Cave Science

The Transactions of the British Cave Research Association

BCRA

Volume 12 Number 4 December 1985

Cave Science

The Transactions of the British Cave Research covers all aspects of speleological science, including geology, geomorphology, hydrology, chemistry, physics, archaeology and biology in their application to caves. It also publishes articles on technical matters such as exploration, equipment, diving, surveying, photography and documentation, as well as expedition reports and historical or biographical studies. Papers may be read at meetings held in various parts of Britain, but they may be submitted for publication without being read. Manuscripts should be sent to the Editor, Dr T. D. Ford, at the Geology Department, University of Leicester, Leicester LE1 7RH. Intending authors are welcome to contact either the Editor or the Production Editor who will be pleased to advise in any cases of doubt concerning the preparation of manuscripts.

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Abstract: All material should be accompanied by an abstract stating the essential results of the investigtation for use by abstracting, library and other services. The abstract may also be published in CAVES AND CAVING.

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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.

Illustration: 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 sequence 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.

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Speleological expeditions have a moral obligation to produce reports (contractual in the cases 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 latter 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.

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

Cave Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 12 Number 4 December 1985

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Cover: Looking out from an entrance of the Grotte d'Andrafiabé, at the tsingy (pinnacle) karst of Ankarana, Madagascar By Catherine Howard.

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NOTICE TO SUBSCRIBERS

Cave Science will in the future be published in three parts per volume, at the rate of one volume per year. This scheme starts with Volume 13 in 1986. The three parts will be issued in the spring, summer and winter of each year.

The number of pages will be increased in each issue. There will therefore be roughly the same length of material in future volumes as in past volumes; there will however be savings in production and distribution costs.

Indexes will be prepared to cover blocks of five volumes. The first will cover volumes 12 to 16 for 1985-1989 and will be issued with number 1 of volume 17 early in 1990. Annual indexes will no longer be prepared as they are rendered obsolete by the systematic keying of titles on the front cover of Cave Science.

CAVE SCIENCE Vol. 12, No. 3, December 1985
Transactions of the British Cave Research Association

Norway's Longest and Deepest Caves

David & Shirley ST. PIERRE

Abstract: Lists of Norway's longest and deepest karst and non-karstic caves are presented together with brief descriptions and details of exploration and survey. There are more than 23 caves over 100 m deep, and 34 caves over 1000 m long. The data has been abstracted from the authors' cave index and bibliography which was started in 1963. The deepest karst cave is Råggejavre-raige, -620 m, and the longest is the Okshola-Kristihola system with about 10 km of mapped passages. The deepest tectonic cave is Stygghølet -60 m; and the longest non-karstic cave is Halvikhulen a fossil sea cave, 340 m long.

INTRODUCTION

The majority of the limestone caves tabulated in the following lists of Norway's longest and deepest caves are situated in the fylke (county) of Nordland, between latitudes 65 and 68 degrees north. They are formed in marbles generally described as Cambro-Silurian though some may be Precambrian in age (Cribb, Norsk Geol. Tidsskr., 1981, 61: 97-110).

The references cited generally contain a description and often a survey of the cave concerned, though they are not necessarily an account of the first recorded exploration.

For conservation reasons it has been suggested that casual visits and explorations be restricted to a limited number of caves particularly Hamarnesgrotta, Setergrotta, Grønligrotta, and Eiterågrotta ("Caving in Rana. A brief introduction to visitors". 11 pp., surveys. Rana Turistkontoret, 1983).

Cave temperatures are generally low, ice-deposits frequent, and river caves are subject to rapid changes of water level. Rescue call-out is through the police (Lensmannen). Since many caves are remote and communications difficult, self-help should be considered a necessity. Back-up arrangements for supportive action in the event of an accident should be prearranged with local contacts and mutually agreed with other visiting expeditions. Contact can be made through the authors and Norsk Grotteforbund who should be advised of visits.

Non-karstic caves are listed separately in this paper, though glacier caves which are common in Norway are not included.

History of Exploration

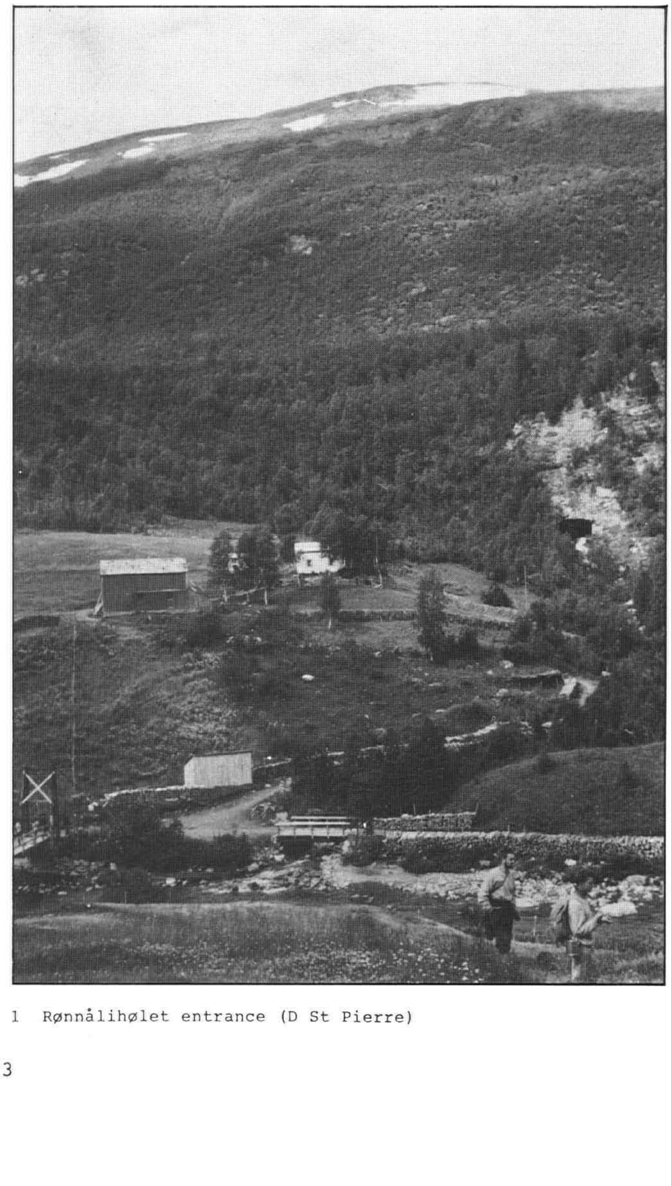
The entrances to many of the caves have been known to local Norwegians and travellers (geologists, hunters and fishermen) since the 1800's. There have been three main periods of exploration and survey: c. 1870 - 1940 mainly by Norwegian geologists and naturalists; 1951 - 1965 by mainly British caving club, school and university expeditions; and 1965 to date, with continuing exploration by foreign cavers, particularly the British, but also including Swedish and French expeditions, and the increasing activity by Norwegian cavers which now exceeds that of foreign visitors.

Rana Grotteklubb was formed in 1966 and Mo Speleologisk Selskap in 1968. The first issue of the national caving journal Norsk Grotteblad appeared in 1977 and the national speleological society Norsk Grotteforbund was founded in 1981. Cavers active today are found in clubs and small loosely knit groups such as Bodø og Omegn Bre-, Tinde- og Grottegruppe, Båsmo Grotteklubb, Harstad Grotte og Klatreklubb, Rana Turistforening Fjellsportgruppe, Tromsø Klatreklubb and Østlandske Grotteklubb, in addition to individual interest.

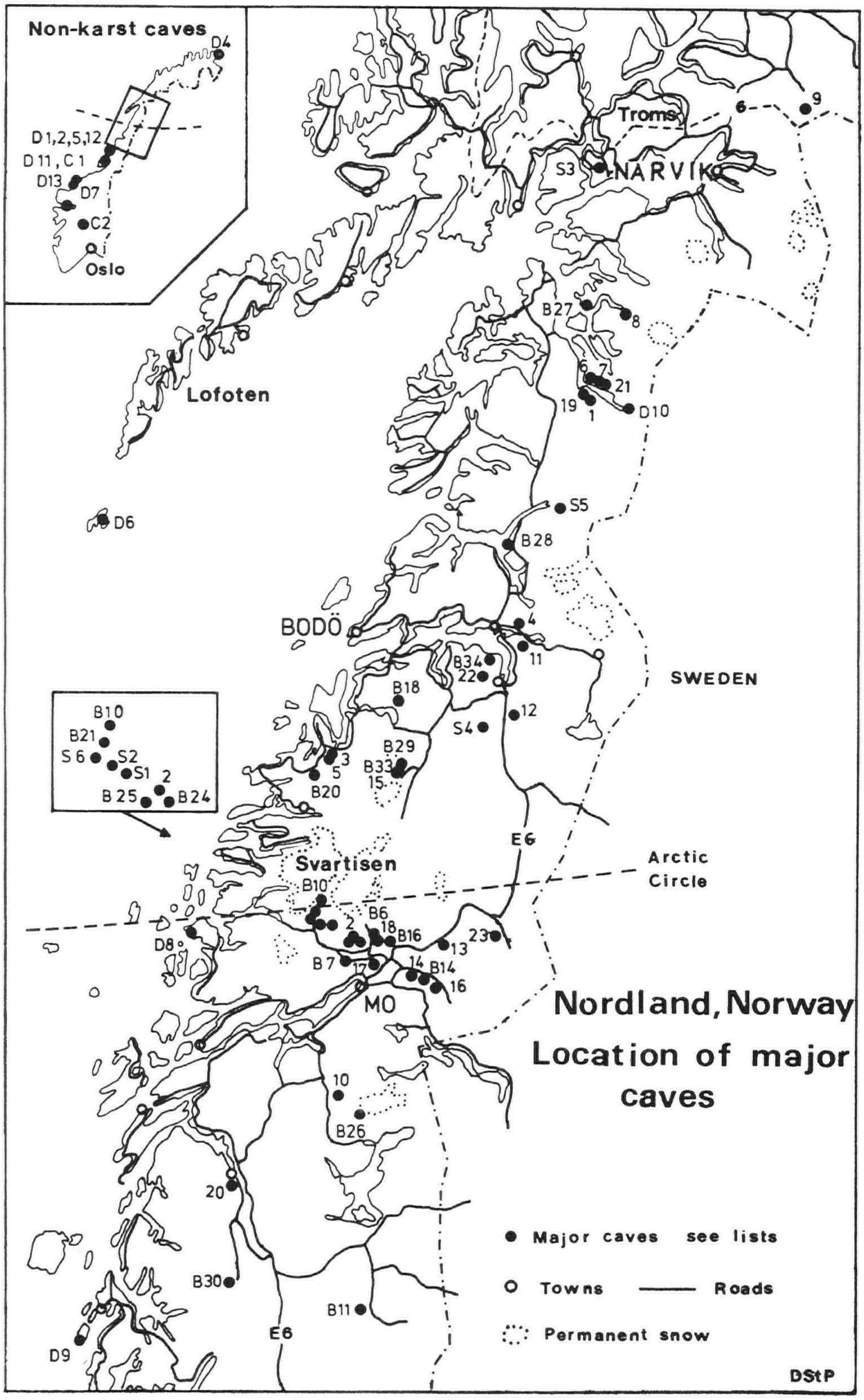
The main British activity at the present time is by members of the Gritstone, Kendal, "SWETC", Westminster and Wessex caving clubs often in co-operation with Norwegian cavers.

Cave Descriptions

The classic description of Norwegian caves is Gunnar Horn's "Karsthuler i Nordland", published in 1947 by the Norges Geologiske Undersøkelse (N.G.U, 165, 77pp.) Other information can be found in Norsk Geologisk Tidsskrift, Naturen, Jean Corbel's thesis "Les Karst du Nord-Ouest de l'Europe" (Univ. de Lyon, I.E.R., 1957, (12) 541 pp.), in Per Gunnar Hjorthen's "Grotter og grotteforskning i Rana", (N.G.U. Småskrifter, 1968, (9) 40 pp.) and in publications by Shirley and David St. Pierre such as "Cave studies in



1 Rønnålihølet entrance (D St Pierre)



Nordland, Norway", (Studies in Speleology, 1965, 1 (5): 275-284, and "Caves of Gråtådalen", (Cave Research Group Trans., 1966, 8 (1) 64 pp.), "Caves of Rana" (C.R.G. Trans., 1969, 11 (1) 71 pp.), and "Caves of Velfjord" (B.C.R.A. Trans, 1980, 7 (2): 70-82). Many of the major caves are described with surveys in the reports of expeditions led by David Heap (Kendal Caving Club). Much recent work has been published in Norsk Grotteblad, British Cave Research Association (B.C.R.A.) Transactions and Bulletin - Caves and Caving, Grottan (Sveriges Speleolog Förbund), Spelunca (Federation Français de Spéléologie) and, by Stein-Erik Lauritzen, in Norsk Geografisk Tidsskrift (see particularly 1984, 38 (3/4): 139-214 - Arctic and Alpine karst, Symposium).

Early descriptions of non-karstic caves are usually found in archaeological and geological literature. Finds and cave paintings occur from the Stone Ages and later, and the topography of many of the caves has been determined in connection with studies relating to isostatic uplift and the glaciations. Hans Reusch describes many such caves for example in "Traek av havets virkninger på Norges vestkyst", (Nytt Magasin for Naturvidenskarbena, 1877: 169-242). A number of articles on caves in non-limestone rocks have been published in recent years by Iain Schrøder in Norsk Grotteblad, and by Rabbe Sjøberg in Grottan. Descriptions of caves formed in glacier ice include those by Theakstone, at Svartisen, (Norsk Geografisk Tidsskr, 1966, 20: 38-43), and on Spitzbergen (Svalbard) - Pulina, (ibid., 1984, 38: 163-168) and Gallo, (Cuarnède, 1977, (9): 17-25, survey).

Cave Lists

Lists of Norwegian caves have previously been compiled and published by the authors (Speleo, 1966, 4 (2): 53-55; C.R.G. Nl., 1968, (110): 2-10; B.C.R.A. Bull., 1975, (9): 20-23 and Norsk Grotteblad, 1977, (3/4): 5-13); by Ulv Holbye - "Om vern av kalksteingrotter og grotteområder i Norge", (1974, 59 pp.); by Claude Chabert, "Les grandes cavités mondiales", (Spelunca, 1977, (2) suppl. : 47-48); and by Iain Schrøder, 1984. A Norway sump index compiled by Trevor Faulkner has been published by the Cave Diving Group (1979, 45 pp., maps and surveys).

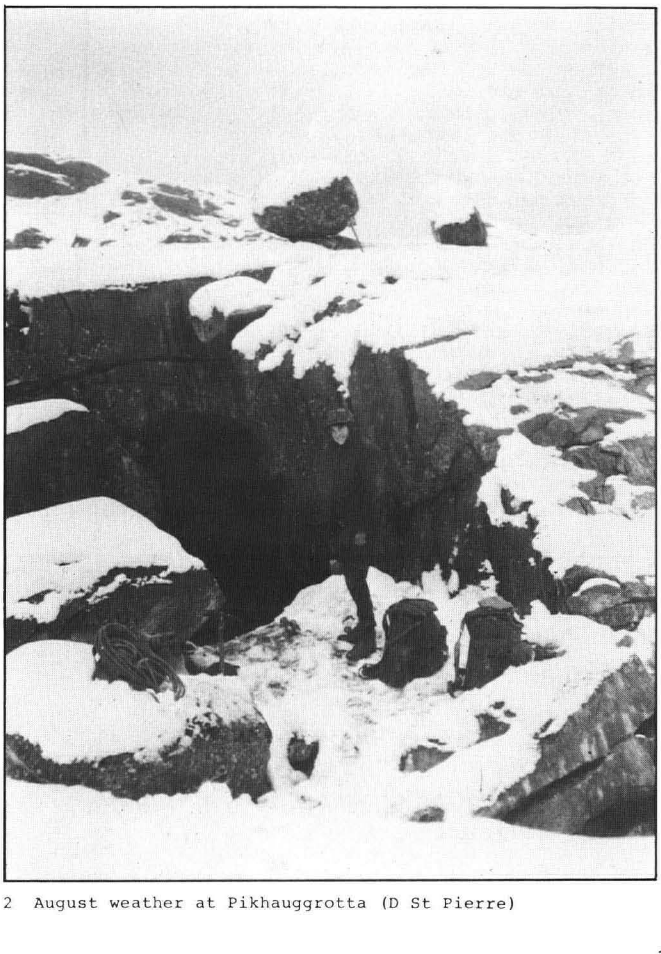
Cave Bibliographies

A number of bibliographies have been published by the authors for example on caves in Beiarn (Norsk Grotteblad, 1982, (9): 22-25), Greftgrottene (ibid., 1984 (14): 21-23), and on French literature on Norwegian caves (Grottes et Gouffres, 1985, (93): 15-21). In preparation are bibliographies on the caves of Tysfjord (5 pp. publication pending), on the caves and karst of Svalbard and Bjørnøya and on Norwegian cave archaeology (4 pp. and 10+ pp. respectively).

A regular Norwegian news feature is compiled for Caves and Caving.

Cave Records

Larshølet, once Norway's deepest cave, was listed as the world's 16th deepest in 1955.



2 August weather at Pikhauggrotta (D St Pierre)

3 138m pitch in Råggejavre-raige (A Grønlie

However by 1973 Råggejavre-raige, then -575 m and nearly twice as deep, was only 34th on the world list in the "Atlas des grandes gouffres du monde" by Paul Courbon.

The Råggejavre-raige through trip (c. -617 m, see list) was claimed to be the world's 3rd deepest (Seconde, Claire Obscure, 1981, (30): 16-21, survey) using a value of -634 m.

Norway's longest cave dive was made in July 1985 by an Anglo-Norwegian Expedition, at the 500 m long underground outlet to the lake Glomvatn, Glomdal, Rana (Ive, Brown & Root News, Oct. 1985, : 3 & 7; England, Sunday Telegraph Magazine, 1985, Nov. 24th, (474): 22-28). The underground section is split by a series of karst windows giving a downstream dive of about 300 m to the resurgence. Maximum depth reached is about 24 m. Attempts were previously made in 1981 and 1982 (Lauritzen, Ive & Wilkinson, BCRA Trans., 1983, 10 (2): 102; St. Pierre, Caves and Caving, 1982, (18): 14-19).

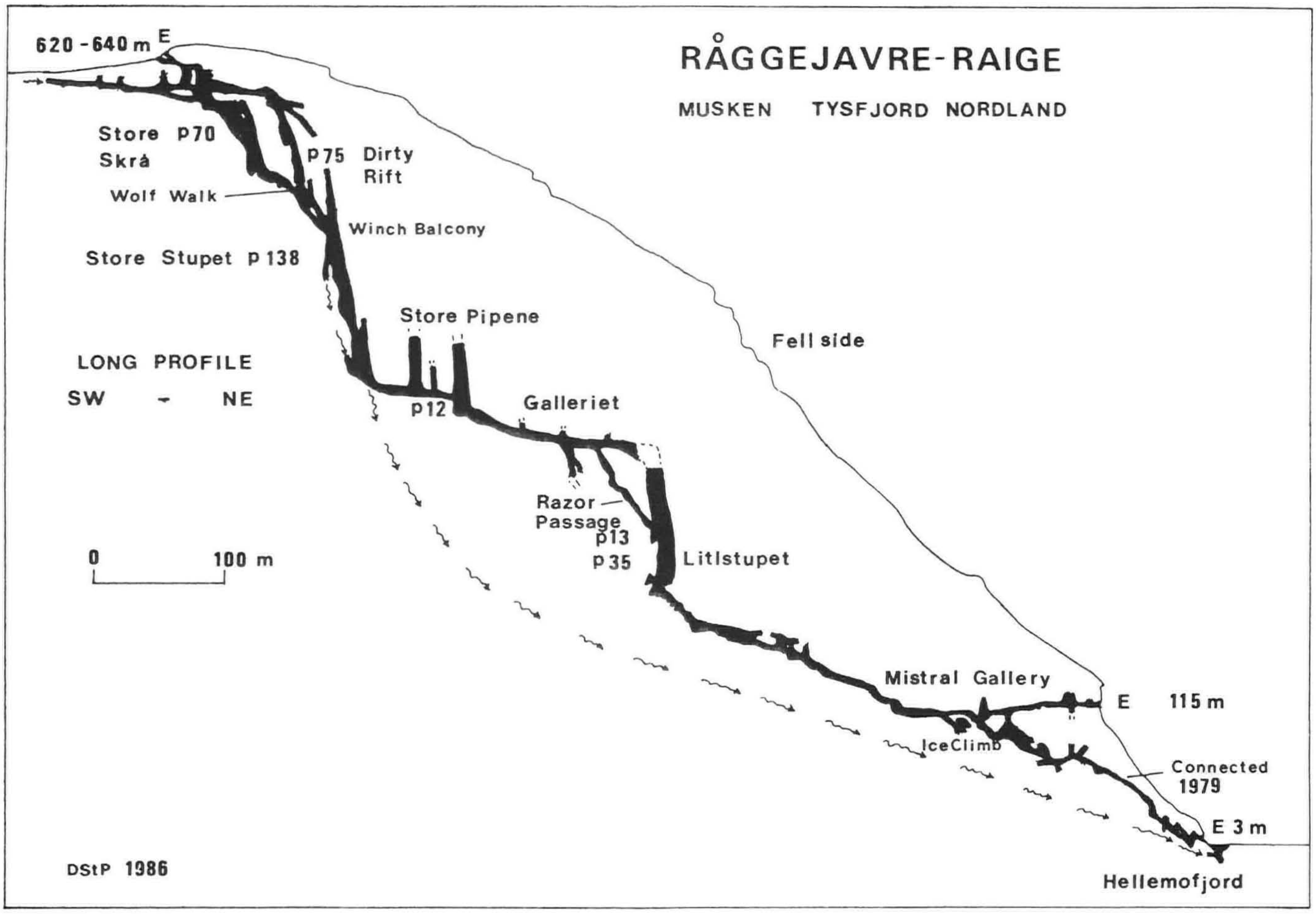
New world lists will be published by the U.I.S. in 1986. Corections and additions to the lists for Norway should be sent to the authors for future updates.

NORWAY'S DEEPEST KARST CAVES

A1. RÅGGEJAVRE-RAIGE -620m

Hellemofjord, Tysfjord, Nordland

There are three entrances at altitudes of about 620 m, 115 m and 3 m above sea level (Heap, Report of the British Speleological Expedition to Arctic Norway, 1969 (& 1968). Kendal Caving Club, 1969: 1-21, survey). The altitude of the upper entrance has not been accurately determined and various surveys within the cave give conflicting values. K.C.C. reached depths of -180 m in 1968 and -564 m in 1969 in the cave which is characterised by large steeply inclined shafts up to 138 m deep. In 1979 a small British expedition connected the lower, fjord-side entrances (Rogers, Descent, 1980, (46): 10-11, survey), making a total through trip depth of approximately 617 m. Other reports include those by Holbye (Norsk Grotteblad 1977, (1) 58 pp., long-section), which describes the first SRT through-trip, by a small party of Norwegians; Fontana (Spelunca, 1979, (3): 122-124, survey); St Pierre (Grottes et Gouffres, 1980, (78): 25-26); Seconde (Speleo-Flash, 1981 (127): 10-15, survey); and Graham (Wessex C.C. Jnl., 1983, 17 (198): 102-6). Also see B13, Longest caves list.

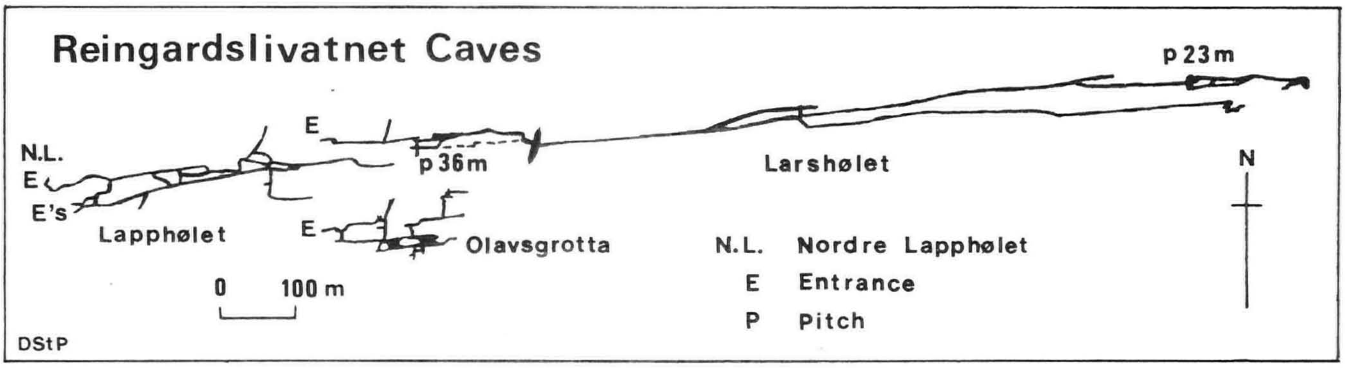


A2. LARSHØLET -326m
Reingardslivatn, Rana, Nordland
Alt. 394 m. The cave was discovered by Lars Bjørnnes in the 1870's. A small, gated, entrance leads to a mainly dry, inclined, linear phreatic system with a low entrance series joining a very large major conduit which divides into two parallel passages. Horn's survey, -270 m to the top of the 23 m pitch in the Nordgang and to -284 m in the sand-blocked Sørgang, was made in 1934 (N.G.U., 1947, 165: 45-49, survey). The cave was bottomed in 1951 by the Railtons, Corbel and local Norwegians Odd Stormo and Anton Svartisdal (C.R.G. Trans., 1954, 3 (1): 27-39, plan). Also see B4.

A3. GREFTKJELEN -315m
Greftvatn, Gildeskål, Nordland
Alt. 350 m. A complex system formed along Caledonian fold axes with successive phases of partially eroded phreatic loops. The large snow plugged entrance shaft was mentioned by Helland in 1907 and the cave was partially explored and surveyed in 1971 and 1972. The depth of the bottom (-340 m) was an estimation (Heap, William Hulme's Grammar School, Manchester, Expedition to Arctic Norway, Report. 1972 : 13-22, survey). Exploration and survey continues under the auspices of BOBTOG the Bodø based club (Holbye, Norsk Grotteblad, 1983, (11): 36 pp., surveys; ibid, 1984, (14): 15-23, surveys, bibliog.). A fine sporting cave. Also see B2.

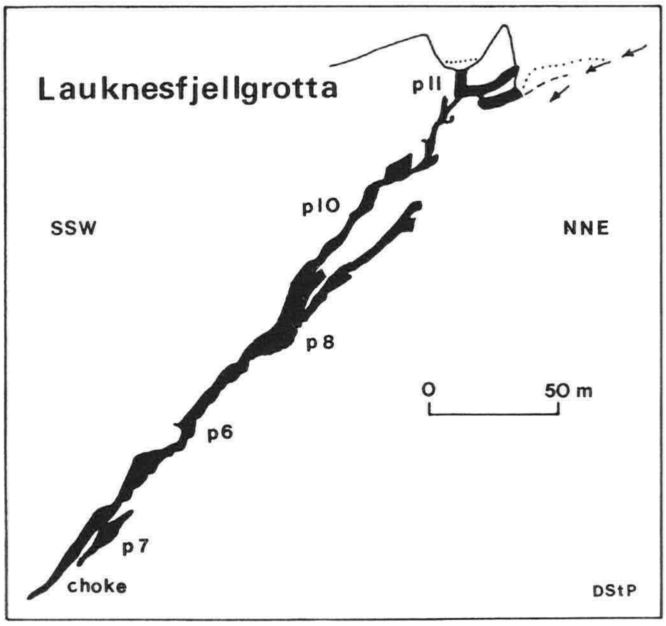
A4. OKSHOLA-KRISTIHOLA 300m
Vatnan, Fauske, Nordland +161 m /-139 m
Alt. 170 m. Entered by Holbye, 1967. Explorations by Kendal C.C. and William Hulme G.S. begun in 1968 connected the two caves and in 1969 reached a depth of -161 m in Kristihola (Heap, Report of the British Spel. Exped. to Arctic Norway, 1969 (& 1968). K.C.C., 1969: 22-28, survey). Additional exploration and survey by Norwegian cavers. Holbye (1974) produced a preliminary survey of the Okshola series. Also see B1.

A5. GREFTSPREKKA -250m
Greftvatn, Gildeskål, Nordland
Alt. 336 m. Entrance discovered by K.C.C.

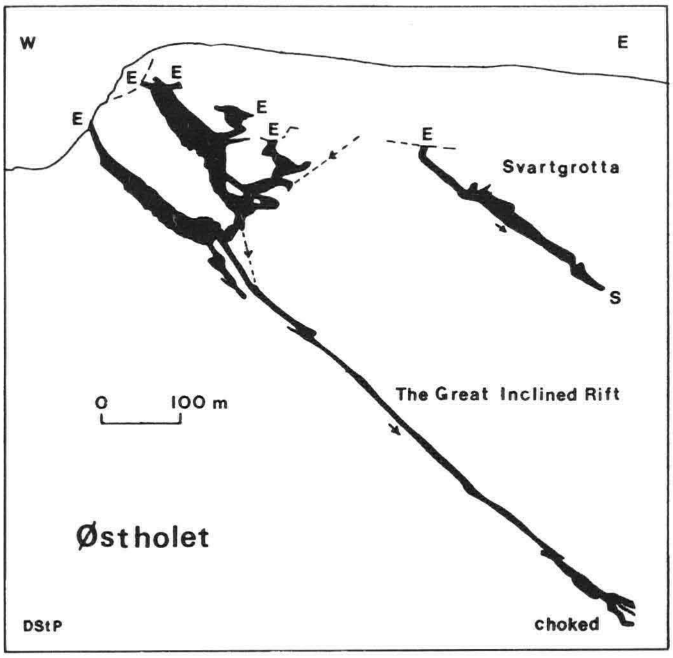


1971. Pushed to - 132 m in 1976 by Grønlie, Holbye and Lauritzen. A Norwegian International camp in 1977 bottomed the cave at - 250 m and started surveying (see refs. A3 and Lauritzen, Norsk Grotteblad, 1977, (2): 70-83). Also see B5.

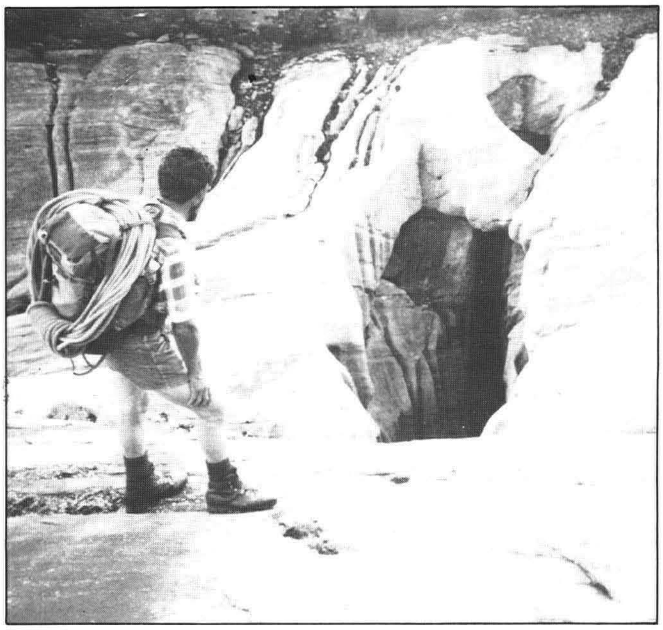
A6. LAUKNESFJELLGROTTA -214m
Hellemofjord, Tysfjord, Nordland
Alt. 630 m. Explored in 1971 by the Craven Pothole Club (Beck, C.P.C. Jnl., 1971, 4 (5): 242-246, survey). Entered at Ice Hall down valley of large sink. A dry steeply descending series of climbs and pitches up to 10 m deep. Length 400 m.



A7. ØSTHOLET -210m
Hellemofjord, Tysfjord, Nordland
Alt. 650 m. Explored in 1971 by Craven P.C. (ibid.,: 244 & 246-247, survey). Complex series with five entrances decends steeply to "a great inclined plane", 150 m deep, terminating in a collapsed choke. Length 780 m.



A8. SALTHULENE -195m
Sørfjord, Tysfjord, Nordland
Alt. 620 m. Explored and surveyed (unpubl.) by Lauritzen, BOBTOG et al. 1985. Also see B8.



4 Salthulene entrance (T St Pierre)

A9. STORDALSGROTTA -184*m
Stordal, Bardu, Troms
Alt. 960 m. Explored by Sveriges Speleolog Förbund to -110 m (Andreason, Grottan, 1984, 19 (3): 43-47, plan). Extended Dec. 1984 (p.c. Holbye, see Caves and Caving, 1985, (28): 13) and Feb. 1985 (Holbye, Norsk Grotteblad, 1985, (15): 6-13, plan). Est. depth -260 m * - 83 m plus measured depths of climbs and pitches. Also see B17.

A10. YTTERLIHOLET -180m
Brygfjelldal, Hemnes, Nordland
Alt. c. 840 m. Explored by William Hulme's G.S. (Heap, Report of Expedition to Nordland, 1974. 1975: 9-15, survey). A sporting stream passage with wet pitches, rapids, tight crawl and duck terminating at a sump. Length 700 m.

A11. SVARTHAMARHOLA 157m
Mefjell, Fauske, Nordland -80 m/+77 m
Alt. 250 m. Explored 1970 by Holbye and William Hulme's G.S. (Heap, W.H.G.S. Spel. Exped. to Arctic Nordland, 1970. 1970: 13-16, survey). The large cavernous passages contain a 250 m long ice lake with an ice fall to a lower chamber. Also see B12.

A12. NESMØLNELVGROTTA -133m
Nes, Saltdal, Nordland
Alt. 220 m. Explored in 1971 by William Hulme's G.S. (Heap, W.H.G.S., Manchester, Expedition to Arctic Norway 1971 and 1972. 1972: 7-8, survey) Three sporting entrances to an impressive stream passage ending at sumps. Also see B32.

A13. DUNDERHØLET -125m
Dunderlandsdal, Rana, Nordland
Alt. 600 m. Explored 1968 by the Northern Exploration Group. (Report of the N.E.G. Spel. Exped. to Arctic Norway, 1968. 1968: 7-8, survey). A series of pitches leads to a sporting stream passage with 17 m wet pitch. Length 300 m.

A14. KRYSTALLGROTTA -115m
Plurdal, Rana, Nordland
Alt. 410 m. Known to Olaf Grundstrøm, a local farmer for over 50 years, this generally spacious and well decorated cave was explored by the Northern Speleological Group in 1965 (Mitchell, N.S.G. Bull., 1966, Oct., : 6-10). Surveyed N.S.G. 1965, Rana Grotteklubb 1966 (St. Pierre, C.R.G. Trans., 1969, 11 (1): 53-56, plan). Also see B22.

A15. RØNNÅLIHØLET -110m

Gråtådal, Beiarn, Nordland

Alt. c. 320 m. Remarkable tunnel-like resurgence, alt. 210 m, described by Vibe (Det norske geogr. selsk. aarb., 1892, (3): 87-90) and Corbel (1957: 179-181, survey). Upper entrance discovered by SWETC 1963 and explored downstream, below 9 m and 5 m wet pitches and junction with inlets from surface Store Rønnåga and Satisfaction and Tunnel Caves 1964-65 (St. Pierre, C.R.G. Trans., 1966, 8 (1): 29-37, plan). Connection made 1972 by climbing second, inner, 6 m waterfall from below (SWETC C.C. Occasional Pub., 1973, (3): 23-26, plan - Holbye, St. Pierre et al.). Also see B19.

A16. JORDBRUGROTTA -110m

Plurdal, Rana, Nordland

Alt. 608 m. A classic through-trip emerging at Sprutfossen. Main explorations 1962 and 1964 by Haberdashers' Aske's Hatcham School (Poston, Cave Science, 1964, 5 (36): 217-228, plan; Wolfe, N.S.S. Bull., 1967, 29 (1): 13-22). Also see B3.

A17. LISETERBEKKGROTTENE -110m

Røvassdal, Rana, Nordland

Alt. 200 m. Sink (Tekkelhølet) and resurgence caves explored in 1967. (St. Pierre, C.R.G. Nl., 1967, (109): 22; Newill, The Speleologist, 1968, 2 (15): 18). Caves surveyed 1969 (unpub.) and connected 1975 by Orpheus Caving Club (Potts, O.C.C. Nl., 1969, 5 (8): 3-4; ibid., 1975, 11 (7/8): 40-41). Also see B23.

A18. GRØNLIGROTTA -107m

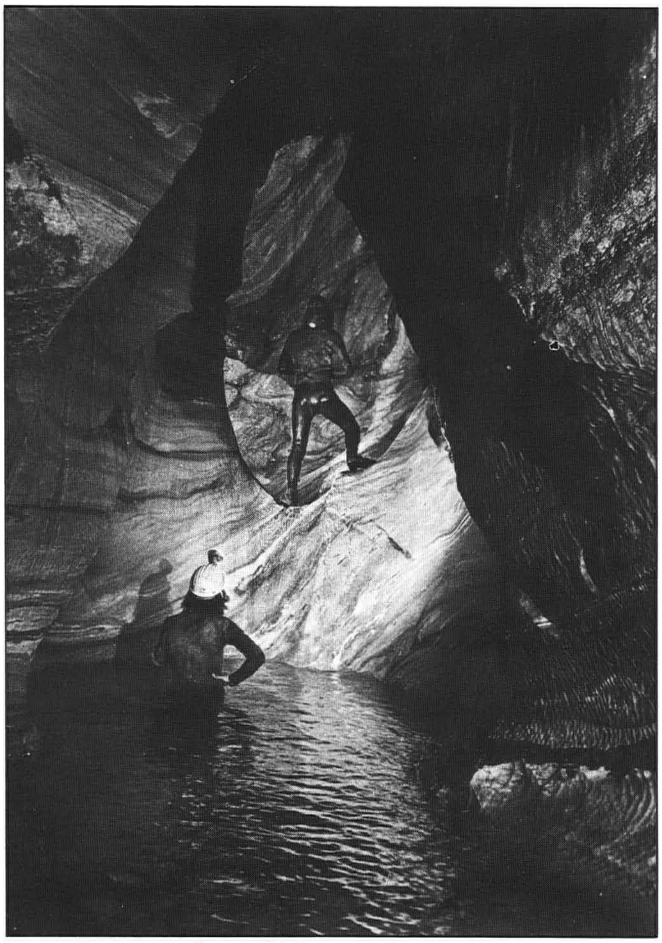
Røvassdal, Rana, Nordland

Alt. 236 m and 223 m. Entrances in cliff face lead to planar phreatic network roofed by overlying micaschist in places. Partially invaded by vadose streamway which has cut separate canyon below maze in lower part of cave. Final 12 & 7 m deep pitches in the Labyrinten first descended by Kaptein Hvoslef in 1906. Cave studied and surveyed by Oxaal (N.G.U., 1914, 69 (2): 5-24, plan). Also see B9.

A19. BUMPERHØLET -107m

Hellemofjord, Tysfjord, Nordland

Alt. 600 m. Sink cave with 45 m inclined pitch and series of sumps. Stream dye traced to fjord near Råggejavre-raige resurgence by Hulme's School/K.C.C. in 1969 (Report, 1969: 19 & 30, survey. Depth c. 50 m, length c. 180 m). Exploration continued by Craven Pothole Club (Beck, C.P.C. Jnl., 1971, 4 (5): 245-246, survey). Length 390 m.

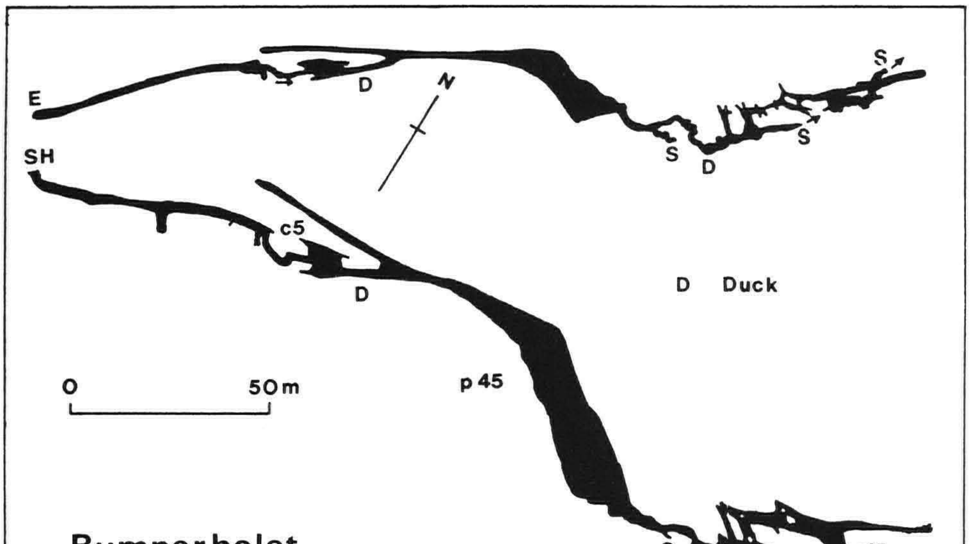


5 Jordbrugrotta (A Grønlie)

A20. ØYFJELLGROTTA -106m

Øyfjell, Vefsn, Nordland

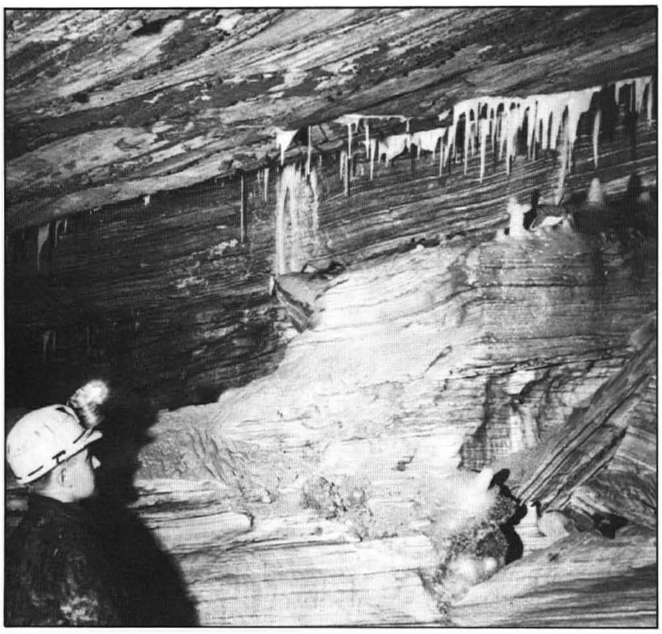
Alt. 150 m. Drained vertical phreatic network of tubes up to 6 m diameter with a vadose streamway. Partially surveyed by Bjørn Grimsby in 1960's. New series explored and surveyed in 1967 (Heap, Report of the Ermysted's G.S. Spel. Exped. to Northern Norway, 1967. 1967 : 11, plan). Also see B31.



A21. NORALDAGRAIGE -100m
Hellemofjord, Tysfjord, Nordland
Alt. 660 m. Sink in large shakehole and undersea resurgence noted by Foslie (N.G.U., 1942, 150: 103-104). Explored and surveyed by Kendal C.C. 1968 (Heap, Report of the British Spel. Exped. to Arctic Norway 1969 (and 1968). 1969 : 8-9, plan). Extended by Craven P.C. (Beck, C.P.C. Jnl., 1971, 4 (5): 242-243, plan). The streamway and parallel interconnected chambers descend steeply to a series of sumps and a choked rift. Length 500 m.

A22. VIKGROTTA (Tørrågrotta) -100m
Vikfjell, Saltdal, Nordland
Alt. 110 m. An attractive cave above the course of the underground Storåga. Length 752 m. (Heap, Hulme's G.S., Manchester, Report of Speleological Expedition to Arctic Norway, 1970. 1970 : 18-20, survey).

A23. JORDBEKKGROTTA -100m
Virvassdal, Rana, Nordland
Alt. 580 m. Sink entrances mentioned by Helland (Norges Land og Folk, 1907: 470). Explored since 1965 by Orpheus C.C. Linked with Jordbekkhølet 1969. Also see B15.

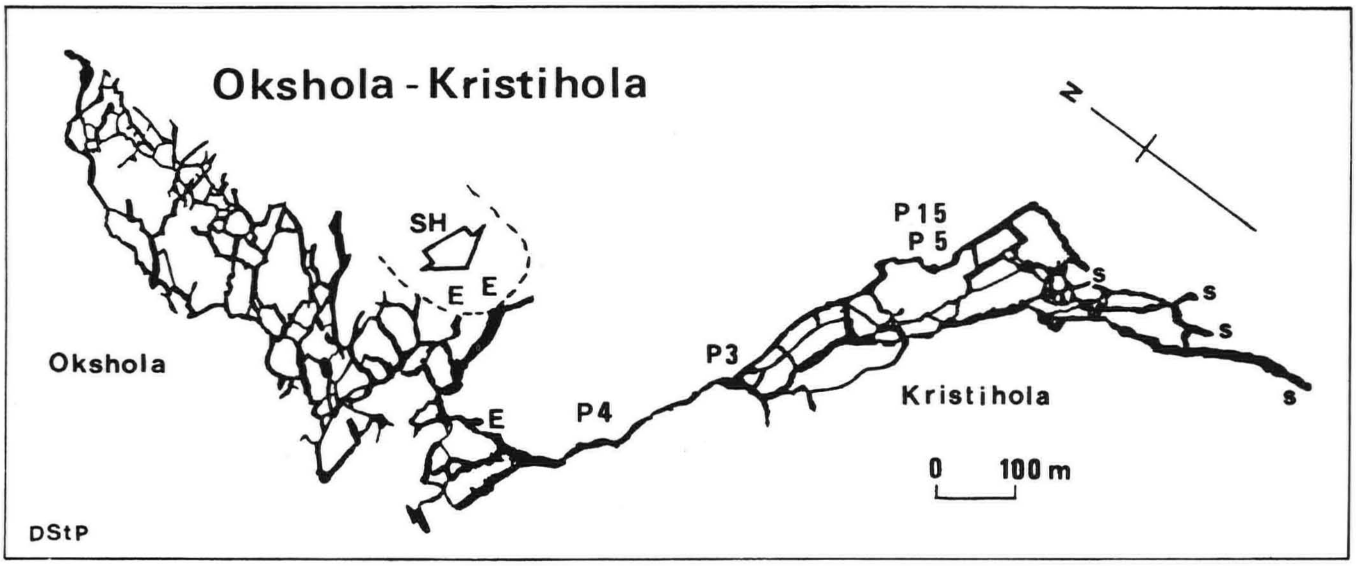


6 Larshølet (S St Pierre)

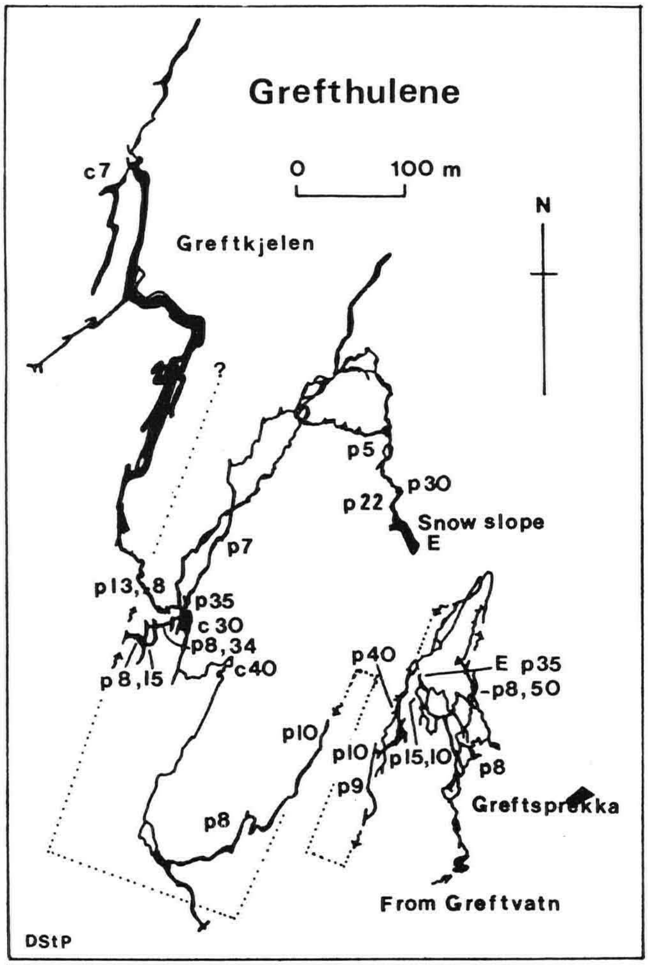
7 Okshola sink (D St Pierre)

NORWAY'S LONGEST CAVES

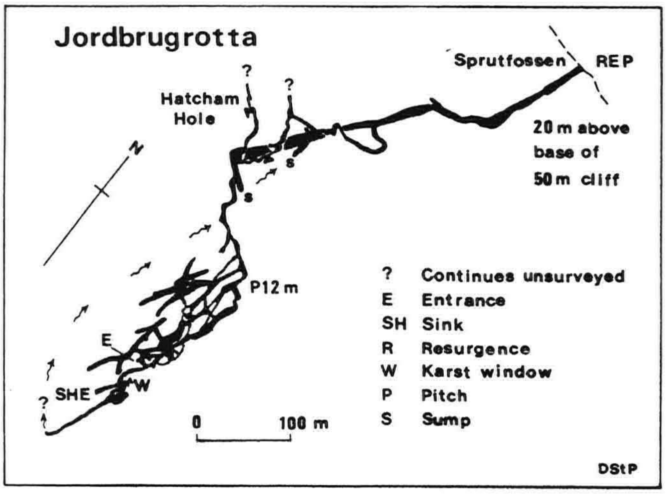
B1. OKSHOLA-KRISTIHOLA 9500m
See A4. Okshola a predominantly dry maze cave with several entrances, connects with Kristihola a 900 m long stream passage leading to a series of sumps and a dry phreatic network. Norway's only major cave rescue took place here (Holbye, Norsk Grotteblad, 1984, (13): 3-8; Lysén, Grottan, 1984, 19 (1): 3-4). Estimated length 11000 m.



B2. GREFTKJELEN 3725m
(Cave of the Lost Waters)
See A3. Estimated explored length 4890 m. A connection with Greftsprekka (B5) is being sought. Bibliography: St. Pierre, Norsk Grotteblad, 1984 (14): 21-23.



B3. JORDBRUGROTTA 3000m
See A16. Dry upper phreatic network, described by Otnes (Norsk Geografisk Tidsskr., 1954, 13 (5/6): 362-364) following a visit with Martin Jordbru, connects with streamway at 12 m pitches. Passage at sink, explored by Newill and St. Pierre (C.R.G. N1., 1967, (109): 21-22), was blasted by Grønlie and Opsjøn to make a passable dry weather connection with the lower stream passage (Norsk Grotteblad, 1979, (5): 46). There is a lower inlet from Hatcham Hole.

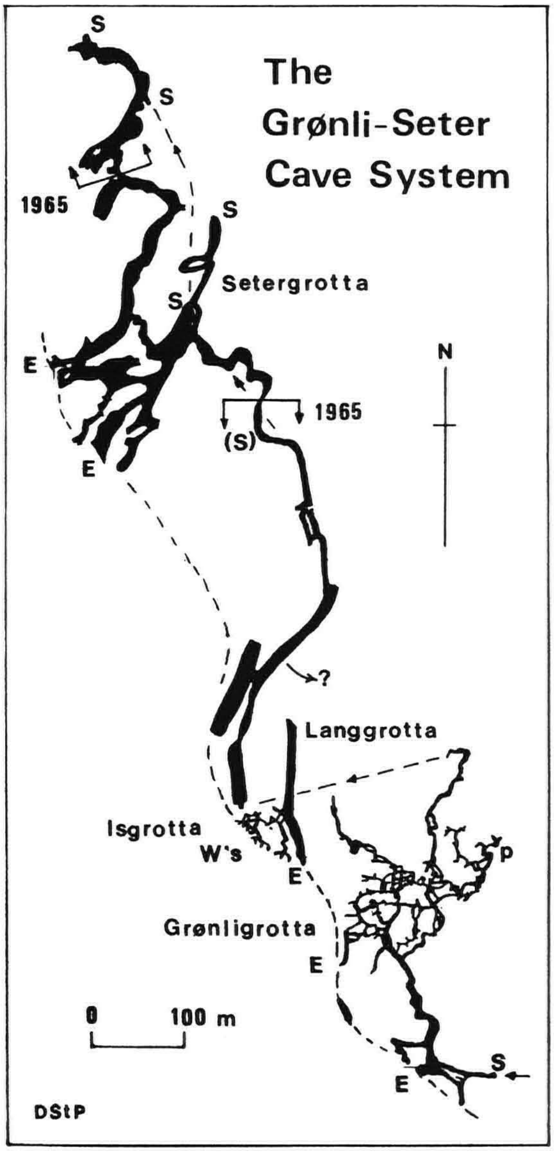


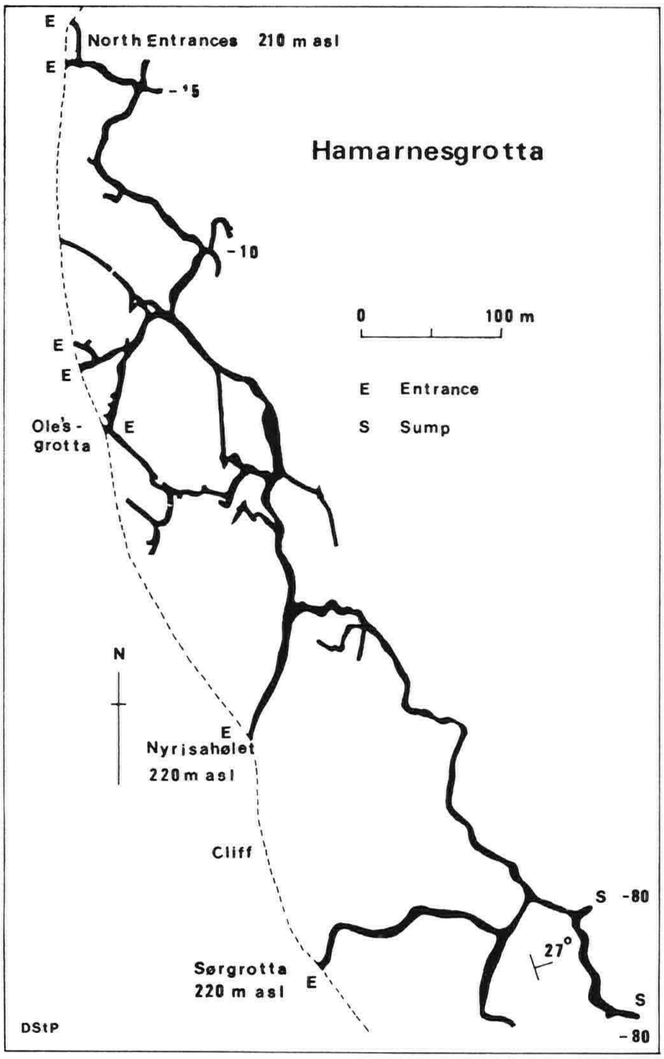
B4. LARSHØLET 2900m
See A2. Surveyed length of c. 500 m (Oxaal, N.G.U., 1914, 69 (2): 24-27, plan) extended by Horn, 1934, to 2300 m. Further extensions in 1951 by Railton and Corbel and in 1957 by Cambridge University C.C. (Wells, C.R.G. Trans., 1957, 5 (1): 23-33, survey).

B5. GREFTSPREKKA 2600m
See A5. Estimated explored length 3200 m. Swedish extensions, a maze of rifts and shafts scaled and surveyed by H.G. Karlsson and Umeå cavers, 1984 and December, 1985, to just below small inlet from sink in the upper large shakehole (p.c. Holbye, January 1986).

B6. SETERGROTTA 2400m
Røvassdal, Rana, Nordland
Alt. 100 m. Entrances at base of Grønli cliff; see B9. Large collapse chambers and drained phreatic passages lead to separate sections of vadose streamway. Horn surveyed 1500 m in 1939 (N.G.U., 1947, 165: 39-42, plan). Extended, upstream of intermittent sump into collapse chambers (St. Pierre, Speleo, SWETC C.C. N1., 1965, 4 (1): 11-14, plan - pace & compass) and downstream to sump (Mitchell, N.S.G. Bull., 1966, Oct.: 6-7, plan).

B7. HAMARNESGROTTA 2200+m
Langvatn, Rana, Nordland
Alt. 210-220 m. A zig-zagging dry phreatic system with seven entrances truncated by cliff





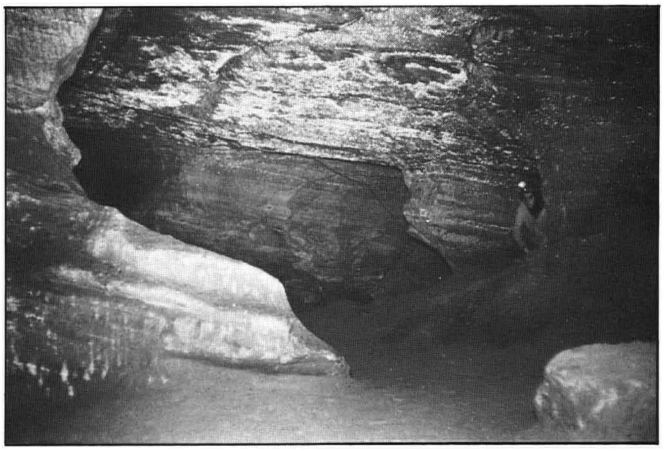
face. At junction of marble with underlying schists. Corneliussen mapped 300 m in 1874 (N.G.U., 1891, 4: 178-179) extended to 445 m by Oxaal (Naturen, 1915: 23-28, plan), to 975 m by Natvig (D.N.T. Arbok, 1923: 170-183, plan) and to 2200 m by Horn, 1934-1939 (NGU, 1947, 165: 20-29, plan). Lauritzen (Norsk Grotteblad, 1981, (7): 21) shows a further 180 m. Depth 80 m.

B8. SALTHULENE 2056m

See A8. A number of shafts in a narrow marble band give access to a series of large ice-filled passages. Entrances described by Foslie (N.G.U., 1941, 149: 262) and Corbel (Karsts du n.o. de l'Europe, 1957: 111-115, survey).

B9. GRØNLIGROTTA 2000m

See A18. Tourist cave. Oxaal's surveyed length of 1210 m (1914) was extended to 1500 m by Horn (N.G.U., 1947, 165: 37-39, plan). Baekkeslugten extended 300 m by SWETC (St. Pierre, Speleo, 1965, 4 (1): 14) was surveyed with other extensions by Grønlie, Haugane et al. 1969/70 (Norsk Grotteblad, 1979, (5): 22-38, plan). Hydrologically linked with Setergrotta (B6).

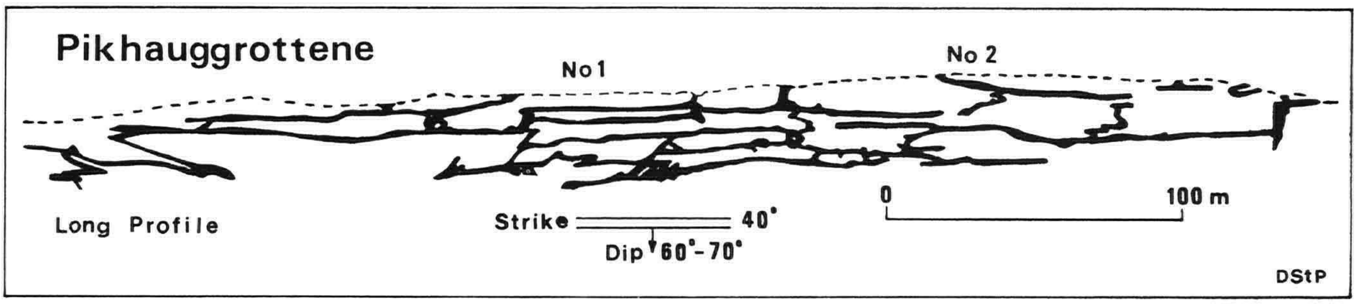


8 Grønligrotta maze (D St Pierre)

9 Grønligrotta streamway (A Grønlie)

B10. PIKHAUGGROTTA No. 1. 2000m

Alt. 540 m. Remote, predominantly dry, phreatic, sub-vertical, maze system, aligned along the strike, with several entrances. Horn surveyed 110 m in 1937 (N.G.U., 1947, 165: 34-36, plan). Extended by Cambridge Univ. C.C. in 1957/58 (Jenkins, Cave Science, 1959, 4 (29): 209-220, survey). Further study by Lauritzen, (Norsk Geografisk Tidsskr., 1982, 36: 183-209, survey). Depth c. 50 m.



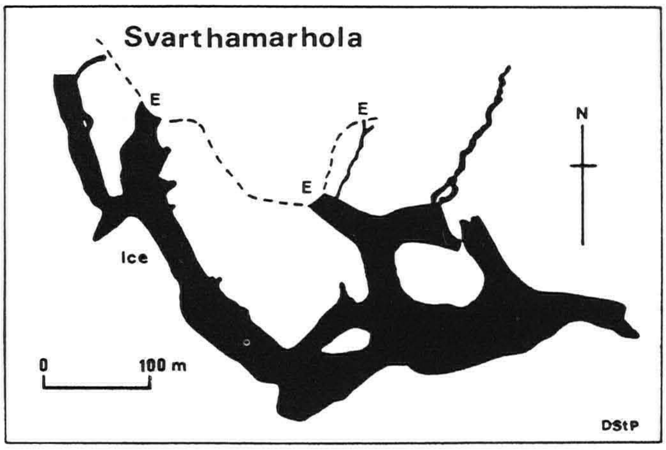
B11. STORE GRUBLANDSGROTTA 1900m

Ivarrud, Hattfjelldal, Nordland

Alt. 480 m. A sporting and impressive cave. Depth 50 m. A complex upper series of overflow sink passages lead to the underground Store Grublandselv which backs up from the Siphon Series and floods the lower part of the system. (Report of the Ermysted's G.S. Spel. Exped. to Northern Norway, 1967. 1967 : 12-16, plan). The explorable length (July 1985) was much less due to the whole of the phreatic maze from "White Trout" downwards being blocked by a recent infilling of silt and sand (p.c. Heap, Dec. 1985).

B12. SVARTHAMARHOLA 1814m

See A11. The cave was extended 100 m by the Sveriges Speleolog Förbund in 1975 (Haugum, Grottan, 1975, 10 (4): 24-27, plan).



B13. RÅGGEJAVRE-RAIGE 1810m

See A1. Foslie (N.G.U., 1942, 150: 103) mentions the underground course which resurges in the sea. He estimated the length as 1.5 km and the depth as 675 m. Also see A19.

B14. FISKEGROTTA 1650m

Plurdal, Rana, Nordland

Alt. 280 m. A large stream passage entered at the sink. (Whitehouse, Eldon Pothole Club Exped. to N. Norway, 1968. 1969 : 10-11, plan).

B15. JORDBEKKGROTTA 1450m

See A23. Eldon Pothole Club surveyed 7-800 m (Cooper & Huntingdon, E.P.C. Recce Exped. to N. Norway, 1966. 1966 : 4-6 survey). Further exploration and unpublished surveys by Orpheus C.C. (Potts, B.C.R.A. Bull., 1982, (18): 43) and BOBTOG (St. Pierre, ibid., 1982, (16): 25). Estimated explored length 2000 m.

B16. SØYLEGROTTA 1400m

Dunderlandsdal, Rana, Nordland

Alt. 295 m. Possibly the cave mentioned by Oxaal (N.G.U., 1914, 69 (2): 33). Eldon P.C. dug crawl and surveyed 360 m down a series of pitches (Cooper & Huntingdon, 1966: 8-9, survey). Extended 400 m by Rana Grotteklubb, 1967 and further 450 m by Mo Speleologisk Selskap the same year. A second entrance was dug by White Rose Pothole Club in 1968. (St. Pierre, C.R.G. Trans., 1969, 11 (1): 39-40, plan). Depth 82 m.

B17. STORDALSGROTTA 1400m

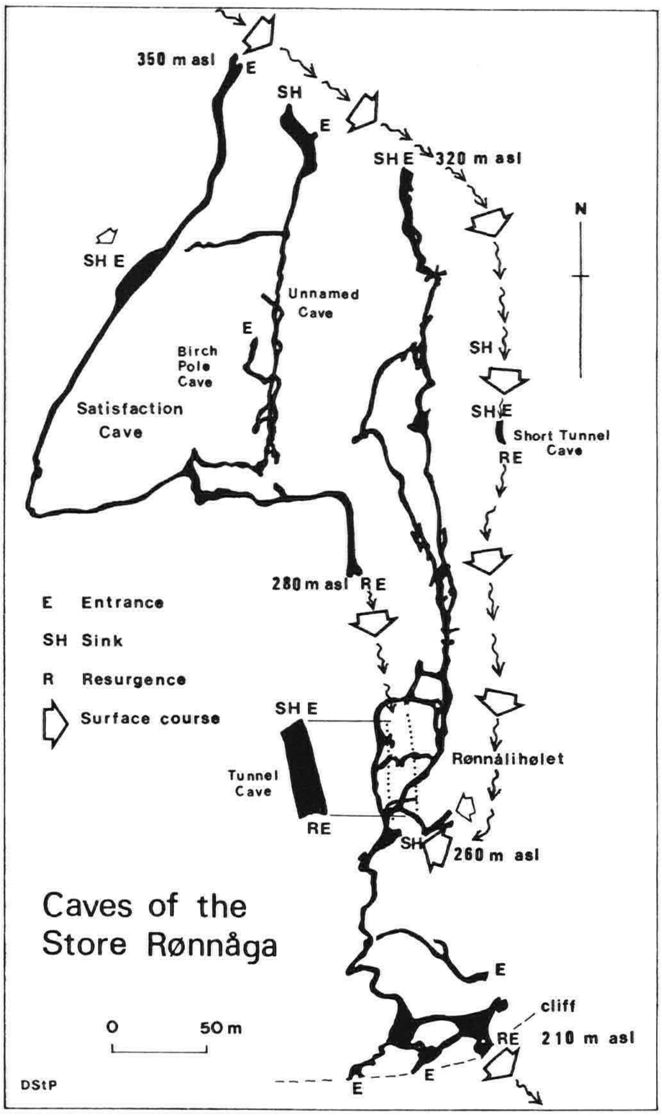
See A9. Norway's highest major cave system nearly 1000 m a.s.l. Two entrances, one a 40 m shaft at the sink. Remote location. Mainly a single passage with a number of climbs and 27 m, 20 m and 70 m deep shafts. Exploration has reached the start of a collapse zone. Estimated explored length 1730 m.

B18. UGLEGROTTA 1300m

Galtåga, Beiarn, Nordland

Alt. 540 m. From sizeable dry resurgence a small passage, between slabs of granite-gneiss leads to ice chamber and large phreatic cave with streamway in places. Remote location. Cave entered 1967 (St. Pierre, C.R.G. N1., 1967, (109): 20 & 22; SWETC C.C. Occ. Pub., 1977, (4): 58-63). Main exploration and survey 1972/73 (Hobbs, Gritstone Club Jnl.,. 1975, (5): 51-57, plan). Depth + c. 60 m.

B19. RØNNÅLIHØLET See A15 1200m



B20. NONSHAUGGROTTA 1200m

Alt. 300 m. Sub-horizontal, dry, maze cave truncated by cliff face. Explored by Railtons and Corbel with Jens Arntzen in 1951 (C.R.G. Trans., 1954, 3 (1): 33-36, plan; Karsts du n.o. de l'Europe, 1957: 155 & 159, plan). Surveyed by Holbye et al 1969 (unpubl.).

B21. TRUDEHULLET 1200m

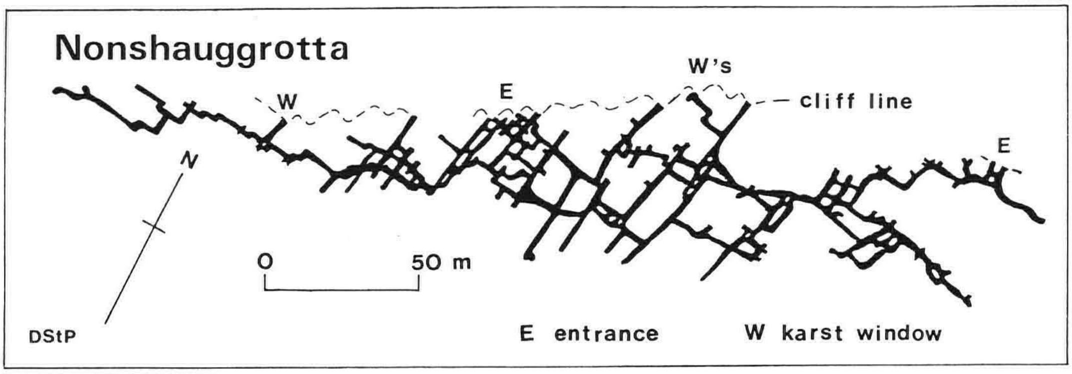
Glomdal, Rana, Nordland

Alt. 430 m. Multi-level, strike-aligned system with two separate streamways. Named after Trude Wansvig. Surveying and study by Lauritzen et al. continues. Estimated length 2-3000 m (St. Pierre, Caves and Caving, 1982, (18): 14-19, schematic long section). Depth 66 m.

B22. KRYSTALLGROTTA See A14 1160m

The entrance near the sink of the Storelv is gated. The underground river enters the cave in a spectacular 20 m high arched fall.

B23. LISTERBEKKGROTTENE See A17 1150m



B24. OLAVSGROTTA 1150m
Reingardslivatn, Rana, Nordland
Alt. 397 m. Maze cave. Named after Olav Sjånes. Horn surveyed 425 m in 1933 and 1935 (N.G.U., 1947, 165: 49-51, plan). Extended 1967 (Franck and Muxart, Spelunca, 1973, 13 (1): 10-11, plan). Depth 60 m.

B25. LAPPHØLET (Bjørnågrotta) 1120m
Reingardslivatn, Rana, Nordland
Alt. 398 m. Described by Corneliussen after a visit in 1874 (Den Norsk Turistforening Årbok, 1875 : 66-69). Two gated entrances give access to two spacious, interconnected, drained phreatic passages ending in sand chokes. Oxaal's 1914 survey extended by Horn (1947: 50-53, plan) and Cambridge Univ. C.C. (Wells, 1957: 25-33, survey). Connected with Nordre Lapphølet 1967 by Franck and Muxart (1973: 9-12, survey). Depth 70 m.

B26. GRØNNDALGROTTA 1110m
Grønndal, Hemnes, Nordland
Alt. 580 m. A river system with several entrances. Explored and surveyed Holbye, Lauritzen et al. since 1972. Survey (unpubl.) Holbye, 1972. (Lauritzen, Norsk Grotteblad, 1977, (2): 15-17 & 34-43, survey). Depth 76 m.

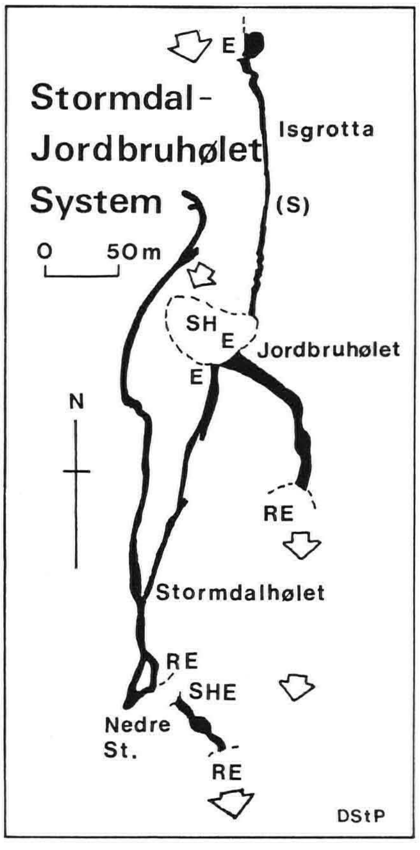
B27. STORSTEINHULA 1100m
Kjøpsvik, Tysfjord, Nordland
Alt. 55 m. Discovered by quarry workers. Side passage joins, at lake, a large dry passage terminating in sumps. Surveyed by Holbye (C.R.G. Nl., 1969, (115): 2-7, plan) and Craven Pothole Club (Beck, C.P.C. Jnl., 1971, 4 (5): 247-248, plan) who named it Kjøpsvikgrotta. Depth 32 m.

B28. STORTUVHOLA 1097m
Aspfjord, Sørfold, Nordland
Alt. 250 m. Upper series of large drained phreatic passages with stream descending to lower cave. (Heap, Report of the British Spel. Expedition to Arctic Norway, 1969. 1969/70: 35-37 plan - Aspfjord-grotta). Depth +21/-61 m.

B29. STORMDALHØLET-JORDBRUHØLET 1039m
Gråtådal, Beiarn, Nordland
Alt. 300 m. Jordbruhølet a large through river cave 110 m long was described by Vibe, (Det norsk geogr. selsk. aarb., 1892, (3): 87-90) and Sommerfeldt (Trondhjems Turistforening Årbok, 1901: 17-18, illus.). Stormdalhølet, 670 m, and Isgrotta, 20 m downstream to sump, explored and surveyed with Jordbruhølet by SWETC C.C. 1963. Isgrotta extended downstream to second sump, 122 m 1964. (St. Pierre, C.R.G. Trans., 1966, 8 (1): 38-44, map, plan, illus.). Isgrotta through-trip upstream from Jordbrugrotta shakehole 1972 (SWETC C.C. Occ. pub., 1973 (3): 26-27, plan), length 239 m. Connection, 20 m long, made between "Overflow Passage" and upper entrance of Jordbruhølet by BOBTOG, 1983 (Norsk Grotteblad, 1985, (15): 16, plan). System subject to rapidly changing water-levels. Depth c. 60 m.

B30. SIRIJORDGROTTA 1009m
Eiteradal, Vefsn, Nordland
Alt. 200 m. Vertical looping system of phreatic passages with vadose streamway. Several

10 Lapphølet (S St Pierre)



entrances including 40 m shaft with pitfall bone deposits. Explored by members of SWETC, Eccles and Wessex Caving Clubs 1978/79. Depth 90 m (Faulkner, B.C.R.A Trans., 1980, 7 (2): 53-69, survey). Stalagmite dated to 7.57 ± 0.42 ka B.P. (Lauritzen and St. Pierre, Norsk Geogr. Tidsskr., 1982, 36: 115-116). Estimated length 1400 m, 1984 (p.c. T. Faulkner, 1986).

B31. ØYFJELLGROTTA See A20 1000m

B32. NESMØLNELVGROTTA See A12 1000m

B33. SATISFACTION CAVE 1000m
Gråtådal, Beiarn, Nordland
Alt. c. 350 m. A predominantly vadose through cave; part of the Store Rønnåga cave system. Explored SWETC C.C. 1963. (St. Pierre, C.R.G. Trans., 1966, 8 (1): 34-37, plans). Linked with Birch Pole and Unnamed Caves by Holbye et al. 1969 (Faulkner and St. Pierre, SWETC C.C. Occ. Pub., 1973, (3): 23-24, plan - end paper). Altitude revised to new N.G.O. mapping. Depth c. 70 m. Resurging stream passes through Tunnel Cave and sinks in Rønnålihølet shakehole, see A15.

B34. KVANDALHOLA 1000m
Kvandal, Skjerstad, Nordland
Alt. 260 m. Sporting cave with several stream inlets ending in a sump. Sinks described by Vogt (N.G.U., 1897, 22: 230-231). Explored Kendal C.C., Handsworth G.S., 1979 (Cowle and Wilcock, B.C.R.A. Bull., 1982, (17): 19-22, survey). Depth -67 m, +4 m.

SUPPLEMENTARY LIST OF UNSURVEYED LONG CAVES

S1. DEVIL'S HOLES 3000-6000m
Burfjell, Rana, Nordland
Complex system of large sandy passages above a streamway with a number of entrances. Signs of previous visitors. (Hawkes, Wessex C.C. Jnl., 1985, 18 (202): 14; Tuck, Belfry Bull., 1985, 39 (1): 15-16).

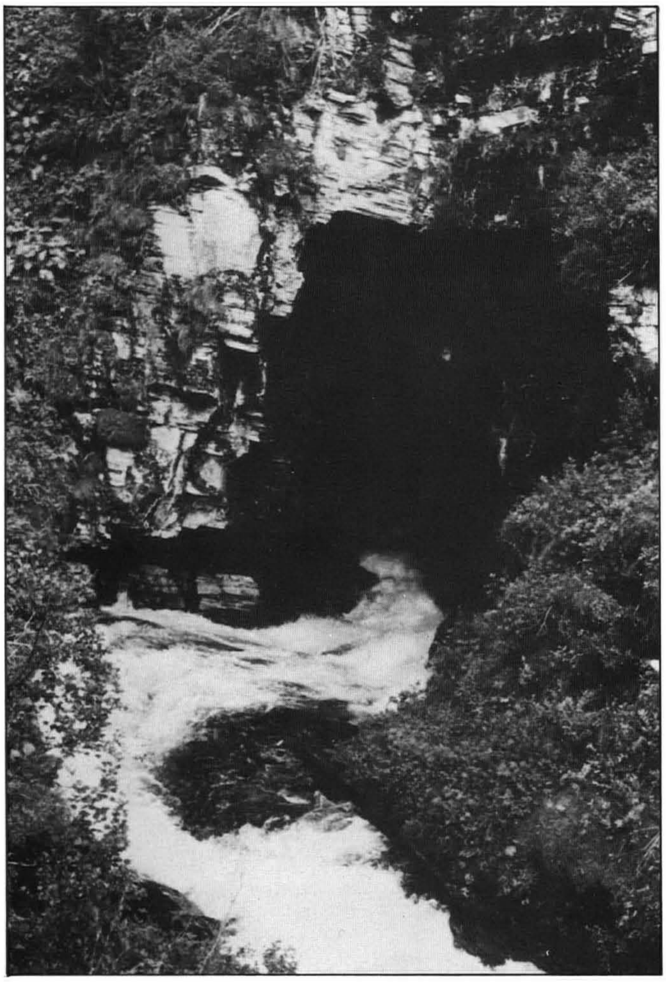
S2. UNIVERSITY OF EAST ANGLIA CAVE 2000m
Glomdal, Rana, Nordland
Stream cave 759 m long surveyed (unpubl.) by Univ. of E. Anglia cavers in 1984. A connection (unsurveyed) was made via a maze of sandy crawls by Wessex Cave Club the same summer (Hawkes, ibid., 1985: 12-13; Tuck ibid., 1985: 14) to a down valley cave also partly explored by U.E.A., 81 m surveyed + 200 m estimated (p.c. Bottrell, 1986).

S3. TROLLKIRKA (Trollkjaerringhola) 1500m+
Lavangseidet, Evenes, Nordland
Alt. 80 m. Large river sink cave with dry inlet passage ending at a sump. Extensive high level series. Explored Grønlie, Jensen and Skog, (p.c. Grønlie, 1981).

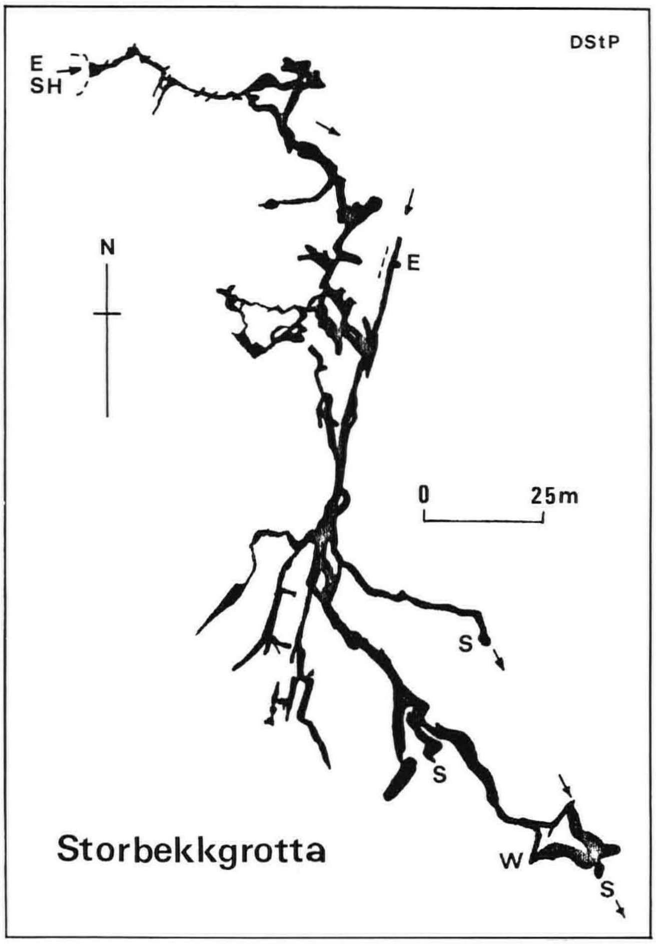
S4. HAGENHULLET 1500m
Jordbrudal, Saltdal, Nordland
Alt. 385 m. 465 m surveyed by Ermysted's G.S. 1965/66 (Heap, Report of Spel. Exped. to Saltdal, Nordland. 1966: 11-12, survey). Extension (Holbye, pc, March 1978). Depth 48 m.

S5. SVERREHOLA 1500m
Kobbelv, Sørfold, Nordland
Alt. 270 m. 950 m surveyed (Herstad, Norsk Grotteblad, 1984, (14): 3-5, plan). Depth 70 m.

S6. STORBEKKGROTTA 1018m
Glomdal, Rana, Nordland
Alt. 250 m. Incised tubular passages ending in sumps. Cambridge Univ. C.C. surveyed 300 m in 1958 (Jenkins, Cave Science, 1959, 4 (29): 226-227, plan). Dry upper series extended and surveyed to 918 m with a further 100 m estimated (Lauritzen et al. 1977-79). Depth c. 55 m.



11 Trollkirka (D St Pierre)



CAVES IN NON-LIMESTONE ROCKS

DEEPEST CAVES

C1. STYGGHØLET, Steinvik, Bjugn, Sør Trøndelag -60m
Alt. 160 m. Tectonic cave, 100 m long (Schrøder, Norsk Grotteblad, 1982, (9): 7).

C2. LJØTEHØLET, Ål, Buskerud -55m
Alt. 700 m. Tectonic cave, 70 m long (Schrøder, Norsk Grotteblad, 1980, (6): 10, survey).

LONGEST CAVES

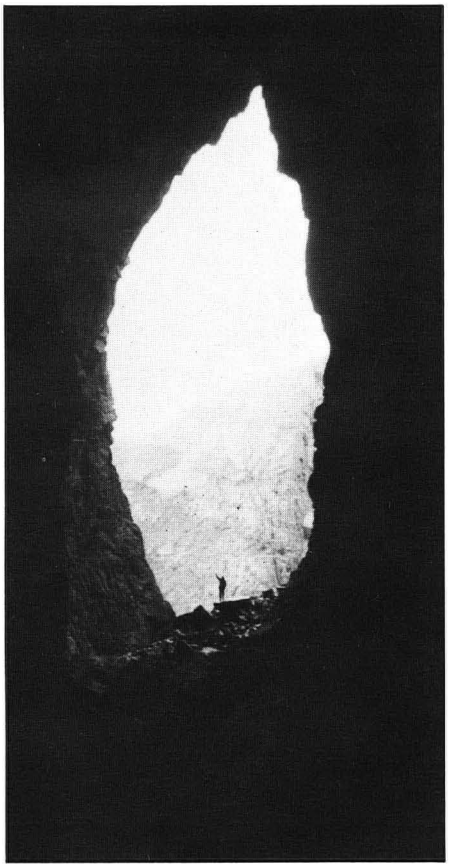
D1. HALVIKHULEN (Helvikhulen), Osen, Sør Trøndelag 340m
Alt. 117 m. Fossil sea cave. Massive entrance, 250 m wide, 80 m high. (Helland, Norges Land og Folk, 1898: 32; Sommerfjelt, Trondhjems Turistforening Årbok, 1906: 13-30; Sjøberg, Grottan, 1984, 19 (4): 9-10, survey).

D2. GUTVIKKIRKEN, N. Gutvik, Austra, N. Trøndelag 325m
Alt. 114 m. Fossil sea cave in granite also known as Lispingdalskyrka (Rekstad, N.G.U., 1910, 53 (5): 14; Sjøberg, Grottan, 1984, 19 (4): 10-11, survey).

D3. TROLLHOLA No. 2., Reksten, Sogn og Fjordane 300m
Alt. 52 m. Fossil sea cave (Helland, Norges Land og Folk, 1901: 172).

D4. STORHOLA, Domen, Varanger, Finnmark 300m
(Helland, Norges Land og Folk, 1905: 163).

D5. HARBAKHULEN, Stokksund, Åfjord, Sør Trøndelag 200m
Alt. 97 m. Fossil sea cave. Depth 37 m. (Krefting, Illustreret Nyhedsblad, 1865, (14): 84; Sommerfjelt, 1906, see above; Sjøberg, Grottan, 1983, 18 (3): 23-25).



12 Harbakhulen (R Sjøberg)

D6. REPHELLEREN, Sørland, Vaerøy, Nordland 188m
(Helland, Norges Land og Folk, 1907: 211).

D7. DOLLSTEINHOLA, Sandøen, Sande, Møre og Romsdal 180m
Alt. 60 m. Fossil sea cave. Depth 40 m. The cave is mentioned in the Orkney Sagas of the 12th Century and is described by Pontoppidan, (Norges Naturlige Historie, Copenhagen, 1752: 76-77); Reusch (Nytt Magasin for Naturv., 1877: 173-183, survey, illus.; and Sjøberg (Grottan, 1984, 19 (4): 8-10).

D8. TONNESHULEN, Melfjord, Lurøy, Nordland 170m
Alt. 100 m. Fossil sea cave. (Kraft, Topo. Stat. Beskr. o. Kongeriget Norge, 1838, 6 (2): 302; Rekstad, N.G.U., 1912, 62: 64-65).

D9. TORGHATTENHULLET, Brønnøy, Nordland 160m
Alt. 112 m. Fossil sea cave. A legendary through-cave in gneiss. Early descriptions by De Cappel Brook ("Travels through Sweden, Norway and Finnmark in 1820", 1823: 202-212); and Martel (La Nature, 1895, (1176): 19-22). Main description by Rekstad and Vogt (N.G.U., 1900, 29: 95-105, survey); also see Sjøberg, (Grottan, 1983, 18 (3): 19-21, survey). There are a number of strandline within the cave.

D10. FINNEKIRKEN, Tysfjord, Nordland 160-200m
Alt. 145 m. Tectonic cave in granite at Hellemobotnvatn, (Hoel, Norges Land og Folk, 1907, (4): 412-413 cited in Foslie, N.G.U., 1942, 150: 104).

D11. GAUPEHULA, Rømmesfjell, Bjugn, Sør Trøndelag 150m
Alt. 170 m. Calcite lens formation. Depth 30 m. (Schroder, Norsk Grotteblad, 1982, 3 (9): 7-12, survey).

D12. ROSVIKHOLA, Solstad, Nord Trøndelag 150m
Fossil sea cave in granite. At strandline. (Rekstad, N.G.U., 1910, 53, (5): 14).

D13. SKJONGHELLEREN, Valderøy, Giske, Møre og Romsdal 140m
Alt. 57 m. Fossil cave in gneiss. Classic palaeozoological excavations. (Neumann, "Bjerghulene i Bergens stift". Urda, 1837: 201 - 229; Reusch, Nytt Magasin for Naturvidenskarbena 1877 : 185-194, survey, illus.; Sjøberg, Grottan, 1983, 18 (4): 26-28; Larsen, "Weichsel stratigrafi og glasialgeologi pa Nordvestlandet. 1984, Dr scient. diss., Bergen Univ., unpublished). Bones from top part of 20 m thick sediment bank have been dated as 29,590 ± 800 years B.P. Others may be as old as the Eem interglacial, 120,000 years B.P.

ACKNOWLEDGEMENTS

The above lists have been compiled from data abstracted from the authors' Norwegian Cave Index and Bibliography which was started in 1963 with the aim of cataloguing all Norwegian caves and related literature. Acknowledgements are due to the many individuals, in Norway, Britain and elsewhere who have contributed information thus helping to keep these records complete and up to date. Simon Bottrell, Claude Chabert, Trevor Faulkner, Andrew Ive, Arne Grønlie, David Heap, Ray Mansfield, Rabbe Sjøberg, Per Straumfors, Roger Sutcliffe and particularly Ulv Holbye have assisted with recent contributions and suggestions relating to this article. The assistance of Tony Waltham in the preparation for publication is gratefully acknowledged.

Any errors however remain our own and the authors would like to be informed of any mistakes and omissions so that suture lists can be amended and updated. They would also be grateful for details of any new discoveries, surveys and publications even those of a minor nature.

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The Quaternary Bone Caves at Wallingford, Jamaica

D A McFARLANE and R E GLEDHILL

Abstract : A group of caves associated with the sink of the One Eye River in St. Elizabeth Parish, Jamaica, have been the subject of numerous important palaeontological investigations beginning 1919. Unfortunately, considerable confusion has arisen in the literature through inadequate documentation of different sites. The caves of the immediate area are described and located, and their palaeontological significance is summarised in the light of recent taxonomic review and relevant geochronological evidence.

The caves at Wallingford, St. Elizabeth Parish, have been the focus of palaeontological investigations in Jamaica since they were first discovered by H. E. Anthony in 1919 (Anthony, 1920). Subsequent work has been intermittent and until very recently, hampered by inadequate documentation of the stratigraphy, the sites and their locations. Nevertheless, the palaeontological record from the caves remains of critical value to the interpretation of Caribbean vertebrate history, and a recent re-evaluation of some of the material (MacPhee, 1984) has established the Wallingford record as amongst the oldest known from the Caribbean.

The first attempt at a consistent cataloging of the Wallingford caves was that of Fincham (1977) as a small part of a comprehensive catalogue of Jamaica's caves. Unfortunately, Fincham's register located only one of the fossiliferous caves in the area and did not address the confusion of sites established in the palaeontological literature. MacPhee (1984) pointed out that prior to his own work, not a single fossiliferous cave site had been adequately described from Jamaica with respect to map location and physical description. MacPhee's work has cleared up much historical confusion resulting from these inadequate site descriptions, but his summary emphasises only Wallingford Roadside Cave and does not provide surveys or detailed descriptions of the other caves in the immediate area. The purposes of this review are to locate precisely and to describe the known caves of the immediate area and to summarise their palaeontological and geomorphological significance.

Wallingford Roadside Cave

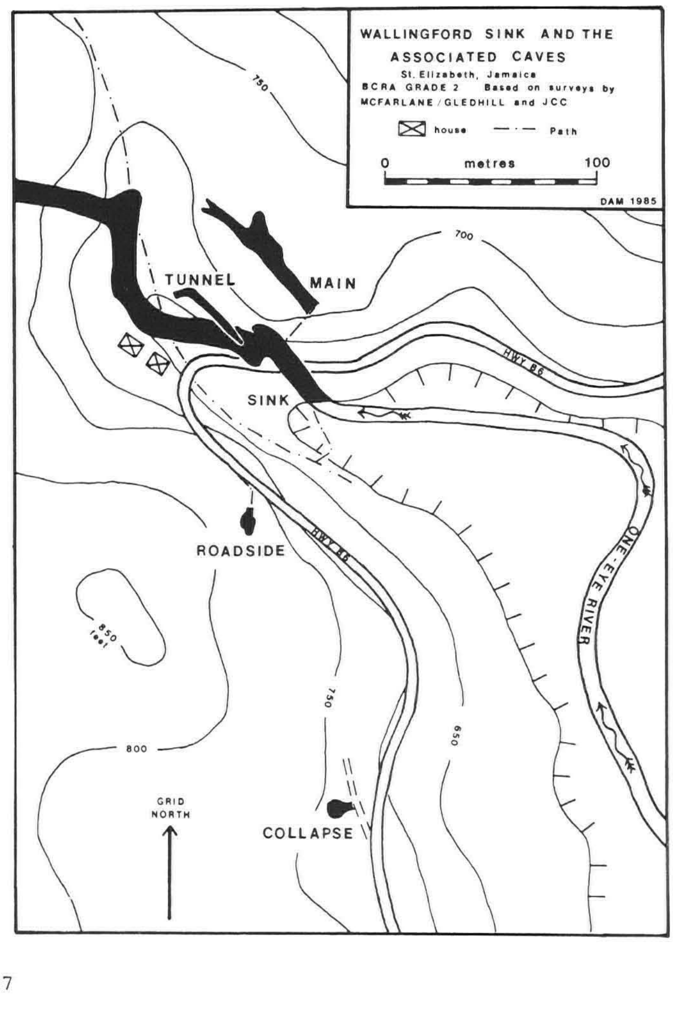
Grid Reference; 3275 4664. Altitude; 234 m. Length; 11 metres.

Located 6 m above the road (Highway B6), 61 m southwest (bearing 217°) of the sink of the One Eye River.

The entrance to Roadside Cave is a rift-like opening with a steeply sloping floor of earth and flowstone. Immediately within, the cave opens out into a small chamber and then closes in to a substantial earth and flowstone choke. The floor of the chamber consists of a hard-packed, brown earth which is at least one metre deep at the back of the cave. This earth has been the source of fossil or subfossil representatives of the extinct Rice Rat Oryzomys, the extinct bat Tonatia, and a variety of other mammalian and reptilian taxa. The rear wall of the cave has a heterogeneous, calcite-indurated 'breccia' accreted to it, although the bulk of the original deposit has now been removed by successive generations of palaeontologists. Frequently referred to in the literature simply as a "cave breccia", the material is a clay-rich earth intimately cemented with calcite and interspersed with thin calcite layers and vugs. Examples of this material are housed in the collections of the Florida State Museum and the American Museum of Natural History in New York.

Also known as: Wallingford Cave; Balaclava Cave; "J1" (Anthony, 1920, field notes in the American Museum of Natural History); Wallingford I (Patten, 1966 c.f.MacPhee, 1984).

The palaeontology has been reviewed by MacPhee (1983, 1984). This site is the type locality for the Heptaxodotid rodent genus Clidomys and its two recognised species C. osborni Anthony 1920 (includes the synonomised taxa Speoxenus cundalli Anthony 1920 and Alterodon major Anthony 1920) and C. parvus Anthony 1920 (includes the synonomised taxon Spirodontomys jamaicensis Anthony 1920). The cave is also the type locality for the phyllostomatid bat Tonatia saurophila Koopman and Williams 1951. Other fossil remains include; (Mammalia) Geocapromys brownii, Oryzomys palustris, Natalus major, Phyllonycteris aphylla, Eptesicus sp.. (Reptilia) Celestus sp., Crocodylus sp., Pseuemys floridana Alisophis sp., Tropidophis sp., and Anolis sp.



Wallingford Main Cave

Grid Reference; 3278 4671. Altitude; 240 m. Length; 77 metres.

Located 17 m above the road (Highway B6), 45 m due north of the sink of the One Eye River.

Main Cave is large, dry, strike-oriented passage with a boulder floor. Remnants of cave fill are present, but the cave was formerly mined for guano (Peck, 1975) with the resultant loss of palaeontological materials. At its furthest reaches the cave closes down to two bifurcating crawls which rapidly become choked with flowstone deposits.

The structure and location of Main Cave clearly indicates its role as a former sink of the One Eye River, long since abandoned. MacPhee (1984) has proposed a Sangamon (125,000 yr BP) age for secondary bone-bearing conglomerates in Wallingford Roadside and Main Caves based on taphonomic considerations, implying a minimum downcutting rate of 28 cms/Kyr. Additionally, Gascoyne (1981) has presented uranium series speleothem dates from the abandoned Oxford Cave and active Coffee River Cave at the upstream resurgence of the One Eye River. Although Gascoyne has only calculated downcutting rates within these caves, their altitudinal separation can be used to derive a downcutting rate between the caves of 27 cms/Kyr, neglecting the complexities introduced by the migration of the subterranean drainage channel. This compares very favourably with the rate of 28 cms/Kyr derived from MacPhee's estimate and suggests that an Interglacial age for active development at Main Cave is highly probable.

Also known as: Wallingford Cave (Fincham, 1977); Balaclava Cave; "J2" (Anthony, 1920, field notes in the American Museum of Natural History); Wallingford II (Patten, 1966 c.f. MacPhee, 1984).

The palaeontology was originally similar to Roadside Cave but much less rich. Both Anthony and Patten seem to have collected Clidomys fragments here, but the location and extent of the breccia is unclear. At Roadside Cave the fossiliferous breccia is intimately associated with the earth choke at the back of the cave, but at Main Cave the choke is of much purer white flowstone alone. Breccia was noted by the present authors in 1985. The nature and extent of the original cave fill was most unfortunately not described or documented adequately by any of the earlier workers and it is now impossible to determine what may have been lost.

Wallingford Sink

Grid Reference; 3278 4667. Altitude; 205 m. Length; 413 metres.

The sink of the One Eye River, located 65 m east-southeast and 21 m below the centre of the hairpin bend in the road (Highway B6) at Wallingford.

The sink is a large, strike-orientated river passage which carries the entire flow of the One Eye River. A number of gour pools and swims (in wet weather) lead to a sump and thereafter by an unexplored route to a resurgence in Mexico Cave approximately 1500 metres to the east. The cave is subject to periodic, severe flooding which may submerge the entrance by 10 metres or more.

Also known as: Wallingford Cave; "Gulf" (local parlance).

No palaeontological remains have been reported. However, Peck (1975) reported observing indurated breccias in Wallingford Sink, which led him to confuse this cave with Roadside Cave. This observation has never been followed up.

Wallingford Tunnel Cave

Grid Reference; 3272 4671. Altitude; 228 m. Length; approx. 40 m.

Located 88 m northwest of the sink of the One Eye River, on the north side of the foot track and opposite a small house.

The small overgrown entrance descends steeply to the northeast and then swings southeast as a low, heavily decorated crawl eventually becoming choked with flowstone.

It has no other names, but was referred to by Peck (1975) as an un-named site near Wallingford (Main) Cave.

No palaeontological material has been reported.

Collapse Cave

Grid Reference; 3279 4655. Altitude; 250 m. Length approx. 12 metres.

Located 205 m due south of the sink of the One Eye River, on the west side of, and 22 m up a dirt road ascending from Highway B6.

A small entrance opens onto a walking-sized passage with a steeply descending boulder floor. At the bottom, a chamber is almost completely filled by a large, flat-topped slab apparently fallen from the roof. Rifts and crawls around the periphery of the slab give access to portions of a mud and gravel floor.

No prior reference to this cave has been found.

No palaeontological record is known. Remains of a feral house cat were observed by the authors in 1985. The sediments have not been systematically examined, but appear to be of more recent origin than those in Roadside Cave.

Wallingford Sinkhole Number 1

Grid Reference; 332? 467? (unconfirmed). Altitude; Unknown. Length; Unknown.

Located to the west of the track approximately 450 m north of Wallingford Tunnel Cave. Reported by Fincham (1977) but not seen by the present authors in 1985, and not known (?) by locals.

A shaft some 10 m in diameter and 20 m deep. Apparently choked, but not undescended.

Wallingford Sinkhole Number 2

Grid Reference; 327? 467? (unconfirmed). Altitude; Unknown. Length; 15 metres.

Exact location unclear. Described as "a few metres north of road, opposite house" (Fincham, 1977). Not seen by present authors in 1985, and not known to locals.

Apparently a 7 m pitch to a descending passage choked by a rock.

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Towards a Mousterian Chronology

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Abstract: The chronology of Mousterian industries from southwestern France has been derived from archaeological cave sites. Currently, few absolute dates are available and chronology relies upon a composite inter-site sequence based upon sediments. The sampling of these sediments, however, has not been taken into account in formulating the scheme. This paper outlines the importance of dating the Mousterian and questions the sediment-based scheme. A need for closer examination of sampling procedures and for control studies is suggested and also for greater co-operation between archaeologists and environmental scientists.

It has been argued on the basis of revised dating that in situ evolution of Neanderthals into H. sap. sapiens could not have taken place in France, for too little time separates the two forms (Ap Simon, 1980). This revised dating is the product of an inter-site sedimentary comparative scheme (Laville, Rigaud and Sackett, 1980). As yet, this scheme appears to have been rather uncritically accepted. The immediate and obvious benefits from it tend to obscure possible limitations and complications. As the scheme has serious implications for both physical anthropology and palaeolithic archaeology, it will be reviewed here.

Archaeological explanations of the behaviour of Neanderthals in southwest France hinge around different interpretations of the significance of what has become known as 'Mousterian variability'. This has been the subject of a protracted debate and certain general points have emerged. Firstly, this debate is limited to the early last glacial (Würm), phases I to II/III interstadial, and its interests end with, although they are not without significance for, the onset of the Upper Palaeolithic in phase III. These phases have been defined on the basis of pollen, fauna and sedimentological evidence. Secondly, the southwestern French case is important because it is particularly rich and comparatively well documented; especially notable is the typological work of Bordes (1961). This remarkably inclusive and extensive study yielded a series of five assemblage types, the 'Mousterian variants', which are recognized by characteristic forms of cumulative percentage frequency graphs and technological indices. These variants have been adequately described elsewhere (Bordes, 1961, 1968, 1972, 1973,; Mellars, 1967, 1969, 1970) and therefore will not be repeated here. However, it is useful to note their names: the Typical, Denticulate, Ferrassie and Quina Mousterian and the Mousterian of Acheulean Tradition (MAT). Explanations of the significance of these variants have been the perennial archaeological arguments of function (Binford 1973; Binford and Binford, 1966, 1969; Freeman, 1966), culture (Bordes, 1972, 1973; Bordes and de Sonneville Bordes, 1970; Collins 1969, 1970) and chronology (Mellars, 1965, 1969, 1970). One particularly convincing aspect of the debate has been the study of chronology. Mellars examined the succession of variants occurring within sites and from this it was noted that within the Greater Perigord region, twelve sites had the MAT variant stratified above Quina variants whilst no clear reversal of this order could be demonstrated elsewhere. Further, it was noted that MAT frequently occurred directly beneath Upper Palaeolithic levels and that at the important site of Combe Grenal, where a remarkable fifty-five layers of Mousterian are documented, the MAT occurs only in the top four layers, clearly above the Quina variant levels. Tying these observations in with evidence from faunal and pollen records, it was suggested that the MAT was chronologically the latest Mousterian variant, probably occurring in the relatively mild conditions of the Würm II/III interstadial and in Würm II. In addition to this succession, another less clear stratigraphic argument could be made for a succession of the Ferrassie evolving into the Quina. This was documented at only two sites and must, therefore, remain tenuous. However, the typological and technological seriation (Mellars, 1969) strengthens this view.

A limitation of this technique is, however, that the two variants are assumed to be linked but separate forms; time is an assumed explanation (see Orton, 1980: 80). Bordes (1968, 1972, 1973) has, with other workers, noted the close resemblance between Ferrassie and Quina variants, which are grouped together as 'Charentian' types. It may be that the classic typology has been over-cladistic in this case and that a single Charentian is to be preferred as a variant in its own right. After all, the tool types which comprise the Bordes type list have never been subjected to statistical analysis to determine how far they represent distinct, and how far similar, forms. Also, recent work has shown the technological trends in the use of Levallois technique, platform facetting, etc., that Mellars takes to represent a Ferrassie-Quina evolution, continue within the Quina itself (Le Tensorer, 1978). This aspect of the chronological succession requires further investigation.

Recently, this view of chronological succession has been rejected (Laville, 1973; Laville, Rigaud and Sackett, 1980). On the basis of sedimentology it is claimed that interdigitation of the variants occurs without significant chronological patterning - if not at any given site then throughout the early last glacial in the Perigord region. This conclusion was reached following the examination of the series of sediment layers from four different sites; it noted their morphology as representing the environmental regime of their production and a master stratigraphic sequence was constructed for the region, tied into the climatic fluctuations of the early glacial. Thus, the interdigitation of the variants necessary to refute the chronological succession is created indirectly. The result of this is to leave the question of the significance of Mousterian variants back with the culture-function debate and the variants, to some degree, contemporary, without significant change or interaction for tens of thousands of years. Similar work in Spain (Butzer, 1981) fails to inform on the chronological sequence established by Mellars although showing Denticulate and Typical Facies were coeval. The question must then be 'how valid is the new sediment-based sequence?' The problems inherent in interpreting any sequence of sediments are many. Cornwall (1958: 31-34) has shown how delicate the balance between temperature, moisture and location is in both cryoclastic weathering of cave surfaces and in the pedogenetic cycles of cave contents, a point noted in the field by Legge (1972) for the sites of Asprochaliko and Kastritsa. This means that the sediments within a cave will be unique relating to its individual circumstances. This uniqueness of a cave's geomorphic history is not overlooked in the Perigord sequence, but the degree to which sediment sequences can be matched needs questioning.

The bulk of our understanding of cave sediments has been obtained from archaeological sites. It is the archaeology which usually draws attention to a site and is the reason for study. While to a large extent the effects of human occupation may be small, in combination they require further consideration. Not only is an empty cave's sedimentary history likely to be unique but occupational histories of sites will also vary. This point is generally recognised but where further thought may be required is in the sediment sampling itself. Human use of fire in caves is well-documented in the Perigord sites and the lighting of fires will produce local air movements, alter gradients of temperature and humidity and may locally increase the amount of water present by liberating it from frozen rock. All these phenomena will alter rates of weathering in the cave relative to where it might otherwise occur. Cornwall stated (1958: 34): "Samples taken from close to the entrance of a cave may not show climatic and chronological zoning very clearly"; work at Creswell Crags is currently investigating the internal variability of cave environments (Smithson, 1985). It is suggested that the presence of fire in a site will require due account in sampling strategy and analysis. This may also be a relevant point for pollen studies.

These comments question the straightforward sampling of sediments from archaeological sections without due account of the archaeology itself. The degree to which the above effects operated in the past will depend upon the duration and number of occupations, numbers of people involved and the activities they undertook. Bouchud (1966) has suggested that occupation was generally occurring all year round, on the basis of studies of reindeer teeth. However, this view has recently been challenged (Binford, 1981). The archaeological layers themselves are often noted as rich in tools and as being relatively thick with many hearths occurring. This may be taken to suggest stays of some duration. However, evidence on this remains unclear (Binford, 1982).

The Perigord sequence for the Mousterian is essentially based on four archaeological sites: Combe Grenal, Pech de l'Aze I, Le Moustier Lower Shelter and Caminade Est. At three of these sites, erosional phases have been documented and some removal of sediment has occurred. Thus, at each site a gap in the sequence exists. Further, the site of Le Moustier has had the bulk of the deposit removed by archaeologists prior to the development of refined sedimentological techniques. Recent work has been carried out on a block of 'control' sediments that remain. However, it is likely that this controls only for archaeology. There is no way of assessing how representative these control blocks are of the sedimentary history of the site; the sequence is based on two non-abutting sections and comprises both cryoclastic and water-lain deposits. The only site without a hiatus in the sequence is Pech de l'Aze I. However, there, too, past excavations have removed a considerable amount of the deposit. It is possible that at all of these sites some events in sedimentary history may be omitted. Thus it is that the gaps in the sequences are flaws in the master sequence. The sediments, when correlated, show parallelism in environmental erosional regimes but do not prove synchroneity: it is possible that longer sequences have been telescoped together. Synchroneity is an assumed feature strengthened by further correlations above and below in the sequence. However, it may be that phases of occupation and abandonment create their own pedogenic and erosional cycles; how far these would correlate with the major climatic fluctuations of the region remains to be demonstrated. It has yet to be seen how fine-grained the sedimentological record is. Cross-correlation between sediment layers at different sites that are not synchronous would be dangerous, for once a basic correlation is made, such a scheme is partly self-fulfilling. This is particularly an important consideration in the light of new dating for the Mousterian using uranium series dating (Dennell, 1983; Schwarcz and Blackwell, 1983) which expands the possible range of the Mousterian succession considerably.

It is unfortunate that the sedimentologist is so often dependent upon the archaeologist for sections to sample. It cannot usually be determined how representative the sample is and very often in publication no account is given of the cave as an enclosure (see, for example, Schmid, 1969). The face of a cliff, outcrop, etc., in which a site occurs may recede during a site's lifetime, a feature apparent at Combe Grenal. Thus, the sample taken at the middle of a site and representing the erosional events of a central entrance environment may have once been much deeper within the cave and, therefore, subject to a different erosional regime. The location may change its 'place' (Parkington, 1980). These problems will only be resolved following further work in the region and a new concentration on gaining representative samples by archaeologists as well as sedimentologists. What is needed in any attempt to create a regional master sequence of sediment stratigraphies is a development of 'middle-range' investigation (Binford, 1977). To account for the relative effects of human occupation and archaeological sampling, a control sequence, or set of sequences from unoccupied sites, could be used, through the expansion of studies into variation of sediment forming factors for single layers within a site. This could be used to devise a consistent set of factors to be incorporated into sediment sampling strategies and so increase comparability. This would develop the picture of regional climatic fluctations without the complications of archaeology. Against this picture could be employed a comparative approach using the archaeological data, with an allowance for the use of statistical techniques, to demonstrate the relative strengths and weaknesses of correlations in the series. Until the regional stratigraphic sequence of the Perigord has been strengthened in this way, it must remain tenuous. The succession of Mousterian variants documented by Mellars (1969 and 1970) has the intrinsic strength of being based upon intra-site stratigraphy and until the inter-site composite sediment stratigraphy can match this strength, the chronological ordering of certain Mousterian variants may remain a strong viewpoint.

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B.C.R.A. Cave Science Symposium, November 1985

Abstracts of papers presented at the meeting

University of Sheffield, November 1985

GEOTHERMAL DETECTION OF SHALLOW CAVITIES. RESULTS FROM THE SOUTH WALES KARST

M. Noel, Department of Geology, University of Sheffield.

Estimates based on simple models suggest that shallow cavities may be detected from their associated ground temperature anomaly as measured by thermistor probes placed below the range of diurnal fulctuations. In karst areas the anomaly arises from the heat flux refraction, ventilation cooling and hydrothermal effects caused by the cavity. The relative importance of these factors is dependent on the conduit type but model calculations suggest that a 10 m cavity could be detected at a depth of 60 m. The technique has proved successful in locating Pwll y Pasg cave, Powys.

THE MINING HISTORY OF THE SPEEDWELL CAVERNS, CASTLETON, DERBYSHIRE

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

A re-assessment of contemporary historical sources in conjunction with the results of recent explorations in Speedwell and Peak Caverns enables some deductions to be made about the sequence of events leading to the driving of the Speedwell Levels 1771-1782. The Oakden-Gilbert partnership clearly designed the Level to intersect previously known stream caverns so as to develop a boat-haulage lead mining operation. There is now considerable evidence for there having been at least two routes into the stream cave system before the Level was driven.

THE HYDROLOGY OF MYNYDD LLANGATTWG

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Mynydd Llangattwg is an upland area of the northern outcrop of Carboniferous Limestone in the Powys and Gwent areas of South Wales. The mountain contains many caves including the extensive systems of Agen Allwedd, Craig-a-Ffynnon and the recently discovered Daren Cilau. All the caves so far discovered drain the limestone to large resurgences in the Clydach Gorge to the south-east of the mountain upland. Using dyes and lycopodium spores, flow patterns have been drawn up for water sinking into the limestone and passing through the strata to the resurgences and these patterns seem to point to water courses being at three or four different levels within the limestone strata; some cave streams being able to pass over other streams without any mixing of the waters occurring. The results to date indicate a complex history of underground water flow within the mountain probably related to the formation of the Usk river valley to the north and the Clydach gorge to the south-east.

TEMPORAL CONTROLS ON THE COMPOSITION OF DERBYSHIRE RESURGENCES

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Research has shown the existence in Derbyshire of a complete spectrum of groundwater types. Previous research by the authors in spatial controls on groundwater composition will be reviewed briefly. Weekly water samples from these representative resurgences were collected and analysed for all principal ions. The data was then computer analysed in conjunction with climatic information. Principal component analysis has identified 57-83% of the variance of the sites. The dominant control on the concentration of Ca, $HC0_3$ and Mg is soil temperature. Whereas K, Na, Cl and $N0_3$ are dominantly controlled by flow and rainfall. Sulphate and silica are affected by both factors. A similar picture emerged from both conduit and resurgences and diffuse flow resurgences, although the proportion of unexplained variance in the latter case is high (45%). This is tentatively assigned to random error in the analytical chemistry accounting for a larger proportion of overall variance in a chemically stable resurgence.

HYDROLOGY AND GEOMORPHOLOGY OF THE VALE OF TRALEE KARST, CO. KERRY, IRELAND

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The vale of Tralee is a narrow tract of Carboniferous Limestone lowland, bounded to the north by the Stacks and Glanaruddery Mountains (Namurian Shales) and to the south by the Slieve Mish Mountains (Old Red Sandstone). In common with most Irish lowland karsts the limestones are mantled with a variable thickness of superficial deposits including drift, alluvium and bog which mask the pre-glacial karst topography and support a considerable amount of surface drainage. Prior to 1980 the area had received very little attention from cavers and was one of the least known of the Irish karsts. During 1980 Kerry County Council became concerned at a deterioration in the quality of water from a karst rising which supplies some 5000 domestic consumers in Castleisland town. The writer was asked to carry out water tracing experiments to identify the source of pollution. During the course of this investigation several caves were discovered and this lead to further studies which are still continuing. By September 1985 some 7500 m of cave had been explored and surveyed, inlcuding Crag Cave which is now the eighth longest cave in Ireland at 3810 m. This cave and the Ballymacelligott Caves (1442 m) contain substantial clastic sediments and speleothems which it is hoped will shed light on the late Quaternary history of the area. Water tracing experiments are also being undertaken to evaluate the present day underground drainage patterns in the Vale of Tralee.

THE CASTLEGUARD FORMATION, ITS AGE AND ITS IMPLICATIONS FOR CENOZOIC LANDSCAPE DEVELOPMENT IN THE CANADIAN ROCKIES

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C O Hunt, Creswell Crags Visitors Centre, Worksop.
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Castleguard Cave is an 18 km long karstic drainage conduit located beneath the Columbia Icefield in the Canadian Rockies. The cave is in-filled by a unique, laminated sedimentary unit which is exposed along almost the entire length of the conduit. This unit, defined as the Castleguard Formation, the first cave sedimentary unit to be fromally defined in these terms, appears, on the basis of palynological evidence, to be of Upper Miocene age. Since the oldest deposits previously known in the cave are speleothems dated by palaeomagnetic and Uranium-series methods to between 0.73 and 1.25 Ma bp, these results necessitate a radical revision of previous ideas regarding the age of the landscape of the Rocky Mountains and the rate at which the relief of the region has developed.

DYE TRACER AND STABLE ISOTOPE STUDIES OF THE UNSATURATED ZONE ABOVE WHITE SCAR CAVE, YORKSHIRE

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The behaviour of water in the unsaturated zone of an aquifer is interesting from the point of view of protecting groundwaters from pollution, estimating percolation times of pollutants to the water table, and estimating the flushing time needed to clear away accidental pollutant spills. Caves provide entry to the unsaturated zone and allow its study from the inside. The unsaturated Carboniferous Limestone over White Scar Cave varies from 0-60 m thick. Transit and residence times of water in this zone were studied with dye tracers injected beneath the soil in a shallow pit, or into fissures. The natural variations of the stable isotope composition of rainfall provided a second type of tracer, with an input which was evenly spread over the whole area. Both types of tracer showed similar results. The unsaturated zone shows strong mixing behaviour, with mean residence times in the order of tens of days. These results can probably be extended to other strongly fissured or fractured rocks such as some granites or sandstones.

THE PRESENT DISTRIBUTION OF CAVE FAUNA IN THE BRITISH ISLES AND ITS SIGNIFICANCE IN THE INTERPRETATION OF QUATERNARY HISTORY

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The relatively few obligate cave-dwellers in the British fauna can be divided into two groups: the ancient, relict "palaeotroglobites" and the much more recently sub-terranean "neotroglobites". The latter are widely distributed and were probably derived from a tundra or taiga fauna which, at the end of the Pleistocene, followed the retreating glaciers in a generally northward direction. The palaeotroglobitic fauna, however, shows marked differences between areas and, although not confined to previously unglaciated regions, is virtually absent from the more northerly parts of the country. Its present distributional features might be indicative of earlier divergence as island faunas if, as has been suggested, there has been a considerable overall eustatic fall of sea-level since the end of the Tertiary.

PONTNEWYDD CAVE: CONTINUING EXCAVATIONS AT A MIDDLE PLEISTOCENE ARCHAEOLOGICAL AND HOMINID SITE IN WALES

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Pontnewydd Cave, Clwyd, is the only known Middle Pleistocene hominid cave-site in Britain. It has produced an Upper Acheulian industry associated with the fragmentary remains of at least the hominids who have been compared, on the basis of the characteristics of taurodontism with early Neanderthals. The industry includes frequent hand-axes, the use of the Levallois technique for the production of flakes, blades and points, and numerous side-scrapers, normally with minimal retouch. The finds have all been emplaced by the mechanism of debris flow, which has resulted also in the intra-cave preservation of the finds in an environment which has seen several subsequent episodes of glaciation. The most likely age of the hominids and of the archaeological artefacts is within Oxygen Isotope Stage 7. Recent work has continued to produce prolific finds and has demonstrated that the archaeological/hominid cave-deposits continue for a substantial distance into the cave and the future promise of the site is thus considerable. This promise has been further increased by the discovery of a new entrance, deeply buried under hill-slope deposits, which will be excavated in 1987.

RATES OF VALLEY INCISION IN THE CARBONIFEROUS LIMESTONE OF THE SOUTHERN PENNINES

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Uranium series dating has been used to determine the ages of speleothem samples taken from fossil phreatic caves in the sides of the Manifold Valley, Staffordshire. Many samples have proved to be beyond the range of the method (350 ka). Palaeomagnetic analysis of samples taken from thick flowstones in Elderbush Cave, near the crest of the valley side indicate that both normally and reversely magnetised calcite is present. Some of the normally magnetised material lies beneath reversely magnetised layers. Uranium series analyses suggest that, whilst some of the normally magnetised calcite is probably of Jaramillo age (0.91 - 0.97 My), some may well be of Olduvai age (1.6 - 1.8 My). The maximum average downcutting rate for the valley at this point over the last 1.6 My is calculated to be 6.87 cms/ka. This compares with calculated entrenchment rates in the Yorkshire Dales of between 5 cm/ka and 20 cms/ka (Gascoyne et al 1983), around 21.0 cms/ka in the Mendips (Atkinson in preparation) and 0.04 - 2.07 m/ka in the Rocky Mountains (Ford et al 1981). The evidence indicates that exposure and dissection of the limestone plateau of the Southern Pennines was well under way 1.5 My ago.

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Ecology of the Crocodile Caves of Ankarana, Madagascar

Jane M WILSON

Abstract: This brief introduction to Malagasy caves focuses on one of Madagascar's longest cave systems which is in the Ankarana limestones of the tropical north-east. A survey of the 11 km long Grotte d'Andrafiabé and species lists of cavernicoles are given.

Résumé: Une courte introduction aux grottes malgâches se concentre sur les calcaires d'Ankarana au nord-est du pays, où se trouve l'une des plus longues grottes de la Madagascar (plus de 11 km de galeries). Nous présentons un plan de la grotte et des tableaux d'espèces cavernicoles.

The island of Madagascar is 1600 km long and lies 235 km from the nearest point on the mainland of East Africa. Most of Madagascar's 33,000 square kilometres of karst (fig. 1) (Balazs 1980) have been ngelected by geologists and speleologists, although Decary and Keiner (1971) provide a useful inventory of the island's caves.

The depth potential on Madagascar is limited: the highest limestone outcrop is under 600 m and the deepest known pothole is only 160 m. There is, nevertheless, great scope for discovering many kilometres of fine new passage, as the French have demonstrated on their repeated trips to Ankarana in the northern tip of the island.

Madagascar's caves have considerable ethnological and biological interest as well as sporting potential. Some caves are used by Malagasy to inter their ancestors between pentennial 'Body Turning' (Famadihana) exhumation celebrations, and are all likely to contain fascinating fauna. Madagascar boasts a marvellous variety of endemic species : an ecological and evolutionary museum of plants and animals whose nearest relatives became extinct either with the appearance of carnivorous mammals on the mainland or later with anthropogenic environmental changes. The island lacks large predators (if one excludes man) and it was colonised by man less than 2000 years ago.

Most of Madagascar's epigean (surface-dwelling) species are endemic and odd. For example, the little known sucker-footed bat, Myzopoda aurita, is the only representative of a family of bats characterised by mushroom-shaped ear processes. The cave-adapted animals are even more bizarre and difficult to classify. One of the two known species of blind troglobitic Malagasy fish, for example, lacks a lateral line or any other obvious external sensory apparatus and yet is particularly adept at avoiding capture (Decary and Arnoult 1981).

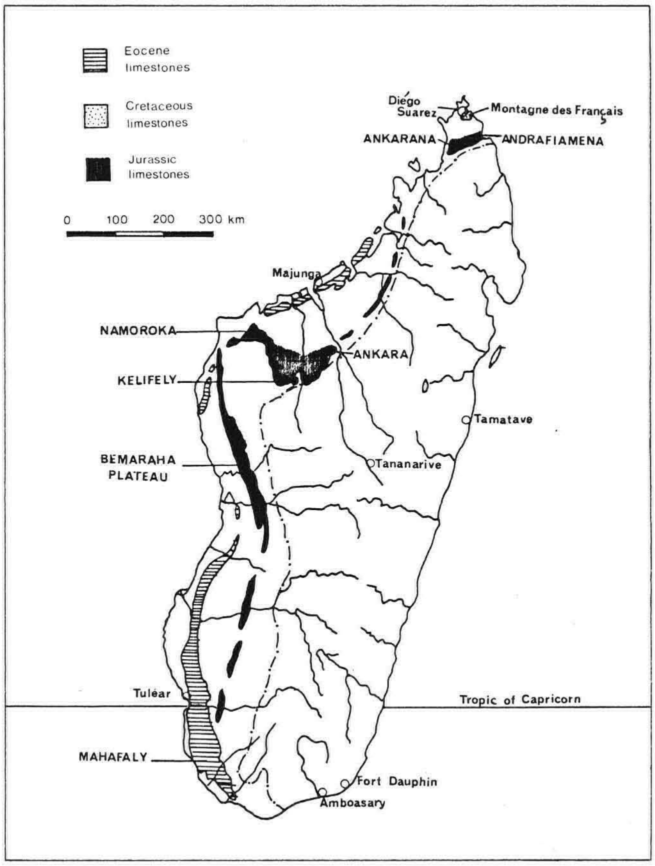
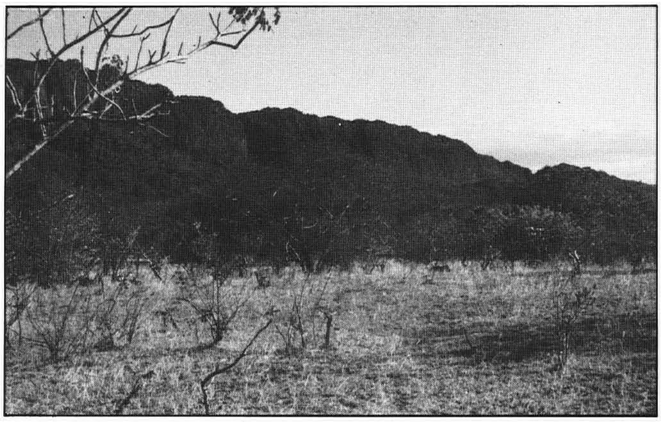


Figure 1. Karstic areas of Madagascar (after Balazs 1980) Sedimentary rocks are only found west and north of the chain-dotted line. The small outcrop of Cretaceous limestone which overlooks Diego-Suarez contains caves but these are dirty and vandalised.



The northwest-facing cliffs of the Ankarana Massif. The Cassure des Buttes Chaumonts (=Gorge) is left of centre.

A discussion of the cavernicoles of Madagascar was presented by Decary and Keiner (1970) and there are lists of Malagasy cave-dwellers in reviews by Paulian (1961) and Remillet (1973). Although Remillet refers to 152 papers on Malagasy cave invertebrates, they all seem to be purely taxonomic descriptions with no ecological information. Further biospeleological work in Madagascar, which has had very little attention so far, is likely to be rewarded by the discovery of new "missing link" species with fascinating ecology.

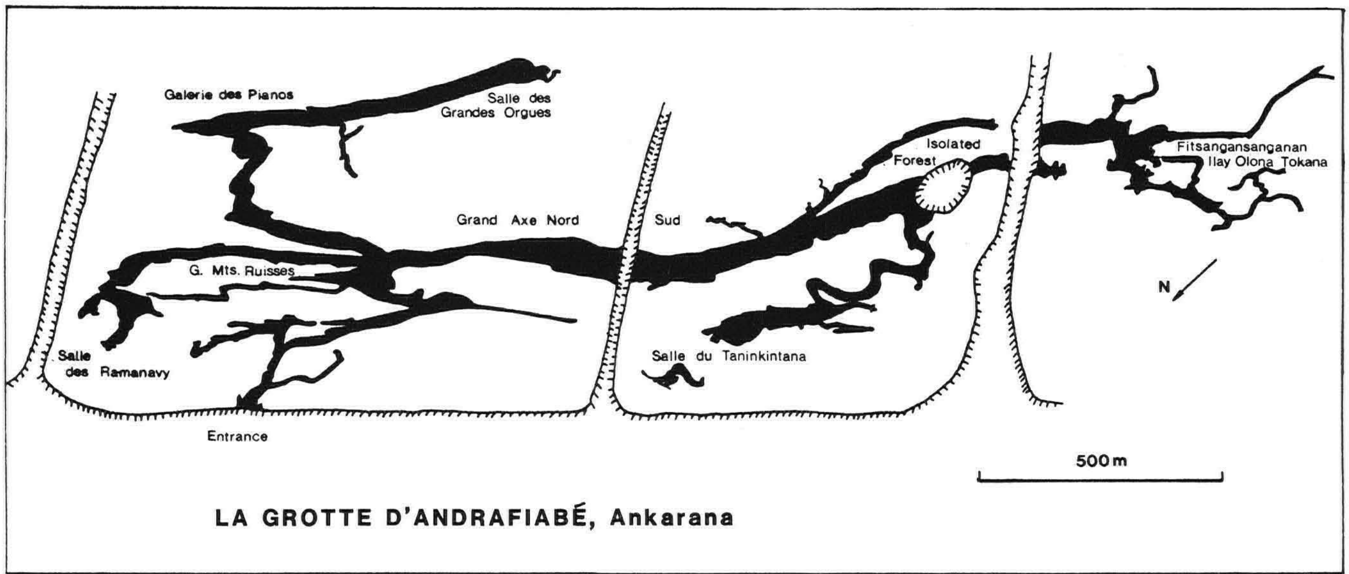


Figure 2. A plan of la Grotte d'Andrafiabé from surveys by Jean Radofilao.

THE ANKARANA MASSIF

The middle Jurassic limestones of the Ankarana Massif, 60 km south of Antsiranana (Diego-Suarez) in the tropical northern tip of the island, have been searched for caves over the last 20 years (Radofilao 1977) and since 1981, yearly expeditions by French cavers (Peyre 1982, 1984) have revealed 93 km of passage. There is still more to be found (Radofilao 1985, pers.). The Massif has been the subject of some hydrological and geomorphological studies (Rossi 1974, 1975) and a useful aerial photograph has been published (Rossi 1976).

The Ankarana Massif is small, only 28 x 8 km, and a little over 200 m higher than the surrounding basalt plains, but even in the dry season it contains substantial subterranean rivers and provides high humidity, alkaline refuges from the desiccating conditions of the surrounding bush. Nile crocodiles (Crocodylus niloticus) capitalise on this rare water source and hide in the caves from hunters. They seem to thrive in the deepest sections of the caves, even in the Dark Zone.

HABITAT TYPES WITHIN ANKARANA

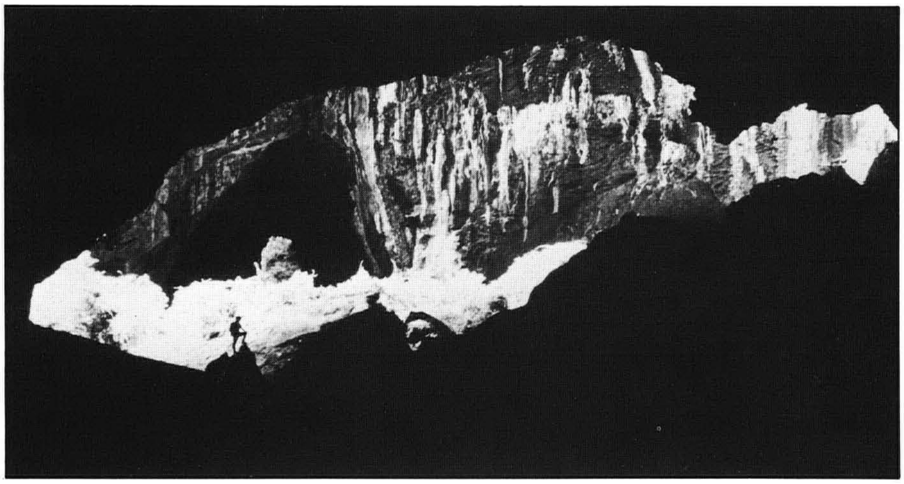
In 1981 (Adamson 1984), the longest known cave system was la Grotte d'Andrafiabé in the Ankarana Massif (figure 2). This has over 11 km of dry phreatic passage, much of which is 50 m in diameter, with some avens reaching heights of 150 m. (Boase, Wilson and Wilson 1982).

The Southampton University Expedition of 1981 was the first to attempt any systematic biological work in the Ankarana caves. La Grotte d'Andrafiabé with its contrasting habitat types (from blue underground lakes to desiccated guano beds) proved to have a striking variety of fauna, including several species which were new to science. Some of its passages open out into dramatic and luxuriant gorges and isolated forests. This contrasts with the smaller but very fine Antsatrobonko river cave.

High Humidity Refuges (Andrafiabé)

In the blind passages, particularly towards the Salle des Ramanavy the air is still and the humidity approaches 100%. Here several hundred large leaf-nosed bats (Hipposideros commersoni) roost providing food (faeces and carcases) in abundance for the invertebrates on the cave floor: fruit flies and two troglobitic paranelloid springtails (Troglopedtes madagascarensis) (Wilson 1982) and another yet to be described thrive there with some of their predatory mites, troglobitic spiders (Psechridae) and black troglophilic ants (Pheidole megacephala).

Unlike the higher insects, springtails (Collembola) continue to moult periodically even after reaching maturity, but since they only continue to moult when they are well fed, frequency of moulting could be used as an indirect index of food availability. This is of interest because in some cave environments food



Several ravines interrupt the large passage of the la Grotte d'Andrafiabé. This view is looking out of the Grand Axe Nord across Cassure des Buttes Chaomonts. (Photo: M Boase)

Hipposideros commersoni from a roost in the northwest portion of la Grotte d'Andrafiabé.

availability seems to limit populations. The abundance of springtail exuvae (shed skins) wherever there was bat debris therefore implies that springtails were gaining adequate nutrition from either the bat detritus itself or (more likely) from the fungi growing upon it. This rather obvious relationship illustrates how dependent troglobites can be upon food imported from the surface and shows how vulnerable these troglobites might be to any changes outside the cave which might affect the ecology of the bats.

Intermediate Humdity Passages (Andrafiabé)

In sections of the cave where the substrate is 'sterile' silt, rather than guano, white troglophilic woodlice, Synarmadillo madagascar, are to be found. These were most abundant in le Grand Axe Nord.

In the furthest sections of the cave system, Fitsangansanganan Ilay Olana Tokana (Gallery of the Lone Barefoot Stranger) the cave floor is covered by vast mud banks, some 20 m high. Wherever there is sufficient organic material to allow fungus to grow, troglobitic white diplura and springtails are to be found grazing upon it.

Pools (Andrafiabe)

There are many small muddy-bottomed lakes throughout the cave and troglobitic shrimps live in these (Gurbey 1984). They measure just 8 mm and despite their reduced or absent eyes, they were surprisingly good at avoiding capture. Remarkably, nine closely related shrimp species, which should compete with one another for food and space, live in one small corner of the Massif. In two instances, three con-generic species were sharing the sames small pools. Shrimps, like springtails, are good at withstanding starvation but it is difficult to understand how such close relatives can avoid competition which usually brings about the extinction of all but the most successful species. In caves where food is often at a premium, uncompetitive species are rapidly excluded (Culver 1973).

Dry Guano Beds (Andrafiabé)

Wherever the cave takes a through draught, the humidity is much lower and so cave adapted (usually humidity-loving) animals are scarce. Here the more resilient troglophiles can thrive; booklice, pseudoscorpions, and (most numerous of all) crickets. These crickets, with antennae more than four times longer then their bodies, resemble animals collected in the extreme south east of the island, hundreds of kilometres from any sedimentary rocks and living an epigean lifestyle. Where desiccated guano beds have formed (up to 12 m high in places) the American cockroach proliferates: Peripleneta americana is particularly numerous in Grand Axe Sud.

River Passages (Antsatrobonko)

Without a boat, it is impossible to penetrate more than a few hundred metres into this fine river cave. The animals listed in the table represent the small proportion of the cave's fauna which inhabit the boulder ruckles and subterranean river banks.

Entrances, Cliffs, Gorges, Isolated Forests

These zones within the Ankarana Massf provide shelter and roosting sites for the Madagascar Turtle Dove, the Madagascar Black Swift and the little Rousettus fruit bats. Apparently the local people smoke these bats out of the caves (Paulian 1981:80), knock them down as they leave and collect them, presumably for the pot. This contrasts with behaviour in other parts of Madagascar where bats and butterflies are seen as incarnations of The Ancestors and it is fady (taboo) to kill them.

The two diurnal lemurs of the region (Lemur coronatus and L. fulvus sanfordi) and many birds and insects come to drink at the pools at the foot of the Ankarana cliffs and at streams within gorges of the Massif and so this "island" of lush vegetation seems to act as an oasis for the inhabitants of the surrounding dry basalt scrublands. Within the Massif are numerous patches of luxuriant forests walled in by 200 m limestone cliffs. In an environment threatened by over-felling, over-hunting and slash-and-burn

Madagascar Black Swift (Apus apus balstoni) which roots in the entrance of la Grotte d'Andrafiabe.

agriculture these act as important natural nature reserves since some may only be entered via the caves. The speciation which must be going on within each isolated forest and in the caves which link them will provide plenty of wotk for any biologists granted permission to enter this fascinating region.

ACKNOWLEDGEMENTS

I owe a great debt to the Government of Madagascar for permission to conduct this work and to many Malagasy friends who helped us, especially Mr J Radofilao. I am also enormously grateful to the other members of the 1981 Southampton University Madagascar Expedition: Andre Adamson, Mike Boase (who drew the survey), Catherine Howarth (who drew the map), Mary Wilson (who helped with much of the invertebrate collections) and Elizabeth Sparke. Eric Gordon and many other members of Southampton University gave much appreciated encouragement. We received technical advice from Peter Lawrence, Dr R Hay, Phil Chapman, Harry Pearman and John Middleton, and financial support from the University of Southampton, Churchill Trust (to Mary Wilson), Sports Council, Ghar Parau Foundation, British Ecological Society, French Protestant Church of London, Cadbury Trust, Westcroft Trust, Royal Geographical Society, Twentyseven Foundation, Gilchrist Trust, John Spedan Lewis Trust Fund, Flora and Fauna Preservation Society, and the Mammal Society. Finally, thank you to Jill Wilson for translating the résumé and to Simon Howarth for criticism of this paper.

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CAVERNICOLES FROM ANKARANA CAVES, MADAGASCAR

La Grotte d'Andrafiabé	
INVERTEBRATES	
INSECTS	
COLLEMBOLA (Springtails)	
Troglopedetes madagascarensis* (Wilson 1982)	troglobite
A new troglopedetine from an undescribed genus	troglobite
DIPLURA	
A blind white sepcies which seems to be new to science	troglobite
BLATTODEA	
Periplenata americana: a ubiquitous cockroach	troglophile
HYMENOPTERA (Formicoidae: ants)	
Pheidole megacephala	troglophile
CRUSTACEA	
ISOPODA (Woodlice)	
Synarmadillo madagascarensis	troglophile
DECAPODA (Shrimps and crabs)	
Parisia dentata*	troglobite
Parisia macrophthalma	troglophile
Parisia microphthalma	?troglobite
Caridina norvestica	entrance pool
Caridina nilotica	entrance pool
Caridina isaloensis	entrance pool
DIPLOPODA (Millipedes)	
Undetermined juveniles of the family Paradoxosomatidae	?troglophile
CHILOPODA (Centipedes)	
Cormocephalus lambertoni	accidental
ARACHNIDA	
ARANEAE: spiders of the families: Ctenidae, Psechridae (troglobites), Tetrablemmidae and Filistatidae	
VERTEBRATES	
BIRDS	
Streptopelia picturata: the Madagascar Turtle Dove	entrance roost
Apus apus balstoni: Madagascar Black Swift	entrance roost
MAMMALS	
CHIROPTERA (Bats)	
Hipposideros commersoni	trogloxene
Tadarida jugularis	trogloxene
Miniopterus minor	trogloxene
Rousettus sp.	trogloxene
PRIMATES (Lemuridae)	
Hapalemur simus: Broad-nosed gentle lemur sub-fossil skeleton	
La Grotte d'Antsatrobonko (river cave)	
INVERTEBRATES	
INSECTS	
DIPLURA	
Blind white species similar to those in Andrafiabe	troglobite
COLEOPTERA (Beetles)	
Undetermined pigmented species	?troglophile
CRUSTACEA	
DECAPODA (Shrimps and crabs)	
Caridina parvoculata*	troglophile
Caridina crurispinata*	troglophile
Caridina unca*	
A white crab was also seen but not collected	?troglobite
ARACHNIDA	
ARANEAE: spiders of the family Pholcidae	troglobite
OPILIONES (Harvestmen)	
Fageibantes bicornis	troglobite
Specimens included the first male to be collected	
VERTEBRATES	
OSTEICHTHES (Bony Fish)	accidental
Gobius sp.	
MAMMALS	
CHIROPTERA (Bats)	
Miniopterus minor	trogloxene

* indicates a species collected for the first time during our expedition.

Specimens were identified by : Barry Bolton, Joan Ellis, Ann Gurney, Paul Hillyard, Keith Bannister, G.S. Cowles, J.E. Hill and P.D. Jenkins of the British Museum (Natural History), London, I.J.L. Dobroruka of Prague, J.P. Mauries of Museum National d'Histoire Naturelle, Paris and the author. The spiders are with Prof. P.M. Brignoli, L'Aquila University, Italy.

APPENDIX: HISTOPLASMOSIS IN ANKARANA, by Mary E Wilson

Very little work is done upon cave flora, but the dimorphic fungus responsible for histoplasmosis is sometimes difficult to ignore (Frnakland 1974). Histoplasma capsulatum occurs in both Africa and India (Fincham 1978) and it is quite likely that the disease exists in Madagascar, despite the lack of literature to support this.

Members of the expedition (Adamson et al 1984) were skin-tested for the disease before and after visiting Madagascar, and samples of bat guano were collected from various sites within la Grotte d'Andrafiabe during the September dry season. On return to England, suspensions of guano were inoculated into mice, which were later examined histologically for Histoplasma (see Hay et al 1981 for methods).

Neither the skin testing nor the culture methods showed any evidence for the presence of histoplasmosis in the Ankarana caves. This may be because the disease does not exost in this area (it is of course impossible to prove it is absent) or that disease acquisition is seasonal. It would seem, then, that there is a low risk of catching histoplasmosis in Ankarana in September.

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Morphology and Hydraulics of an Active Phreatic Conduit

Stein-Erik LAURITZEN, Jim ABBOTT, Ronny ARNESEN, Geoff CROSSLEY, Dag GREPPERUD, Andrew IVE and Stein JOHNSON

Abstract: The underground outlet of the Glomdal lake, Svartisen, North Norway, was explored and surveyed along its full length by cave diving. The conduit is 580 m long, with cross-sections exceeding 20 m^2. It is basically a true master conduit, making two bathyphreatic (State 1) loops, intersected by one shallower (State 2) loop with water-table features. Scallop morphometry was in accordance with the continuity equation, giving a mean discharge of 26.8± 8.9 m^3/s. This belongs to the high flow regime, supporting previous results. At high discharges, the hydraulic gradient relationshiop approaches the hydraulic equations for turbulent flow. D'Arcy-Weissbach friction factors and Manning numbers, derived from scallops and hydrodynamic records, are consistent with comparable studies

The purpose of this paper is to update a previous, preliminary study of the morphology and flow rates of a completely phreatic cave system in Glomdal, Svartisen, North Norway (Lauritzen et. al. 1983). Traditionally, the study of phreatic passages has been confined to the case of drained or "fossil" conduits. Active phreatic conduits are completely waterfilled and cannot normally be entered by man. This situation is a direct parallel to the case of anatomists dissecting a dead body rather than studying the physiology of the living organism.

In terms of speleology, cave diving is a unique opportunity to study phreatic caves when they still are active. A cave diver may perform a direct study of the process of scallop formation, sediment transport modes or rates, or of water chemistry deep into the phreatic zone. Even with relatively simple scientific equipment, very important information may be collected, information that will help us to understand and interpret more correctly what we see in to-day's fossil phreatic conduits. The questions approached in this paper are the calibration of scallop flow rates to the variable conditions of nature, the morphology and the hydraulics of a master conduit which is known to have been functioning for a considerable time.

SCALLOPS

Many fossil conduits bear scallop markings on their walls, i.e. regular concavities formed by a current of aggresive water that moved along the limestone surface at a certain velocity. Scallops are also asymmetric; in their longitudinal profiles, the steepest side is always on the lee side of the crests. A scallop pattern therefore provides information about both direction and probable velocity of the water which the conduit once conveyed. The experiments of Curl (1974) and of Blumberg and Curl (1974) have revealed that the size of scallops is dependent on the rate of flow as follows:

$$\bar{u} = (v/L_{32})Re^*[2.5[\ln(R_h/L_{32})-3/2]+B_L] \quad (1)$$

Where $\bar{u}$= the mean velocity for the conduit, v= the kinematic viscocity of the water at a given temperature, L_{32} = the "Sauter-mean" of the scallop lengths ($L_{32} = \Sigma L_i^3/\Sigma L_i^2$), Re^* = the scallop Reynold's number, 2.5= a proportionally constant, R_h= the hydraulic radius of the conduit, and B_L = is a friction factor. This equation is valid for a circular conduit, a shape which is rarely encountered in nature. Blumberg and Curl (1974) performed laboratory experiments, where they were able to generate scallops on plaster blocks under different flow velocities, and they could determine Re*=2,200 and B_L = 9.4. Substituting these constants into (1) and adjusting the other constants to a compromise between a circular and parallel wall conduit, the following equation results (Curl, pers. comm. 1982):

$$u = (v/L_{32})[55.\ln(D_h/L_{32})+81] \quad (2)$$

where D_h is the hydraulic diameter of the conduit. Equation (2) has been used throughout this work and in the previous studies (i.e. Lauritzen 1982; Lauritzen et. al. 1983).

From equation (2), a certain set of scallops, the dimensions of the conduit and a qualified guess of the water temperature, we may calculate the rate of flow which correspond to the scallop sizes. However, in nature, discharge is never constant. Flow rates vary, often drastically with seasons and rainstorms. Hence, a cave conduit may experience a wide range of discharges. The question then become, which of these discharges corresponds to the one represented by the scallops? In other words; are scallops formed under flood or baseflow conditions, or both? Only direct calibration in a natural system may answer these questions. The previous study approached this problem with slightly incomplete data, which suggested that phreatic scallops probably represent the upper parts of a flow regime, i.e. periods of flooding (Lauritzen et. al. 1983). In the present work, we have gained more complete information to investigate this problem further.

THE GLOMDAL AREA

The only outlet of Lake Glomdal at Svartisen, North Norway, is through a more than 500 m long, completely phreatic cave. The lake and its drainage area are shown in Fig. 1. The present catchment area is 27.7 km^2, with a specific discharge of 90-95 l/s /km^2, giving a mean annual runoff of 2.5 m^3/s. The principal point is that all runoff from the catchment has to pass through the cave system. The karstic marble bands are relatively narrow, which eliminates the possibilities of major leaks elsewhere. Therefore, if the cave system could be adequately explored, to correct for possible oxbows or major tributaries, scallops might be compared with the present hydrology with greater confidence.

METHODS OF INVESTIGATION

Cave diving

The remoteness of the area would prove to be a problem if decompression sickness occurred. The nreaest decompression chamber is several hours drive from the site. It is therefore of paramount importance to stay well within the safety margins of the repetitive dive tables produced for Norwegian cold waters. However, the dives tended to be mostly "bounces" down to 23 m with stops in

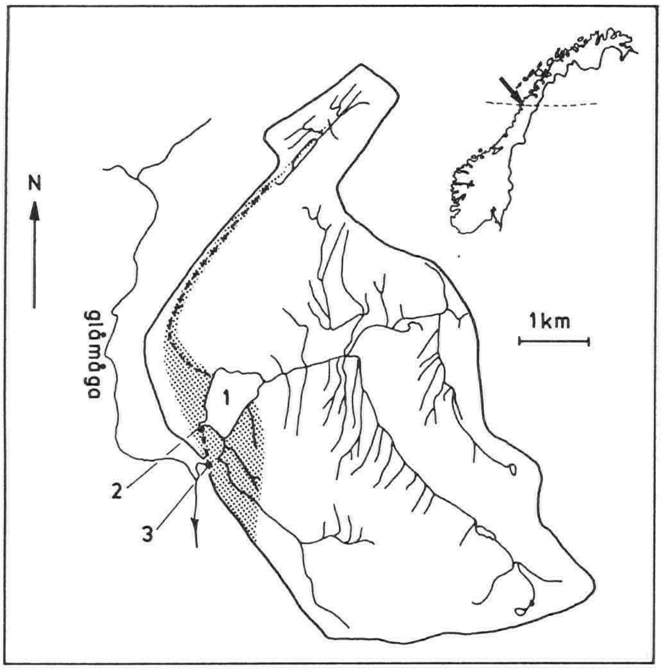

Figure 1. Location of the study area, catchment area and marble outcrop. 1) Lake Glomdalsvatn, 2) Jordtulla Sink, 3) Resurgence. Shaded Area: Marble outcrop.

chambers and for surveying. Oxygen was on hand for all dives and a strict log kept for all dives and times.

Air was supplied by a portable petrol-driven compressor, kept at the diving base beside the lake. This tended to be somewhat slow, but gave us no problem with starting, or with impure air. The lamps were charged using a portable generator (1500 watts). Basic cave diving equipment was used for all dives.

Lighting was generally with aquaflashes on the helmet and hand held beamguns. The beamguns proved to be invaluable. Due to the large dimensions of the passages, we were able to use a back-mounted bottle and two side bottles, using 3 sets of valves. Some dives were done using 2 side-mounted bottles only. In most dives, 1 x 10 l and 2 x 7 l cylinders were used on each. Most of the dives were done with dry-suits. Bouyancy compensators were used by all divers, with direct feeds from first stages, if available. The Norwegian team members have developed their own equipment requirements. A chest harness is used to carry side bottles which are held by carabiners to steel loops on the tanks. The divers also carry a spare mask taped to the wrist.

Sea diving techniques were possible in the system, meaning buddy-teams of two divers or more. This proved to be vital, when taking passage cross-sections. Line laying was done mostly by using 4 mm orange Nylon on 70 or 80 m drums. One diver would lay the line, and a second diver or dive team would secure the line in place with pieces of inner tube strips around boulders. The smooth, boulderless floor inhibited the use of this technique in some places, but generally it worked very well.

Except for Grodzicki (1983), this is one of the few studies of submerged caves carried out till now. Scallop measurements and survey data were taken and noted on underwater slates with flipover pages. This caused a problem in that the slate, pencil and measure all had to be tied on and got somewhat tangled. Crossley overcame this problem by having a wrist-mounted unit with compass, depth gauge, pencil etc, all incorporated on a slate.

Surveying

The phreatic sections were surveyed using the diving line as base line. The diving line had previously been marked for every 10th, and in some cases, 5th metre. Depth readings were recorded at every mark, as well as the compass bearing of the line between them. It was also recorded at which side of the passage the line was running. Passage outlines and dimensions were noted at regular intervals, depending on the diving logistics and the conditions of visibility. Prominent landmarks, such as buttresses, flat floors, boulder fills, silt banks, etc. were recorded as well.

The surface and the air-filled sections of the cave were surveyed conventionally. The underwater survey bearings were converted to conventional bearings (declination, inclination and distance) before the complete data set was computer processed and plotted. The horizontal misfit between surface and underwater survey distance was less than 1%, which is acceptable, considering the apparently crude survey conditions prevailing under water in a dark cave.

Scallop and passage morphometry

At selected sections, which were chosen for thier regularity, the long and short axis of cross-section (assuming an elliptical cross-sectional profile) were measured along each cross-section. The scallop data were processed by computer, according to equation (2), assuming a mean annual water temperature of +2°C.

Hydrology and Runoff

Water stage scales were set up in the lake outlet, the cave sink (Jordtulla) and in the first air-filled section of the cave (Mellomgrotta). An automatic stage recorder was set up in Jordtulla sink. The scales and stage recorder have been in operation since 1980 and 1983, respectively. Volumetric discharge and water stage was calibrated using flügel (propeller) and salt dilution gauging. Based on hydrographs for the years 1983 to 1985, a flow duration curve was constructed (Fig. 7).

RESULTS AND DISCUSSION

Cave Morphology

The cave survey is shown in Fig.2. A total of 580 m was surveyed along the underwater course, as well as 90 m of air-filled passages, giving a total of 670 m surveyed cave. Diving has confirmed that the cave consists of only one conduit (i.e. master conduit) with a cross-sectional area in the range of 15.7 - 28.3 m^2 (corresponding to a diameter of 4.6 to 6.0 m), with one constricted section of about 9 m^2 (3.4 m diameter). Oxbows have only been detected in one location, between Mellomgrotta and Valtergrotta, (Fig.2). Cross-sections were recorded as either tubular (ellipses), rifts, or of the flat-floored railway-tunnel type. Angular boulders and tree trunks were frequently seen along the floor. The greatest depth recorded was 22 m below the water table. This depth was reached 3 times; twice in the first phreatic loop between the sink and Mellomgrotta, and once more in the long, deep loop between Valtergrotta and the resurgence.

Overall, the conduit is of the looping type, with only 3 water table intersections between sink and resurgence: Mellomgrotta (upstream and downstream), Valtergrotta and Tinker bell. The cave is therefore definitely of the phreatic looping type, i.e. State 2 of Ford and Ewers (1978). However, the phreatic loops are irregularly spaced, and it would have been justifiable to classify the cave as consisting of two bathyphreatic (State 1) sections, separated by a shallower, State 2, section.

The cave follows the contact between a karstified marble (on the NW side) and the impermeable mica schist (SE side). This contact plane strikes 350-015° with a dip of 20-30° to the SE. The most prominent master joints in the vicinity of the cave display a NNW/SSE strike or almost due N/S, both with a very steep NW dip. These three structural elements are sufficient to explain the attitude of the cave passages (Fig.3).

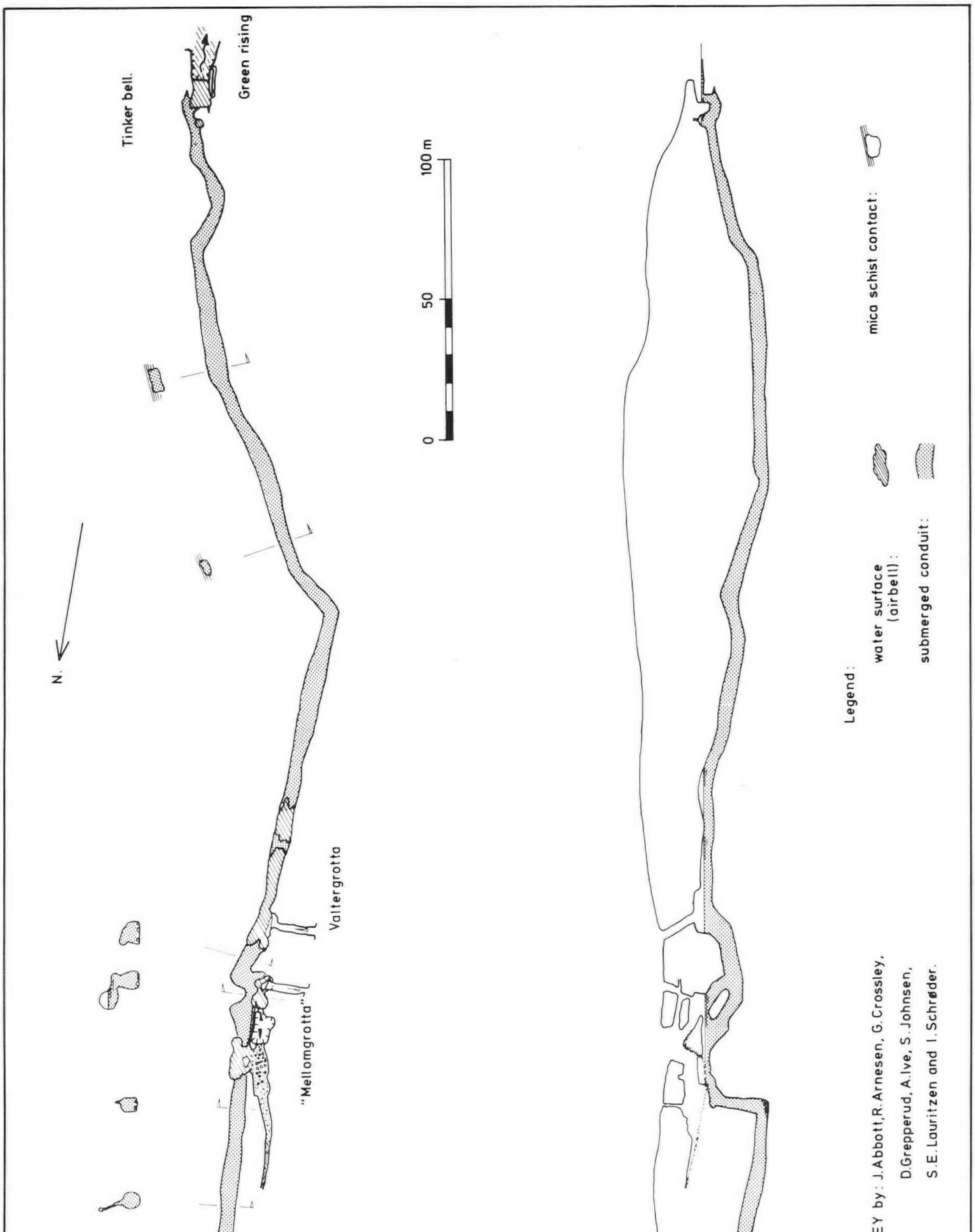
PLAN:
SECTION:
Tinker bell.
Green rising
Jordtulla sink
"Mellomgrotta"
Valtergrotta
N.
0
50
100 m
Legend:
water surface (airbell):
submerged conduit:
mica schist contact:
GLOMDALSVATN
underground outlet,
BCRA grade 3 and 5.
Drawn by S.E.L.
SURVEY by: J.Abbott, R.Arnesen, G.Crossley,
D.Grepperud, A.Ive, S.Johnsen,
S.E.Lauritzen and I.Schrøder.

Figure 2.

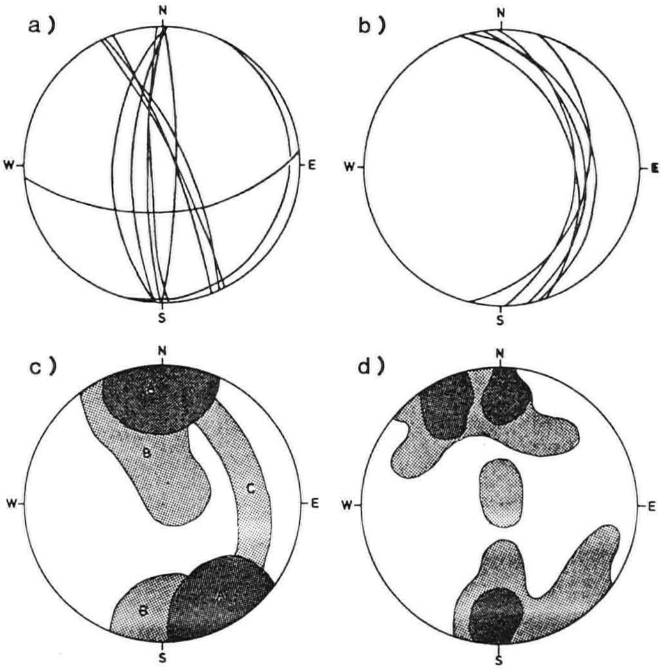

Figure 3. Comparison of geologic structure with cave survey data.
a). Wulff stereonet diagram of the traces from 10 prominent joints in the near vicinity of the cave. Two prominent, steeply dipping master joint sets are distinct; one almost N/S, another at 335° NNW/SSE.
b). Traces of the marble/mica schist contact plane; the strike is approximately N/S, with a 20-30° dip to the E.
c). Attitudes of intersections of the planes of weakness. A: Intersections between master joints and the mica schist interface. B: Intersections between master joints alone. C: Mica schist interface plane.
d). Cave survey bearings, as they intersect the Wulff net. The shaded areas represent the allowance for a +/-5° error in the survey data related to the passage direction. The darkest shade cover 75% of all bearings.

Cave passages in general are either formed along a single plane of weakness, or along a line of intersection between two or more such planes. Hence, cave passage bearings should appear as lineations on the stereographic traces of the guiding joints and bedding planes, preferrably concentrated around the zones of intersection between them. From Fig.3, we may infer that the conduits are controlled by:

A) The directions of intersections between the mica schist/marble interface and the N-S striking master joints.

B) Intersections between the two prominent master joint sets.

C) Mica schist/marble interface alone.

In decreasing order A, B and C correspond to the shaded areas in Fig.3c. For example, the shift in passage direction from almost due south to south-east (between Valtergrotta and the resurgence) coincides with a descent of almost 20 m. This is to be expected if the conduit is controlled by the confining mica schist. This plane dips SE, and with the mica schist acting as an aquiclude (rock layer that is impermeable to water), any eastward turns and descents will have to coincide (Fig. 4). A vertical projection of the cave, seen from the resurgence, along the apparent strike of the contact plane, is shown in Fig.5. The slight syncline suggested in Fig.5. is also consistent with Fig.3b, where the strike of the mica schist/marble contact rotates about 30°

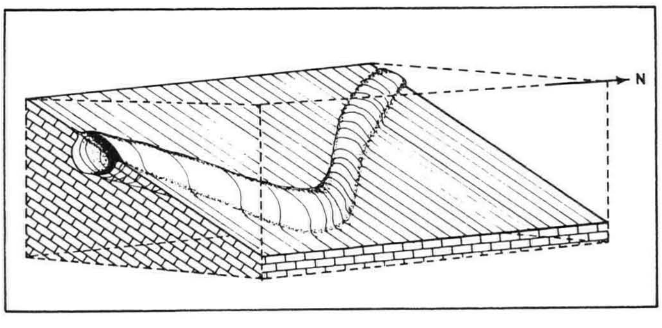

Figure 4. Phreatic loop in the sloping contact plane between an aquiclude (transparent top) and a karstic aquifer. The plane is given the same strike and dip as the marble/mica schist interface in the cave. Any descending segments within this plane must turn down dip (i.e. east), ascending segments must turn up dip (west).

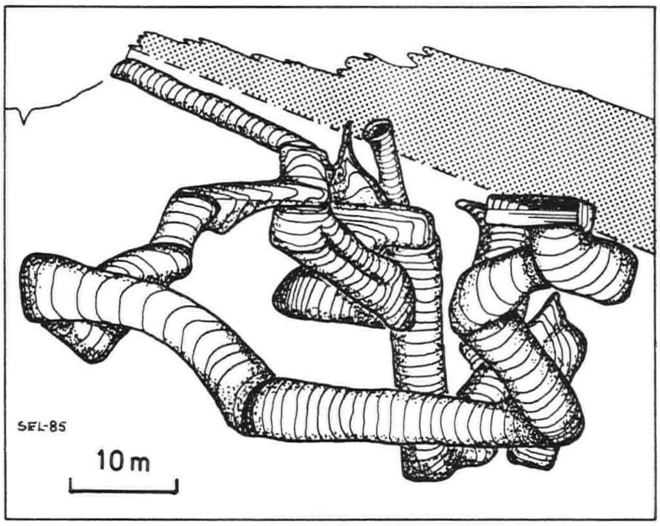

Figure 5. Vertical projection, looking 350° (NNE), into the resurgence. This is approximately along the strike of the schist/marble contact, as it is observed in the sink, Mellomgrotta and the resurgence. The mica schist projection is shaded. However, mica schist was also observed in the passage roof in the Valtergrotta/Resurgence loop (left bottom of figure). This may reflect a slight syncline in this part of the contact plane.

Scallop discharge, continuity of flow

Including the resurgence site, which was measured in 1982 (Lauritzen et. al. 1983), scallop discharges have been calculated at 5 stations along the phreatic course of the cave. The results are summarised in Table 1 and in Fig. 6. The volumetric discharge varied between 8.8 and 33.2 m^3/s. However, the statistical errors in the calculations are up to 60% of the mean, making the differences less significant.

At station II (between Mellomgrotta and Valtergrotta, Fig. 6.), the only known oxbow is located. Unfortunately, only the deepest of the two limbs could be measured. The measured scallop discharge, 8.9 $m^3 s^{-1}$ is, however, conceivable as a realistic fraction of the total flow through the bifurcation.

Rejecting the oxbow from the data, the remaining 4 stations are not significantly different within 1σ standard deviation. Station V displays the lowest value and may reflect a minor bifurcation. The original surveying in the resurgence (Lauritzen et. al. 1983), suggests small side tubes close to the resurgence. However, with the present data, we have no statistical evidence to say that the discharges were really different. The size distribution inherent in scallops is not sensitive enough to detect bifurcations that are less than about 20%. We may therefore conclude that the scallop discharges support the continuity equation, which states that the same amount of liquid has to pass through each section of a continuous conduit. Hence, the scallop data suggest that there is no major tributary or distributary along the phreatic conduit. We are therefore dealing with a master conduit in the true sense, which is also confirmed by the divers' observations. The weighted arithmetic mean of the scallop discharges through sections I, III, IV, and V is 26.20 ± 8.9 m^3/s. This is almost twice as high as the estimate done in the previous study, which was based on station V alone.

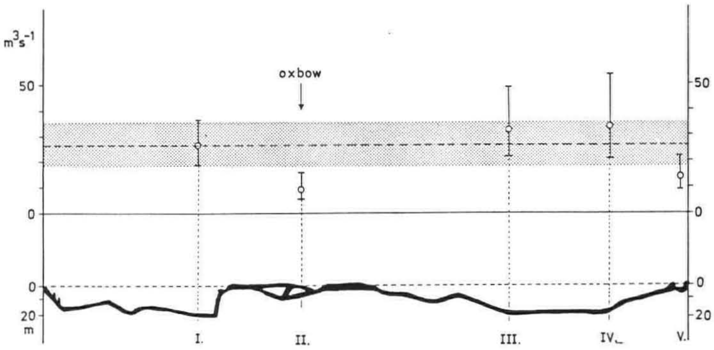

Figure 6. Scallop discharge along the cave conduit. Except for the oxbow value at station II; the discharges satisfy the continuity equation, with a weighted mean discharge of 26.2 +/- 8.9m³/s (shaded area).

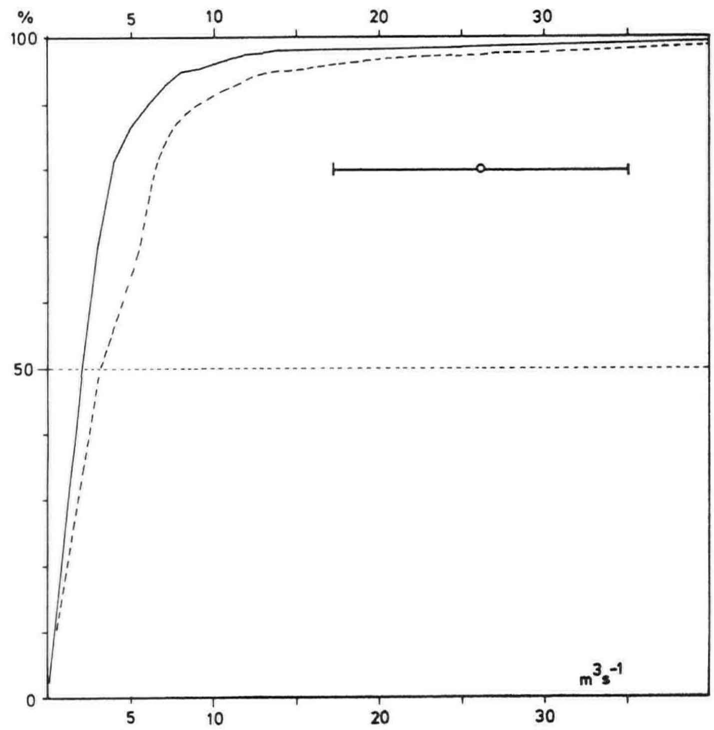

Figure 7. Flow duration curve for the period Sept. 1983 to April 1985. The flow rate deduced from scallops with 1σ is shown. This discharge only occurs in 2% or less of the time of flow, representing the highest peaks of snow-melt and rainstorm floods. Adding the probable contribution of flow from glaciers in the past, yielded the dashed duration curve. This shifts the duration of scallop discharge up to 5% or less of the duration of the flow. See text for further discussion.

Scallops and the hydraulic regimes of the conduit

In Fig.7 the flow duration curve for the system based on 21 months of hydrograph records is shown. The discharge deduced from scallops occurs for less than 2% of the total duration of flow. However, hydrochemical and micro-erosion meter studies have revealed that the direct corrosion rate corresponds to approximately 0.025 mm/a. (Lauritzen in prep). This implies that the scallops need ∽800 years to develop if the preceding pattern was different. Such a timespan introduces another problem, which is the proximity to glaciers. Glacier expansion, which at least happened 250 years ago, in The Little Ice Age, would affect the runoff conditions. Then, the catchment area increased by about 10 km^2 of glaciers. The present glaciers of the area have a specific runoff of about 100 $l/s/km^2$. This adds another 1 m^3/s to the annual mean, i.e. an increase of 40%. A crude assumption would be that this increase was distributed in proportion with the present-day discharge, but only through the melt season, i.e. April - September. This will concentrate the increased runoff to periods when the present-day system also displays high discharges. This gives an increase of approximately 2.4 m^3/s to the higher discharges with frequency of less than 5/12 for about 40% of the time. This addition has a relatively small effect on the duration of the scallop discharge (Fig.7). Discharges higher than 15 m^3/s would occur for less than 4-5% of the time. We judge this as a reasonable estimate on the order of magnitude that a glacial influence would have on the relative duration of scallop discharges.

Hence, the new results do not contradict the previous, preliminary conclusion (Lauritzen et. al. 1983): scallops are formed at the highest discharges, representing less than 5% of the total time of flow. These are also the periods when the majority of the total annual dissolution takes place in a snow melt and glacier melt dominated climatic regime as this (Hellden 1974).

Hydraulic gradient as a function of discharge

Smith et. al. (1976) discussed the hydraulics of closed conduits in relation to cave conduits, and suggested the D'Arcy — Weissbach equation to describe the relationship between hydraulic gradient, discharge, conduit diameter and wall friction:

$$Q^2/a^2=[2dg/f] \, . \, [\Delta h/\Delta l] \qquad (3)$$

where Q= discharge, a= cross-sectional area, d= diamteter of tube, $\Delta h/\Delta l$ =the hydraulic gradient, and f= a friction factor.

Rearranging equation (3), yields:

$$Q = K \, . \, [\Delta h/\Delta l]^{1/2} \qquad (4)$$

$$K = (2dga^2/f)^{1/2} \qquad (5)$$

Station	x,(m)	y,(m)	A (m^2)	$L_{32} \pm \sigma$ (cm)	$\bar{u}$,(cm s^{-1})	$\bar{u}*$,(cm s^{-1})	Q, (m^3 s^{-1})
I	6.0	5.0	23.6	5.11 $^{+1.69}_{-1.27}$	110.4	7.26	26.01 $^{+10.23}_{-7.39}$
II	3.6	4.6	13.0	7.40 $^{+4.42}_{-2.77}$	67.8	5.0	8.82 $^{+6.46}_{-3.77}$
III	5.5	4.5	19.4	3.46 $^{+1.80}_{-1.18}$	170.7	10.7	33.18 $^{+20.56}_{-12.78}$
IV	6.5	5.0	25.5	4.6 $^{+1.98}_{-1.38}$	125.2	8.1	31.96 $^{+16.34}_{-10.88}$
V	6.0	6.0	28.3	10.48 $^{+4.67}_{-3.23}$	43.6	3.5	13.66 $^{+7.41}_{-4.84}$

Table 1 Scallop measurements and flow rate calculations, Glomdalsvatn underground outlet.

This form is very similar to the Manning-Stickler equation, which is widely used in applied hydraulics (Engelund and Bo Pedersen 1978, Bögli 1978):

$$Q = M.A.R_h^{2/3}.[\Delta h/\Delta l]^{1/2} \quad (6)$$

Here, M is the so-called Manning Number, A= the cross-sectional area of the conduit, R_h = D/2, the hydraulic radius of the conduit. The Manning Number is also given by the empirical relationship:

$$M = 25.4/k^{1/6} \quad (7)$$

where k = the height in metres of the protrusions inside the pipe (roughness). The D'Arcy-Weissbach "f" has some advantages in being dimensionless number, and Atkinson (1977) and Gale (1984) both used this form in their studies of conduit hyrdaulics. However, the Manning equation is also widely used by engineers; values of M are already worked out for most practical situations, and are tabulated in engineering handbooks. In this work, we shall consider both.

The Manning Number varies between 90-130$^3\sqrt{}$m/s for smooth tubes, to 30-40$^3\sqrt{}$m/s in crudely blasted rock tunnels. Bögli (1978) sugested that passages with abundant breakdown may have M = 15 – 20$^3\sqrt{}$m/s. The latter two cases would be the most relevant to compare with actual caves, but - except for Atkinson's study (1977) - we lack information from in situ determinations of friction factors in active phreatic conduits.

Equations (4) and (6) may be linearized:

$$\log Q = 1/2 \log[\Delta h/\Delta l] + \log K \quad (8)$$

bearing in mind that K may also represent the constants in Manning's equation (6). Therefore, by plotting log[Δh/Δl] against log Q we should obtain a straight line with slope 1/2 and a y intercept = logK. Then, the D'Arcy-Weissbach "f" may be calculated from equation (5), and the Manning Number from equation (6). To do this we need simultaneous readings of water stages at each end of a phreatic loop, and we also need to know the horizontal distance between them. This has been done for the Jordtulla-Mellomgrotta loop.

Friction factors for the phreatic loop

The Jordtulla-Mellomgrotta loop is the section of conduit which is closest to the bathyphreatic case of Ford and Ewers (1978). It has uniform dimensions, is un-branched and has no free surface between the two points of measurement. The horizontal distance between the two recording sites is 155 m.

The two scales were correlated at a very low winter stage when discharge was almost nil and Δh was close to 0. Δh/Δl was then calculated by subtracting the corrected water stages and dividing with the horizontal distance. Due to the large diameter of the conduit, Δh is always very small. It is difficult to read the water stage with a better accuracy than +0.5 cm. This error will propgate into the Δh, which itself is a small number resulting from the difference between the larger numbers. Consequently, we must accept a considerable scatter in the data.

The discharge/water stage relationship at the sinkhole stage recording station was determined as:

$$Q = 0.7478 \,.\, e^{0.0337.h} \quad (9)$$

when Q = m^3/s and h is water stage in centimetres. This was calibrated by flugel and salt dilution gauging, covering the discharge range of 1.00 - 8.8 m^3/s (r^2= 0.96). In Fig. 8 log Q vis. log [Δh/Δl] is shown. Linear regression yielded the line,

$$\log Q = 0.77 \log[\Delta h/\Delta l] + 3.56 \; ; \; r^2 = 0.69 \quad (10)$$

The slope of 0.77, equation (10), is higher than for the D'Arcy-Weissbach and Manning equations, but the deviation is within the inherent error of the data.

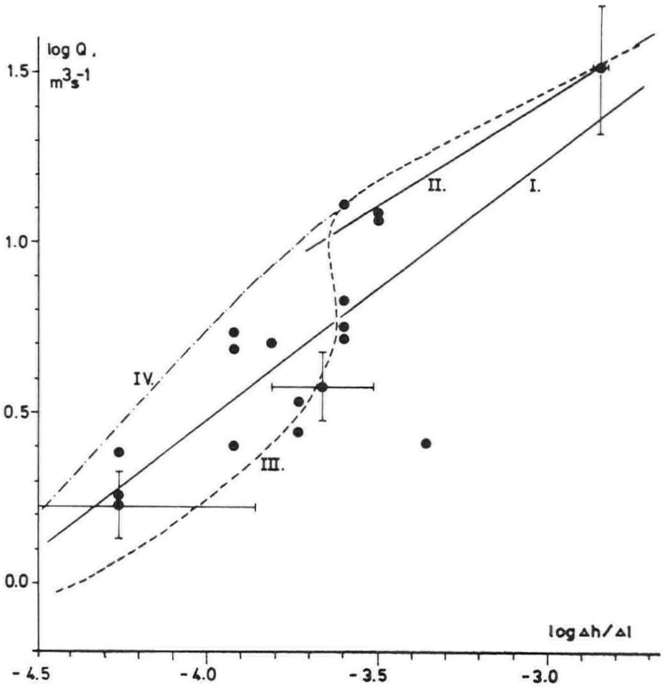

Figure 8. Plot of log Q vic. log[Δh/Δl]. Error bars are shown for extreme and mean positions in the data. Different regression lines are shown. I: line based on all data, slope = 0.77 (eqn. 10). II: line based on data for Q greater than 10 m³ /s . slope = 0.6 (eqn. 11); the data approach the D'Arcy-Weissbach (and Manning) ratio of 0.5 with increasing discharge. III: eqn.(12) substituted into the D'Arcy-Weissbach equation. IV: smoothed transition from laminar flow (slope=1.0) to turbulent flow (slope=0.5).

Solving for log K = 3.56 yields a Manning roughness constant of 125.0, +386 /- 93$^3\sqrt{}$ m/s, which cover the ranges of a perfectly smooth (i.e. glass) tube down to a crudely blasted rock tunnel! Obviously, only the lowest part of that range is compatible with the known roughness of cave passages. However, realizing that the error in [Δh/Δl] increases dramatically with decreasing Q, it might be justified to reject the lowest part of the data set. Using only data for discharges greater than 10 m^3 /s, leaves only four observations. These points yield the line:

$$\log Q = 0.63 \log[\Delta h/\Delta l] + 3.31 \; ; \; r^2 = 0.96 \quad (11)$$

giving M = 44.0, and D'Arcy - Weissbach "f" = 0.0144. Moreover, the observed scallops protrude approximately 2 cm on average from the walls. Equation (7) then yields a Manning constant of 48.8$^3\sqrt{}$m/s. The conduit seem to approach the D'Arcy-Weissbach and Manning equations with increasing discharge.

This effect may be further investigated by calculating the apparent D'Arcy-Weissbach "f" for each data point in Fig.8. This yields apparent friction factors which show a dramatic decrease with discharge, until they attain a constant value of 0.116. This behaviour may be modeled by an exponential decay function which attains a constant value:

$$f = 5.9853\, e^{-0.4143\, Q} + 0.116 \quad (12)$$

which is the enveloping curve in Fig.9.

The transitional regime between laminar and a fully turbulent flow in pipes occurs at Reynolds Numbers between 5.0·E2 to approximately 1.0·E5 (Smith et al 1976). The apparent D'Arcy-Weissbach friction factor is dependent on discharge at Reynolds Numbers lower than about 1-5·E5. This effect is also apparent in Atkinson's (1981) Mendip data.

In our case, the apparent "f" becomes constant when the discharge exceeds about 14 m^3/s,

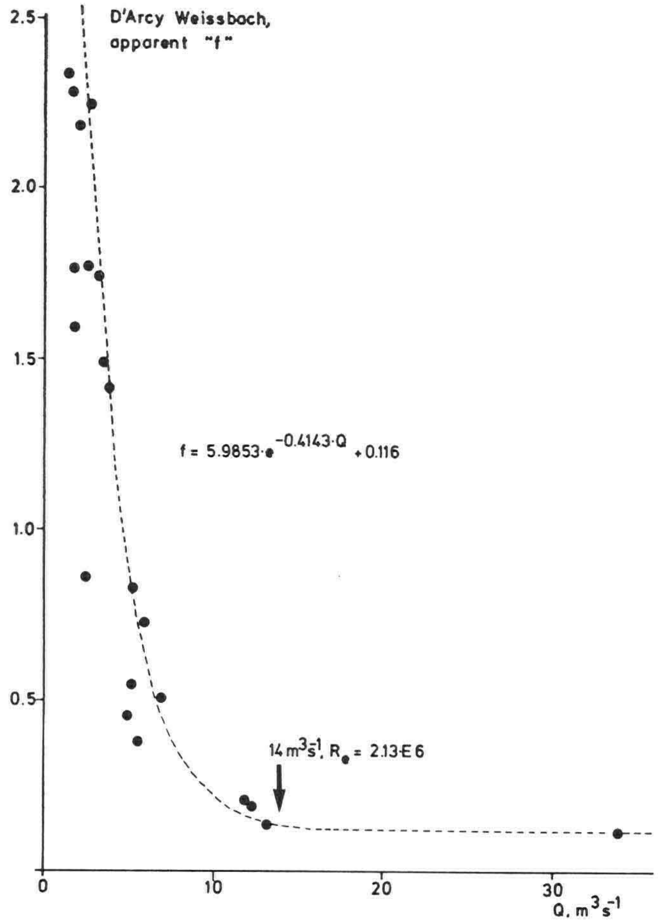

Figure 9. Apparent D'Arcy-Weissbach friction factors as a function of discharge. The strong decrease of "f" with discharge indicates that the friction is not fully developed when Q exceeds 14 m^3/s, which corresponds to a Reynolds Number of about 2·E6. The constant "f", independent of discharge is 0.116.

which corresponds to a Reynolds Number 2·E6. This high value may reflect the large dimensions of the conduit, where roughness is fully developed only at very high discharges. This effect also brings up an interesting question whether turbulence in itself may be a threshold for scallop development. The constancy of the apparent "f" and the scallop flow rates coincide well (Figs. 7 and 9).

We may therefore conclude that the hydraulic behaviour of the cave conduit approaches the D'Arcy-Weissbach and Manning equations with increasing discharge. In Fig.8, we have suggested two different approaches to model the behaviour of the conduit at lower discharges. Assuming that the D'Arcy-Weissbach equation may apply to flow at Reynolds Numbers down to about 5·E4, equation (12) may be substituted into equation (3) to yield the line III in Fig.8. However, a behaviour, governed by equations for laminar flow at lower discharges (exponent approaching 1.0), gradually changing into the D'Arcy-Weissbach exponent, is suggested by line IV in Fig.8.

In Table 2, the results are converted to the D'Arcy-Weissbach friction factor, and compared with the previous determination of Atkinson (1977), Atkinson et al (1983) and Gale (1984). Atkinson's (1977) approach was the same as ours, but the cave systems studied (Mendip Hills underground drainage) are much more complex and of unknown geometry. High-resistance collapses and bends are likely to occur, making his values of "f" higher by several orders of magnitude than those derived from simple tubes of known geometry (Gale, 1984; this work). Atkinson et al (1983) used the measured draught through 10 km of passages in Castleguard Cave to calculate apparent "f"'s for the whole cave. They are about 20 times higher than our apparent "f" at high discharges.

Gale's (1984) study was restricted to fossil, scalloped conduits, using the established hydrodynamic equations for scallops to calculate $f = 8/(u/u^*)^2$, where u is given by equation (1) or (2), and $u^* = Re^*(v/L_{32})$. Substituting this into (1), we get:

$$f = 8/[2.5[\ln(R_h/L_{32}) - 3/2] + B_L]^2 \qquad (13)$$

for a circular conduit. Recalling that B_L is a constant, we see that "f" is a square function of $\ln(R_h/L_{32})$, the latter is the ratio between the radius of the tube and the length of the scallops. This equation is solved for all L_{32}'s and R's in Fig.10. The minor deviation of our and Gale's scallop data from the line (eqn.12) is due to that neither study considered a perfectly circular conduit, i.e. the constants were different from those of equation (13). Moreover, Gale used the arithmetic mean of the scallops, whilst our study uses the "Sauter-mean". Fig.10 is not corrected for this, assuming that L_{32} approximates to L_{mean}

It is evident from Fig.10, that our and Gale's data are consistent with equation (13), but that the two studies considered two slightly different R_h/L_{32} ranges. In other words, an "f" derived from scallops and passage dimensions is just a logaritmic transformation of the R_h/L_{32} ratio. The hydrodynamic approach is then an independent determination of "f", taking account of the total cave geometry, like bends, constrictions and floor debris. The Jordtulla-Mellomgrotta loop possesses two bends of 120° and two of 90°, as well as some tree trunks and boulders along the floor. Moreover, we cannot totally exclude any damming effect from the passages downstream affecting the water stage in Mellomgrotta.

In conclusion, our apparent friction factor of 0.116 is fully consistent with the other studies, being about twice as high as the scallop roughness, and 20 times lower than the Castleguard conduits, which are much more constricted and irregular than ours. It is possible that more accurate results might be gained with a more sophisticated stage recording device (i.e. a gas pressure sensor). Future studies should also concentrate on conduits of smaller dimensions, which would then give a better resolution in the Δh variations with discharge.

Table 2

D'Arcy- Weissbach friction factors from different studies.

Method of investigation	apparent "f"	true "f"	Reference
Active conduits, Mendip	24 - 340	-	Atkinson (1977)
Air draught, Castleguard Cave	0.87- 2.31	0.33- 0.90	Atkinson (1983)
Fossil, scalloped conduits, Morecambe karst	-	0.077 ± 0.037	Gale (1984)
Jordtulla, discharge/stage ($Q \geq 14\ m^3 s^{-1}$)	0.116	-	This study
Jordtulla, scallops	-	0.039 ± 0.086	"

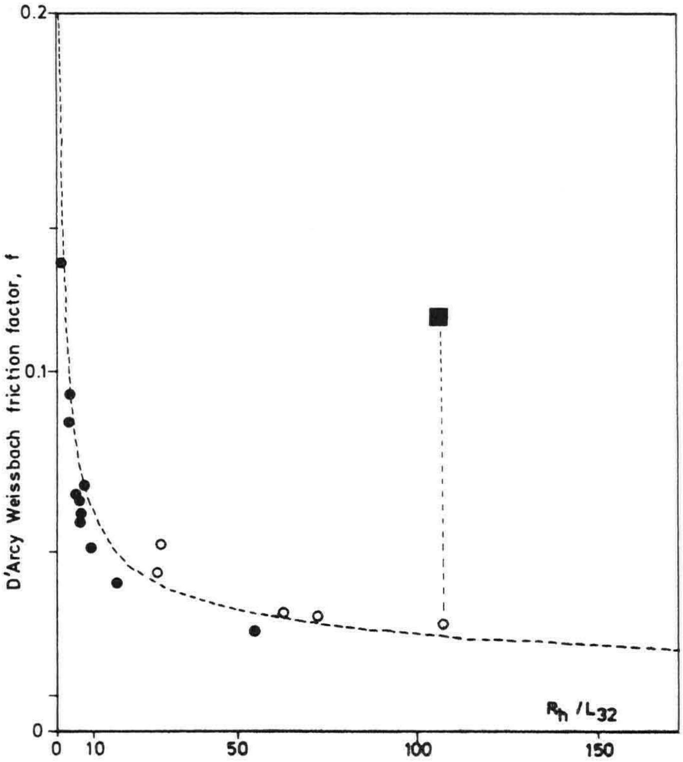

Figure 10. D'Arcy-Weissbach friction factors calculated for most realistic R_h/L_{32} ranges (dashed curve). Scallop data from Gale (1984) (black dots) and this work (open circles) are plotted for comparison. Square spot; the friction factor determined from equation (13).

CONCLUSIONS

Cave Morphology

Cave diving has made it possible to gain precise information about the morphology of the underground outlet of Lake Glomdal. The cave is a phreatic master conduit. Along the underwater course, it intersects the watertable only 3 times. The phreatic loops are up to 23 m deep. The cave is therefore composed of two bathyphreatic loops (state 1), separated by a shorter state 2 looping section. This middle section also contains the only oxbow or bifurcation known. The phreatic conduit was surveyed to 580 m total length. The cross-sections are generally very large, most often exceeding 20 m.. There shapes are either tubular, sometimes with a flat, sediment-covered floor, or occasionally of the rift type. All marble surfaces are scalloped. The course of the cave is controlled by two prominent master joint sets which run NNE/SSW with an almost vertical dip and by the marble/mica schist contact.

The Scallop Flow regime

Scallop morphometry with corresponding discharge calculations at 4 independent sites along the conduits was in accordance with the continuity equation, and supports the divers' observations of a single, unbranched master conduit. The mean scallop discharge was 26.2 ± 8.9 m^3/s, supporting the previous conclusions that scallops represent the upper 5% of the flow regime in this climatic zone. Scallops seem to be formed preferentially in periods of flood.

Hydraulic behaviour, friction factors

Within the scatter and scarcity of the data, the relationship between hydraulic gradient, discharge and the observed scallop roughness obey the equations for turbulent pipe flow. The D'Arcy-Weissbach friction factors, calculated both from scallops and from hydrodynamic measurements, are consistent with other comparable studies.

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