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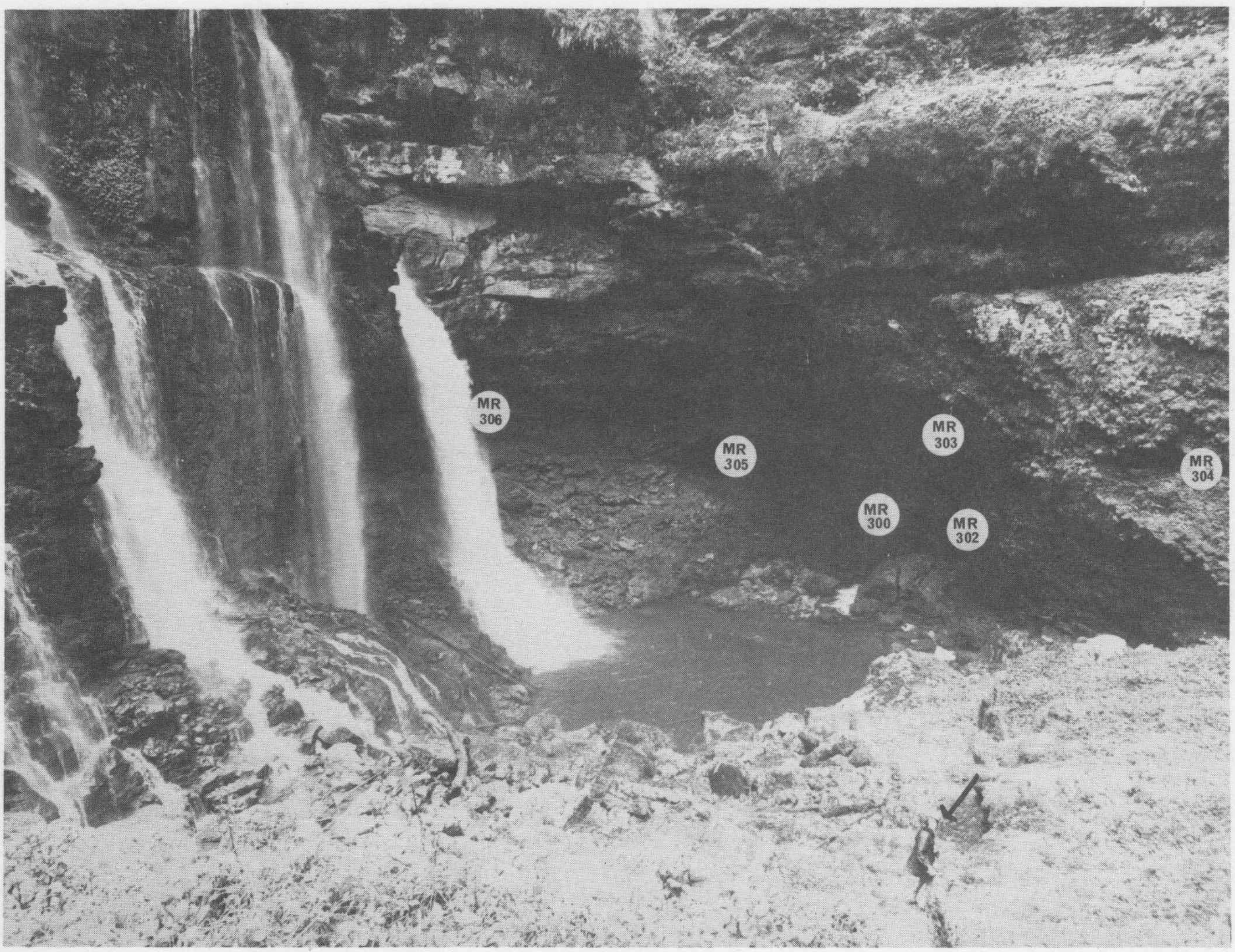

Atea Kanada Entrance Doline in low flow conditions, showing entrance to the cave. photo: M. Handel

H E L I C T I T E

Journal of Australasian Cave Research

Foundation Editors

E.A. Lane, Aola M. Richards

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A.J. Pavey, J.M. James

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REVIEW

James, J.M. (editor) Papua New Guinea Speleological Expedition 1973 Speleological Research Council Limited, 1974, 69 pp., 52 plates, 14 maps, 3 figures.

The prospect of the deepest caves in the world in the high mist enshrouded mountains of central New Guinea has long excited the imagination of speleologists. Perhaps the Fly-Sepik Patrol by Karius and Champion in 1927-28 was the first expedition to give a hint of what was in store:

> All the morning we had been travelling over difficult rough limestone country, but it had been comparatively easy to what we now encountered. Worse and worse it grew; limestone rocks with razor-like edges to clamber over; chasms 20 to 30 feet deep to cross by rotten tree trunks ... a false step would have meant falling into an abyss or impalement on needle-pointed pinnacles of limestone. We descended into large pot-holes varying from fifty yards to a hundred yards in diameter, and from thirty to a hundred feet deep ... sometimes we heard the sound of water in some subterranean channel, but of surface-water there was none.
> (Champion 1928)

This descrption is of the limestone ranges inland from the "Limestone Barrier" in the same general area as recently explored by the 1973 Niugini Speleological Research Expedition. The expedition report does not exaggerate in claiming that "conditions in the Muller Range ... are gruelling, making PNG high limestone areas the most difficult in the world to explore". The problems of strenuous work at an altitude of 2000-4000 m are severe for a team with only a short period of acclimatisation. Very heavy rainfall in the vicinity of 2500 mm (compare Auckland 1268 mm, Canberra 626 mm, Sydney 1209 mm) and cool temperatures, about 12°C mean daily at 3000 m with 12°C diurnal range, also result in an uncomfortable chilly damp environment, where it's difficult to get things dry after the last torrential downpour. These limestone ranges are the kind of place where after a few weeks muddy slogging through tangled bush and with the doubtful comfort of a damp sleeping bag you'll swear never to return to again. Yet the lure of the unexplored mountains and caves soon clouds the most unpleasant memories, and so it's not surprising to learn of new expeditions being planned, often with a nucleus of Niugini-tested personnel going back for more.

The results of the 1965 Australian Star Mountains Expedition were not very encouraging from the speleological point of view, reporting mainly debris-blocked streamsinks above the tree-line. But further investigations through the late 1960's and early 1970's led to greater confidence in speleological prospects in Papua New Guinea, particularly with the exploration of Bibima in 1972. However, in a country where information on the karst terrain is so sparse, planners of expeditions have a perplexing problem in judging just where to go. The 1973 expedition leaders made, I believe, one of the best choices in opting for the Muller Range, and while there must have been disappointment in not attaining anywhere near the then world depth record of 1174 m, the expedition could not realistically expect to accomplish much more than a reconnaissance survey in the three or four weeks available to them.

The expedition has provided valuable experience of caving conditions in Papua New Guinea and of planning and financial requirements. The expedition report is extremely valuable in its detailed description of logistics. This information will aid immensely the planning of future expeditions. The section on the peoples of the expedition area is also important in this respect.

The expedition log conveys very well the atmosphere and humour of the expedition, and while the concept of "Van hours" may be lost on some readers, it will certainly be appreciated by those who know him. The abundant and excellent photographs also do much to bring the written descriptions to life and are particularly important for those who have not been to Papua New Guinea.

The scientific sections of the report covering surface flora and fauna, geology, and physiography provide adequate background information on the natural environment of the area, but accomplish little more than this. Perhaps when the biological specimens are fully identified and the isotopic work has been done on the speleothem collected, there will then be some more notable results. Although the majority of the expedition members were scientists, and it was decided early on to make the venture a scientific expedition rather than an exclusively sporting one, there was little apparent overall research design or planning. Understandably in the context, cave discovery came first, science second - even if that was not the official intention. In order to improve the scientific value of future expeditions, it would undoubtedly pay to have a carefully selected and integrated research programme with clearly defined objectives and priorities. But such planning can only be successfully undertaken when some reasonable background knowledge is available. This Expedition Report provides this for the Atea River area.

After reading the Report one is left wondering whether, in pursuit of the deepest cave in the world, it would be best to return to the area to push the extremely hazardous Kanada Atea with its potential of 1500 m or to venture elsewhere. My view is that the water problem in the Atea Sink is so unpredictable and of such large magnitude that the danger does not warrant the possible gains. A more acceptable proposition would be to tackle smaller tributary systems which might link up with the main system at depth. Alternatively, of course, there are numerous other areas that would profit from reconnaissance expeditions like this one: some in the Muller Range perhaps closer to the Strickland Gorge, in the Saruwaked Mountains of the Huon Peninsula, or inland New Britain. Failing that, there's always scope for the longest cave in the world in the Darai Hills southwest of the Kikori River, but about 250 km of surveying in the lowlands is a much more daunting prospect than 1174+ m rapid descent in the highlands.

Paul W. Williams

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GLOSSARY OF GEOLOGY REVISION

I have been asked to coordinate the revision of entries relating to speleology and karst for a new edition of the Glossary of Geology, published by the American Geological Institute. Please send suggestions regarding revision of definitions in the 1972 edition, notes on new terms that have recently come into the English language, and comments and references to me at U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025.

George W. Moore

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ATEA KANADA

JULIA M. JAMES*, RANDALL H. KING** and

NEIL R. MONTGOMERY***

Abstract

The Atea Kanada in the Muller Range, Southern Highlands of Papua New Guinea, was investigated during the 1976 Muller Range Expedition. Four kilometres of cave passage were surveyed and the cave map is presented. The cave is described together with a tentative history of its development. The possible sinking points and resurgences of the cave water are discussed. The paper concludes with a discussion of the depth and length potential, and feasibility of further exploration in such a river system.

INTRODUCTION

Atea Kanada has a spectacular entrance doline (see plate 1), the focal point of a complicated karst drainage system which has been the subject of study on two speleological expeditions. The 1973 Niugini Speleological Expedition made a brief visit to this cave, which is located in the Muller Range of the Southern Highlands Province, Papua New Guinea, (James et al. 1974). This paper is the result of a more exhaustive study by the 1976 Muller Expedition which demonstrated that the Atea Kanada exhibits a remarkable complexity in development especially in consideration of the short geological period available for the system's formation, namely since the Pleistocene orogeny.

ATEA RIVER BASIN PHYSIOGRAPHY

The peaks of the Muller Range rise to 3600 m; however, the Atea Kanada doline is located well below the highest. Although relief data are sparse, the estimated height of the Atea Kanada entrance is 2200 m. The most likely resurgence of the river in Atea Kanada is 2 km to the SW of the Atea Kanada doline: the

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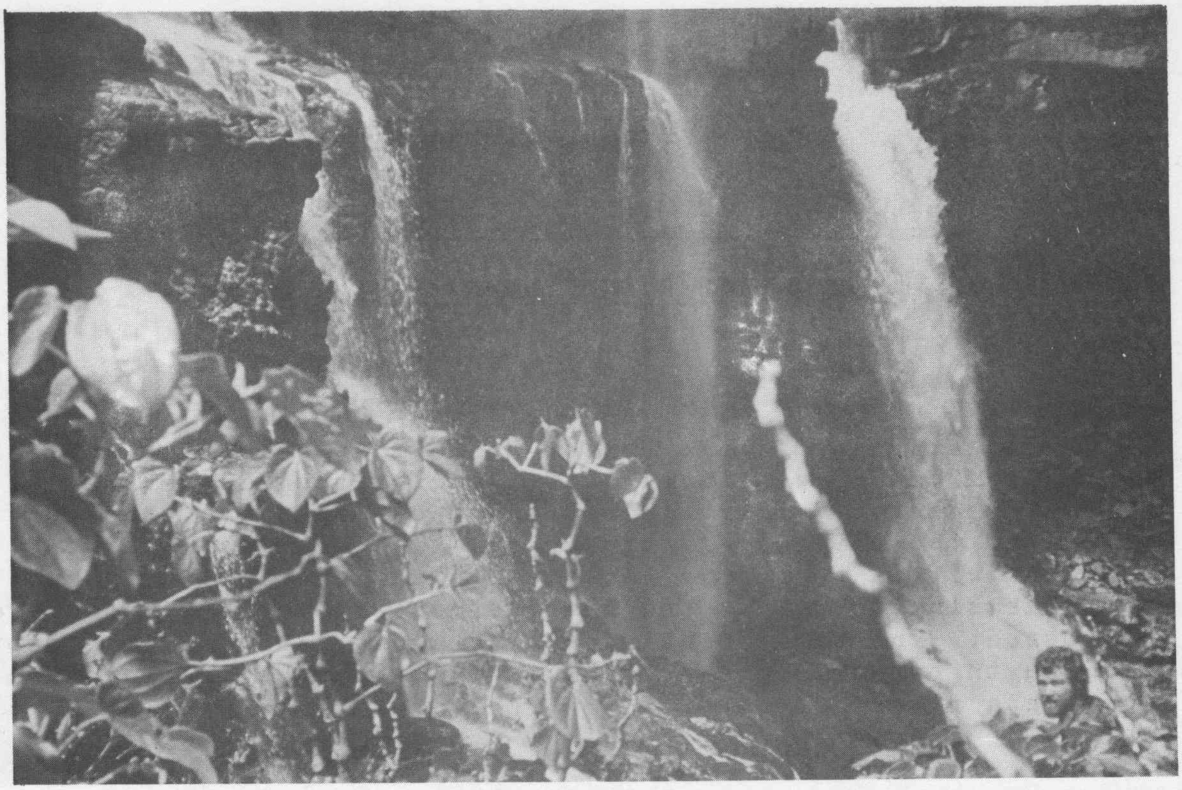


(a) Low flow.

(b) After a heavy thunderstorm.

Plate 1 – Waterfalls in the Atea Kanada Entrance Doline. photos: D. Rothery

height difference between this resurgence and the doline measured by Suunto PB5 clinometer and fibreglass tape was 750 m.

Climatic information has been discussed by Caffyn (1974(b)). The exact precipitation in the Atea drainage basin is unknown but is estimated to be 5000 mm annually. During the 1976 Muller Expedition precipitation fell on over 50% of days, with a diurnal pattern of rainfall during afternoons and evenings. July and August are usually the driest period, but the start and finish of the dry season are not regular from year to year.

The temperature in Atea Kanada is approximately 15 °C and although the area is only 4° south of the Equator the surface temperatures vary from very hot to occasionally below freezing. However, the cave temperature probably reflects the low mean annual temperature. Dense tropical montane rain forest covers the whole of the Atea drainage basin. This combination of low temperature, mammoth precipitation and dense vegetation (producing acidic soils) has been suggested as approaching the optimal conditions for limestone solution.

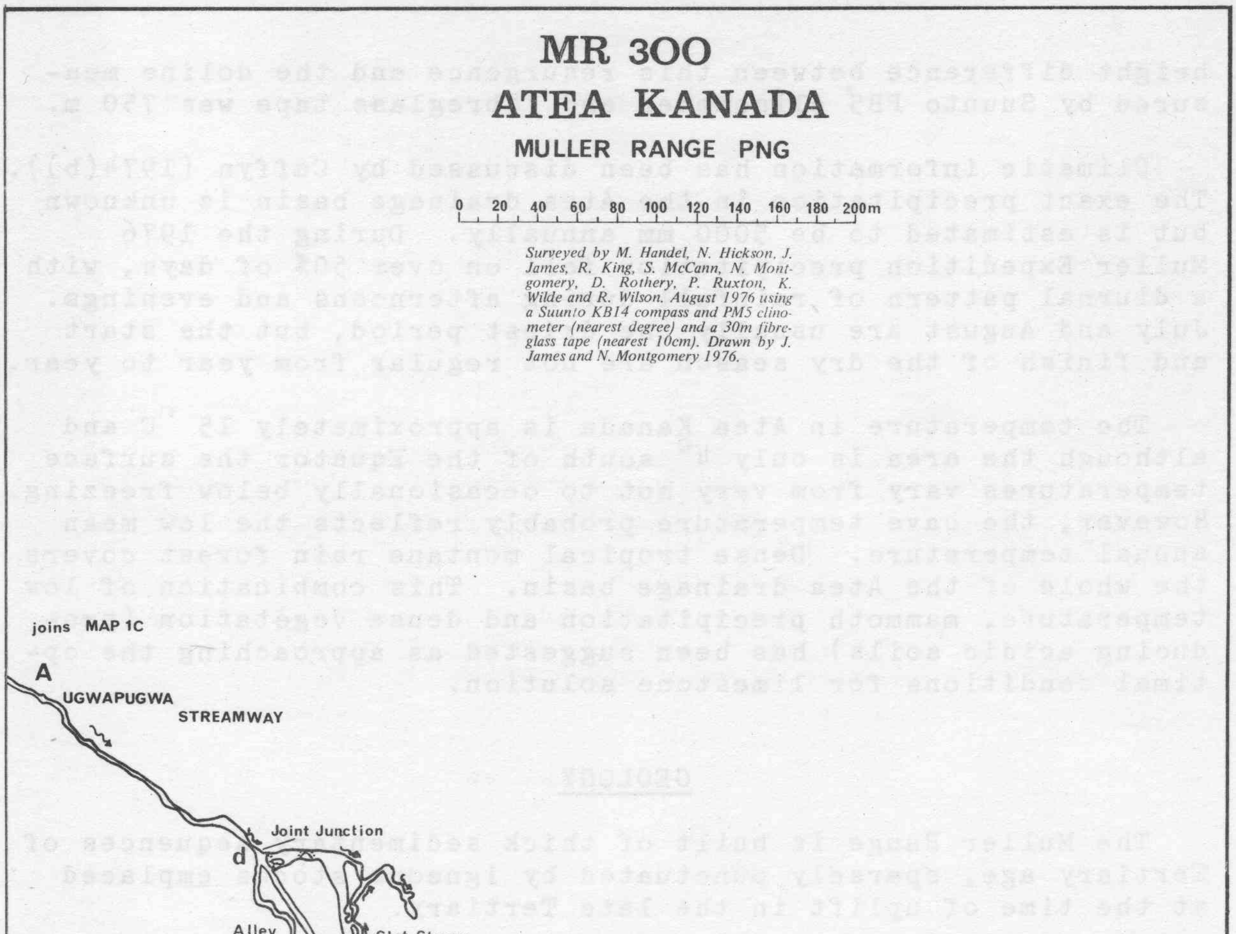
GEOLOGY

The Muller Range is built of thick sedimentary sequences of Tertiary age, sparsely punctuated by igneous stocks emplaced at the time of uplift in the late Tertiary.

The geology of the Muller karst region and its history are discussed by Caffyn (1974(a)). The main feature of importance in the development of Atea Kanada is the vast deposit of Darai Limestone, a sequence of over 1200 m of marine sediment of Upper Eocene to Middle Miocene age, gently folded in a broad anticlinal structure tending roughly WNW.

The Atea Kanada system and its catchment are in the southern limb of the Muller Anticline, whose general dip is 15° to the south. At the Atea Kanada doline itself, dip was measured at 10° towards 155° magnetic (Caffyn 1974). The limestone is a massive cream rock which in most sections appears to be pure, although locally it can be quite shaly.

Large scale jointing and faulting are apparent from the aerial photographs and these may exert a strong influence on the development of the Atea Kanada, but in the passages so far explored, bedding is by far the dominant control, and only minor passage segments follow joints.


MR 300
ATEA KANADA
MULLER RANGE PNG
0 20 40 60 80 100 120 140 160 180 200m
Surveyed by M. Handel, N. Hickson, J. James, R. King, S. McCann, N. Montgomery, D. Rothery, P. Ruxton, K. Wilde and R. Wilson, August 1976 using a Suunto KB14 compass and PM5 clinometer (nearest degree) and a 30m fibreglass tape (nearest 10cm). Drawn by J. James and N. Montgomery 1976.
joins MAP 1C
A
UGWAPUGWA
STREAMWAY
Joint Junction
d
Alley
Slot Stream
Brus
Junction
Duck Walk
c
MILL SERIES
e
Grindstone
Alley
Confluence Dome
Atearege
Crucible
ATEA
RIVERWAY
Ship Canal
k
Turbine
ESCAPE
SERIES
Fury Tube
Rapid
Bypass
n
Glop Drop
Millrace
Roary
Hall
Kanagare
f
Drone
Drop
The
Beeline
PLAN
b
6
5
3
1
g
m
2
Beeline
Connection
4
h
a
ATEA KANADA
DOLINE
mn

MAP 1A

CAVE DESCRIPTION

For the purposes of description Atea Kanada (see map 1, A, B and C) can be divided into five sections, which interconnect in a complex manner.

1. The Atea Riverway
2. Older Atea Passages
3. The Ugwapugwa Streamway
4. Older Ugwapugwa Passages
5. The Slot Stream Passage

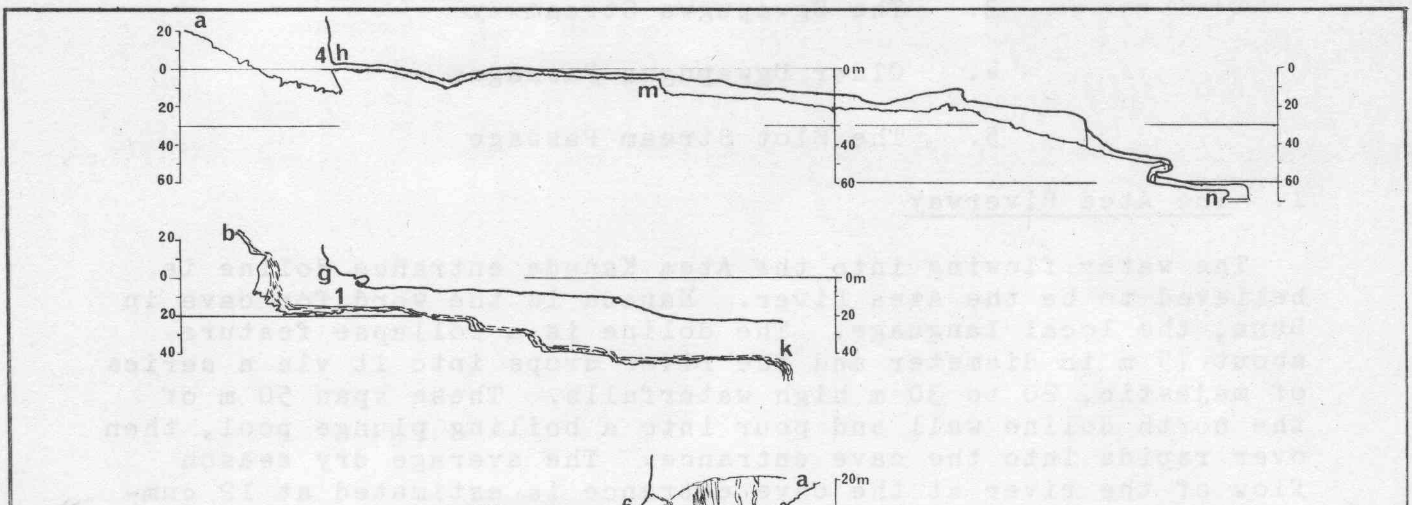
1. The Atea Riverway

The water flowing into the Atea Kanada entrance doline is believed to be the Atea River. Kanada is the word for cave in Duna, the local language. The doline is a collapse feature about 75 m in diameter and the river drops into it via a series of majestic, 20 to 30 m high waterfalls. These span 50 m of the north doline wall and pour into a boiling plunge pool, then over rapids into the cave entrance. The average dry season flow of the river at the cave entrance is estimated at 12 cumecs. The Atea Riverway entrance (MR300) is 15 m high and 20 m wide, and is formed in the overhanging lower face of the 150 m high cliff forming the southern doline rim. This entrance is reached by a track on the north-western side of the doline. The track traverses a 30° to 40° slope of collapse blocks, covered by dense shrubbery up to 1 m high.

The 'Atea Riverway Entrance' can be negotiated by traversing a ledge on the right-hand side of the rapids. An alternative entrance, MR302, is a small hole on the south side of a large boulder and is 15 m south of the Atea Riverway Entrance. The Atea Riverway lies in chambers 40 m wide and up to 25 m high; the river occupies a channel cut along the eastern wall. A small stream enters the chamber from the west and passes through a series of rimstone pools to join the river.

The river covers this chamber during flood, since sand has been deposited in the southern end, and a 13 m tree trunk rests within the cave.

The river flows as rapids through the chamber, cascading over the waterfalls of 2, 6 and finally 10 m to enter a canyon 30 m high and 7 m wide. A slippery, sloping ledge continues


ATEA KANADA
DEVELOPED LONG SECTIONS
MAP 1B
ENTRANCES
1 — MR300 Main Atea Riverway Entrance
2 — MR 302 Minor Atea Riverway Entrance
3 — MR303 Window overlooking MR300
4 — MR304 Wet Weather Entrance 10m pitch
5 — MR305 Escape Series Entrance
6 — MR306 Fury Tube Entrance

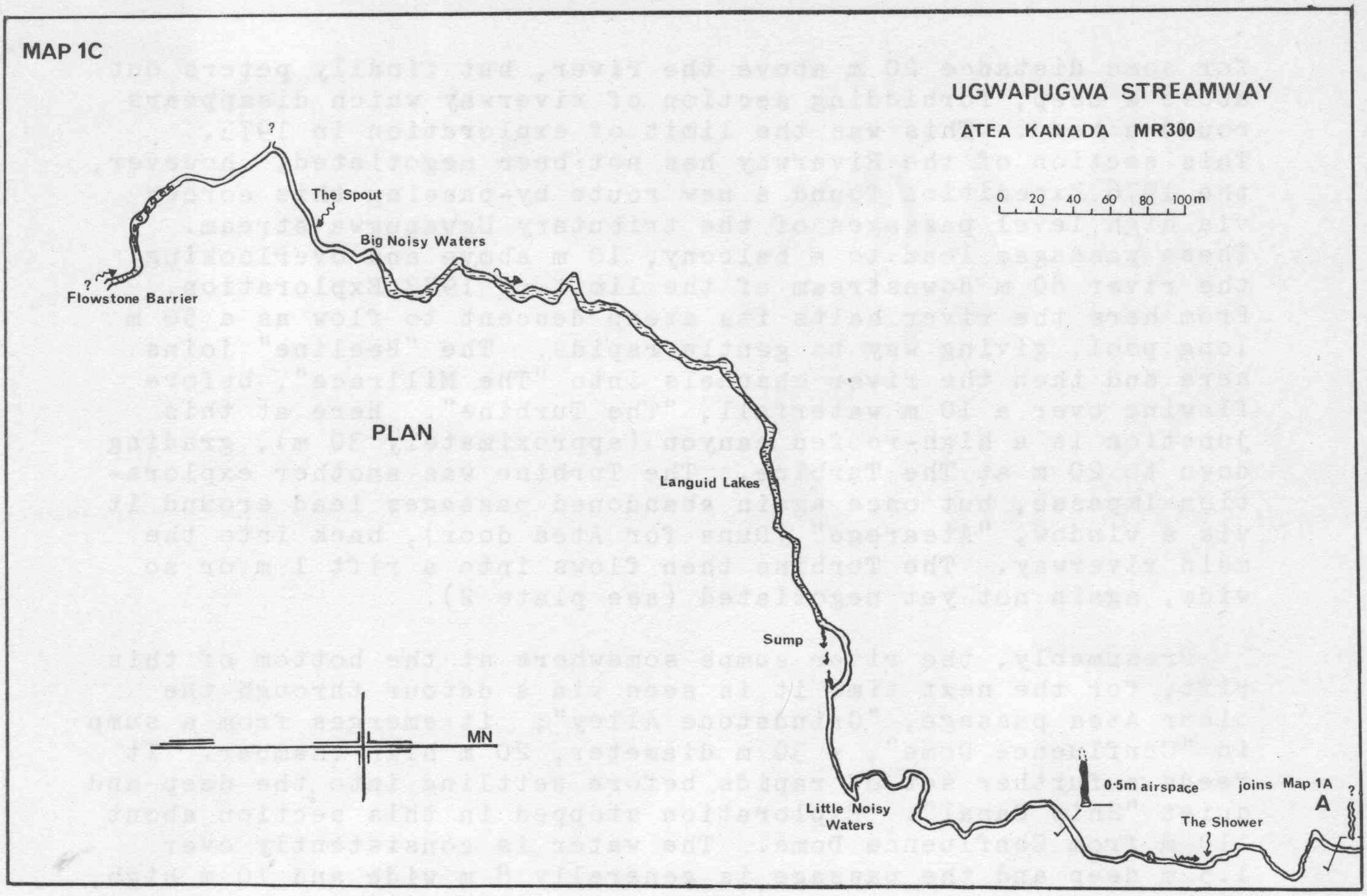
for some distance 20 m above the river, but finally peters out above a deep, forbidding section of riverway which disappears round a bend. This was the limit of exploration in 1973. This section of the Riverway has not been negotiated; however, the 1976 Expedition found a new route by-passing this corner via high level passages of the tributary Ugwapugwa stream. These passages lead to a balcony, 10 m above and overlooking the river 80 m downstream of the limit of 1973 Exploration. From here the river halts its steep descent to flow as a 50 m long pool, giving way to gentle rapids. The "Beeline" joins here and then the river channels into "The Millrace", before flowing over a 10 m waterfall, "The Turbine". Here at this junction is a high-roofed canyon (approximately 30 m), grading down to 20 m at The Turbine. The Turbine was another exploration impasse, but once again abandoned passages lead around it via a window, "Atearege" (Duna for Atea door), back into the main riverway. The Turbine then flows into a rift 1 m or so wide, again not yet negotiated (see plate 2).

Presumably, the river sumps somewhere at the bottom of this rift, for the next time it is seen via a detour through the older Atea passage, "Grindstone Alley"; it emerges from a sump in "Confluence Dome", a 30 m diameter, 20 m high chamber. It feeds a further set of rapids before settling into the deep and quiet "Ship Canal". Exploration stopped in this section about 110 m from Confluence Dome. The water is consistently over 1.5 m deep and the passage is generally 8 m wide and 10 m high, although the initial section is low, only 4 m high. At the 110 m point there is a small sand bank from where the passage can be seen continuing without change for at least another 30 m.

2. Older Atea Passages

"Atearege" is a balcony formed where a former route of Ugwapugwa intersects the Atea River canyon, just downstream of the Turbine. The howl of the Turbine makes the Atearege an awesome and frightening place; however, a 18 m pitch offering a fine view of the Turbine to the Atea River level ends not in white water, but on the dry floor of Grindstone Alley, a 120 m long old route, and now a floodway of the Atea. It is mostly 3-10 m wide and 20-30 m high and exhibits superb examples of rock mills (see plate 3). Well-rounded grindstones up to 1 m across are strewn throughout the passage, but accumulate in large numbers at the bottom of the mills. Perched logs indicate that this path is followed regularly by flood waters.

Downstream in the floodway, the floor slopes up briefly (presumably due to erosion by The Turbine in flood) and then becomes horizontal. Several dry mills are passed before a de-


MAP 1C
UGWAPUGWA STREAMWAY
ATEA KANADA MR300
0 20 40 60 80 100m
The Spout
Big Noisy Waters
Flowstone Barrier
PLAN
Languid Lakes
Sump
MN
Little Noisy Waters
0·5m airspace
joins Map 1A
A
The Shower

lightful obstacle is met in "The Crucible" - a peanut shaped double mill, 12 m long, 6 m wide and over 9 m deep. It has beautifully smoothed and rounded walls and there is a 5 m drop from the rim into water over 4 m deep. The Crucible was passed by climbing to the right onto a platform above it, abseiling down into it, penduluming around to the far side, and climbing onto a ledge 2 m above the water (see plate 4). Two smaller mills follow, both full of water, the second mill ending at the top of a 7 m pitch. The passage is only 2 m wide at the edge of the drop, but widens beyond into a chamber 7 m wide and 25 m long. Ahead the roar of the Atea is now heard distinctly. The pitch ends in a pool and a 20 m swim across this pool gains access to a gravel bank. A 3 m climb over a jammed log marks the end of Grindstone Alley in Confluence Dome. A slight current in the pool may indicate a connection with the sump in the present active Atea riverway.

"The Beeline" leaves the Atea canyon about 30 m above the present river level upstream of the Millrace and winds its way around in a bow shape to rejoin the main riverway several hundred metres downstream, about 20 m above river level in the roof of Confluence Dome. It seems likely that, at one stage, the Beeline also was the major course of the Atea River, although prior to Grindstone Alley, and for a much shorter time. The Beeline itself consists of a phreatic tube 2-3 m in diameter with an incised vadose floor canyon up to 10 m deep, giving it a keyhole shape. The tube is probably the earliest underground course of the Atea. The roof canyon in the main Atea Riverway, which could not be reached, may be a similar feature.

The Beeline descends to the south (downstream) for most of its length, steepening towards the end to about 20°. The floor consists of breakdown and sediment of sand size and smaller. The latter is derived from back flooding of the Atea River. Scattered throughout the passage are little heaps of rotting vegetation, as well as logs placed there by the Atea River.

At its end the Beeline swings north for a few metres to join Confluence Dome, whereupon a younger, vadose and joint controlled passage 2-3 m high, "Rapid Bypass", continues southwards to finish in the 5 m "Glop Drop" which leads down into the Ship Canal. In its length of 90 m, Rapid Bypass falls 30 m, much of this depth is achieved in a 3.5 m drop and a 5.7 m pitch.

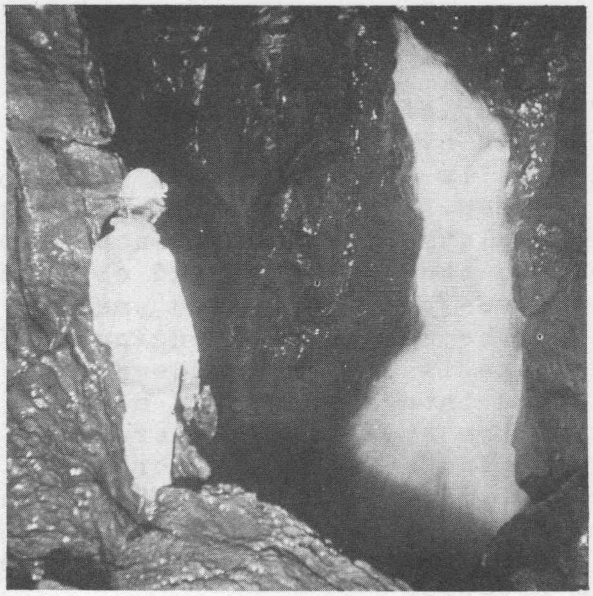


Plate 2 – The Turbine. photo: J.M. James

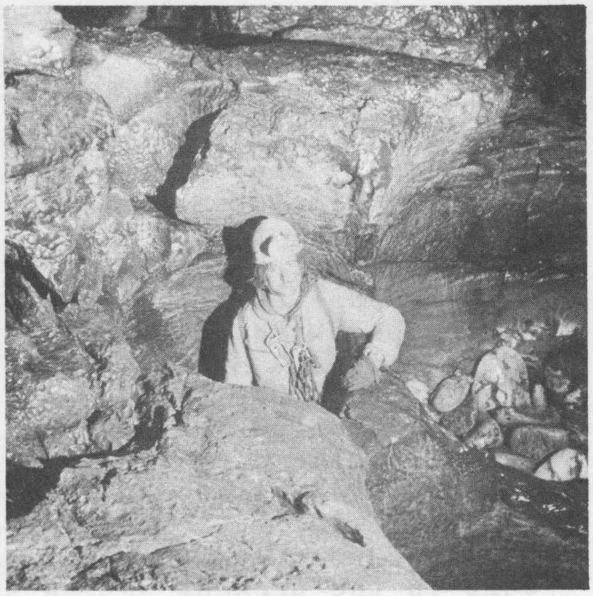


Plate 3 – Small Rock Mills 1.3m deep in Grindstone Alley. photo: J.M. James

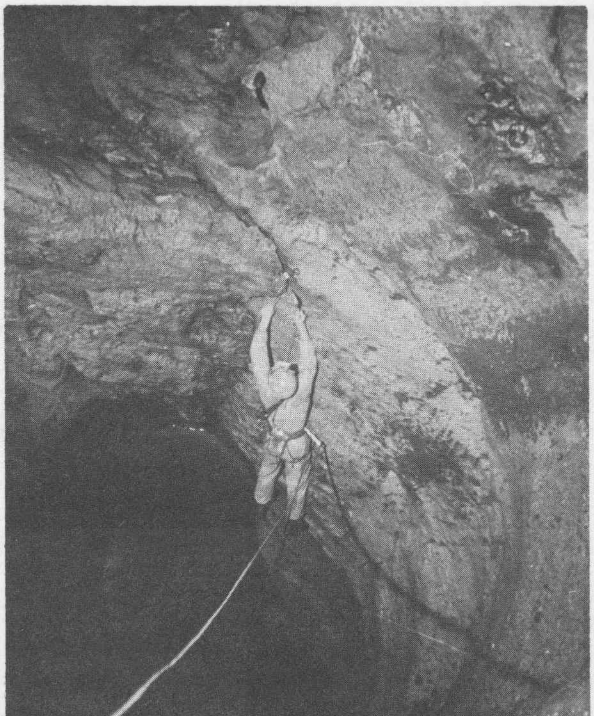


Plate 4(a)

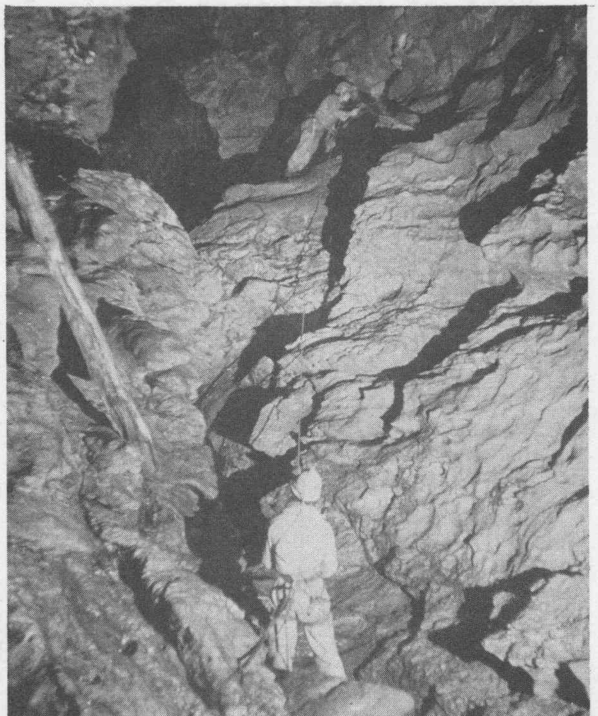


Plate 4(b)

Mechanical climbing techniques being used to pass the Crucible, a large rock mill in Grindstone Alley. photo: J.M. James

3. Ugwapugwa Streamway

The Ugwapugwa section starts at Joint Junction. Upstream it starts as a vadose canyon with the remnants of a phreatic tube at its roof, and carries a stream of about 20 litres/second. After 100 m, this half tube disappears beyond the reach of light and the bedrock roof of the passage is not seen again. The first 0.5 km of this passage is narrow, with a width of between 1 m and 2.5 m; it is a vadose canyon having classical meanders with an amplitude of about 13 m. Since the stream changed position as it cut down, in parts these meanders are interleaved. This section of the passage is well-decorated with flowstone stalagmites and stalactites, usually on the walls (see plate 5). Where the speleothem tips are low enough to be covered by the regular floods, they develop as twisted fingers, all pointing downstream. The colours of this section of the passage are intense, and vary through the spectrum from the crystal white of the recent growth, to the reds, browns, and blacks of the older decorations coloured by organic and mineral material. At some stages, the flowstone has greedily covered the entire passage, causing the caver to stoop and crawl in the water. Three hundred metres upstream of Joint Junction, a small stream enters from a flowstone covered crack in the left-hand wall. Immediately after, another very small tributary stream, "The Shower", sprays in from the roof. More streamway follows a set of noisy cascades, "Little Noisy Waters", and then comes a 2 m climb into a dry oxbow which is the old vadose passage, whose roof high above is still unseen.

The stream takes a younger route, which sumps at its upstream end. Just after this oxbow, the passage widens to 4 m and becomes filled with water from wall to wall. There are convenient gravel banks and the passage can be negotiated without swimming. These 'Languid Lakes' are quiet and poorly decorated, the canyon above being of the same nature as that previously encountered. When the "Big Noisy Water" is heard, the cave takes a sharp left turn and again the passage narrows to 1 m. A large stream emerges from a slot 1.5 m up the left hand wall. This slot can only cope with low flow conditions, and in slightly higher flow the stream emerges from two other slots upstream in the same wall. This is the source of most of the water in Ugwapugwa.

Thirty metres further upstream there is a dry passage 4 m up the wall which may lead back into the stream. However, clearly the Ugwapugwa water is taking a new route, while the main passage, with the same lofty vadose canyon character, now has only a small stream trickling through the boulders on its muddy floor. There tends to be more breakdown on the floor here, but

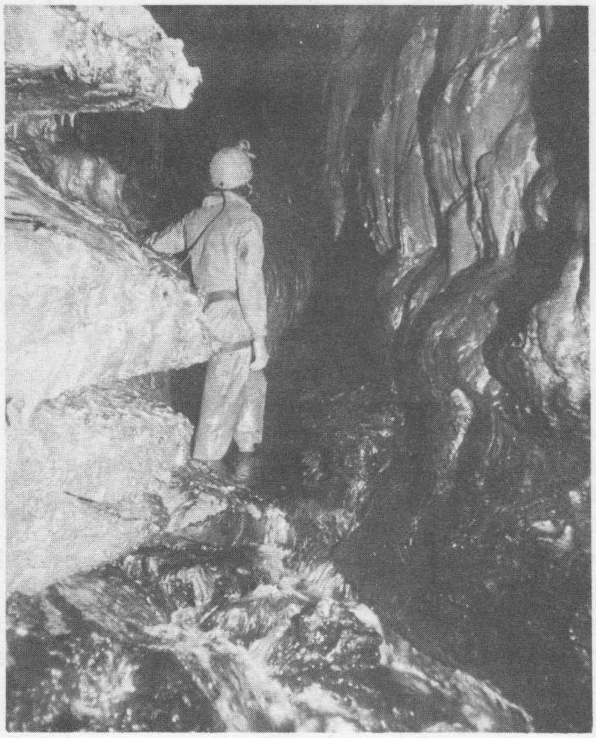


Plate 5(a)

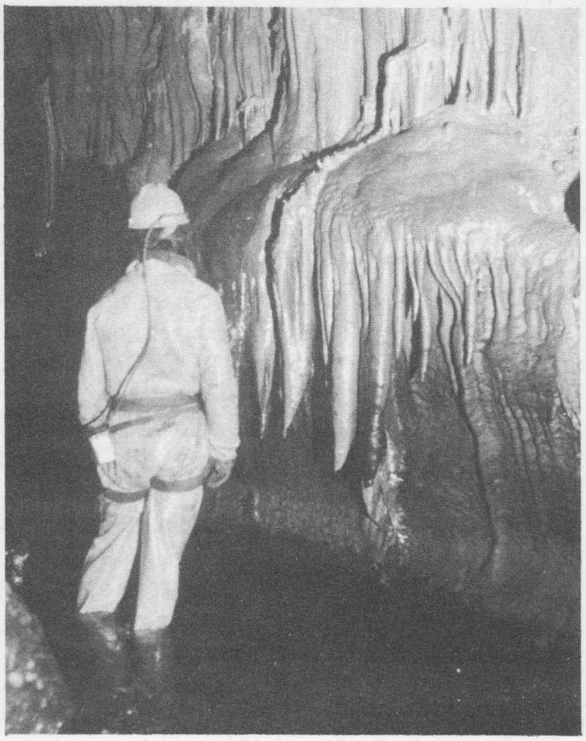


Plate 5(b)

Decorated sections of the Ugwapugwa streamway. photo: J.M. James

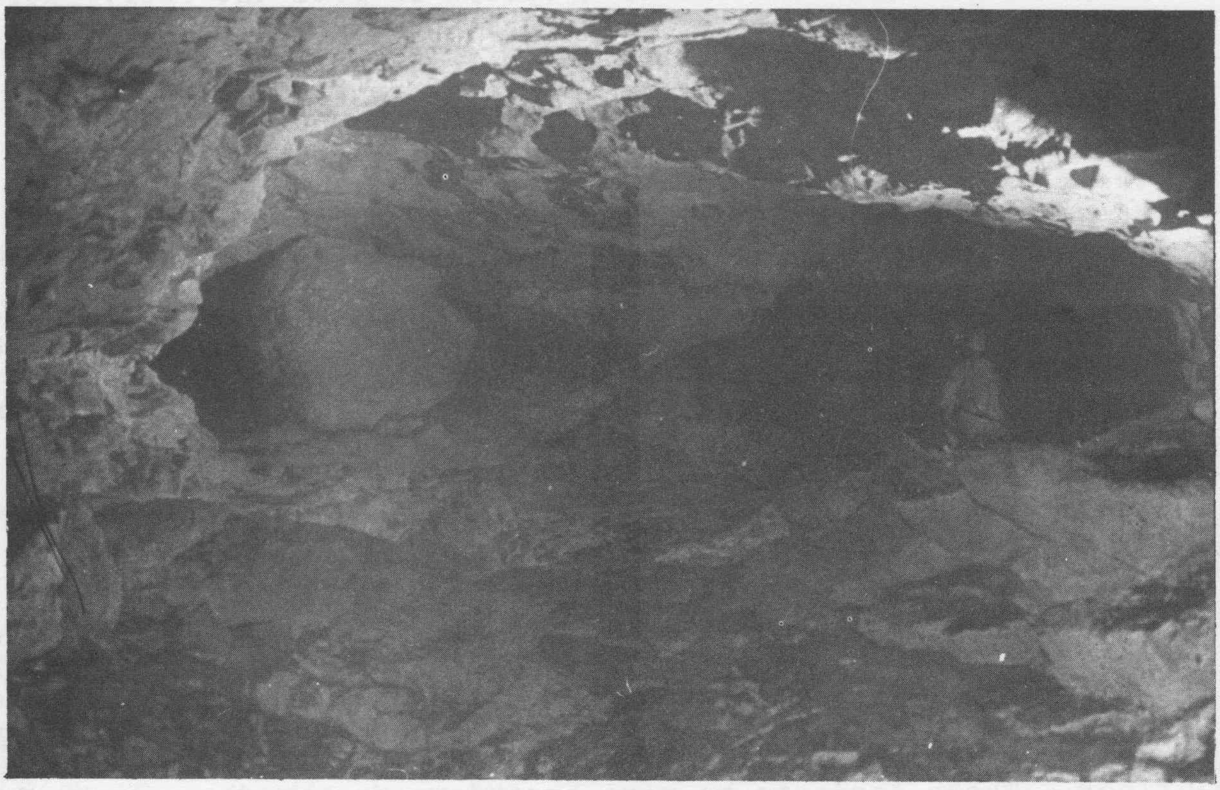


Plate 6 – The Fury Tubes close to MR306 Entrance. photo: J.M. James

this may be because it has not been washed away as in the first section of passage. A flowstone blockage is reached 1.3 km upstream from the Joint Junction; it can be climbed on the downstream side, but requires a 5 m hand line for a safe descent on the other side. Beyond this, the Ugwapugwa passage continues as the same roofless vadose canyon till it disappears. It was not investigated further. For its whole length the passage is in massive Darai Limestone, trending NNE and steadily proceeding upwards at 1.5^{o}.

The character of the Ugwapugwa streamway changes completely downstream of Joint Junction. The high canyon passage continues south west, whilst the stream follows a younger route in a passage which continues south. This stream passage is 1.5 m high and 3 m wide at its start. It contains some breakdown on the floor, and exhibits a bedding plane roof. After 30 m, a passage of similar dimensions is passed on the right, the "Mill Series", which again runs south-west, and for the second time, the stream has cut a younger route to the south. Now the passage becomes a clean crawlway 1 m high and wide which after 20 m plunges into a narrow, 5 m deep joint rift. This can be traversed well out of the water. The "Slot Stream" joins here, and the streamway, carrying the combined flow, becomes an unpleasant crawlway up to 1 m high and 0.3 m wide and half-full of water. A change in the lithology from fairly pure limestone to a shaly limestone probably accounts for the change in passage size. Finally the stream sinks into a gravel-filled slot 40 m from the 5 m chimney. Spines of very sharp and deceptively weak rock, together with the crawl in water and the chance of rapid flooding, make this short length of passage dangerous.

4. Older Ugwapugwa Passages

The entrance maze of the Atea Kanada is a result of a number of re-routings of the Ugwapugwa stream during its history. They yield an array of parallel and sub-parallel joint controlled branches on several levels. The uppermost level contains large phreatic passages, which suggests that the stream flowed here for a long time, or had a greater volume than is observed at present. This early scene contains "The Duck Walk", "Fury Tube", "The Escape Series" and "Beeline Connection". All of it is above the -10 m level (using MR304 as a datum). It is just possible that the Atea formed this series (and not the Ugwapugwa stream), but this would imply a former sink for the Atea upstream of the present entrance doline. In this section typical features are a phreatic roof with rock pendants or a breakdown floor covered in mud and silt from flooding. The sediment fill can be nearly complete as in the "Duck Walk" or it may be nearly absent as in parts of "Fury Tube". Leading from Entrance MR306 (see plate 6) the upper

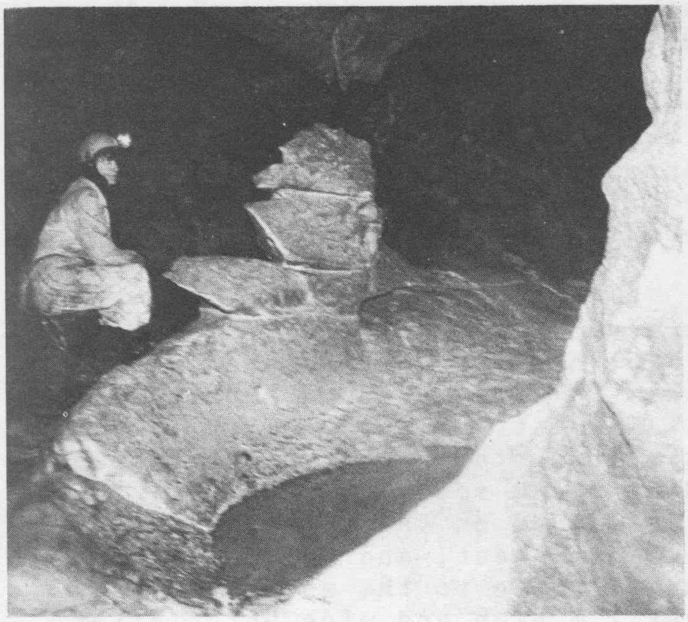


Plate 7 – Phreatic passage forms in the Mill Series. photo: M. Handel

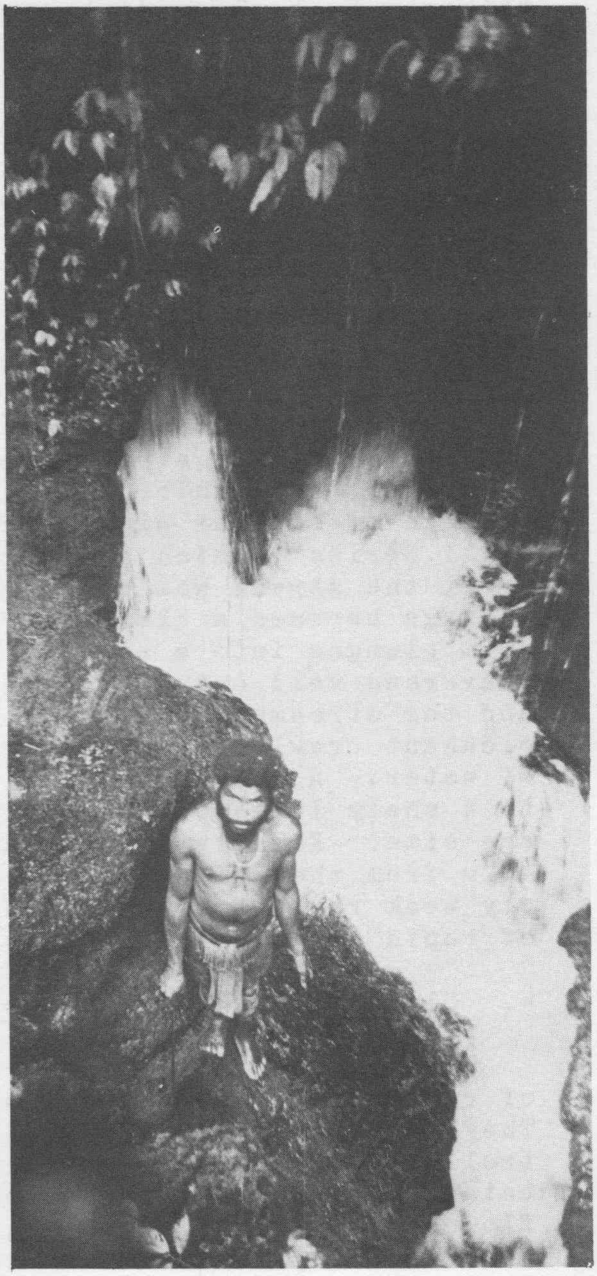


Plate 8
A cave from which part of the river that feeds the waterfalls in the Atea Kanada Doline emerges. photo: M. Handel

Plate 9 – The East Nali Source postulated resurgence of the Atea Kanada. photo: N.R. Montgomery

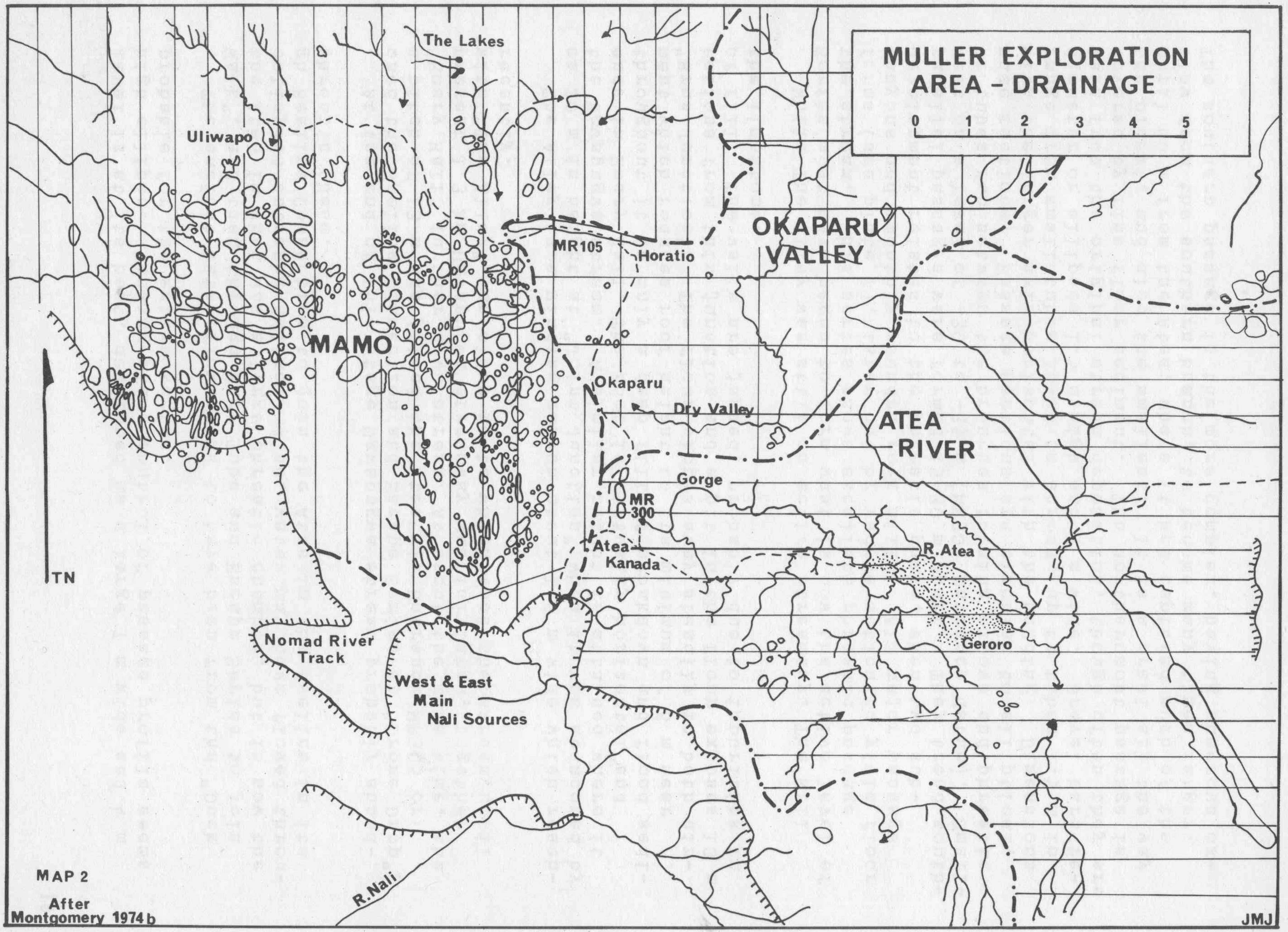
level is at its best, developed as a large 7 m wide and 4 m high ellipse. Bedding plane control of passage profile seems probable for the entire series.

The ancient water flow seems to have been from the "Duck Walk", and then through Fury Tube and Escape Series to join the Atea in what was a large phreatic chamber, but is now the collapsed entrance doline. Also, water may have flowed through Beeline Connection to join the Atea in the Beeline in its phreatic phase.

At the end of this stage Ugwapugwa stream probably abandoned the Beeling Connection and Escape Series at "Drone Drop", a pitch of 13 m and joined the Atea via Entrance MR305 or "Roary Hall" further down stream. At about the same time, the present 1.3 km Ugwapugwa streamway was initiated, together with "The Alley", an older route which took the stream until recently.

The Alley is a winding canyon about 1.5 m wide which reaches 20 m in height at "Joint Junction" when it was abandoned by the Ugwapugwa stream. A similar height is attained where it ends in Roary Hall. The roof is virtually horizontal and throughout it is only a deep fill of breakdown and flood sediment which reduces roof height to its minimum of 6 m near "Brus Junction". The floor slopes away steadily in both directions from this junction and a pit in the floor exposes 10 m of fill. The walls are jagged, probably due to impurities in the limestone.

While The Alley was still an active streamway, The Mill Series must have begun to form what is now the active level of the stream. This series shows excellent phreatic passage forms (see plate 7), later cut by vadose action to yield floor canyons and smoothly rounded rock mills. All major passage development relates to the phreatic phase, when two sub-parallel passages were formed 15-30 m apart. They trend southwest on a level of -30 to -35 m (MR304 Entrance datum). Smaller tubes run between the branches forming oxbows and phreatic maze sections. Passage sections are circular to elliptical, with the larger axis horizontal with the bedding. Dimensions range from small tubes 10-20 cm across, up to tubes 1.5 m in diameter or ellipses 1.5 m high and 3 m wide. Gravel bars remain from the original stream deposition, though often they are covered by fine floor sediment. The northernmost passage is the oldest, and also the smallest. It is a crawl all the way until 60 m from the Atea, where it has captured much of the flow from the southern branch, to become many times larger. The southern passage is the more complex, having numerous ox-



MAP 2
After
Montgomery 1974b

bows. Vadose action in both passages increases markedly as the Atea is approached, with floor canyons up to 2 m deep and numerous rock mills up to 3 m in diameter and 2 m deep. The "Mill Series" is the best decorated part of the older series, though it is not as fine as the Ugwapugwa streamway upwards of Joint Junction. Stalactites and stalagmites are the prominent forms. The Mill Series joins the Atea in an impressive stretch of balconies and windows. A large balcony terminates the northern passage and a 10 m pitch drops to the riverway. From the southern passage Atearege opens in the wall of Grindstone Alley.

5. The Slot Stream Passage

This minor streamway, carrying about 40 litres/second, crosses both passages of the Mill Series 60 m south-west of Joint Junction. It has cut a floor canyon about 0.5 m deep in each passage, and disappears into a narrow floor slot in the southern passage to join the Ugwapugwa stream. The entire passage length is around 70 m at the upstream end; the passage degenerates into four small bedding plane feeders which may be followed only with difficulty (the expedition members considered this too dangerous). Part of their source may be from a narrow streamway which crosses the entrance phreatic series near the MR305 entrance. In this case the Atea River itself is the probable source.

HYDROLOGY

This interpretation of the hydrology of Atea Kanada (see map 2) and the surrounding area of the Muller Plateau is based solely on inferences, and future water tracing experiments are required to test it.

Sinks and Resurgences

In 1973 the entrance doline of Atea Kanada was believed to be the sink of the Atea River. In 1976 when the area above the waterfalls of the entrance doline was explored the water feeding them was found to emerge from four separate caves (see plate 8) as well as leading into the doline from numerous smaller crevices and caves in a gorge. The relationship between this water and the Atea River observed flowing through the Geroro clearing was not ascertained, although it may safely be assumed that the Atea River supplies a substantial amount of the water that flows into the Atea Kanada entrance doline. Some of these springs in the gorge above the doline must represent the reappearance of the Atea River, which now avoids a meander in its old surface route by cutting directly through a ridge. In 1973 the aerial photographs were interpreted as indicating a continuation of the surface course of the Atea River through the gorge (Montgomery, 1974(b)). Caffyn and Bourke (Caffyn 1974(b)) suggested the possibility of a "relict stream sink" in the Atea River Valley to the east of the doline. This may be the present Atea Sink.

The resurgence of the Atea Kanada was believed to be the main headwater of the Nali River. The 1976 Expedition found the situation to be more complex than was interpreted from the aerial photographs. This source of the Nali River was found to be two major resurgences, both at the bottom of a 500 m high escarpment. The Atea resurgence is believed to be the more easterly of the two. Its flow, estimated at 30 cumecs, was three times the volume of water flowing into the Atea Kanada entrance doline two days earlier. The water surges out from amongst a mass of rocks and boulders (see plate 9). A close inspection of this resurgence or of a cave entrance 30 m above it could not be made as it was impossible to cross the Nali River or the stream issuing from a gorge leading to a westerly resurgence. Both streams may be fed by the Atea Kanada or more probably they have independent sources. It is possible that a north-south ridge running the length of the western side of the major dry valley to the north acts as a divide between the drainage areas, "Mamo" (The Cheese of 1973) to the north-west and the Atea River Basin to the east. In addition the Nomad River track cuts across a dry valley between the scarp and the Nali. The dry valley is in line with the dolines on Mamo and the westerly main Nali resurgence. Thus there seems to be at least two major underground systems in the Muller to be investigated.

An important aspect of the Muller hydrology is whether the Atea Kanada captures the Okaparu Valley drainage. In 1976 the obvious river valley to the east of Okaparu was explored for 1 km "eastwards" but no river was found in this distance. It would thus appear that the river inferred from aerial photographs (Montgomery, 1974(b)) has abandoned this surface route for an underground route. The valley floor is lined with dolines which may indicate that the present underground course follows the general direction of the valley. This river is important because its catchment area is 0.75 that of the Atea. In Table I and map 2 the Muller Expedition Area is divided into three possible drainage areas. The size of these areas can give some indication of the volume of waters available to the West and East Main Nali sources, although it must be clearly understood that the rainfall each of these areas receives is not uniform. It is influenced by

Table I

Drainage Areas - Muller Range Exploration Area

Catchment	Area (km ^{2})*	Area (% total)
1 Atea River Basin	90	34
2 Okaparu Valley	75	28
3 Mamo and The Lakes	100	38
Totals	265(+)	100

* Area of catchments taken from aerial photographs and not completely shown on Map II.

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the proximity of the area of the plateau to the scarps and to the peaks of the Muller Range. The available Atea catchment is about the same as that calculated for Mamo and The Lakes.

Nevertheless the postulated Atea resurgence has 1.5 times the outflow of that believed to be coming from Mamo. So the prospects of the Atea Kanada having a major tributary from the Okaparu Valley are good. It should be the aim of any future expedition to locate the river in this valley and explore its underground course.

The volume of water in the Atea Kanada Riverway appears to be less than that flowing over the waterfalls into the plunge pool in the entrance doline. This observation was made at a time of low water. The base of this plunge pool consists of fractured rocks and boulders, and water presumably infiltrates the base of the pool, draining into a very young Atea Kanada which may join the existing system in its lower reaches. The capacity of this young Atea Kanada is very limited and in high water any increase in flow drains directly to the Atea Kanada Riverway.

Floods

Fluctuations in flow, especially the extent and duration of floods, and the response time of the cave to heavy rains are of major concern in the exploration of Atea Kanada.

The Atea Kanada Riverway at present seems to take the light rain that the area receives in the late afternoon without any significant increase in water levels. Although flow rate and turbidity increased in the Riverway, the horizontal sections of the Riverway were still negotiable by swimming. It remained fordable at the entrance for several days without lifelines. But after four days of persistent rain only the heavier members of the Expedition could cross on lifelines. In one night of heavy thunderstorm rain the waterfalls into the entrance doline doubled (see plate 1); the crossing at the Atea Entrance was impassable but still the Atea water was contained within the passages shown on the survey and did not invade its lowest floodway, Grindstone Alley. The large volume of flow over the waterfalls was maintained for several days after the storm and during this time it was still possible to swim without lifeline assistance against the flow of the water in the Ship Canal. So it appears that a flash flood in this cave is unlikely, although highwater levels and flow as produced by the thunderstorm may last for several days if followed by regular rain.

The Atea Kanada entrance doline has only sparse vegetation, extending 50 m up the doline. This may indicate that it is subjected to intermittent flooding. Alternatively, the vegetation type may be controlled by the constant humidity supplied from the waterfalls.

Exploration of all the known passages of the Atea Kanada makes it clear that somewhere in its recent past the cave has completely filled with water. Logs are jammed 30 m up in the main riverway, organic material is intermingled in the speleothems in the roof of the Mill Series and a fine layer of mud covers all walls and ceilings in the higher levels. Already, however, calcite is growing on top of this mud and the speleothems in the Ugwapugwa streamway have been washed clean and new calcite deposited. A speleothem taken from the Mill Series when examined showed there had been a flood of similar magnitude some period in the distant past but this sediment layer is now covered with 2 cm of pure white calcite.

We believe that floods of this magnitude are rare and appear to be back-flooding from some blockage in the main Atea Riverway. The magnitude of such floods must be impressive; the Nali resurgences during this time would be awesome. The Pogaio tribesmen who have gardens on the flood plain of the Nali fear the area of the resurgence and stories of floods are carried by legend from generation to generation. The flood plain close to the resurgences contains evidence of a recent mighty flood. Vegetation consists only of saplings and juvenile undergrowth at a maximum only five years old and boulders, 3-4 m in diameter, scattered all over the plain, bear witness to the might of such floods. This, together with the evidence in the cave, seems to indicate a large flood within the last ten years and prior to 1973, because a 13 m tree trunk found in the main Atea Riverway has not decayed or shifted its position since 1973.

Regular flooding must take place, probably in the rain season, in Grindstone Alley and in the Mill Series. The Mill Series floods because the new route of the Slot Stream and the Ugwapugwa stream courses to the Atea are too young to accommodate all flood waters. The Beeline receives waters directly from the main Atea Riverway by a back flooding process as indicated by the arrangement of the organic debris and the log jams deposited.

The Ugwapugwa streamway remains clear and the flow increases slowly during normal rain. It remained open during the whole Expedition. At one point the speleothems descend to 0.5 m above the water level. In the early exploration it was feared that this section of passage would block easily. Yet it never became impassable even after the thunderstorm discussed above. The water in the Ugwapugwa streamway never became turbid during the Expedition.

CONCLUSION

The Atea Kanada MR 300 is one of the most spectacular and exciting river caves in the world. The 1976 visits to the cave have indicated that with adequate radio and telephone equipment, and stations equipped with food and survival equipment above flood levels, it may be explored and studied safely. The fate of traces of the 1976 exploration will provide further useful evidence of the extent and frequency of major flooding.

Atea Kanada has a depth of 750 m between the present entrance doline and its postulated resurgence, the eastern source of main Nali River. However, if the Atea Kanada can be connected with the deep caves to the north such as Uli Guria MR105 (Montgomery, 1974(b)), then depths of 1000-1500 m are possible. Uli Guria is at present 314 m deep. The tributary passage of Ugwapugwa heads in this direction achieving height steadily and at two places shafts appear to enter the streamway from above.

The Atea Riverway drops 750 m between its entrance doline and the eastern main Nali source and the horizontal distance is only 2 km (a gradient of 1 in 3). At present the Atea Riverway has dropped 50 m in 400 m towards the postulated resurgence (a fifth of the available distance). The character of the Atea Riverway is expected to change lower down since to reach its resurgence its gradient necessarily involves cutting sharply through the beds of the Darai Limestone instead of following them as it does in the known section. Aerial photographs show a rectilinear pattern which is certainly controlled by near vertical jointing that would favour such a change. It is anticipated that in the Riverway there will be larger drops than those so far encountered. The Atea Kanada has already yielded four kilometres of cave passage, consisting of relict passageways, floodways and two tributary streams, one of which, Ugwapugwa, is still not fully explored. The existence of a relict entrance, 8-10 m high and 30 m above the resurgence and the unexplained volumes of water issuing from the latter, make these types of passage lower in the system a certainty.

So the Atea Kanada is expected to be of considerable length as well as depth. The prospects for scientific investigation of this system, which already shows remarkable variety in development, and the technical challenge of its exploration make it the most exciting exploration prospect for the southern hemisphere speleologist.

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A TRIPLE DYE TRACING EXPERIMENT AT YARRANGOBILLY

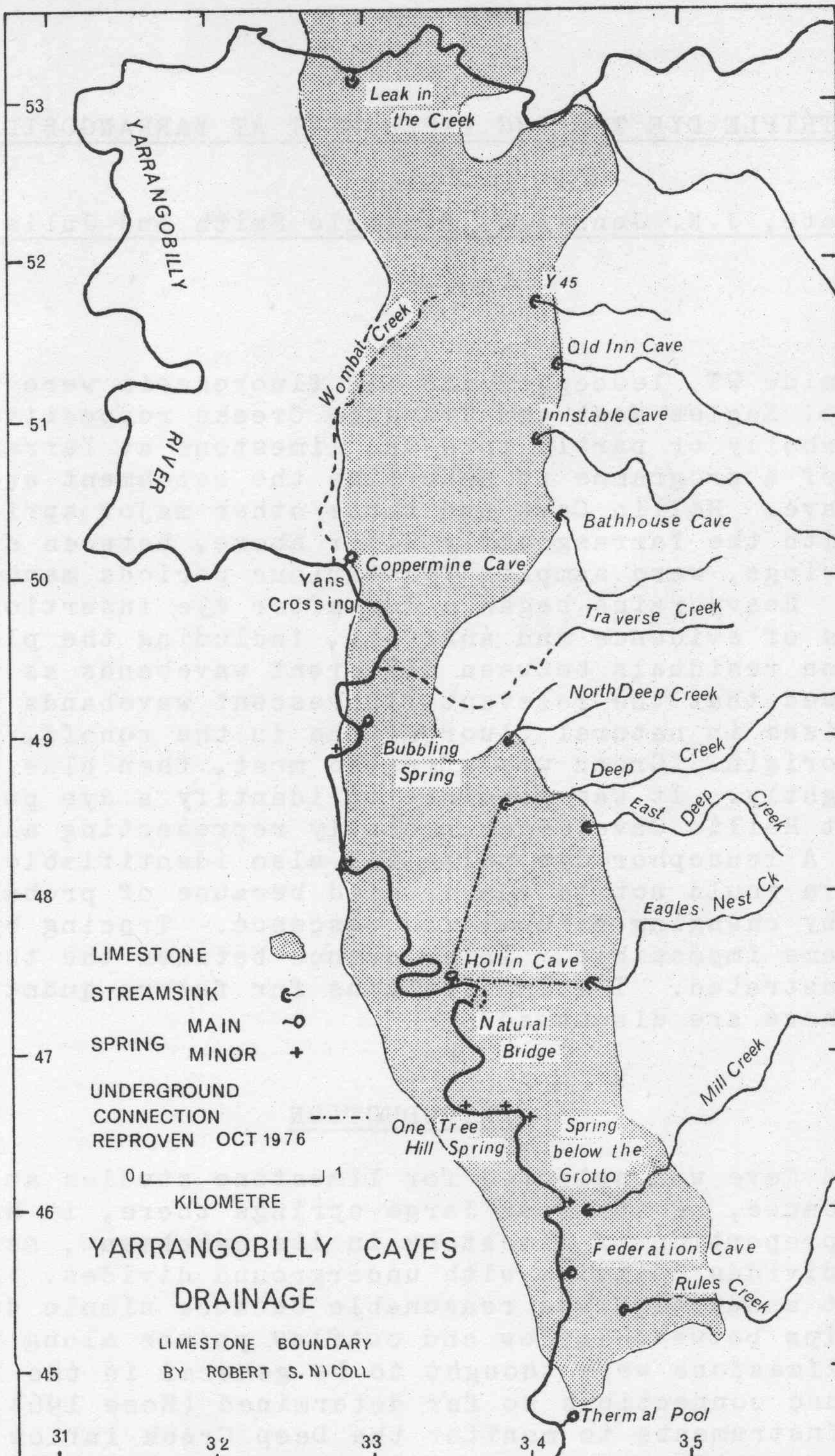
A.P. Spate, J.N. Jennings, D. Ingle Smith and Julia M. James

Abstract

Rhodamine WT, leucophor HBS and fluorescein were inserted into Deep, Eagles Nest and Traverse Creeks respectively, all sinking wholly or partly into the limestone at Yarrangobilly, as part of a programme to determine the catchment area of Hollin Cave. Hollin Cave and three other major springs, together with the Yarrangobilly River above, between and below these springs, were sampled for various periods manually or by machine. Heavy rains began a day after dye insertion. Various lines of evidence and analysis, including the plotting of regression residuals between different wavebands as time series, showed that the relevant fluorescent wavebands were affected by rises in natural fluorescence in the runoff, probably of organic origin. Green was affected most, then blue, and orange only slightly. It was possible to identify a dye pulse of rhodamine at Hollin Cave, most probably representing all the dye put in. A leucophor dye pulse was also identifiable here but a load curve could not be constructed because of probable interference by changing natural fluorescence. Tracing by fluorescein became impossible. Interference between the three dyes was demonstrated. The implications for future quantitative tracing here are discussed.

INTRODUCTION

Hollin Cave was selected for limestone studies at Yarrangobilly because, of the four large springs there, it has the largest proportion of limestone in its catchment, assuming surface divides coincide with underground divides. At that time that assumption was reasonable because simple downdip relationships between inflow and outflow points along the strike belt of limestone were thought to be general in the light of underground connections so far determined (Rose 1964, 1965, 1966). Instruments to monitor the Deep Creek inflow and the Hollin Cave outflow were installed prior to determining the underground catchment (Figure 1). It would have been wiser to have made that determination first because soon afterwards Pavey and Shannon (1974) claimed to have traced water from Leak-in-the-Creek, on Yarrangobilly River where it crosses the limestone, to Hollin Cave as well as to Bubbling Spring and Coppermine Cave, using fluorescein and charcoal detectors. The order of appearance of the dye was, however, not the one


Leak in the Creek
YARRANGOBILLY
RIVER
Wombat Creek
Y 45
Old Inn Cave
Innstable Cave
Bathhouse Cave
Coppermine Cave
Yans Crossing
Traverse Creek
North Deep Creek
Bubbling Spring
Deep Creek
East Deep Creek
Eagles Nest Ck
Hollin Cave
Natural Bridge
Mill Creek
One Tree Hill Spring
Spring below the Grotto
Federation Cave
Rules Creek
Thermal Pool
LIMESTONE
STREAMSINK
SPRING
MAIN
MINOR
UNDERGROUND CONNECTION REPROVEN OCT 1976
0
1
KILOMETRE
YARRANGOBILLY CAVES DRAINAGE
LIMESTONE BOUNDARY BY ROBERT S. NICOLL
53
52
51
50
49
48
47
46
45
31
32
33
34
35
Fig 1

to be expected. The dye reached the most distant point, Hollin Cave, first (less than 6 days), the nearest point, Coppermine Cave, second (between 6 and 16 days), and the intermediate point last (between 16 and 40 days). This order is all the more surprising in that, although in all cases the movement is along the strike, it is with the hydraulic gradient (as judged from the contour map) in the case of Coppermine Cave but beyond this point at right angles to it.

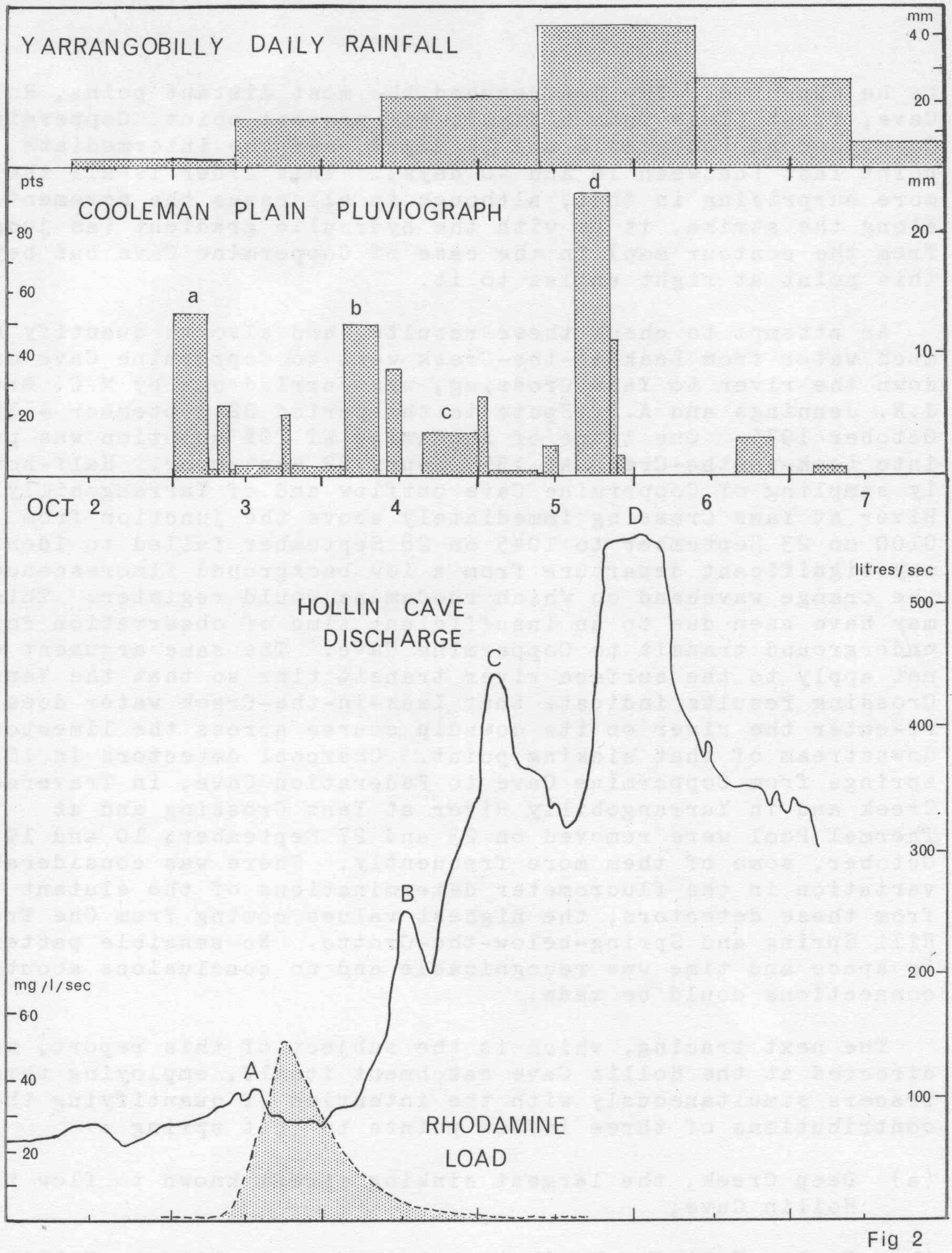
An attempt to check these results, and also to quantify how much water from Leak-in-the-Creek went to Coppermine Cave or down the river to Yans Crossing, was carried out by M.C. Brown, J.N. Jennings and A.P. Spate in the period 22 September - 19 October 1975. One litre of rhodamine WT 20% solution was put into Leak-in-the-Creek at 1355 hours 22 September. Half-hourly sampling of Coppermine Cave outflow and of Yarrangobilly River at Yans Crossing immediately above the junction from 0100 on 23 September to 1045 on 28 September failed to identify any significant departure from a low background fluorescence on the orange waveband on which rhodamine would register. This may have been due to an insufficient time of observation for an underground transit to Coppermine Cave. The same argument does not apply to the surface river transit time so that the Yans Crossing results indicate that Leak-in-the-Creek water does not re-enter the river on its downdip course across the limestone downstream of that sinking point. Charcoal detectors in 10 springs from Coppermine Cave to Federation Cave, in Traverse Creek and in Yarrangobilly River at Yans Crossing and at Thermal Pool were removed on 23 and 27 September, 10 and 19 October, some of them more frequently. There was considerable variation in the fluorometer determinations of the elutant from these detectors, the highest values coming from One Tree Hill Spring and Spring-below-the-Grotto. No sensible pattern in space and time was recognisable and no conclusions about connections could be made.

The next tracing, which is the subject of this report, was directed at the Hollin Cave catchment itself, employing three tracers simultaneously with the intention of quantifying the contributions of three inflow points to that spring :

(a) Deep Creek, the largest sinking stream known to flow to Hollin Cave;

(b) Eagles Nest Creek, the southernmost supplier to Hollin Cave;

(c) Traverse Creek, the first possible feeder north of North Deep Creek, which is the northernmost known supplier.



YARRANGOBILLY DAILY RAINFALL
mm
40
20
COOLEMAN PLAIN PLUVIOGRAPH
pts
mm
80
60
40
20
20
10
a
b
c
d
OCT 2
3
4
5
6
7
D
HOLLIN CAVE
DISCHARGE
litres/sec
500
400
300
200
100
C
B
A
mg/l/sec
60
40
20
RHODAMINE
LOAD

Fig 2

PROCEDURE

At 2155 on 1 October 1976, 0.98 litre of 20% rhodamine WT solution was put into Deep Creek above its streamsink. At 2330 the same day, 2.8 kg of fluorescein (in 11 litres of 5% KOH solution) were added to Traverse Creek at a waterfall above the contact with the limestone. At this time the creek was seeping underground into its bed progressively but ending well above its steep drop to join the Yarrangobilly River. At 0630 on 2 October, 8.4 litres of leucophor HBS, an optical brightener, were placed in Eagles Nest Creek above its entrance into Eagles Nest Cave.

The water sampling sites consisted of the four major springs, Coppermine Cave, Bubbling Spring, Hollin Cave and Federation Cave, and the Yarrangobilly River above each of these springs and below them all at Thermal Pool. Collection of samples began manually about midnight on 1-2 October at all points except the river at Thermal Pool where an automatic water sampler was started up in mid-afternoon of 1 October. Initially samples were collected half-hourly at most points either till the evening of 3 October or till the early morning of 4 October when the longer interval of one hour was in force at all sites. From mid-morning of 4 October hourly sampling continued at the river at Thermal Pool, Hollin Cave and Federation Cave with automatic samplers till the mid-morning of 7 October at the first two sites and till the morning of 6 October at Federation Cave. In addition a few sporadic tracing samples were collected before and after the programme specified. Larger samples for chemical analysis were collected at 12 hourly intervals at the 4 springs and sporadically from Traverse Creek, North Deep Creek, Deep Creek, East Deep Creek, Eagles Nest Creek, and Rules Creek.

It was intended to make regular fluorescence determinations in the field with a Turner III Fluorometer with a far ultraviolet lamp (GEC G474.1) and with appropriate filters (Table 1). However difficulty about maintaining a constant voltage with the field generators available hindered this. The samples were brought back to the Australian National University and determinations on selected samples in a constant temperature laboratory with mains electric supply are the basis of this account.

Rain began to fall about midnight on 2-3 October and continued with varying intensity throughout the field observation period, bringing a series of flood peaks and turbid water to the main river, input streams and springs, with the exception of Coppermine Cave and Bubbling Spring. The last remained clear at the actual points of emergence around and in its pool but, as

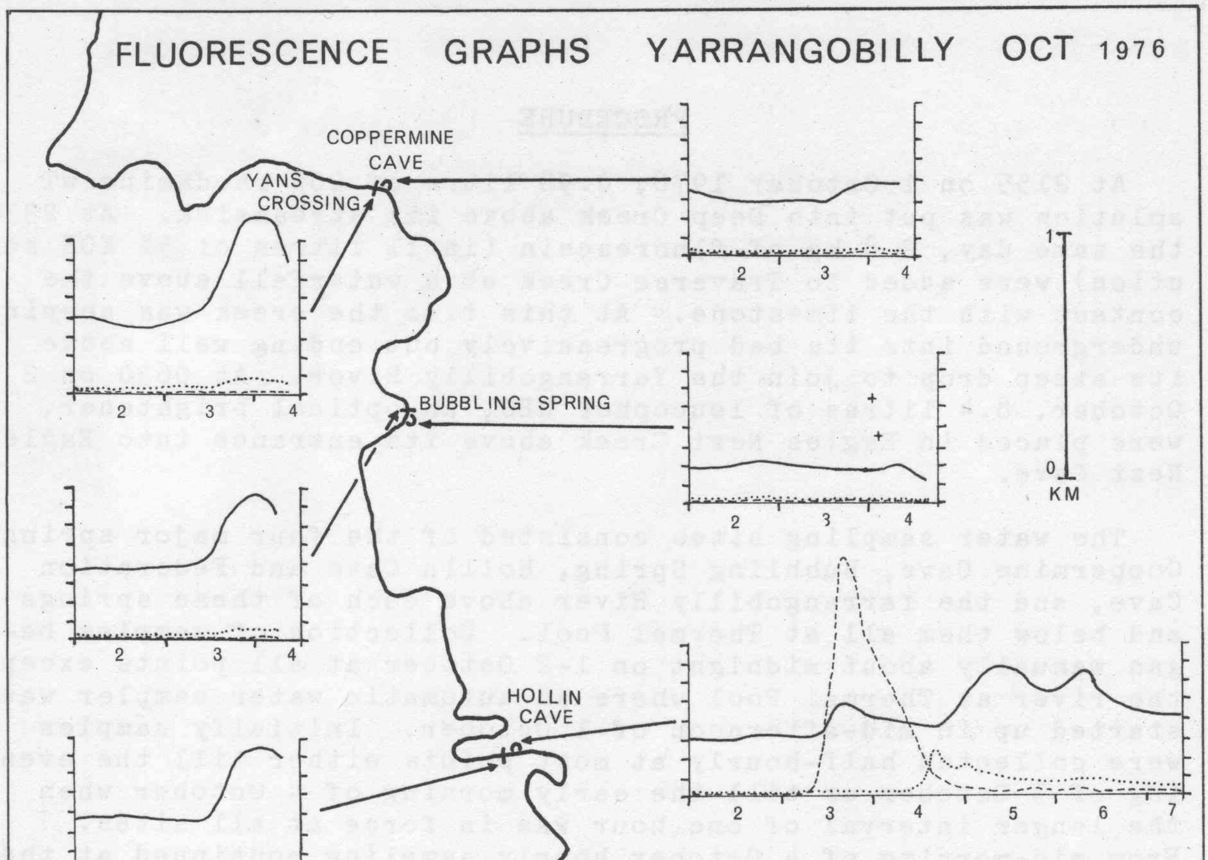

FLUORESCENCE GRAPHS YARRANGOBILLY OCT 1976
COPPERMINE CAVE
YANS CROSSING
BUBBLING SPRING
HOLLIN CAVE
FEDERATION CAVE
THERMAL POOL
KM
Fluorometer units
Wave band
Green
Blue
Orange
Days

Fig 3

Table 1 Fluorescent dye wavelengths and fluorometer filters

Tracer	Waveband colour	Maximum excitation (nanometres)	Maximum emission (nanometres)	Primary filters (range in nanometres)	Secondary filters (range on Fig. 6)
Leucophor HBS 20% solution	Blue	355	440	Corning 7-37 (300-380)	Wratten 98
Fluorescein	Green	490	520	Wratten 2A + 47B (360-500)	Wratten 2A + 12
Rhodamine WT	Orange	555	580	Corning 7-60	Corning 3-66 + 4-97

the river rose, it flooded varying proportions of the Bubbling Spring pool with turbid water. During the morning of 3 October the increased runoff carried Traverse Creek into the river.

Hydrographs for Deep Creek and Hollin Cave were available from the automatic stage recorders maintained there. Figure 2 shows the discharge of Hollin Cave over the period of tracer observation, the daily rainfalls at Yarrangobilly Caves Ranger Station and a pluviograph record from Cooleman Plain some 20 km away. Small peaks of discharge at 1450 on 3/10 (A), and 1520 on 4/10 (B), and larger ones at 0630 on 5/10 (C), and over the period from 1800 on 5/10 to 0400 on 6/10 (D) probably relate to rains on 0000-0630 on 3/10 (a), 0300-1200 on 4/10 (b), 1500 on 4/10 to 0100 on 5/10 (c) and 1500-2200 on 5/10 (d).

Results

Figure 3 presents smoothed curves for the fluorescence determined in three filter bands in fluorometer units, and Table 2 sets out the first significant rise in each band.

There is a remarkable similarity between the five river stations shown on the left in Figure 3. After a period of relatively constant background values running into the middle of 3 October, there follows a sharp rise in the green wave-

Table 2 Times* of First Significant Rise in Fluorescence

Site	Orange	Blue	Green
Yarrangobilly River at Yan's Crossing	3/10:0930-1400	3/10:1030-1230	3/10:0930-1400
Yarrangobilly River above Bubbling Spring	3/10:1430-2200	3/10:1300-1430	3/10:1300-1700
Yarrangobilly River above Hollin Cave	3/10:1430-1730	3/10:1230-1630	3/10:1330-1730
Yarrangobilly River above Federation Cave	3/10:1200-1400	3/10:1300-1500	3/10:1300-1500
Yarrangobilly River at Thermal Pool	3/10:1000-1200	3/10:1500-1700	3/10:1600-1800
Coppermine Cave	Nil	3/10:1300-1700	3/10:1600-1700
Bubbling Spring	Nil	Nil**	Nil**
Hollin Cave	3/10:0630-0830	4/10:0750-0950	3/10:1300-1500
Federation Cave	4/10:1100-1900	3/10:1200-1600	3/10:1600-1800

* Some of these timings could have been sharpened up since samples at close intervals were available. However after an initial selection of samples had been determined, the fluorometer gave trouble and stopped work.

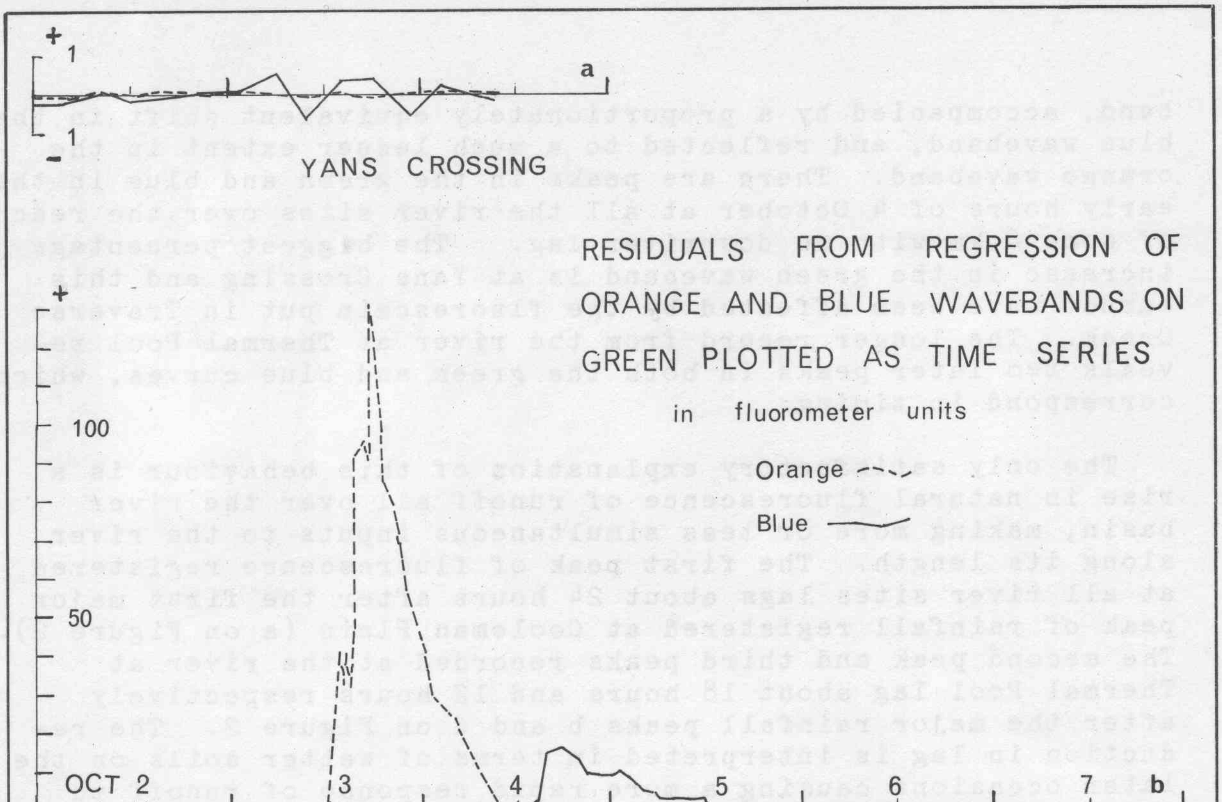
** Two samples at 0100 and 0200 on 4/10 had extraneously high values for the green and blue wavebands. This is attributed to failure to collect spring water uncontaminated by river water flooding into the spring pool at this time in the night.

band, accompanied by a proportionately equivalent shift in the blue waveband, and reflected to a much lesser extent in the orange waveband. There are peaks in the green and blue in the early hours of 4 October at all the river sites over the reach of some 6 km with no downriver lag. The biggest percentage increase in the green waveband is at Yans Crossing and this cannot have been affected by the fluorescein put in Traverse Creek. The longer record from the river at Thermal Pool reveals two later peaks in both the green and blue curves, which correspond in timing.

The only satisfactory explanation of this behaviour is a rise in natural fluorescence of runoff all over the river basin, making more or less simultaneous inputs to the river along its length. The first peak of fluorescence registered at all river sites lags about 24 hours after the first major peak of rainfall registered at Cooleman Plain (a on Figure 2). The second peak and third peaks recorded at the river at Thermal Pool lag about 18 hours and 12 hours respectively after the major rainfall peaks b and d on Figure 2. The reduction in lag is interpreted in terms of wetter soils on the later occasions causing a more rapid response of runoff to rain. The lesser rainfall c on Figure 2 may be expressed by the hump on the falling curve of the second green fluorescence peak.

The springs behaved more individually as might be expected. Bubbling Spring showed no significant change in any of the wavebands. Two successive samples taken in the middle of the night of 3-4 October with high green values are completely aberrant in the sequence of values and are interpreted as due to accidental inclusion in the samples collected of river water which was by this time contaminated by the flood. The lack of turbidity in the spring water is attributed to a long transit time for this spring and runoff due to the heavy rains did not reach this spring in the observation period and so affect the fluorescence. Coppermine Cave reveals modest rises in green and blue beginning in the early afternoon of 3 October, unaccompanied by any visible increase in turbidity. This is thought to be due to little runoff water entering and passing through the system during the observation period.

Federation and Hollin Caves springs became turbid and behaved like the river in some respects as regards fluorescence but not in others. Hollin Cave has its initial constant background values disturbed by a big rise in orange fluorescence beginning earlier and reaching a high peak some 5-6 hours earlier than the first peak along the river. It is accompanied by a small peak in the green waveband but with very little



YANS CROSSING
a
RESIDUALS FROM REGRESSION OF ORANGE AND BLUE WAVEBANDS ON GREEN PLOTTED AS TIME SERIES
in fluorometer units
Orange
Blue
+
1
1
-
+
100
50
OCT 2
3
4
5
6
7
b
50
-
HOLLIN CAVE
+
2
1
1
2
3
-
c
THERMAL POOL

Fig 4

change in the blue. After this peak, the orange fluorescence falls practically back to its original level but remains slightly higher to the end. This orange peak with an asymmetry much more marked than the green peaks of the river is interpreted as a rhodamine dye pulse with its peak lagging 43½ hours and its onset 33 hours behind the time of insertion of the dye. The parallel but small change in the green waveband could be due to a response in that waveband to the strong fluorescence of the rhodamine dye (cf. Smart and Laidlaw, 1977). The green curve has two larger peaks after the orange has fallen to low values. It is difficult to see in the green curve at Hollin Cave anything which is not due to changing background fluorescence or to interference from rhodamine. In contrast with its behaviour elsewhere, the blue curve has its first and main peak coinciding with a trough in the green curve and after the rhodamine pulse has nearly passed. This is therefore regarded as a dye pulse and the lag of the peak after insertion is 58½ hours. This greater lag of the leucophor pulse in passing through Eagles Nest Cave than that of rhodamine through Deep Creek Cave is in reverse of previously recorded transit times for these two systems (Pavey 1975). A secondary peak on the falling limb of the blue curve corresponds with the rising limb of the first major green curve peak and it is uncertain whether this is due to dye or to rising background fluorescence. A third very modest blue peak corresponds with the second major green peak here and so it is best interpreted as due to background change.

Federation Cave registered only a small response with no clear peaks in the green and blue wavebands at the time of the first peaks along the river. Again this may be due to little surface runoff being incorporated in the cave stream at this time as with Coppermine Cave. There followed a substantial peak early on 5 October in the fluorescence in the green part of the spectrum. This is accompanied by higher blue values. There is nothing in this behaviour which points to dye pulses rather than changes in background fluorescence as with the river.

Smart and Laidlaw (1977) suggest the use of regression analysis to distinguish between dye pulses and background fluctuations. Regressions of fluorometer readings of orange and blue on green wavebands at Yans Crossing are highly significant with 99.9% confidence. Figure 4a plots these residuals as a time series. These residuals are very small and oscillate about zero in an erratic way. This supports the interpretation already presented that the results at Yans Crossing are entirely measures of fluctuation of natural fluorescence. Figure 4b is a similar plot for Hollin Cave, but

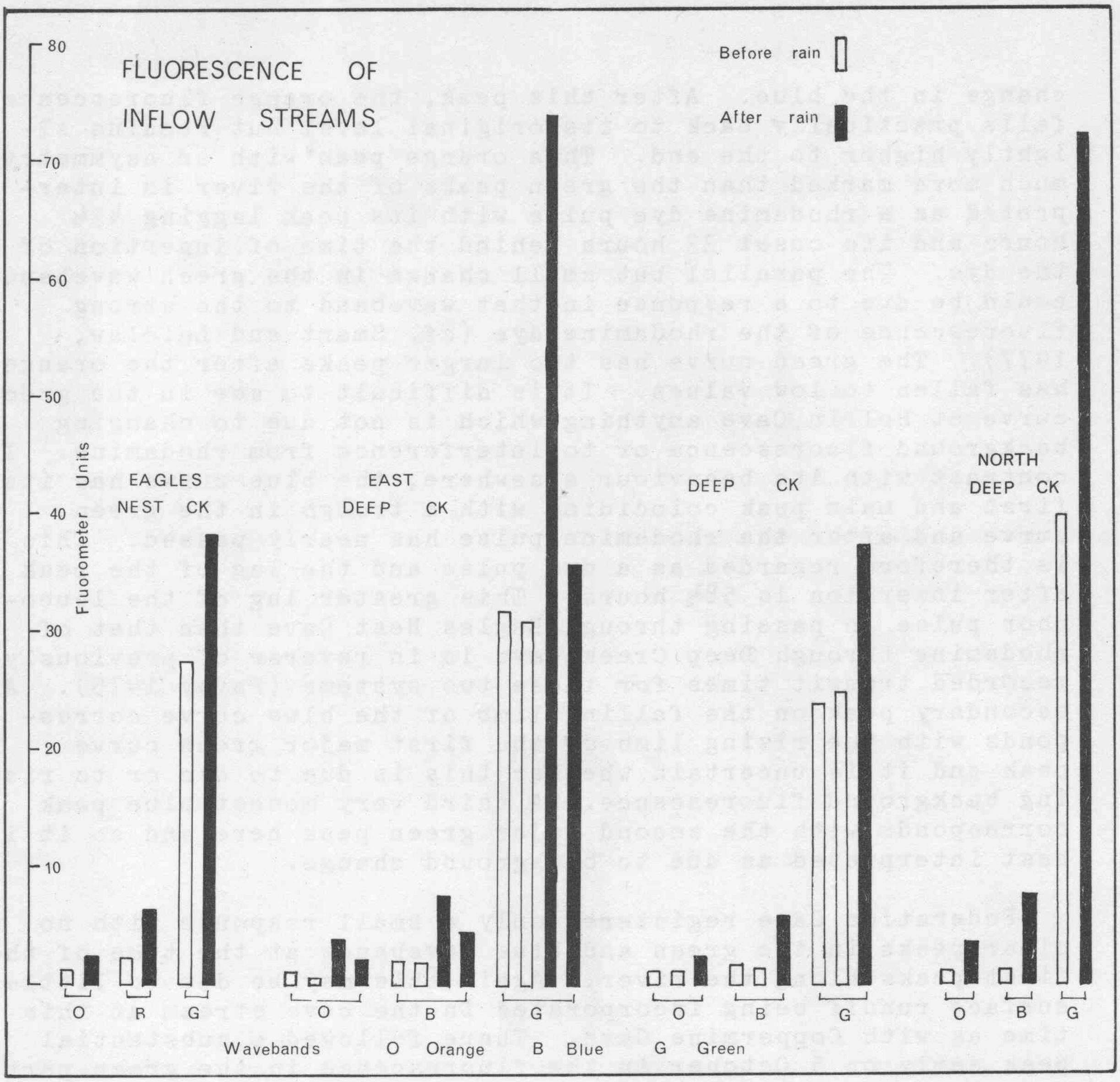

FLUORESCENCE OF
INFLOW STREAMS
Before rain
After rain
Fluorometer Units
80
70
60
50
40
30
20
10
EAGLES
NEST CK
EAST
DEEP CK
DEEP CK
NORTH
DEEP CK
O
R
G
O
B
G
O
B
G
O
B
G
Wavebands
O Orange
B Blue
G Green

Fig. 5

with the ordinate scale much compressed. In this case, neither regression is significant. With both blue and orange bands, periods of small residuals are interrupted by asymmetric peaks of positive residuals; these peaks are the dye pulses. An additional feature of interest is the reciprocal nature of the negative residuals of the orange waveband during the peak of the blue fluorescence; this is too marked to be coincidental. It must be the result of interference at the green waveband by the leucophor dye pulse. This rise in green fluorescence above background levels causes the natural orange fluorescence to register negative residuals.

Figure 4c, a plot of residuals for the Yarrangobilly River at Thermal Pool on the same ordinate scale as Figure 4a, was constructed to see whether any dye pulses might remain discernible despite tremendous dilution in the flooding river. The blue regression on green is highly significant at the 99.9% level but the orange one is not significant. The residuals are larger than at Yans Crossing, though they remain small compared with those for Hollin Cave. The striking feature is the similarity of the main orange peak of Hollin Cave and of the river at Thermal Pool, with a lag of 2-3 hours by the latter. The peak of positive residuals of the orange band at Thermal Pool is in advance of the first absolute peak of the green fluorescence at this site and it is taken to represent the passage of the rhodamine dye pulse here. The blue residuals at Thermal Pool have a complex pattern which cannot be interpreted.

The identification of dye pulses at Hollin Cave finds support from the results obtained by setting out detectors at the sampling points (with the exception of the river at Thermal Pool). Strips of unbleached calico prepared with antimony tartrate in tannic acid (Leitch 1962) for rhodamine detection did not change colour at any of the stations except Hollin Cave (though the one in the river above Federation Cave was washed away in the flood). Unbrightened cotton wool detectors for leucophor gave positive results at Hollin Cave and the river above Federation Cave. These findings confirm the conclusion drawn from the fluorometer analyses of the water samples about the destination of these dyes.

To test the explanation of most of the changing fluorescences by background variation, the samples collected for chemical analysis were brought to bear. Figure 5 represents the fluorometer results from a selection of these. The congruence of the results from the four inflow streams - North Deep Creek, Deep Creek, East Deep Creek and Eagles Nest Creek - offsets the small number of samples. All four creeks show higher values in all three wavebands after the rains than before (Figure 5). Treating the measurements from the four creeks for each waveband as separate data sets, the values before and after the rains started are significantly different by Mann-Whitney U-tests. Moreover in fluorometer units the mean values for the different wavebands have the same relative magnitudes as in the river and the springs, green being the greatest followed by blue with orange least. It is clear that these streams are behaving in fundamentally the same way as the river and yet these cannot possibly have been affected by the introduction of the tracers.

The fluorescence load curve for Hollin Cave for the orange waveband has been plotted on Figure 2. It has the one pulse only with a peak at 1800 on 3 October; this is 3 hours later than the first small discharge peak on the hydrograph (Figure 2). This substantial independence of the load curve from the discharge curve further supports the argument made earlier from the concentration curve that this is truly a rhodamine dye pulse. However the area under the curve represents 270 grams of rhodamine WT which is 40% greater than the amount of dye used. This discrepancy can only be attributed in small part to some rise in natural orange fluorescence associated with the small discharge peak with which the dye pulse is in part confused. This dye budget, combined with the absence of any rhodamine peak at other sampling springs, suggests that all of this tracer went to Hollin Cave and that at these stages at least Deep Creek is a simple feeder of that cave.

A similar plot for the blue fluorescence load has two pronounced peaks with overlapping bases; the second of these corresponds in part with the final and greatest discharge peak at Hollin Cave. It does not seem feasible to make an effective separation of the dye pulse from variation of background origin. No green fluorescence peak has been interpreted as a dye pulse. Therefore budgets are not presented for these two wavebands.

FURTHER ANALYSIS AND DISCUSSION

In their review of natural fluorescence in relation to underground water tracing, Smart and Laidlaw (1977, Table 6) give results from monitoring of karst resurgences in the Mendip Hills and agricultural catchments in the Cotswolds which illustrate greater fluorescence in the relevant wavebands with storm discharges. The blue and green fluorescences vary much more than the orange. The Yarrangobilly triple dye tracing experiment reported here extends this information by providing a case where the changes in fluorescence associated with storm discharge were sufficiently large to confuse an underground water tracing attempt. Here also the leucophor and fluorescein wavebands were much more affected than that for rhodamine WT.

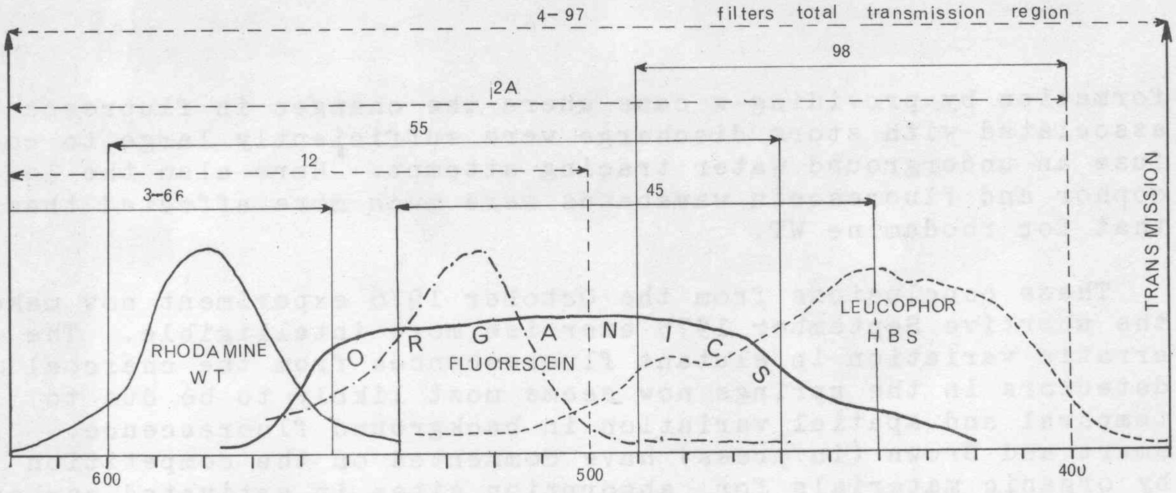
These conclusions from the October 1976 experiment now make the abortive September 1975 exercise more intelligible. The erratic variation in elutant fluorescences from the charcoal detectors in the springs now seems most likely to be due to temporal and spatial variation in background fluorescence. Smart and Brown (in press) have commented on the competition by organic materials for absorption sites in activated carbon.

Smart and Laidlaw (1977) include data showing that dissolved and colloidal organic matter frequently contains fluorescent structures with emission maxima at wavelengths from 420 to 520 nanometres and that total organic carbon concentration has a linear relationship with fluorescence between 400 and 600 nanometres. Organic matter is therefore the likely source of the background fluorescence at Yarrangobilly. Probably both overland flow and throughflow contributed this organic matter as well as inorganic sediment to streams and the rise of fluorescence due to organics far outweighed the effects of suspended sediment. Even the percolation water through the limestone may have suffered the same effect through more rapid rates of infiltration after the rains.

Table 3 Total organic carbon (TOC) of inflow streams

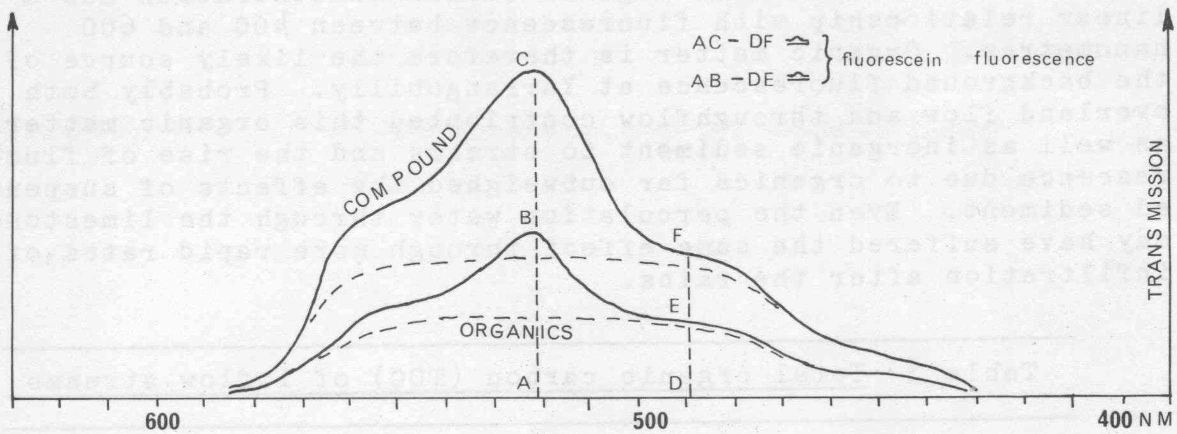
Stream	TOC before rains		TOC after rains	
	Date	Mg/l	Date	Mg/l
Eagles Nest Creek	2/10	12.0	5/10	15.0
Deep Creek	1/10	12.2	4/10	17.6
East Deep Creek	2/10	12.2	4/10	15.0
North Deep Creek	2/10	12.4	6/10	15.0

Therefore some of the water samples from Yarrangobilly were analysed for total organic matter with a Beckman Model 915 Total Organic Carbon Analyser, though this unfortunately was done after they had been stored for some time. There



4- 97 filters total transmission region
98
2A
55
12
3-66
45
RHODAMINE
WT
O R G A N I C S
FLUORESCEIN
LEUCOPHOR
HBS
TRANSMISSION
600
500
400
WAVELENGTH IN NANOMETRES

Fig 6



AC - DF
AB - DE
fluorescein fluorescence
C
B
F
E
A
D
COMPOUND
ORGANICS
TRANSMISSION
600
500
400 NM

Fig 7

were anomalies in the results from samples from the Yarrangobilly River and the springs as a result of contamination by the organic dyes. Those from the inflow streams were not affected in this way and Table 3 shows the total organic carbon contents from them in two sets collected before and after rain. From the significant increase in organic carbon from the one set to the other, it may safely be inferred that organic materials are the source of the accompanying increases in background fluorescence.

Smart and Laidlaw (1977) also consider that the similarity of fluorescence spectra between background fluorescence and the dyestuff fluorescences renders distinction between them by spectral analysis difficult. However Drew (1968) reports successful use of a spectrophotometer to distinguish between pyranine conc. and background fluorescence. To examine the range of organic interference at Yarrangobilly, the fluorescence of a number of samples from inflow streams was measured with an Aminco-Bowman monochromatic spectrophotometer. No absorption spectrum could be obtained as the concentrations of the organic material were too low and any laboratory procedure to concentrate the organics present might have changed their properties. Therefore the fluorescence emission spectrum was measured at 5 nm intervals and transmitted radiation of wavelength below 510 nm was found to give a broad flat emission band between 420 and 560 nm (Figure 6). Drew (1968) reports wavelengths of background between 359 and 420 nm whereas Smart and Laidlaw (1977) found that organic material from the Cotswolds had an emission range of 420-520 nm. It seems likely therefore that organic material from different sources has varying fluorescent properties. The tall open eucalyptus forest at Yarrangobilly is a very different vegetative cover from those of the areas studied by the authors mentioned above. It is clear that in any test where high background fluorescence is found, the range of the fluorescence emission spectrum of the interfering material should be measured in order to examine the extent of that interference.

Figure 6 shows the fluorescent emission bands of the three dyes used and the overlap with that obtained from the inflow waters at Yarrangobilly uncontaminated by tracers but containing organic materials. It illustrates the same kind of situation which made Feuerstein and Selleck (1963), finding similar high background fluorescence levels in estuarine waters, advise against "the use of fluorescein as a quantitative fluorescent tracer in all but waters of the highest quality". This comment may be too stringent as the success of a water trace using fluorescent dye in high background conditions depends on the sensitivity of the fluorometer used.

From Table 1 which sets out the transmission ranges of the primary filters employed, it is evident that, when the filter to make leucophor HBS fluoresce is used, fluorescein and rhodamine WT will also be excited. The lower wavelength radiation will cause any dyes with a higher wavelength for maximum absorption to fluoresce though they will not give maximum fluorescence. The use of a filter transparent above 530 nm will only cause rhodamine WT to fluoresce and interference from the other two dyes and from organic material such as was found at Yarrangobilly would be eliminated. A Wratten 16 filter appears ideal for this purpose. The range of the source lamp needs checking before use in this way.

The overlap of tracer results caused by the primary filters can be eliminated by careful selection of secondary filters. The secondary filters for rhodamine WT (Corning 3-66 + 4-97) and for leucophor HBS (Wratten 98) are sufficiently specific for fluorescein not to interfere with the other two dyes. But with these filters both rhodamine WT and leucophor HBS are subject to interference by dissolved organic material.

The two filters used in combination for fluorescein detection - Wratten 2A + 12 - give a range of transmission that will allow the fluorometer to record, along with the desired fluorescein, any concentration of rhodamine WT present and most of the organic fluorescence. The alternative Wratten 55 (Smart and Smith 1976) is less effective still. In triple dye tests where the dyes pass through the system as distinct units over time, the problem of this overlap will not arise. However if the dyes are likely to appear together, an alternative filter combination for fluorescein would be that of Wratten 12 + 45. Unfortunately this has only a 9% transmission at 520 nm. Other possible solutions of the problem are the use of interference filters (Smart and Laidlaw 1977) or of a specially filtered mercury source.

Both of the problems encountered at Yarrangobilly - dye interference and background interference - can be resolved by the use of a more sophisticated spectrofluorometer than the Turner filter fluorometer such as the Aminco-Bowman. With such an instrument the tracer dyes can then be excited at their maximum absorption wavelength increasing the sensitivity of the test for rhodamine WT and their intensity measured specifically at their emission maxima. This would enable complete separation of the three dyes used. The problem of floods increasing background fluorescences and nullifying the result for fluorescein can be dealt with in the following way. The range and shape of the organic peak must be monitored through the flood peak and if they remain uniform, the intensity of the background emission measured on the broad top of the organic peak but clear of the fluorescein peak can be subtracted from that of the apparent fluorescein (i.e. compound) peak measured at the fluorescein maximum wavelength of 520 nm (Figure 7). In this way a corrected peak value is obtained.

Nevertheless it is certainly advisable to carry out dye tests when steady weather seems likely to be experienced in the observation period, rather than to salvage results by the use of more sophisticated equipment and more laborious analyses. However, as long as numbers of helpers are needed, the incidence of holidays governs the choice of time for such experiments, and such salvages may be necessary. Despite the diseconomy of single dye tests in terms of time and effort, the greater effectiveness of a series of tracing tests employing the dye least affected by background change, i.e. rhodamine WT, suggests reliance on this approach at Yarrangobilly. On this basis each streamsink likely to feed Hollin Cave would be investigated separately and quantitatively with this dye. Spore tracing can usefully be brought in to explore patterns of discharge qualitatively as a preliminary to such quantitative attacks. In particular this could be useful at flood stage when dye methods are most likely to encounter difficulties because of changing background fluorescence, especially if the pattern remains the same at flood stage as at lower stages. However this is not always the case with karst drainage (Smith and Atkinson, in press).

The findings of this triple dye test have bearings on the use of detectors ('fluotransducers', Andre and Molinari 1976!!). Charcoal detectors for fluorescein have occasioned some disfavour because of negative results which can arise from adsorption of non-fluorescent organics that deactivate the charcoal (Smart and Smith 1976). But now there is the indication that spurious positive results may occur if the transit time is at all prolonged with the increased chance of periods of increased background fluorescence due to floods, and the adsorption of fluorescence by the charcoal. However the findings of this experiment suggest that this stricture does not apply to the detectors for the other two dyes.

The overall conclusion is that the objective of quantified delimitation of the Hollin Cave catchment remains achievable but only by the use of more laborious approaches or more sophisticated techniques.

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PROTECTING ROPES FROM ABRASION IN SINGLE ROPE TECHNIQUES

NEIL R. MONTGOMERY

Abstract

The risk of abrasion of rope used for abseiling and prusiking on a pitch depends on the nature of the pitch, the characteristics of rub points on it and the technique of the caving party. This paper attempts to isolate these factors and discuss methods by which a rope can be protected from them.

INTRODUCTION

To many, total reliance on one rope is the most frightening aspect of abseiling and prusiking, and not without good reason. The most commonly used ropes (Nylon and Terylene) are sufficiently strong for these single rope techniques, but they are also soft and easily abraded. A caver, bouncing during an abseil or prusik, faces some danger from rope abrasion at every point where the rope rubs against the rock. Rub points with significant abrasion risk must be recognised and safeguarded against, if the rope and the caver are to last very long.

There are a number of characteristics of rub points, pitches and caving techniques which contribute to abrasion risk. These are discussed individually below. The impact of each characteristic will vary from situation to situation and the order of discussion is unimportant.

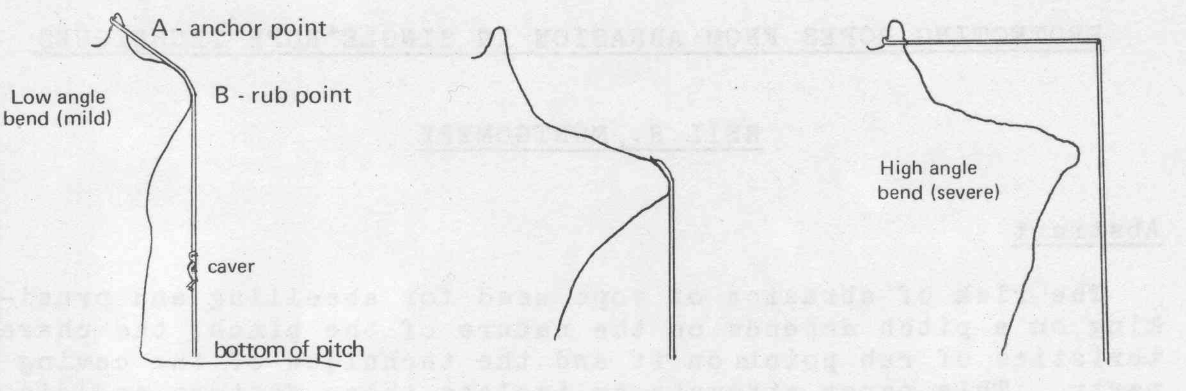
IMPORTANT FACTORS IN ABSEILING RISK

Type of rock

To determine abrasion risk at a rub point it is important to examine the roughness of the rock surface, the grain of the rock, its hardness, and whether it contains chert or quartz mineral veins.

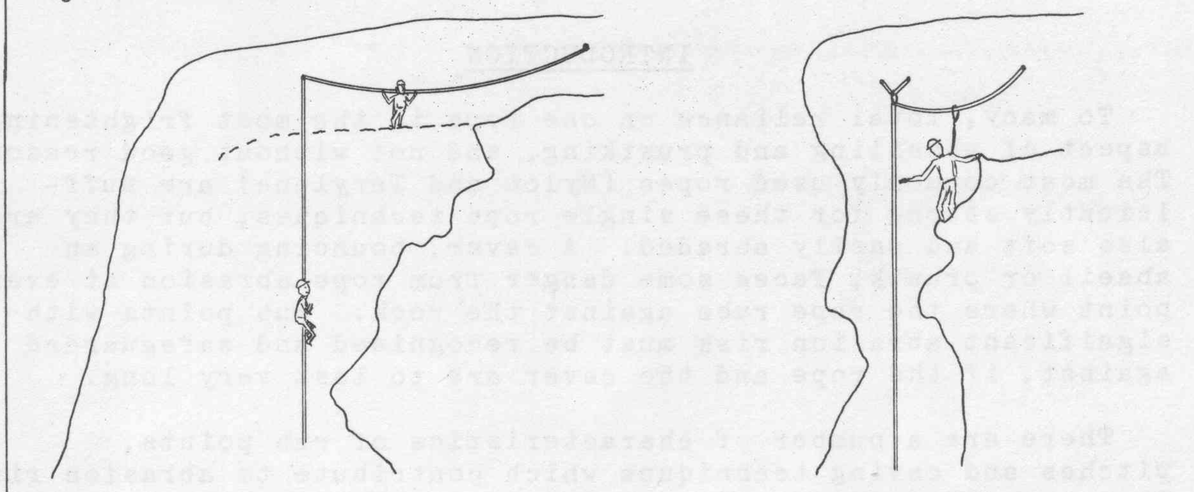
Rough, coarse grained, hard rock with mineral veins (eg some marble) is the most abrasive type, while smooth, fine grained, soft rock with no veins (some chalk) is probably the least dangerous. Most rock types encountered in caves will lie between these extremes.

Fig 1 - The position of the rub point, and rigging for protection



(a) Poor (b) Better (c) Good

Fig 2 - Use of traverse lines



(a) Dynamic rope may be needed for long traverse.

(b) Use of the safety clip on a short traverse

Fig 3

(a) Breaking up a pitch (b) Redirecting in a narrow shaft (c) Reaching below rub point

Shape of the Rubpoint

In general, a sharp lip poses more of a risk than a rounded bulge, but care is required if a rounded bulge has a small irregularity which is only obvious on close inspection.

A jerk in a rope under load lying across a sharp lip can immediately sever the rope.

The Bend in the Rope

The situation where the rope forms a sharp angle over a lip is more dangerous than that where it just touches (Figure 1a & c) The abrupt edge at the top of many pitches is a very dangerous point. The smaller the radius of the bend the greater will be the abrasion risk.

Length of the Pitch

The amount of abrasion caused by any rub point will be greater and the effect more serious on long pitches. On a short pitch (10 m or under) the abrasion risk is rarely great, although care is still required. On pitches longer than about 25 m abrasion risk must be seriously considered.

The Position of the Rub Point on the Pitch

Bounce in the rope occurs during abseiling and prusiking because of non-uniform forces exerted by the person on the rope. In Figure 1a the caver is causing bounce and there is a possibility of abrasion at B. The amplitude (or length) of bounce at B becomes greater as distance AB increases, and abrasion risk is highly dependent of this amplitude. Limited testing by Eavis (1974) in the case of sharp rope bending at the rub point, led him to the conclusion that abrasion risk increases with amplitude of bounce and therefore with distance AB.

The author's experience supports Eavis' conclusion when AB is between 1.5 m and 12 m. If AB is less than about 1.5 m then rope bounce at B is slight and there is little danger as long as there are no very sharp edges. Beyond 1.5 m abrasion risk begins to present problems and over 3 m it is a serious consideration, particularly where stretchy ropes are being used.

The picture when AB is more than 12 m is unclear since few cases of serious abrasion have occurred in this range. Several factors may contribute to this:

(a) rub points cluster near the tops of pitches. This is because many pitches start with a sloping face which becomes vertical or overhanging lower down.

(b) where rub points do occur at depth they usually only involve a glancing rub.

(c) as AB increases on a pitch, B becomes closer to the bottom. The nearer B is to the bottom the less the rope is endangered, because the caver's movements can abrade the rope at point B only while below it. Abrasion risk is nearly always negligible in the last 5 m or so of a pitch.

However, should a rough rub point be encountered at some distance from both the top and bottom of a pitch, until further research is done Eavis' tests demand that it be treated with the utmost care.

The Number of Rub Points on a Pitch

A rub point nearly always poses less risk if there are a number of rub points below it. The friction caused by the rubbing at a rub point reduces the amplitude of rope bounce above this point and hence the abrasion risk, so that if the rope is rigged against a wall where there are many rub points all but the worst can be ignored. The most dangerous situation arises where a rub point has a long free hang below it.

Rub Points on Wet Pitches

There is a strong possibility that where a rub point is actually in a stream, the action of the water alone may cause abrasion by swirling the rope back and forth across the rub point. Testing by Eavis (1974) shows this to be much more likely with Nylon than Terylene rope.

Type of Rope

Eavis (1974) examined a selection of ropes commonly used in caving and showed that they vary in abrasion resistance. No attempt will be made here to discuss the merits of the various brands; all rope requires careful protection from abrasion. Several general comments can be made however.

(a) In general Nylon or Terylene fibres are more suitable for caving use than any others.

(b) Low stretch is an advantage because it reduces rope bounce. (Eavis 1974).

(c) Tightly sheathed ropes are more abrasion resistant than loosely sheathed ropes.

(d) Eavis (1974) discovered that Nylon ropes have a significantly reduced abrasion resistance when wet (1/4 to 1/3 of dry value) but Terylene ropes are little affected.

(e) Abrasion is substantially dependent on the rope diameter. The most suitable diameter appears to be 11-12 mm for pitches over about 25 m. If the diameter is any larger most mechanical ascenders will jam and the rope becomes heavy on long pitches. Below this diameter the margin of safety is much reduced: thin ropes will be abraded much more quickly than thick ones because they are more stretchy and each individual fibre is under more tension. Also there are fewer fibres which have to be broken before the rope will fail. A rope abrades slowly at first but as more of the finer fibres are cut the tension in the remainder grows and they will break sooner. A rope which has been abraded until half its fibres are cut is liable to extremely rapid failure.

Ropes of 9-10 mm diameter should only be used on short (less than 25 m) pitches, or free hanging pitches where abrasion need not be considered.

<u>Amount of Use</u>

Abrasion will be dependent on the number of times the rope on a pitch is climbed. Thus a large party faces greater risk from abrasion than a small one.

<u>Abseil-Prusik Technique</u>

Abseiling and prusiking techniques can cause bouncing on the rope and the larger this bounce the more abrasion there will be, so it is important to develop technique to minimise bounce. A steady descent rather than a jerky one and a regular smooth rhythm during ascent can do much to reduce bounce. Jerky motion should be avoided at all times, as should using the bounce of the rope to gain upward lift. This only increases the tension in the rope, making it more easily cut. (Patten 1968)

TWO APPROACHES TO ROPE PROTECTION: RIGGING FOR PROTECTION AND PADDING

There is no easy way of recognising rub points which need protection. The factors discussed above should be borne in mind when making the decision but there is still a large element of experience involved. Even very experienced cavers have misjudged the effects of a rub point so it is wise to err on the side of safety. There is also an element of personal responsibility, for aversion to risk varies from person to person, as does care in the use of equipment.

A caver has two choices when confronted with a lip or bulge which could cause abrasion. On the one hand the rope can be rigged to avoid the protrusion or at least make it harmless; on the other a pad can be put on the rope or the rock to reduce the abrasion. The pad can be either a mat of tough material which covers the protrusion or one that fits over the rope for the length of rope which is at risk.

Rigging for protection of the rope is neater and safer as there is always the chance that a pad could come off the rope or rock. However rigging can take a great deal of time and effort and could put the party at further hazard by requiring complicated or risky manoeuvres so that in many instances pad placement is simpler. In any situation a number of possible alternatives will be available and only experience can help decide which technique will be used.

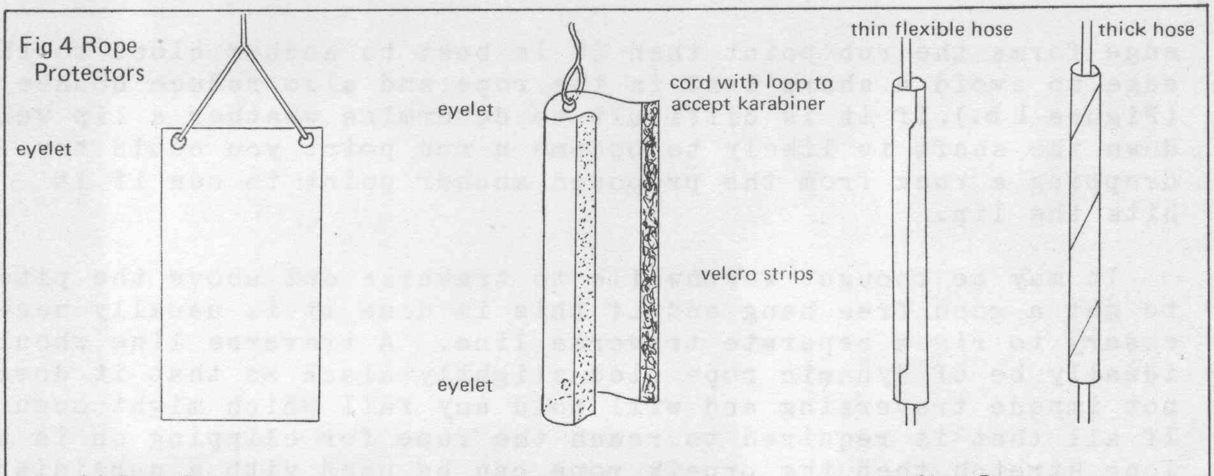
RIGGING FOR PROTECTION

Choosing Anchor Points

On any pitch it is possible to pick an anchor point (or combination of several) either natural or artificial which minimises abrasion risk. The ideal anchor will give a free hang with convenient access for getting on or off the rope. It will also be clear of hazards such as loose rock and waterfalls. Sometimes a little inventiveness is called for as in the example shown in Figure 1 c. Here a free hang has been found by using two anchors and spreading the force from the rope in such a way that large forces will not be generated in the tieoff lines. To do this it is only necessary to ensure that the angle between the two tieoff lines is less than about 120°. If it is greater than 120° the tieoff lines will be loaded in excess of body weight.

If it is not possible to rig the pitch as a free hang then, as is clear from the earlier discussion of abrasion risk, the nearest to a free hang is not necessarily the best alternative. Two rub points close to the rope anchor would often pose less risk than one rub point 10 m below it. If the shaft

Fig 4 Rope Protectors



(a) Rope Pad (b) Jerry Protector (c) Hose Protectors

Fig 5

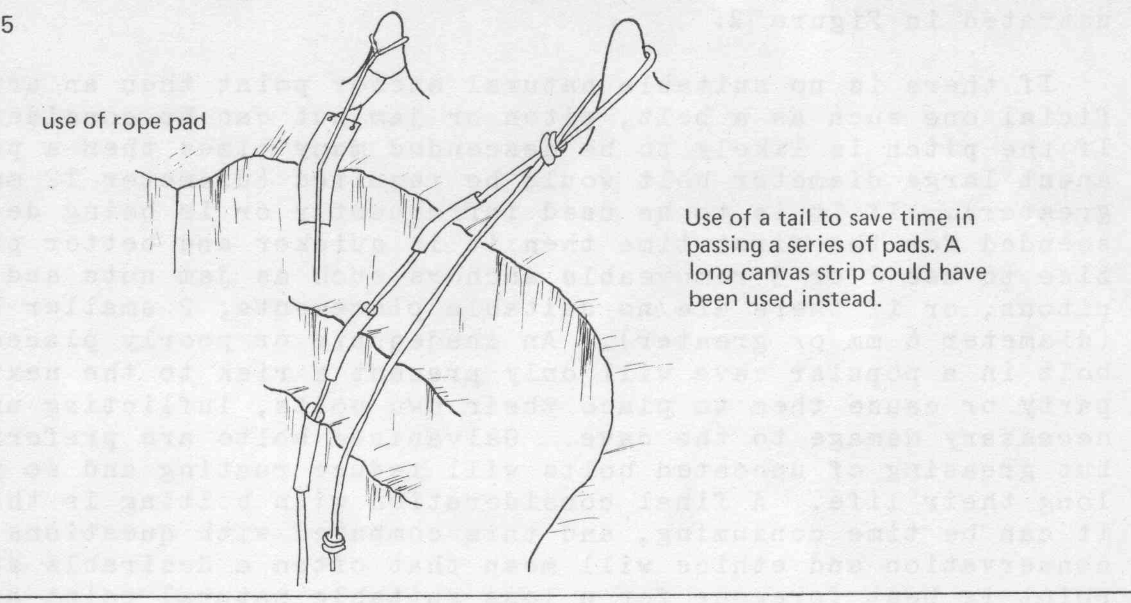
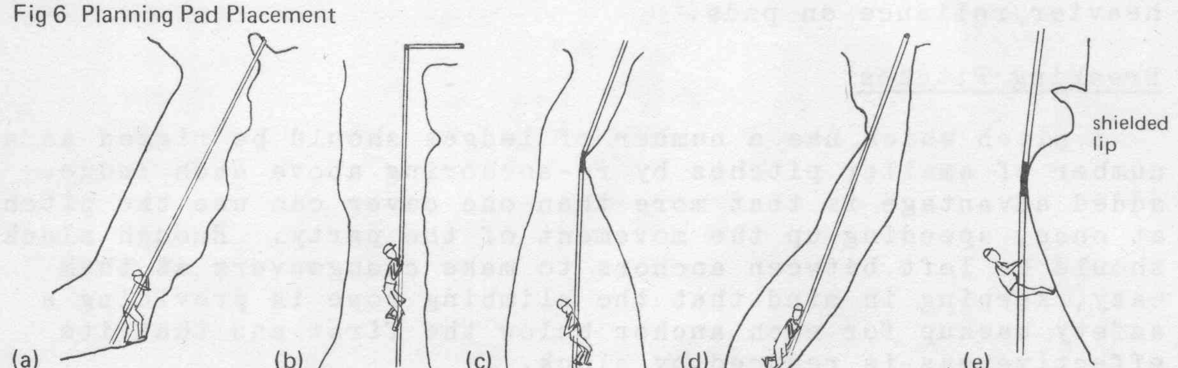


Fig 6 Planning Pad Placement



(a) & (b) Concave and vertical walls - no pads except perhaps on top edge.

(c) Convex wall - padding required

(d) Concave wall with rub point on opposite side.

(e) The shielded lip.

edge forms the rub point then it is best to anchor close to the edge to avoid a sharp bend in the rope and also reduce bounce (Figure 1 b.). If it is difficult to determine whether a lip well down the shaft is likely to become a rub point you could try dropping a rock from the proposed anchor point to see if it hits the lip.

It may be thought worthwhile to traverse out above the pitch to get a good free hang and if this is done it is usually necessary to rig a separate traverse line. A traverse line should ideally be of dynamic rope tied slightly slack so that it does not impede traversing and will hold any fall which might occur. If all that is required to reach the rope for clipping on is a long stretch then the prusik rope can be used with a subsidiary tie back well away from the lip. These arrangements are illustrated in Figure 2.

If there is no suitable natural anchor point then an artificial one such as a bolt, piton or jam nut can be considered. If the pitch is likely to be descended many times then a permanent large diameter bolt would be required (diameter 12 mm or greater). If it is to be used infrequently or is being descended for the first time then it is quicker and better practice to use 2 or 3 removeable anchors such as jam nuts and pitons, or if there are no suitable placements, 2 smaller bolts (diameter 6 mm or greater). An inadequate or poorly placed bolt in a popular cave will only present a risk to the next party or cause them to place their own bolts, inflicting unnecessary damage to the cave. Galvanised bolts are preferred but greasing of uncoated bolts will reduce rusting and so prolong their life. A final consideration with bolting is that it can be time consuming, and this compared with questions of conservation and ethics will mean that often a desirable anchor point is best foregone for a less suitable natural point and a heavier reliance on pads.

Breaking Pitches

A pitch which has a number of ledges should be rigged as a number of smaller pitches by re-anchoring above each ledge. An added advantage is that more than one caver can use the pitch at once, speeding up the movement of the party. Enough slack should be left between anchors to make changeovers at them easy, keeping in mind that the climbing rope is providing a safety backup for each anchor below the first and that its effectiveness is reduced by slack.

Rub Points on the Pitch Face

Even with the most careful attention to the placement of the primary anchor it is still possible to come upon serious rub points on the rock face well down the pitch. Rigging for protection is usually superior to padding in this situation, especially if the rope is subject to a side-ways or vertical force which could move the pad away from its protective position. There are two approaches to this problem:

(a) redirecting the rope at the rub point.

This is not often possible but it is a very effective technique where it can be used. An anchor is chosen near the rub point so that a sling attached between the anchor and the rope directs the rope away from the rub point. The anchor can be chosen either on the opposite side of a narrow shaft (Figure 3 b) or to the side of the rub point in a large shaft or on a wall. To pass the redirecting sling and carabiner it is necessary to release the tension on the sling and unclip the carabiner from the rope; move down and then reclip the carabiner. If the deflection is very large it can involve considerable effort but for a small deflection it is an easy task.

(b) reanchoring below the rub point.

An anchor must be chosen at, or just below the rub point (Figure 3 c). If there is more than one rub point at the problem spot then the new anchor must be chosen below the lowest rub point. When reanchoring, a metre or so of slack should be allowed to enable easy passing of the anchor. Practice in passing these obstacles must be obtained before using the method underground. Reanchoring has the added advantage of enabling two or more people to climb the shaft simultaneously.

PADDING

There are two classes of rope pads; mats which cover the rub points and leave the rope free and protectors which fit onto the rope on the endangered section.

Mats

The mats are strips of material which may be tied in place with cords (Figure 4 a). Mats should be about 0.5 m wide to allow for side-ways movement of the rope. It is advisable to have a range of lengths upwards of 0.5 m. These mats are most useful for shaft lips where they can be easily attached to the rope anchor or even to the rope itself (Figure 5.). Used in this position they will cause no hindrance to the party. In contrast protectors need to be removed and replaced each time a caver passes them.

If the rub point to be covered is some distance down the pitch then the mat can be tied off to a suitable anchor or, failing that, onto the rope itself. A problem with this usage is that rope movements during an ascent or descent can either flip the rope off the mat so that the rope rubs elsewhere or turn the mat over so that the rope runs underneath it, directly on the rock. Smith (1974) recommends fixing cords to the sides of the mat so that it may be tied around the rope but this system suffers the disadvantage that each member of the party must untie and retie these cords as he passes. This is time consuming and often awkward. If there is a likelihood that the rope will work off the mat it is better to protect the rope itself with a "protector" as described in the next section.

The mat itself rarely suffers much wear because it is stationary against the rock so a light material like canvas is quite adequate. Heavier materials such as carpet have been used but they are bulky and rarely necessary. To allow for the range of conditions likely to be encountered in a cave it is sensible to have a range of materials available.

Light canvas is adequate for minor rub points, heavier canvas for serious rub points and occasionally carpet for rare cases such as a long free drop. Tackle bags used for transporting ropes in caves make quite effective mats for pitch lips and are in an appropriate position for their normal use when it comes to detackling the cave.

Protectors

(a) Jerry protectors were developed by Jerry Atkinson and Julia James and are generally the best pads for handling rub points below a pitch top. They are made from strips of tough canvas about 12 cm wide and up to 60 cm long fastened into a cylinder with Velcro strip. Longer lengths are awkward to handle and rub points requiring such lengths can be covered by tying two or more protectors together. The construction and use of these pads is shown in Figure 4b,5. It is important to have the Velcro the full length of the protector and not to skimp by using short Velcro tabs or by substituting press studs. Heavy duty Velcro is necessary. The added security and ease of use is worth the small extra expense.

The Velcro fastening is durable and will not become muddied, provided that the pads are carried through the cave mated. The pads can easily be carried while on a pitch by slipping them to a carabiner on the waist harness.

To pass a Jerry Protector the Velcro is unmated by running a thumb up it. Usually the knot is untied as well but is can be passed when prusiking by then removing the ascenders from the rope. This is useful if there is concern for retaining the protector's position accurately. However the whole protector has to be removed when abseiling.

(b) Hose protectors are lengths of plastic hose with a lengthwise slit. They are cheaper than the Jerry Protectors and can be as effective on mild rub points. Lengths of 40-60 cm are best, fitted with cords to tie them to the rope and enable them to be carried on a carabiner when not in use.

Various hose thicknesses can be used (Figure 4 c). The most popular has been thin wall (about 2 mm) hose of an internal diameter to fit snugly on the rope. The hose has a slit lengthwise with a half spiral at each end to stop the hose working itself off the rope. When fitting the hose to the rope the hose is twisted in the direction of the half spiral to secure it. The slit should always be positioned so that it faces away from the rub point. Spiralling along the whole length of the thin hose should be avoided as it reduces holding power.

Thicker hose (wall thickness about 4 mm) is usually stiffer and harder to handle but can be more secure. The most flexible variety is chosen and even so it may be necessary to split the hose in a spiral for its whole length to improve flexibility. The internal diameter can be chosen to give a snug fit or to be looser on the rope.

The major problem with hose protectors is that the rope can work its way out, esnecially on rub points where there is a sharp bending angle. The hose flattens out at the bend and then flips over, forcing the rope out of the slit and onto the rub point. Hose also has an inherent curve from its initial storage on a reel and this increases the risk of rope loss. This problem is worse in long hose protectors and in stiffer thick walled types. One solution (as yet untried) may be to immerse the hose in hot water and hold it straight during cooling.

Too Many Pads?

The more pads that are fitted on each pitch the slower will be the party ascending or descending the pitch. The practical limit is three pads spaced fairly close together.

Particularly on heavily used pitches it is essential to find an alternative arrangement to save time and effort. It may be possible to use a long canvas or carpet mat but it would be better to rig for protection.

Another possibility if the rub points are near the top of a pitch is to rig a short rope alongside the heavily padded rope (Figure 5). Cavers can then use the tail (as the short rope is called) and transfer onto the main rope below the rub point. The first caver to descend should determine the protection necessary for the safe return of the party. The second last caver to descend should make note of all possible rub points and communicate with the last one down so that all points are covered and the last man does not use protectors on minor rub points near the top which should be used on serious rub points lower down.

In the case where the whole pitch is visible from the top, the first caver fixes any abseil protection while the last one fixes all additional prusik protection. Any abseil protection will definitely be needed for the prusik as well.

When the time comes to ascend the pitch the first one up should carry extra pads in case a serious rub point has been missed during descent. It may even be necessary to rerig the pitch if serious abrasion has occurred during the first ascent. If the rope has been abraded during the ascent it may be necessary to rerig the rope so that the abraded section is higher or lower than the rub point and then to abseil down and protect the rope.

If a troublesome rub point is located at or near a ledge it can be a wise precaution for the first or second caver up the pitch to stop on the ledge and watch the protector while the rest of the party ascend the pitch.

Planning Pad Placement

Planning pad placement by looking at the whole pitch can save effort. If the pitch is concave or vertical then the cavers body will hold the rope away from any possible rub points during the ascent (Fig. 6a,b). In this situation the only protector needed might be one on the top lip. If the pitch is convex then a protector will almost always be necessary at the major rub points. If the pitch is too concave then the rope may find a rub point on the opposite side of the shaft (Figure 6d). This type of rub point is often difficult to predict as it only becomes obvious after the caver has passed it on the descent. Cooperation between party members in watching for these rub points while others are on the pitch is essential.

It is possible that a rub point will be shielded by a larger, lower one (Figure 6e). Here it is only necessary to protect against the lower rub point.

If it is uncertain whether a particular ledge or knob will become a rub point it is advisable to flatten the body against the wall and watch where the rope lies. If a ledge can be seen to become a rub point when the caver is well below it then he should prusik back up and protect the rope.

The tail should have a knot in its end so that someone cannot inadvertently abseil off into space. The tail does not need padding itself due to its short length.

Safety Limits to the Use of Pads

A pad will be ineffective if it is placed or replaced at the incorrect position. The lower on the pitch that the rub point is encountered the harder it is to judge the correct positioning of the pad. The problem is accentuated not only by the cavers weight on the rope (causing stretch) but also by sideways and vertical movements of the rope. The severity of the rub point determines how much care must be taken in such positions.

If the rub point is not severe, incorrect initial placement can be corrected by the next member of the party but if it is a severe rub point one descent or ascent could be sufficient to sever the rope, and rigging for protection is far safer than padding. Experience and common sense are the best guides. These situations generally only arise on pitches longer than 50 m and here greater care is needed in all aspects of technique.

Different Padding Needs for Abseiling and Prusiking

Most abrasion occurs while prusiking due to the cyclic loading of the rope. An experienced caver is able to descend a rope by abseiling at a steady rate and can cause virtually no bounce in the rope. It is easier to pass a pad when prusiking than it is when abseiling and this should be borne in mind when protecting the pitch.

Protection for Abseiling

Protection for abseiling should only be necessary when inexperienced cavers or large numbers of cavers are likely to use the rope, when sharp rub points are encountered, when there is grit or mud near the pitch top, or on long pitches. Under normal conditions only a pad at the lip of the pitch is necessary and it should be a canvas or carpet mat type.

Protection for Prusiking

Protection to serve for the return trip is usually placed on the descent. The actual procedure depends on the pitch.

If it is not possible to see the whole length of the pitch and its nature or length is not known then the first caver to descend must place sufficient protection to enable a return should the rope not reach the bottom or a convenient ledge or if some other hazard is encountered. If all is well then the second caver to descend can remove any protection not needed for the descent and the last caver can fix all additional protection.

Conclusions

Protecting ropes from abrasion is one of the most important safety procedures in the use of single rope techniques in caves. Planning ahead and careful observation are both necessary in assessing the possible risk of abrasion presented by any rock surface on a pitch. Deciding which technique of protection for the rope is required in any particular circumstance is a matter for experience. Time spent in carefully and safely rigging and protecting a pitch will be rewarded with faster and safer ascents and less damage to expensive equipment.

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PALYNOLOGY AND HISTORICAL ECOLOGY OF SOME CAVE EXCAVATIONS IN THE AUSTRALIAN NULLARBOR. By H.A. Martin. Aust. J. Bot., 21, 1973: 283-316.

Apart from its main purpose, this paper also provides the best account of the vegetation of the Nullarbor Plain yet available in terms of three communities succeeding one another from the semi-arid coast to the arid interior - mallee scrub, arid scrub and shrub steppe. Pollen from this vegetation has been blown into the cave mouths and cave shelters to accumulate along with inorganic dust and rock fall. Desiccation has fortunately preserved the pollen despite an alkaline and oxidising environment. Surface samples from such deposits in caves from the dry interior to moister coastlands show that the dominant pollen of Myrtaceae (probably mainly mallee eucalypt) and of chenopod type (probably mainly saltbush and bluebush) vary with the rainfall gradient, the former increasing towards the coast and the latter decreasing in accordance with the nature of the present vegetation.

The pollen from archaeological excavations in N145 cave shelter near Eucla, Madura (N62) Cave and Norina Cave also near Madura show variation with depth in the deposits, particularly in the Myrtaceae/chenopod (M/C) ratio. At the N145 cave shelter, now in the mallee belt, shrub steppe must have prevailed from 28000 to about 10000 B.P. to give the low M/C pollen ratios found in horizons of this age. Then M/C ratios rose so that by about 5000 years ago vegetation had improved to its present condition and remained so. The N62 Cave record starts at 10000 and Madura Cave at 7000 B.P. Both show rising M/C ratios till 5000 B.P. in agreement with N145 but then show falling ratios. The author attributes the latter happening to increased burning of the bush in association with greatly increased Aboriginal population in this time for which there is archaeological evidence.

The climate change from earlier drier conditions to modern moister conditions can be explained solely in terms of low sea levels of glacial times giving these sites a more continental climate formerly. - J.N. Jennings

END OF VOLUME 14