost into an unentered low passage on the right. The stream now flows amongst boulders and enters The Hall, a large flat roofed chamber with a major boulder collapse on its left side. The water flows into a wide deep sump pool. On the right just before the downstream sump is a resurgence sump fed by water from the previous low side passage. To the left of the main sump is a silt-choked inclined crawl. The Ultimate Roof Series, with passages at 3 main levels, is entered by stepping across into a continuing roof passage at Step Over Rift. After passing pits in the floor, a small dirty hole leads down to the start of the large Trunk Passage. Behind a cairn, a tiny hole on the right emits the sound of a stream and leads down a boulder slope to a very wet and low stream passage emerging in the floor of the main streamway before The Hall.

Along Trunk Passage, 4 low passages to the left lead into Lower Union Passage, which is generally low, rocky and wide. Another left turn reaches the base of the National Car Park Aven which has horizontal joint aligned passages at many levels making complex interconnections to both north and south. The way on is to ascend The Ramp. This rises from Trunk Passage up on the left hand side.

At the top of The Ramp a small hole leads up into the large Union Passage, which has large blocks in a chamber 10m wide and 5m high to the east. The way lowers to the west as the floor displays some mud formations. Again the way on is upwards, via a block to reach a passage hanging directly above the hole from The Ramp. This passage leads to a dig; the route out is to free climb a sloping chimney from near the balcony above Union Passage. The top of the climb emerges under the wall of East-West Passage; to the left two passages lead to chokes. Right ends dramatically at Union View, a ledge overlooking the large east end of Union Passage. Before this, a passage to the left passes below a 10m pitch to reach chambers and an aven near a surface shakehole. The final exit is made by climbing the 10m pitch and following flatout crawls to the Lower Entrance (T4). This is situated in a series of shakeholes running parallel to the main boulder valley. (Note that the hole at the Lower Entrance should never be entered head first as it leads directly to a steep blind pit.)

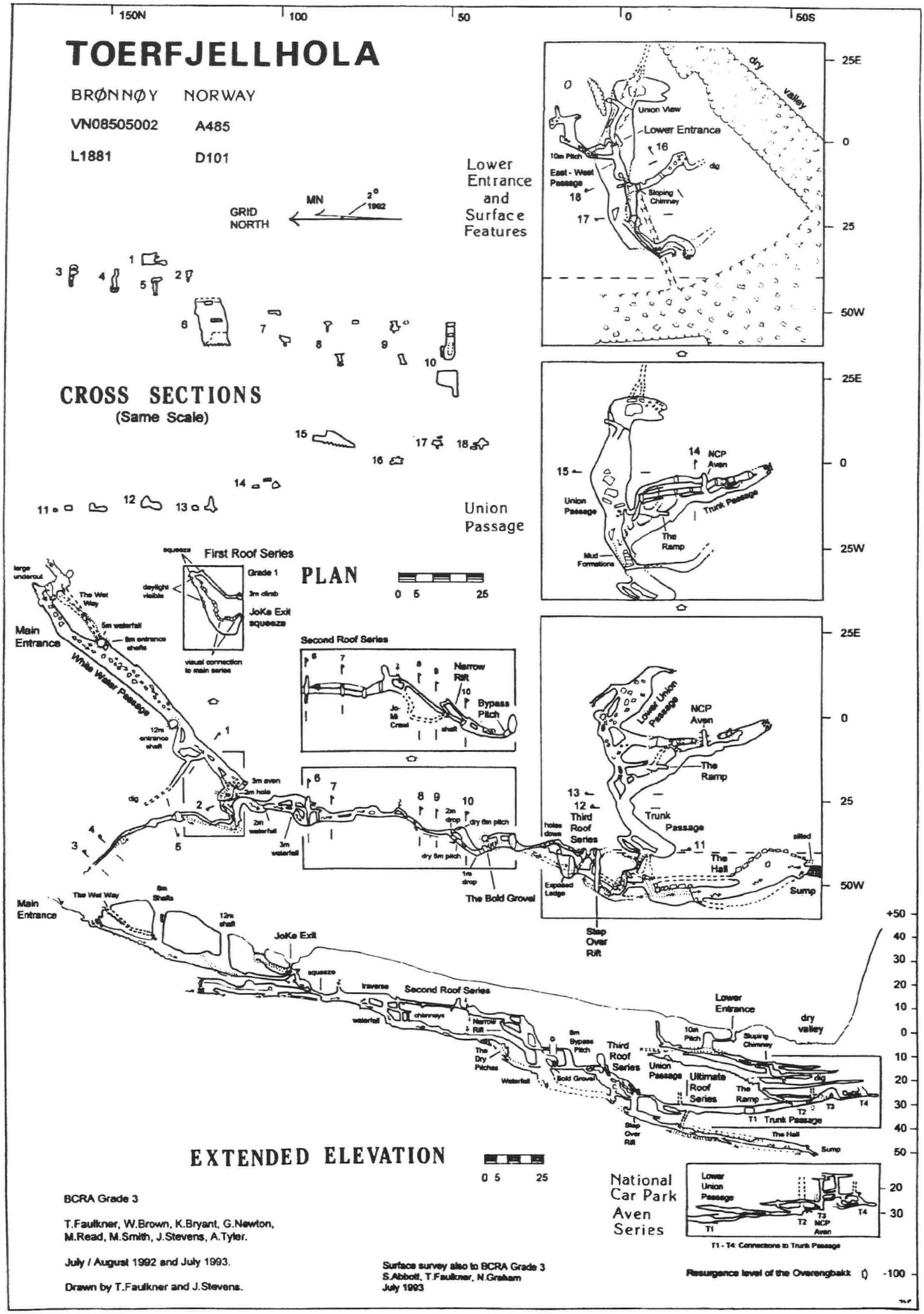


Figure 16. Survey of Toerfjellhola, South Nordland.

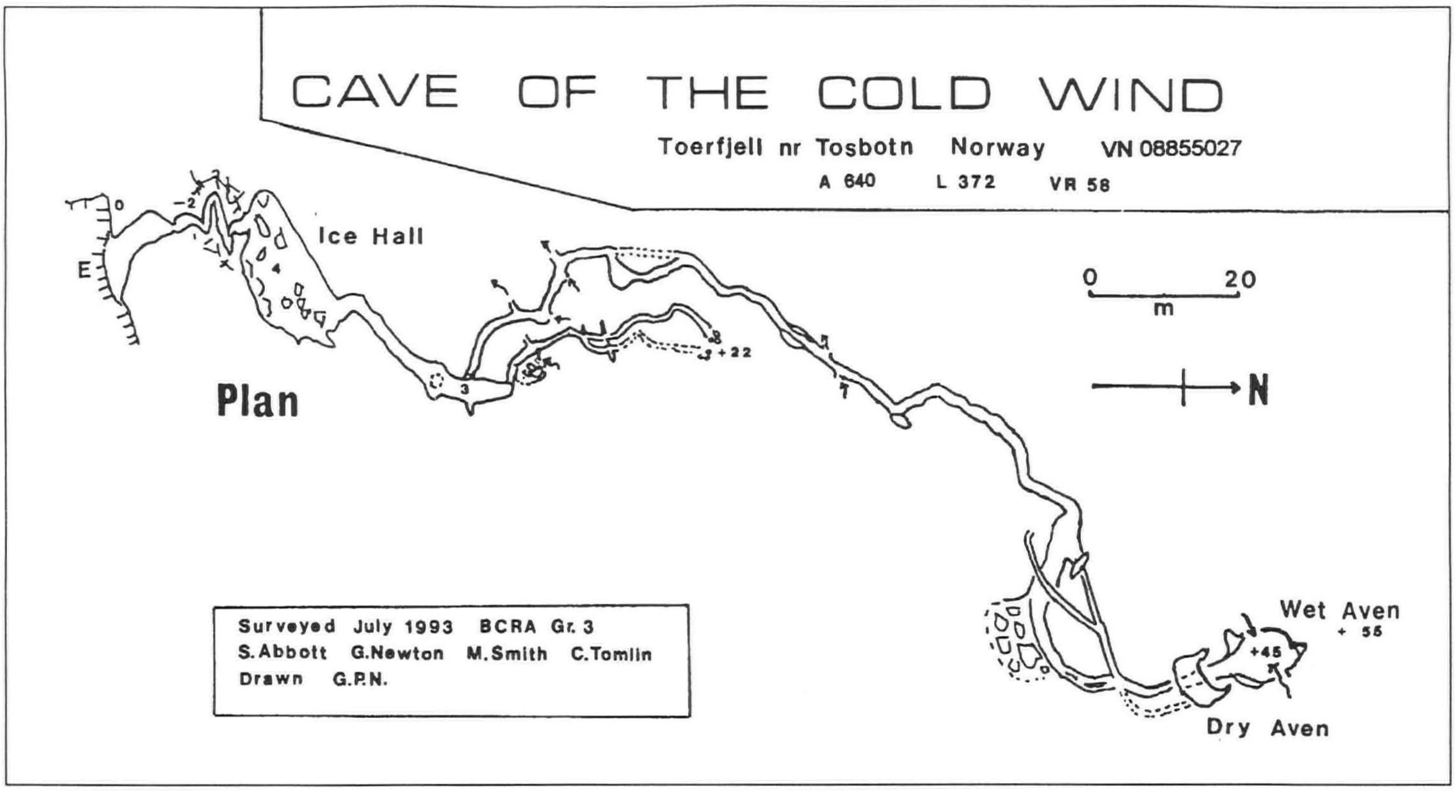


Figure 17. Survey of Cave of the Cold Wind, South Nordland.

Through trips between Toerfjellhola and its lower entrance provide interesting and varied caving in a system that, according to St.Pierre and St.Pierre (1985), is the twelfth longest in Norway. (This ranking is believed not to have changed in the intervening years.)

Perhaps fortunately, due to the cave's sporting attraction, there are only a few (straw) stalactites in the system. It is the large Union and Trunk Passages, and the many visual situations in the streamway and above that provide a strong aesthetic appeal. Note that to attempt the through trip, ladders need to be placed at the Lower Entrance 10m pitch and at one of the dry pitches before the Bold Grovel, or at the Bold Grovel Bypass Pitch. There are still many leads to investigate, although all the final south trending passages seem to become choked with boulders or sediments as they continue, at depths of 10-20m, under the surface boulder valleys on their way to previous resurgence outlets. At some 50m below the surface, the mainstream sump may be low enough to continue in a completely formed passage, perhaps joined by waters from the Ice Tunnel Sink. It may even lead to a streamway with an air surface before losing the 50m of elevation to the source of the Overengbakk. Exploration by diving seems to be the only feasible approach to resolve these questions.

CAVE OF THE COLD WIND (T7) VN08855027 **A** 640 **L** 372 **VR** 58

The entrance is at the foot of a crag high on the north side of the valley, reached by climbing steep slopes. These are often snow covered and then demand great care. The large entrance passage quickly funnels into an icy crawl that zigzags sharply and ascends into Ice Hall. This large chamber can have ice formations at the far end. Beyond these a climb down over boulders gains a major passage that descends until an aven is passed, then rises gently to a careful climb up through boulders. The climb leads to a pleasant abandoned vadose inlet passage that eventually splits in two, each branch becoming relatively small and tight. They end in a damp black choke. The main way on is found back in the large passage and goes from a crawl in the floor at the lowest point. This soon rises and becomes more spacious. Two streams are passed, entering from one wall and sinking beneath the wall opposite. The passage becomes more complex in the vicinity of a large breakdown area, with a hidden oxbow and two short side passages. Shortly after, a dry aven is passed and the end of the explored cave is reached at a fine, wet, black aven over 10m high. The picture is completed by two streams arcing down from above. Surprisingly, the survey shows the cave to head NNE, not under T8 nor towards the sink to its east.

DAAARANJUENIEHOLA (T12) VN08805006 **A** 580 **L** 100 **D** 15

The lower northern slope of Rismaalstind has many shakeholes with incompletely explored sinks and caves up to 10m long. (These are not listed due to the uncertainty of their positions; in 1993 many were obscured by snow). This mis-named cave is found at a dry gorge south of the main upper dry gorge at Toerfjell. It lies in a bouldery depression against a 10m-high brown cliff with two calcite veins producing a prominent inverted 'V'. This depression was first dug due to large amounts of "steam" billowing from the entrance.

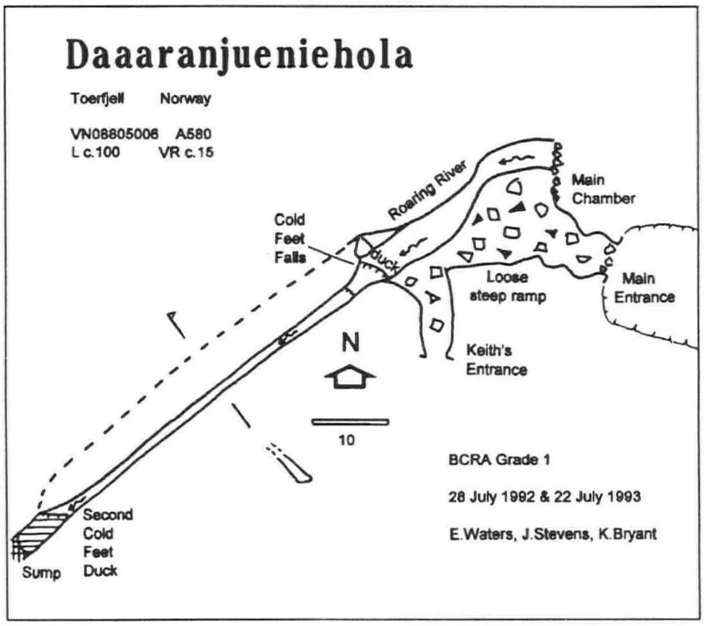


Figure 18. Survey of Daaaranjueniehola, South Nordland.

At the back of the depression a powerful roaring noise can be heard from the entrance, a slot between boulders. Below a short drop a very loose boulder slope descends 12m to the Main Chamber, which is about 20m long with a boulder floor sloping steeply into the stream. Upstream (right) the stream appears from a choke, and downstream a small cascade with low airspace forms Cold Feet Falls. Just before this, a hole on the left can be ascended carefully, through boulders, to Keith's Entrance. This lies in a boulder pile and is very difficult to find from the surface.

60m of pleasant streamway leads on beyond Cold Feet Falls, the passage seeming to be in a washed-out 1m-wide limestone band inclined at about 30° to the horizontal. The passage walls are of very dark mica schist. Exploration has ceased at another low section, very much like Cold Feet Falls, but with even less airspace, that leads to a sump after only 2m.

DURMAALSTIND

A huge dry gorge lies a kilometre NW of the Durmaalstind peak (978m). Access is difficult, with possible starting points being Kromdal, Tosdal or the eastern end of the Tosen Tunnel. The site was visited once, by climbing over the steep shoulder of Durmaalstind from Tosdalen via Stordalen. The steeply descending ravine is about 50m deep with a rocky floor and a small pool at one point. Lower down, the dry gorge has been buried beneath a scree slope of huge blocks where the valley side has been shattered by glaciation. There is little marble to be seen but lines of parallel rifts probably indicate the strike of thin impure bands. It is interesting to note that the line of the Tosen Tunnel has deliberately been curved to the south to avoid this feature.

STORVATN

This area lies west of road 76, between Sausvatn and Tosen. A farm at Saus lies at the southern end of Sausvatn. To the SW is a large outcrop of white marble in an area of low lying hills and marshy lakes. The northern edge of the marble lies along the lower slopes of Sausfjell, whilst the western edge appears to run through a valley containing Mølnvatn between Hardangsfjell and Fortiheia. Below Sausfjell, the marble contact was walked along from a point 1km west of Saus towards an area called Strauman, 3km farther west. The depth potential in this area is limited. All the stream sinks were choked with gravel, with one exception about 100m east of the junction of the Saus to Svanvollen road with a forestry track.

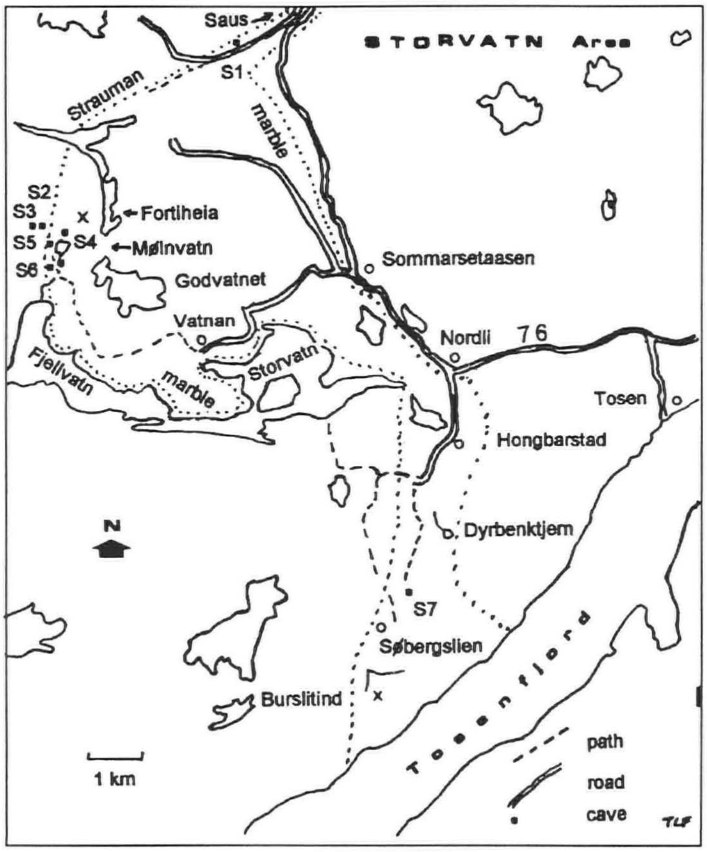


Figure 19. The Storvatn area, showing cave locations and limits of marble outcrop.

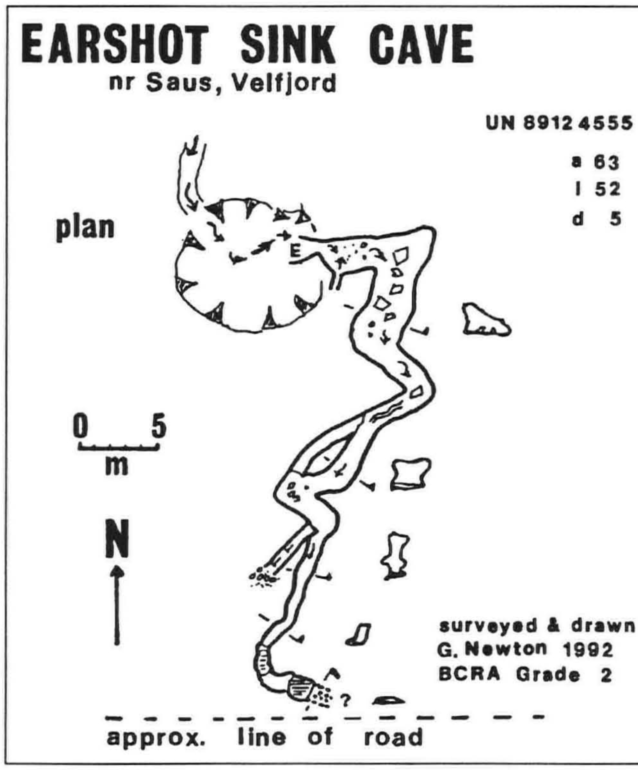


Figure 20. Survey of Earshot Sink Cave, South Nordland

EARSHOT SINK CAVE (S1) UN89124555 A 63 L 52 D 5

A small stream sinks in a shakehole 30m from the road and the initially pleasant stream cave in white marble becomes tight and wet as the water table is approached. The opposite side of the road to the cave is an area where small streams flow underground in shallow impenetrable caves. All the stream sinks farther west were either too tight or choked with mud or gravel. The marble contact was locally obscured by the new forestry road, built from crushed marble from a nearby quarry and possibly blocking formerly open entrances. However, the road improves access to areas of marble farther west. South of Strauman is Mølnvatn, reached by driving along a gravel road from Sommarsetaasen to its end at Vatnan, and then walking along a good forestry track south of Godvatnet for about an hour. The marble outcrop from the col north of Mølnvatn south to Fjellvatn has been covered by these Expeditions, but its northward continuation from the col awaits investigation.

SKYTTERGRAVGROTTA (S2) UN856425 A 185 L 56 D 21

This is on the west flank of the col at the head of the dry valley north of Mølnvatn on a limestone bench in an area of depressions. A stream follows a long unroofed trench to a choked sink. The entrance is in a 5m deep shakehole further along the trench, and opens onto a 3m climb down to the stream. Upstream is narrow and divides, becoming too tight. Downstream a white marble streamway leads to a waterfall cut in a vertical schist band, where the water sinks. Ahead is a dry horizontal passage to a 6m pitch into a bell-shaped chamber, where the stream reappears and flows away along a small tube.

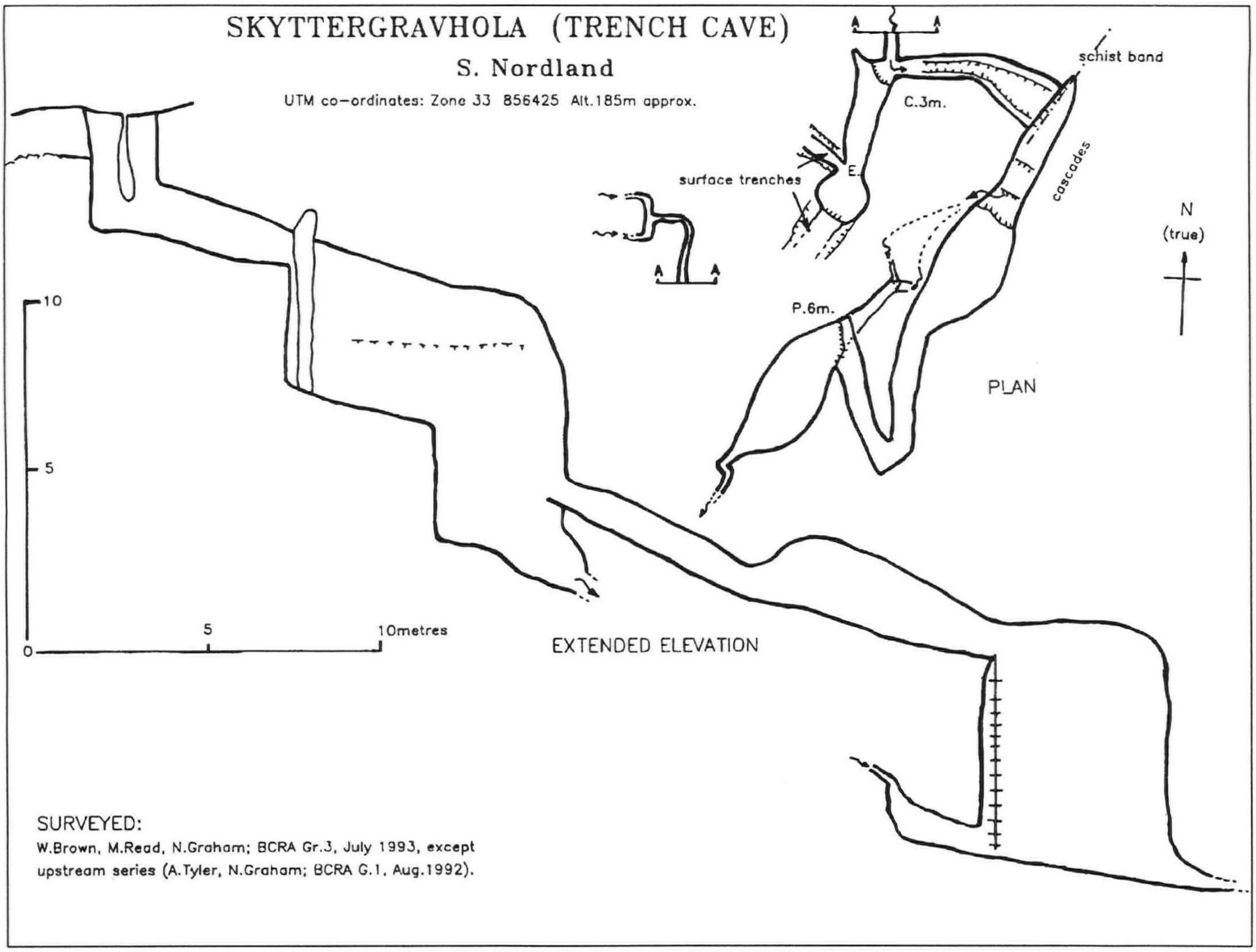


Figure 21. Survey of Skyttergravhola (Trench Cave), South Nordland.

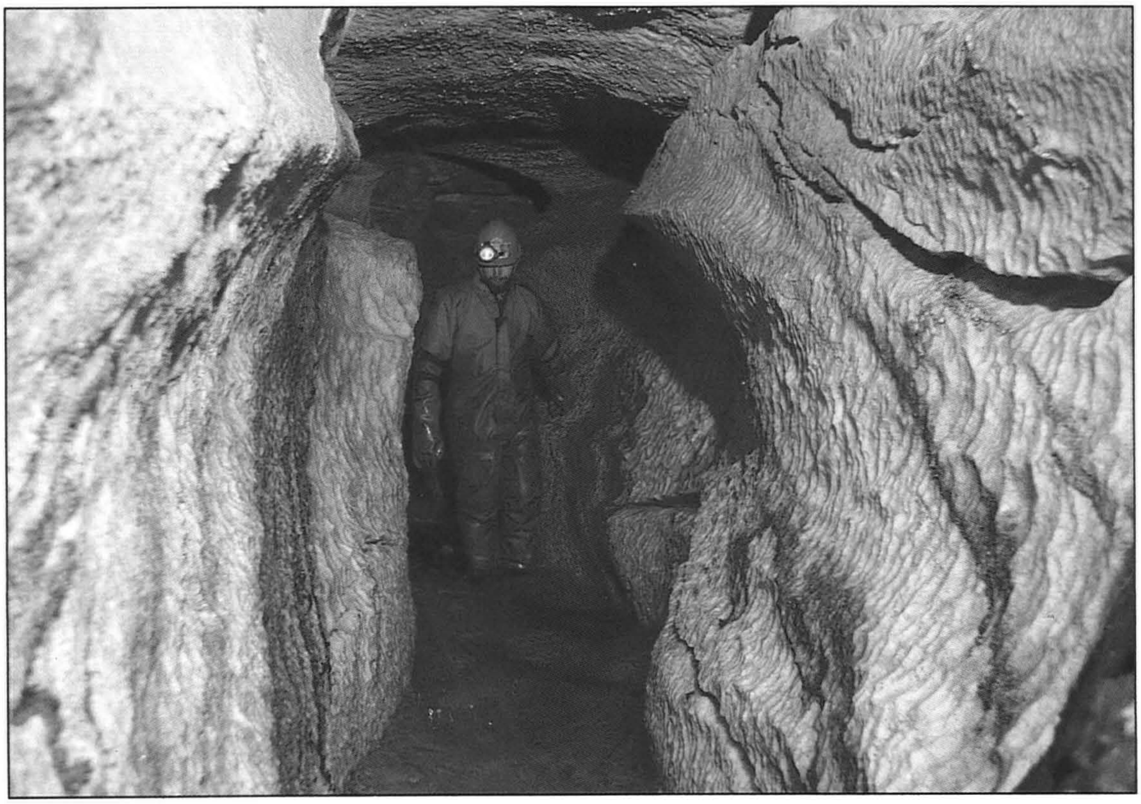


Plate 4. Stream in White Marble Passage, Mølnvatngrotta (Photo: T. Faulkner)

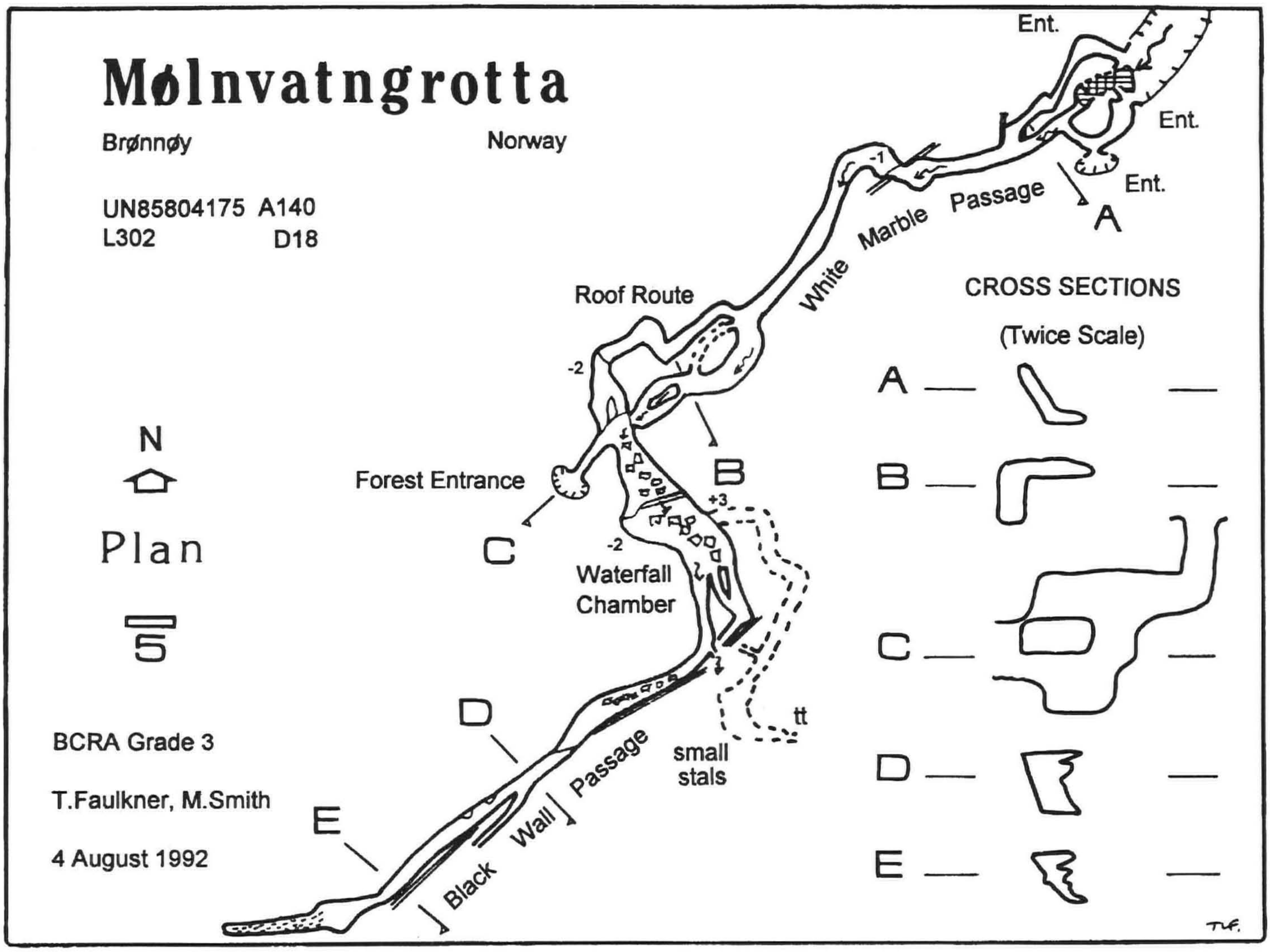
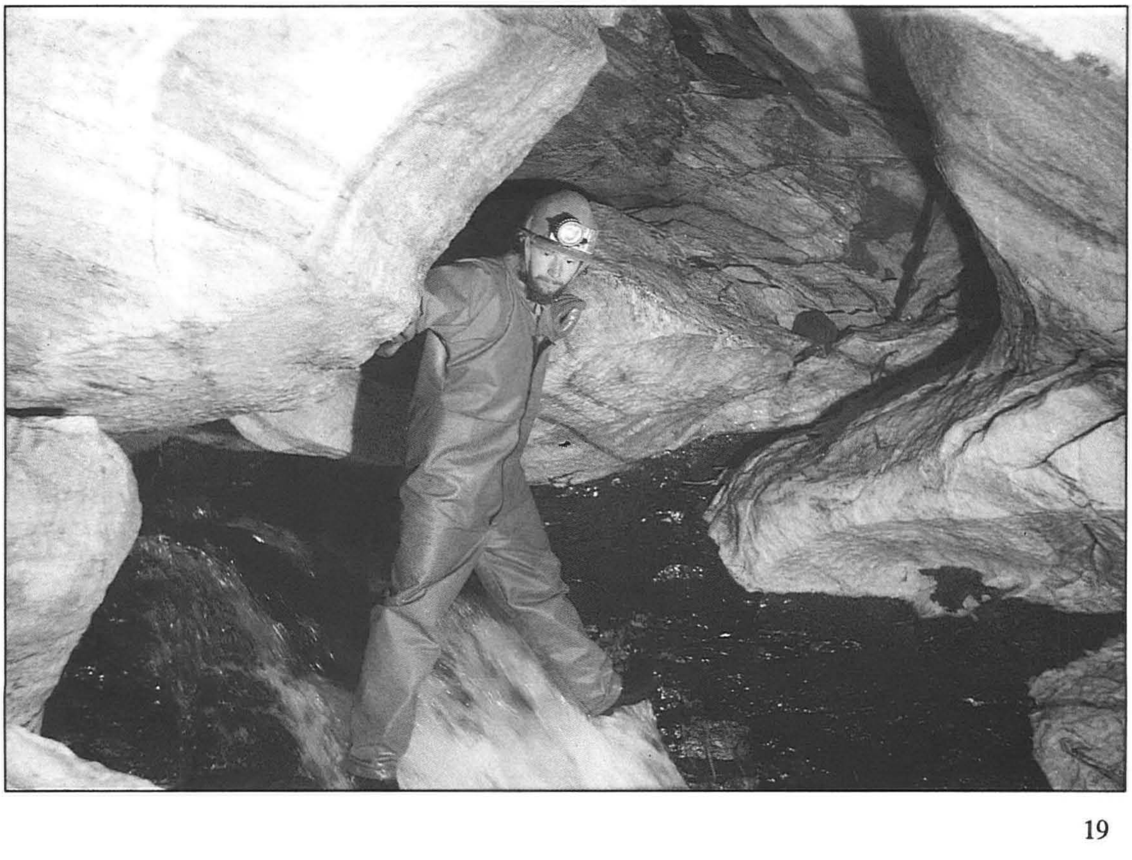


Figure 22. Survey of Mølnatngrotta, South Nordland.

Plate 5. Waterfall formed by a non-carbonate band in Mølnvatngrotta. (Photo: T. Faulkner)



MØLNVATNGROTTA (S6) UN85804175 **A** 140 **L** 302 **D** 18

The stream flowing south from Mølnvatn sinks into a sumped entrance below a cliff marked by collapsed trees about 100m from the lake. An entrance crawl near the top of the cliff leads via a smaller entrance to the roof of the inner streamway, just downstream of the short sump. A junction is soon reached where a dry passage ascends back to another entrance near the cliff. Downstream a fine passage in white marble leads SW, past waterfalls formed by impermeable SW-aligned barriers. Steepening meanders and boulder obstacles end at the large Waterfall Chamber, lit through a vaulted ceiling ascending to the Forest Entrance. The final section of this passage can be bypassed by taking a roof passage to a balcony overlooking Waterfall Chamber. Here the stream turns SE and falls noisily over a 2m-high waterfall at a thick impure rock band. At the SE extremity of the chamber, the water disappears finally into a narrow floor slot. The hading dry Blackwall Passage continues SW, with its left wall formed from impure black rock dipping at about 70° towards the NW. The cave terminates at a muddy choke that, like Forest Entrance, has obviously previously functioned as a resurgence. A tricky climb up the left wall beyond the waterfall in Waterfall Chamber leads to a dry roof series. Whilst the cave is a delight to explore and photograph, it is unlikely to be further extended. The stream resurges about 400m SE from a green boulder choke with immature cracks behind: clearly the unexplored stream route is a quite recent capture.

The marble continues southward from Storvatn, as a 1 to 2km-wide band, to the cliffs above Tosenfjord. A small stream flowing from Dyrbenktjern flows over the southern end of a steep cliff that overlooks the limestone bench on the NE side of the outcrop. The stream flows into the limestone at two places but development is immature as the water soon reappears. The track from Hongbarstad may be followed as a wide footpath to the abandoned farm of Søbergslia. 1km SW of here small streams flowing from Burslitind sink into marshy ground. Tiny limestone features occur near here, but there are no enterable caves. This area was visited by all members of the 1986 Expedition on 4 August. The only cave found was S7.

CONCLUSION

After a slow start, with only about 800m of passage found at Visten and Storborja after a week of walking in the rain, the luck of the 1992 Expedition fortunately changed, with the discoveries of Toerfjellhola, the Bulandsdal caves, and Mølnvatngrotta. With 15 days in the field available to us, that year we were only able to use 12 days effectively due to travelling between sites and the effects of the weather. On this basis finding almost 3 km of cave was a good outcome, although it would have been much less with a smaller team. The 1993 Expedition was also very successful, extending Toerfjellhola by another 1km, finding Cave of the Cold Wind, extending the knowledge of Bulandsdal and Klausmark, and, at the end, finding a whole new area for cave discovery, making an extra 2.8km altogether. This Report marks another fairly complete phase of exploration.

ACKNOWLEDGEMENTS

The Expeditions thank the Sports Council for grant aid, the Pederson family for hospitality at Visthus and Einar Aasvedd for transport across Velfjord and accommodation at Nevernes. This report has been compiled from contributions by many members of the 1992 and 1993 Expeditions and in particular: David St.Pierre (Bønnaa), Andy Tyler (Bulandsdal and Tettingsdal), Geoff Newton (Tettingsdal and Toerfjell), Keith Bryant (Pylon Cave), Nigel Graham (Thunder Pot and Mølnvatn area), John Stevens (Tettingsdal and Toerfjell), Martin Smith (Hornet Pot) and Eddy Waters (Daaaronjueniehola).

REFERENCES

This list includes papers about south Nordland published since Faulkner and Newton, 1990, which itself referenced previous work in the area.

Bryant, K, 1991. A Cold Walk in Odds' Country. *Chelsea Speleological Society Newsletter*, 33 (6), 76-77.

Faulkner, T, 1980. Sirijordgrotta and other caves in Eiteraadal, Vefsn, Norway. *Transactions of the British Cave Research Association*, 7(2), 53-69.

Faulkner, T, 1983. Kvannlihola 2 and other caves in Fiplingdal and other areas of Nordland, Norway. *Transactions of the British Cave Research Association*, 10(3), 117-144.

Faulkner, T, 1987. Caves of the Jordbruelv and Jordhulefjell, south Nordland, Norway. *Transactions of the British Cave Research Association*, 14(1), 31-45.

Faulkner, T and Newton, G, 1990. Caves of Bjørkaasen and Elgfjell, south Nordland, Norway. *Transactions of the British Cave Research Association*, 17(3), 107-122.

Gustavson, M, 1988. Mosjoen. *Berggrunnsgeologisk Kart 1:250000 Beskrivelse. Norges Geol. Unders.* 42pp.

Lowe, D J, 1993. The Forest of Dean Caves and Karst: Inception Horizons and Iron-ore deposits. *Transactions of the British Cave Research Association*, 20(2), 31-43.

Newton, G, 1991. South Nordland 90. *Caves and Caving*, 52, 33-35.

Newton, G, 1993. South Nordland 92. *Caves and Caving*, 60, 11-13.

Newton, G and Faulkner, T, 1992. The Caves of Svenningdal. *Chelsea Speleological Society Records*, 21. 37pp.

Rekstad, J, 1917. Vega beskrivelse til det geologiske generalkart. *Norges Geol. Unders.*, 80. 85pp.

Sjoberg, R, 1994. *Grottan*, 2-94, 31.

St.Pierre, D, 1993. Norwegian Caving News. *Caves and Caving*, 60, 33.

St.Pierre, D and St.Pierre, S, 1985. Norway's Longest and Deepest Caves. *Transactions of the British Cave Research Association*, 12 (4), 113-125.

Stephens, M B, Gustavson, M et al, 1985. The Caledonides of central-north Scandinavia - a tectonostratigraphic overview. 135-162 *in* Gee, D G and Sturt, B A, (Eds), *The Caledonide Orogen - Scandinavia and Related Areas*. John Wiley and Sons Ltd.

APPENDIX OF CAVE SITES *[S = Survey Grade]*

Ref	AREA and Cave	UTM	Alt	S	L	VR	
	VISTEN	UN					
VS1	Going Cave	95159300	565	-	10	6	Pushable. Resurges 150m to south
VS2	Karma Sutra Cave	95009300	560	1	10	5	Two entrances. Tight to sump. Resurges 100m south
VS3	Top Bed Cave	95009220	400	-	5	3	Unentered. 3m rift resurgence in top marble bed. May give through trip
VB1	Trondjordhula	96108235	5	1	38	-	Minor resurgence to low ascending looping passage
VB2	Risehula 1	96058250	50	3	30	5	Undulating fossil system above vegetated slope
VB3	Risehula 2	96058250	53	3	30	4	Short fossil passage near Risehula 1 upper entrance
VB4	resurgence	95808365	390	-	-	-	Impenetrable; stream flows to sink
VB5	sink	95808375	380	-	-	-	Unenterable
VB6	Multi Entrance System	97058585	370	-	50	5	Series of 5m-deep dolines connected by fossil passage
VL1	Langkilagrotta	88608650	40	-	18	4	Tight bell-shaped passage up to cross rifts and second entrance
VL2	Staulangrotta	87908475	140	1	10	1	Low phreatic resurgence to choked sump
VL3	Dry Waterfall Cave	87958440	210	1	60	5	Deep canal to dry passage to draughting choke
VL4	Dry Waterfall Resurgence	87958440	205	1	17	2	Wide entrance to canal and sump
VT1	cave	863 847	300	-	6	3	3m open pot to narrow inclined opening
VT2	cave	858 845	280	-	6	-	Resurgence cave on bank of Spruten
VN1	Vistnesoddgrotta	86209315	10	1	6	2	20m east of house. Walk-in entrance. Previously inhabited
	Area Total				296		
	KLAUSMARKDAL	UN					
	Swanlake Cave	84558020	350	1	30	10	Small stream to partly roofed canyon and sump
	Nilslitindgrotta	86158135	330	1	8	1	Small dry cave in forest
	Storhaugvatngrotta	86108110	310	1	19	10	Stream sink at 5m shaft to rift and low crawl
	Trap Cave	86208010	180	3	105	20	Three entrances to low streamway
	Green Gorge Cave	86257980	160	3	60	12	Near aerial ropeway. Ascending dry galleries above resurgence sump
	Cave Above	86257980	180	-	7	3	Shakehole sink
	Twin Stream Cave	86307955	180	2	106	12	Shakehole south of Green Gorge, with hole to small passages
	Marble Arch Sink	86457925	140	-	3	-	Stream sinks under 3m-wide arch overlooking Klausmarkelva
	JOBshullet	86507866	167	3	320	46	3 pit entrances to large phreatic route to 30m pitch
	Klausmarkgrotta	86577851	131	3	230	11	Large streamway between sumps
	Klausmark Resurgence Cave	86557842	123	3	93	17	Large passage on two levels to large rising pool
	Through Cave	86557842	120	1	10	2	Just downstream from the Resurgence Cave
	Area Total				991		
	BULANDSDAL	UN					
B0	Øvre Bulandsdalgrotta	90986675	380	1	58	8	Crawl to wet Black Chamber. Dry higher level tubes all choke
B1	Resurgence cave	90656705	345	-	12	1	1m tube. Stream from B0 enters at 2cm slot
B2	Bulandsdalgrotta	90606720	340	3	326	11	Cleanwashed streamway to Square Chamber and wet and dry passages
B3	Wayne's Exit	90566738	330	-	-	-	Squeeze exit to B2 near its resurgence
B4	Tributary resurgence	90506740	335	-	-	-	Small stream appears from bank above B3
B5	Sink	90526745	325	-	-	-	Sink under boulders, Valley now dry as far as B7
B6	Valleyside Cave	90456755	300	1	35	7	Large loose chamber to deep sump. Water flows out under entrance
B7	Bulandselvgrotta	90406765	260	3	176	29	Nasty resurgence cave between mica schist walls to unclimbed waterfall
B7a	Two Bridges Cave	90456770	300	3	395	36	Dry phreatic passage zig-zagging and spiralling downwards
B8	Shakehole Cave	90356775	270	2	100	20	At foot of large shakehole. Rift traverse to streamway and choke
B9	Next up Cave	90356780	280	-	53	-	Unstable entrance to linear streamway along non-carbonate wall
B10	Hornet Pot	90336785	270	3	160	-	Phreatic and rift passages to 15m pitch and sump
B11	Hornet Hole	90336785	270	1	25	-	Two entrances in cliff above B10 to tight streamway
B12	Bilberry Sink	90256790	230	-	-	-	A stream sinks at most northerly shakehole
B13	Wet Sink Entrance	90306770	220	-	-	-	Part of main stream falls into unentered spray-lashed pothole
B14	Rising	90256775	210	-	-	-	Rising for B13, some 40m distant
	Area Total				1340		

APPENDIX OF CAVE SITES, continued *[S = Survey Grade]*

Ref	AREA and Cave	UTM	Alt	S	L	VR	
	STORBØRJA	UN					
ST1	Keith's 1990 Cave	97356105	140	1	20	3	Through stream cave via 3m-high rifts and crawls
ST2	Black Space Cave	96706025	240	-	9	3	Phreatic descent to tiny tube
ST3	Rift Cave	96606025	240	-	10	5	Rift to two entrances at base of cliff
ST4	Balcony Cave	96806020	200	3	175	18	Phreatic network on five levels
ST5	Nettle Pot	96856025	160	3	85	34	Through cave in gorge below Tettingsfors
ST6	cave	967 592	230	-	10	-	SE of hill 359. Small entrance with loose roof to tight marble passage
ST7	sink	96505835	240	-	-	-	Small stream to impenetrable sink
ST8	rising	96755850	210	-	-	-	? same stream from tiny passage
ST9	Sandy Cave	96855865	205	1	3	1	1m-high open passages near risings in main valley
ST10	Pylon Cave	96205790	310	3	137	14	Horizontal N-S passages linked by sloping E-W crawls
ST11	Øst-Vat Grotta	96185780	311	-	35	15	45° slope down to lower crawls and dig
ST12	Top Sink	96155775	312	-	2	1	Just enterable top sink for the three caves
SK1	Klavvbekk Rising	952 593	420	-	3	3	Plumbed depth to large sump
SK2	Thunder Pot	952 590	440	1	25	10	Large shaft in rifts to deep sump below fissure
SK3	sinks	952 587	440	-	-	-	Largest sink is 50m south of SK2
	Area Total				296		
	TOERFJELL	VN					
T1	Overengbakk Source	08104960	334	-	-	-	Multi-point resurgence
T2	Edge Cave	08354980	425	-	5	5	Pit near cliff edge
T3	Doline Cave	08354987	440	-	5	3	Dry crawls with potential for digging
T4	Toerfjellhola (Lower entrance)	08474986	435	-	-	-	ENTER FEET FIRST!
T5	Toerfjellhola (JoKe Exit)	08434998	465	-	-	-	Tight entrance in large shakehole
T6	Toerfjellhola	08505002	485	3	1881	101	Intimidating streamway with complex roof series to lower entrance
T7	Cave of Cold Wind	08855027	640	3	372	58	Spacious passages lead upwards north to black aven
T8	Squeeze Cave	08935030	680	-	-	-	Unentered
T9	Ice Tunnel Sink	08704998	490	-	-	-	Large stream runs into ice tunnel to sink in boulders
T10	High Cave	08675000	500	-	2	-	Tube to small slot with sound of (?) stream
T11	Blocked Cave	08705006	530	-	5	3	T12 resurgence from passage choked with large blocks
T12	Daaaranjueniehola	08805006	580	1	100	15	Loose slope to big stream with two ducks to sump
	Other caves	-	-	-	28	-	Generally east of T12. Noted in 1992 but probably snow-covered in 1993
	Area Total				2398		
	STORVATN	UN					
S1	Earshot Sink Cave	89124555	63	2	52	5	Pleasant stream cave in white marble
S2	Skyttergravgrotta	856 425	185	3	56	21	Trench Cave. Climbs and white streamway to final 6m pitch
S3	Fløytehule	855 425	190	1	70	-	Flute Cave. Stream flows south to north. Two sumps with bypassing crawls
							Unstable shakehole to small stream passage towards sink
S4	Øvre Mølnvatngrotta	858 423	170	1	20	3	Streamway above a rising on west shore of Mølnvatn
S5	Mølnvatn Kilde Hule	857 421	150	-	25	-	Stream cave in white marble via large daylit chamber
S6	Mølnvatngrotta	85804175	140	3	302	18	Fossil stream sink, found in 1986
S7	Unscheduled Cave	91903560	320	1	8	2	
	Area Total				533		

SUMMARY	Visten	296
	Klausmark	991
	Bulandsdal	1340
	Storbørja	514
	Toerfjell	2398
	Storvatn	533
	Total	6072

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An analysis of Sediments in Caves in the Assynt area, N.W. Scotland

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Abstract: Analysis of a range of different types of sediment from caves in the Assynt area suggests that they are derived largely from local glacial deposits, washed into the caves by both basal meltwater beneath one or more ice sheets, or by meltwater streams on deglaciation. There has been considerable localised modification of these deposits by both cave breakdown processes and postglacial flooding events. Although outwardly similar in appearance, relict fine-grained deposits occupying abandoned phreatic passages show considerable variability in their physical attributes. The lack of dateable material within or below the various sedimentary units means that only minimum ages can at present be assigned to them. However, certain dates obtained so far clearly indicate that some of the clastic infills predate the last ice sheet to cover the Assynt area (c. 25 ka to 13 ka B.P.).

INTRODUCTION

An area of approximately 34km^2 of Cambrian dolomitic limestone crops out in the Assynt area in N.W. Scotland (Fig. 1). The thickness of the calcareous strata within this area of the Moine Thrust Belt has resulted in the development of a karst landscape that sits majestically, but somewhat uncomfortably, within a typical Scottish upland area.

As part of a wider survey (Lawson, 1983) a study was made of the sedimentary fill of the caves in the Traligill and Allt nan Uamh basins in the hope that a lithostratigraphy could be determined which would aid an understanding of the events of the Late Quaternary and the development of the present landscape in the Assynt area.

The majority of the caves in the area are small and associated with active streamways, but all the larger cave systems (Cnoc nan Uamh, Allt nan Uamh and Uamh an Claonaite) have sections of high level, formerly phreatic passages, many of which are choked with largely fine-grained sediment deposits. To these can be added the short caves of the Creag nan Uamh, which are truncated sections of once larger systems (Lawson 1981, 1988, 1993).

Three broad sedimentary units were initially distinguished in the caves, based on their visible attributes: fine-grained deposits, gravel layers and large-scale breakdown material.

METHODS

Several representative bulk samples of the various sedimentary units were taken from a number of the caves, together with samples of deposits from above-ground locations for means of comparison. Particle size analysis was undertaken for all the sediment samples, and samples from the various gravel layers and tills were analysed for lithological composition and roundness.

(a) Particle size analysis

As admixtures of sticky muds and coarser particles are common in the cave environment, standard dry-sieving techniques were seen as unsatisfactory, so the author chose to analyse the 59 Assynt samples by the wet-sieve replicate method of Folk (1974) and similar techniques advocated by Buller and McManus (1979). Details of the actual method used are given in Lawson (1983). Size parameters of mean particle size (M_z), sorting (σ_I), skewness (Sk_I) and kurtosis (K_G) were calculated from cumulative percentage frequency curves drawn from the particle size data for each sample, using the inclusive graphic statistical technique of Folk and Ward (1957) with McCammon's (1962) calculation for the mean (considered to be more representative of the total sample (Folk, 1966)). This enabled a direct comparison between the different samples.

(b) Lithological analysis

The -2 to -3 phi size fraction was analysed for lithological composition after being separated from the rest of the sample during the particle size analysis. From preliminary studies, four main lithological classes could be distinguished: (i) dolomite, (ii) quartzite and Torridonian sandstone (whose particles were not readily inter-distinguishable at that size), (iii) vosgesite and (iv) a miscellaneous group containing all the other lithologies.

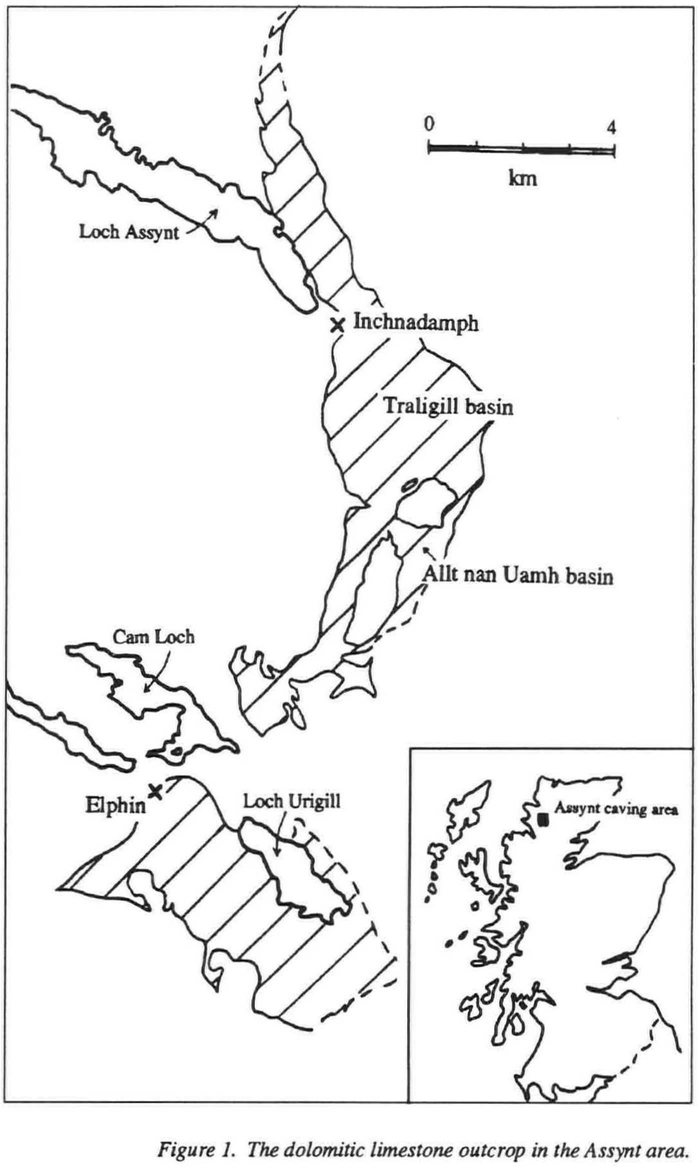

Figure 1. The dolomitic limestone outcrop in the Assynt area.

Where possible, a minimum of 300 particles was counted for each sample. A total of 16,034 stones from 32 samples was counted during the course of this research.

Twelve samples of the fine sediments were analysed by X-ray diffraction to determine their mineralogy. The same samples were also analysed by acetolysis in a 10% solution of dilute acetic acid; subsequent weight loss was taken to represent their carbonate content, and hence the proportion of the sample composed of $CaCO_3$.

(c) Roundness analysis

Roundness of a particle is dependent on mode and distance of transportation, its lithology and its size (e.g. Krumbein, 1941; Pettijohn, 1957). In view of these last two factors, dolomite and quartzite particles from the -2 and -3 phi size fraction of each of the cave gravel and till samples were analysed separately for roundness. For speed of analysis, use was made of the visual comparison charts of Powers (1953) which show six classes of increasing roundness at two levels of sphericity. A total of 6000 stones was analysed in this way. Following the rho-transformation method of Folk (1955), inclusive graphic statistical techniques enabled the calculation of mean roundness ($\bar{x}_\rho$) and standard deviation (σ_ρ) for each sample to allow results to be compared on a scale from zero, indicating very angular particles, through to 6.0, indicating well-rounded particles.

ANALYSIS OF THE FINE-GRAINED DEPOSITS

(a) Results

In the Assynt caves the sub-division of fine-grained sediments into modern flood deposits and relict fine deposits is based on both geomorphic evidence and colour of the sediments. Flood deposits are not found in the high-level phreatic passages of the larger cave systems, being restricted to those parts of a cave above the level of the active streamways where quiet-water conditions exist when backing-up of waters occurs on flooding. Commonly they are medium brown, or deep brown, in colour and laminated, possessing sedimentary structures indicative of a unidirectional water flow (e.g. ripples and small-scale cross-bedding). The relict fine deposits are paler in colour (Munsell colours of 10YR 5/4 and 10YR 6/3 being most commonly recorded) and occupy many of the large high-level passages that are not prone to modern flooding. In some cases, these large passages are filled to the roof with these deposits (e.g. Reindeer Cave on the Creag nan Uamh, the East Block in Uamh an Claonaite and Rabbit Warren in the Cnoc nan Uamh cave system) and in other locations there is evidence that passageways formerly contained much more of these deposits than they do at present (e.g. Oxford Street in Allt nan Uamh Stream Cave). Only the sediments studied in the section near to the Stream Chamber and those in Landslip Chamber, both in Uamh an Tartair (Traligill), were clearly laminated; all other sections examined lacked signs of bedding, but a progressively drying out of these quite friable silty-sands since their deposition may have removed any visual contrast between adjoining laminae, especially if differences in grain size and shape are minimal. It was hoped that further analysis of this latter group of rather enigmatic sediments would shed some light on their provenance and possible mode of deposition.

Particle size analysis of the relict fine-grained deposits shows that there is a degree of variation between samples from different localities despite similarities in outward appearance. Of 17 bulk samples, 11 were unimodal with median particle size ranging from 4.9ϕ to 7.9ϕ (i.e. silt-sized particles). Three samples taken from the inner Reindeer Cave were multimodal and three from Badger Cave were bimodal.

Fig. 2 shows bivariate scattergram plots of the different size parameters. Most of the samples plotted within the zone drawn two standard deviations from the mean value of the combined data of size parameter, indicating a fairly close degree of similarity; however, three samples did not (11.10.80/3 from Reindeer Cave was more poorly sorted than the rest, 6.8.79/1 also from Reindeer Cave was slightly negatively skewed, and 30.5.81/2 from the East Block of Uamh an Claonaite was very leptokurtic). Fig. 2 also incorporates bivariate plots for other sediment samples collected for comparison with the relict fine deposits. Many show similarities, especially the modern cave flood deposits and some of the fluvial cave sands. Fine deposits taken from above ground plot variously around and within the 2σ-zone.

The ternary diagram (Fig. 3) showing the relative proportions of sand, silt and clay in each sample once more indicates a degree of inter-sample variation despite their similar appearance. Two samples plot outside the 2σ-zone drawn around the mean proportions of sand, silt and clay for the combined data set: 4.7.79/2b (Badger Cave) had an above-average sand content, and 12.4.81/3 (Allt nan Uamh Stream Cave) had no sand-sized particles at all. Again, Fig. 3 shows plots for comparative fine-grained sediment samples from other caves and from above-ground locations.

Ten samples of the relict cave silts and seven samples of other types of fine-grained sediments from the area were analysed for carbonate content, the results being shown in Table 1. Four of the relict cave silt samples contained more than 10% carbonate by weight, and the sample from the East Block of Uamh an Claonaite contained over 30% (although this sample is from an area subjected to much roof drip, which has most probably artificially increased the carbonate content). In the other relict cave silt samples, carbonate content is relatively low, the bulk of each sample being composed of insoluble particles. Other samples shown in the table, analysed for comparison, had various carbonate contents. Two surface alluvium samples compared favourably with the majority of the relict cave silt samples, having low carbonate contents as might be expected from their locations close to the quartzite-dolomite boundary (Fig. 1). The other analysed cave deposits had carbonate contents that were generally higher than those of the relict cave silts, and grey silts taken from the base of the karren features on dolomite exposed along the Traligill Main Thrust Plane had a carbonate content of nearly 40%.

	SAMPLE	CARBONATE (%)
Relict cave silts		
	30.5.81/2 East Block, Uamh an Claonaite	32.57
	11.10.80/2 (Pale silts) Inner Reindeer Cave	18.62
	12.10.80/3 Landslip Chamber, Cnoc nan Uamh	14.31
	12.4.81/2 Oxford Street, Allt nan Uamh Stream Cave	10.91
	12.4.81/3 Oxford Street, Allt nan Uamh Stream Cave	5.63
	11.7.81/1 Viaduct series, Uamh an Claonaite	5.32
	4.7.79/4 Badger Cave	4.39
	12.7.81/1 Uamh an Tartair (Traligill)	3.96
	28.5.81/2 Uamh an Tartair (Traligill)	3.39
	11.10.80/3 (Reddish silts) Inner Reindeer Cave	0.03
Other fine deposits		
	29.3.80/1 Silts from exposed thrust plane, Traligill valley	39.63
	29.5.81/1 Flood deposits, Lower Traligill Cave	20.95
	18.5.80/2 Flood deposits, Uamh an Claonaite	15.43
	28.5.81/5b Red silts, Uamh an Tartair, (Traligill)	14.83
	31.5.80/1 Wash deposits, Bone Cave	13.78
	11.4.81/4 Alluvium, An Claonaite flood channels	3.55
	14.8.80/1 Alluvium, Allt a' Bhealaich	1.40

Table 1. Analysis of carbonate content.

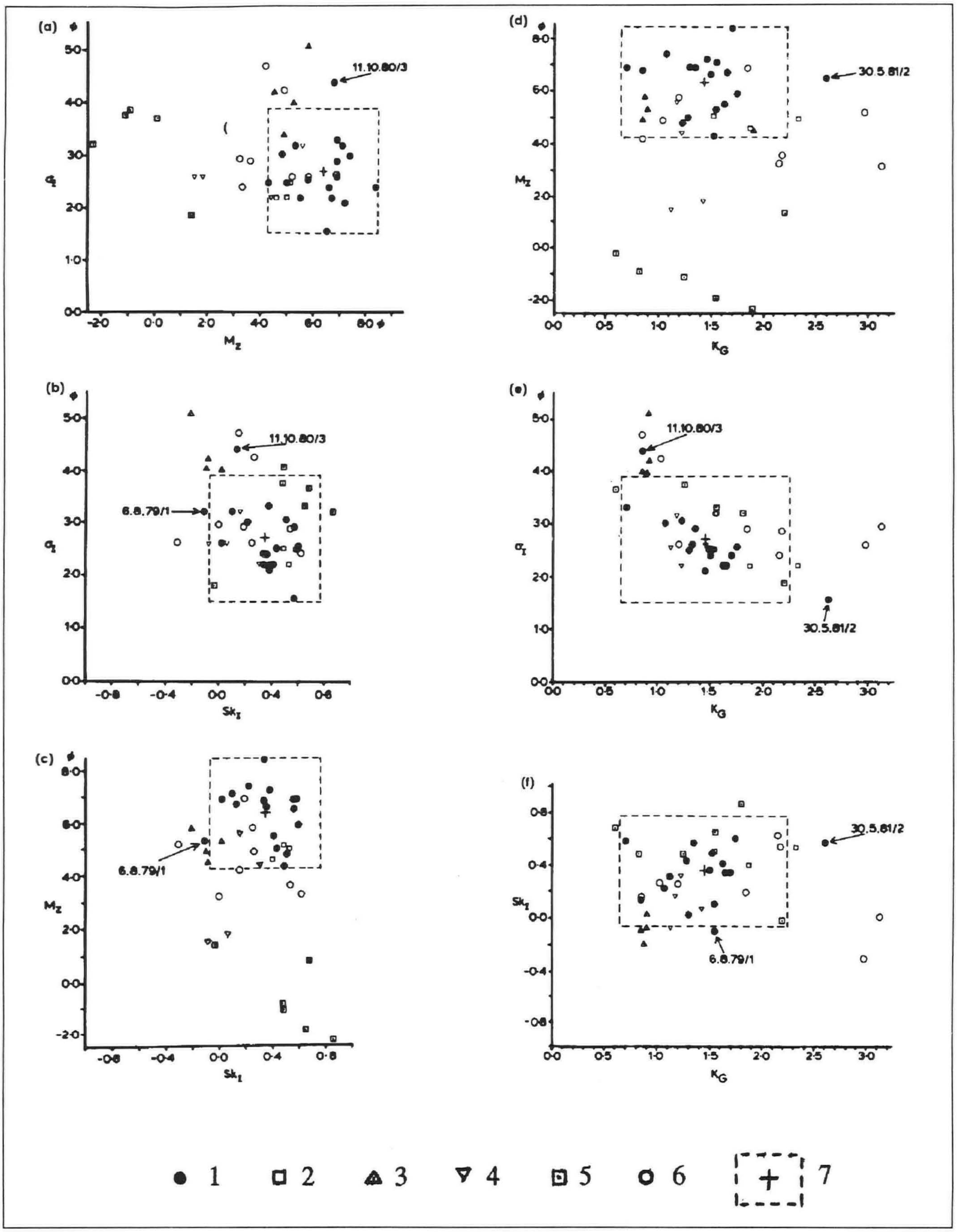

Figure 2. Bivariate scattergrams of various size parameters of sediment samples from the Assynt area.

1. *Relict cave silts.*
2. *Modern cave flood deposits.*
3. *Cave wash deposits.*
4. *Fine-grained deposits from present cave streams.*
5. *Coarse-grained deposits from present cave streams.*
6. *Fine-grained deposits from elsewhere in the study area (above ground).*
7. *Mean value for relict cave silt samples, surrounded by a 2s zone (i.e. 95% confidence limits).*

The results of the XRD analyses show that the mineralogical composition of the relict cave silts is predominantly quartz with varying amounts of dolomite. Clay minerals (illite and chlorite) and feldspars are also present in very small quantities (Caswell S.A., personal communication).

(b) Interpretation

The literature on fine-grained deposition in caves has been reviewed by Bull (1981). Early work on sediments of this type, which are often laminated, concluded that they were deposited in ponded water due to climatically-induced flooding of the cave system. Sweeting (1950) ascribed a derivation from glacial deposits and sedimentation in underground, glacially-derived lakes, noting the similarity to varve deposition. The idea that these laminae were varves was subsequently developed (e.g. Siffre 1960, Masriera 1970), but Bull (1976, 1977) has argued against the use of this term, which implies deposition related to annual climatic fluctuations. Bull's detailed analysis of the laminated 'Cap Muds' in Agen Allwedd, South Wales, led him to suggest (Bull 1976, 1977, 1981) that they were the result of multi-source pulsed inputs of sediment-bearing water through joints and fissures in the limestone into flooded cave passages. Persistence of similar laminae over large areas of the cave system was seen to suggest "climatic control rather than internally developed stochastic pulsations" (Bull 1981, p. 20).

The pale yellow relict fine-grained deposits in the Assynt caves have been shown to be silts and silty sands, occupying primarily the large, abandoned phreatic passages in the larger cave systems. They are largely allochthonous, with quartz as the dominant lithology, believed to be derived from the local quartzite-rich tills. The varying amounts of calcareous sediment probably represent the products of glacial abrasion of the dolomite bedrock. It is therefore suggested that these sediments represent the finer fractions of the surficial glacial deposits - the glacial 'rock flour' washed into the caves by way of the various fissures running through the dolomite. The relatively large proportion of clay-sized particles in samples of this material (Fig. 3) suggests that they were deposited in still-water conditions. The areal extent of these deposits, commonly the roof of passages, could only have been achieved in flooded cave systems. The presence of silt at levels higher than the present cave entrances (e.g. in the inner chamber of Reindeer Cave) requires those entrances to be blocked. In the absence of material evidence of these barriers, the only likely solution is that the cave entrances were blocked by glacier ice. It is therefore suggested that all the present evidence points to the deposition of these sediments under an ice sheet.

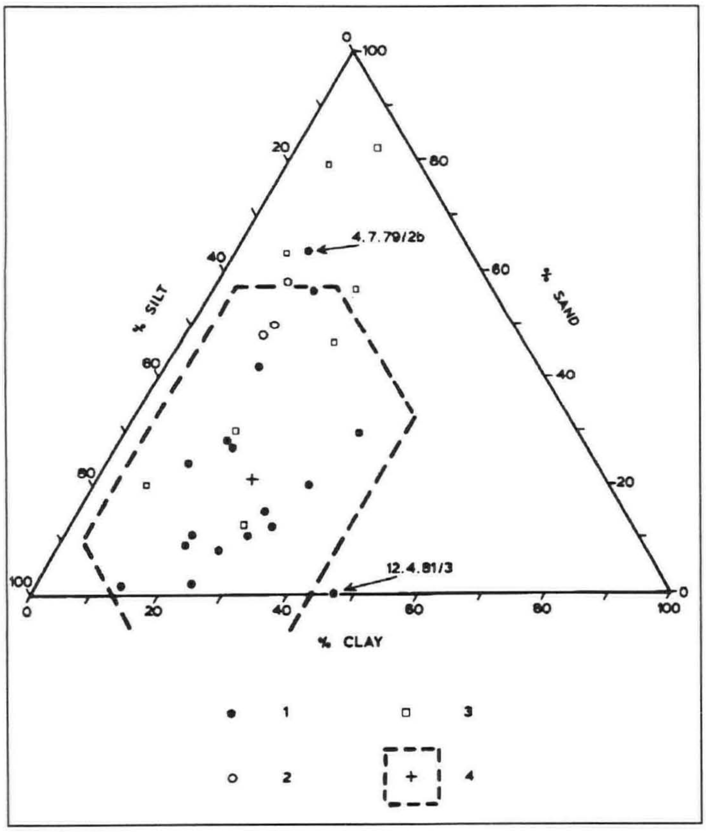

Figure 3. Ternary diagram showing the percentage of sand, silt and clay in some fine-grained deposits from the Assynt area.

1. *Relict cave silts.*
2. *Cave flood deposits.*
3. *Fine-grained deposits from above ground.*
4. *Mean value for relict cave silt samples, surrounded by a 2σ (i.e. 95% confidence limits).*

There is an apparent lack of lamination in the relict cave silts. Some were found in Uamh an Tartair (Traligill), but all the other dried-out sections showed no stratification. If an essentially continuous input of sediment-laden water into flooded caves occurred during this period, a degree of mixing could be expected that would tend to mask such laminations. There is in fact no need to invoke Bull's pulsed input mechanism, which would anyway have been initiated on the surface by periglacial freeze-thaw processes that would not be present under a cover of glacier ice. Under ice, the controlling mechanism for sediment input into the caves would have been the presence or absence of basal meltwater, in turn dependent on such glaciological variables as ice temperature and thickness.

The other suite of fine-grained sediments occupy positions in caves close to presently active streamways, in areas prone to flooding. They are therefore interpreted as flood deposits laid down in quiet-water conditions as water recedes after flooding events. Their darker coloration reflects the inclusion of soil and peat particles, washed in from the surrounding area, although a large proportion of their bulk (>95% by weight) is made up of particles derived from local tills, hence the various similarities with the relict cave silts.

ANALYSIS OF GRAVEL DEPOSITS

(a) Results

Figs. 4 and 5 show the results of the lithological analysis of the 4-8 mm fraction of seven samples from various caves and six samples from till sections in the Traligill and Allt nan Uamh basins.

The cave gravels appear to fall into two groups: one shows a clear preponderance of quartzite/Torridonian clasts with varying lesser amounts of other lithologies, and the other is dominated by dolomite clasts. One sample, from Uamh an Claonaite (Fig. 4c) is transitional between the two groups. Mean roundness values of 1.81 ± 0.50, 1.69 ± 0.84, 1.97 ± 0.88 and 1.32 ± 0.31 were obtained respectively for samples (c), (e), (f) and (g) in Fig. 4, indicating high clast angularity. Fig. 5 clearly shows that the till samples contained little or no dolomite clasts. The decalcified nature of the till was emphasised by the lack of any reaction when small sub-samples of the $<-1\ \phi$ fraction were immersed in 10% dilute hydrochloric acid. Both lines of evidence suggest that it is reasonable to assume that dolomite stones in the Assynt cave gravels were derived internally from autochthonous breakdown of the cave roof and walls.

An attempt was therefore made to quantify the relative proportions of autochthonous and allochthonous clasts in each cave gravel sample. Intrusions of vosgesite occur within the dolomite bedrock, so vosgesite clasts could either have been derived internally from breakdown or derived externally from glacial deposits. For the purpose of this study, half the vosgesite stones together with all the dolomite clasts were classed as autochthonous and the remainder of the clasts in the sample as allochthonous. The ratio of allochthonous to autochthonous clasts was then computed ('D' - values in Fig. 4). Samples with low 'D' - values reflect large proportions of internally-derived clasts. Fig. 6 shows the results of the roundness analysis of quartzite stones from the gravel samples analysed. There is little difference in the overall roundness values between the till and cave samples, with most clasts exhibiting markedly angular characteristics.

(b) Interpretation

There has been little written about stream gravels in caves. Siffre (1959) and Siffre and Siffre (1961) suggested that cave stream pebbles are highly rounded but more flattened than comparable pebbles from surface streams because of increased pressure flow. Similar results were presented by Sweeting (1972) but Bull (1976, 1978) questioned these conclusions as he found that gravel form, sphericity and roundness were controlled by rock type and suggested that the previous studies might reflect a thinly-bedded cave breakdown deposit subsequently rounded and redeposited. Newson (1971), who included the Traligill valley as one of his study areas, concluded that the dominant movement of stream boulders and cobbles occurred during flood events, and then more often down the surface flood channels than through the cave systems. Bull's (1976, 1978) results appear to support this view, with discrete sampling areas showing the effect of lithological dilution from localised breakdown, with gravel deposits having largely remained in place since deposition.

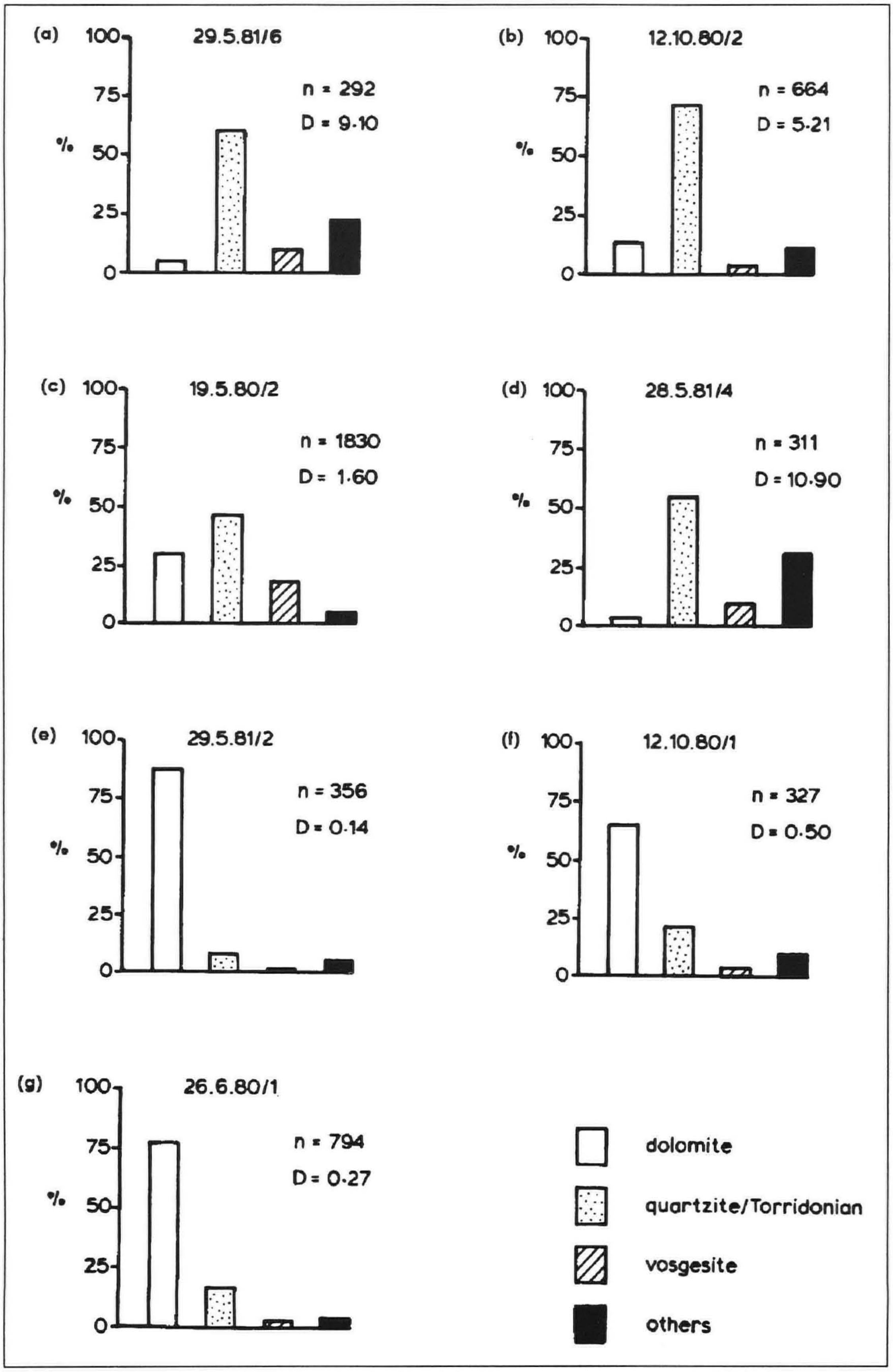

Figure 4. Results of the lithological analysis of the 4-8 mm size fraction of fluvial gravels from certain Assynt caves. (For an explanation of 'D' values, see text).

In the Assynt caves, the high allochthonous clast content in subterranean gravel samples suggests a derivation from glacial deposits. Certain of the samples have this allochthonous content masked by high local inputs of breakdown material, supporting Bull's findings, above. The presence of bedding and the rounded appearance of many of the stones testifies to their having been deposited in a fluvial environment. The lack of any appreciable general rounding of quartzite/Torridonian clasts probably reflects short transportation distances or the high durability of this lithology. It is likely that the gravels were washed into the caves by glacial meltwaters and by floodwaters in intervening interglacial periods. Once in place in the cave, further transportation of the gravel is likely to have been minimal.

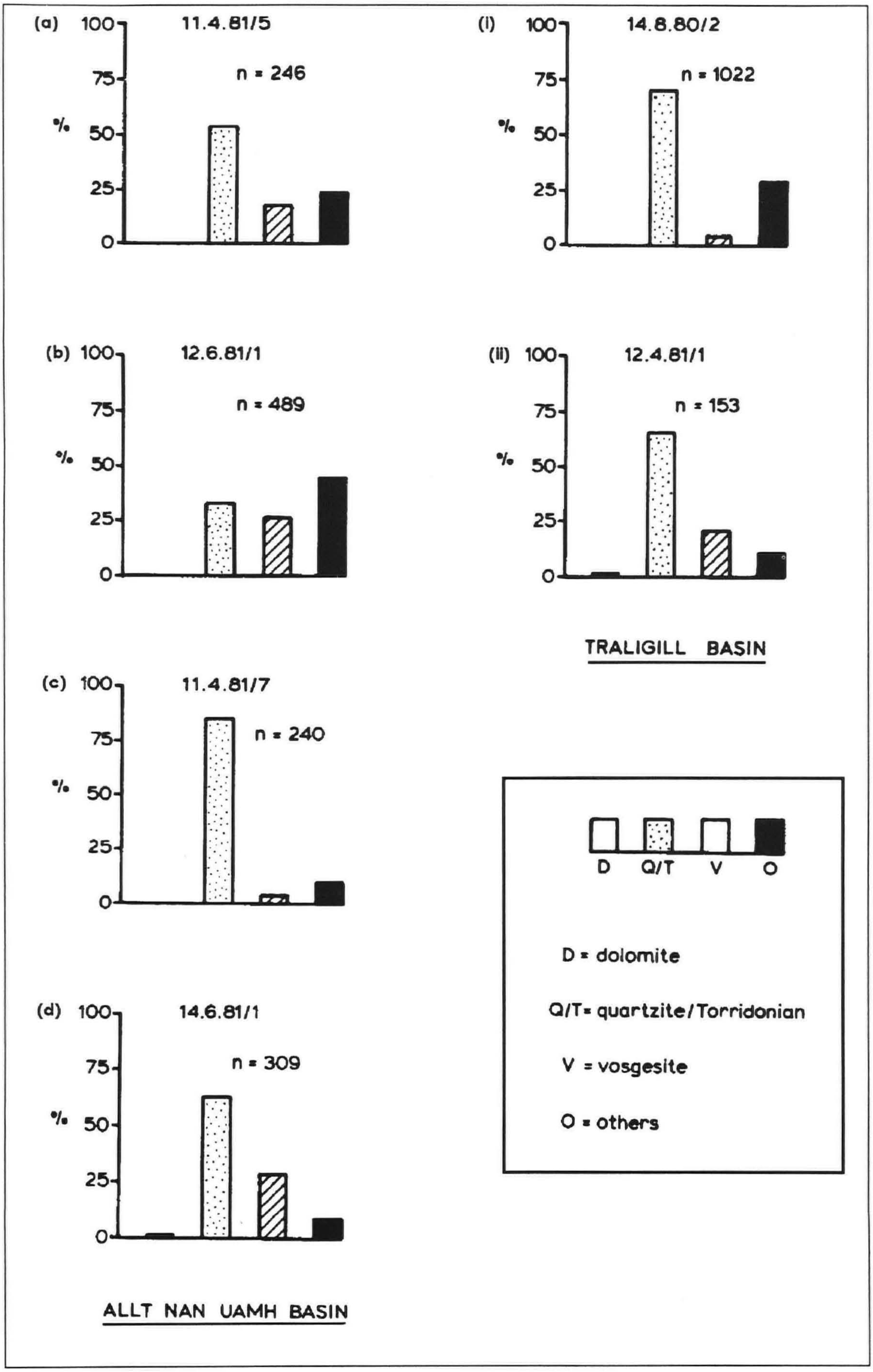

Figure 5. Results of the lithological analysis of the 4-8 mm size fraction of certain till samples from the Allt nan Uamh and Traligill drainage basins.

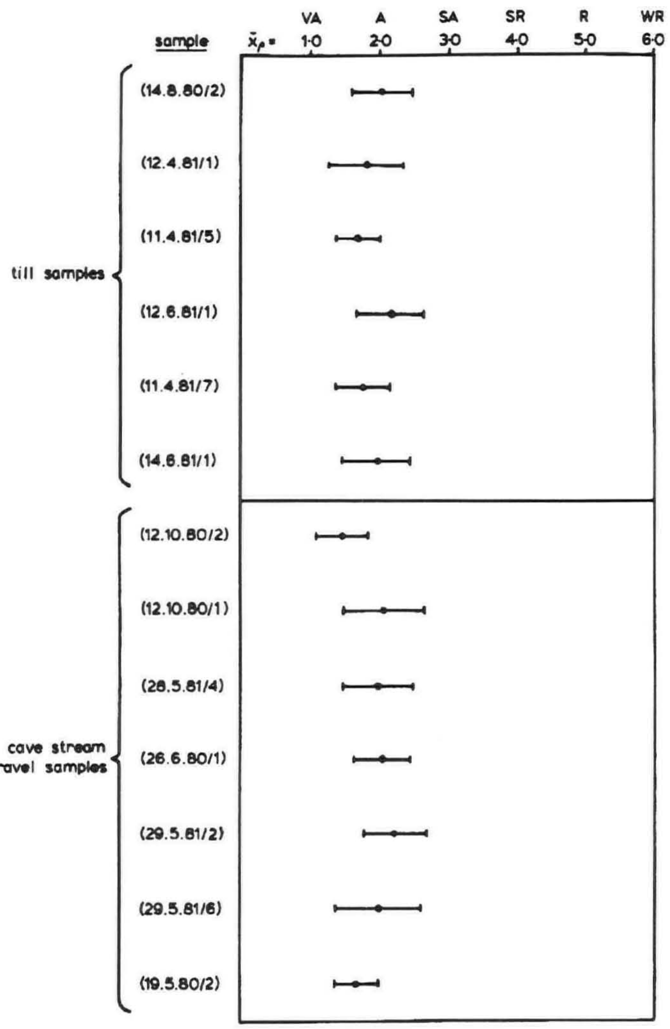

Figure 6. Roundness analysis of quartzite/Torridonian stones in certain Assynt cave gravels and the local till.
The error bars represent 1σ from the mean sample value.
VA= very angular; A= angular; SA= subangular; SR= subrounded; R=rounded; WR= well rounded.

CAVE BREAKDOWN DEPOSITS

Mention must be made here of the autochthonous deposits resulting from the collapse of cave roof and/or walls, and which have undergone little or no subsequent transportation. Davies (1949, 1951) has suggested a genetic classification of breakdown into blocks, slabs and plates, and discussed the possible mechanics of the breakdown process. In the literature, earthquakes, frost-shattering, solution along planes of weakness, undercutting of walls by cave streams, the formation of dilation cracks by unloading after glaciation, and the drainage of a phreatic cave leading to the removal of the internal support of the walls and roof offered by the water, have all been postulated as possible caused of breakdown (e.g. Warwick 1956, 1971; White and White 1969; Simons 1965; Miskovsky 1966; Tratman 1969; Sweeting 1972; Bull 1976).

Breakdown has been found in many locations throughout the Assynt caves and at a variety of stratigraphical levels - as the most recent deposits, situated on the surface of other cave sediments; above, below and within the fossil cave silts; and in various relationships with speleothem deposits. As the causes of breakdown are dependent on so many factors, it is unlikely that one will find specific layers of breakdown that correlate from cave to cave across an area, to be related to specific catastrophic events. Such breakdown events are usually discrete phenomena, occurring within different areas of different caves at different times. Furthermore, in the case of a single, thick deposit of large breakdown slabs or blocks there are few ways of ascertaining whether or not one or several breakdown events occurred.

DISCUSSION

Application of the above broad conclusions to arrive at some sort of lithostratigraphy for caves in the Assynt area proved to be very difficult. Only the high-level, abandoned phreatic passages in certain of the caves contain sedimentary sequences that have not been dramatically modified by more recent vadose drainage activity. A composite stratigraphy for Uamh an Tartair in the Traligill valley was proposed by Atkinson et al (1986, p. 70). ^{230}Th/^{234}U dates on speleothems from caves in this area both post-date and pre-date the last ice sheet. Four dates on samples overlying sedimentary sequences containing all of the three sedimentary

Plate 1. Bedded gravel from Allt nan Uamh stream cave.

units discussed here suggest that speleothem growth has been continuous since c.11 ka. Unfortunately, all the speleothem samples that have yielded dates older than this (i.e. 26 ka B.P. or earlier) cannot be directly related to the clastic sediment fill in the caves. Although it is likely that much of the sediment was deposited in the caves during or immediately after the area was covered by the last ice sheet, washed in by glacial meltwater streams, some of the sediment is likely to be much older. This has been emphasised by a series of radiocarbon dates obtained from reindeer antler fragments from various stratigraphic levels within Reindeer Cave on the Creag nan Uamh (Murray et al, 1993). The dates range from c. 24 ka back to c. 47 ka, indicating that the relict silty-sands and gravel sequences in the inner chamber of that cave must pre-date the last ice sheet. Until datable material is found directly beneath some of the sedimentary units in the caves in this area, the exact ages of those units can only be speculative.

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REFERENCES

Atkinson, T C, Lawson, T J, Smart, P L, Harmon, R S and Hess, J W, 1986. New data on speleothem deposition and palaeoclimate in Britain over the last forty thousand years. *J. Quaternary Sci.*, Vol. 1, 67-72.

Bull, P A, 1976. Cave sediment studies in Agen Allwedd. Unpublished PhD thesis, University of Wales, Swansea.

Bull, P A, 1977. Laminations or varves? Processes and mechanisms of fine-grained sediment deposition in caves. *Proc. 7th Int. Speleol. Congr.*, Sheffield, Sept. 1977, 86-89.

Bull, P A, 1978. A study of stream gravels from a cave: Agen Allwedd, South Wales. *Zeit. Geomorph.*, Vol. 22, 257-296.

Bull, P A, 1981. Some fine-grained sedimentation phenomena in caves. *Earth Surface Processes and Landforms*, Vol. 6, 11-22.

Buller, A T and McManus, J, 1979. Sediment sampling and analysis *in* Dyer K.R., (ed.), *Estuarine Hydrography and Sedimentation*. Cambridge, 87-130.

Davies, W E, 1949. Features of cave breakdown. *Bull. Nat. Speleol. Soc.*, Vol. 11, 34-35 and 72.

Davies, W E, 1951. Mechanics of cave breakdown. *Bull. Nat. Speleol. Soc.*, Vol. 13, 36-42.

Folk, R F, 1955. Student operator error in determination of roundness, sphericity and grain size. *J. Sedim. Petrol.*, Vol. 25, 297-301.

Folk, R F, 1966. A review of grain size parameters. *Sedimentology*, Vol. 6, 73-93.

Folk, R F, 1974. *Petrology of Sedimentary Rocks* (2nd edition). Austin, Texas.

Folk, R F and Ward, W, 1957. Brazos River bar: a study in the significance of grain size parameters. *J. Sedim. Petrol.*, Vol. 27, 3-26.

Krumbein, W C, 1941. Measurement and geological significance of shape and roundness of sedimentary particles. *J. Sedim. Petrol.*, Vol. 11, 64-72.

Lawson, T J, 1981. The 1926-7 excavations of the Creag nan Uamh bone caves near Inchnadamph, Sutherland. *Proc. Soc. Antiq. Scot.*, Vol. 111, 7-20.

Lawson, T J, 1983. Quaternary geomorphology of the Assynt area, N.W. Scotland. Unpublished PhD thesis, University of Edinburgh.

Lawson, T J, 1988. *Caves of Assynt*. Grampian Speleological Group, Occasional Publication No. 6, Edinburgh.

Lawson, T J, 1993. The Creag nan Uamh caves *in* Gordon J.E. and Sutherland D.G., (eds.), *Geological Conservation Review: Quaternary of Scotland*. Nature Conservancy Council, Peterborough.

Masriera, A, 1970. Contribucion al estudio de los sedimentos varvados hipogeos. *Speleon.*, Vol. 17, 27-39.

Miskovsky, J C, 1966. Les principaux types de depots des grottes, et les problemes que pose leur etude. *Rev. Geomorph. Dyn.*, Vol. 16, 1-11.

Murray, N A, Bonsall, C, Sutherland, D G, Lawson, T J and Kitchener, A C, 1993. Further radiocarbon determinations on reindeer remains of middle and late Devensian age from the Creag nan Uamh caves, Assynt, N.W. Scotland. *Quaternary Newsletter*, 70, 1-10.

Newson, M D, 1971. The role of abrasion in cavern development. *Trans. Cave Res. Gp. G.B.*, Vol. 13, 101-107.

Pettijohn, F J, 1957. *Sedimentary Rocks* (2nd edition). New York.

Powers, M C, 1953. A new roundness scale for sedimentary particles. *J. Sedim. Petrol.*, Vol. 23, 117-119.

Siffre, M, 1959. L'indice d'emousse des alluvions karstique. *Boll. Soc. Venezuela Cienc. Nat.*, Vol. 95, 53-61.

Siffre, M, 1960. Sur un cas de fossilisation de varves souterraines craquelees. *Ann. Speleol.*, Vol. 15, 73-80.

Siffre, A and Siffre, M, 1961. Le faconnement des alluvions karstiques. *Ann. Speleol.*, Vol. 15, 415-420.

Simons, J, 1965. Some basic principles of cave formation and methods of sedimentation. *Newsl. Cave. Explor. Gp. E. Africa*, Vol. 3, 2-20.

Sweeting, M M, 1950. Erosion cycles and limestone caverns in the Ingleborough district. *Geog. J.*, Vol. 115, 63-78.

Sweeting, M M, 1972. *Karst landforms*. London.

Tratman, E K, (ed.), 1969. *The Caves of North-West Clare, Ireland*. Newton Abbot.

Warwick, G T, 1956. Caves and glaciation: I. Central and southern Pennines and adjacent areas. *Trans. Cave Res. Gp. G.B.*, Vol. 4, 125-160.

Warwick, G T, 1971. Caves and the Ice Age. *Trans. Cave Res. Gp. G.B.*, Vol. 13, 123-130.

White, E L and White, W B, 1969. Processes of cavern breakdown. *Bull. Nat. Speleol. Soc.*, Vol. 31, 83-96.

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Pseudokarst in the Western Cape, South Africa: Its palaeoenvironmental significance

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Abstract: Pseudokarst is well developed in many areas of the Western Cape on quartzitic sandstones of the Table Mountain Group. Two areas on the Cape Peninsula are described. Both have large surface dolines and pinnacle karst as well as cave systems. Area 1 refers to Table Mountain itself and the Back Table. Area 2 is the Silvermine Kalk Bay Mountain region further south. There the density of pseudokarst forms, including over 70 known caves, are concentrated in a relatively small area. Most caves are shallow phreatic in origin and appear to have developed as conduits feeding water movement towards the Noordhoek - Fish Hoek trough to the south. The pseudokarst is relict. This pseudokarst has formed beneath plateaux developed on horizontally bedded Peninsula Formations sandstone of the Table Mountain Group, at varying heights, 1000m on Table Mountain, 750m on the Back Table and 500m on the Silvermine Reserve. The discussion focusses on the age of the weathering that created the pseudokarst landforms and thus the age of the karst itself. It is concluded that the pseudokarst developed beneath the Late Cretaceous-mid Miocene African Surface and that Miocene and later Pliocene uplift caused differential uplift of the fault blocks along the Cape Peninsula mountain chain.

INTRODUCTION

The term **karst** is applied to landforms and landform assemblages where chemical solution overrides regional geomorphic processes. The term is conventionally restricted to landforms developed on carbonate rocks, although karst features also occur on halite and on gypsum. Karst landscapes are characterised by disrupted surface drainage since water disappears underground through enlarged fissures to flow through caves and emerge elsewhere as springs. Dolines, enclosed hollows of variable dimensions, are a common surface characteristic. Joint enlargement may result in negative troughs and aligned upstanding pinnacles. Underground, network caves can be characteristic.

Pseudokarst is a term applied to landscapes that have many karstic features but which have developed on rock types normally considered as insoluble. Pseudokarst in southern Africa occurs in the Western Cape, along the Eastern Transvaal Great Escarpment (Marker, 1975), in Swaziland (Watson, 1985;1986) and on Chimanimani mountain in Zimbabwe (Craven and Penney, 1994). It has also been reported from many other parts of the world such as Venezuela (White et al., 1966), Central Australia (Jennings, 1979) and from Mainland China (Anon, 1988). The existence of pseudokarst, karst characteristics developed on normally insoluble rocks, implies strong chemical weathering over a long period of time. This paper focuses attention on the importance of pseudokarst in the Western Cape of South Africa.

In the Western Cape, pseudokarst areas are recognisable from surface widening of joints, the development of cavernous weathering on upstanding pinnacles and the opening of keyhole slots in cliffs by seepage water. These surface forms constitute the spectacular landscape of the Cederberg, with joint widening particularly conspicuous in the Wolfberg Cracks. Their effects can be seen on the summit plateau of Sir Lowry's Pass and on the Cape Peninsula mountain chain. We will focus on two areas of the Cape Peninsula: Table Mountain itself, particularly the Back Table which is designated Area 1, and the Silvermine/Kalk Bay mountains designated as Area 2 (Fig.1).

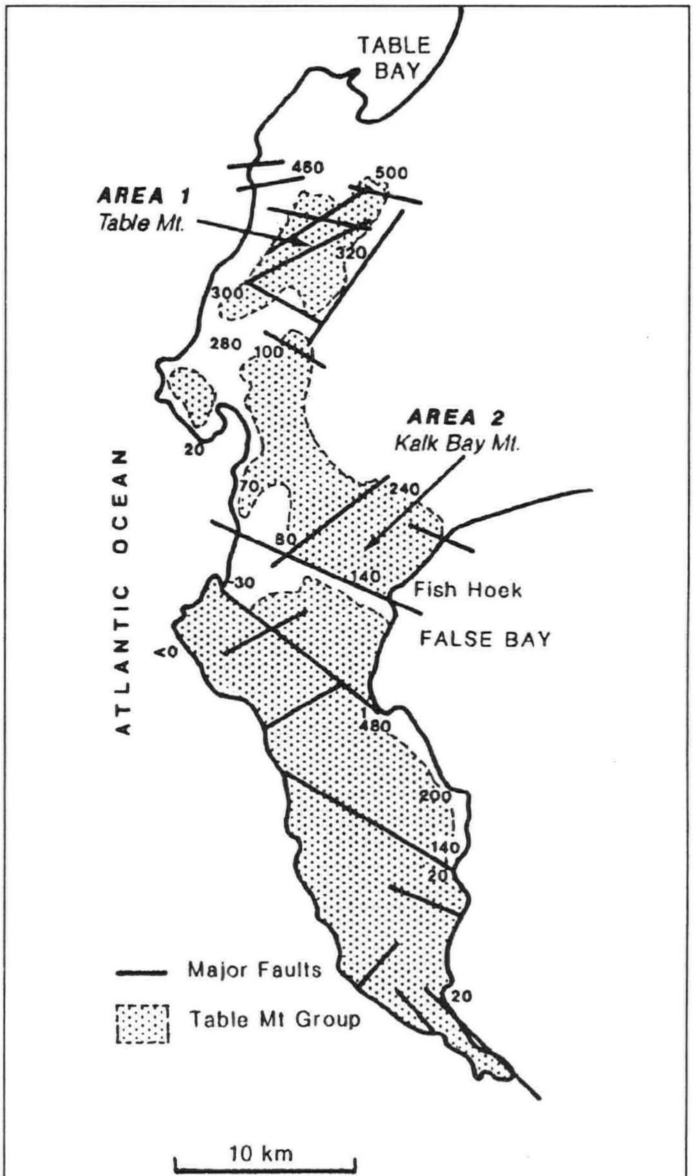


Figure 1. The Cape Peninsula showing the location of the Table Mountain (Area 1) and the Silvermine/ Kalk Bay Mountain (Area 2) pseudokarst areas. Major faults shown. Figures denote basal altitudes of the Peninsula Sandstone Formation.

GEOLOGY

The host rock, in both areas, is Palaeozoic Peninsula Formation sandstone of the Table Mountain Group (Table 1). The Table Mountain Group are the basal members of a suite of quartzites and shales that constitute the rocks of the Cape Fold Belt. In the Cape Peninsula only the uppermost Table Mountain Group are present (Table 1). The Peninsula

GROUP	FORMATION	LITHOLOGY	AGE
Table Mountain Group	Pakhuis Formation	Glacial sediments and shales	Silurian
	Peninsula Formation	Quartzitic sandstone with minor shale bands	Silurian
	Graafwater Formation	Red shales	Ordovician
UNCONFORMITY			
Cape Granite Suite			Precambrian
Malmesbury Group		Shales	

Table 1. An Outline Geological Sequence for the Cape Peninsula.

more closely bedded. It is well jointed and overlies a bed of reddish hued sandstone and mudstone which constitutes the basal Graafwater Formation shales (Theron, 1984). Commonly, massive and thinner bedded units alternate. The most spectacular pseudokarst is developed in the massive well-jointed beds. The lithology is silicious throughout. The matrix of both quartzite and sandstone beds is crystalline silica.

TOPOGRAPHY

The Cape Peninsula mountains are essentially tabular, in contrast to the steeply folded Table Mountain Group sandstones that make up the majority of the Western Cape mountains. Late Palaeozoic to early Mesozoic orogenesis was accommodated by block faulting in the Cape Peninsula and not by folding. The Cape Peninsula mountain chain is therefore divided into separate blocks at different elevations (Fig.1). Strong structural lineaments exist, in addition to faults that cause considerable displacement.

TABLE MOUNTAIN (AREA 1)

On Table Mountain small water absorbing dolines occur along the edge of the Central Table, and in Echo valley (Fig.2). Between Echo and Ark valley there is surface joint-widened karst with strongly developed small-scale etching associated with flared slopes. The Valley of Isolation is a large karst depression, about 1000m in length and about 500m in width (Plate 1). This depression has a minimum depth of 16 m. The northern side is cliffed and reaches an altitude of 900m On this cliff there are two caves. Both are characteristic of water emergence (spring) sites. The upper cave is now perched and dry whereas the lower cave is still an active spring emergence. Numerous keyhole slots, a form of phreatic tube, are visible in the same cliff face. The emergent water disappears into one of the floor depressions leading into a cave (Plate 1). The depression floor contains a number of small dolines developed in sand overlying massive collapse blocks. The entire doline complex is clearly old as shown by the large block collapse that underlies the more modern floor infill. It is the underlying collapse material which facilitates formation of the small dolines.

Another huge enclosed hollow is located on the northern slopes above Orange Kloof, in length 2750m and width 500 m. The northern side of this depression reaches an altitude of approximately 750m whereas the southern slope is lower, reaching only 720m. Pinnacle karst forms are associated with the plateau surface at 750m. Several caves including Wynberg Cave, Bats, Giants, the Metro system, Climbers, Smugglers and Vivarium caves, are associated with the higher ridge and the hollow. Most of these caves are considered to be caused by solutional widening of rifts, associated with unloading towards Orange Kloof (Fig.2).

THE SILVERMINE/KALK BAY MOUNTAIN AREA (AREA 2)

One of the most spectacular pseudokarst areas on the Cape Peninsula is located in the Silvermine Reserve (Figs.1 and 3). The mountains there reach a maximum altitude of 537m in the north on Upper Steenberg Ridge. A plateau terminating in three ridges aligned northwest-southeast, is the main pseudokarst area (Fig.3; Plate 2). The main drainage is into

Plate 1. Valley of Isolation doline on Table Mountain looking north-east.
(1 = Upper dry emergence cave, 2= position of active lower emergence cave, arrow shows approximate location of cave absorbing flow, actual position hidden by vegetation).

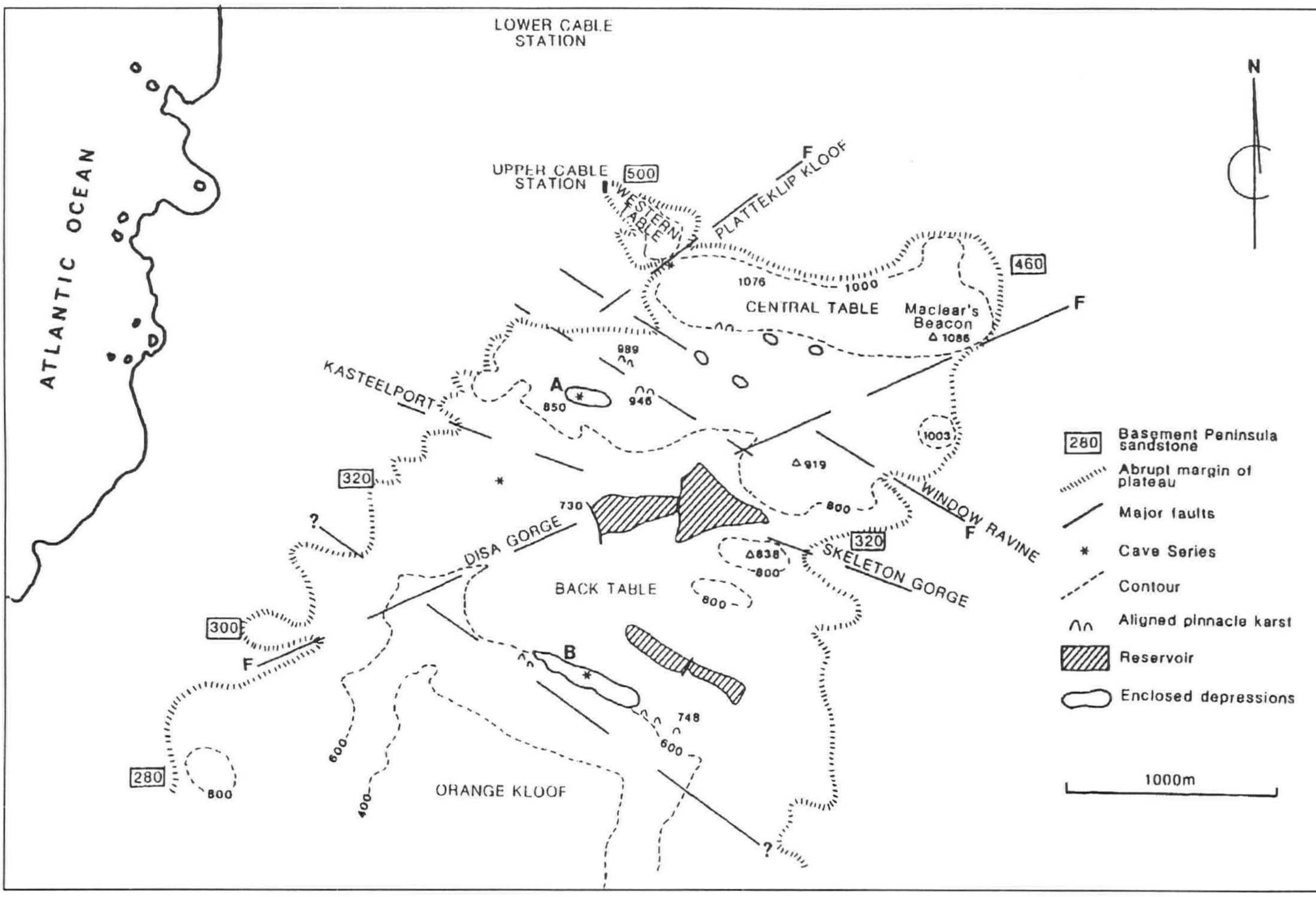


Figure 2. Pseudokarst areas on Table Mountain : Area A is on the Back Table; Area B is Wynberg Peak.
(No altitudes are shown below the plateau level. On the plateau both contours and spot heights give altitudes in metres)

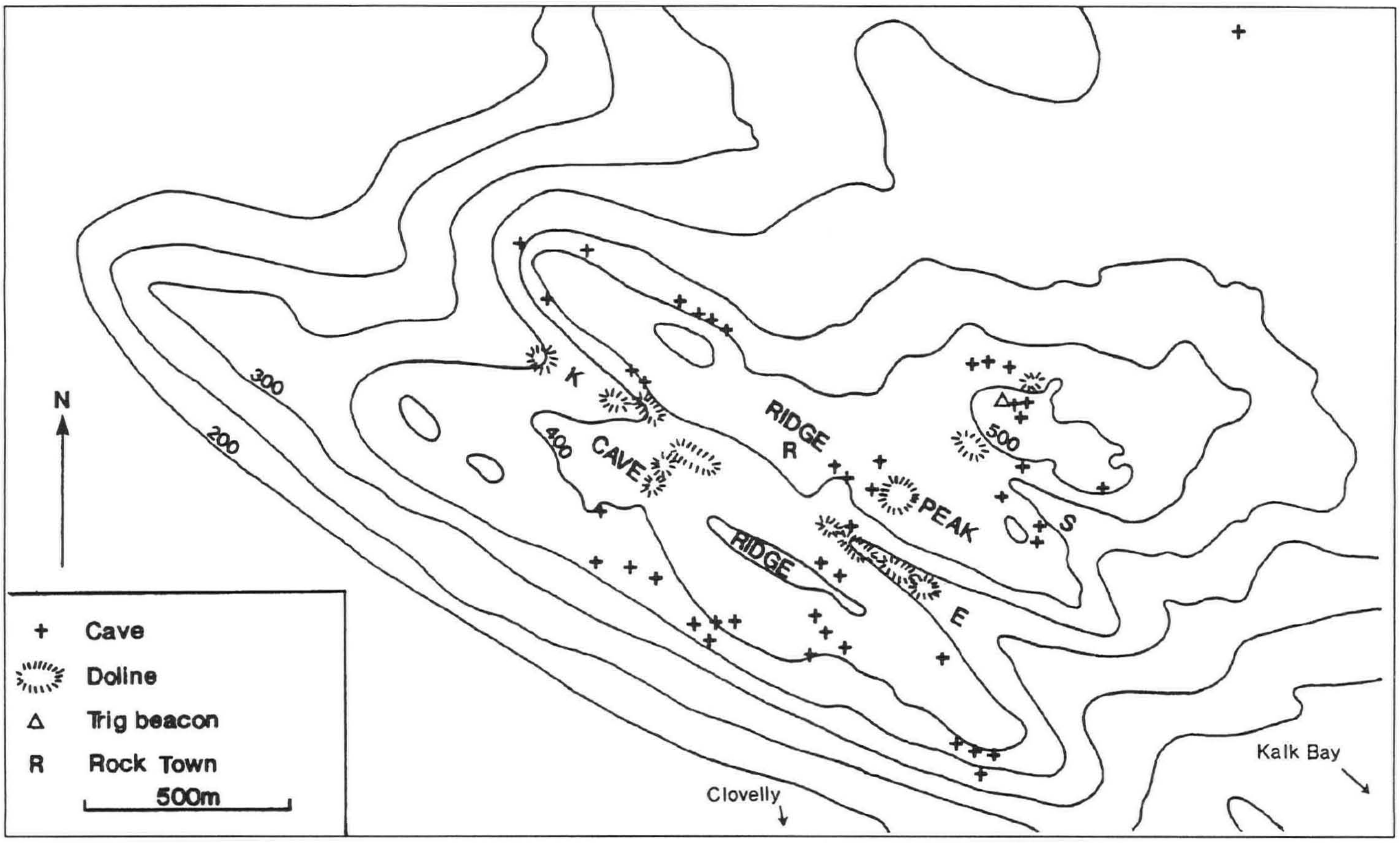


Figure 3. Silvermine/Kalk Bay Mountain pseudokarst area (contours at 50m interval, 100m interval contours labelled on uphill side. S= Spes Bona valley; E=Echo valley; K= Kleintuin kloof).

Plate 2. Pseudokarst surface on the Silvermine Reserve showing Cave Peak (1), Ridge Peak (2) separated by Echo Valley (4) and the Amphitheatre (3) view southeast. The Robin Hood entrance to Ronan's Well is indicated by an arrow).

the Silvermine River. All the major valleys carry small streams, many of which dry out at the height of summer. Aligned dolines occur within these valleys. The Silvermine area also has well-developed surface aligned pinnacle forms associated with joint widening. This type is restricted to areas above 400m altitude. The most spectacular location is close to The Amphitheatre and several large caves, and is known locally as the Rock Town (Fig.3; Plate 3). These pseudokarst landforms will be described in detail.

Surface landforms

Large **karren** or pinnacle forms, occur above 400m altitude on or close to the summit of all the ridges. The best examples can be seen on Upper Steenberg Peak and Kleintuinkop (Fig.3; Plate 3). In these areas the terrain consists of large clint-like blocks separated by troughs (grikes). The troughs range from 0.8m to 2.5m in width and may reach 4m in depth. The floors are on bedrock with a shallow veneer of sand. In places these grikes are deeper and may lead into caves. Sunbeam Cavern is one example. This cave is 18m deep and the entrance is covered by rock collapse (Swart, pers. comm). The entrance to Robin Hood's Cave is another example. The trough there is 25m in length and has a maximum depth of 22m. This is one of the entrances to Ronan's Well, some 200m in length.

Small **arches** also occur. The best known can be found at the northern end of Echo valley and on top of Kalk Bay Mountain. Solution rill karren groove many blocks. The entrance to Climax Cave has good examples. Many horizontal rock surfaces show basins, or kamenitza, development. Floors and sides show evidence of case hardening. Even in vertical rock faces, small tubes, 5 to 10cm in diameter and between 5cm and 15cm deep, penetrate the rock. During wet weather water and silt pour from some of these holes, suggesting that they extend further than is at first apparent. Rib-like structures occur in some of these holes. These are all examples of phreatic or epiphreatic weathering. Tentatively it is suggested that ancient phreatic tubes now truncated by slope recession, are utilised by current winter drainage.

Dolines occur in three of the larger valleys (Fig.3). A number of these are small, up to 2m in diameter and 1m in depth. The larger depressions are more than 20m in diameter and up to 10m in depth. Many are choked by fallen boulders, derived from collapse and cliff recession. Some dolines occur in series as in Kleintuin Kloof, which are associated with the movement of underground water down the kloof. Massive collapse has also occurred in Echo valley, again related to water movement. Some dolines at lower elevation are hidden within forest remnants both in Echo and Spes Bona valleys.

Most of these depressions are stable but one, at the head of Echo valley, is active. This collapse first appeared in about 1976 and has grown wider and deeper each winter. It is currently 14m by 11m in dimension and 3m maximum depth. It has formed in sandy valley infill which feeds through the bottom of the sinkhole. Another large doline is located above the Amphitheatre at an altitude of about 455m. This depression is 15m in length and 8m wide. The entrance to Drip Water Pot is located among the boulders at the southern end of this depression (Fig.4; Plate 2). Other caves entered from depressions are Six Moles Cave and Mossies Den.

Water sinks and springs

Surface water tends to be seasonal, drying out at the height of the summer dry season. The streams either drain to the northwest into Silvermine River or to the southeast directly to False Bay. There are two types of springs: cliff resurgences and valley floor resurgences. The majority of cliff resurgences occur on southwest facing cliffs and are small in volume. There is no consistency in altitudes. In caves such as Bettie's cave on Kleintuinkop, water actually runs into the cave and soaks away into the sand in the terminal chamber. Valley floor springs are the source for bigger streams (Table 2). None provide the entrance to caves.

VALLEY	ALTITUDE (m)
Spes Bona	410
Pecks	400
Kleintuinkloof	320
Bailie's	320
Echo	310

Table 2. Valley Floor Springs.

Figure 4. The concentration and alignment of caves associated with The Amphitheatre lying to the northeast of Kleintuin Kloof and Echo valley.

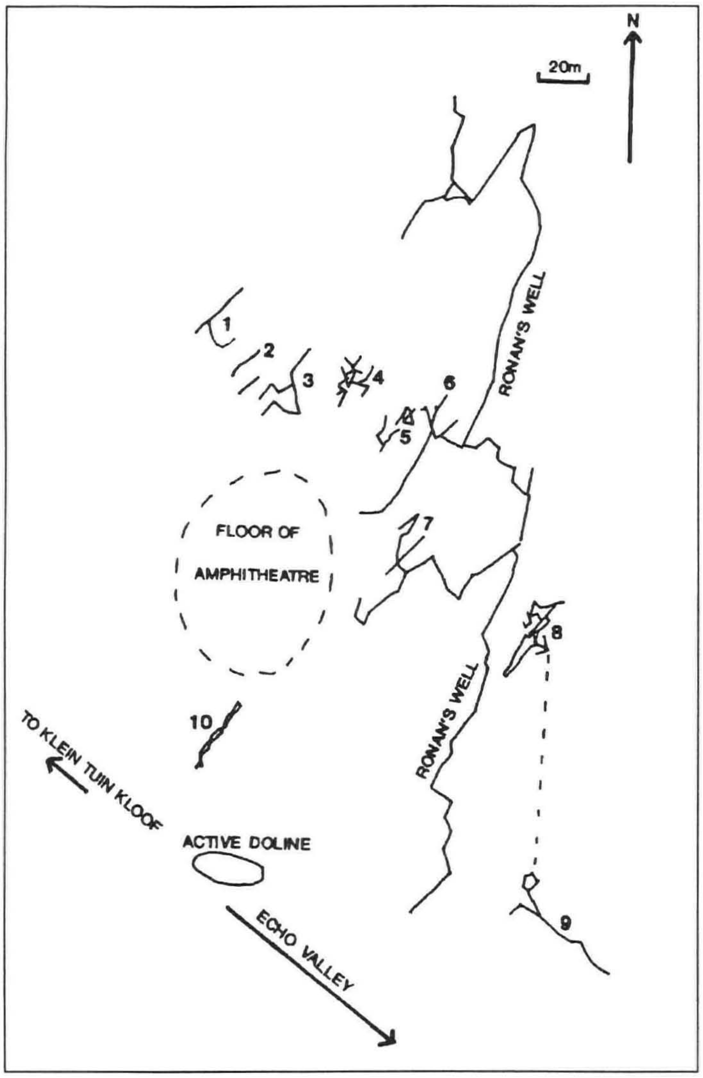


Table 3. Cave Dimensions.

CAVE NAME	A	B	C	D
Avernus	176	85	35	
Boomslang	507	130	70	
Clovelly	191	67	53	
Devil's Pit	78	40	34	22
Drip Water Pot	122	38	15	
Echo Halt	124	71	16	
Harbour View	260	57	23	35
Labyrinth	210	71	32	
Muizenberg	196	58	30	
Oread Halls	333	110	82	
Ronan's Well	615	291	59	20
Tartarus	162	57	26	
Tjoklet's Grotto	77	51	13	
Vier Grotte	107	45	18	
Ystervark	125	49	42	

All dimensions in metres
A= total passage length
B= length along major axis
C= overall width along minor axis
D= depth from surface unless horizontal

Although isolated caves occur in the northern part of this area, cave density is exceptionally high in association with the three ridges overlooking Kalk Bay-Fishhoek, known as Cave Ridge, Ridge Peak and Kalk Bay Mountain (Fig.3). The ridges are separated by the Spes Bona and Echo valleys. Within this high cave density area, a particularly high density of caves occurs in association with the Amphitheatre, possibly a large breached doline surrounded by well-developed pinnacle pseudokarst (Fig.4; Plate 2). Most caves are shallow phreatic and are either linear or network in plan (Figs. 5 and 6). Caves are most frequent on the northeast of the valleys: only small, apparently truncated cave remnants occur along the southwest walls. There are approximately 70 known caves ranging from 10m over 750m in length (Table 3).

Cave surveys demonstrate that most are network caves developed along well defined joints (Figs.5 and 6). Most are shallow and suggest shallow phreatic dissolution (Kavalieris, 1977). Passages show a number of characteristic cross sections: low, wide passages correspond to bedding planes, whereas vertical narrow slots exist along defined vertical joints. A circular cross section is sometimes seen, notably in Oread Halls. This form is characteristic of conduit flow within the upper phreatic zone. These passages appear to meander slightly. This is characteristic of master conduits. A number of cave passages have domed terminal chambers. Rock pillars occur within the passages. Some are free standing, others are attached to both floor and ceiling. Partially formed pillars, not separated from the cave walls form ribs (Plate 4).

Although no large speleothems occur in these pseudokarst caves, they are not entirely devoid of formations. Small 5mm to 10mm stalactite nodules occur on the ceilings and walls of many caves. These consist of an amorphous silica. No calcite is present.

DISCUSSION

The existence of pseudokarst implies strong chemical weathering to dissolve the silica matrix before fine sand washes or blows out (Martini, 1984). The Cape Peninsula pseudokarst is relict, as shown by its altitudinal position and by the breakdown that affects many karstified valleys and many cave entrances. The Harbour View - Lower Aladdin cave complex is truncated by cliff retreat above Clovelly. The present multiple entrances formed part of the network plan.

Cave Peak, Ridge Peak and Kalk Bay Mountain, separated one from the other by the Spes Bona and Echo valleys, carry the highest density of caves (Figs. 3). These caves are essentially phreatic tubes narrowing and becoming impassable northwards, but coalescing to form larger conduits towards the south. Some caves still carry drainage in winter and flow is southwards. Because they are now truncated by Echo and Spes Bona valleys and by cliff recession, they indicate an ancient water movement towards the Fish Hoek - Nordhoek valley. The concentration of cave development on the three ridges overlooking Kalk Bay and the clear

Figure 5. Ronan's Well, the longest sandstone cave showing network development.
(E= horizontal usual entrance. Surveyed by S.A.S.A. (Cape) 1982 by A.Hitchcock and S. Hine).

evidence of conduit flow towards the Fish Hoek - Noordhoek fault trough suggests that the fault trough must have been in existence as a negative landscape feature when the pseudokarst developed.

The development of a joint-guided surface pseudokarst with flared slopes and pinnacles indicates sub-soil solution followed by stripping of the overburden. The cave characteristics are indicative of a shallow water table with water movement through phreatic tubes joining to form conduits (the caves entered by people). The association of cave levels indicates a falling water table with periodic still-stand. Cavernous weathering and surface micro features form subsequent to exposure. Clearly much of the superficial cavernous weathering still occurs today, enhanced by salt weathering (Young, 1987). However the disintegration of associated case-hardening would seem to suggest reduced process at present.

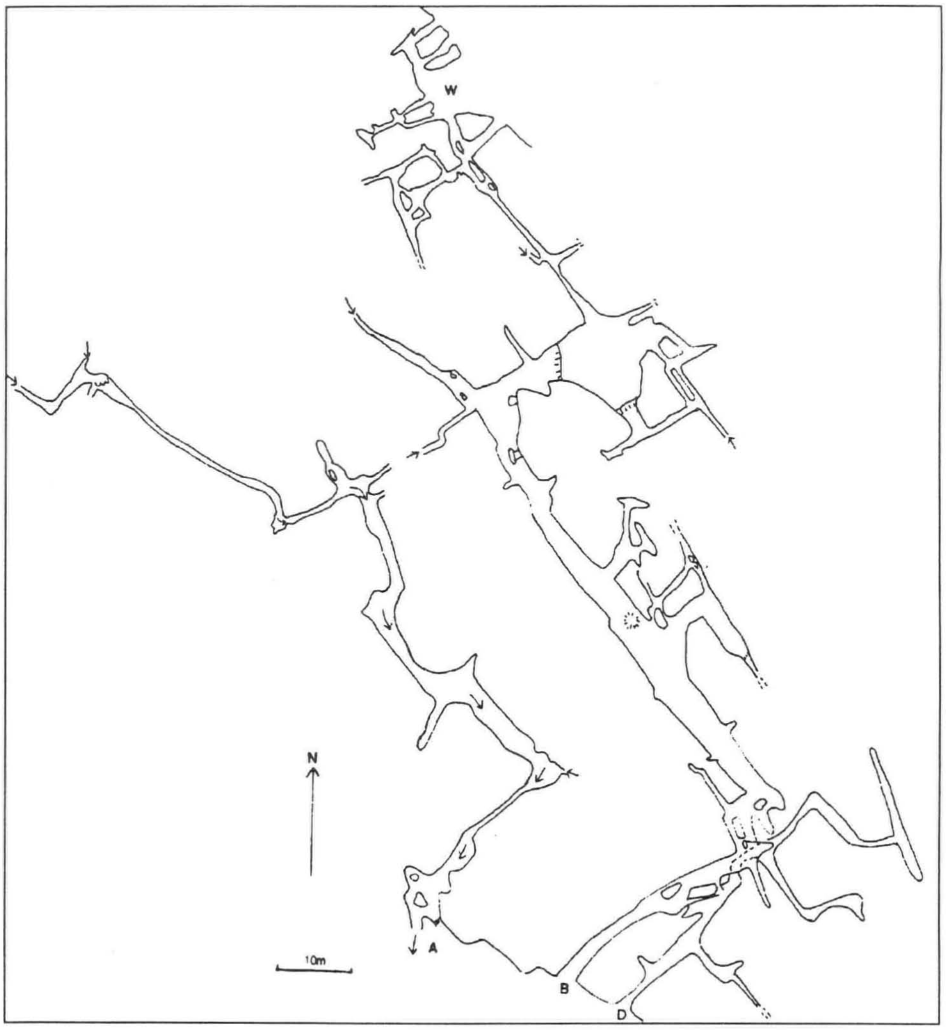
High temperatures, regular rainfall and a forest cover are the likely conditions for such concentrated solution in a non-carbonate rock. Throughout the Cape Province, remnants of a coastal platform considered to be part of the extensive Late Mesozoic African surface are capped by silcrete and laterite overlying deeply altered saprolite. African Surface planation took place over at least 40 million years, following the separation of the southern continents (break-up of Gondwanaland). The African surface below the Great Escarpment developed in relation to the current sea level. Uplift in the Miocene and Pliocene periods brought this period of planation and deep weathering to an end. The African surface was then uplifted and warped. Could the pseudokarst have been formed contemporaneously? This weathering period is certainly the most pronounced in the Cenozoic geomorphic record and the most likely to account for strong weathering of silicious rocks and the development of pseudokarst.

The very different surface elevations of the various pseudokarst localities even on the Cape Peninsula itself must be addressed. (Table 4). Could late Tertiary faulting with displacement have occurred? The different blocks are undoubtedly separated by major faults but conventional wisdom decrees that South Africa forms part of a stable plate. Only now are the effects of Cenozoic tectonics being appreciated (Maud and

LOCATION	SURFACE ALTITUDE	CONTACT ALTITUDE	ALTITUDE DIFFERENCE
Table Mountain:			
Central Table	c. 1050	500	550
Blinkwater/Echo	c. 950	480	470
Back Table	c. 750	320	430
Silvermine:			
Steenberg Peak	c. 500	240	260
Cave Peak	450	140	370
Ridge Peak	500	c. 100	400
Kalk Bay Mountain	510	80	430

Table 4. Height of Pseudokarst Surfaces.

Figure 6. An example of a shallow phreatic network pseudokarst cave. (Arrows show direction of water flow. A= Avernus Cave, B= Boomslang Cave, D= White Dome cave, W= Wesssel's Grotto. Surveyed by S.A.S.A. (Cape) 1982 by C.J.Larkin and A.N. Hitchcock).



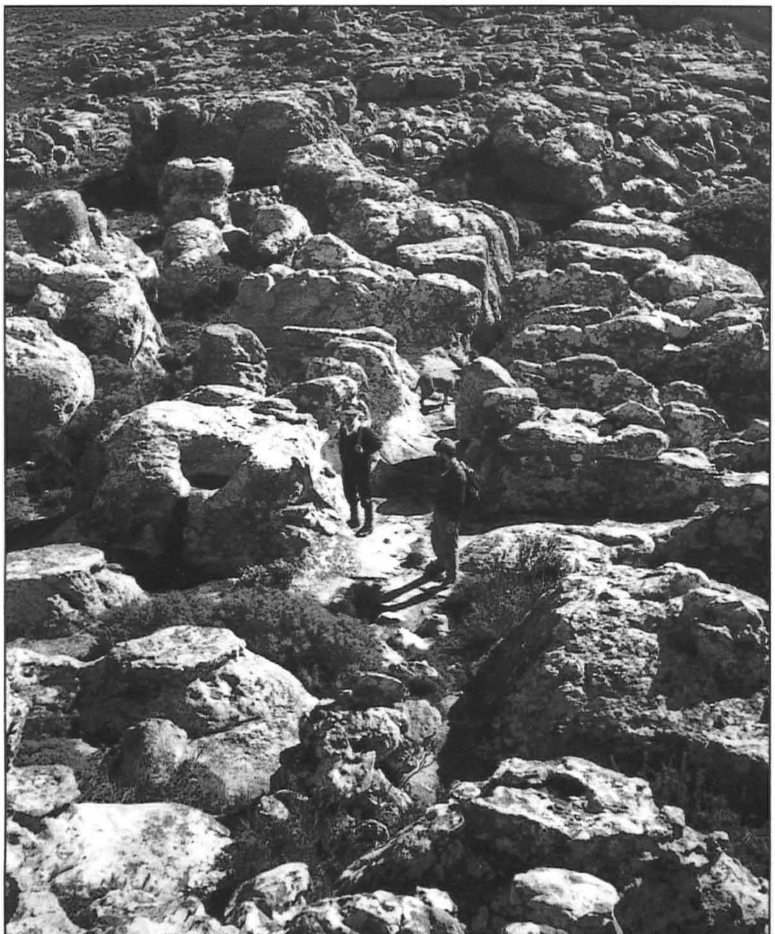


Plate 3. Rock Town, aligned pseudokarst pillars and grikes. People for scale. The high ground in the middle ground is Upper Steenberg Peak.

Partridge, 1987). When the elevations of the pseudokarst areas are related to the basal altitude of the Peninsula Sandstone at the contact with the underlying Graafwater Shales, it is clear that the blocks must have undergone differential uplift (Table 4). On Table Mountain, the Central Table has a surface altitude of 1050m, whereas the Back Table has an altitude of 750m and the three ridges in the Silvermine Reserve reach altitudes of only about 500m (Table 4; Fig.2). With one exception the relative constancy of altitude above the Peninsula Sandstone base suggests that differential uplift is a reasonable assumption. Furthermore Tertiary flora reported from the Noordhoek basin at the western end of the Fish Hoek trough, rests on weathered granite with ?silcrete at a depth of -80m (Coetzee, 1986).

A long period of time was necessary for the planation of the African Surface and the development of deep weathering mantles on it. Uplift is known to have occurred in both the Miocene and the Pliocene Period (Maud and Partridge, 1987). The dismemberment of the African Surface during the Pliocene uplift is hypothesised as having caused differential uplift of the Cape Peninsula mountains so that they now stand at differing altitudes above sea level. The presence of deeply weathered granite in the Noordhoek Basin and at -80m on the west coast is corroborative evidence that the African surface weathering previously affected the Cape Peninsula and that differential uplift occurred. As a consequence, surface pseudokarst also occurs at different altitudes in different areas on different fault blocks.

Most surface pseudokarst sites show large block weathered collapse, which, in kloofs such as Echo Valley and Kleintuin Kloof, is overlain by more recent cliff spall forming scree. The latter may well be a product of the Last Glacial event when the Cape Peninsula lay almost 200km inland and annual temperatures dropped between 5° and 8°C. The massive block collapse is very much older as the blocks are themselves weathered. Pseudokarst development pre-dates even that event. Perhaps the disintegration of the karst by massive block collapse accompanied the uplift and disruption of the African surface?

CONCLUSION

Attention has been focused on the existence of well-developed pseudokarst on the mountains of the Cape Peninsula. Two areas have been discussed in detail. The formation of the pseudokarst is considered to have been due to strong chemical weathering associated with the formation of the Cenozoic African Surface. The present differences in elevation of these pseudokarst areas are attributed to Pliocene differential uplift.

ACKNOWLEDGMENTS

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REFERENCES

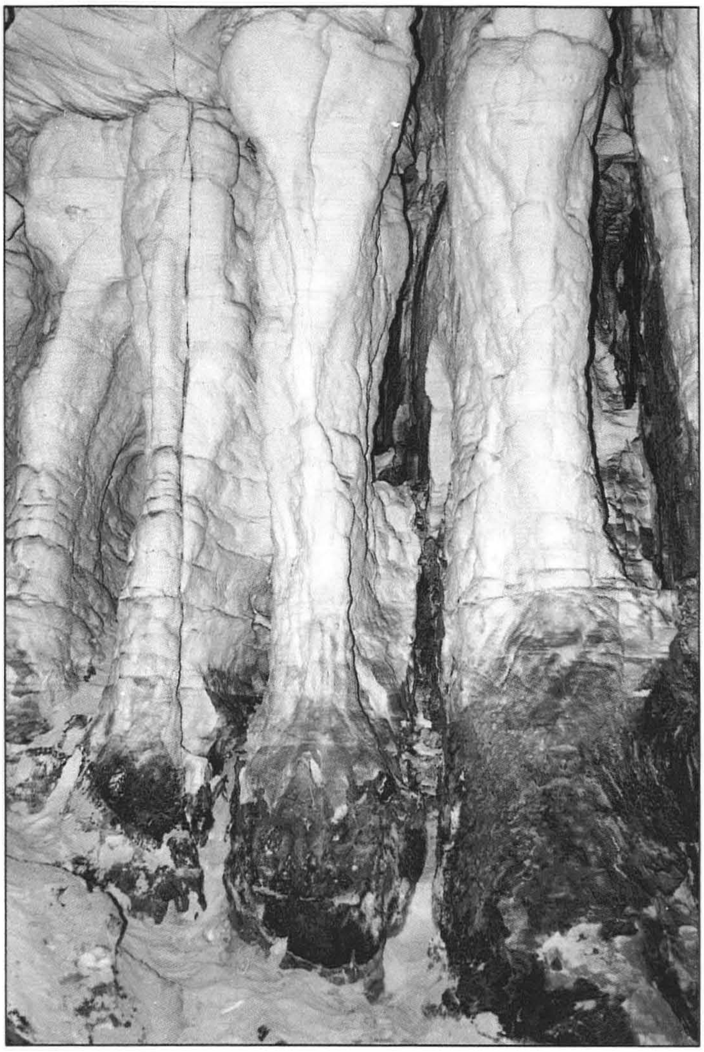
Anon., 1988. *Sandstone Pseudokarst at Wulingyuan, Hunan Province, China.* Poster paper and tourist brochure.

Coetzee, J A, 1986. Palynological evidence for major vegetation and climatic change in the Miocene and Pliocene of the southwestern Cape. *S.A.Journ. Science* 82, 71-72.

Craven, S A and Penney, A J, (eds.), 1994. The 1993 Chimanimani Expedition. *S.A.Spelaeological Association Bull.* 35, 88pp.

Jennings, J N, 1979. Arnhem Land, the city that never was. *Geog.Mag.*51, 822- 827.

Plate 4. Rock ribs (columns) developed by solution in the shaft entrance to Ronan's Well. Each rib is approximately 4 m in height.



Kavalieris, I, 1977. The formation of Ronan's Well. *S.A.S.A. Bull.* 6-7.

Marker, M E, 1975. Note on some South Africa pseudokarst. *Boletin de la Sociedad Venezolana de Espeleologia.*7, 5-12.

Martini, J, 1984. The rate of quartz dissolution and weathering. *S.A.S.A. Bull.*25, 7-10.

Maud, R R and Partridge, T C, 1987. Regional geomorphic evidence for climatic change in southern Africa since the Mesozoic. *Palaeoecology of Africa* 18, 337-348.

Theron, J N, 1984. *The geology of Cape Town and environs* (an explanation of 1:50 000 Geological Series sheet: Kaapse Skiereiland. Geological Survey. Cape Town.

Watson, A, 1985. Pseudokarstic microrelief and other weathering features on the Mswati Granite (Swaziland). *Zeit.fur Geomorph.* 29, 285-300.

Watson, A, 1986. The origin and geomorphological significance of closed depressions in the Lubombo Mountains of Swaziland. *Geog.Journ.* 152, 65-74.

White, W B, Jefferson, G L and Haman, J F, 1966. Quartzite karst in SE Venezuela. *Internat. Journ.Spel.* 2, 309-314.

Young, A R M, 1987. Salt as an agent in the development of cavernous weathering. *Geology* 15, 962-966.

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Evidence for two phases of Late Palaeozoic karstification, cave development and sediment filling in south-eastern Australia

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Abstract: Two phases of Late Palaeozoic karstification, cave development and sediment-filling, separated by an erosional event, have taken place in Early Palaeozoic limestones of the Lachlan Fold Belt in south-eastern Australia. Evidence for these two phases is found at three localities:- Bungonia Caves, New South Wales, Jenolan Caves, New South Wales, and Ida Bay, Tasmania, where the limestones are adjacent to the margins of the unconformably overlying Permo-Triassic Sydney and Tasmania Basins. Caves and dolines developed during the older phase have been filled with turbiditic limestones of marine origin, megabreccias with marine turbiditic limestone matrix, and crystalline void fillings. No remnants of similar sediments are found in surface outcrop, except where they fill palaeokarst features. Caves developed during the second phase have been filled with clastics of terrestrial origin including quartz sandstones, gravels and diamictites. Remnants of these rocks are found adjacent to the caves in surface outcrop, unconformably overlying the Lower Palaeozoic sequences which contain the cavernous limestones. Late Palaeozoic cave-filling clastics can be distinguished from similar lithotypes deposited during the Cainozoic by the presence of secondary sulphide minerals, most likely deposited by basinal fluids derived from the overlying Permo-Triassic strata.

INTRODUCTION

Although Australia's longest and most extensive cave systems are developed in the Tertiary limestones of the Nullarbor Plain, significant caves and other karst features are developed in the impounded karsts formed on the Early Palaeozoic limestones of the Lachlan Fold Belt in south-eastern Australia.

Research over the past ten years has shown that many of these caves, including the best known and most extensive limestone cave systems in south-eastern Australia, Jenolan Caves in New South Wales and Exit Cave in Tasmania, are associated with palaeokarst deposits resulting from repeated exposure of the limestones to subaerial conditions (Osborne 1984,1991; Osborne and Branagan 1988). These and a number of other large cave systems with significant mineral decoration in both New South Wales (Bungonia, Colong) and Tasmania (Mole Creek) are developed in limestones adjacent to or overlain by the unconformable base of Permo-Triassic basinal sediments.

Osborne (1993b) argued that removal of weathered pyrite-bearing palaeokarst deposits in the vadose zone is a significant cave-forming process at Jenolan Caves, resulting in the exhumation of karst conduits initially formed during Permo-Carboniferous times. Osborne (1994) suggested that large, highly decorated caves in the limestones adjacent to the Sydney and Tasmania Basins owed their origin, in part, to vadose weathering of sulphide-bearing palaeokarst deposits, the sulphides being emplaced by basinal fluids.

Current research, which is focusing on the role of palaeokarst-hosted and other sulphide deposits in cave development, has resulted in further examination of the palaeokarst deposits in the Early Palaeozoic limestones of south-eastern Australia. It is thus now possible to make comparisons between palaeokarst stratigraphy in New South Wales, towards the north of the Lachlan Fold Belt, and in Tasmania, towards the south of the Lachlan Fold Belt.

BACKGROUND

Australia, along with South America, South Africa, India and Antarctica, is a remnant of the southern supercontinent, Gondwana. Australia separated from Antarctica and began to move northwards to its present location as late as 55 million years ago. For much of the Late Palaeozoic and all of the Mesozoic, south-eastern Australia was located at high latitudes, often within the Antarctic Circle.

Marine sedimentation in the Lachlan Fold Belt ended with the Early Carboniferous Kanimblan Orogeny (see Cas, 1983), which cratonised the fold belt and formed a major north-south trending mountain chain. A major period of subaerial exposure is recognised in south-eastern Australia during the Late Palaeozoic following the Kanimblan Orogeny. Conditions in Gondwana during the Late Carboniferous to Permian were quite cold, with ice sheets covering parts of South Australia and valley glaciers developing in the mountain ranges.

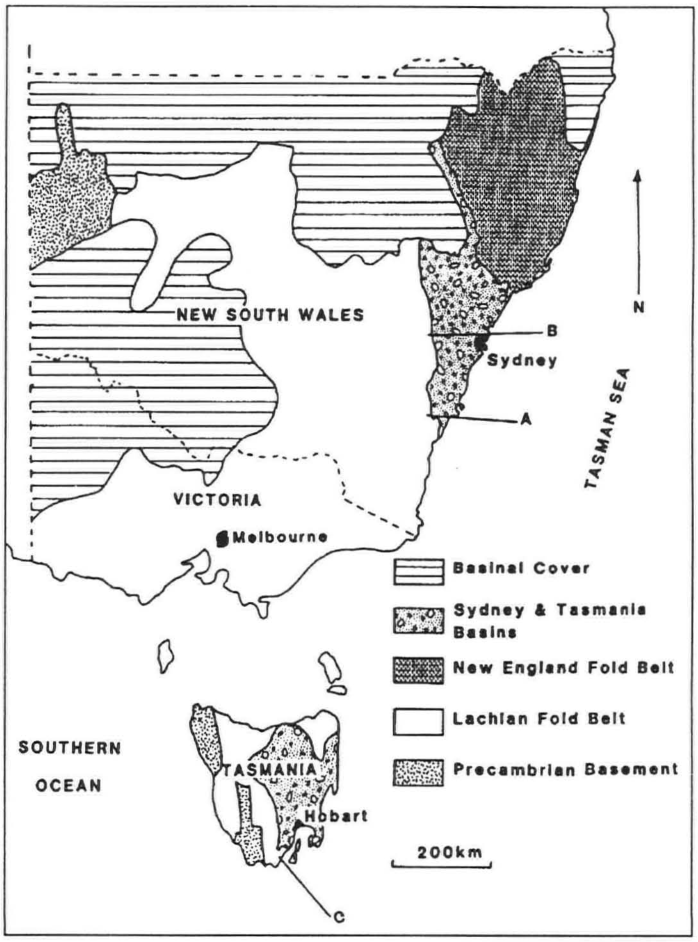


Figure 1. Eastern Australia showing karst areas mentioned in text and major tectonic zones: A - Bungonia Caves; B - Jenolan Caves; C - Exit Cave, Ida Bay.

Rifting during the Late Carboniferous formed the Sydney-Bowen and Tasmania Basins partly overlying the eastern portion of the Lachlan Fold Belt. These basins filled with similar sequences of Permo-Triassic marine, terrestrial siliceous and volcaniclastic sediments, including significant Permian coal measures. An unconformity, in places with a relief of 1500m, separates the highly folded strata of the Lachlan Fold Belt from the relatively undeformed Permo-Triassic sequences.

EVIDENCE FOR TWO PHASES OF LATE PALAEOZOIC CAVE DEVELOPMENT

Osborne (1984, 1991; Osborne and Branagan 1988) have established the existence of Late Palaeozoic palaeokarst deposits in south-eastern Australia. Although direct dating of these deposits has not yet been possible, the stratigraphical relationships of these deposits, suggest that they fill caves and other karst features that developed during the Late Carboniferous or Early Permian. The palaeokarst deposits are unconformable within the Early Palaeozoic limestones that enclose them, show no signs of Carboniferous folding and are truncated by modern caves, suggesting that they formed after the Kanimblan Orogeny and prior to the deposition of the Sydney and Tasmania Basins.

Research at three localities, Bungonia Caves and Jenolan Caves in New South Wales and Ida Bay in Tasmania, where the limestones are adjacent to the margins, and unconformable bases, of the Permo-Triassic Sydney and Tasmania Basins, has indicated that two distinct phases of Late Palaeozoic cave development and filling, separated by an erosional event, have taken place in Early Palaeozoic limestones of the Lachlan Fold Belt in south-eastern Australia.

Bungonia Caves, New South Wales

Bungonia Caves (Fig. 1, "A") are developed in a plateau of Silurian limestone which is partly overlain unconformably by thin remnants of both Permian marine quartzose sandstones and Tertiary ferricretes (Fig. 2). Some of the deepest caves on the Australian mainland are developed at Bungonia Caves in massive limestone members of the Bungonia Group (Bauer, 1994). Osborne (1993a) recognised that modern (i.e latest Cretaceous to Recent) cave development at Bungonia involved a latest Cretaceous to Early Tertiary phase of phreatic development, a period of cave filling and a Late Tertiary to Recent phase of exhumation and vadose incision.

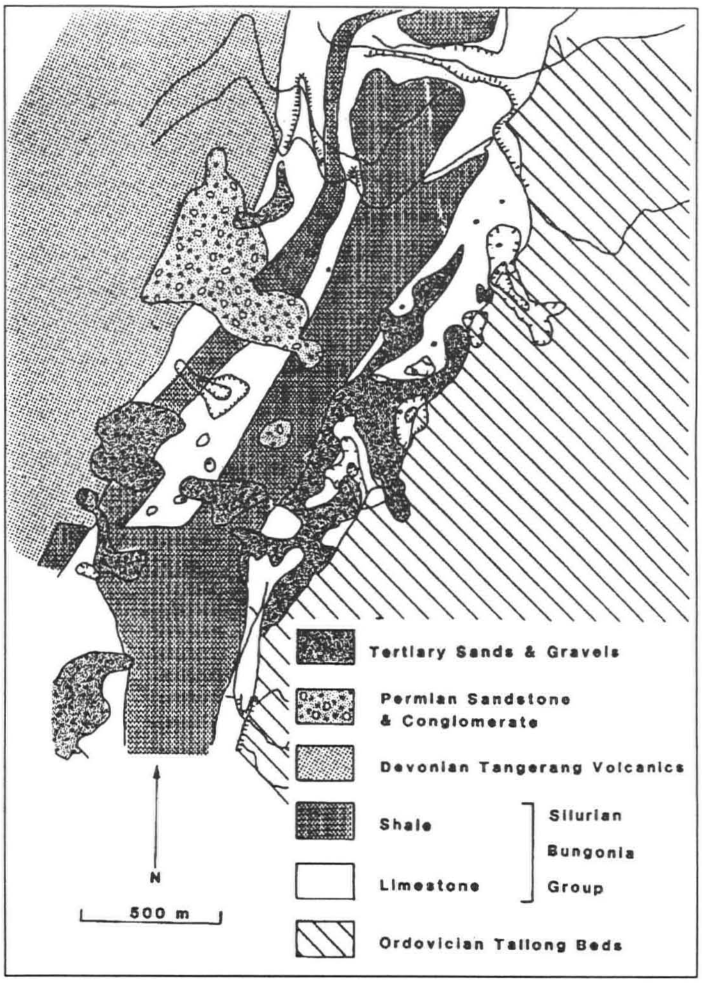


Figure 2. Bungonia Caves.

Osborne (1987) identified both carbonate and siliclastic palaeokarst deposits at Bungonia Caves. The carbonate palaeokarst deposits, which included breccias and graded-bedded crinoidal grainstones, were found exposed in the caves and at the surface in deposits that were clearly truncated palaeokarst features. Secondary dolomite and pyrite were common constituents of the carbonate palaeokarst facies. The siliclastic

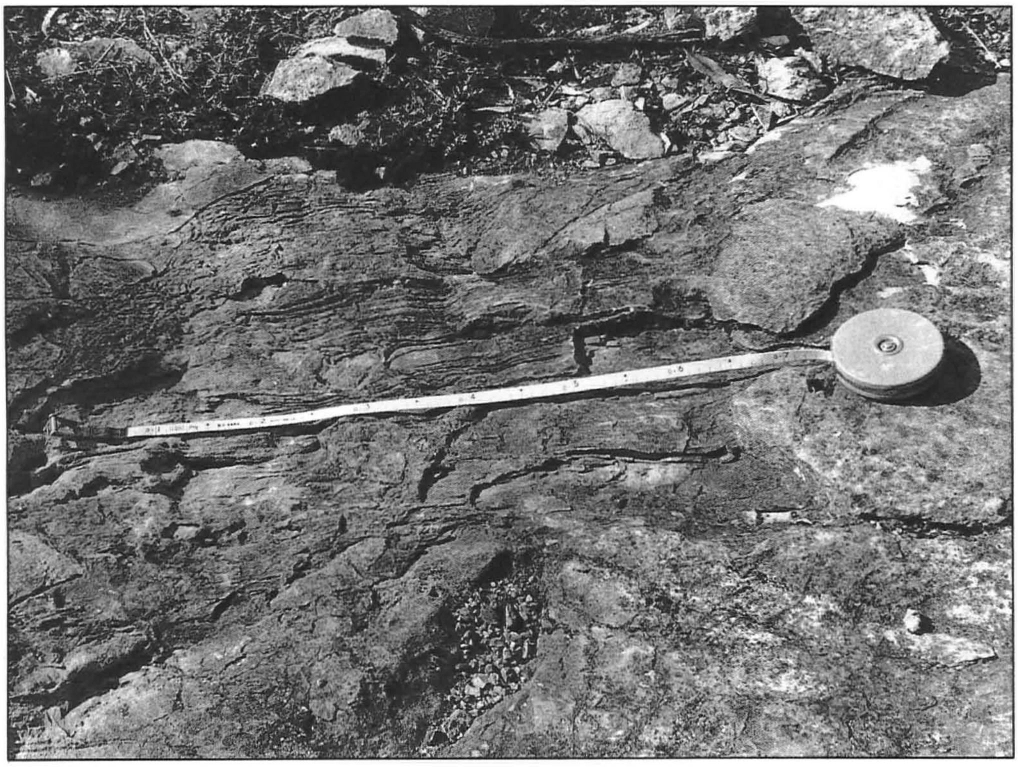


Plate 1. Exposure of laminated carbonate palaeokarst at Bungonia Caves in flat eroded limestone surface. Bedding runs parallel to tape measure.

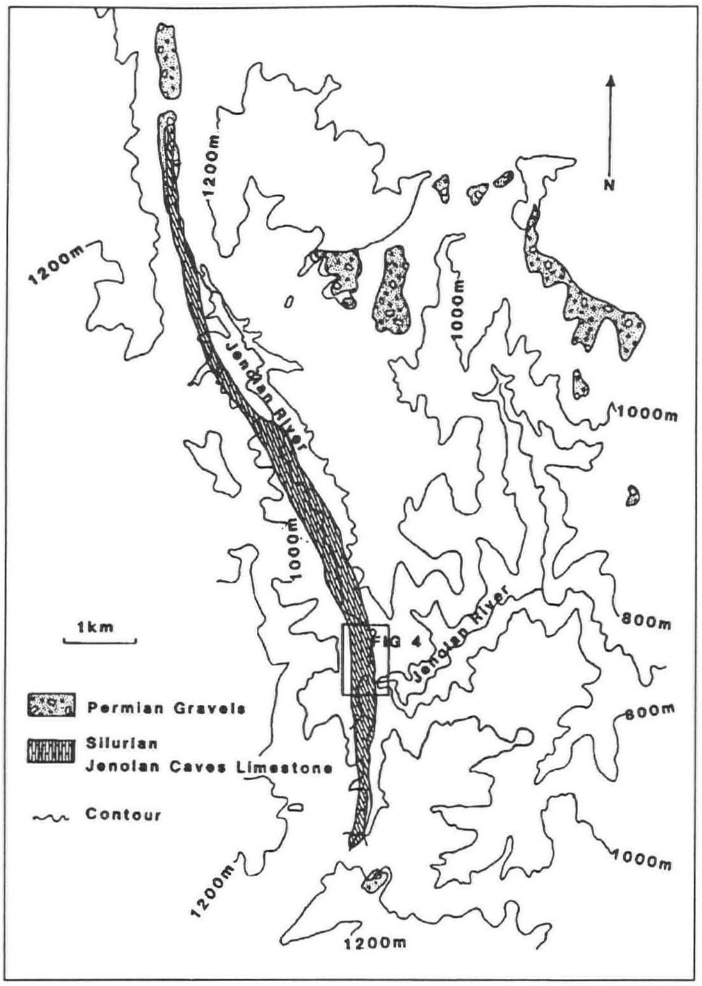


Figure 3. Outcrop of the Jenolan Caves Limestone.

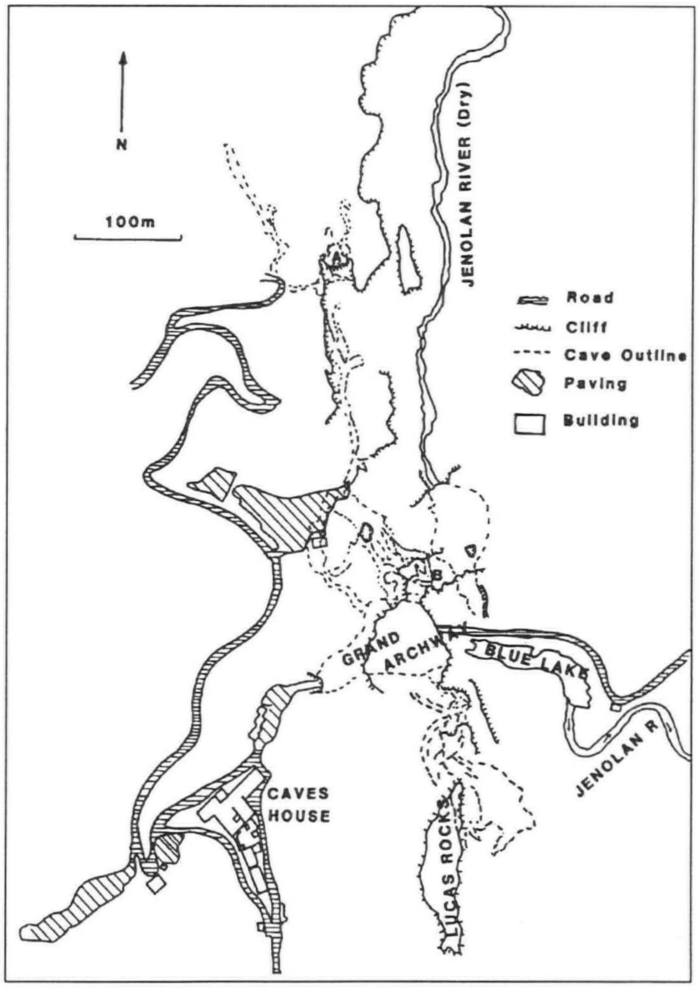


Figure 4. Jenolan Caves.

facies consist of quartz wackes and sandy mudstones, and contain no carbonate. They are similar to sandstones from the Permo-Triassic Sydney Basin Sequence, which are found in surface outcrop. Limonite pseudomorphs after secondary pyrite are common in the siliclastic palaeokarst facies.

Outcrops that expose the boundary between the carbonate and siliclastic palaeokarst deposits are yet to be found at Bungonia. Their quite different compositions, the truncation of carbonate palaeokarst deposits at the ground surface, the lack of cover similar to the carbonate palaeokarst on the surface and the presence of Permian sandstones very similar to the siliclastic palaeokarst deposits are consistent with there being an erosional (disconformable) boundary between the two palaeokarst facies.

Jenolan Caves, New South Wales

Jenolan Caves, Australia's premier show cave locality, are developed in the Late Silurian Jenolan Caves Limestone, which crops out as a series of limestone bluffs in deeply incised topography close to the western margin of the Sydney Basin (Fig. 1, "B").

Osborne (1991, 1993b) recognised the presence of laminated and graded-bedded carbonate palaeokarst deposits of marine origin at Jenolan Caves, including graded-bedded crinoidal grainstones, considering them to be Permo-Carboniferous in age on account of their lack of deformation and unconformable relationship with the Jenolan Caves Limestone. The carbonate palaeokarst deposits are exposed in the caves and in surface outcrop, where they form vein and fissure fillings. Secondary dolomite and pyrite are present in these deposits. Remnant Permian gravels occur within 3km of the caves. Recent work by Dougherty (pers. comm.) has shown the presence of in-situ Permian gravels low in the landscape, within the valley of Camp Creek ("A" in Fig. 4).

Gravels similar to those recognised as Permian by Dougherty occur commonly in places on the limestone and as cave fillings in the area of the Jenolan Caves system. Some workers, e.g. D. Branagan (pers. comm.), have considered these gravels also to be of Permian age. One particular group of suspected Permian gravels are those filling Dreamtime Cave (Fig. 4, "A"), a high level cave remnant located directly below a river terrace. As these gravels are apparently unfossiliferous, the question of their age has until now remained open. Recent examination of the gravels from Dreamtime Cave has shown that secondary pyrite is developed in the carbonate cement of the gravels. This strongly suggests that they are not Cainozoic in age, but are Permian sediments that have been subjected to the same dolomitisation and pyrite emplacement event that has affected the carbonate palaeokarst deposits.

Similar gravels exposed in Arch Cave (Fig. 4, "B"), which also contain secondary pyrite, have an erosional boundary with, and clearly postdate, laminated carbonate palaeokarst deposits. Thus, at Jenolan Caves there is now evidence of two phases of Late Palaeozoic karstification and filling, separated by an erosional event.

Lune River Quarry and Exit Cave, Tasmania

At Ida Bay (Fig. 1, "C") in south-east Tasmania, extensive caves, including Exit Cave considered to be the most extensive cave in eastern Australia, are developed in the Ordovician Gordon Limestone. Exit Cave is developed under Marble Hill (Fig. 5) which has a sandstone cap where the Gordon Limestone is unconformably overlain by clastic rocks of the Permian Parmeener Supergroup, one of the oldest units in the Tasmania Basin. Lune River Quarry, north-east of Marble Hill, exposes caves and stream sinks that drain into Exit Cave (Kiernan, 1993).

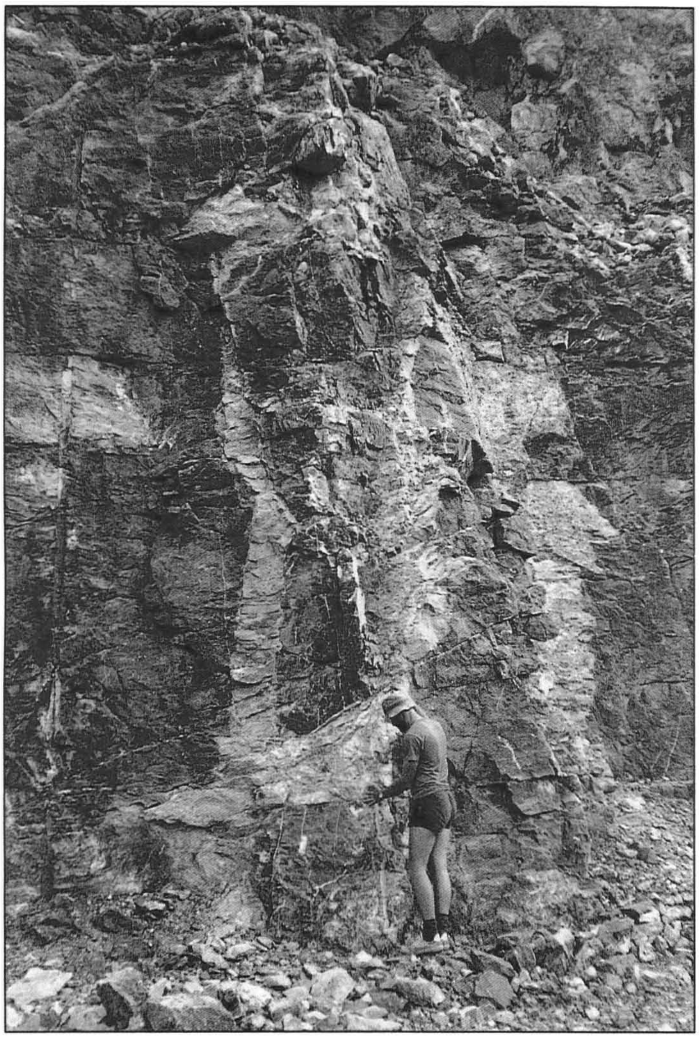


Plate 2. Fissure fills of marine laminated carbonate, light coloured, in Ordovician Gordon Limestone , dark coloured, at Lune River Quarry.

Sharples (1979) recognised fissure-filling sediments in the quarry and considered that they had a tectonic origin. Work in progress by the author in association with I. Cooper, Department of Geology and Geophysics, University of Sydney, has shown that these sediments are palaeokarst deposits. Two principal facies are recognised, a marine carbonate facies, including graded-bedded crinoidal grainstones, and a diamictite facies similar to the overlying strata of the Permian Parmeener Supergroup. Secondary pyrite is found in both facies.

As is the case at Bungonia, exposures have yet to be found at Ida Bay that expose the boundary between the siliclastic and carbonate facies of the palaeokarst. However, the compositional and hence provenance differences between the facies, the lack of strata similar to the carbonate facies overlying the limestone and the similarity between the diamictites and the overlying strata suggest that the two palaeokarst facies have a disconformable relationship; the diamictite facies is the younger.

DISCUSSION

The regional geological settings of Bungonia, Jenolan and Ida Bay indicate that the three karst regions have very similar Late Palaeozoic histories. In each case the limestone was exposed to subaerial conditions prior to the deposition of Permo-Triassic basinal sequences that unconformably overlie, or are exposed in close proximity to the limestone. Comparison of the palaeokarst stratigraphy at the three localities has revealed a number of similarities:-

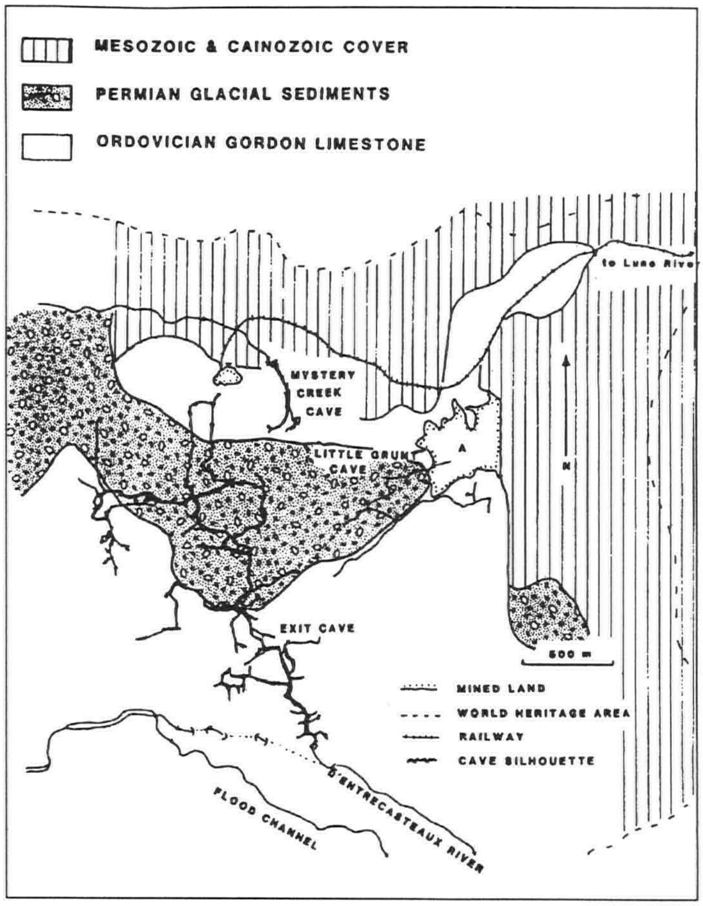


Figure 5. Exit Cave and the Lune River Quarry.

1) Marine carbonate palaeokarst deposits, including graded-bedded crinoidal grainstones, and siliceous palaeokarst deposits are found at all three localities;

2) Secondary pyrite is found in both carbonate and siliceous palaeokarst deposits at all three localities;

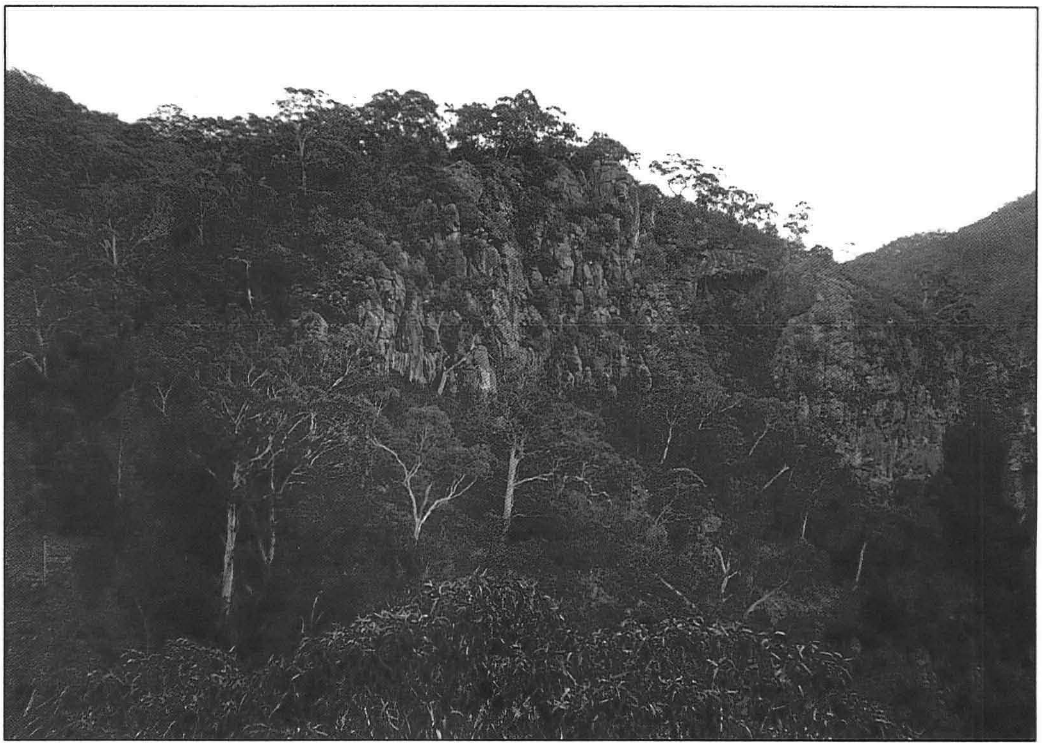
3) No surface exposures have been found of strata similar to the carbonate facies of the palaeokarst deposits, except where they form vein deposits or fill clearly truncated palaeokarst features;

4) Clastic palaeokarst sediments similar to the overlying Permian sediments have been relatively easy to recognise at Bungonia and Ida Bay, but only the recognition of secondary pyrite has allowed Permian clastic palaeokarst sediments at Jenolan Caves to be distinguished from Cainozoic sediments of similar composition;

5) There is clear evidence at Jenolan and inferential support from Bungonia and Ida Bay for an erosional (disconformable) boundary between older marine carbonate palaeokarst deposits and younger siliclastic palaeokarst deposits.

Taken together these observations indicate that two phases of karstification and filling occurred in limestones exposed during the Late Palaeozoic in south-eastern Australia. The first phase of karstification, which at Jenolan (Osborne 1991, 1993, 1994) produced large phreatic conduits, and at Ida Bay formed fissures and dolines, ended when a marine transgression covered the limestones and introduced crinoidal sands and lime-muds in to the caves and other karst cavities. As no trace of these crinoidal limestones is found overlying the surface of the limestone, and there are good exposures of truncated filled palaeokarst features at Bungonia and Jenolan, a period of significant erosion must have followed filling of the first phase of cave development. Given the

Plate 3. Dreamtime Cave, left background, viewed looking west.



similarity of the siliclastic palaeokarst sediments to the Permo-Triassic strata unconformably overlying the limestones, it would seem most likely that the erosional event responsible for the second phase of karstification and truncation of the carbonate palaeokarst deposits is that which produced the landsurface forming the basal unconformity of the Sydney and Tasmania Basins.

As determinable fossils have yet to be found in the marine carbonate palaeokarst facies its age remains problematical. Osborne (1991) considered the marine carbonate palaeokarst facies to be either Permian or Carboniferous in age for the reasons outlined above; lack of Early Carboniferous folding and truncation by modern caves. The recognition of two phases of karstification in the Late Palaeozoic, however, complicates this matter.

Crinoidal and oolitic limestones are found in Carboniferous and Permian strata in the the New England Fold Belt, to the north of the Sydney Basin (Fig. 1). The Early Carboniferous limestones (Engel, 1980), formed at about the time that the Lachlan Fold Belt was undergoing the Kanimblan Orogeny. The Permian limestones are contemporaneous with Early Permian marine strata of the Sydney Basin which overlie glacial deposits at the margins of the Sydney Basin. The marine carbonate palaeokarst facies could represent a slightly younger episode of Carboniferous marine sedimentation. If this is the case then initial Late Palaeozoic karstification probably occurred in the latest Early Carboniferous or the earliest Late Carboniferous (Viséan to Namurian) following cessation of folding. The marine carbonate palaeokarst facies would then be likely to be of Late Carboniferous age.

Plate 4. Exposure of laminated palaeokarst and gravel in Arch Cave. Laminated carbonate palaeokarst (centre, bedded, near lens cap) is truncated by pyrite-bearing highly cemented gravel (right, mottled). Grey rock forming cave roof is Late Silurian Jenolan Caves Limestone.

Gravels near the edge of the Sydney Basin, such as those at Jenolan Caves are commonly interpreted as having a glacial origin (Herbert, 1980b). Where it has been possible to date such gravels by palynology (Herbert, 1980a) a Latest Carboniferous to Earliest Permian (Stephanian to Sakmarian) age is indicated. This would suggest that the second period of karstification took place in the Latest Carboniferous and that filling of the caves and burial of the limestones occurred in the Latest Carboniferous to Earliest Permian.

From the data currently available, from a consideration of the regional geological history, and without the benefit of biostratigraphy or absolute dating, the following outline gives the probable history of karstification during the Late Palaeozoic in south-eastern Australia:-

1	Early Carboniferous (Viséan)	regression, uplift and folding during Kanimblan Orogeny
2	Late Early Carboniferous (Viséan)	exposure leading to extensive karstification, extensive phreatic conduits develop at Jenolan, dolines at Ida Bay, fissures at Bungonia, Ida Bay and Jenolan
3	Late Carboniferous (Namurian or Westphalian)	marine transgression; caves, fissures and dolines filled with crinoid debris and lime mud
4	Latest Carboniferous (Westphalian or Stephanian)	regression and major erosional event, probably associated with glaciation, large caves formed at Jenolan, fissures at Bungonia and Ida Bay
5	Latest Carboniferous to earliest Permian (Stephanian to Sakmarian)	gravels, diamictites and quartz sandstones fill caves and fissures
6	Post Early Permian	dolomite and pyrite emplaced in palaeokarst sediments by basinal fluids.

ACKNOWLEDGEMENTS

Ian Cooper, Nigel Scanlan, Steve Reilly, Julie Bauer, Arthur Clarke and Ian Houshold assisted with field work. The National Parks and Wildlife Services of New South Wales and Tasmania and the Jenolan Caves Reserve Trust permitted sampling from their caves. Research has been assisted by funding from the University of Sydney Research Grants Scheme and an Australian Research Council Small Grant. I would particularly like to thank Ian Percival for reviewing the typescript.

REFERENCES

Bauer, J, 1994. The Siluro-Devonian Bungonia Group, Southern Highlands, NSW. *Helictite*, Vol. 32 (2), 25-34.

Cas, R, 1983. *Palaeogeographic and tectonic development of the Lachlan Fold Belt in southeastern Australia.* Geological Society of Australia, Special Publication No 10, 104pp.

Engel, B A, 1980. Carboniferous biostratigraphy of the Hunter-Manning-Myall Province. *New South Wales Geological Survey Bulletin,* Vol. 26, 340-349.

Herbert, C, 1980(a). Southwestern Sydney Basin. *New South Wales Geological Survey Bulletin,* Vol. 26, 82-99.

Herbert, C, 1980(b). Evidence for glaciation in the Sydney Basin and the Tamworth Synclinorial Zone. *New South Wales Geological Survey Bulletin,* Vol. 26, 274-293.

Houshold, I and Spate A, 1990. The Ida Bay karst study, geomorphology and hydrology of the Ida Bay karst area. Report to the World Heritage Planning Team, Department of Parks, Wildlife and Heritage, Tasmania. Unpublished, 63pp.

Kiernan, K, 1993. The Exit Cave Quarry: Tracing waterflows and resource policy evaluation. *Helictite,* Vol. 31(2), 27-42.

Osborne, R A L, 1984. Multiple karstification in the Lachlan Fold Belt in New South Wales: Reconnaissance evidence. *Journal and Proceedings of the Royal Society of New South Wales,* Vol. 117, 15-34.

Osborne, R A L, 1987. Multiple karstification: The geological history of karsts and caves in New South Wales. Unpublished PhD thesis, University of Sydney.

Osborne, R A L, 1991. Palaeokarst deposits at Jenolan Caves, New South Wales. *Journal and Proceedings of the Royal Society of New South Wales,* Vol. 123, 59-73.

Osborne, R A L, 1993(a). A new history of cave development at Bungonia, N.S.W.. *Australian Geographer,* Vol. 24(1), 62-74.

Osborne, R A L, 1993(b). Geological Note: Cave formation by exhumation of Palaeozoic palaeokarst deposits at Jenolan Caves, New South Wales. *Australian Journal of Earth Sciences,* Vol. 40 (6), 591-593.

Osborne, R A L, 1994. Caves, dolomite, pyrite, aragonite and gypsum : The karst legacy of the Sydney and Tasmania Basins. *Twenty Eighth Newcastle Symposium on "Advances in the Study of the Sydney Basin"*, University of Newcastle (N.S.W. Australia) Department of Geology Publication. No. 606, 322-324.

Osborne, R A L and Branagan, D F, 1988. Karst Landscapes of New South Wales. *Australia. Earth-Science Reviews,* Vol. 25, 467-480.

Sharples, C E, 1979. The Ordovician System in the Ida Bay Area. BSc (Hons) Thesis, University of Tasmania, unpublished.

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Transactions of the British Cave Research Association

Forum

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

SCIENTIFIC NOTES

AN ACCOUNT OF PSEUDO-PLEOCHROISM IN SOME BRITISH SPELEOTHEMS

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INTRODUCTION

When viewed in thin section, a mineral's colour is the result of certain wavelengths of white light having been absorbed. In anisotropic minerals, the wavelengths and amount of light absorbed depend upon the direction in which the transmitted light vibrates. Thus, by rotating an anisotropic mineral in plane-polarized light (i.e. light that is vibrating in one plane), a colour change may be observed. This phenomenon is known as *pleochroism*. An anisotropic mineral may exhibit a pleochroic scheme of up to three 'end-member' colours, one for each of the three possible refractive indices (RIs) that such minerals can have.

Calcite, the most frequent mineral occurring in speleothems, has 2 refractive indices, the ordinary index (ω) and the extraordinary index (ε); the latter is coincident with calcite's **c** crystallographic axis. In thin section, calcite is colourless and displays no pleochroism.

An allied effect to pleochroism is that of *pseudo-pleochroism*. It is caused by the scattering of light by inclusions in the host mineral producing an apparent absorption. Sandberg and Hudson (1983) noted that there was no consistent relationship between the orientation of inclusions and the host mineral in calcite-replaced *Neomiodon* bivalve shells. They suggested, therefore, that the pseudo-pleochroism was controlled by the optic orientation of the host. The variable intensity of pseudo-pleochroism reflects the inclusion's refractive index being closer to one of the host's RIs than the others.

PSEUDO-PLEOCHROISM IN CALCITE

The presence of pseudo-pleochroism in formerly aragonitic, now calcite-replaced, fossil shells has been known for quite some time (e.g. in the bivalve *Neomiodon*; Hudson, 1962) and for even longer in other cases (e.g. calcite-replaced olivine in andesite (Schöder van der Kolk, 1900) and calcite in arkose (Corin, 1931)). Hudson (1962) and Sandberg and Hudson (1983) have observed that the *Neomiodon* shells exhibit a deep brown colour when the plane-polarized light is coincident with the index whilst they are colourless (or nearly so) when the light is coincident with the index. The pseudo-pleochroic colour schemes of Schöder van der Kolk's (1900) and Corin's (1931) samples, however, are reversed (i.e. ε = colourless, ω = brown) reflecting different types of inclusions to those in the calcite-replaced *Neomiodon* shells. Hudson (1962) and Sandberg and Hudson (1983) also reported a reversed pseudo-pleochroic colour scheme in unrecrystallized (i.e. aragonite) *Neomiodon* shells. Sandberg and Hudson (1983) found that the inclusions in the calcite-replaced *Neomiodon* shells were aragonite relics believed to be coated in organic sheaths probably of degraded conchiolin from the original shell. Hudson (1962) suggested that the inclusions in Schöder van der Kolk's (1900) and Corin's (1931) samples were likely to be colloidal clays.

PSEUDO-PLEOCHROISM IN SPELEOTHEMS

Kendall and Broughton (1978) noted pseudo-pleochroism in the calcite speleothems they examined and found ε = colourless and ω = mid-brown (i.e. opposite to the calcite-replaced shells of Hudson (1962) and Sandberg and Hudson (1983)), but did not identify the inclusions in their samples. Essentially the same colour scheme as noted by Kendall and Broughton (1978) was observed by the current author in flowstones from Cwm Dwr Quarry, Cwm Dwr Quarry Cave (both South Wales, NGR SN 857 156) and Eldon Hill Quarry (Derbyshire, NGR SK 116 812). Plates 1 and 2 show an example from Eldon Hill Quarry.

Plates 1 and 2. Pseudo-pleochroism displayed in laminae in flowstone EHF1 (Eldon Hill Quarry, Derbyshire).
Note particularly the 3 central laminae. Scale bars are 0.125mm. Plane polarized light. (Both photo's: A.M. Perkins).

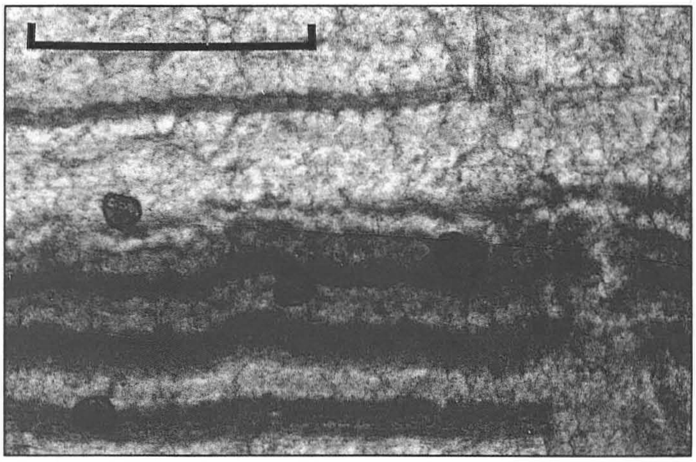

Plate 1: Light vibration direction is E-W (coincident with the index), laminae are a mid-brown.

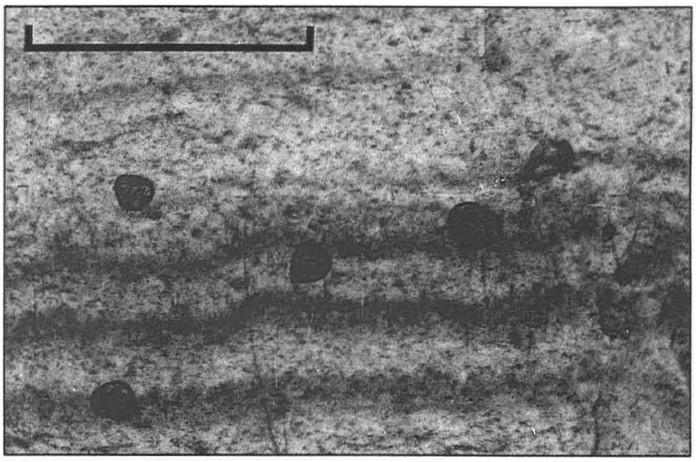

Plate 2: Light vibration direction is N-S (coincident with the index), laminae are a very-light brown.

In the material reported here, specific identification of the inclusions was not attempted, but it was found that laminae exhibiting pseudo-pleochroism fluoresce under ultra-violet light indicating a significant content of organic material. Under high-magnification, these organic-rich laminae have a diffuse, brown, semi-translucent appearance. Such organic matter is either deposited by floodwaters or introduced with the feedwaters from surface soil horizons. The latter case seems more likely as the organic matter does not seem to be associated with significant quantities of detritus that one might expect if deposited by floodwaters (the fissures used by the feedwaters usually being sufficiently constricted to exclude all but very fine-grained detritus). Specific identification of the organic matter has not been attempted.

Non-organic inclusions cannot be disregarded, however. X-ray diffraction of residues remaining after dissolution in buffered ethanoic acid showed the presence of quartz and the clay mineral chlorite in the Derbyshire samples and quartz in the Welsh samples (Perkins, 1993). It is possible, therefore, that very fine-grained detritus, beyond the resolution of the optical microscope, may contribute in part to the scattering of light akin to Hudson's (1962) suggestion of Schröder van der Kolk's (1900) and Corin's (1931) samples (*q.v.*). Whatever the identity of the inclusions in the speleothems, their RI must be closer to the opposite RI in calcite to that of the inclusions in Sandberg and Hudsons' (1983) calcite-replaced shells.

SUMMARY

The phenomenon of pseudo-pleochroism caused by the scattering of light by inclusions in a host mineral has been observed in several speleothems. The inclusions in these cases seem to be (unidentified) organic material often occurring as laminae. The organic material is probably introduced onto the speleothem in feedwaters and derives from surface soil horizons. Very fine-grained detritus, beyond the resolution of the optical microscope, may also contribute to the scattering of light.

The pseudo-pleochroic colour scheme observed for calcite speleothems is ε = colourless (or nearly so, often a very pale brown) and ω = mid-brown.

ACKNOWLEDGEMENTS

AMP would like to thank: Dr. Peter Smart for involvement in the Eldon Hill Quarry Project and Ready Mixed Concrete for access to it; Dr. Julian Andrews for discussions on pseudo-pleochroism. This work formed part of a doctoral thesis for which AMP received a NERC studentship (No. GT4/89/GS/030).

REFERENCES

Corin, F, 1931. Contribution à l'étude de la pseudo-absorption, *Bull. Soc. franç. Minér.*, 54, 57-63.

Hudson, J D, 1962. Pseudo-pleochroic calcite in recrystallized shell-limestones, *Geol. Mag.*, 99, 492-500.

Kendall, A C and Broughton, P L, 1978. Origin of fabrics in speleothems composed of columnar calcite crystals, *Jnl. Sedimentary Petrology*, 48(2), 519-538.

Perkins, A M, 1993. Magnetic studies of speleothems, Unpublished Ph.D. thesis, Univ. East Anglia, 244pp + appendices.

Sandberg, P A and Hudson, J D, 1983. Aragonite relic preservation in Jurassic calcite-replaced bivalves, *Sedimentology*, 30, 879-892.

Schröder van der Kolk, J L C, 1900. Beiträge zur Kenntniss der Gesteine aus dem Molusken III Gesteine von Buru, *Zbl. Miner. Geol. Paläont.*, for 1900, 373-374.

RADON, CAVES AND RABBITS

David PRIME
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Magicians have traditionally astounded an audience (not necessarily a naive one) by producing rabbits from hats where all logic suggests a rabbit could not possibly be. What has this got to do with radon and caves? Showing admirable sleight of hand, the International Commission on Radiological Protection (ICRP) appear to have produced a logic-defying trick with radon and dose limits. In 1991 the ICRP suggested the adoption of a new set of dose limits for persons occupationally exposed to radiation. This involved the reduction of the present equivalent dose limit of 50 mSv/y (millisieverts per year) to 20 mSv/y and reflected concern that radiation is more likely to cause cancer than had previously been thought. In terms of the most commonly used and understood unit for radon progeny, the present dose limit is 4 WLM (Working Level Months). The WLM is the radiation dose received if a person is exposed to a concentration of radon progeny of 1 WL (Working level) for a working month of 170 hours. Since 4 WLM were thought, from respiratory tract modelling, to be equivalent to 50 mSv, it would have seemed logical that the new dose limit for radon progeny would be reduced accordingly.

This is where the rabbit is pulled out of the hat. The ICRP have introduced a different approach to radon detriment based on epidemiology (ICRP, 1994). Introducing a term called a 'conversion convention' they suggest that 1 WLM only seems to give a chance of developing cancer equivalent to an equivalent dose of 5 mSv. The new limit of 20 mSv/y is therefore equivalent to an exposure of 4 WLM -exactly the same as the present limit!

What does this mean to a caver? If you believe the new ICRP figures and spend 170 hours underground in a cave with a radon progeny concentration of 1 WL, the risk that you run is equivalent to receiving a radiation dose of 5 mSv. You would receive a similar radiation dose from 250 chest x-rays or 500 air flights from Britain to Spain! The chance of developing fatal cancer from this radiation dose is approximately 0.02%. This represents good news since previously the risk was calculated as about 0.04% (i.e. 4 in 10,000)!

REFERENCES

ICRP (1991). ICRP Publication 60 - 1990 Recommendations of the International Commission on Radiological Protection. *Annals of the ICRP*, 21 (1-3). Pergamon, Oxford, UK.

ICRP (1994). Protection Against Radon-222 at Home and at Work. ICRP Publication 65, *Annals of the ICRP*, 23 (2). Pergamon, Oxford, UK.

BAILEY, D.E., 1994

Habitat Reconstruction as a Technique for the Reclamation of Limestone Quarry Faces.

Unpubl. PhD thesis, Manchester Metropolitan University, England, 414pp incl. appendices. [Available from the British Library].

Modern limestone quarry faces are dangerous, conspicuous, engineered landforms which stand in stark visual, ecological and geomorphological contrast to the unexcavated landscape. Their reclamation is a fundamental mineral planning requirement but there are few practical, technical and economic techniques currently available to achieve this goal. With regard to this problem, research into 'Landform Replication as a Technique for the Reclamation of Limestone Quarries' was commissioned by the DoE in May 1988. 'Landform Replication' aims to construct, from disused limestone quarry faces, landform/vegetation assemblages which resemble those in the unexcavated landscape around the quarry. The first stage of 'Landform Replication' is *Restoration Blasting*, a drilling and blasting technique which constructs from quarry faces a suite of landforms whose outward form replicate those of natural limestone slopes. The second stage is *Habitat Reconstruction*, which aims to establish self-sustaining plant communities which resemble those of the natural limestone slopes on the restoration blasted landforms. The present thesis addresses the problems associated with Habitat Reconstruction.

The research was undertaken in the White Peak of Derbyshire at Buxton Lime Industries Tunstead Quarry and Blue Circle Industries Hope Quarry. The aim of the research was to determine whether vegetation could be established on limestone rock landforms constructed by restoration blasting such that the resulting daleside landform sequences **visually resemble**, and **function in a similar way** to, the natural limestone dalesides in the White Peak. In particular the research sought to examine whether grassland similar to that of the NVC calcicolous community, Festuca ovina - Avenula pratensis grassland, Dicranum scoparium sub-community (typical of the White Peak dalesides) could be established on the restoration blasted landforms. Tree establishment was also examined because of the visual and ecological importance of tree cover as a component in natural dalesides.

An informed understanding of both natural and excavated limestone rock slopes and the ecosystems they support was considered essential to Habitat Reconstruction. Thus, the climate, geology, geomorphology, hydrology, soils and vegetation associated with natural limestone dalesides was examined, a daleside model for replication selected and its frequency in the White Peak identified. The geomorphological and ecological development of excavated limestone rock slopes in disused black powder quarries was also studied to determine whether active revegetation is required to achieve an ecosystem which resembles the daleside model. The results of the investigation suggest that, in the absence of intervention, the probable fate of restoration blasted landforms would be the gradual development, over many years, of an open tree community. As the time-scale for restoration in modern quarries is normally driven by planning conditions it was considered that active revegetation will be required. Thus, the potential for limestone grassland and tree establishment on restoration blasted landforms was assessed.

The physical characteristics of the scree blast piles produced by restoration blasting made it necessary to identify a cover material which could act as a substrate for grassland establishment. The use of top soil other than that from a daleside, was rejected on ecological and economic grounds. Alternative materials, comprising wastes and stone of low economic value produced during the quarrying operation, were investigated. The limitations of the materials were poor water retention, a high pH and a low content of essential plant nutrients, especially nitrogen and phosphorus. Laboratory and quarry floor field trials were designed to identify the most suitable cover materials, the need for organic amelioration treatments, the application rate of phosphorus fertiliser, the nature and amount of nutrient capital to be applied and the most suitable legume species. The conclusions drawn from these trials were used to design a revegetation strategy for the landforms constructed by restoration blasting. A series of large scale landform replication projects were carried out and these provided further knowledge about Habitat Reconstruction. The grasslands established on the landforms were in the correct spectrum of the NVC communities although the swards most closely resembled a Avenula pubescens grassland community rather than the Festuca ovina - Avenula pratensis grassland.

Tree establishment on the daleside landform sequences was also examined. Trees were planted into the rock screes generated by restoration blasting at Tunstead Quarry and into the cover material applied to the restoration blasted landform at Hope Quarry. Tree planting into the applied cover material resulted in few losses (1%) whilst tree planting directly into the rock screes resulted in only 18 - 21% losses over a twenty eight month period despite below average summer rainfall and a large rabbit population.

HYLAND, R.Q.T., 1995

Spatial and temporal variations of radon and radon daughter concentrations within limestone caves.

Unpublished PhD thesis, the University of Huddersfield, Huddersfield, England, 213pp plus figures and tables [Available from the British Library]

This thesis outlines results from an investigation of radon and radon daughter concentrations in limestone caves, from a geographical and geological perspective. Investigations were conducted at all geographical scales, ranging from a national investigation in the four major caving regions of England and Wales to a detailed survey within a single cave in the Peak District.

The measured radon concentrations in some limestone caves in England and Wales are amongst the highest ever recorded in the world. Significant spatial and temporal variations were recorded in concentrations at all scales, within a single cave, between caves in the same region and between different regions. Additionally, seasonal and diurnal variations in concentrations were highlighted. External climatic variables and the cave radon budget were demonstrated to account for variations in cave radon concentrations.

Within limestone caves seven primary sources of radon were identified and the relative importance of each to the overall radon budget was determined. Sediments and the containing limestone rock were the major sources although in certain cases water and the soil were demonstrated to be influential.

Models were developed to predict cave radon concentrations within a single cave. However, these could not be transposed to predict radon concentrations in other caves in the same region or other regions.

The users of limestone caves were identified, their potential exposure times were examined and legislation concerning their exposure was discussed. Four groups were identified as being at risk from radon while underground, and three groups were identified as being at little risk. Methods by which the risk from radon exposure can be reduced were examined.

HARDWICK, P., 1995

The Impact of Agriculture on Limestone Caves: With Special Reference to the Castleton Catchment, Derbyshire.

Unpublished PhD Thesis, Manchester Metropolitan University, March 1995, 225pp.

This thesis addresses the shortfall in knowledge of environmental and anthropogenic impacts on karst geoecosystems and particularly the impacts of agriculture on limestone caves. This shortfall is considered detrimental to the conservation of British caves. Documented agricultural impacts in the British and international literature are reviewed, and a general theoretical model to predict the potential impacts of agricultural practices on caves is proposed. The model is tested by a detailed study of the P8 cave, Castleton, Derbyshire, and its relatively intensively farmed autogenic catchment. Two factors, plant nutrient and clastic sediment inputs to caves, received particular attention. Data from this study is compared with those obtained from caves beneath less-intensively farmed land both in the Castleton catchment and elsewhere in Britain.

Concentrations of nitrogen and phosphorus were found to be significantly higher in autogenic recharge to P8 than to caves beneath less-intensive land-uses. This is thought to be due to applications of phosphate and nitrate rich fertilisers, including digested sewage sludge, to the field above the cave. High levels of nitrite in autogenic recharge to P8 suggest that sludge leachate is rapidly transmitted through the soil and drift cover. Soil investigations revealed a marked degree of anisotropy due to macropores. These function as extensions of karst drainage systems into the soil zone, thereby linking the land surface to the cave. The presence of the radionuclide ^{137}Cs at depth in macropores but not in the surrounding soil, indicates clast migration by turbulent flow. ^{137}Cs-labelled sediments washed into the cave by percolation waters suggest a direct route from the land surface, contrary to what would be expected from the Translatory Flow Model of Bull (1981). The sediment transmission rate of c. 0.5m a^{-1} is two orders of magnitude greater than previously recorded. However, an estimated mechanical erosion rate of $0.3 m^3 km^{-2} a^{-1}$ for a vadose flow in P8 is negligible compared to solutional erosion rates for the outcrop.

The demonstrated rapidity of sediment movement from the surface to the underlying cave indicates that agrochemicals normally considered immobilised on soils could impact on karst geoecosystems and groundwater quality if transported into the subcutaneous zone, bedrock, or caves. Previously, it has been assumed that a thick mantle of soil or drift deposits overlying a cave provides a buffer against such agrochemicals. In this regard, the soil zone has been shown to be of particular importance in the Castleton karst, and elsewhere deserves far more attention than has previously been given.

The thesis focused on inputs of sediment in autogenic recharge, but measurements were also made of sediment inputs from two contrasting allogenic streams. The inputs from P6 (16.1-29.5 t $km^{-2} a^{-1}$) draining an improved catchment, were an order of magnitude greater than from the unimproved P10 catchment (1.5 t $km^{-2} a^{-1}$). However, in the absence of any catchment disturbance by agriculture during the study period, it was not possible to determine whether the differences are a result of natural or of anthropogenic change.

CORRIGENDUM

THESIS ABSTRACT - PERKINS, A.M., 1993
Cave and Karst Science, Vol. 21 (3), p. 115.

The last line of the third paragraph should read:

"On a qualitative basis, however, detrital grains (<0.01 µm to >10 µm, composed of magnetite, hematite and titanomagnetite), hexagonal or cubic grains (<0.01 µm, composed of magnetite) and needle-like grains (<2 µm, possibly goethite) have been observed."

RESEARCH FUNDS AND GRANTS

THE JEFF JEFFERSON RESEARCH FUND

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

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

The award scheme will not support the salaries of the research worker(s) or assistants, attendance at conferences in Britain or abroad, nor the purchase of personal caving clothing, equipment or vehicles. The applicant(s) must be the principal investigator(s), and must be members of the BCRA in order to qualify. Grants may be made to individuals or small groups, who need not be employed in universities or research establishments. Information and applications for Research Awards should be made on a form available from Simon Bottrell, Dept. of Earth Sciences, University of Leeds.

GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a minimum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Farm Barn, Cutler's Lane, Castlemorton Common, Malvern, Worcs., WR13 6LF. Closing date 1st February.

NCA/ENGLISH SPORTS COUNCIL GRANT AID IN SUPPORT OF CAVING EXPEDITIONS ABROAD

Grants are given annually to all types of caving expeditions going overseas from the UK (including cave diving), for the purpose of furthering cave exploration, survey, photography and training. NCA delegates administration of the awards to the Ghar Parau Foundation, to prevent duplication of cost and effort, and to provide a desirable degree of independence from NCA. Application arrangements are as for Ghar Parau Foundation Expedition Awards, see above.

Expedition organisers living in Wales, Scotland or Northern Ireland, or from caving clubs based in those regions should contact their own regional Sports Council directly in the first instance. It is possible that the inauguration of the National Lottery may result in different arrangements for grant aid.

THE E.K.TRATMAN AWARD

An annual award, currently £50, made for the most stimulating contribution towards speleological literature published within the United Kingdom during the past 12 months. Suggestions are always welcome to members of the GPF Awards Committee, or its Secretary, David Judson, not later than 1st February each year.

BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

CAVE & KARST SCIENCE - published three times annually, a scientific journal comprising original research papers, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.
Editors: Dr. D.J. Lowe, c/o British Geological Survey, Keyworth, Notts NG12 5GG and Professor J. Gunn, Limestone Research Group, Dept. of Geographical and Environmental Sciences, University of Huddersfield, Huddersfield HD1 3DH.

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

CAVE STUDIES SERIES - occasional series of booklets on various speleological or karst subjects.
No. 1 Caves & Karst of the Yorkshire Dales; by Tony Waltham and Martin Davies, 1987. Reprinted 1991.
No. 2 An Introduction to Cave Surveying; by Bryan Ellis, 1988. Reprinted 1993.
No. 3 Caves & Karst of the Peak District; by Trevor Ford and John Gunn, 1990. Reprinted with corrections 1992.
No. 4 An Introduction to Cave Photography; by Sheena Stoddard, 1994.
No. 5 An Introduction to British Limestone Karst Environments; edited by John Gunn, 1994.

SPELEOHISTORY SERIES - an occasional series.
No. 1 The Ease Gill System-Forty Years of Exploration; by Jim Eyre, 1989.

CURRENT TITLES IN SPELEOLOGY - from 1994 this publication has been incorporated into the international journal Bulletin Bibliographique Speleologique/Speleological Abstracts; copies of which are available through BCRA.

Obtainable from BCRA Administrator:
B M Ellis, 20 Woodland Avenue, Westonzoyland, Bridgwater, Somerset TA7 OLQ.