

MULU CAVES 2022



An Anglo-Malaysian Expedition to the
Gunung Mulu National Park, Sarawak



REPORT
on the findings of the
MULU CAVES 2022
Mulu Caves Project Expedition
to the
GUNUNG MULU
NATIONAL PARK
SARAWAK

This 30th expedition in the series took place during
October to December 2022

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the **MULU** Caves
Project



Bats flying from Deer Cave
Photo: Chris Howes

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I. INTRODUCTION

Andy Eavis

NEARLY thirty Anglo-Malaysian speleological expeditions have taken place to the Gunung Mulu National Park. These expeditions have established Mulu as one of the greatest caving regions in the world, with many of the largest caves in the world particularly by volume.

The 2022 expedition was delayed for two years due to the covid pandemic; it should have taken place in 2020, but it was postponed until 2021 and finally took place at the end of 2022. It was always planned to be a big trip with several different major objectives:

1. Continuing the exploration of many different areas of the southern end of the park.
2. Laser scanning some of the passages in Clearwater Cave.
3. Continuing resurveying the original early expedition discoveries, which were only recorded on paper with no original coordinate information.
3. Initiating an ambitious scientific programme, particularly looking at post-active fluid cave development.
4. Trying to make some of the elusive connections between Clearwater Cave and some of the other nearby caves.

Twenty-eight western cavers came out in five groups. The first seven arrived in Mulu on Monday 31st October, with the following groups arriving on 7th November and 14th November. People started going home on Tuesday 15th November, so there was only one day when the whole expedition was together; there was a party.

In addition to the western members, predominantly from Britain but also three from America and two from Norway, there were two Malaysian cavers and a host of local cavers and expedition helpers.

A large number of cavers in the field at the same time had always seemed like an advantage when tackling the distant objectives where, if an underground rescue arose, a lot of manpower would be required. Thankfully, this was not a problem.

As you will see from the following report, all of these objectives were accomplished – some more successfully than others – and overall the expedition can be considered as very successful and, as ever, leads to more questions.

Many more Mulu Caves Project expeditions will be required to continue this work. Above all else the expedition functioned well and worked within a modest budget, and I think it could be said that a good time was had by all.



The party held on the one day that the whole team was present. *Photo: Chris Howes*

A Personal History of Mulu Exploration: the Eighties

Colin Boothroyd

OUR wondrous editor delicately asked me to write the section in this report on the history of exploration in Mulu. I grunted and delicately tiptoed backwards. And then our esteemed leader waded in. Apparently I was the perfect writer as I had a deep background set within the caves of Mulu and I also had a unique writing style. I guffawed and gently fell off my chair.

Two days later his slightly pre-browned nose was pressed against the phone again. He said he was desperate and that he was relying on me, only me, to fill this last piece of the report writing jigsaw. He said he would be forever indebted to me. I couldn't bear the thought of him pathetically dribbling on. I said OK.

And then immediately regretted it.

The History of Exploration in Mulu has been written comprehensively in every past expedition report. All that happens is that texts are slightly modified and the results of the last expedition is summarised at the end. In total there are 7 or more pages of chronicled text with maps and references that perfectly take the reader on a whistle stop tour of the Mulu cave exploration history. I could see no merit in rewriting it (it would certainly become less accurate and less readable). So I was stuck.

But then, eureka!, I got a crayon out and scribbled in 'A personal' in front of history of exploration in Mulu. And then as an afterthought added 'in the eighties'

So, here goes.



Colin Boothroyd. Photo: Chris Howes

Mulu '80

MY milk teeth were just emerging through my gums when Ben Lyon and Andy Eavis pounced on me back in 1980. They were looking for someone small, young and impressionable to join them on their second jolly to the caves of Mulu. Apparently, my experience crawling through the tightest caves in Yorkshire proved I had the skillset needed in Mulu. God knows why.

So, a few months later, I found myself with Tony White in the heart of a sandfly and leech feeding frenzy, lost in the forest some near the northern tip of Gunong Buda. Andy had seen 'a feature' from a helicopter and Tony and I had been selected to climb over the back of the mountain to see if it was interesting. It wasn't. And I got a bad case of Mulu foot. So, I was grumpy. And it was all Andy's fault. So there.

We spent almost a month looking for caves in Gunong Buda. We bumbled and fumbled in some marginal caves before we were allowed to venture south. From our camp near the Terikan resurgence we found and explored the aptly named labyrinth – Blue Moonlight Bay Cave.

I then made one of my first attempts at dying (there have been many others since then). I contracted Leptospirosis. It was a little gift that the rats in our camp had left me in their urine. I was completely knocked out, had a very high temperature and was unable to swallow or move from my hammock. Antibiotics eventually helped bring me back to a normal state. I was lucky.

Then it was down to Melinau Gorge, gazing at and lusting over women for the first time in over a month, seeing the sun and sharing a beer.

Across the Gorge and we were climbing upwards in Tiger Foot Cave where we broke out in to Benerat Caverns. This was more like it. A large tunnel heading north deep inside Gunong Benerat. I settled into my first night in an underground camp only to be rudely woken by a barking dog. Barking Dog Bivi site got its name from the echoey sound when a drop of water landed on a flake of rock. Pits were descended and climbs climbed. My first big exploration with more leads left unexplored than those explored. Brilliant.

But we were getting drawn to Gunong Api. Other team members were discovering really large passages and we want to eat some cake.

So we headed down to the base camp in Long Pala (where the Marriot Hotel now sits) to meet others, learn of new discoveries and the death of John Lennon. And, as it was Christmas, we learnt to dance properly as directed by our new Penan and Berawan friends, drink far too many spirits and fail to convince our hosts that we had already had just the right amount of the delightful borak.

Clearwater was revealing many new secrets: Ronnie's Delight and The Secret Garden both showed that the cave was offering a lot more than just large tunnels. But it was the surprising discovery of Sarawak Chamber in Lubang Nasib Bagus that really opened our eyes to the enormity of the passages and potential for world beating caves.

We discovered just over 50 kilometres of cave passage on the 1980 expedition over a period of three and a half months. We needed to do better.

Sarawak '84

WITH Andy and Ben at the helm again we were back. Ben's group at Camp Five and Andy's group down in Long Pala with Gunong Api in their backyard. I was in Ben's group.

The climb at the northern end of Benerat Caverns led directly to an impassable choke. The large, wide open passage named Homeward Bound didn't live up to its name. The climb to the enticing Tiger Cave was overcome courtesy of a back door – Lower Tiger Cave.

But a ramble along the lower flanks of Gunong Benerat did bear one succulent fruit. Cobweb Cave, named after the now long gone profusion of cobwebs across the entrance, lived up to its name in other ways. The passages kept on winding around themselves and then splitting. One passage was appropriately named The Bypass. And then another was named The Bypass Bypass. We struggled to understand the complex, cobweb like, nature of the entwined passages. And we struggled to come up with sensible names.

Meanwhile the Api team were making great headway. Drunken Forest, Cobra and Lagang's Caves were all added to the new cave list and Clearwater Three was discovered together with an entrance into the system from the Melinau Paku.

Another 54 kilometres of passage had been surveyed. More than any other expedition before and since.



Limestone and rainforest. Photo: Chris Howes

I next returned in 1989. This time Matt Kirby was at the helm. The big mega expeditions had had their day. No more helicopter reconnaissance or Himalayan logistics and leadership. Everything was smaller. And simpler. The whole team were huddled under a camp sheet adjacent to the Melinau river for 5 weeks.

A trek through the forest and into Snake Track and on to Scumring before we started the assault on Ronnies Delight and everything that lay beyond. Or so we thought. Tim Fogg had noticed a large 'stare you in the face' passage directly opposite our wonderful campsite. The next morning we were in Armistice (it was 11 November) and we were off. The Snow Slopes, The Y Frontier, The Cairn Farm, The Big U-ee and the discovery of Clearwater Five were the main rewards from that expedition.

So that was the 1980s for me. Part of me looks back at those trips and thinks they were the hay days. The days of easy pickings and more virgin cave than you could wave a stick at. But that would be nostalgia muscling to the front. In fact it's not like that. The expeditions now are even more rewarding. We have to work harder to make the breakthroughs. But that's what makes them better – the harder the effort, the greater the reward. I love Mulu.

And now the boring bit. An overview of recent discoveries.

There were two expeditions in 2019. Within Southern Api teams visited the Dune Series and East Passage and discovered the Scientific Method and The China Shop. Although they didn't breakthrough into the sought after holy grail – a big passage heading east through the beds – the discoveries nonetheless pointed towards the possibilities.

A sump pool in Cave of the Winds and another in Racer Cave proved to be incredibly close as a beam of light could be seen pass through the water between the two caves.

Extensions in Lagang's Cave and Easter Cave brought the two caves even closer together, but as yet no connection has been made.

The 2019 expedition based at Camp Five was focussed on Whiterock and the Racer Series in Blackrock. Rewards were hard earned but led to the discovery of Shimmering Showers, Clickbait and Cheesemauler.

In 2020 an expedition to Benerat re-examined many leads in Cobweb, Moon Cave and Blue Moonlight Bay. Although there were not many great breakthroughs there were many promising leads to explore further and a return trip is planned in 2024.

A History of Exploration in Mulu

Expedition members

THE existence of large caves in the Gunung Mulu area of Northern Sarawak has been documented for over 150 years. In 1858 reference was made to Detached masses of limestone, much water-worn, with caverns and natural tunnels around the base of Mulu by Spenser St. John in his book *Life in the Forests of the Far East*. St. John was Consul General in the Great Island of Borneo and made some of the earliest exploratory journeys of any European into the interior of Sarawak. His attempts to reach the summit of Mulu were thwarted by limestone cliffs, dense forest and sharp pinnacles of rock and he says, It is almost impossible to conceive the difficulty of ascending this mountain. Mulu was to keep the secrets of its summit for a further 74 years until Edward Shackleton successfully climbed the mountain during the Oxford University Expedition of 1932.

In 1961 G.E. Wilford of the Malaysian Geological Survey visited the area to explore its caves.

His work included the surveying of Deer Cave and parts of Cave of the Winds. He predicted that Mulu would yield many more caves in the future. During 1977-8 the Royal Geographical Society Mulu Expedition spent 15 months in the area studying many aspects of the rainforest. This was the largest scientific expedition ever to leave the UK. Included in the team were six speleologists who, in three months, explored and surveyed 50kms. of cave passages including parts of Clearwater Cave, Green Cave and others.

During the expedition a forest camp was established in Hidden Valley from where two major caves were explored. Wonder Cave on the north side of the valley was found to have some of the largest passages in Mulu. Prediction Cave on the south side also contained enormous passages which were almost filled with river sediments.

It was obvious from these findings that Mulu ranked as one of the world's foremost caving regions. As a result of the RGS expedition two large-scale caving expeditions were mounted in the early 80s. The Mulu 80 expedition explored and surveyed a further 50km of cave passages, including the largest underground cavity, in the world, Sarawak Chamber, which forms the final chamber of Lubang Nasib Bagus or Good Luck Cave. The end of this chamber lies very close to the end of Prediction Cave in Hidden Valley and tantalising draughts at the end of each cave suggested a connection.

In 1984, the Sarawak 84 expedition spent one month in the field and explored 54km of caves.

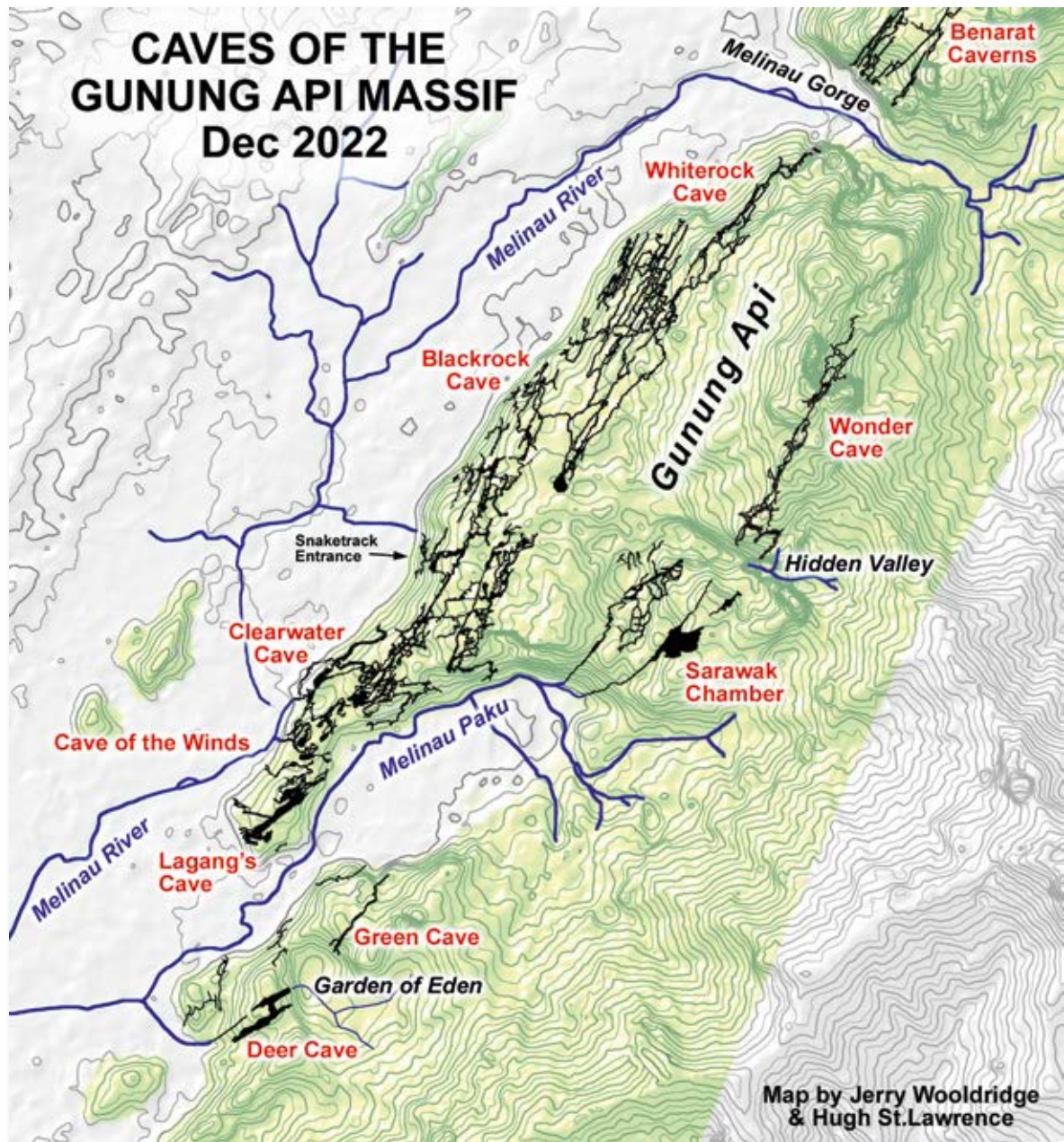
Clearwater Cave was extended by 14km but a great deal of work was carried out in Benarat, where Cobweb Cave was discovered, adding a further 15km of passages to the Benarat total. Sarawak Chamber was also photographed for the first time. These two expeditions carried out a great deal of scientific research associated with the caves, including dye-tracing, geology, geomorphology, ecology, cave mineralogy, etc. However, although 150km of some of the largest caves in the world had been surveyed, some very significant areas of limestone remained totally unexplored, presenting enormous potential for further exploration.

During late 1987 and early '88 plans were made to mount another caving expedition to the area. This would be the first expedition to visit the park since its opening to the public in 1985 and was primarily aimed at exploration, surveying and photography. Unlike the previous expeditions this was to be a lightweight venture with only six team members. The Mulu Caves 88, expedition once again proved the potential of Mulu with a further 16km of passages explored. It was also shown that exploration in Mulu using a small team was both feasible and successful. The major discovery of this expedition was Blackrock Cave lying to the north of Clearwater and almost certainly part of the same system.

As a direct result of this discovery, an eight strong group, including five of the 1988 team, returned to the Park exactly one year later as the Mulu Caves 89 expedition. Once again a lightweight venture proved to be successful, with over 24km of passages explored and surveyed in only one month. Major extensions were found in Clearwater Cave, totalling 15km, and the gap between it and Blackrock Cave was brought to within 90m. The Clearwater 5 streamway was discovered and explored for over 1km.

A new cave, provisionally named Simon's Cave, but later named Racer Cave, was discovered and explored and water tracing experiments proved a hydrological link from the Melinau Gorge through Blackrock and into Clearwater Cave. The discoveries made by these two expeditions had greatly altered the map of Gunung Api's caves.

During 1990 another British team visited the Park and continued the exploration of Racer Cave. The Clearwater 5 streamway was explored to an upstream sump. Although a sump bypass was found to lead into Clearwater 6, rain caused the bypass to sump which prevented further exploration. A physical link was established between Drunken Forest Cave and Alexandra Palace in Clearwater. During February 1991 a Korean Team visited the Park. Some minor discoveries were made. Unfortunately these findings were not published.



In 1991 a group of nine explorers, five of whom were from the '88 and '89 expeditions, returned to the Park to continue exploration in the Blackrock/Clearwater area. A connecting passage was discovered which linked the two caves. This discovery made the Clearwater System the seventh longest cave in the world at over 102km. This was the Mulu Caves 91 expedition. A vast amount of work had, by this time, been carried out on the western flanks of Gunung Api and although discoveries were by no means exhausted it was becoming increasingly difficult to find major objectives which would justify another expedition to that side of the mountain. The remaining significant lead, the Clearwater 6 Streamway, was weather dependent and, therefore, could not be relied on as a sole objective.

Attention now focused on the more challenging eastern flank of Gunung Api with Hidden Valley as the first objective. This area was less accessible than the west as there were no major rivers which could be used for transport of stores and equipment. Tentative enquiries were made in 1990 to see whether it would be possible to visit the Valley during the '91 expedition. A positive response was received and this became one of the secondary aims of that expedition. Unfortunately, this was not achieved as other discoveries closer to park headquarters took priority. Instead, part of the '91 team returned approximately one year later in January 1993 as the Hidden Valley 93 reconnaissance expedition with the sole objective of carrying out a lightweight reconnaissance of Hidden Valley. The reconnaissance expedition proved a success with potential for further discoveries to be made in the two known caves

within the valley and a new cave discovered in the dolines to the west. Other entrances were noted for further investigation and surface reconnaissance suggested even greater potential further south in the deeper Third Doline, which was not entered.

With the Hidden Valley reconnaissance expedition indicating potential for further discoveries in Hidden Valley a full exploratory expedition, Mulu Caves '96, was mounted and returned to the Park in October 1996. A base camp was established within the Hidden Valley gorge between the entrances of Prediction and Wonder Caves. Although very little was found within the main gorge exciting discoveries were made in the dolines to the southwest. Arch Cave was explored in the second doline. Prediction and Bridge Caves were found within the third doline and the fourth doline revealed Cloud Cave which matched Deer Cave in scale. During the last few days of the expedition a descending boulder ramp was followed which led into the far reaches of Cobra Cave. This established a through-route to the Melinau Paku valley.

During 1997 an American expedition, which was exploring Gunung Buda, carried out surface searching on the northern slopes of Benarat. This led to the discovery of Deliverance Cave on the north-east corner of the mountain. 3.5km of passages were explored which were heading in the general direction of Cobweb Cave.

With the success of the '96 expedition a second Hidden Valley expedition, Mulu Caves 98, was mounted which returned to the Park in February 1998. As the centre of exploration was to be in the dolines it was known that this would not be best served by a camp within the Hidden Valley gorge. Not only would a camp in Hidden Valley be remote from the caves, it would also be almost impossible to supply without helicopter backup, which would be very expensive and could not be relied upon. With this in mind, a gamble was taken on being able to reach the Fourth Doline from the Melinau Paku valley via a route, over the surface, which had never been explored. It was thought that the route through the caves would be used only as a back up; however, the severity of the climb up from Nasib Bagus, together with the surface terrain, proved to be far more difficult than the underground route via Cobra Cave, which soon became the main thoroughfare.

This expedition proved a great success with further extensions in Perseverance Cave and a connection established between Cloud and Bridge Caves establishing the Cobra Cloud Bridge system at 16.1km with a vertical range of 459m, the greatest vertical range of any cave in the Park at that time.

Owing to the El Nino year, river levels were exceptionally low so a further attempt was made to explore beyond the Clearwater 5 upstream sump into Clearwater 6. This led to another sump which was bypassed into Clearwater 7 and the inevitable upstream sump which was not passable. Hidden Valley would then not be visited by an expedition for seventeen years. Another American expedition visited Buda in 2000



The boardwalk to Deer Cave. *Photo: Chris Howes*

and carried out further work in Deliverance Cave, bringing its total length to 4.3km. With exploration in Api now without any significant leads the attention of the British team was drawn to Gunung Benarat. It had been sixteen years since a British expedition had visited the mountain, during the Sarawak 84 expedition. The Benarat 2000 expedition continued the exploration of Cobweb Cave, where a further 10.7km of passages were explored bringing the total length of the cave to 25.9km.

As a follow up to the 2000 expedition, the Benarat 2003 expedition returned to the Park. A further 4.4km were explored in Cobweb Cave, but the significant discovery of the expedition was made in Terikan Rising Cave where 12.5km of passages were explored. Included in the team were two Api veterans who were to use the expedition, based at Camp 5, as an opportunity to prospect the northern slopes of Api between the Melinau Gorge and Blackrocks Racer entrance. This revealed a significant entrance 2.8km south west of Camp 5. The cave was named Whiterock and within the remaining three days of the expedition it had revealed 3.7km of new passages. Owing to its proximity to Blackrock, it was thought that it would soon connect and might be of little significance.

During 2005, the Benarat 2005 expedition, based at Camp 5, continued the exploration of Whiterock, which exceeded all expectations when a further 17.2km of passages were discovered, mostly lying above Blackrock. Two connections were made between the two caves, which linked Whiterock into the Clearwater System.

On the Benarat side of the gorge an attempt to climb up to an entrance high in the cliffs opposite Camp 5 was cut short when a small entrance was discovered only 60m above the ground. This cave was named Moon Cave and was explored for 6.6km in an almost straight line into the mountain. A connection was also established with Benarat Caverns making the total length of this system 16.4km. Included in the expedition were two divers who investigated the sumps in the Terikan system. This proved connections between the individual elements of the system to make a total length of 32.5km.

The total length of caves surveyed in Benarat was now 90.4km and in Api was 172.6km. During January and February of 2007 the Mulu Caves '07 expedition continued the exploration of Whiterock and Moon Caves. Significant discoveries were made in the northern section of Whiterock, where two major passages were discovered, both of which came to within 400m of Camp 5 with no apparent entrances/exits found. These two passages, the Northern Line and the 1954 Series, ran northwards in parallel with 60m of vertical separation. A great deal of in-filling was carried out, with new passages providing short cuts between previously discovered trunk routes. This reduced considerably the travel times to the northern reaches of the system. These discoveries extended the known cave to 42.9km. A major success of the expedition was the connection of Moon and Cobweb caves via an unexplored passage in Moon Cave. This connection linked Benarat Caverns, Moon Cave and Cobweb Cave to produce the Benarat Caverns System, which ranks as the second longest system in the Park at 50.7km. In the Melinau Gorge, considerable surface survey work was carried out to tie together all the known caves on the Api side of the river and link these back to the datum at Camp 5. This allowed them to be linked into the Survex master dataset. Some minor entrances were explored in this area.

During January to March of 2009 the Mulu Caves 2009 expedition continued to explore Whiterock Cave and discovered a further 24km of passages. Owing to the proximity of the northern passages to the cliffs in the Melinau Gorge, a considerable amount of effort was given to establishing a northern entrance. Five days were spent attempting to gain entry via a small cave to the east of Camp 5. Unfortunately, this ended in a boulder choke with a draught emitting, within 100m of Whiterock. A significant discovery in Whiterock brought its northern passages to a point underneath the Pinnacles track and even closer to Camp 5. Late in the expedition a steeply descending ramp off 1954 led into the Whiterock River, the upstream continuation of Clearwater streamway. Although not fully explored, this streamway was left at a point 60m beneath Camp 5 with potential for further discoveries.

During May 2010 a small team visited the Park. The Mulu Caves 2010 expedition was to be a small-scale venture, based at Park headquarters, with the aims of photography, science and surveying. Modern digital images were made of the caves close to Park headquarters. Further samples of speleothems, sediments and quartz were collected to enhance the scientific programme. 14.6km of surface survey was completed to tie together all the known entrances in the Southern Hills. Although not a primary aim of the expedition, a small amount of exploration was carried out, with 2.4km of previously undocumented caves explored and surveyed. During 2011 the Mulu Caves 2011 expedition spent two months in the field. This was a two centre, two-month expedition the first month based at Park HQ and the second at Camp 5. The expedition successfully laser scanned the vast Sarawak Chamber allowing volume calculations for be made. Radio-location was used in Whiterock Cave and the Melinau Gorge to determine the precise position of the end of the cave in relation to the surface topography. A series of Geodetic GPS fixed points were established around the park to better understand the relative levels of the caves within the Survex

dataset. In Whiterock Cave 13km of new discoveries were made. A series of sampling was carried out for uranium series dating.

The Mulu Caves 2012 expedition was to be the 20th in the series of Angle Malaysian ventures and was based at Park HQ. A series of high level caves were found in the Melinau Paku valley with Train Cave extending the Cloud/Bridge/Cobra system to 20km. Attempts to connect Lagang's Cave into Racer Cave were unsuccessful but the cave was extended to 5.7km. October 2013 saw the Mulu Caves 2013 expedition based at Camp 5. Scientific work was carried out in Whiterock cave to better understand the geology and geomorphology of this area. Further sampling was carried out for uranium series analysis. A further 7km of new passages were explored in Whiterock Cave and Deliverance Cave at the northern end of Benrat was revisited without any major breakthroughs.

During April/May of 2014 the Mulu Caves 2014 expedition was focused on exploration at the southern end of Gunung Api. Based at Park HQ the expedition continued the attempt to connect Racer Cave and Lagang's Cave into the Clearwater system. Although the connection was not made a new cave was discovered, Easter Cave which proved to connect with the higher levels of Racer Cave.

The significant success of the expedition was to discover the 8km of passage in the Creedence series which forms the fourth horizon of development 450m above base level confirming the existence of higher levels within the cave. This discovery pushed the total length of the Clearwater System to over 200km.

The Mulu Caves 2015 expedition was an ambitious project centered on three locations, Southern Api, Hidden Valley and Camp 5. In Hidden Valley a lightweight recce was carried out to investigate a large entrance identified from helicopter video footage in the north wall of the gorge. This revealed Conviction Cave which connected into Wonder Cave, unfortunately a serious accident curtailed some of the work here. Further exploration was carried out in Racer and Lagang's caves but no connection made. From Camp 5, 8,065m of new passages were explored in Whiterock Cave where a new level was entered 100m above anything previously discovered. This was 380m above the lowest part of the cave confirming the existence of higher levels within the cave and potential for far more discoveries in the future.

During April 2017 the first of two Mulu Caves 2017 expeditions visited the park and was based at Park HQ. Further work was carried out in southern Clearwater and in Cave of the Winds where the Eureka series was discovered lying just above the river passage. This discovery has taken the Clearwater system to within metres of the Racer/Easter cave system and renewed enthusiasm in connecting the caves of the Southern peninsula. The second team at park HQ concentrated on exploration of the Creedence series. This was accessed by the High Noon entrance discovered in 2014 and led to significant extensions over a number of trips. In addition to these two teams, a third team visited the Hidden Valley and extended the length of Wonder Cave. The cave trended north towards the Melinau Gorge, with approximately 12km of new passage discovered.

The second expedition was based at Camp 5 during October where 4.2km of new passages were explored in Whiterock Cave bringing the total length of the cave to over 100km and the Clearwater System to 226.3km. Within just 15 years Whiterock had become a 100km cave, the longest cave in the park.

The Mulu Caves 2018 expedition was a smaller affair, with a focus on trialling environmental monitoring hardware in the strong draughts felt in Mulu. A small amount of exploration was completed in Clearwater and Whiterock, and a resurvey was started to lay fixed survey stations through Clearwater.

Two expeditions were completed in 2019. The first in spring was based at HQ with teams working in northern Clearwater, where the Scientific Method series was explored with lots of potential towards Whiterock, and in the south peninsular region. Here a light connection through a short sump 'connected' Cave of the Winds and Racer Cave. Much work in Easter Cave brought it yet closer to Lagang's, but with no connection made.

The Autumn 2019 expedition was predominantly based at Camp 5, from where 7km of new passage was discovered in Whiterock, including a connection between Africa Camp and the Racer Series in Blackrock. A smaller team based at HQ used the Snake Track entrance of Clearwater to explore 2.4km above the Dune Series. Also, the Mother of all Voids in Hurricane Hole was aid-climbed for a further 100m without reaching the top!

The 2020 expedition was the first in recent years to concentrate solely on the caves of Benarat. Sakai's Cave and Moon Cave were both revisited with some success and further leads identified. Much work was done in Cobweb, with climbs leading up to new levels and a new potential for a connection to Terikan in the lower levels. Blue Moonlight Bay was also revisited with much still to investigate.

The Mulu Caves 2022 Expedition Members



The 2022 expedition team. *Photo: Chris Howes*

The 2022 expedition team was 35 strong, with most cavers based in the UK and Europe plus others from the USA. In addition the team was joined by Malaysian cavers, guides and porters. The team is named from left to right:

Jimmy Jarau (Malaysia)
Colin Boothroyd
Tim Kent
Max Koether (USA)
Tony 'Badger' Radmall
Chris Blakeley
Hazel Barton (USA)
Ash Gregg
Rostam Namaghi
Derek Bristol (USA)
Andrew McLeod
Andi Smith
Rob Eavis
Will Yu-Pearson
Maya Williams
Veno Enar (Malaysia)
Martin Holroyd

Andy Farrant
Andy Eavis (leader)
Gareth Davies
Dave 'Moose' Nixon
Mark Kuneiglibuan Tisen (Malaysia)
Jon 'JJ' Beavan
Zarris Kem (Malaysia)
Jo White
Pete Hall
Kevin Munn
Judith Calford
Rida Rambli (Malaysia)
Christos Pennos
Roo Walters
Stein-Erik Lauritzen
Chris Howes

2. EXPLORATION

Clearwater Cave

Entrance / River Area

Unclear Passage, Clearwater Entrance

Rob Eavis

SITUATED high above the Clearwater River, just about visible from the showcave path, is a high-level passage heading north. This was originally explored and surveyed in 1984 to a crossrift. Without any further details (and with the intended trip being postponed due to floods) a team in 2022 went for an explore.

It's slightly tricky to find the passage as it's hidden by large calcite formations, all very old looking and quite deteriorated. Initially a tall passage, it soon reduces to a crawl over dry mud before reaching a window overlooking the rift chamber. A short handline assisted the climb down into this which has two ways on.

To the west a loose climb up a sediment bank gained access to the continuation of the passage, now very well decorated. This soon reached another crossrift which also required a handline to safely descend. This chamber, filled with calcite decorations, unfortunately had no way on.



Maya in the new Clearwater entrance passage
Below: Roo and Andi with formations in Unclear Passage
Photos: Rob Eavis



Back to the first chamber a route under a prominent flowstone boss lead into a meandering passage heading north for 50m before reaching a strong E-W fault. The passage descends to the right down a clean-washed ramp (which should have been rigged) to reach a window overlooking a 40m long rift chamber. A 13m freeclimb down (which also really should have been properly rigged) accesses the flat floored chamber which has two large avens in the roof that were not climbed. At the far eastern end a small aven series was climbed which leads to a tall vertical series going up and down that was not explored. This is very close to the Clearwater River but there was no sound of it connecting yet.

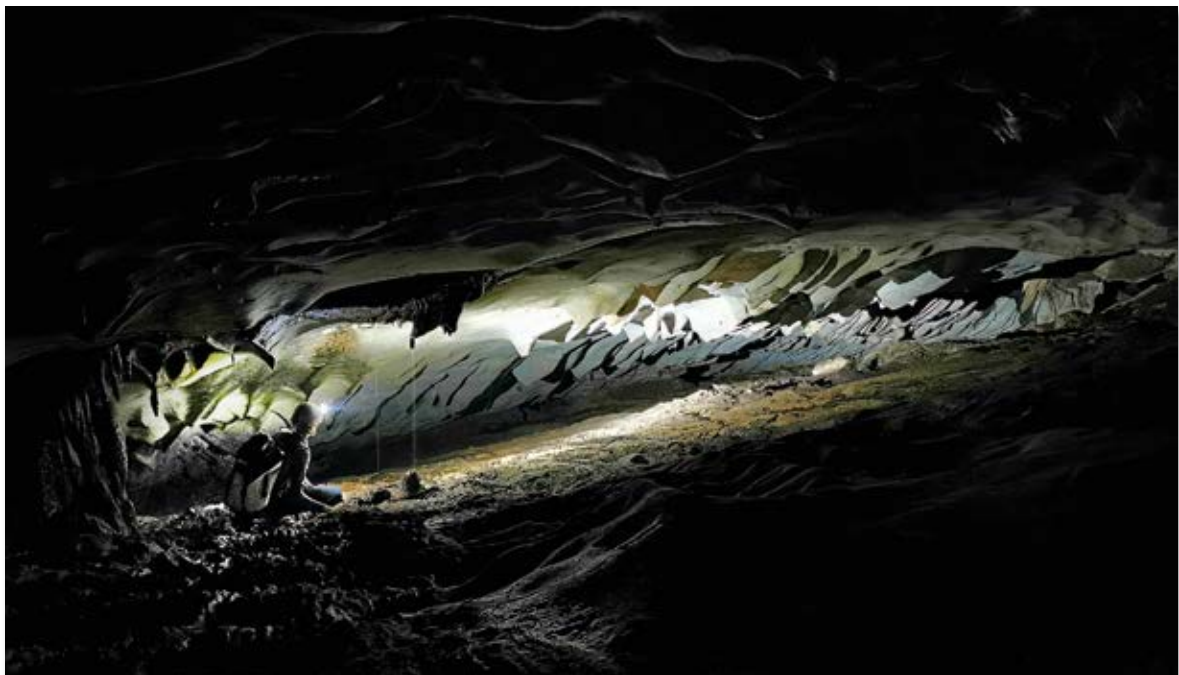


Tim Kent by a large curtain in Unclear Passage, with the passage below providing the way on
Photo: Rob Eavis

Rancid Rift, Clearwater Streamway

19/11/2022

Rob Eavis, Andi Smith



APPROXIMATELY 100m downstream from Battleship is a hard left-hand corner (when travelling upstream) with an obvious passage up to the right (west). This was marked on the 1980 survey as presumed to link to another high-level passage visible 150m downstream. The 3D scanning conducted a few days before suggested this may not be the case.

Following a slightly intricate route it was possible to free-climb up into this passage to see that indeed the passage did not head NW but instead went SSW along a 45° sloping rift. This was pushed hard for nearly 100m until it choked with mud and calcite in the roof of the rift. No draught was present.

Later that day the other high-level passage downstream was also free-climbed into by Andi, but unfortunately this closed down within 40m.

Sandstorm

Colin Boothroyd

THE objective was to break through the beds and fill the enticing white space between Creedence and Api Chamber with loads of beautiful black squiggles. And here follows a description of what was found.

The direct connection, achieved on the previous expedition, between the 20m pitch up from the end of Sheer Delight and Great Wall Chamber, was the key that brought the exploration of the zone at the southern end of Blackrock easily in reach.

Heading north from the gentle rocky ridge running along the spine of Great Wall Chamber there are two passages, originally explored in 1978: West Passage and East Passage.

West Passage

WEST Passage, to the left as one enters Great Wall Chamber from Sheer Delight, can be followed along the base of a high rift passage. A 4m pitch drops into a small chamber. The passage continues with an 8m ascending climb into the continuation of West Passage. The climb was not ascended on the 2022 expedition.

The survey produced following the 1978 explorations shows the complete connection between the two ends of West Passage so it is assumed that it was traversed at that time.

The northerly end of West Passage drops down a vertical 8 metre wall of truncated cobbles into East Passage as it emerges in the southern end of Gnome Oxbow. There are two other links between East Passage and West Passage that have been linked and a Guesstimated P60 that has not been completed.

The northernmost pitch bypass is a squeeze in a crack in the side wall of East Passage that emerges in West Passage following a short climb.

The easier connection, a little further south along East Passage discovered on the 2022 expedition, is Joanna Lumley's Fallopian Tubes, which is a small passage that pops out in West Passage half way between P8 and the Stone Waterfall.

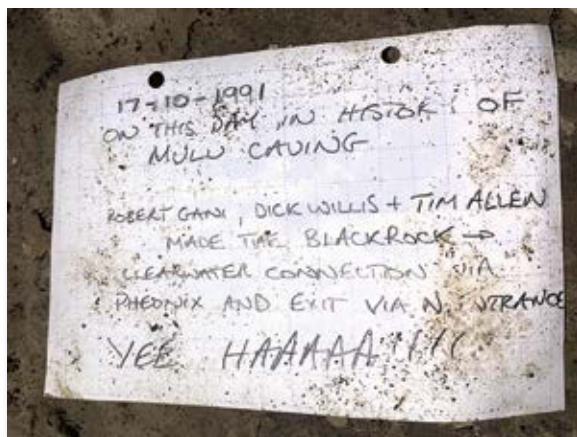
The Stone Waterfall is a fluted rock amphitheatre which, when heading south, is a 6m climb.

At the top of the Stone Waterfall there is junction marked with a cairn. The cairn is the point at which the explorers coming from No Justice in Blackrock Cave recognised that they had connected to West Passage in Clearwater.

West Passage continues towards the south at the top of the Stone Waterfall. After 50m a passage on the right abruptly ends at a deep pitch. This pitch is undescended but it is the Guesstimated P60 described above that drops into East Passage as well as going up to Sandstorm passage described below.

A short distance after the junction, West Passage develops into a rift-like profile. Exploration was stopped at the lip of a pitch with a perilous traverse on the left wall. From the lip of the pitch and looking along the passage ahead the sound of the explorers traversing across Black Blizzard could be heard.

The pitch at the end of Sheer Delight, rigged in different ways (none of them satisfactory). Photo: Will Pearson



The note left by the original explorers who made the connection between Clearwater and Blackrock. Photo: Colin Boothroyd



East Passage

THIS is by far the easier, sometimes notched, passage to follow between Great Wall Chamber and Gnome Oxbow and, as detailed above, provides the key links to West Passage and No Justice in Blackwater.

No Justice

THIS is the section of passage that runs from the Stone Waterfall in West Passage to Petrus Dream Series. It was originally explored from Blackrock and included descending a pitch, following an underlying section and then climbing back into the main passage. The pits in the floor have now been found to be relatively straightforwardly traversed over (with the benefit of bolts and traverse lines). Heading from the Stone Waterfall a pit is traversed over (a 3m traverse line is recommended.) 50m further along the passage is a large fallen block. This is point where the 54m bolt climb into Sandstorm Passage started.

Sandstorm Passage

FROM the top of what became a fine 37m free-hanging pitch, the Sandstorm Passage climbs over blocks.

A small side passage heading southeast can be followed by climbing down a block to a pitch lip dropping into large passage. The pitch is 12m and is followed by 10m and 8m drops which arrive in the zone where Petrus' Dream Series, No Justice and the route to Broken Hope Hall come together.

Sandstorm Passage then heads down, under a low arch, to a T-junction. On the right Guesstimated shaft both ascends above and drops below. The drop down has not been descended although a voice connection was made with West Passage. The shaft above has been bolt climbed for 40m and continues ascending.

Left at the T-junction leads shortly to a large window overlooking Black Blizzard.

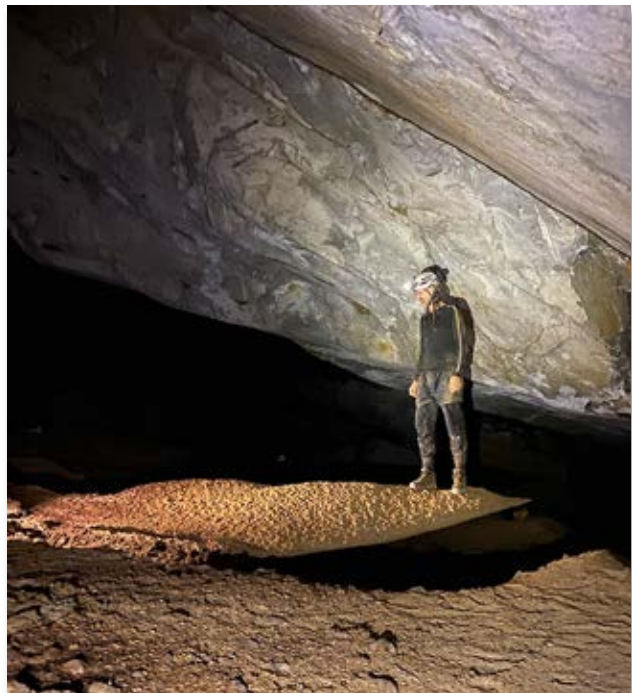
Black Blizzard is a large inclined void. The drop down has not been descended but a voice connection with west passage reinforces the assumption that Black Blizzard drops into West Passage.

High Steppes Camp

AROPED traverse, with two short vertical drops, traverses the chasm and at the far side, the climb up towards High Steppes Camp starts. A series of ramps and pitches are ascended. The original climbed route is



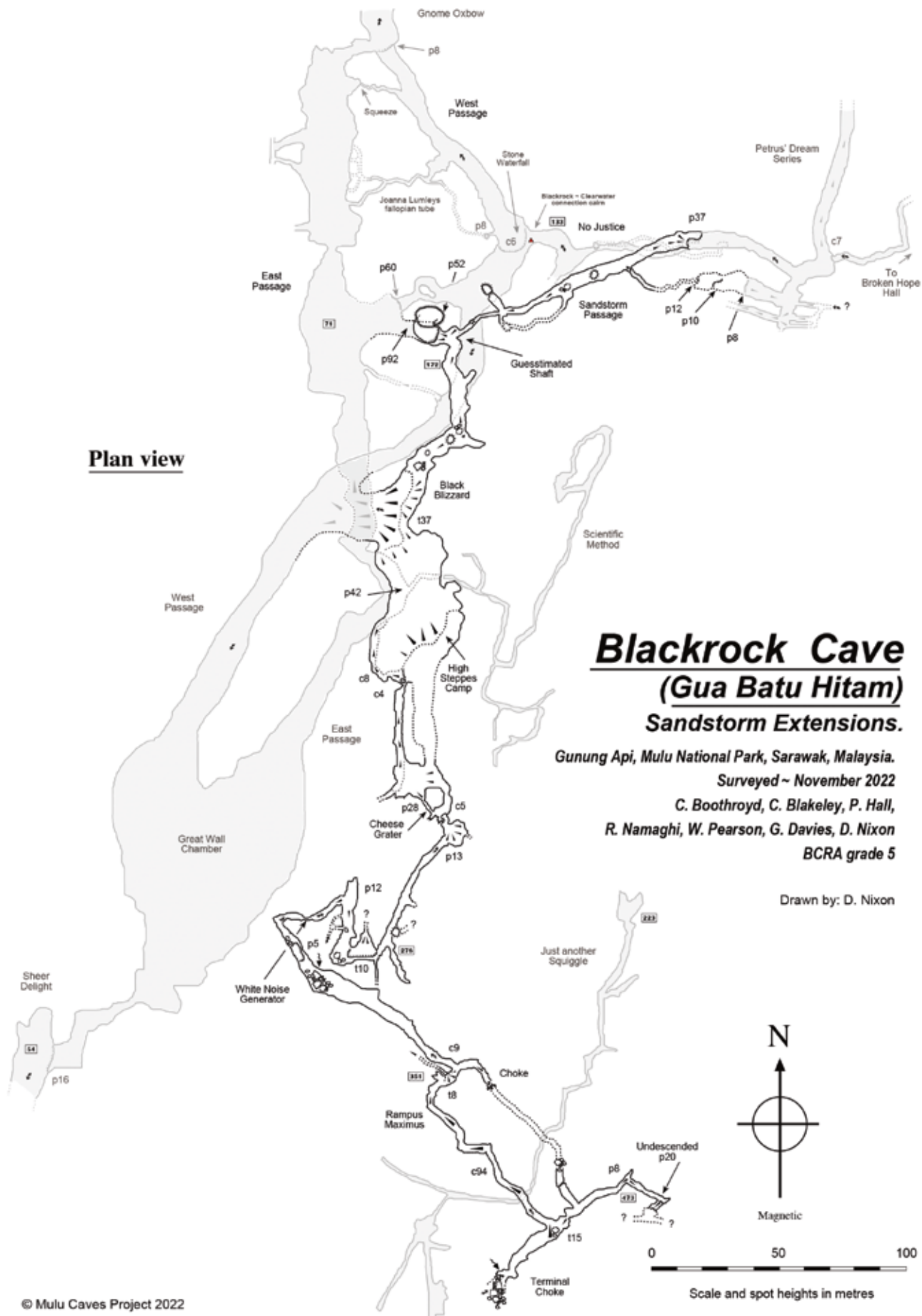
A surprise visitor to the Sheer Delight camp: a cave racer snake
Photo: Colin Boothroyd



Chris Blakeley balancing on a fine rock spear in East Passage
Photo: Colin Boothroyd



A curious 'bull ring' formation in Sandstorm. Photo: Pete Hall



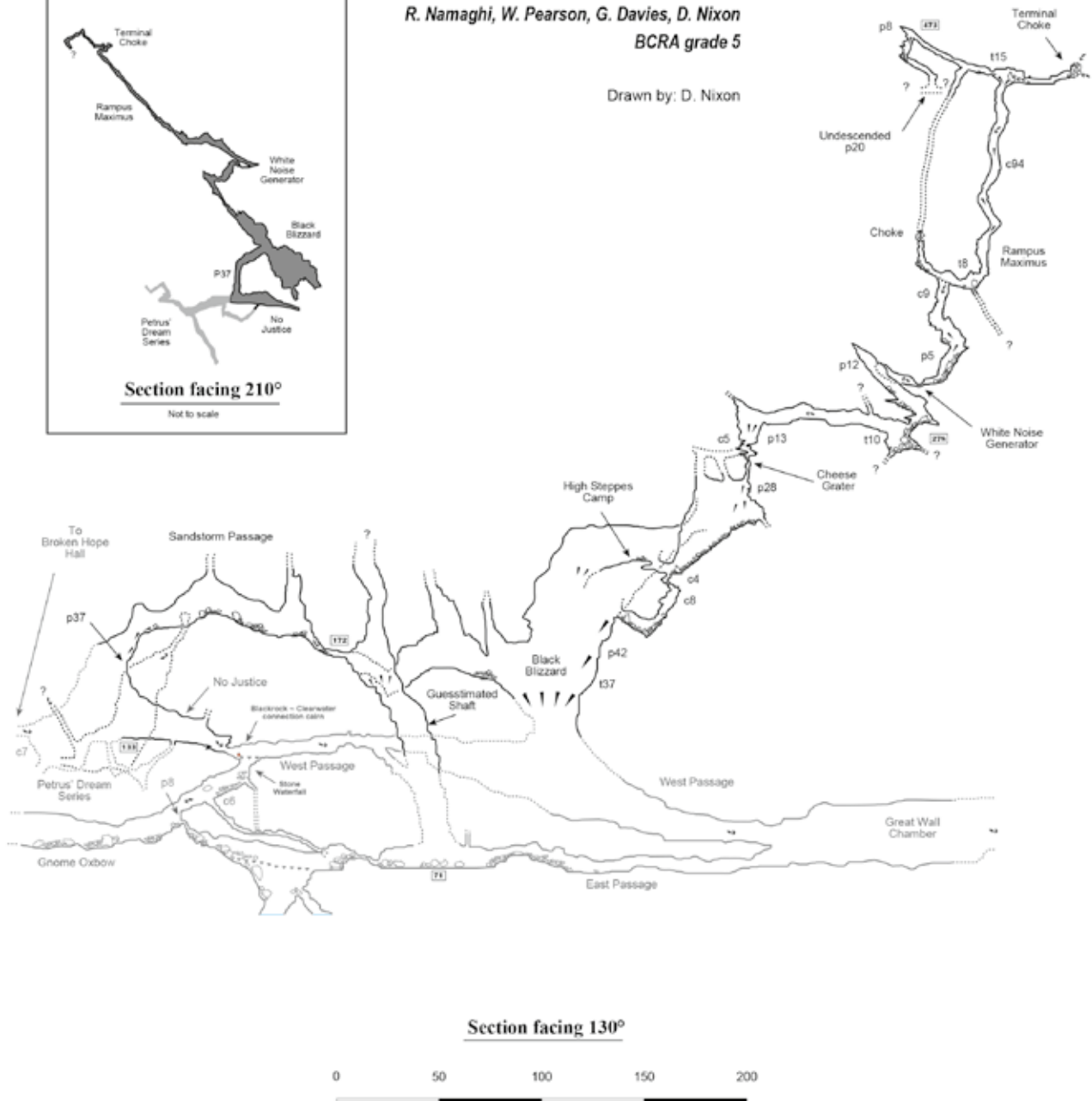
Blackrock Cave ***(Gua Batu Hitam)*** ***Sandstorm Extensions.***

Gunung Api, Mulu National Park, Sarawak, Malaysia.

Surveyed ~ November 2022

C. Boothroyd, C. Blakeley, P. Hall,
R. Namaghi, W. Pearson, G. Davies, D. Nixon
BCRA grade 5

Drawn by: D. Nixon



Scale and spot heights in metres

© Mulu Caves Project 2022

detailed on the survey however it would be better if the ropes went directly from High Steppes into Black Blizzard to avoid the awkward climbs. A traverse from High Steppes Camp to across the top of Black Blizzard doesn't reveal any more passage as all prospects either closed down or dropped back into Black Blizzard.

The climbs continue beyond High Steppes Camp, through the narrow Cheese Grater and onto a series of consecutive ramps and traverses to the White Noise Generator. A very powerful and noisy wind passes this low point which was originally passed following excavation of the sandy floor. Immediately beyond the White Noise Generator there is a bright light green deposit on the surface of the walls.

A short pitch and more ramps continue through a chamber with a few drips to a T-junction. Left ends at a boulder choke after a few metres and right traverses over a deep hole to the base of Rampus Maximus. This extends as a long free climbable, though often loose, ramp up to another T-junction.

Right at the T-junction heads to a terminal choke. This was examined thoroughly but, with little draught and loose, it was felt unlikely that it would relent very easily. Left at the T junction is a traverse into a short section of passage with a drop on the left that is assumed to lead towards the first T-junction. Right continues past helictites and through into another bed of limestone before arriving at the high point with a steep col with an 8 metre pitch. At the base of this pitch an enticing vertical pitch of 15m to 25m appears to drop into a large passage below. Unfortunately the exploration team had run out of time and rope at this point. The pitch remains undescended, although no draught was noticeable.

Note: the entire section of passage from West Passage has almost no water whatsoever. The terminal choke has a slow but useable drip spot and all future visitors should ensure that they are carrying enough water before venturing into this series of passages.



Wind speed recording in the White Noise Generator
Photo: Colin Boothroyd



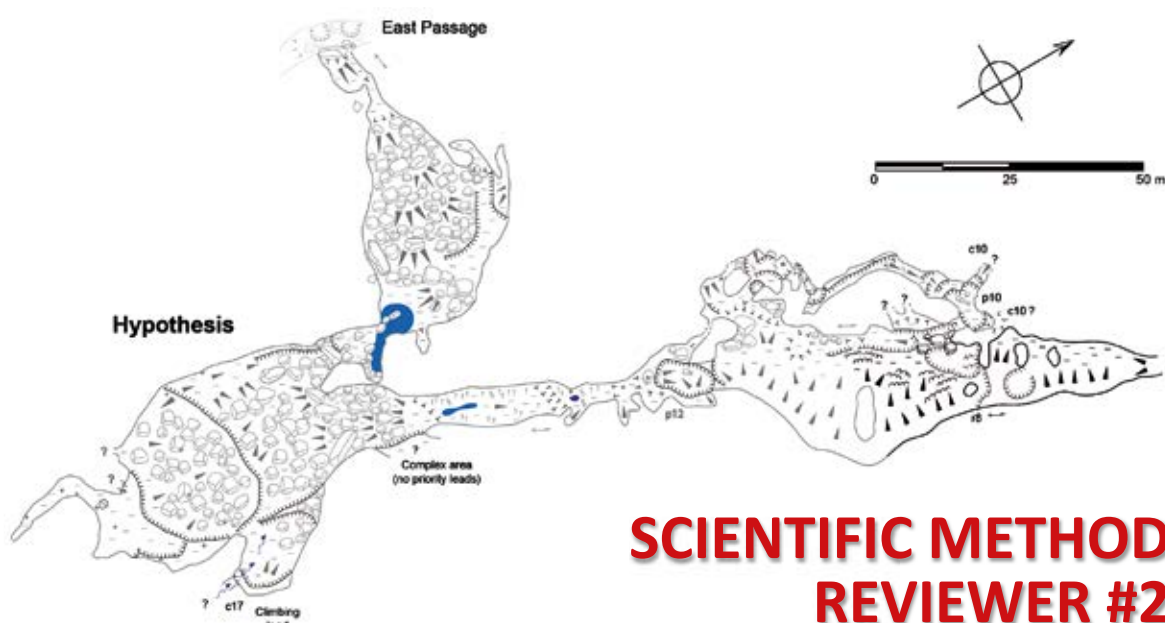
The Sandstorm exploration team: Dave 'Moose' Nixon (left), Chris Blakeley, Pete Hall, Colin Boothroyd. *Photo: Colin Boothroyd*

Continuing work in Scientific Method: Reviewer #2

Derek Bristol, Hazel Barton, Max Koether

25th November 2022

WE had originally planned to head out on a three-day camp into Clearwater via the Snake Track entrance, staying at Sheer Delight camp, and taking the new route up to the Chinese Wall Chamber avoiding the Dune Series. But there were mixed messages on whether it would be easy/hard to find both the entrance and then the camp. Later in the expedition, Pete and Moose were planning an overnight derig trip of their new finds and offered to show us the way. This ended up being valuable, as while it was easy to follow the established trail to the cave entrance, finding camp with the 'turn left, then turn right, then left again' would probably not have gotten us where we needed to go.



SCIENTIFIC METHOD REVIEWER #2

Following Pete (Moose was off like a whippet) we made it to camp and had a cup of tea, before following them both up the ropes to find the Great Wall Chamber. We then separated at the east passage and headed off into Scientific Method. We had found a good climbing lead at the far end of Hypothesis during the last expedition. Derek had free climbed this during the previous expedition, and it didn't look great, but a dynamic move was needed to get into the passage, which needed some protection. With Max belaying, Derek was able to re-climb, only for it to end in a flowstone choke just beyond where he had stopped in 2019.

We then headed over to the blowing lead that we had left to the north in 2019. It was not possible to get into this passage the previous year, as we didn't have any climbing gear, and it looked as though an aid climb was needed. We spent the rest of the day with Max doing an aided traverse, high across the rift. The issue was the number of bolts we had brought (8), which were turning out to be insufficient for the distance needed to travel. Max was able to get to a large bridge, that allowed him to perform some gymnastics to preserve available bolts. On the bridge, Max could look down into narrow, miserable, sump mud-filled, ongoing passage. By this time, it was getting late, and the decision was made to drill two bolts to create a permanent anchor, clean the traverse, and then return for survey the next day. Cleaning the route involved some entertaining acrobatics and rope swinging from Derek, as he was less than clear on the rules of physics in his attempt. We then headed back to camp meeting up with Pete and Moose at the rope down into sheer delight and arrived at camp at 21:00.

26th November 2022

GIVEN the amount of effort to gain what was not stumping borehole, enthusiasm was low to return to the mud-filled slope hole at the end of Scientific Method. Luckily, we'd left the drill, survey, and aid gear behind, so we had little choice. Once we arrived, Derek and Hazel began to survey, while Max climbed



up to the ledge and dropped the rope down the other side to look at the passage beyond. The rift headed northwest, toward a climb that would need additional protection. As he headed toward the climb, Max saw footprints in the mud, suggesting this area had already been scooped. Given the location and direction, this presumably means that this passage had been discovered from Leopard Cave in the past, but not surveyed.

With great disappointment, we mapped 65m toward the climb and left the rope rigged in the cave, in case there was some pressing need to complete the connection to an area that Moose said was “The Seat of Fear Area” of Black Rock Cave. He also said that it was aptly named, being extremely slick and extremely exposed. Apparently, there is a 50m pitch that connects Leopard Cave and Black Rock, and the Scientific Method passage may connect along that pit. We named the area Reviewer #2, in reference to the tendency of the second reviewer to always miss the point of any scientific effort.

We headed back to camp. On the way, Derek’s negation of the ropes was interesting and were even invoked when Derek was asked to describe his most embarrassing moment in a cave. We arrived at 14:00 to help the other team carry gear to the entrance, then arrived for the appointed boat at 17:00.



The camp in Sheer Delight. *Photos: Hazel Barton*



Far left: Derek belaying Max as he heads up to begin the aided traverse into Reviewer #2. *Photo: Hazel Barton*

Scumring-based Extensions

Rob Eavis

Serve Cool, Houblon

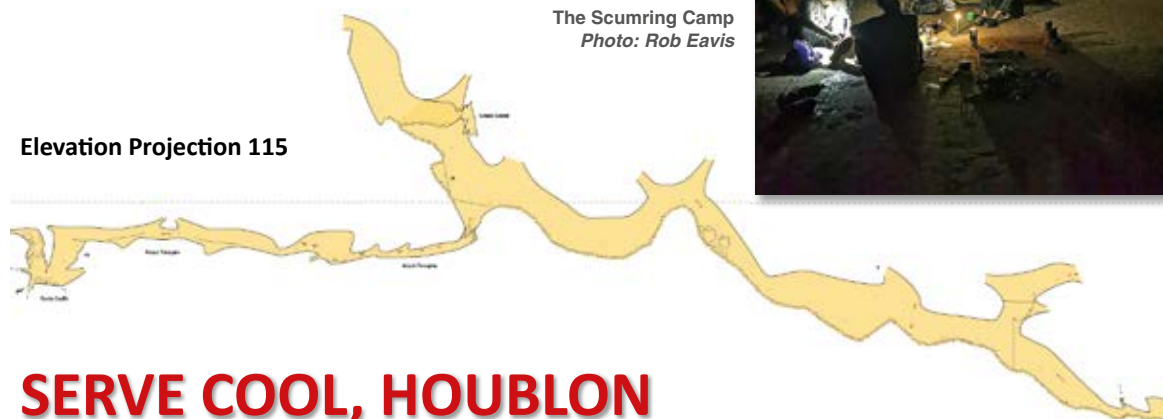
THIS was the #1 objective out of Scumring Camp for 2022, partially because it was an undescended pitch heading north into a blank area, but mostly because it was the closest identified lead to camp.

It is situated at the northern end of the Scumring Series beyond Ronnie's Delight. In 2014 they left a "P7 undescended" where they turned around and then bolt climbed up Hot Pitch and finding +14km of cave up in Creedence.

We returned with 25m of rope and only just descended this 22m pitch into a sizeable passage, roughly 6m wide and 10m high. To the south this dropped down a series of boulder slopes to end after 65m at a mud floor plus a small and loose choke taking a draught. However to the north the passage continued in style, ascending at a steady 15°. After 120m a ferreting route through boulders was found to bypass a large boulder blocking the way and beyond the cave continued to grow to ~15m wide and up to 30m high.

After another 120m the way on was stopped by a 30m high wall. At the top a passage could be seen to continue north and this lines up well with a 30m undescended pitch off from Land of Nod in the Upskirt levels. That pitch was number #9 on our list, owing to its distance from camp! Serve Cool, Houblon may well now provide a faster route into these farther reaches higher up (once the pitch down has been rigged from above).

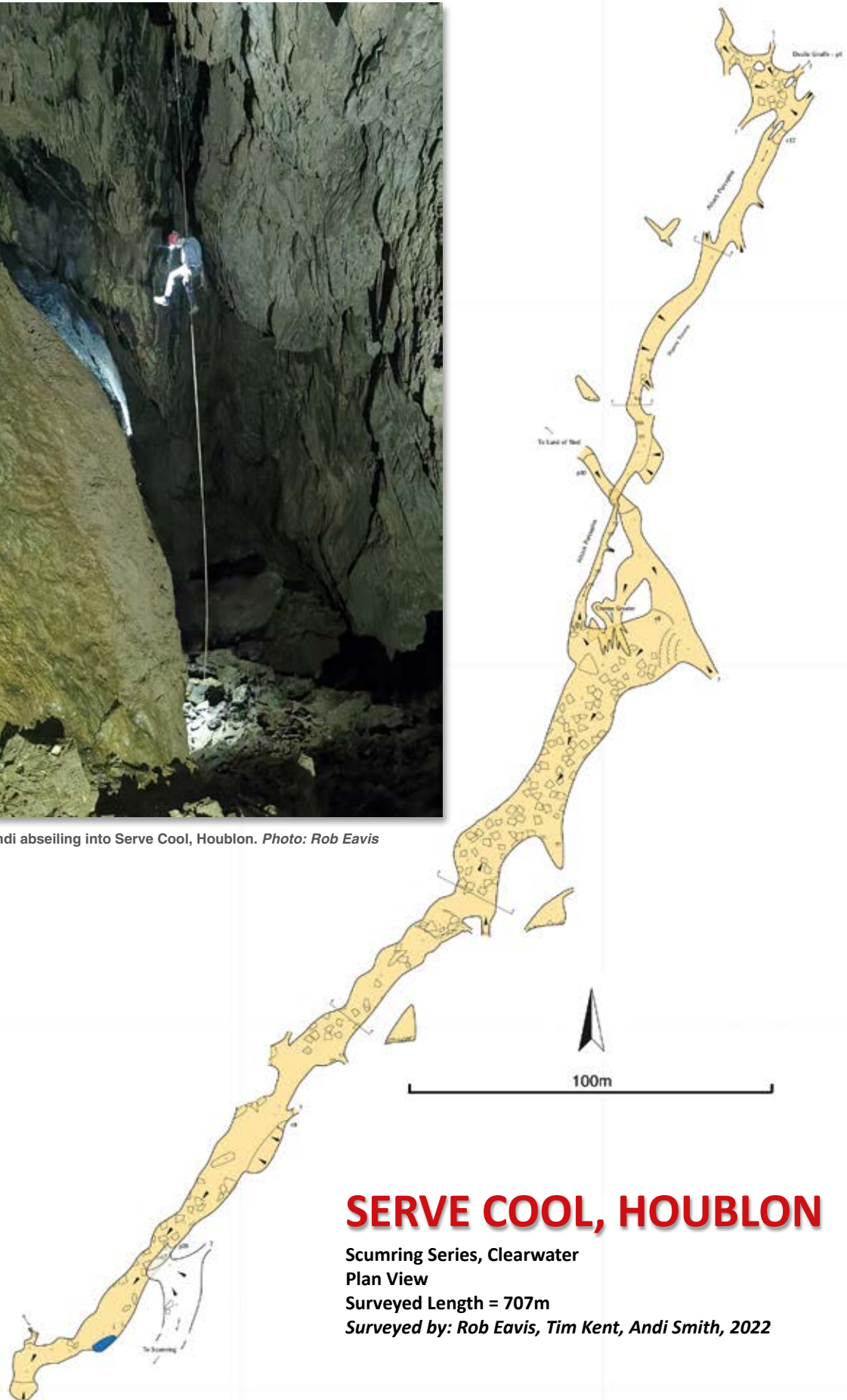
On the return two routes off to the west were spotted. The first, the Cheese Greater, lead only to a small and sharp section of parallel rifts. However the second, hidden through a pile of boulders, unfortunately provided more.



SERVE COOL, HOUBLON



Andi abseiling into Serve Cool, Houblon. Photo: Rob Eavis



SERVE COOL, HOUBLON

Scumring Series, Clearwater

Plan View

Surveyed Length = 707m

Surveyed by: Rob Eavis, Tim Kent, Andi Smith, 2022

Named after a Porcupine in Attack mode, this draughting passage varies between flat out crawls over spikey boulders to body-width, slippery rifts caked in mud and helictites! After 150m of this it finally drops down an easy 10m free-climb down into a pleasant 15m wide chamber with thankfully a source of water to drink.

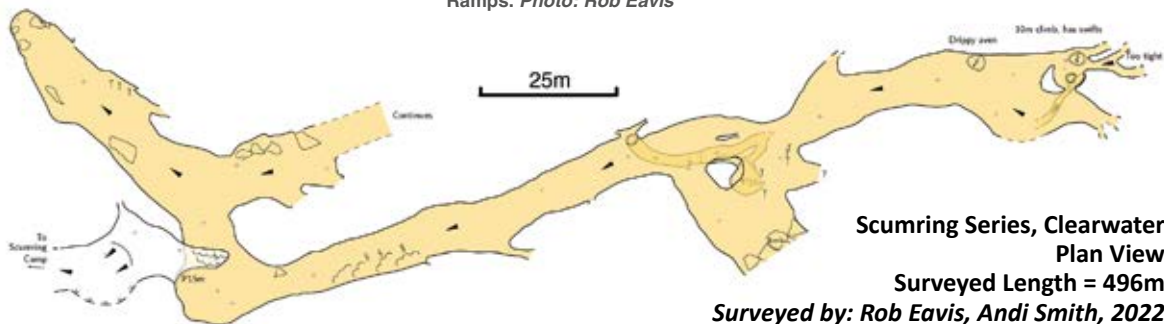
From this chamber (named Docile Giraffe) there's an undescended pitch at the northern end where most of the draught emits from. If it wasn't for its access this would be a fine lead to potentially access the blank area to the north. To the west the chamber was ascended for 20m up through dry, mud-cemented boulders to some more leads/digs that close up but also draught. A speedy trip back to Scumring Camp from here was about three hours.

Hot Pitch Ramps

HOT PITCH RAMPS



Near the top of Hot Pitch Ramps. Photo: Rob Eavis



IN 2014 some ramps up beyond the base of Hot Pitch were partially explored but not favoured as the best way on, probably primarily due to the lack of draught. This 2022 team went back to survey the passages and finish exploring them.

From the turnoff to Hot Pitch a short handline up (~7m) leads to a short passage and a 20m pitch down. This lands in the main rift which is indeed a stonker at 220 vertical metres in total, all explorable with no rope!

Downhill initially heads north then can be followed to the left, down to the west in a degenerating fashion eventually ending in muddy boulders. This is 20m away from the downhill end of Serve Cool Houblon. Turning right the rift continues up but was not pushed conclusively.

Back at the pitch the main rift heads up in a straight line at an angle of 38° from horizontal. It is a relatively easy freeclimb, helped by the occasional stalagmite and the slight trench in places. Some unusual angular flowstone is seen here. After 97m a small hole down was followed to a 13m pitch but no obvious way on.

Further up the ramp widens to ~40m wide, albeit partially split into different sections of smaller development. A boulder choke is reached in the southern side but was not pushed hard. This is roughly 20m below and directly beneath a wide section of the Upskirt Level so is deemed likely to connect (through boulders). Skirting to the north the boulders are passed and the ramp continues up another 50m to a section where water comes in and a few avens are left unclimbed. One has good swift movement suggesting a connection to the level above. The ramp does continue higher but it is much smaller here and closes up.



Serve Cool, Houblon. Photo: Rob Eavis

Heron Passage Rift

HERON Passage is a side passage heading East off of the Quattro Formaggi level, below Upskirt Lower. Originally explored in 2014 it contains a very impressive section of helictites, but unfortunately it ended at a pitch down after only 40m.

This year this 17m pitch was descended and the development was found to immediately turn 180° and start descending down a steep ramp heading West. After 60m (40m vertical) of cautious free-climbing a 28m pitch was rigged which dropped into a series of well decorated chambers, but unfortunately the way on closed. The draught was lost. The bottom here is quite close to Quartermass and 30m vertically lower than Scumring Camp.



*Above and below: The downward slope of Heron Passage
Left: The top of the Gin Palace ramps
Photos: Rob Eavis*



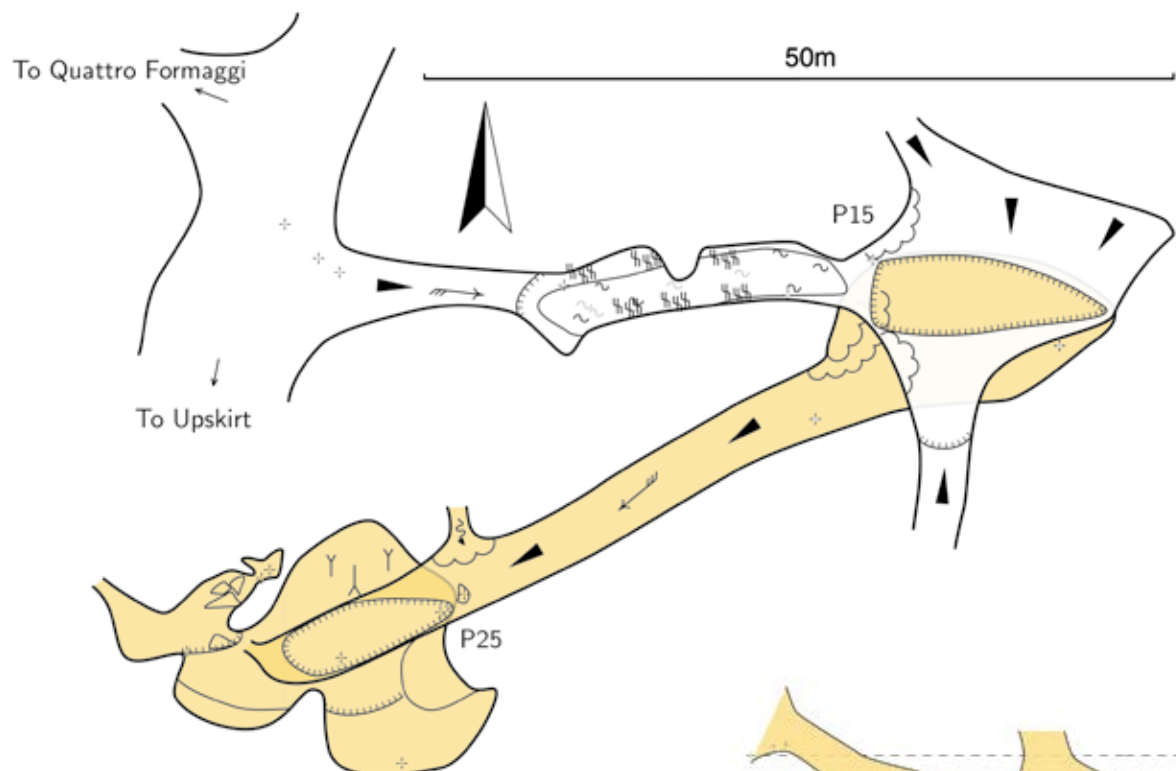
Gin Palace

THIS short passage off Creedence was originally pushed in 2017 when the explorers dug through a low crawl to ongoing passage but then were stopped at a 3m pitch down into a large passage. Its location suggested it could be a key way into a potential southern continuation of the main Creedence passage, and with ~700m of straight line distance to the edge of the mountain the potential here was great.

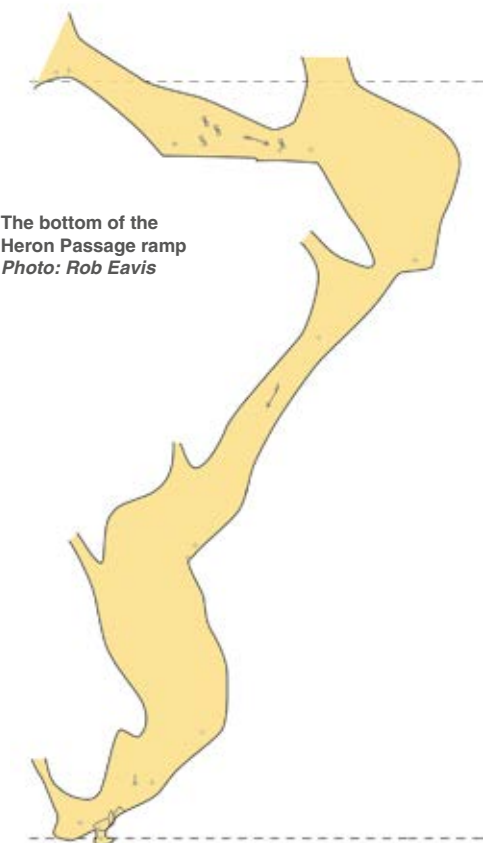
The trip up from Scumring is a long way but surely one of the best caving trips possible, with a great mixture of pitches, massive formations, huge boreholes, and more pitches! The two of us arrived at the

HERON PASSAGE

Upskirt Level, Creedence, Clearwater
Plan View
Surveyed Length = 137m
Surveyed by: Rob Eavis, Andi Smith, 2022



The bottom of the
Heron Passage ramp
Photo: Rob Eavis



Elevation Projection 115
Surveyed Length = 137m
Surveyed by: Rob Eavis, Andi Smith, 2022

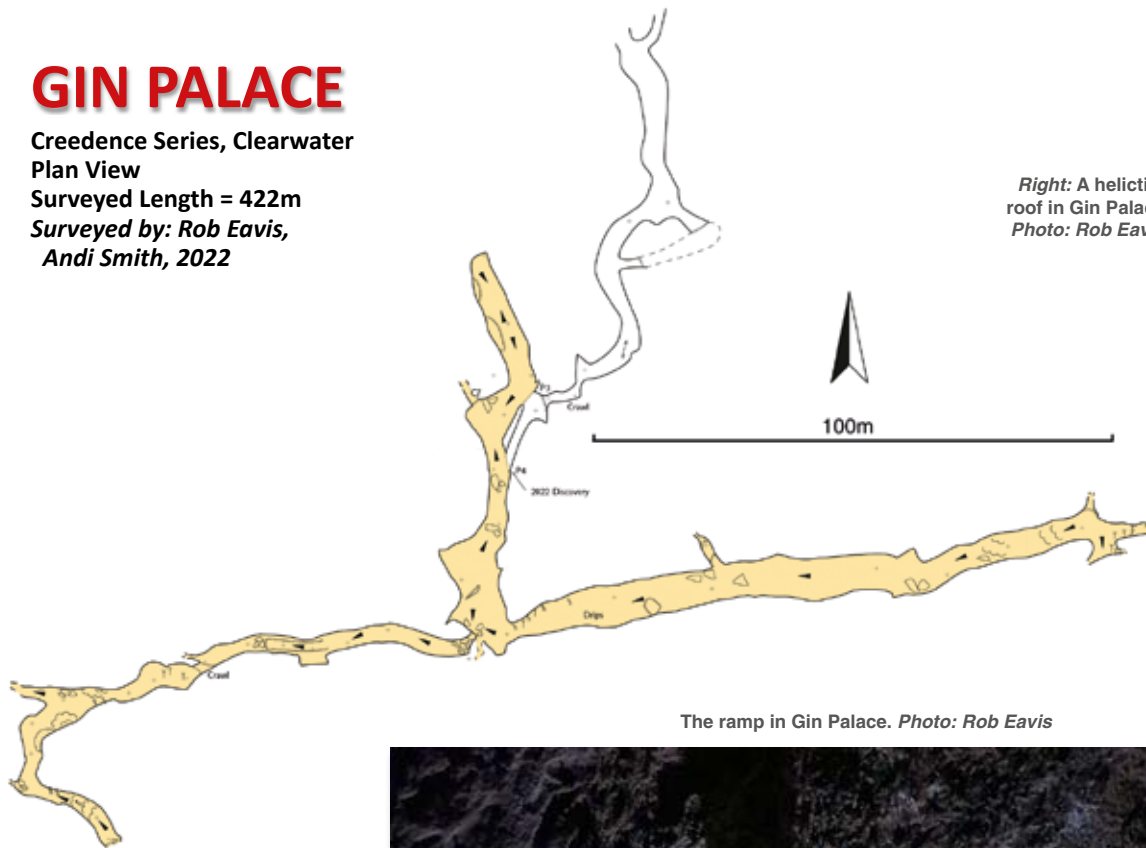
GIN PALACE

Creedence Series, Clearwater
Plan View

Surveyed Length = 422m

Surveyed by: Rob Eavis,
Andi Smith, 2022

Right: A helictite
roof in Gin Palace
Photo: Rob Eavis

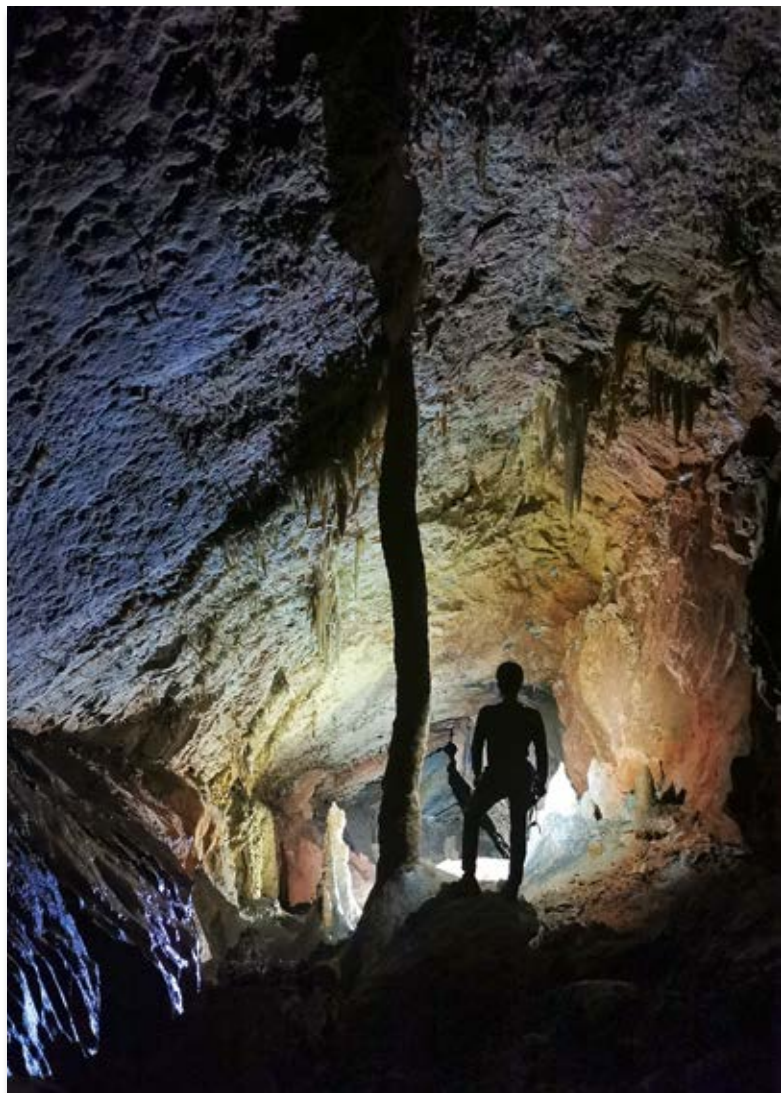


The ramp in Gin Palace. Photo: Rob Eavis

lead in time for lunch which we enjoyed at the balcony overlooking the large ongoing passage. After concurrently whetting and filling our appetites we dropped this passage and started exploring south. Unfortunately the DistoX compass was totally broken upon arriving so we improvised with a combination of backup instruments and manual entry on the phone.

Unfortunately after only 30m of good sized passage the development changes entirely into a incredible rift system going up (to the east) and down (to the west). Up was explored first passed some impressive helictites in a passage roughly 4m diameter which continues for 150 at an angle of 30°, gaining some 85m in elevation. The calcite blockage at the top is at an altitude of 525m, making it the second highest point in Clearwater.

Back at the junction, the downwards ramp was only notice by chance, hidden down between



boulders in the floor. Once through the ominous choke the ramp is slightly smaller than the uphill variant and with more sediment. After 110m it starts to close and looks ominous but actually veers left for a short section of easy walking passage to quickly start heading back up hill again! Here not only did it thankfully close down after 20 hear metres, but it also has a small gurgling stream, our first running water all day!

Once finally back at the balcony we now headed north, knowing that this wasn't a tantalising direction as it's heading straight back towards Creedence. After 45m this ended in a 20m high chamber but with no obvious way on. Gin Palace is in summary a strange section of passage with no obvious way in nor out for the main development. Also the draught through the entrance crawls are lost beyond, so seemingly something has been missed ...



Dogfood and more ...

Ash Gregg

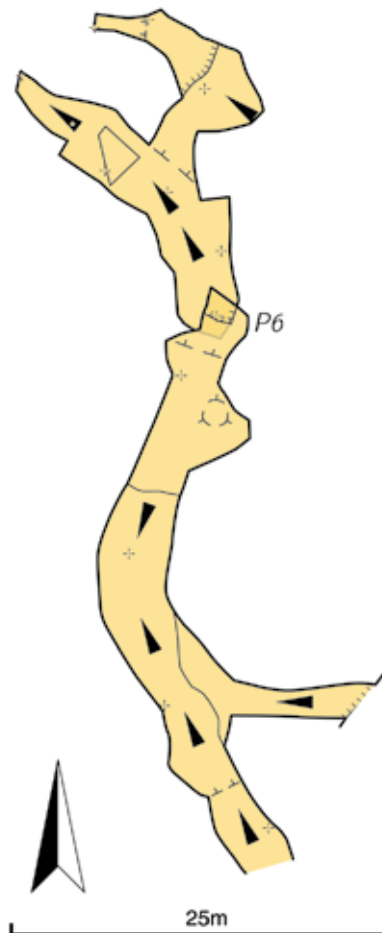
Extra Dogfood for You

Length: 103.38m – explored 22nd November 2022

Explored by: Ash Gregg, Will Pearson, Rostam Namaghi

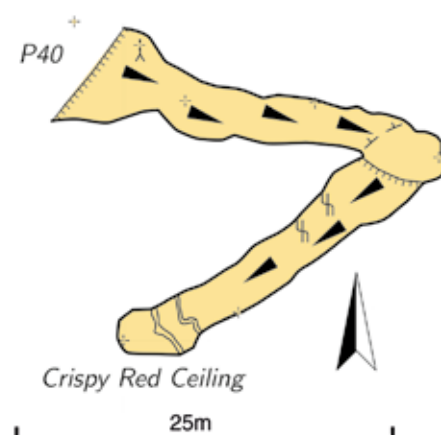
Location: Travel north from Camp Scumring for approximately 300m, down a short 9m pitch and then immediately up a rope climb. Extra Dogfood for You is a smaller passage on the left which slopes downwards, shortly after the top of the rope climb.

THE walking-sized, sandy floored passage slopes down, soon passing another connecting passage on the right which slopes very steeply back to the main passage. The passage bends right and levels off before reducing to a crawl, passing under a tight aven. A 6m pitch down immediately follows, with an awkward, crawling, pitch head. At the bottom the passage becomes more boulder-floored, sloping downwards and eventually splitting in two. Both routes degenerate to damp



EXTRA DOGFOOD FOR YOU

*Surveyed by: Ash Gregg,
Rostam Namaghi, 2022*



IBIZA SUNSET

*Surveyed by: Ash Gregg,
Will Pearson, 2022*

Ash descending the pitch in Extra Dogfood for You
Photo: Will Pearson

muddy crawls, with the odour of decay and an abundance of woodlice type creatures (cavelice?).

There are no further leads off this section of cave.

Scumring series – Ibiza Sunset

Length: 67.03m – explored 25th November 2022

Explored by: Ash Gregg, Will Pearson

Location: Travelling north from Camp Scumring, the first side passage on the right of the main passage leads to Ibiza Sunset. This is approximately 100m out of camp and is an obvious muddy downward slope.

THE passage slopes steeply down (~50 degree incline) east for 20m before levelling off slightly, bending sharply to face south-west. The passage then continues sloping down as before with stalactites and helictites now decorating the ceiling for another 20m. 50m of rope is required for this muddy inclined pitch. At the bottom the passage levels off, a couple of rimstone dams and an interesting red ceiling mark the end of the passage.

There are no further leads off this section of cave.

Upskirt Lower – Busy Earnins

Length: 64.08m – explored 21st November 2022

Explored by: Ash Gregg, Will Pearson

Location: Travelling east from the top of Downdraft / bottom of Upskirt reaches the drafting passage of Upskirt lower. An obvious bolt climb on the right leads up to Busy Earnins.

THE initial pitch up is 15m high, starting vertically before becoming a steep slope over loose boulders, up into a window. At the top a passage goes left and right, with a small dripping aven above. Left leads up a slope to a higher window back into Upskirt Lower. Right quickly reaches another pitch, which drops down 10m to continue. Upon descending the pitch, a rift with an abundance of coral and popcorn leads immediately to another pitch, with a small blind aven above this. This final pitch drops 30m down into Iron Maiden. Caution is required due to the significant amount of loose material coating the walls of the pitch.

There are no further leads off this section of cave.

Upskirt Lower – Iron Maiden

Length: 514.63m – explored 26th November 2022

Explored by: Ash Gregg, Will Pearson

Location: Drop down the 30m Pitch from Busy Earnins (Off of Upskirt Lower) to Reach Iron Maiden.

At the bottom of the pitch is small boulder pile in a walking-sized passage. The passage continues as a ramp, both up and down, inclined at 45 degrees.

Down slope the passage stoops to a crawl, continuing at a steep incline for approximately 50m. Crawling under stalactites the passage drops into a small boulder sink. A small trickle of water comes in to the sink on the left from a small passage that quickly becomes too tight.

Up slope the passage widens into a chamber before splitting in two as it continues up slope. Several interconnecting branches link the overall ramp together, featuring a multitude of stalactites. The ramp reaches a perpendicular fault approximately 50m upslope from the bottom of the pitch, from which the overall ramp fragments into four main branches.



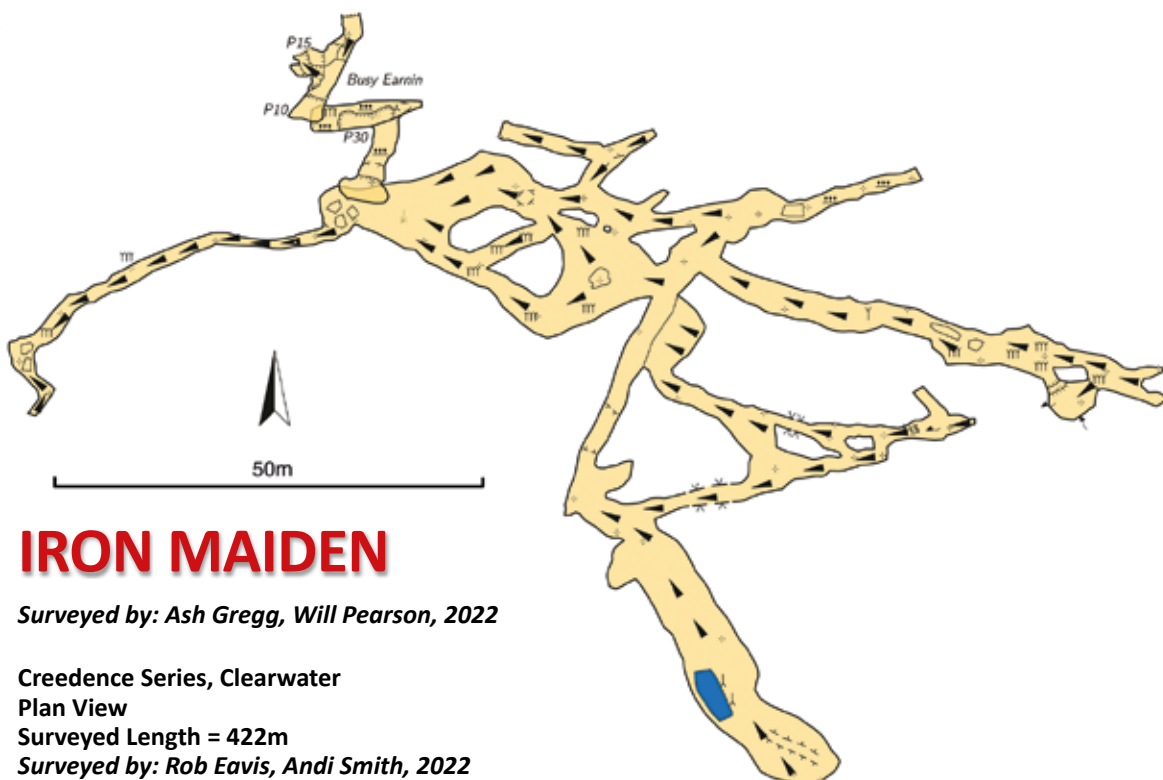
Tim at a side passage opposite Extra Dogfood. Photo: Will Pearson



The north-most branch (left as ascending the ramp) narrows into a tall popcorn-lined rift. This can be followed for 20m before becoming too tight.

Andi on the route to Scumring Camp
Photo: Rob Eavis

The second branch along continues in a similar fashion as the ramp did before, stooping to a crawl, passing under a multitude of stalactites. After approximately 60m the passage lowers to a flat-out crawl, before becoming completely blocked by calcite. Shortly before the end an oxbow on the right drops down to intersect a faint stream.



IRON MAIDEN

Surveyed by: Ash Gregg, Will Pearson, 2022

Creedence Series, Clearwater

Plan View

Surveyed Length = 422m

Surveyed by: Rob Eavis, Andi Smith, 2022

The third branch is considerably muddier and is an uphill crawl, with a couple of side branches interconnecting with one another. The passage passes under several large helictites before ending in mud, with a faint inlet, likely from the previous branch.

The fourth (most southerly) branch is similar to the ramping passage prior (downslope) to it. Crawling and stooping over damp rock uphill for approximately 50m the passage passes several formations and a small pool fed from drips. The passage terminates with a too tight rift upwards, in which a couple of swiftlets were observed.

There are no further leads off this section of cave.





Scumring water collection
Photo: Rob Eavis



Upskirt – Loose Threads

Length: 351.98m – explored 27th November 2022

Explored by: Ash Gregg, Will Pearson

Location: From the top of the Upskirt pitch (P28), the passage traverses around to solid floor before continuing to another short, roped pitch and on through large passage to the bottom of Jet Stream. Loose Threads consists of a series of parallel passages off of the side of Upskirt in this area, connecting in several places.

JUST before the short roped pitch (P6), after the top of Upskirt, an obvious ramp up on the right branches off the main passage. After a short distance this emerges into the top of a large rift parallel to the main passage. Carefully climbing around boulders the rift can be followed at higher level northwards, or can then be dropped as a 5m pitch to reach the lower level, which can be followed southwards. In addition, on the opposite side of the rift a large window, several metres higher up, connects to an additional parallel passage.

Heading north up the rift the passage reduces in size, passing several large boulders and formations. A significant amount of popcorn covers a boulder floor, with a couple of small, too tight branches on each side. The passage enlarges, coming onto the side of a slope which links through a large window back to the main passage on the right, and on the left slopes up to another parallel passage. This second parallel passage also continues northwards to connect with the main passage through another large window. The second parallel passage also continues southwards, past formations to a boulder-floored chamber, opposite the original ramp and connecting back the first, large rift.

Dropping down the large rift (10m rope required) and heading southwards the passage lowers to a crawl. The passage branches, the main rift continuing, while a very steep sandy slope on the right leads back down to the main passage (10m rope required), emerging as a crawl at low level. Continuing south down the main rift, the passage enlarges, allowing walking. A short climb down and the passage emerges after 30m, of generally sloping downhill, at a T-junction with a larger passage.

Left at the T-junction leads up slope, where the passage quickly reduces, ending at the bottom of an aven. This can be climbed, and is broken into several sections, as the passage winds upwards. Eventually, approximately 20m up, the aven reaches a rift which is too tight to follow.

Right at the T-junction the passage increases in size and slopes downslope. This emerges on a boulder-strewn balcony in the middle of the Upskirt pitch.

There are no new leads off this section of cave.

LOOSE THREADS

Surveyed by: Ash Gregg, Will Pearson, 2022

Dr Yu Fen's Extension

Rob Eavis



On 20th November, after arriving in good time at Scumring Camp, Andi and Rob went for an evening jaunt to resurvey part of the cave near Dr Yu Fen's Mystical Earthly Paradise. Starting at the top end of the large boulder slope above Revival, they resurveyed 709m in total although not quite making it to Dr Yu Fen's. On the way a large ramp between two levels was noted to have not been surveyed, so new legs were placed down this. Halfway down a passage heading north was entered and followed in easy walking passage for 150m, with some fine formations. After a short squeeze an ascending ramp lead back up to the top level, to emerge from behind a large flake in the main passage. Only 211m of new passage was surveyed, but it goes to show that looking again at areas can be worthwhile.

Top: New ramps in Dr Yu Fen's Extension

Right: Strike Passage in Dr Yu Fen's

Photos: Rob Eavis



Cave of the Winds

The connection dive

Martin Holroyd

A **CHANCE** meeting with Andy Eavis in London and the usual banter and reminiscing led the conversation to the next Mulu trip. The dates worked well for me and there was a small diving project to complete. Andy was keen to link Racer Cave to Cave of the Winds through the likely short sump that had been recently found. Light and voice connections had already been made.

Travelling with the first team the meeting place was LHR, T4. With a limited baggage allowance our bundle of tackle sacks was impressive, all necessary for an expedition. The excess came in at over £800. Time to turn on the charm, or rather the faff. With a long check-in queue behind it's amazing how unpacking bags to try to lose kit changes the dynamics. Within minutes the supervisor had us on our way with full bags and hand luggage and no excess to pay. The last time I took cylinders on a plane I was required to leave them empty and simply open the cylinder valves at security. At both check-in and outsize baggage, we stressed, contained cylinders and we were told it was fine and no checks were made.

Arriving in Miri a member of the baggage company greeted us to inform us one bag was still in London and would be sent the next day. Of course, it was the cylinders. After a week of emails, phone calls and no cylinders, the option was for the second team to try. They were able to collect the cylinders, remove the valves and to check them in again. This time it worked and the cylinders arrived.

During this first week in Mulu a number of set-up trips took place. Firstly, a route-finding and pitch-rigging trip with Badger to Racer Cave. This was followed by a set-up trip to Cave of the Winds (CotW) with Andy, Will and Zarris. Having now seen both sumps, we decided to dive upstream from CotW to try to retain some visibility.

Once the cylinders arrived Andy and I made the final set-up trip, taking the cylinders along with the rest of the diving kit. This was ultimately was nothing short of the blind leading the blind and deaf. A few Laps of Eureka Chamber later, the way out was found! For myself at least. Andy kept shouting 'Where are you?' and despite calling back endlessly, he was oblivious and continued wandering around in the wrong place. We eventually met up again and did make it out.

For the day of the dive a team headed to Racer whilst I was supported to the sump in CotW by Derek and



Martin Holroyd in the Cave of the Winds sump pool. Photo: Zarris Kem



Martin in the Cave of the Winds sump pool
Photo: Zarris Kem



Will. Kitting up there was cramped and muddy, but it was possible to keep out of the water. The underwater route dropped down a rift, went forward a short way then through a rock arch to a low, steeply rising slope. A pre-placed light could be seen above, indicating the way on, and the connection was made. I was met by Andy, Zarris, JJ and Badger and, after a few photos, we headed out with the dive kit.

This had been a fun project despite the initial difficulties with the cylinders. Whilst relatively short at 15m long and only -3m depth I personally would not recommend a free dive due to the low nature of the passage on the Racer side and the low arch. I called it 'I can see the connection', partly because I could and also it is the lyrics from a favourite Stiff Little Fingers record I found myself singing underwater.

Thanks everyone who helped.

Backing into the sump pool. Photo: Will Pearson

Connection Efforts between Easter Cave and Lagang's Cave

Derek Bristol

IT is clear that the southern end of the Gunung Api ridge is underlain by a single master cave system, but proving this through the integration of several of the more significant known caves has been elusive at times. The 2022 expedition had a major success by connecting the Racer/Easter system to the Wind/Clearwater system via a sump dive. That feat was accomplished early in the expedition, leaving several weeks to focus on the next most important opportunity: connecting Easter Cave to Lagangs.

Easter Cave sits above Lagangs and there are a few passages in Easter that sit directly above large passages in Lagangs. A connection between these caves was prophesied in 2016 when the Road to Lagangs passage was discovered in Easter Cave. This led to the Express Elevator, a 90m pit that comes within 10m of connecting to the Fast Lane in Lagangs. Another passage from the bottom of Express Elevator was explored in 2019 following a howling wind, but this frustratingly went to a new entrance in the cliff face halfway between the two largest Lagangs entrances, avoiding a connection. In 2022 several day trips were taken to Lagangs to push leads under Easter in the hopes of finding a way up, and a few day trips as well as two camp trips were made into Easter Cave to push down.

Lagang's Cave: Disappointment Passage

A **SHORT** distance along the boardwalk from the west Lagangs entrance is an obscure hole that leads up into Disappointment Passage. A handful of leads had been left, but required short climbs or rope-tossing tricks to access. A few of these holes were inspected, but were simple alcoves. One of the high leads was accessed with help from a shoulder stand and led to passage with good airflow. A recoverable survey station was not found, so a data-only survey line was run to the narrow entrance west of this lead.

The passage quickly split with the right fork going past a narrow aven with a lead above and ending in a flowstone constriction with strong airflow coming through a tight constriction on the right-hand side that could be easily opened with a hammer. The left-hand fork went up a short climb to the base of another aven that bifurcated higher up. The left side of this aven was free-climbed to a perch about 15m up that connects to the right side of the same aven, and a short horizontal passage also connects to the top of the previously observed aven from the right-hand branch. The aven continues higher, but becomes narrower and would require direct aid in poor quality rock. No airflow was detected and this lead was not pursued.



Formations in Road to Lagangs at the top of the Express Elevator
Photo: Hazel Barton

A return trip was made later and the formation choke at the end of the right-hand branch was enlarged with a hammer to allow passage. The strong airflow from this branch was found to be coming from a very narrow rift in the floor. This was pushed for a short distance, but became too tight with poor prospects for enlargement. The main passage continued around a corner and up a flowstone ramp into a progressively tighter rift until it became too tight and blocked by flowstone. No airflow was detected, so the area was declared finished and the handline that was used to access the initial climb-up was removed. This area was dubbed Connection Fever.

Lagang's Cave: Fast Lane and Fast Lane Aven

THE closest point of connection between Easter Cave and Lagangs Cave is between the bottom of Express Elevator in Easter and the Fast Lane of Lagangs. A very careful exploration of holes and alcoves along the length of Fast Lane was conducted including a short dig effort, but nothing with any real potential was uncovered. The west wall of the main passage in Lagangs was also followed and pushed in the hopes of finding a rift that might connect to higher level passages in Easter, but this also did not produce any leads of interest. There are still high avens in some areas towards the north end of the main Lagangs trunk passage, but these would require heroic aid climbing efforts to reach, and if they did connect to Easter Cave then it would almost certainly be more efficient to find the connection area from above.

There were several question marks left on the map in Fast Lane Aven that held the possibility of connecting to Easter Cave so a couple of days were spent exploring in this upper-level network. The first trip up into Fast Lane Aven used the route that goes through Around the Houses, which does not require rope but does require some exposed climbing on razor edges. A narrow side passage was surveyed for about 50m to a climb-down into a complex junction room. A return trip was made later by traveling up to Disappointment Passage and then down a pit in the floor that leads to this same area. The pit out of Disappointment Passage was described as free-climbable, but was found to be quite steep and exposed and not recommended even with a handline. The complex junction room was surveyed and reconnects with the huge rift at the start of Fast Lane Aven.

A west-trending passage was also surveyed out of the junction room, following airflow up through breakdown to an obscure entrance in the west face of Gunung Api. At the top of the rift at Fast Lane Aven, about 25m over the Fast Lane boardwalk, is a steep but low ramp that is a lead that may be worth pursuing. Safe access to this ramp would require a few bolts and a lead rope. The far side of this vertical rift aligns with the ceiling of the Fast Aven and appears to pinch down. Retreat from this area was made using the Around the Houses passage and the hand line was retrieved later. Around the Houses is recommended as the best route for accessing Fast Lane Aven in the future.



Easter Cave: Road to Lagang's and Pass Go

AT the far end of the Road to Lagangs is the Express Elevator. Above this pit there is a series of three ramps that require direct aid to access. The eastern-most of these was climbed in 2019, but reportedly did not connect to the other two ramps. A bolt climb was made into the western-most ramp, which connects to an overlook at the very top of Express



A meal at Camp Gusher in Easter Cave, and Derek hanging water at Camp Gusher in Road to Lagangs. Photos: Hazel Barton



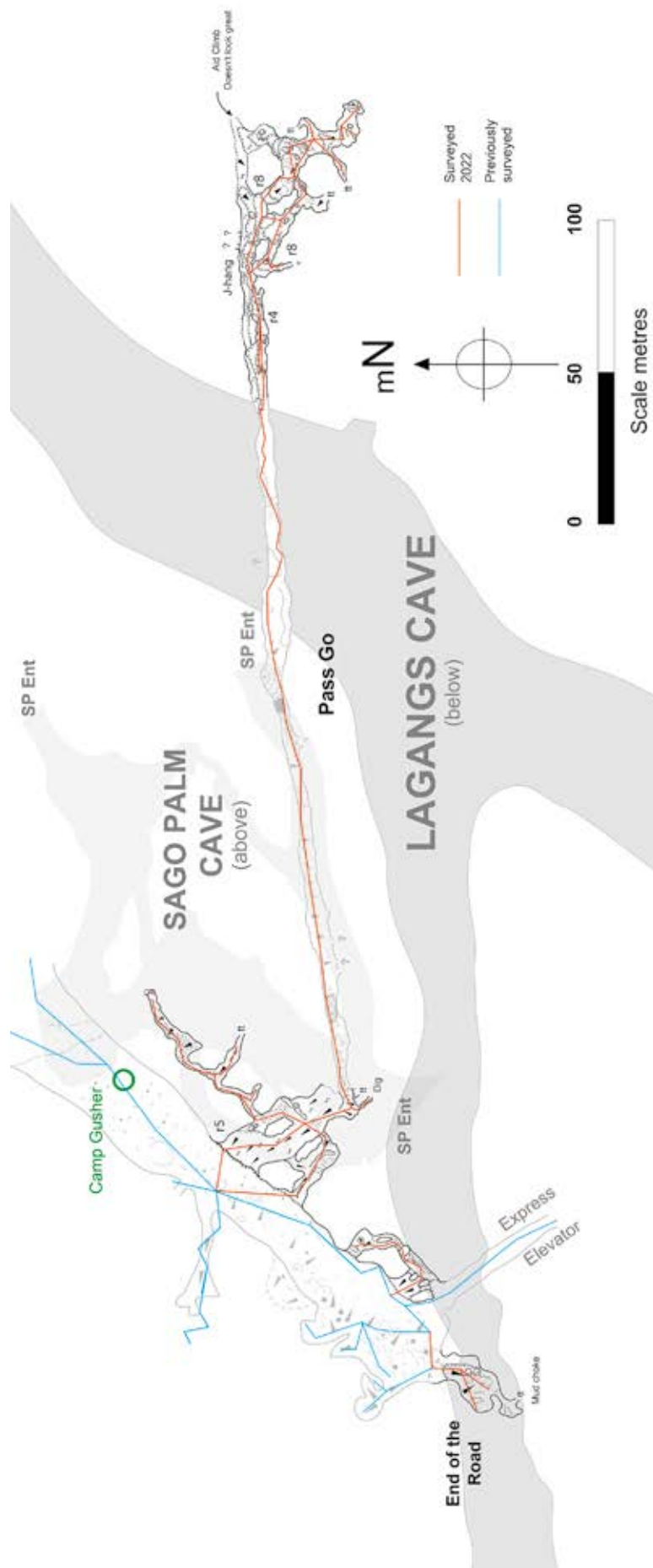
Elevator. A short passage heading back east was surveyed to a hole that overlooks the Road to Lagangs, but no other passages were found so the climb was derigged.

Derek rigging a traverse at the end of the Pass Go extension. *Photo: Max Koether*

The middle ramp was also aid-climbed to a steep slope that made an obvious connection back to the eastern-most ramp. This was surveyed and provided access to the Pass Go area at the top of the first ramp. At the very top of this first ramp are a series of holes in the ceiling that seemed to be attracting a lot of swiftlets. A study of the map shows that the ceiling at the top of the ramp is within only a few metres of the bottom of Sago Lilly Cave above. Several efforts were made to push into these holes and a little bit of passage was found, but it became too tight and did not seem to have



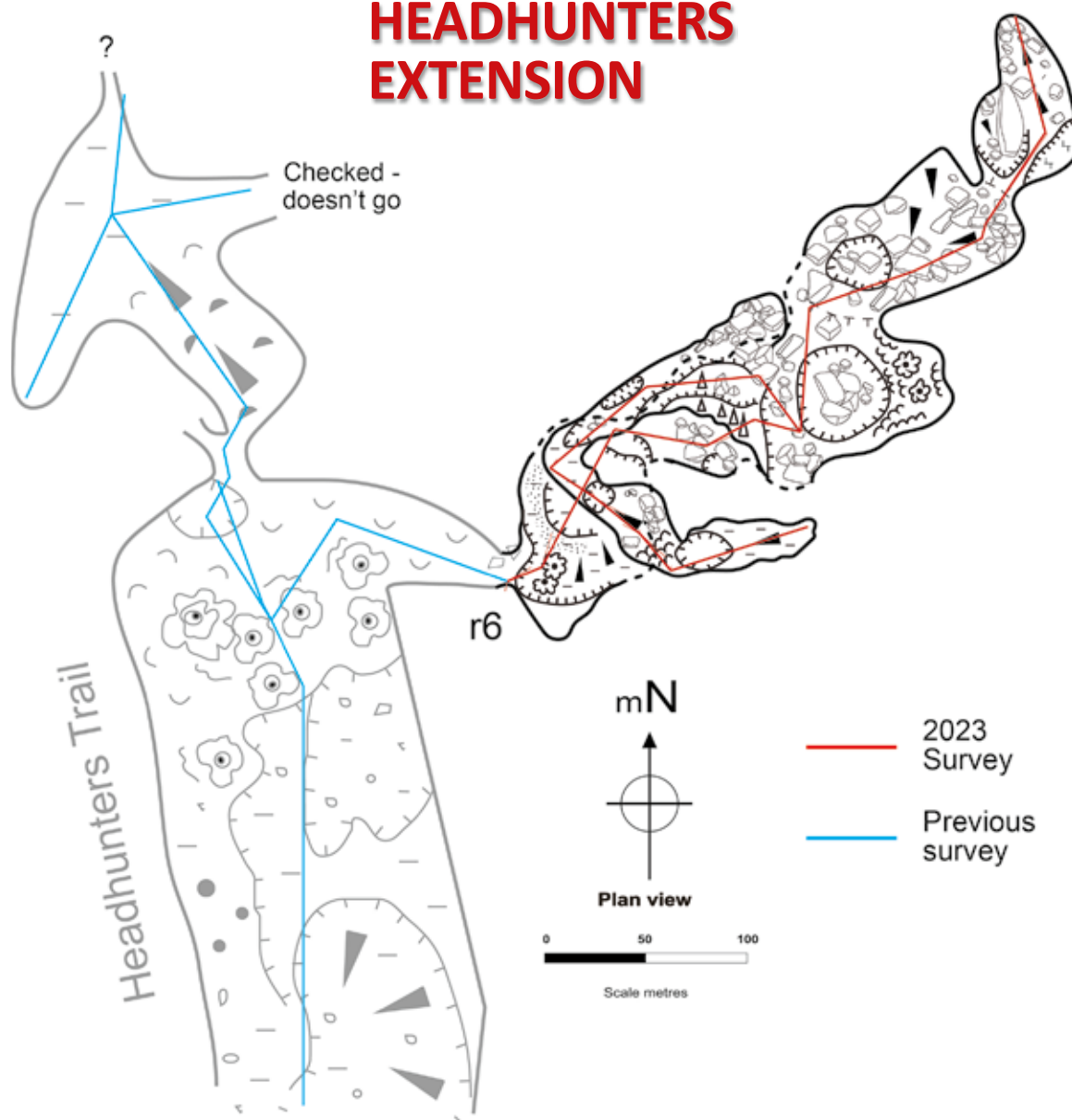
Relaxing at Camp Gusher after a day's surveying. *Photo: Hazel Barton*





Max on the mud traverse around the drop
into Lower Easter. Photo: Hazel Barton

HEADHUNTERS EXTENSION



air. A three-day camp was held based out of a flat area in the Road to Lagangs that is just 20m east of the main ramp into Pass Go. The camp was named Camp Gusher after it was discovered that an intermittent waterfall arises right next to camp during heavy rain and makes an excellent shower. A ceiling drip in another nearby aven is reliable enough to provide water for camp by placing Darren drums below.

The tall rift at the end of the previous survey in Pass Go continues to the east but required rigging traverse lines and J-hangs to safely explore. The rift continued for about 100m to the east with several pits dropping down to lower levels. This area is directly over the large trunk passage in Lagangs Cave and it was hoped that a pit series would provide a way down. The area was thoroughly pushed, but no continuation could be found. The eastern limit of the rift near the ceiling level was not accessed due to running out of rope, hardware, and the nerve to traverse the final exposed climb to reach it, but it did not look promising.

Back at the main ramp up to Pass Go another side passage was discovered and surveyed to nearly complete a loop back into a fractured area along the south wall of Road to Lagangs. A few side passages went to vertical rifts that were too tight and held little promise.

Easter Cave: Squalor Bypass and Headhunters Passage

A **SECOND** camp trip was conducted out of Camp Gusher, where the west end of Road to Lagangs was pushed hard but no significant passages found. A hard look was made along Squalor Bypass and a few short passages were surveyed going east, but these became too tight to follow. The final hope for this expedition was a blowing lead at the far end of Headhunters Trail that was left as a 10m pit. This was



rigged and descended into a very fractured room filled with breakdown. Crossing an exposed slope led to a jumble of rocks with loose walls that eventually ended. Another passage out of the original room led to a rift that could be free-climbed to an upper level. The passage continued to corkscrew higher, but eventually ended with no leads left unexplored.

Traversing along the main passage and Max and Hazel testing the pH of bird guano at the camp in Road to Lagangs, Easter Cave. Photos: Max Koether

The top of the 10m pit has very strong airflow, but there was no success in following this air. It's certainly possible that something significant in this area was missed. In order to connect Headhunters Trail to Lagangs Cave will require finding leads that are descending, but most of the potential in this area seems to be heading in the wrong direction.



Climbing out of the entrance to Easter Cave
Photo: Chris Howes

Lagang's Cave

Scorpion Dig

Rob Eavis

15/11/2022

Rob Eavis, Andy Eavis

LOCATED at a sharp right-hand bend of the showcave, just before it reaches Fastlane, is a chamber off to the north-east. At the eastern end of this chamber a walking sized passage raises up along the bed heading east which ends in a blockage of mud and rock. This bedding looks to be the same as much of the southern end of Easter and maybe that of Sago Palm, making it an enticing spot. Also there is a draught, although quite slight.

Without tools there was no hope of moving the rocks, so mud was dug out of the floor underneath a perched rock and access was eventually enabled through to a small (4m across) chamber beyond. At the back a small rift could be climbed to a boulder choke from which water issued. At the very top a tiny hole between boulders showed a passage continuing up to the east, but access was too dangerous and scaffolding may be necessary to pass more safely.

A few weeks later a team went in and a capped the perched boulder near the entrance making access to the chamber easier.

1/12/2022

Rob Eavis, Andi Smith

NEAR the start of this passage but still almost in sight of the showcave walkway a drippy aven was free climbed by Andi to 6m high but unfortunately the way on east and upwards closed down to too-small phreatic tubes.

Fifty metres north from here is a tall rift passage which was marked as a dead-end, but it carried a slight draught. A wet pool was traversed around and the end of the rift free-climbed to 12m high to enter a small passage heading north. After a short distance this intersected another rift passage in the roof. To the left (west) dropped down to a mud floor with no obvious way on, whereas north headed up through some more demanding rift climbs to a tightening in the roof but the way on continued with the draught. All pretty hard work without bolting equipment and only low prospects remaining.



Andy emerging from the dig through to Scorpion, and looking through the squeeze just beyond the breakthrough point
Photos: Rob Eavis

Porcupine vs Leech

Ash Gregg

Length: 57.91m – explored 29th November 2022

Explored by: Ash Gregg, Andi Smith

Location: Take undercut passage northeast until it reaches David's Loop. Shortly after starting the loop (going clockwise) the crawl enlarges to walking passage, passing the bottom of the aven, the passage then continues over boulders around the loop.

PORCUPINE vs Leech is an aven which can be free-climbed (with care). At the bottom of the aven there is clear evidence of porcupine habitation, indicating an alternative route to the surface somewhere nearby. Approximately 10m upwards the passage twists around and back on itself as it continues upwards for another 10m. Upon reaching the top a parallel aven can be reached via a connecting passage, climbing past large stalagmites. This passage drops for 5m to a large quantity of guano with no further routes onwards. There are no new leads off this section of cave.



Looking down the tall rift
Photo: Rob Eavis

3. SURVEYING

3D Survey of Clearwater Cave

Roo Walters

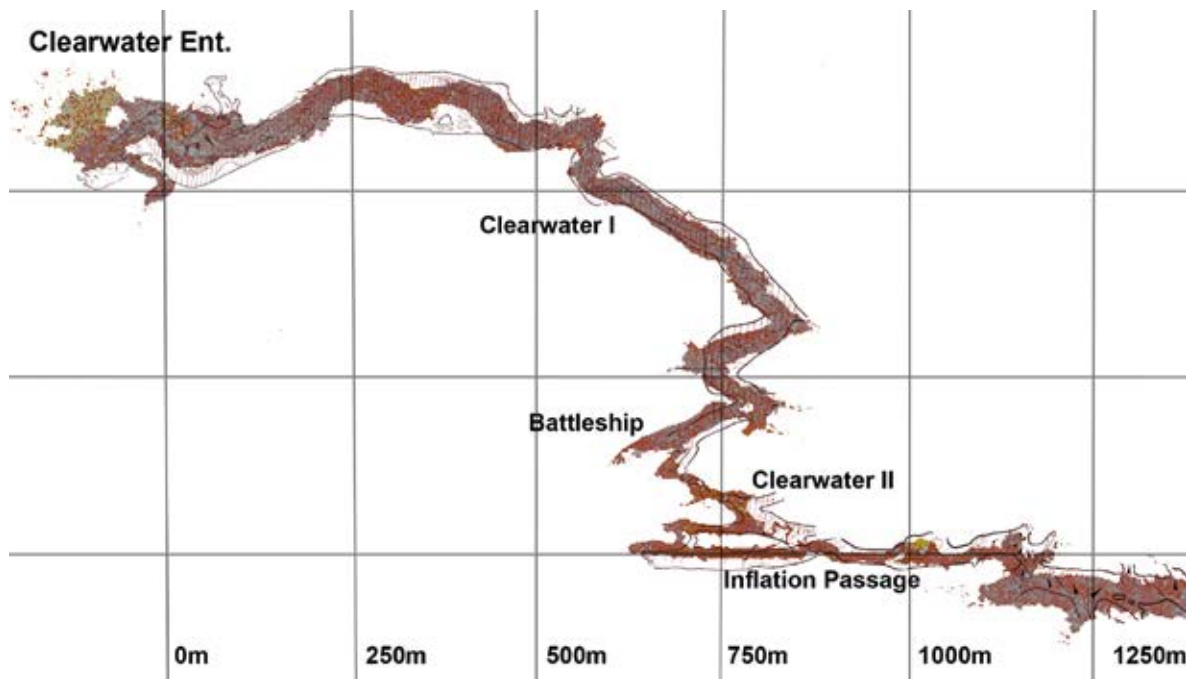


HAVING completed surveys of the large chambers of Api in 2015¹, some deliberation took place as to what to survey next. The logic subject was a 3D survey of Clearwater from the main river entrance to Snake Track a distance of almost 5km. We realized from the outset that this would be the biggest single 3D project so far, and let's be honest, it was Andy Eavis encouragement that made this happen. The main concern other than the huge size of the project was storage capacity on the Riegl VZ-400 scanner – at the point density we have found to be the best compromise between detail and volume of data, we can get about 100 scans on its internal disc drive, this and having enough power. Though we have never actually run out of power on a trip, it remains a constant concern. The issues were really all logistics. Roo did not want to purchase new specialist Riegl batteries, notwithstanding that airport security has taken a huge dislike to them in recent years, even with airline certification to carry them, they now cost over £1500 each. Therefore, we arranged to purchase four large (12V, 18AH) motorcycle batteries in Miri instead. These proved to work very well, if somewhat heavy. We could get about 70 scans out of one battery which worked out very well because in this terrain 60 scans per day is frankly enough as it is always important to stop before one gets too tired as mistakes are always a big headache.

Roo Walters laser scanning in Clearwater Cave. Photo: Chris Howes

We started with the easy end, Clearwater. At first the water levels proved very high so we refrained from any river crossings, though John Beavan and Roo found the high water enormous fun as long as we weren't carrying anything. We surveyed through to the beginning of Inflation Passage via day trips from Clearwater. It was all straight-forward if time-consuming. During this time we were able to point Rob Eavis and Andy Smith in the direction of a couple of leads, oddly or perhaps, as usual, the unexpected one just off the show cave path at the entrance was the one that went.

Largely due to high water, we took a trip to Snake Track to begin the survey from that end. It was clear that no-one, had been to the entrance from the outside and it is not clear now that anyone ever had before. So, it was a good couple of hours before Veno and Jimmy located it less than 300m away. We made our first camp in the entrance. The camp at Upper Snake Track entrance proved to be a bit damp, but as we were to see, the whole cave was dripping after the heavy rain. That day we surveyed the entrance series into Revival and the following day continued surveying into the cave. Will Pearson generally found the route, whilst Roo



and Jimmy surveyed. We had expected to be able to climb down into the lower part of the cave and survey on into true Revival but found the 20m climb impossible as it was teeming with water, but we were able to complete a comprehensive survey of this area of the cave.

Andy took up the reins next and departed on a two night surveying trip from Snake Track to Inflation whilst Roo processed data back at base. Andy, Veno and Rida were able to survey all the way to a rendezvous point at Junction Passage, where he met up with Roo and Badger who continued the survey out towards Clearwater. It all worked remarkably well.

The resulting scans have been assembled and they look superb. A fly-through will be assembled in due course, but this is not a straight-forward job given there are over 400 scanning stations, almost 5km of passage and 9 billion points of data.

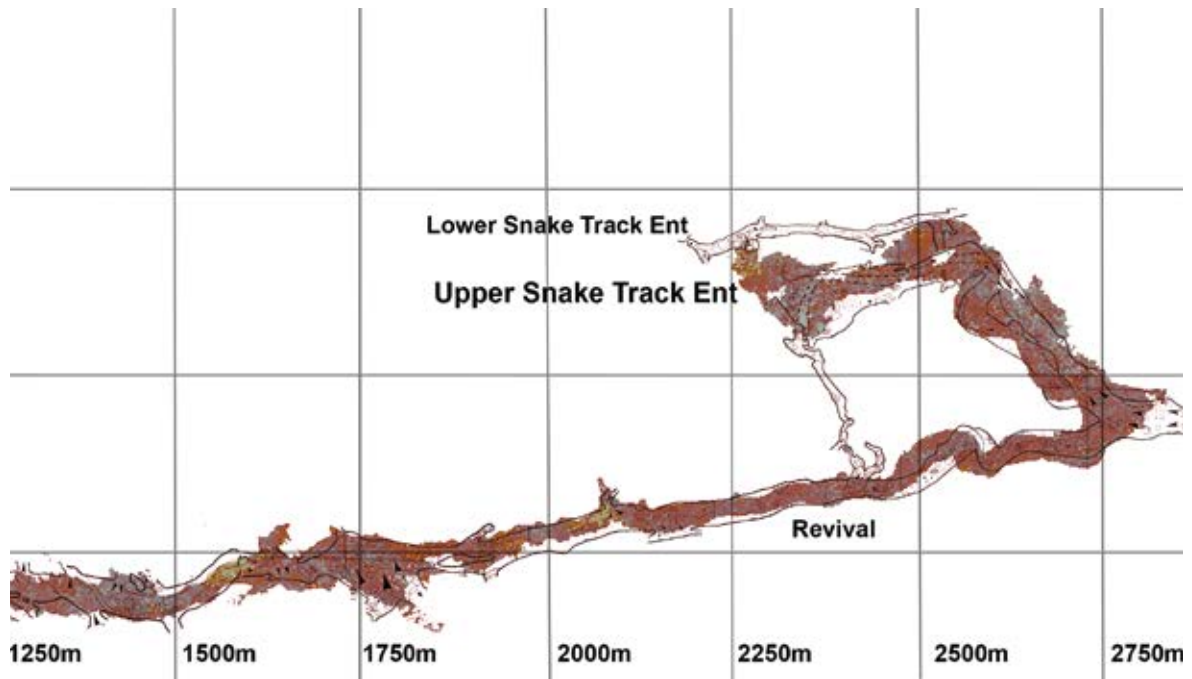
In the process of working at HQ, during the usual friendly banter about the longest, biggest, deepest caves in the world, the author overheard the comment 'Clearwater must be the longest badly surveyed cave in the world'. Curious to see how the original 1980's survey matched up to the 3D scan, Roo plotted one against the other. The results are shown in fig 1. Whilst there are areas that are marginally displaced the overall match is quite staggering and whilst it is impossible to be precise as the survey notes for the original survey have gone missing (hence the resurvey project), this simple test suggests a straight-line distance between CW and Upper Snake Track differs by as little as 5m, surely a great testament to the original surveyors and cartographers. A simplified point cloud set will be added to the Surverx data set, as Rob Eavis has done for Api Chamber, in due course and the data set is available for reasonable scientific work.

Given the success we intend to augment the survey in due course with a firstly a traverse from Junction chamber, through Hyperspace and out of Cave of the winds and secondly from hyperspace and out of Berants in the Paku Valley.

1. WALTERS, Roo. 2016. '3D Scanning of Api Chamber & Sarawak Chamber', *Mulu Caves 2015*, pp48-51



Roo laser scanning in Clearwater Cave. Photo: Chris Howes



Resurvey Project Achievements

Rob Eavis

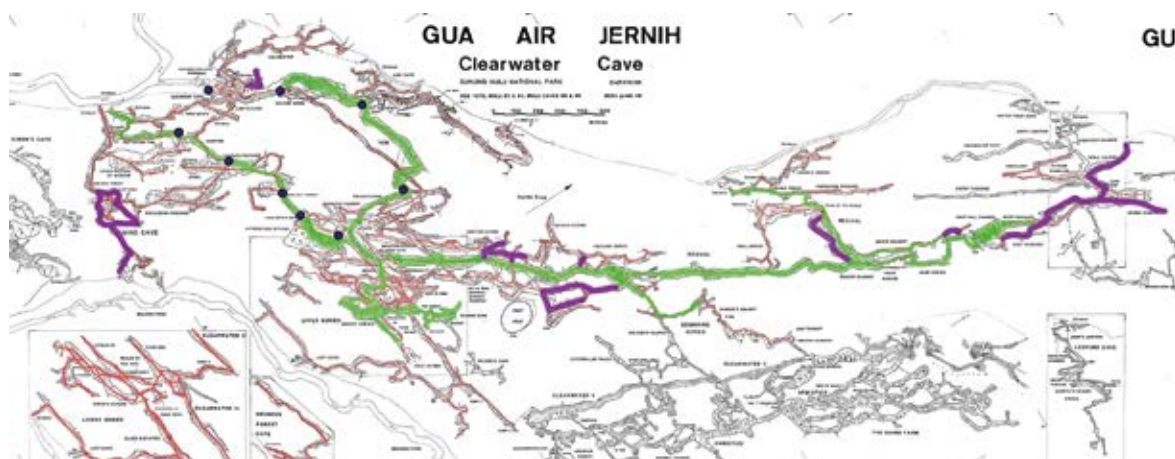
THE loss of raw surveying data from early Mulu expeditions means that a large proportion of the modern survey dataset, mostly in Clearwater Cave, relies on 'fake' data – measurements and coordinates obtained by reverse engineering of a drawn 2D map. Whilst it has been proved that this gives a generally accurate rendition of the cave in the Surverx model, there are problems – most notably that all stations in a fake dataset are 'virtual' and cannot necessarily be located on the ground. This makes it almost impossible to tie in accurately any new surveys or explorations.

An ongoing project therefore is to resurvey all of these 'lost' passages to help to modernise the survey model, and this expedition put this aim high on the project list.

Cave file name	metres
Edge_of_the_World_-_resurvey	287.27
151122DNa_East_passage_resurvey	660.26
161122DNa_Northern_Entrance_Resurvey	518.66
161122DNb_Entrance_Back	215.00
No_Justice_extensions	52.89
20221130REa_Wind_Cave	935.08
20221120REa_Dr_Yu_Fens	709.71
20221117RAN_Gnome_Oxbow	310.65
unclear_passage	121.23
20221122AMa_Volcano_Series	91.33
20221122AMb_Junction_Cavern	341.76
Total	4,243.84

In total 4,244 metres of cave was resurveyed, split over 11 different trips. This includes continuing the new line from West Passage through to and out of the Northern Entrance of Clearwater.

It is worth noting that during seven of these resurvey trips more cave was discovered, totalling 998m.



Clearwater Cave survey overlay showing all the parts of the cave that need resurveying (those with a red centreline through) and those that have been completed so far. Purple passages were completed during this 2022 expedition and green passages were completed previously.

4. SCIENCE

Mulu Caves 2022 Science Report

Andrew Farrant, Hazel Barton, Max Koether, Andrew Smith, Stein-Erik Lauritzen, Christos Pennos, Andrew McLeod and Jo White

THE scientific objective of the Mulu Caves 2022 expedition was to examine the factors that could be responsible for the continued modification and enlargement of tropical caves, and whether this is due to geological or biological processes. Previous expeditions to Mulu had identified features in the caves that suggested that secondary enlargement of the passages was occurring, either from condensation corrosion or from acids leaching from extensive guano deposits throughout the cave. Several researchers employed a variety of techniques to examine the potential mechanisms for secondary speleogenesis. A detailed examination of the geomorphology for evidence of subaerial dissolution identified corroded walls and stalagmites, corrosion pitting, and anomalous scallops. Water samples demonstrated that water condensing on the passage walls was enriched in nitrate, when compared to drip water and atmospheric condensate. The biogeochemistry of the guano suggested that there were significant differences between the bat and bird guanos found within the caves, with the bird guano being much more aggressive. XRD data from mineral precipitates associated with the bird guano support previous studies that had demonstrated that ammonia was being released into the atmosphere. More detailed analysis of the guano aims to identify what geochemical and microbial processes may be contributing to dissolution. It is anticipated that this work will initiate a much longer-term study to understand the activities that lead to the formation of the enormous passages observed in these caves.

Background

THE study of erosion, transport and deposition in the evolution of landscapes is referred to as geomorphology, while biogeomorphology is more specifically used to describe the impact of biological factors on the landscape. Karst geomorphology is known to be heavily influenced by both processes, with an emergent understanding of the important role of microorganisms in the production of carbonic and sulphuric acids in speleogenesis. Zoogeomorphology is a term used to describe landscape remodelling processes brought about by animal and human activities, such as burrowing, digging for food, or even construction.

In 2012, Joyce Lundberg and Don McFarlane identified what appeared to be a zoogeomorphic origin for hemi-spherical pockets along the walls of the Gomantong Caves, Borneo (Figure 1A). They called these pockets *apse flutes* (derived from the domed semi-circular recesses common in gothic churches) (Lundberg and McFarlane 2012), which are common to tropical caves and are found where significant bat and bird populations roost. They suggested that the flutes were produced by the birds and bats that roosted in them, which cause condensation corrosion through a combination of exhaled CO₂ and moisture, along with an increased local temperature. Their studies suggested that this process could generate an erosional rate of 1 m in ~200,000 years and could account for as much as 95% of the post-speleogenetic enlargement of these caves (Figure 1B).

The caves of Gunung Mulu National Park are home to large bat populations. These are largely confined to the near entrance zones, whereas millions of cave swiftlets roost throughout the entire cave length, including the black-nest (*Aerodramus maximus*) and white-nest (*Aerodramus fuciphagus*) swiftlets. During previous Mulu Caves expeditions, we realized that there was a clear relationship between the observed rock

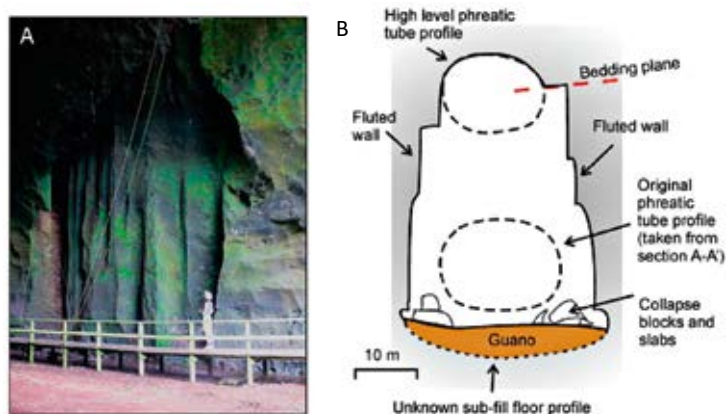


Figure 1. Images taken from Lundberg and McFarlane (2012). A) Wall apses as seen in Gomantong Caves. B) The impact of biogenic enlargement on original phreatic passage structure (as indicated by dashed lines), with the resultant enlargement through bat and bird activity (followed by collapse) obscuring the original passage morphology.

dissolution morphology and the presence of swiftlet guano (Figure 2A). At the bottom of every etch pocket was a small pile of guano. Indeed, this downcutting could be so aggressive in places that rock pinnacles formed, which can be a common obstacle to exploration throughout the caves (Figure 2B and Figure 3).

There has been limited research examining the impact of bird guano on stone, other than the effects of pigeon guano on masonry and concrete. Bird guano is mildly acidic from the presence of uric and phosphoric (H_3PO_4) acids, with a pH that can vary from 5 – 7 (depending on the diet of the bird) and when fresh (<2 weeks) can etch stone. The destructive activity of bird guano is extended if the guano is kept moist, which is likely in the high humidity environment of

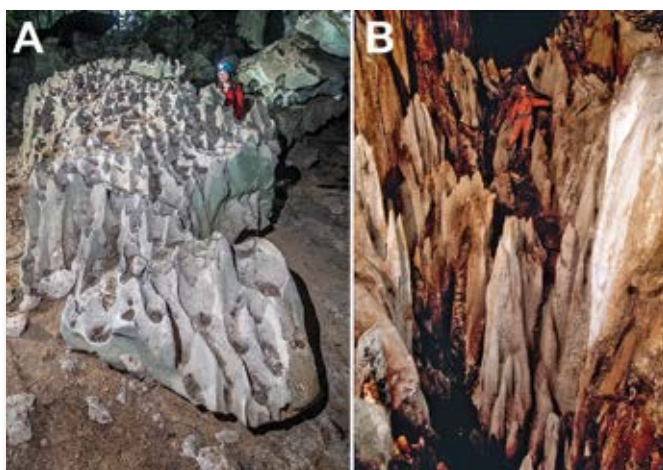


Figure 2. The impact of bird guano on rock surfaces within the Mulu caves. A) Initially, bird guano starts to accumulate on surfaces, creating pockets where the material begins to accumulate. B) In places these pockets become so large and deep that the interconnected limestone bedrock forms a series of spires. Photos: A Chris Howes and B Dave Bunnell



Figure 3. Etch pockets infilled with guano. Lagang's Cave. Photo: Jo White

the caves (>99% relative humidity). Nonetheless, the presence of high organic carbon and uric acid within the guano is likely to drive high levels of microbial activity. In particular, the high concentration of uric acid facilitates its breakdown into ammonia.

If the microbially generated ammonia was oxidized by ammonia-oxidizing bacteria and archaea into nitrite, this could in turn oxidize into nitric acid (HNO_3) by members of the *Nitrobacter* family, which has been shown to damage marble and limestone monuments and cement structures, such as bridges, from bird guano. There is a poorer understanding of H_3PO_4 acid production by microbial activity in bird guano, although the myriad of authigenic phosphate minerals found in association with guano suggests phosphoric acid is important. Together, these data suggested that the microbial decomposition of the swiftlet guano leads to the production of HNO_3 and H_3PO_4 within the guano, which in turn causes dissolution and creates an erosional pocket where material accumulates. As this pocket becomes deeper, it allows the formation of anaerobic conditions in the guano, which can allow a full nitrogen cycle to develop and potentially accelerate acid production. Our goal of the Mulu Caves 2022 Expedition was to determine if this activity was responsible for the dissolution observed in the caves.

With a multi-disciplinary team, we therefore returned to Gunung Mulu to carry out an extensive physical, geochemical, and microbial assessment of the caves and determine if the guano was indeed responsible for the secondary passage enlargement observed within these caves. Our results suggest that, contrary to a rather simplified model of acid production and local dissolution around guano deposits, an interconnected system of macro- and microbiology, along with geochemistry, airflow and other environmental conditions is leading to dramatic passage enlargement through a process of 'zoogeomicrobiospeleogenesis'.

MICROBIOLOGY

TWO primary sample sites were examined to determine there were significant chemical differences between the bat and bird guano.

Bat guano: The bat guano site was in Deer Cave, along the large guano slope near the tourist trail. The depth of the guano pile was significant, being over 50 cm from the surface to the contact with the underlying bedrock. Physiochemical measurements indicated that the guano pile was acidic, with a surface pH of 3.6 and 45% water (w/w) moisture, which dropped slightly to pH 3.4 and 33% moisture content at the guano-rock interface. To explore the chemistry of the guano pile, we examined the mineralogy of the guano-rock interface. At the top of the guano pile, a crust of crandallite and calcium aluminium oxide was formed. Crandallite $[\text{CaAl}_3(\text{PO}_4)(\text{PO}_3\text{OH})(\text{OH})_6]$ and calcium aluminium oxide are rich in aluminium, which is difficult to reconcile with the chemistry of the Melinau Limestone. The aluminium is probably derived from the leaching of aluminium-rich fluvial clays (the 'cricket muds' of early Mulu expeditions) and decomposed sandstone and siltstone cobbles present throughout many of the caves. Another potential source is volcanic ash, which is known to have blanketed the Mulu region around 189,000 years ago and is preserved in many places within the Clearwater cave system. This ash is rhyolitic in composition and rich in aluminium oxide.

At the bottom of the guano pile, where it interacts with the host rock, the minerals produced were hydroxyapatite $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$, variscite $(\text{AlPO}_4 \cdot 2\text{H}_2\text{O})$, and brushite $(\text{CaHPO}_4 \cdot 2\text{H}_2\text{O})$, all of which are indicative of phosphoric acid attack of the limestone. To look at microbial activity, we did direct cell counting of the guano. The top surface contained $\sim 2.1 \times 10^{10}$ cells/g material, while at the bottom (rock contact) contained $\sim 3.2 \times 10^9$ cells/g. These high numbers are consistent with the number of microbial cells found in animal faeces.

Bird guano: The bird guano site was along the Road to Lagang's in Easter Cave. The birds appear to come into the cave from the Express Elevator entrance and possibly from above, via Sago Palm Cave. While there was no connection with Sago Palm, the caves were less than 9 m apart and there was a lot of bird activity in the vicinity of the presumed connection. The result is a lot of guano spread across the whole passage, with significant evidence of guano weathering. Several guano piles were investigated, which contained similar chemistries and microbiology (Figure 4). The guano piles were flatter, without the piling observed with bat guano. The swiftlet guano was also shallower, generally 15 – 20 cm in depth. Physiochemical measurements indicated that the bird guano was wetter and much more acidic, with a pH at the surface of 1.9 and 59% moisture. The pH and moisture content increased slightly at the guano-rock interface, to pH 2.7 and 66%. The increase in pH is presumably due to buffering from the limestone, while the higher water content is consistent with bird guano.

Where the guano contacted the host rock at the bottom of the pile, the mineralogy was consistent with that of the bird guano, with only hydroxyapatite being detected; however, at the surface, the mineralogy was very different. At the top of the pile, XRD indicated the presence of tetramethylammonium carbonate $[(\text{CH}_3\text{CH}_2)_4\text{N}(\text{HCO}_3)]$, ammonium calcium phosphate $(\text{CaH}_4\text{NO}_4\text{P})$, and calcium hydride nitride (Ca_2NH) . These minerals suggest a much more important role for nitrogen metabolism in the bird guano, possibly driven by the breakdown of uric acid to



Figure 4. One of the bird guano piles examined in the Road to Lagang's, Easter Cave. The aggressive down-cutting of the underlying rock is obvious. Photo: Badger Radmall

ammonia. Direct cell counting indicated that the top surface contained $\sim 5.4 \times 10^7$ cells/g material, while at the bottom (rock contact) contained $\sim 4.9 \times 10^7$ cells/g. These numbers are two orders of magnitude lower than the bat guano, and may be related to the low pH and high amount of hydroxyapatite minerals, which can have an antimicrobial effect.

Air chemistry: One of the goals of the expedition was to determine how nitrogen could be mobilized in the guano, and we built a bespoke air condenser to condense atmospheric water for chemistry. We had originally planned on bringing a Peltier cooler, but didn't feel we could bring it on a plane, so used ice in the caves instead. The ice worked moderately well, but only a tiny amount of liquid could be collected over many hours. We therefore focused on collecting material directly over the guano piles.

We set up the condenser ~ 3 mm above the bird guano pile in Easter Cave. Over the course of 4 hours, we were able to collect ~ 100 μ l of condensate, which was not sufficient for analysis. Instead, we placed a litmus test strip in the liquid which suggested a pH >9 . We then started wetting litmus paper and holding it directly over the top of the guano piles (Figure 5), which also indicated an alkaline pH (although none were as high as the condensate). The release of ammonia from the guano piles had previously been identified by Lundberg et al., (2022) who modelled an ammonia plume in Deer Cave associated with the large *Chaerephon plicata* bat colony. They estimated that the total flux of ammonia over 24 hours was 12.26 ± 5.66 g NH_3 . Whilst this relates to a single bat roost, it is indicative of the enormous amounts of ammonia that could be produced throughout the caves of Mulu by the decay of the swiftlet and bat guano.



Figure 5. Litmus paper wetter and held directly above bird guano deposits in Easter Cave. Photo: Max Koether

We had initially considered whether the decomposition of the uric acid in bird guano was leading to the production of nitric and phosphoric acids, but the pathways to uric acid breakdown generate significant quantities of ammonia, rather than nitrate. The oxidation of ammonia to nitrate (nitrification) requires oxygen, which is unlikely to be obtained within an anaerobic guano pile. We therefore wondered whether the ammonia was sorbing onto surfaces within the cave, whereupon nitrification to nitrate, a multi-step process that produces acid during the release of protons. This hypothesis could explain the highly corrosive features observed on the limestone throughout the Mulu Caves.

To determine if this is happening, we are in the process of identifying the microbiology of the bird and bat guano deposits, and determine whether species capable of uric acid breakdown are present. A return trip will further allow us to sample the microbiology of surfaces within the caves to determine if nitrifying species are present.

CAVE PASSAGE MORPHOLOGY

WORK by previous expeditions has often focussed on the geomorphology of the Mulu caves. This work clearly demonstrates that the caves are normal epigenic caves formed by fluvial activity, with locally significant paragenetic development caused by influxes of sediment. This has created the distinctive notches and paragenetic canyons seen throughout the Mulu caves. The impact of guano has been previously noted, with the development of alteration crusts on the bedrock with unusual phosphate rich minerals including hydroxyapatite, variscite and brushite amongst others. A closer examination of the cave passage geomorphology over recent expeditions has identified a suite of features that suggest that the impact of the guano is more significant and that significant secondary dissolution has occurred since the passages were formed by fluvial activity. These features include corroded speleothems and wall rock, dissolution rinds & alteration crusts, and anomalous scalloping and fluting, with sufficient dissolution in some areas to create 'bone-yard' type passage morphologies.

This expedition focussed on a more detailed examination of cave passage morphology to look for evidence of secondary post-abandonment modification of the cave. The most obvious indication is the presence of corroded speleothems. In many cases, the internal banding of the speleothem has revealed by later dissolution. Numerous examples can be seen, notably in the lower levels of Racer Cave (Figure 6) and in Stone Horse Cave.

In some cases, stalagmites can be observed sitting on a bedrock stump, for example at the head of the Ronnie's Delight pitch in Clearwater Cave as highlighted in the Mulu Caves 2014 expedition report. Two small collections of stalagmites occur here, none of which are greater than 1 metre high, but which have clearly been re-dissolved (Figure 7). Careful examination reveals that the lower half of the 'stalagmites' are formed out of the bed rock while the upper half are clearly calcite. The implication is that the bedrock



Figure 6. Corroded stalagmites, Racer Cave. Photo: A. Farrant

around the stalagmite has been lowered by secondary dissolution after its formation, whilst the stalagmite protected the bedrock it grew on, creating a bedrock plinth.

Dissolutional scallops are a common feature observed in many epigenic caves. Their size is related to the velocity of fluid flow, with smaller scallops formed by higher velocity flows. In many of the active river passages, small vadose scallops are common on the passage walls; however, they are remarkably absent in many of the older, high-level passages in Mulu, even in passages with vadose notches. A good example is the Clearwater River passage where scalloping is present in the lower notch, but in the higher-level notch, the scalloping has been largely removed. This suggests there has been sufficient dissolution to remove 10-20 mm of wall-rock, effectively obliterating the earlier scalloping. In some places, the original vadose scallops are still present where films of water run down the walls, but are absent on the passage walls either side. It appears that the flowing water removes any acidic condensation waters before they get chance to dissolve the bedrock, counterintuitively preserving the scallops. This effect was seen in the show-cave path in Lagang's Cave near the Fast Lane entrance, and in Deer Cave. This is consistent with the hypothesis that nitrification could be causing secondary dissolution.



Figure 7. Dissolved stalagmites resting on a bedrock pillar
Photo: Tony White (p.47 of the 2014 Mulu Caves report)

In addition to the removal of small vadose scallops, many of the higher passages have large scallops which have traditionally been interpreted as being of *deep phreatic origin*. These scallops are often tens of centimetres to metres across, and in some cases are more redolent of cupolas. These large scallops are also associated with smooth, rounded bedrock flutings, pendants and projections. These are suggestive of slow dissolutional etching and are more reminiscent of ice ablation forms seen on icebergs; however, these *deep phreatic* scallops occur in passages with vadose notches such as the lower levels of Racer Cave. The co-existence of vadose notches with deep phreatic type scalloping cannot be explained in the traditional cave development paradigm. We suggest that many of these large scallops and flutings are of subaerial origin, form by the secondary dissolution of the passage walls by condensation corrosion. The scalloping reflects the air flow rather than water. In some areas, this secondary dissolution is so intense that *bone-yard* or *spongework* passage morphologies develop (Figure 8). This is characterised by large pendants, sculpted rock fins and deeply corroded, heavily rounded bedrock forms, as seen in The Snow-slopes in Clearwater, in Racer Cave, Stone Horse Cave and other areas of Clearwater.

Other small-scale dissolution features also suggest subaerial dissolution. In many relict passages, calcite



Figure 8. Bone-yard type morphology, Snow Slopes, Clearwater. Photo: Rob Eavis

veins and fossils are often etched out in high relief, forming projections (Figure 9). The bedrock around these projections is sculpted in a manner suggestive of air flow, leaving *crag and tail* type forms or sculpted ridges. The crag is the upstanding vein or fossil, whilst the 'tail' is the bedrock that has been protected from dissolution in the lee of the protrusion. Air flow is reduced in this area, reducing the flux of ammonia and moist air. The rock is often covered by thin rind of soft calcite, typically a few mm to 1-2 cm thick. This appears to be a dissolution residue, formed when aggressive condensation water, or acidified percolation water dissolves the limestone, then evaporates, depositing an amorphous crust of calcium carbonate. When the rind is sufficiently thick,

it sometimes sloughs off. In some areas, this soft, unconsolidated dissolution rind is washed down the walls by condensation or drip waters during wetter periods, forming a thicker *bobbly* crust with a *cottage cheese* type texture (Figure 10), locally forming droplets or globules of dried remobilised calcium carbonate at the base of pendants or rock protrusions (Figure 11).



Figure 9. Crag and tail type etching around calcite veins and other bedrock irregularities, Racer Cave. Air flow from left to right. Photo: A. Farrant



Figure 10. Crag and tail type etching around calcite veins (which form the 'crag') above the finger, where the air flow has been deflected, and the accumulation of a thicker calcite rind with a 'cottage cheese' texture where the dissolution residue has been washed down and been concentrated at the lowest point of the passage ceiling, Racer Cave. Air flow from right to left Photo: A. Farrant



Figure 11. Soft calcium carbonate globules on the passage walls, accumulating at the base of bedrock protrusions. View looking up at the ceiling, Racer Cave. Photo: A. Farrant

WATER CHEMISTRY

In order to examine the explain these anomalous passage morphologies and to investigate role of the guano on dissolution, various samples of drip and condensation waters were collected to analyse their chemistry and aggressiveness. Several sources of water are present and which contribute to dissolution; condensation water (Figure 12), percolation water migrating through the rock matrix, drip waters from speleothems, and vadose flows and drips from fractures or vadose shafts.

In situ measurements of water chemistry were taken using a field pH meter and an assortment of water quality test strips. These provide a quick, cheap, but rough indication of the chemical composition of the drip-waters and can be done in the cave with instant results. The test strips used include pH, conductivity,



Figure 12. Condensation droplets on the cave roof, Racer Cave Photo: A. Farrant

alkalinity, nitrate, nitrite, ammonia, chlorine (free and total) and total hardness. Samples were taken from three caves: Racer Cave (lower level, Figure 13), Lagang's Cave (Fast Lane), Stone Horse Cave, with additional samples from Lady Cave and Cave of the Winds. Three distinct types of cave waters were collected: condensation or percolation droplets on the cave walls, drip waters from speleothems, and condensation water from an ice bottle. These are characterised by different residence times. The condensation drops on the cave walls have potentially long residence times as the drips can sit on the wall for hours to days depending on ambient conditions. The stalagmite drip waters were relatively rapid, with short residence times in the cave air typically measured in minutes. The condensation water collected from ice bottles, and reflect the composition of water that has not interacted with the cave atmosphere or the cave walls. In addition to the *in situ* cave measurements, water samples were also collected for more detailed chemical analysis back in the UK.

The results from the field analyses suggest significant chemical differences between the different types of drip water. The ice bottle condensate samples typically had a lower pH (6.7-6.9) than the cave wall samples (pH 6.7-7.9), with the stalactite drip waters having the highest pH (7.4-8.1). As was expected, the



Figure 13. Racer Cave, one of the key sites for sampling condensation droplets on the cave walls. Photo: C. Pennos

total hardness was lowest in the ice bottle condensate, and much higher in the cave wall and stalactite drip samples. None of the samples contained any chlorine, ammonia or nitrite. Crucially, the wall samples were found to have elevated levels of nitrate, often beyond the limit of the testing strip (50 mg L^{-1}), with negligible or very low levels in both the ice bottle condensate and the stalactite drip waters.

The mostly likely source of the nitrate on the wall-rock droplets is from the nitrification of ammonia derived from the microbial decay of guano. This ammonia gas released from the guano probably sorbs onto the water that has condensed on the cave walls or mixed with slow percolation water entering the caves. This ammonia is an important source of energy for microbial growth, where it is converted to NO_x through a series of steps that produce acids, including nitric acid. This conversion may therefore lead to the formation of highly aggressive water on rock surfaces, accelerating limestone dissolution and resulting in the nitrate-rich water detected on these surfaces. This process would be most active in areas with large guano deposits, coupled with a good draught and a lot of moisture. In these areas, it appears that sufficient dissolution to remove the original scalloping can occur within a few tens of thousands of years, creating distinctive fluting and corrosion forms (Figure 14). In the older higher-level caves, tens of cm to possibly metres of wall-rock retreat may have occurred.

Figure 14. Fluting and air-generated scalloping associated with guano-filled niches, Stone Horse Cave. Air flow is from right to left
Photo: C. Pennos



Determination of chemical aggressiveness:

A key research question is whether the condensation water and other drip-water would be sufficiently aggressive towards cave wall-rock and stalagmite calcite to generate the presumed condensation-corrosion forms that are observed. The challenge with doing 'cave chemistry' in remote places where luggage weight restrictions apply, such as Mulu, implies modifications of other simple equipment and makeshift arrangements on site. Quite small volumes need to be analysed, and bringing vials of water back to laboratories in Europe is problematic, as 'aggressiveness' has a short shelf-life. A very simple, direct and effective technique is to measure the *Stenner Aggressiveness*. The technique was first described by Roger Stenner in the late 1960s (Stenner 1969) and two aliquots of the water in question are sampled. To one of them is added an excess amount of pure calcium carbonate, the other is left as collected. After being left for a short period of time to equilibrate, the two samples are titrated for total hardness; the difference between the two measurements indicate super- or under-saturation. If by adding CaCO_3 the hardness increases, the water was aggressive and had further dissolution capacity. On the contrary, a supersaturated sample would be nucleated by the added calcite and total hardness would drop. This method has been used with great success on Arctic and alpine spring and cave waters (Lauritzen 1981) where the titrations were carried out at camp by means of a micro-pipette modified for titration) on stalactite drip-waters and trickles. The titration was optimised for small volumes (5 mL) and measured by mass on an electronic balance. A very similar technique was used by Stein-Erik Lauritzen in Mulu in 2018 where titration was done using with mass rather than volume.

During the Mulu 22 expedition, condensation droplets were collected from cave passage walls and the small volumes collected demanded a further modification of the methodology. Titrations were not possible on such small volumes. Instead, we used electrical conductance as a hardness proxy (the relationship between hardness and electrical conductance is linear), and a modified conductivity probe. A strip of tape was used to modify the probe such that when held upside down it was able to hold a small volume of drip water rather than put the probe in a bottle. When held upside-down it worked perfectly (Figure 15) although some silicone tubing might have been better. Using this method, volumes up to about 1 mL were acceptable, which matched the internal volume of the probe. Calcium carbonate powder was extracted from CaCO_3 antacid tablets, washed with deionised water until a low and constant conductivity, and used as a wet paste in the field.

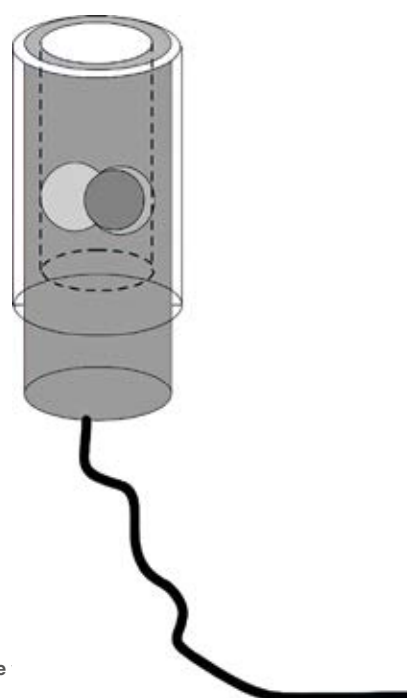


Figure 15. The conductivity cell at the tip of the probe modified for small water sample two side holes were covered with tape, or better, some silicone tubing.



Figure 16. Collecting water samples, Lagang's Cave. Photo: C. Pennos

Condensation water and droplets from straw stalactites were collected with a polyethene pipette in the cave (Figure 16) and transferred to 2 mL sample vials in parallel. Fresh condensation water was collected on plastic bottles containing ice (generated in the research centre freezer) and placed in the cave sites. To one aliquot was added an excess CaCO_3 paste with a spatula and closed. *In situ* conductivity and pH were measured on site with the modified conductivity probe described above and a micro-pH meter. Back in the research centre, the samples were measured again. Excess water sample was tested for nitrate, nitrite, ammonia and total hardness on plastic strip test kits.

The results show a clear distinction between condensation waters collected on the ice bottles (which were very aggressive) and the cave wall drip samples. Most of the cave drip samples were saturated, but some were significantly undersaturated, indicating that they were actively dissolving the bedrock. Those that were saturated tended to have higher conductivity values, suggesting they had dissolved up the bedrock, increasing their hardness. Figure 17 shows quite clearly the aggressiveness of fresh condensation water and partial saturation as soon as the water has been in contact with rock surfaces. This demonstrates that the water droplets on the cave walls were sufficiently aggressive to cause dissolution, either due to condensation corrosion or from acidity induced by ammonia nitrification.

Aggressiveness of cave condensation water

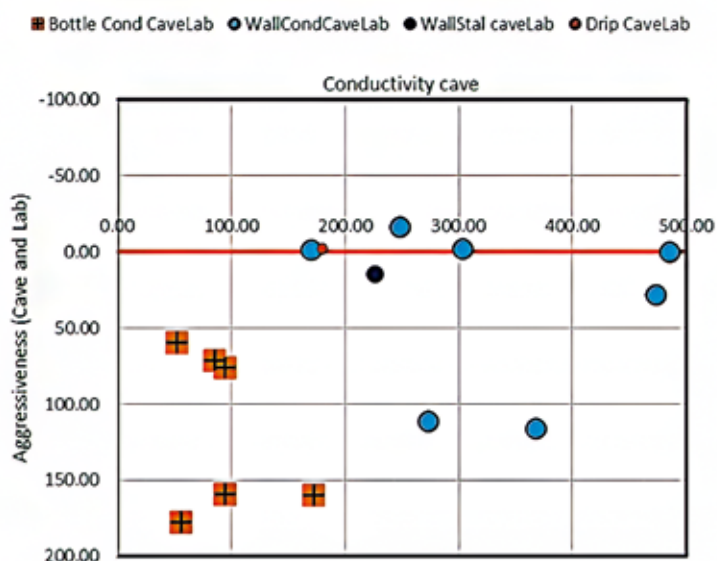


Figure 17. Plot of aggressiveness vs conductivity of the four types of water sample

Stable isotope analysis

Understanding the role that condensation waters may play in the dissolution of cave walls requires a series of geochemical tracers to be employed. As part of this, 34 samples were collected for stable isotope analysis, the majority being analysed for the oxygen and hydrogen isotope composition of water ($\delta^{18}\text{O}_{\text{H}_2\text{O}}$, $\delta^2\text{H}_{\text{H}_2\text{O}}$) and where a big enough sample volume could be collected, for the nitrogen and oxygen isotope composition of nitrate ($\delta^{15}\text{N}_{\text{NO}_3}$, $\delta^{18}\text{O}_{\text{NO}_3}$); 10 samples in total.

At the time of writing the water isotope analysis has been completed for the collected waters. These were sampled from a range of cave pools, speleothem drips, wall condensates and forced condensates (using frozen bottles to create condensate drips) waters. These different sample types were also collected across a range of cave sites including, Fast Lane in Lagang's Cave, Racer Cave, Stone Horse Cave, Lady Cave and Cave of the Winds. The oxygen isotope data highlights the differences between the water collection sites and the different cave sites.

From three of the cave sites direct collections of aquifer water were undertaken from actively dripping speleothems (Figure 18). At the Fast Lane site (Lagang's Cave) these active drip sites showed a level of homogeneity which suggests a single aquifer source, $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -11.01 \pm 0.17\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -73.71 \pm 1.37\text{‰}$ (n=3). In Stone Horse Cave, the isotope composition of the karst waters was more variable, $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -9.72 \pm 1.12\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -62.65 \pm 8.71\text{‰}$ (n=2). For Racer Cave only one drip water was collected, falling between the values of the other 2 cave sites, $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -10.29\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -68.78\text{‰}$ (n=1). Additionally, at the Fast Lane site a single guano and water filled solution pocket was sampled, this again was filled with aquifer water, but would have been more vulnerable to any effects of evaporation or oxygen utilisation during nitrification. The stable isotope composition of this sample confirms these suspicions, $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -8.69\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -54.72\text{‰}$ (n=1), distinct from the homogenous samples collected directly from drip sites in this cave. As both evaporation and O utilisation during the conversion of ammonium (NH_4) to nitrate (NO_3) would leave the residual pool water enriched in the heavier isotope it is difficult to elucidate the exact mechanism for changes in isotope composition of this pool water at this time (Figure 18).

Most of the waters collected in this study were condensation waters, either collected directly from the surface of cave walls or through a process of forced condensation (Figure 18). The cave wall condensates were collected from Lagang's Cave (Fast Lane), $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -10.33 \pm 0.80\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -67.91 \pm 6.38\text{‰}$ (n=2); Cave of the Winds, $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -9.93 \pm 0.08\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -61.53 \pm 3.25\text{‰}$ (n=2), Lady Cave, $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -10.58 \pm 0.03\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -69.38 \pm 0.37\text{‰}$ (n=2) and Racer Cave, $\delta^{18}\text{O}_{\text{H}_2\text{O}} = -9.95\text{‰}$, $\delta^2\text{H}_{\text{H}_2\text{O}} = -64.89\text{‰}$ (n=1). All the cave wall condensate waters have similar or higher isotope values to the aquifer waters collected from the same cave site (Figure 18), and all these waters fall on the same $\delta^{18}\text{O}$ vs. $\delta^2\text{H}$ line as the cave waters. This suggests that either these waters are directly sourced from aquifer water, with in some cases secondary evaporation as they sit on the cave walls or that direct condensation of atmospheric moisture onto the walls occurs with a similar isotope composition to the karst waters.

Where we collected forced condensates by suspending frozen bottles of water and collecting the external

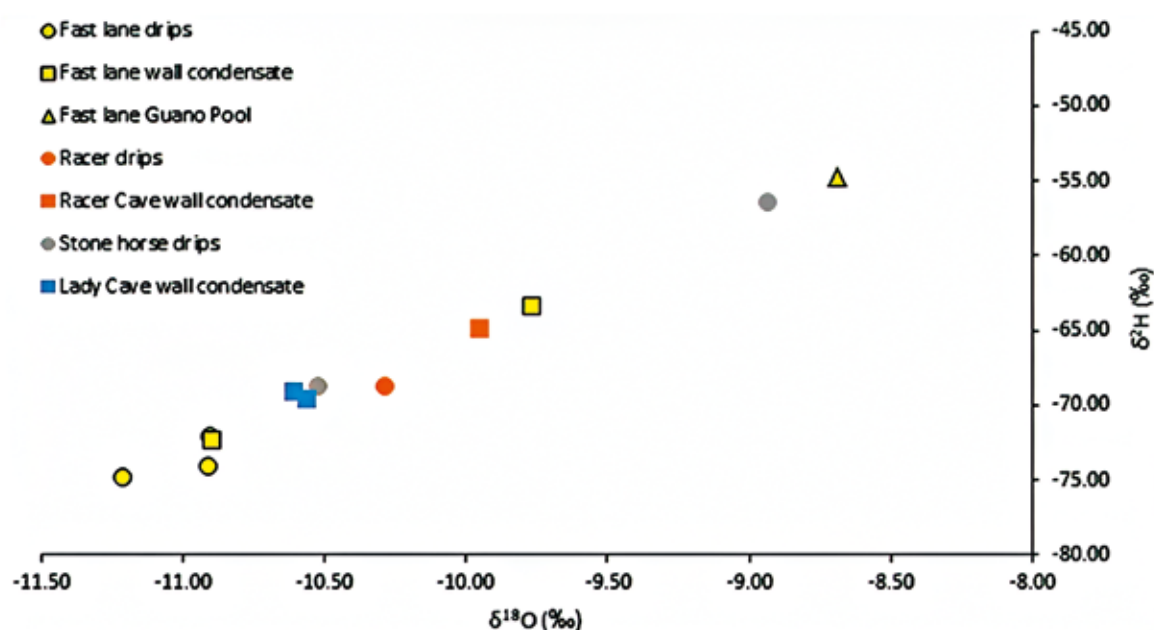


Figure 18: Dual isotope plot of $\delta^{18}\text{O}$ vs. $\delta^2\text{H}$ for all the cave drip, condensate and pool waters collected as part of this study



Figure 19. Anemometer set up in Racer Cave. Photo: Jo White

condensate significant isotope fractionations were observed. This is not an unexpected phenomenon with similar findings reported in Deshpande et al., (2013). As these sites showed significant deviations from the other natural condensates ($\delta^{18}\text{O}$ shifts of 10-15‰) the water isotope data of these samples will not be overinterpreted here, as the effect is one derived from the sampling method; however, these samples are expected to have condensed significant enough volumes to be analysed for nitrate and possibly ammonium ($\delta^{15}\text{N}_{\text{NH}_4}$) isotopes, which will not be affected by the impact of fractionation related to condensation.

Currently, 10 samples comprising cave drips, wall condensates, pool water and forced condensates are waiting analysis for nitrate and if possible ammonium isotope analysis, along with two bird guano samples. We hope that through these analyses we can understand more fully the modes of nitrogen cycling within the cave systems and the extent to which ammonium by-products from birds are converted to more acidic forms capable of wall erosion.

CAVE DRAUGHT AND ENVIRONMENTAL CONDITIONS

THE movement of air through the caves has an important role in carrying moisture, ammonia and other gases in and out of the caves. This airflow is likely to impact where and how much dissolution occurs, particularly in passages downwind of significant bat or swiftlet guano accumulations. To gain an understanding of how airflow through the cave system varies over time, we used the methodology and equipment that was successfully deployed to measure draughts on the Mulu Caves 2018 Expedition.

An ultrasonic anemometer and a pair of temperature, humidity and pressure loggers were installed to record environmental conditions inside and outside three cave locations during the Mulu 2022 expedition. Wind speed and bearing were measured using the anemometer at a single location inside each cave (Figure 19). Temperature, humidity and atmospheric pressure were recorded at a single location inside and a single location outside the cave. Three caves were studied: Racer Cave (15th–18th November), Stone Horse Cave (20th–26th November) and Lagang's Cave (26th November to 1st December).

Racer Cave has a large open entrance just above river level, and consists of about a kilometre of relatively open, largely horizontal passage, with a few constrictions close to the entrance. At the inner end, the passage is blocked by stalagmite. Just before the blockage is an aven which connects with the higher-levels of Racer Cave and the connection to Easter Cave. A strong draught is often felt coming down the aven. The external logger was placed close to the entrance of the cave, inside the drip line but away from the mouth of the main passage. The anemometer and internal logger were placed several hundred metres into the cave at a location where a noticeable draught was felt.

Stone Horse Cave has a large open entrance about 30 m above the path to Deer Cave. The cave connects through to Fern Rock Cave and Paris's Cave, with several other entrances. The internal logger and anemometer were placed relatively close to the entrance, less than 100 m inside the cave. This should capture the full draught of the cave through this entrance. The external logger was hung from a tree near the cave entrance, but away from the cave draught.

Lagang's Cave is a complex cave with at least eight entrances. The 'Fast Lane' entrance comprises a complicated network of passages where draught enters from a variety of nearby entrances. The entrance passages merge into a single large passage (the 'Fast Lane') for some distance, before joining an even larger passage, the 'Main Passage'. The tourist path heads south to another exit, whilst to the north, the passage leads to an entrance in the Melinau Paku valley. Due to issues described later, the external logger was not placed near the cave but instead hung in the shade underneath the main expedition hut, which was elevated around one metre above the ground on pillars. The internal logger and anemometer were placed approximately 500 m into the Fast Lane passage just off the boardwalk. This should capture the full draught of the cave through the Fast Lane passage.

METHODOLOGY

EACH cave location was studied in turn, moving the equipment between caves. The air flow measurements were taken with a WindSonic ultrasonic anemometer connected to an RPR Spacelogger, recording wind speed and bearing to an SD card. Readings were taken approximately, but not exactly, every 4 seconds (due to a slight timing difference between the anemometer and the logger). The anemometer records wind speed in m/s and bearing in degrees. Traditionally, wind bearing is recorded as the direction the wind is coming from, and this is what the anemometer records, but for our purposes we are interested in the direction the wind is flowing, and therefore use the convention that a *wind bearing* of 0° means that the wind is blowing from south to north.

Temperature, humidity and atmospheric pressure measurements were taken by a pair of UNI-T UT330C USB loggers. One was placed outside the cave entrance, while the other was placed by the anemometer in the cave. Readings were taken every minute. The loggers record temperature in °C, humidity as percentage relative humidity, and atmospheric pressure in hPa. Dew point in °C is also calculated by the logger. The clocks on the SpaceLogger and the UT330C were synchronized to UTC before logging commenced (except as noted below).

A DistoX laser/compass survey instrument was used to measure the orientation of the cave passage and to draw a cross-section at the location of the anemometer. Using this cross-section, the area of the cave passage at this location was measured approximately by box counting. The passage orientation at all three sites had similar orientations (around 80°), due to the influence of the local geology.

The anemometer data (speed and bearing) are resampled into 300 second bins. The mean of the speed and bearing over these bins is used. We calculated the standard deviation of the speed and bearing (which for bearings requires calculating the differences between two bearings correctly), and use this as the shaded error region on figures 20, 21 and 22 (wind graphs). The data are plotted against local Mulu/Malaysian time. We describe any bin where the bearing is within 90° of the inward passage orientations as showing inward draught, and any other bin as showing outward draught, which is shown as shaded regions on figures 20, 21 and 22 (wind graphs). The logger data (temperature, relative humidity, pressure and dew point) are also resampled to 300 second bins, and the mean and standard deviation of each quantity are calculated as for the anemometer data. As there are only five readings per bin, the standard deviation is less meaningful and so no errors are displayed on the logger graphs. The data are plotted against local Mulu/Malaysian time.

RESULTS

Racer Cave

The cave cross-sectional area at the position of the anemometer was about 23.3 m². The cave passage was orientated at 71.8° into the cave. For this cave only, the passage orientation was taken from the cave survey as it was not measured in the cave.

Figure 20 (top graph) shows the wind speed and bearing for Racer Cave from the 15/11/2022 at 14:30 to 18/11/2022 14:30 (local time). Figure 20 (middle graph) shows the air temperature and atmospheric pressure inside and outside the cave over the same time period; Figure 20 (lower graph) shows the dew point and relative humidity.

A diurnal wind cycle is seen, with typically a strong outward draught during the day and a weak or erratic inward draught at night. On the night starting 15/11/2022 18:00, wind speeds were low, fairly constant, and consistently inward. After around 09:00, this reversed to a strong outward draught, strongest around mid-afternoon and then dropping away to very low wind speeds during the subsequent night. Unlike the previous night, however, the draught was consistently inward; the draught alternated between inward and outward except for a small period of consistent inward draught between 05:00 and 08:00. The wind speeds were very low during the night. The subsequent day showed a strong, if variable, outward draught

RACER CAVE

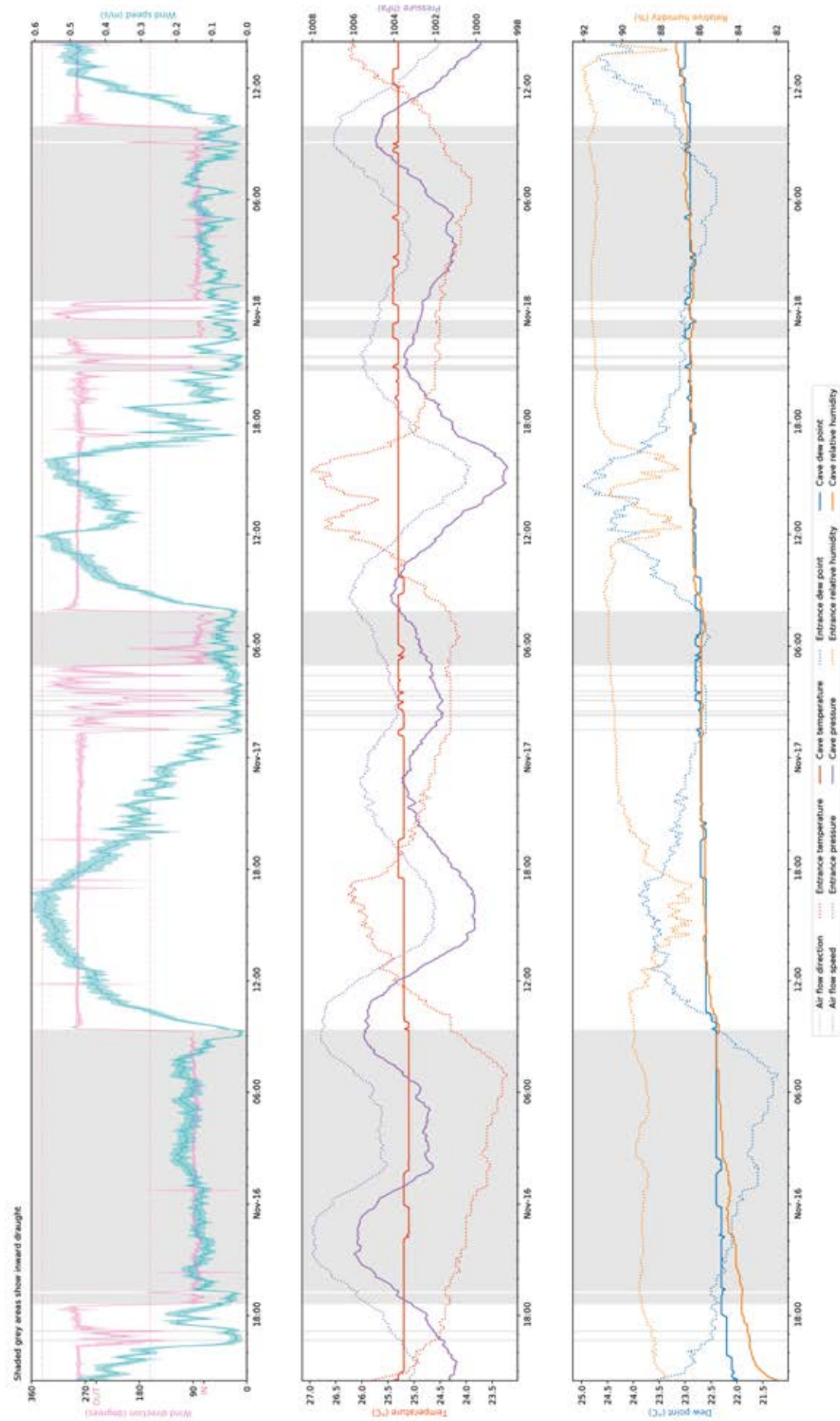


Figure 20. Plot of the wind speed and direction, air temperature and atmospheric pressure inside and outside the cave, and dew point & relative humidity, Racer Cave

until the late afternoon (when it became weaker), and a weak but more consistent inward draught for the subsequent night. Peak flow volumes are about 12 m³ per second.

Atmospheric pressure varied between around 1000 hPa and 1006 hPa over the observation period. The cave and entrance pressure data are extremely similar except that the entrance logger consistently reads about 2 hPa higher than the cave logger. This is equivalent, at a lapse rate of 12 hPa/100 m, to approximately 17 m altitude difference; it is quite plausible that the cave logger is around this altitude higher than the entrance logger; however, this is just as likely to be experimental error. Over the period measured, atmospheric pressure appears to have two maxima and two minima per day. The two maxima, with similar pressures, occur around 22:00 and 08:00. The minima around 04:00 is less significant than the other minima around 15:00 which reaches lower pressures. Pressure is generally higher at night than during the day. Low atmospheric pressure (seen both inside and outside the cave) is generally, but not always, correlated with strong outward draught from the cave.

The cave temperature was around a consistent 25.2°C. External temperature was, as expected, diurnal with temperatures dropping during the night and rising after around 07:00. The external temperature was, on average, lower than the cave temperature during the observed period. Periods of higher external temperature appear to be correlated with low atmospheric pressure and strong outward draught.

Dew point is a function of temperature and humidity so we do not consider it further. The relative humidity in the cave is around 86%, rising slowly over the observation period. The external humidity was also rising slowly, from around 90% to around 92%, but with episodes of lower humidity associated with episodes of high temperature.

Stone Horse Cave

The cave cross-sectional area at the position of the anemometer was about 101.7 m². The cave passage was orientated at 80.0° into the cave. Figure 21 (upper graph) shows the wind speed and bearing for Stone Horse Cave from the 20/11/2022 12:05 to 26/11/2022 11:05 (local time). Figure 21 (middle graph) shows the air temperature and atmospheric pressure inside and outside the cave over the same time period; Figure 21 (lower graph) shows the dew point and relative humidity. The cave logger ran out of battery around 25/11/2022 18:00, and thus its data are missing beyond this time.

Similar to Racer Cave, a diurnal wind cycle is seen, with typically a strong outward draught during the day and a weak or erratic inward draught at night. However, this is much weaker for the early days of the observation period (21/11/2022 and 22/11/2022) where the draught was generally outward throughout with only brief periods of inward draught during the night. Peak volumes of c. 100 m³ per second during the outward phase were observed. Night-time wind speeds remained generally low. For the remaining nights, a much more consistent pattern of strong outward draught during the day and weak inward draught resumed.

Atmospheric pressure varied between around 996 hPa and 1006 hPa over the observation period. As seen at Racer Cave, the cave and entrance pressure data are extremely similar except for a fixed offset. For Stone Horse Cave the cave logger consistently reads around 1 hPa higher than the entrance logger, or around 8 m altitude difference. This is probably within experimental error; as the cave logger is not far into the cave the altitude difference between the cave and entrance loggers is probably quite small. The pressure variations through the day are similar to Racer Cave. There is an overall trend over the period from lower to higher atmospheric pressures; this may be related to the strengthening of the diurnal cycle (strong outward draught in the day; weak inward draught in the night). Low atmospheric pressure (seen both inside and outside the cave) is generally, but not always, correlated with strong outward draught from the cave, as also seen at Racer Cave.

The cave temperature was around a consistent 25.5 °C. External temperature was less smoothly diurnal than Racer Cave, with relatively constant temperatures around 25 °C through the night and then a large peak in temperatures during the day up to 30 °C or more. The external temperature was, on average, higher than the cave temperature during the observed period. Periods of higher external temperature appear to be correlated with low atmospheric pressure and strong outward draught, similar to Racer Cave. There are two major differences comparing this data to the Racer Cave data. Firstly, during extended periods of inward draught the cave temperature does drop slightly, presumably due to drawing in cold night air; at Racer Cave the cave temperature remains constant during inward draught. As the cave logger is relatively close to the entrance, this is not surprising. Secondly, the external temperature is fairly consistent, and close to the cave temperature, when there is not an episode of high temperature; at Racer Cave the external temperature drops smoothly through the night. It may be that the cave draught is contaminating the entrance logger temperature either due to being placed too close to the cave entrance or an unseen entrance or orifice.

STONE HORSE CAVE

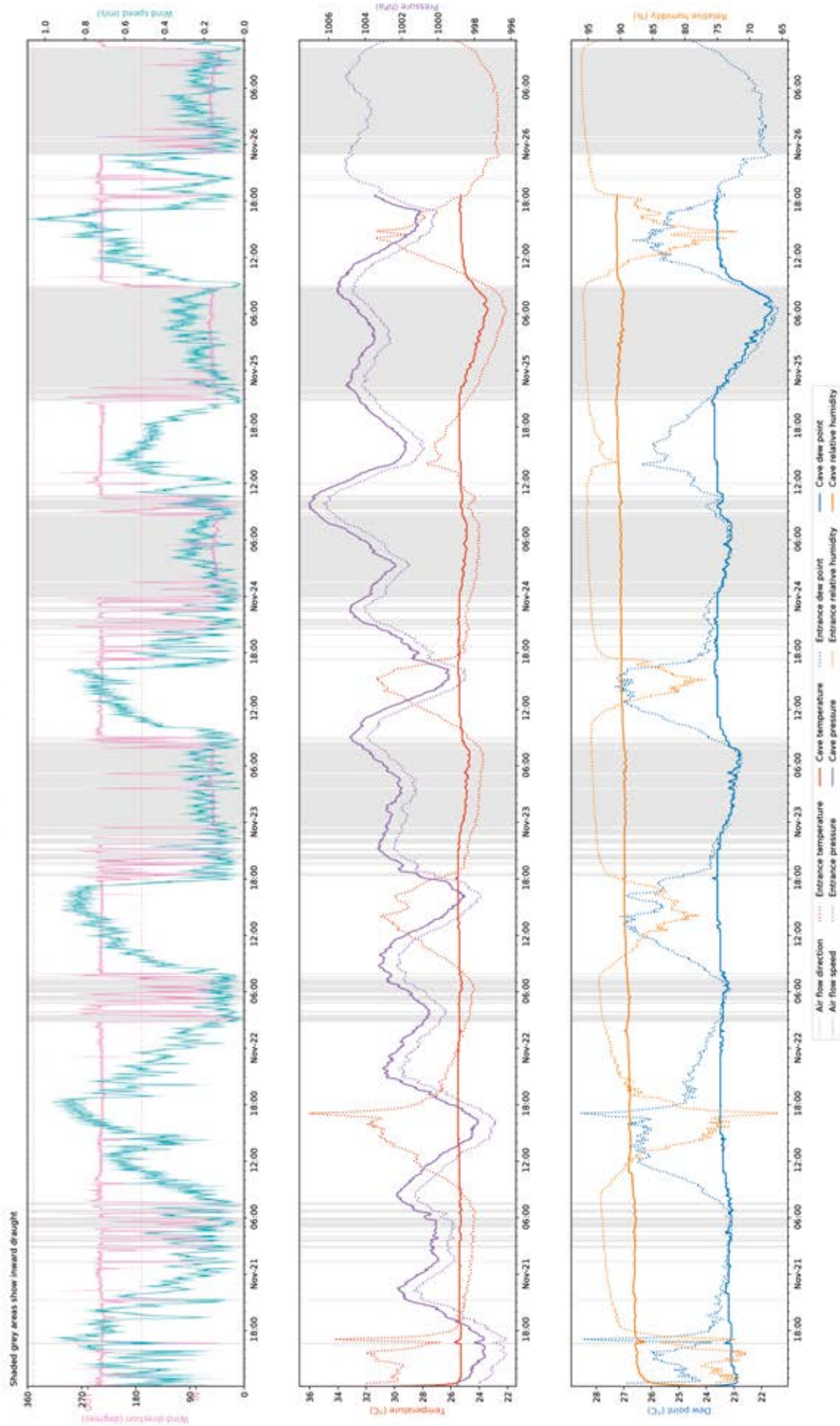


Figure 21. Plot of the wind speed and direction, air temperature and atmospheric pressure inside and outside the cave, and dew point & relative humidity, Stone Horse Cave

LAGANG'S CAVE

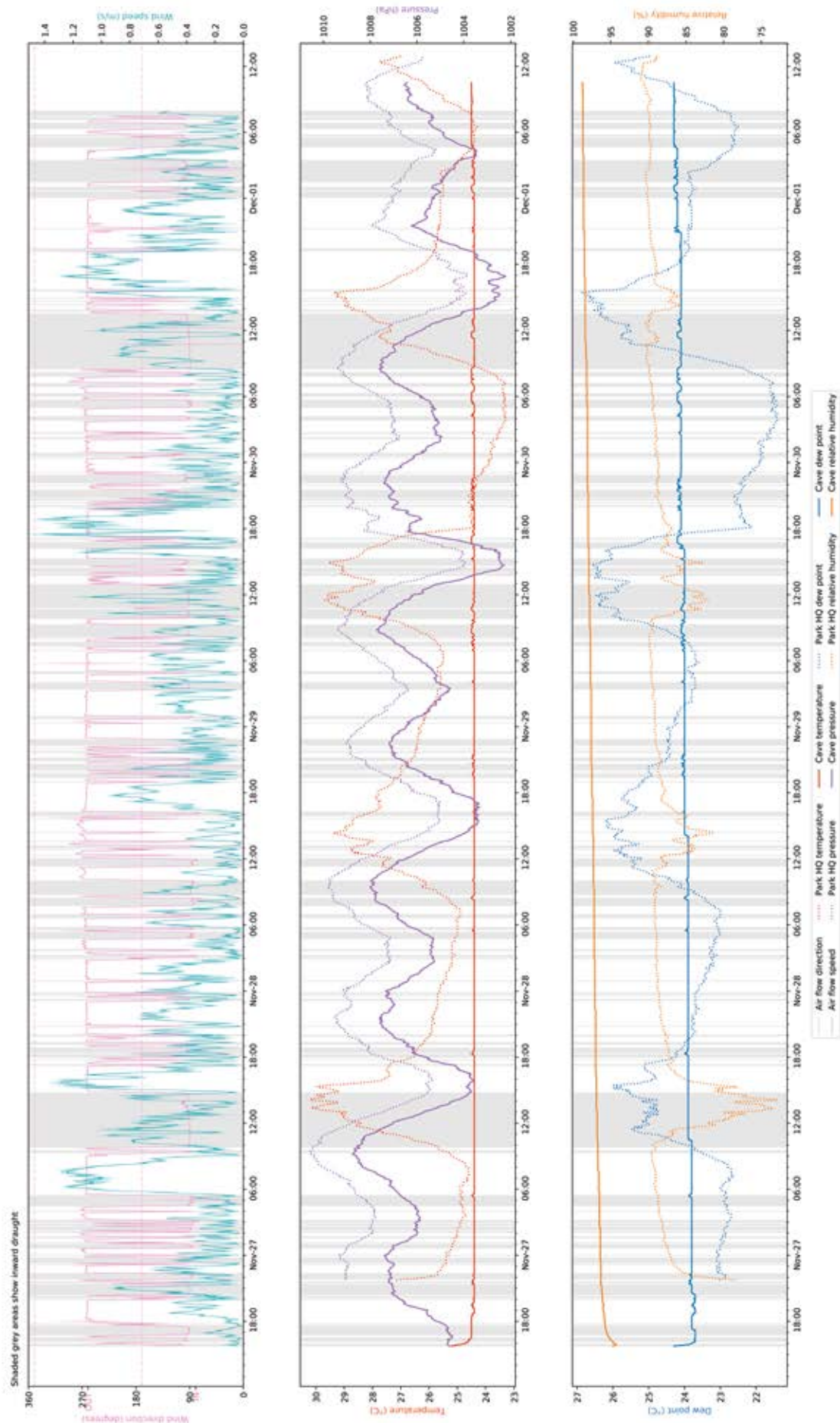


Figure 22. Plot of the wind speed and direction, air temperature and atmospheric pressure inside and outside the cave, and dew point & relative humidity, Lagang's Cave

The relative humidity in the cave is around 90%, and fairly consistent during the observation period. The external humidity was typically around 95% but dropped to between 75% and 85% during periods of daytime high temperatures and outward draught.

Lagang's Cave

The cave cross-sectional area at the position of the anemometer was about 31.2 m². The cave passage was orientated at 80.0° into the cave. The battery on the cave logger failed on the final day of logging Stone Horse Cave, so a temporary battery was rigged up and the logger hung under the main expedition hut when Lagang's Cave was being logged. The logger times are thus estimated to within about 15 minutes.

Figure 22 (upper graph) shows the wind speed and bearing for Lagang's Cave from the 26/11/2022 12:05 to 01/12/2022 18:05 (local time). Figure 22 (middle graph) shows the air temperature and atmospheric pressure inside the cave and under the expedition hut over the same time period; Figure 22 (lower graph) shows the dew point and relative humidity. The logger under the expedition hut was not started until approximately 26/11/2022 21:00, and as previously described we expect that timings for this logger are only accurate to around 15 minutes.

Unlike Racer Cave and Stone Horse Cave, no clear diurnal wind cycle is seen. Instead, a large number of oscillations between inward and outward draught, on timescales of hours to several hours, are seen. The strongest draughts are outward draughts, but there are also some strong inward draughts. Peak volumes were around 30-35 m³ per second. This additional complexity of the draught in this cave may be due to the logger's location in the Fast Lane branch passage of the larger cave. Alternatively, it could just be to different weather conditions during the observation period.

Atmospheric pressure varied between around 1003 hPa and 1009 hPa over the observation period. The cave and entrance pressure data are once again extremely similar except for a fixed offset; the entrance logger consistently reads around 2 hPa higher than the entrance logger, or around 17 m altitude difference. It seems unlikely that the cave logger is at a lower altitude than the logger hung under the expedition hut on the flat plains below the hill, and so we assume this is a systematic experimental error. The pressure variations through the day are similar to the other caves. Atmospheric pressure did not increase or decrease over the observation period. Unlike the other caves, no robust correlation between atmospheric pressure and cave draught can be seen.

The cave temperature was consistent, and around 24.5 °C. External temperature dropped smoothly during the night followed by a rapid increase of temperature during the morning. These daytime temperatures then dropped rapidly back down in the late afternoon to cooler night-time temperatures. The external temperature was, on average, higher than the cave temperature during the observed period (between 25 °C and 30°C). The logger was placed in the shade but the underside of the expedition hut may have produced its own microclimate that might not be representative of the conditions at the cave entrance.

The relative humidity in the cave did not show any diurnal variations, only a slow increase from around 95% to around 98% over the observation period. The external humidity was typically around 90% but dropped as low as 75%, but more typically 85%, during periods of daytime high temperatures. Unlike Racer Cave and Stone Horse Cave, there is no robust correlation between the external temperature and the cave draught. This is probably due to the multiple entrances in this part of the cave.

The data from all three caves shows there is a considerable flow of air through the caves, enabling a significant influx of humid air from outside. Any ammonia generated by microbial decay of guano will be dispersed throughout the cave system relatively quickly.

ESTIMATING DISSOLUTION RATES FROM ROCK TABLETS

As part of the investigation into the possible secondary enlargement of cave passages, an experiment to measure dissolution rates was set up. A common method of estimating dissolution rates is to examine how much rock mass is dissolved over a period of time, which can be done by placing pre-weighed tablets of soluble rock in the cave and then reweighing them at a later date to ascertain how much mass has been lost. This was the method used on the Mulu Caves 22 expedition and two sets of tablets were produced. The first set comprised 118 stone tablets (decorative travertine tiles) that were cut into squares, dried for 24 hours in a laboratory drying cabinet and accurately weighed to two decimal places. Similarly, nine arrays of gypsum beads comprising six beads of various sizes strung together with fishing line, plus an additional two arrays with a larger number of smaller beads.

These tablets and beads were then placed at a variety of locations in Racer Cave, Stone Horse Cave



Figure 23. Rock tablets left *in situ*, Racer Cave. Photo: Jo White

and Lagang's Cave, typically as groups of three (Figure 23). Two sets of control tablets were placed underneath the Research Centre, at top of wooden post just below floorboards at the northwest corner of the building. Tablets 103-104-105 were placed on top of the rafter, Tablets 112-113-114 hanging in air off a bolt. Likewise, Gypsum array 11 was also placed hanging in air off a bolt at the same place. The tablets were placed in variety of settings, on cave floor, on mud/guano, within guano, in drip pockets and suspended in the air.

The rock tablets will be left in place for at least a year before being recovered, cleaned, dried and reweighed. Due to the requirement for advanced testing, this work is ongoing. It is hoped the weight loss will provide an indication of the rate of subaerial dissolution in the cave.

CONCLUSIONS

Evidence from observations of the cave passage geomorphology suggests that significant dissolution has occurred since the passages were abandoned by the formative river. An increasing weight of evidence from the water chemistry, geomicrobiology and mineralogy studies performed during the Mulu '22 expeditions suggests that bird guano may play an important role in this secondary dissolution, probably through the decomposition of uric acid by microbial activity to ammonia gas, which is in turn nitrified on surfaces within the cave by microbial activity. The preliminary work begun here is continuing, with further chemical, microbial, and isotopic analysis, along with studying the rates of dissolution.

The results of this work should not only contribute to our understanding of the processes occurring within the caves of Gunung Mulu National Park, including the impact on equipment and infrastructure. But the results could have a profound impact on our understanding of secondary speleogenetic enlargement in tropical regions, and the critical synergy between the caves and their wildlife populations in the continued development of these systems.

REFERENCES

- Deshpande, R.D., Maurya, A.S., Kumar, B., Sarkar, A. and Gupta, S.K., 2013. Kinetic fractionation of water isotopes during liquid condensation under super-saturated condition. *Geochimica et Cosmochimica Acta*, 100, 60-72.
- Lauritzen, S. E. 1981. A study of some karst waters in Norway. Spatial variation in solute concentrations and equilibrium parameters in limestone dissolution. *Norsk Geografisk Tidsskrift* 35, 1-19.
- Lundberg, J. and D. A. McFarlane 2009. Bats and bell holes: The microclimatic impact of bat roosting, using a case study from Runaway Bay Caves, Jamaica. *Geomorphology* 106, 78-85.
- Lundberg, J. and D. A. McFarlane 2012. Post-speleogenetic biogenic modification of Gomantong caves, Sabah, Borneo. *Geomorphology* 157, 153-168.

Lundberg, J., McFarlane, D.A. and Van Rentergem, G., 2022. The nitrogen dynamics of Deer Cave, Sarawak, and the role of bat caves as biogeochemical sinks in Tropical Moist Forests. *International Journal of Speleology* 51, 205-221.

Stenner, R. D. (1969). The measurement of the aggressiveness of water towards calcium carbonate. *Transactions of the Cave Research Group of Great Britain*, 11, 175-200.



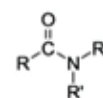
Biogenically modified dissolutional etching of the Melinau limestone on the roof of the main passage shortly beyond the Elephant's Trunk in Racer Cave due to a combination of condensation corrosion and nitrification of ammonia derived from bird and bat guano. *Photo: Chris Howes*

Mulu Ropes Degradation Analysis

J. Max Koether, Tahlia Townsend, James Eagan, and Hazel A. Barton

POLYMERS with repeating amide groups (Figure 1) are referred to as polyamides. The two primary manufactured polyamides are poly (hexamethylene adipamide, known as nylon 6,6) and polycaprolactam (known as nylon 6) (Figure 1). Nylon 6 and nylon 6,6 are used in the production of caving ropes due to their high abrasion resistance, high tensile and impact strength, elasticity, light weight, and comparatively long lifespan (Figure 2).

Amide



Although caving ropes can maintain their strength over decades, ropes left in the caves of Gunung Mulu National Park caves have been observed to lose their strength rapidly, failing under body weight in just a few years. One of the areas of investigation for the science teams during the Mulu 2022 Expedition was to identify the factors that could account for this rapid breakdown of the polymers compared to other cave systems. This included the possible influence of microbial activity.

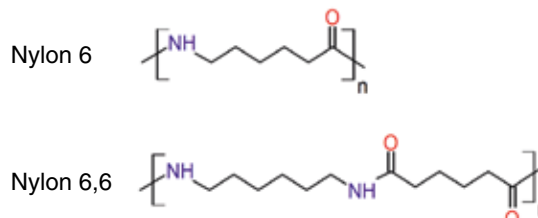


Figure 1. Chemical structures of amide, nylon 6, and nylon 6,6

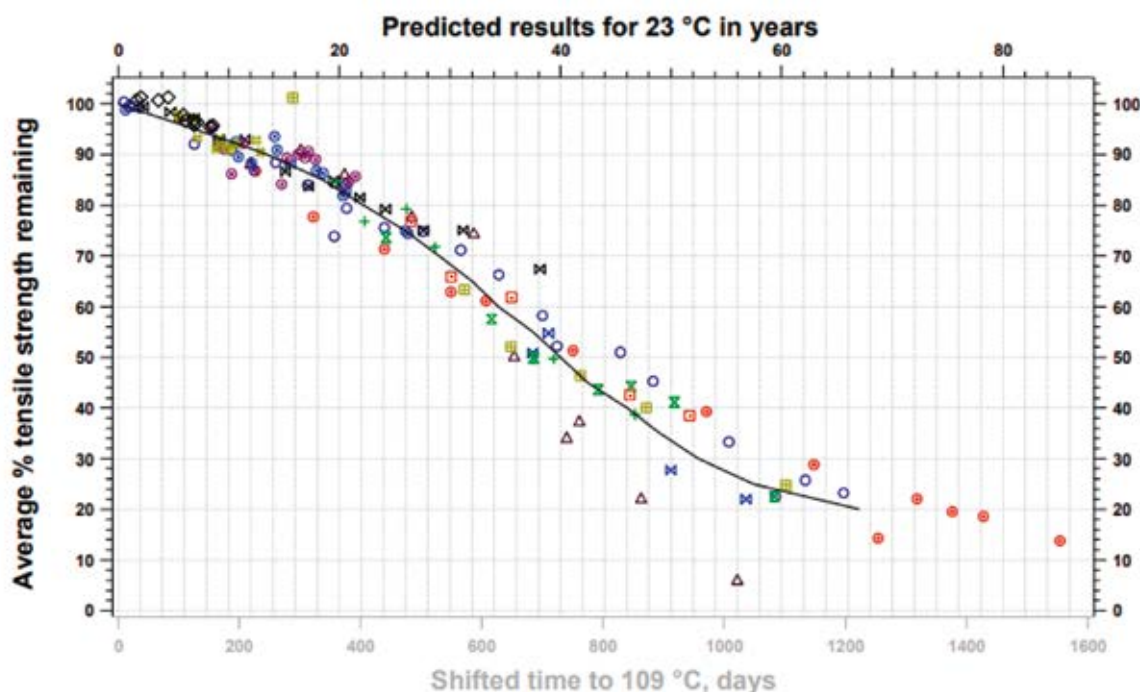


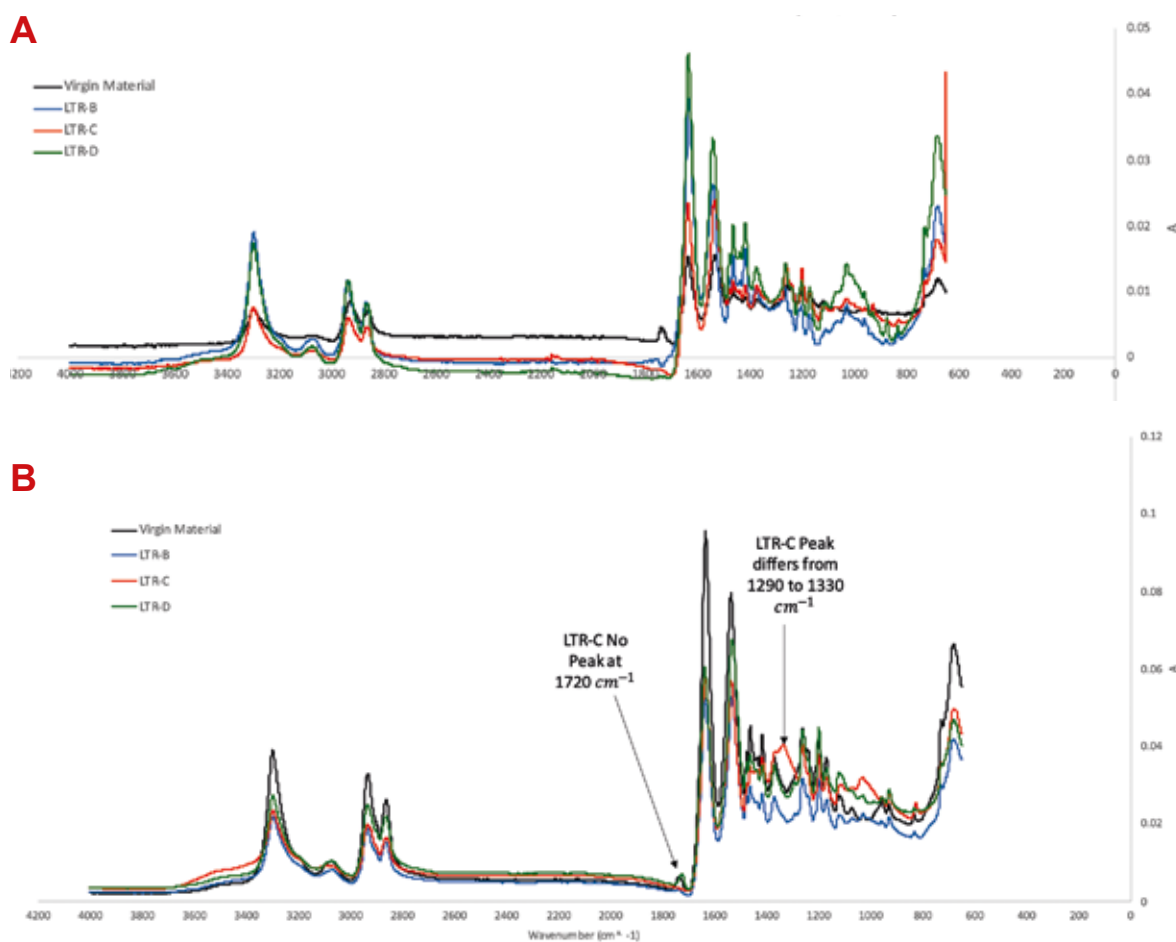
Figure 2. Average % tensile strength remaining in nylon 6,6 over an 80 year timeframe (Bernstein and Gillen 2010)

Degradation and loss of the physical and mechanical properties of nylon fibers can occur following the absorption of thermal or mechanical energy in the polymer, particularly in the presence of moisture or oxygen. Nylon degradation is also influenced by the ability for water or oxygen to break bonds in the polymer backbone, processes that may be catalyzed by enzymatic activity (Stoleru *et al.* 2017).

During the Mulu 2022 Expedition, Pete Hall and Will Yu-Pearson retrieved ropes from the Upskirt Area of Clearwater Cave near Scumring Camp, and noted the date they were rigged, the location, and the environmental conditions (hanging, against the wall, etc). Our goal was to use different tests to characterize the mechanical properties (via Instron) and the chemistry of the polymers using various spectral methods (Fourier-transform infrared spectroscopy [FTIR], gel permeation chromatography [GPC], and nuclear magnetic resonance spectroscopy [NMR]).

Oxidation effects on nylon predominantly take place on the methylene (-CH₂-) groups close to the nitrogen bonds of the amides, and evidence of oxidation may be indicative of the effect of hydroperoxides (especially hydrogen peroxide, H₂O₂), decomposition by acidic carboxyl groups (-COOH), or the oxidation of terminal amino groups (-NH₂) (Cerrutia *et al.* 2004).

Our initial testing was on ropes rigged in 2017 using FTIR to examine the chemical structures within the samples. These preliminary findings show the formation of hydroxyl groups (from the broad peaks in the



3500 cm^{-1} region in the analysis of unwashed samples), consistent with carboxylic acid degradation or surface oxidation (Figure 3A). One of the ropes, which had been used as a rappel line since 2017 and had been lying on a wet wall in an area rich with bird guano, was also shown to demonstrate a distinct lack of a peak at $\sim 1720 \text{ cm}^{-1}$, which may indicate polymer cleavages resulting in carboxylic acid degradation products, as well as a new peak at $\sim 1300 \text{ cm}^{-1}$ which is consistent with the sample experiencing oxidation (Figure 3B).

With these initial findings, our next steps are to expand the scope of our analyses to include larger-scale GPC and NMR analysis, as well as the retrieval of several filaments left in the Mulu caves to see the effects of the environment on nylon (and similar polymer) structures following a 12-month exposure.

Based on our preliminary data, we hypothesize that microbial activity within swiftlet guano is oxidizing the polyamide structure of the cave ropes. This may include bacterially-generated acidic by-products, which may also be contributing to the larger secondary speleogenic enlargement of the Mulu caves. Our goal is to develop an understanding of the swiftlet microbiome effect on secondary speleogenesis processes and whether this plays a role in the unique acceleration on nylon degradation.

References

- BERNSTEIN R, GILLEN KT. 2010. 'Nylon 6.6 accelerating aging studies: II. Long-term thermal oxidative and hydrolysis results.' *Polymer Degradation and Stability*. 95(9):1471–1479.
- CERRUTIA P, RYCHLÝ J, MATISOVÁ-RYCHLÁ L, CARFAGNA C. 2004. 'Chemiluminescence from oxidation of polyamide 6,6.' *Polymer Degradation and Stability*. 84:199–206.
- STOLERU E, HITRUC EG, CORNELIA C, OPRICĂ L. 2017. 'Biodegradation of poly(lactic acid)/chitosan stratified composites in presence of the *Phanerochaete chrysosporium* fungus.' *Polymer Degradation and Stability*. 143:118–129.

5. APPENDICES

Expedition Accounts

Tony 'Badger' Radmall

INCOME

1 Expedition member fees	a) Deposits	30 × £50	1,500
	b) Flights (9 arranged own flights)	21 × £1000	21,000
	c) Food, accommodation and logistics £10/day / 568 man days		5,680
2 Mount Everest Foundation			4,000
3 Ghar Parau Foundation			2,500
4 Oslo University			1,200
5 Food sales			650
6 Payment for insurance for 15 members (15 paid own insurance)			2,311
			£38,841

EXPENDITURE

1 Pre-expedition costs	a) foreman wages		800
	b) equipment	1. drill accessories	396
		2. expedition foods	1,819
		3. freight	275
2 International flights paid the expedition (9 members paid their own)			20,280
3 Insurance for 15 members (15 paid their own)			2,311
4 Field costs:			
	a) supermarket rations Miri and Mulu		1,466
	b) general hardware, including batteries, crockery etc.		425
	c) fridge/freezer		207
	d) washing machine		160
	e) foreman wages and expenses		900
	f) general helpers		1,284
	g) boats and drivers		1,027
	h) Miri taxis		207
	i) overland transport to Mulu for bulky, heavy and prohibited goods		690
	j) park food and accommodation (breakfast and evening meal)		6,594
			£38,841

Notes on expedition accounts

- ◆ Clearly, the total costs and expenditure were considerably higher as 9 people arranged their own flights, so that doesn't enter into these accounts. Also, 15 people covered their own insurance.
- ◆ The total income and expenditure was in the region of £51,000.
- ◆ The fridge/freezer and washing machine were left as donations to the national park and to be used by future expeditions.
- ◆ The difference from budget was largely due to a considerable reduction in porters and boatmen due to working close to national park headquarters and spending a lot of time camping underground.

Equipment Inventory

Pete Hall

THE expedition group depends on a tackle store maintained at Park Headquarters, kindly provided by the park management. The store contains a variety of caving and other equipment used for, among other things:

- ◆ pitch rigging and climbing,
- ◆ cave rescue,
- ◆ first aid and minor medical care,
- ◆ camping,
- ◆ producing surveys and other documents;
- ◆ a washing machine for expedition members based at park headquarters, and
- ◆ various tools

Survey instruments and computers are returned to the UK between expeditions due to their value and for use in completing reports, surveys, etc.

Scientific equipment is not kept in the store or included in the inventory. Some visiting scientists use a separate store in the research centre's kitchen. This store and equipment are shared by successive expeditions, which generally bring or send in advance any additional equipment needed. Veno Enar and park management have access to the keys between trips. It allows an expedition to be planned and only need to bring a minimal amount of equipment. A thorough, detailed inventory of equipment is essential for effective expedition planning. It is also important to keep the store in good order and not to allow it to fill up with redundant equipment.

The store and inventory were overhauled in Autumn 2019 and a large amount of obsolete equipment was disposed of. Further improvement and updates were made by the 2020 expedition team and on this trip. During the break in visits during the pandemic a flood resulted in some equipment being ruined and disposed of, in particular a top loading washing machine. This was replaced at the start of this trip and an additional refrigerator was purchased and for the research centre kitchen.

Although the 2022 expedition was a larger group than in recent years, it included a large science contingent who generally needed less caving equipment. There were no shortages of equipment and trips planned for October 2023 and January 2024 should not need to bring much equipment if they use the inventory.

The following observations may be useful for future expeditions:

Anchors

- ◆ Uncertified anchors must not be brought.
- ◆ Through bolts are preferred; galvanised or zinc-coated steel for exploration and stainless steel with stainless hangers for trade routes.
- ◆ There are plenty of spits, HKDs, etc for those who prefer them.

Food and camping gas

- ◆ No food, however well packaged and long lasting, must be kept in the store. It must be given away or thrown away at the end of each expedition.
- ◆ Successive expeditions have over-catered and accumulated plenty of tinned gas. Keeping it in the store presents a minor fire and explosion hazard, which can be minimised by not buying too much. Tinned gas is available at the Mulu Cafe shop, among others.

Aid Climbing Report

Chris Blakeley

AID climbing, lead climbing and soloing are generally perceived as activities with a certain element of risk. And often they are surface activities. Take them far underground, with a sprinkling of loose blocks, calcite over fractured bedrock, mud, wet rock and wearing a pair of Mulu plimsolls and the associated risk will change.

We are more likely to place an anchor whilst underground than in a similar situation on the surface, as we are all aware of the more serious consequences of otherwise 'trivial' injuries in remote caves.

But this assumes we have enough of everything we need – anchors, bolts, a hammer, a spanner, a drill, batteries, connectors and of course enough rope.. We might also include time as a factor. Not enough time to place a bolt, rig a rope, or just to stop and assess carefully. There is definitely an argument for 'fast and light', but the consequences if it doesn't work out can be pretty severe.

On this trip we brought a handful of removable anchors. In terms of simplicity and efficiency they made a big difference. We used Petzl 8mm Pulse anchors. I had eight, and Gareth Davies brought six. This enabled us to work nicely in two small teams, rigging traverse lines quickly, and aiding small sections where necessary. As they are removable, it meant that if the lead was continuing we could replace the anchors later with bolts and rig it 'permanently'. Or if not, just remove everything and leave only a few holes. We questioned less often whether we should place an anchor. The only question was remaining battery charge, but with the recommended three or four cutting edge drill bits you can get even more holes from a battery than with two-edged bits – and they are perfectly round.

Aid climbing is also quicker and with less weight to carry. It's obviously down to the individual how you approach each placement, and choice of line. But in general I tend to place two Pulses then a bolt. If I can reach them and the bolt is in a good place and I'm happy with it, I can recover the Pulses. Like this, there are good runners at least every three or so metres, and much less rope drag on longer or wandering lines. For example at the end of a 20m climb, I could have drilled 15 holes but left only 5 or 6 bolts.

A couple of times the black plunger of a Pulse got stuck in the 'unlocked' position, this required some fiddling and forcing to free it up for the next use and was a pain whilst seconding and cleaning a pitch. This doesn't affect its holding ability or strength and is due to a tight machining tolerance internally. The new version of the Pulse doesn't have this as the plungers are nylon and made differently for better grip and to eliminate this potential sticking issue.

Moose, Gareth and Will Pearson also had the opportunity to use Pulses on this trip, as we climbed into the Sandstorm Series and headed up towards the surface!

In addition to the Pulses, I was using a pair of Petzl Evolv Adjusts. They are built specially for aiding, and are super easy to adjust – both shortening and lengthening. They remain easy to use even with a bit of abrasion, mud and wetness. They will also absorb some energy in a fall.

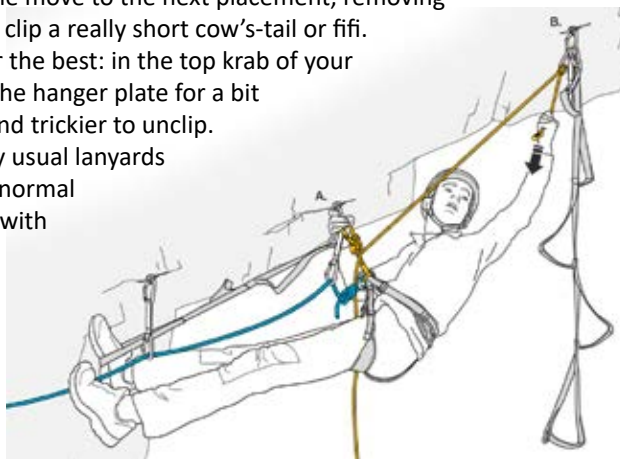
I use them direct into the Pulse or bolt that I've just placed, and can often stand up just by pulling the free end of the Evolv whilst standing in the top of the lower étrier, especially if it's not totally vertical or there are ledges to help. Otherwise I clip an étrier and then stand up as usual. The fact that the adjustment is so smooth means that you are protected for the whole move to the next placement, removing those wobbly moments as you try to stand up and clip a really short cow's-tail or fifi.

There are different thoughts on where to clip for the best: in the top krab of your quickdraw (usually the best option) or direct into the hanger plate for a bit more height, but this can then become crowded and trickier to unclip.

If I know that I'll be aiding, then I just replace my usual lanyards with the Evolvs, and use them for everything. In a normal caving setup though there's the slack rope to deal with as it catches on your knees whilst crawling, or the sewn terminations which find every possible place to trap themselves behind you! Worth finding a pair to try on your next bolting trip.



Petzl 8mm
Pulse
removable
anchor with
built-in hanger
Photo: Petzl



Aid climbing technique using a
Petzl Evolv Adjust lanyard
Illustration courtesy Petzl

Medical Report

Rostam Namaghi

UNFORTUNATELY, Mulu kept me quite busy as the expedition medic – I had 26 consults over the course of three weeks! Most of this was a degree of induced demand: problems that can wait, but if you have a GP on hand it's hard not to want to take advantage.

This seems to have been the case on my last two expeditions: Mulu continues to be medically eventful. In the past I have sutured an eyelid, a disfiguring forehead laceration and a large limb laceration. On this occasion the significant event is worth reflecting on and so I've included a summary of the notes below:

A male in his forties injured himself while climbing a limestone escarpment (above ground, in the jungle). It was a blunt force wound through his right trouser leg and left a 60mm laceration with two lateral leaflet extensions. I prepped the surface with iodine, washed out and explored the wound (myofascial compartment was intact, no debris in wound), gave a one-off shot of co-amoxiclav and sutured the wound closed (3-0 Vicryl Rapide, 10 sutures).

He reopened the wound ten days later (I had been reviewing and redressing the wound every two to three days personally and there had been no signs of infection or dehiscence; I had been pleased with the wound healing). Unfortunately, this was likely at an underground camp and the wound was left open but dressed for two days and he took an exit that involved swimming out of the cave.

I was informed of the breakdown when he returned to camp and I took the old sutures out of the wound, prepped with iodine and washed out with our remaining saline. I started him on oral co-amoxiclav immediately. I made the decision to close the wound due to our being in the jungle (ordinarily I would have left the wound open so that any infection could drain and then suture it up once you have a confirmed sterile wound, but the balance of risk of further infection was high).

There was little change after 24 hours, I dressed the wound, no erythema, no collection. After 48 hours there was some erythema and shiny sheen to the skin - more indicative of 3rd space fluid rather than tense swelling, calves were nice and soft. Observations were stable: temperature 37.0 °C, heart rate of 62. I started clindamycin in addition to co-amoxiclav and made arrangements for him to be flown to the regional hospital. I marked the erythema for tracking. I wrote a letter stating that opening the wound and washing out would be required and that he would likely need IV abx for two to three days.

He was admitted, wound washed out and debrided under a local block. The initial suspicion was that of Necrotising fasciitis. He was kept in for observation and placed on four different regimes of antibiotics while they awaited the microbiology. The wound was left to openly granulate.

The swab results showed two organisms: *Enterobacter cloacae* and *Pseudomonas ariginosa*. Given the large bird populations in these caves this was to be expected. Of significant note is that the *E. cloacae* showed resistance to Co-amoxiclav.

I have debriefed with both Dr Brendan Sloan (BCRC) and Dr Webber-Rookes (my current Educational supervisor). I have also discussed the (anonymised) case with my local Plastics team in Exeter. There was also feedback from the local team from Miri, namely: the choice of suture allowed tracking and a non-resorbable non-braided suture would have resulted in a lower chance of infection.



The wound after stitching. Photo: Chris Howes

Learning points from the above case:

- ◆ Take a wider selection of suture material (my only non resorbable was either too fine or too coarse to repair)
- ◆ Take a set of surgical drapes (I erroneously thought there was a set there – it turned out to be a wound pack) and more saline than had been left there
- ◆ Consensus for relative risk would be to take a full course of antibiotics during the initial injury but that no significant conclusion can be drawn as there was good healing between the initial repair and re-injury
- ◆ Leaving the second wound open for granulation, and there is possibly a role for a reserve of intravenous antibiotics
- ◆ Collusion: As a caver and a doctor I am very well placed to understand both the values of our community

and explain the risks. This does put you at risk of allowing people to push themselves beyond safe limits and that can be hard to judge. It is also uncomfortable practising medicine with people whom you have social connections with

Other general learning points:

- ♦ Confidentiality: while difficult to maintain I do wish I had set up a designated space for consulting/procedures. I was caught by a lot of 'by the way's and 'as you're here' which I don't mind, but ensuring practice away from an audience will result in a better experience for both doctor and the patient.
- ♦ Try not to glue someone's foot to the floor while repairing a finger laceration – while somewhat comedic, what this actually means is setting up a space for procedures. In the past I have used the picnic bench at Camp 5/alpine bunks.
- ♦ I do not think expeditions generally need doctors; however, the ageing trend of Mulu means that I suspect it is incredibly sensible if you have more than twelve people.
- ♦ I would recommend any trips going without a doctor consult one of the doctors connected to expedition as tailored prescriptions based on the medical history of the team is something I spent time considering.

Not the Insurance Report

Gareth Davies

ON the 8th of November, after spending the day at Easter Cave and walking back to meet the boat for a lift to the expedition research centre, I had what at the time I felt to be a rather innocuous slip while descending the limestone pavement. My right shin contacted some exposed rock and while I felt pain, my tights weren't punctured and there was not a lot of bleeding; the only outward sign was some swelling and tenderness.

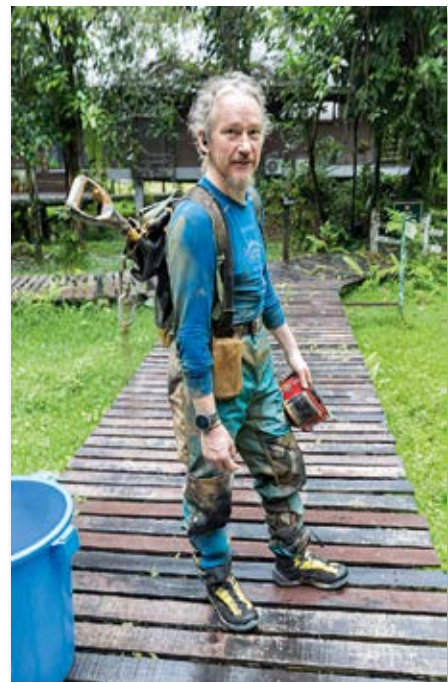
I returned to camp and after washing my leg and a dose of anaesthetic, the leg was exposed and stitched by Rostam. I'm told I passed out and sat up twice, but thanks to Badger and Kevin I didn't suffer any further injuries.

A course of general antibiotics was given and the wound was redressed and assessed for the first week: all seemed well. I'd gone caving every day, starting off with supporting the rescans in Clearwater entrance series, and by the end of the first week I was digging and failing to find the elusive connection between Easter Cave and the main system. All seemed to go well and I was growing bored, so after a chat with Rostam I decided to join Moose, Rostam, Will and Colin in Black Rock to help push a few leads. All was well, despite the leeches, but by day two my wound had reopened. I thought little benefit would come from exposing it to the bat and swift guano, so said nothing and I had a fun exit on day four with Colin in a Clearwater through-trip, exiting via the river system. Back at camp I told Rostam that I might need another stitch or two. After another anaesthetic with ice he cleaned and restitched the wound. I recall I didn't faint on this occasion, but alas the wound was already infected.

Within two days Rostam, Andy and Badger bundled me onto a plane for the mainland Borneo hospital. I thought he was overreacting and I'd have a wash-out, some IV and be back the following day to continue caving. I arrived at Miri and was transferred to Borneo Medical. The junior doctor exposed the wound, which by now even I could smell lying down; his face suggested it was above his paygrade. Despite being a Sunday I was in surgery by 4pm and thankfully, once it was cleaned back to the muscle layer, no further pus was found despite puncturing it twice to check. In conversation with the surgeon he said I'd only be allowed to cave if my wife and daughter (a pharmacist and recently qualified A&E nurse) agreed; he even offered to ring them. Checkmate. So, I lay back in the bed for three nights while they grew the two different bacterial infections – thankfully not the necrotising fasciitis that was feared. It was great care and the surgeon visited me at least twice a day.

After four days I was discharged from surgery with an open wound, and the nearest I got to caving was talking shit and visiting Deer Cave.

I have now been given the 'all clear' by the matron of my practice, and it's almost cleared up with a small scar.



Gareth Davies returning from digging
Photo: Chris Howes

Photography Report

Chris Howes

In the 2019 Mulu (Spring) report I noted a major factor relevant to photography with dSLR cameras and lenses in tropical rainforest locations: humidity affecting camera systems with separate lenses, where moist air can penetrate beyond the body–lens interface. This is always particularly apparent when moving from cold to warm air, causing condensation to form within lenses and requiring full equipment services on returning home.

For 2022 I again used a Canon EOS 5D Mark IV camera for underground work (and a Canon EOS R5, its fully electronic equivalent, for surface work). Both performed flawlessly, though with limitations that would probably apply to other camera systems; future photographers should take these into account. I would normally prefer to have a third body available as a back-up camera (noting that on one non-Mulu expedition I managed to write off two bodies), but aircraft hand baggage weight allowances prevented this (alongside restrictions on carrying batteries). This autumn trip produced constantly wetter conditions on a daily basis and extra care was taken while underground, with no reserve equipment available.

As in 2019, only weather-sealed L-series lenses were used and flashguns were kept in ziplock bags to protect them. Underground problems only arose on one occasion, in the showcave area of Clearwater Cave when moisture was again problematic. Lens changes (to shoot macro as well as general scenes) did not cause any discernible problem while underground, but on this one occasion the hot shoe contacts between the camera and slave trigger failed.

Slaves are an immense boom to underground photography and have progressed to the point of being reliable over huge distances, with modern manufacturers generally producing flashguns with integral receivers that are fired by a transmitter on the camera. In 2014 and 2019 my flash system was based around



The high humidity in Lagang's Cave is evident when backlit. Photo: Chris Howes



Daylight streaming into the entrance of Clearwater Cave. Photo: Chris Howes



a set of five rather ancient (read: cheap, eBay purchases), but hugely dependable Metz 45 flashguns. The downside was bulk, but the power and spread of light was a boon and they were triggered by the addition of small and, again ultra-reliable, RadioPopper Nano slaves.

Unfortunately, during the Covid-19 pandemic the Metz guns lay idle and it proved impossible to resurrect the dedicated battery clusters to a trustworthy condition before use in 2022, so all were retired and replaced with five rebadged (thus slightly less expensive when named as PixaPro) Godox AD200Pro flashguns. These are a better shape than the hammerhead Metz guns, though slightly heavier, and were a perfect fit in a Peli 1400 case; we carried three this way, with two spares in a tacklebag.

The Godox guns were fired using an ST-III transmitter, which has its own hot shoe that makes it possible to piggyback a Nano transmitter and run two slave systems concurrently, allowing supplementary flashes to still be fired. This proved highly beneficial in Clearwater, when humidity caused the ST-III transmitter connection to fail. With high water levels in the river, we were restricted to the showcave area for further work. By removing the Godox transmitter from the setup, the Nano transmitter still worked for the supplementary flash, and photography continued with a hand-held camera; the shutter remained open while an assistant fired a single additional flash manually. These flashguns never failed during the entire trip. In addition, flashbulbs (AG3s) were used to light underwater pools.

Underwater lighting using a flashbulb in Revival
Photo: Chris Howes



Photography in the Clearwater entrance area with reduced flash capability. Photo: Chris Howes



Future photographers using either slaves or dSLR cameras (indeed, any system that requires an electronic connection) should plan on redundancy and alternative means of firing flashes to continue taking pictures if the environment proves too challenging. Battery availability for both cameras and flashguns remains a difficult area of compromise and this is likely to limit viable work during underground camps: one night was relatively easy, but extended camps would introduce restrictions.

The alternative to a dSLR, as mentioned in 2019, is to use a fully sealed, fixed lens camera or, increasingly, a smartphone. The quality of images produced by the latter has increased enormously in recent years and an analysis of available photographs taken in 2022 indicates that about 80% originated on phones and the

remaining 20% a mixture of dSLR and single-lens sealed cameras. A full frame dSLR still has the advantage of higher quality and flexibility, but for most uses – especially lightweight recording of exploration as it happens and ready production of close-up images – smartphones are fully appropriate and their use can only increase.

Finally, mention must be made for photographic assistants. Having one caver help to shoot photos is almost essential and my continued thanks go to Judith Calford. However, adding one or two additional helpers massively increases the speed and efficiency of shooting: it can treble the number of images taken and vastly increase the variety of images, especially in a challenging situation. Kevin Munn joined the 2022 team specifically to provide photographic assistance, and other expedition members and local cavers also gave their time to join photo trips. In particular, my additional thanks for their aid go to: Jon 'JJ' Beavan, Gareth Davies, Veno Enar, Martin Holroyd, Jimmy Jarau, Zarris Kem, Rida Rambli and Richard 'Roo' Walters.



Top: Martin Holroyd with formations in Revival

Left: Martin under a skylight in Snake Track, where a balance between daylight and flash was required. Photos: Chris Howes

Logistics, Politics & Permits

Andy Eavis

As mentioned earlier, because exploration in Mulu is getting a long way into the caves – in some cases several days with underground camps – it was considered that having a large group of experienced cavers in the park at one time was beneficial, as this provided a platform for science, resurveying, laser scanning etc.

From past experience a period of five weeks is generally considered the maximum that people could easily be away from home. The plan was always to stagger arrival and departure with a core period towards the end. The overall timescale of the trip was greatly affected by the covid pandemic, it was originally scheduled for 2020, then postponed for 2021 and eventually actually happened at the end of 2022, a very frustrating period.

There was always a chance that covid could break out again and delay departure or return, in practice this didn't actually happen.

The majority of the flights were booked by the main expedition organiser who then passed the costs onto the expedition members. Similarly, the insurance was done centrally through the British Caving Association expedition travel insurance which is specifically designed for caving expeditions and carries £150,000 rescue cover, which has been found to be necessary if there was a trapped underground rescue which could involve bringing more people out from Europe to assist as has happened on various other caving expeditions around the world.

The latest permit permission is the SORAS (Sarawak Online Research Application System). To fill this in is relatively easy, but a lot of work when you have 28 members and a scientific programme. However, with the help of Rambli Ahmed (our man in the Forestry) it all went smoothly and indeed we were able to adjust it several times because of delays. Inevitably there were some changes in personnel, including (on this SORAS form) the permission to collect and export samples and also immigration permission to do the basic research work.

As with the other recent expeditions, the plan was to fly from the UK to Kuala Lumpur, then onward to Miri overnight, then a short flight to Mulu the next day. This is a very easy and pleasurable way of doing it: overnight in Miri is always a pleasure, and the return flight can get through from Mulu to Europe without a stopover, arriving in Europe early in the morning after an overnight on the plane.

Some heavy and prohibited items were freighted to Miri and then taken by 4-wheel-drive on logging roads, where it was then eventually put on a boat for the last section of the journey to Mulu. The freight from Europe included explosive caps for enlarging parts of cave passages and a reasonable quantity of rehydrated foods for underground camps. Other heavy items were added in Miri, such as a new fridge-freezer and washing machine; the previous ones had been destroyed in a fairly recent mega flood.

Accommodation in Mulu was largely at park headquarters where the research centre housed about half of the team members, while the other half had a dormitory. Other accommodation was at Camp 5 where five people spent five nights; and finally, underground camping where approximately 300 man-days were spent.

Food at HQ was breakfast and evening meal on the expedition account at the Mulu Café. Food at Camp 5 was a combination of locally sourced meat and vegetables, plus rations bought from Miri. Underground camping food was planned as two-thirds dehydrated supplied by Expedition Foods bought out from the UK, and one-third locally sourced dried foods such as rice, noodles, plus tinned and fresh packaged foods.

Underground camping in Mulu is always a pleasant experience where there are some wonderful underground camps, with impressive names such as Hardrock Café, Scumring, Flying Monkey. These zany named comfortable camps tend to be clean and dry, cool and quiet and often very spacious or even enormous, unlike the noisy, wet, humid, claustrophobic conditions on the surface. It's often difficult to persuade cavers to exit.

River transport was used extensively in addition to forest walking and it's an advantage that there are navigable rivers passable by long boats with outboard motors going from park headquarters to Clearwater Cave and nearly Camp 5.

Radio communications around the park using park radios are now quite good, although any repeater stations that they put around the park tend to be knocked out by lightning. Mulu Caves 2022 didn't go as far afield as other trips, with a concentration on Southern Api and science. The excursion to Camp 5 was merely a reconnaissance for several scientists who were interested in the surface geology and geomorphology.

A Personal Experience

Maya Williams

WAS asked by my Dad to come to Mulu to assist him but after he had to drop out last minute due to medical complications I was invited by Andy Eavis to come by myself and of course I jumped at the opportunity. Having not been caving for about 5 years I knew it was going to be an ambitious and challenging trip but that was one of the reasons I wanted to go, to push myself.

So on the 12th of November I found myself waiting at Heathrow Airport for Rob Eavis and a gaggle of cavers to fly to Kuala Lumpur, Miri and then – after a night in a hotel – onwards to Mulu. The flights, although long, went smoothly and after arriving in Mulu we all found our way to Park HQ, which would be my home for the next two weeks.

A group of us then took the 3km walk up Deer Cave to be toured around by Hazel. Even just walking up to the cave was impressive but once I got inside the main large chamber I was truly struck by the size and the beautiful formations of the cave. I have always had a interest in geology and was fascinated to learn about all different kinds of rocks and how the cave was formed. It was also my first encounter with some of the Mulu wildlife, like frogs, spiders and even a catfish. That evening was spent having a BBQ and learning about what everyone was up to on the expedition.

The next day I was back in Deer Cave with Roo, Tim and Rida to do some 3D scanning of the cave. Roo has been scanning many of the caves around Mulu National Park to create 3D images of them, so after being shown how it worked (a lazer that bounced out the light and shadow to build an image) I got to get more up close personal with the rocks I learnt about the day before as well as a large pile of Guano. We scaled the large pile to get the last couple of scans, this was my first experience of “real” caving whilst there and it was very much enjoyable even in 25 degree heat (very different from the small cold wet caves I had been in back in the UK). We sat up on the top of the pile of guano and rocks to wait for the bats to come out of the cave but after an hour of waiting (and napping) it started to rain so we decided it was probably time to head back. Overall an excellent introduction to Mulu.

The day after that (16th November) I joined Andy Farrant, Jo, Andy, Cristos and Stein-Erik in Stone Horse Cave to help them with their scientific research. They were looking at the acidity of condensation in the cave to see how that had an affect on the erosion of the cave, I got the device that measures humidity and temperature. After being taught about scalloping in the entrance of the cave we went further in, over a scary drop and around some interesting tight passages where I took the temperature and humidity again. I was also introduced to my first cave critter known as a ‘hairy mary’. They are about 5cm (or more) long, orangey red, with too many legs for my liking, and I was told that they have a pretty nasty, poisonous bite. I also got the chance to see bats nesting in little holes in the roof of the cave, much cuter than the hairy marys.

A few days later, after more fun exploring caves and drinking cheap beer in the evenings, I got the chance to visit Clearwater Cave – possibly the largest river cave in the world. I went once again with Andy Farrant and the team. To get to the passage where we were going we had to make 8 river crossings, some were as deep as my chest others much shallower but faster flowing. We kept going slowly but surely and we all made it through, it was tiring work but absolutely worth it for



The venomous cave centipede *Thereuopoda longicornis* (formerly *Scutigera decipiens*), aka ‘hairy mary’
Photo: Chris Howes

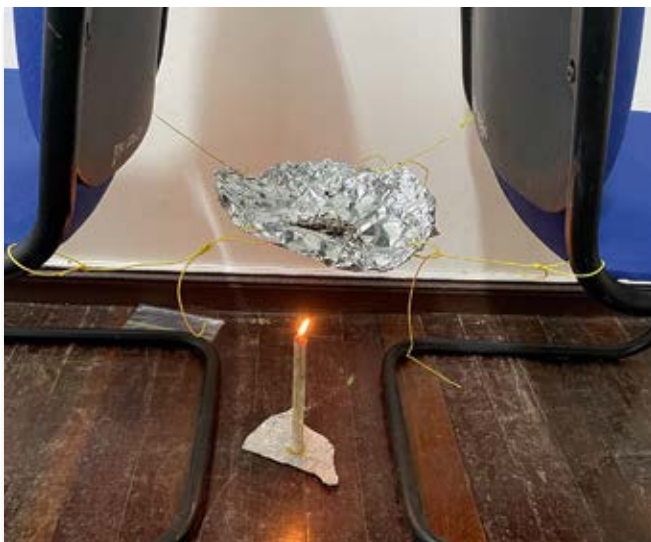
the view of the river and sweeping tunnels.

After that I had a rest day with Hazel, where I learnt all about microbiology and the acidity of bird and bat poo. She had collected samples from a cave the day previous and it was my job to dry them out so she could look at them under a microscope. I spread them out on pieces of tin foil and set them outside in the sun to dry however one piece was taking a long time so we set up a contraption using a candle, two chairs and a bit of string to speed up the process.

I then scraped the dry guano into test tube and sealed them to be used later. That evening Hazel wanted to brush me up on my SRT skills, that I had only learnt a week prior to arriving in Mulu. We headed to the Forrester tower, a lookout point in the middle of the rainforest and set up some ropes that I could ascend and descend. Ascending went reasonably well, descending however was much trickier as the rope we were using was a little too thick for my Petzl stop to manage so even with my full force push the lever I was struggling to move anywhere. By this point it was dark and drizzling and we were surrounded by bugs so decided to call it a day. Altogether it was a great experience and I had fun time.

On my final day in Mulu I decided to take the trip up to Paku Waterfall by myself as everyone else was either down a cave or doing important scientific research. After an unsuccessful try in the morning due to bad weather, I tried again in the afternoon. It was about 2km walk up the boardwalk before turning off into the rainforest on a little path which was led for about 1.5km to the waterfall, so overall a not too long walk. Once I reached the path I saw lots of interesting wildlife in the less walked part of the rainforest: many butterflies, a few small lizards and even a giant tree squirrel. Further along the path I suddenly encountered a large monitor lizard waiting just by the edge of the path, it was about 1m long and not friendly looking. As I took a step towards it, the lizard looked at me unfazed. I was aware that monitor lizards are known to be aggressive and territorial so decided it was probably not worth risking my foot to a reptile that can run faster than me so I promptly turned around and headed back to the safety of HQ, never seeing the waterfall. That concluded my time in Mulu.

Overall I had an excellent experience in Mulu and it reignited the joy I had for caving when I was younger. I would definitely like to return to see more caves and hopefully finally Paku Waterfall. Thank you to Andy Eavis for inviting me and the whole group of cavers who made me feel safe and welcome in an unusual place.



Drying guano with a candle. Photo: Maya Williams



Mulu rainforest. Photo: Chris Howes

A Journey into the Unknown

Rida Rambli

THE first thing that would cross my mind, growing up when dad used to go for caving expeditions: 'Dark, tight spaces, without the certainty of finding an exit ... why would anyone willingly put themselves in that situation?' Curious? I was, of course, but I never thought of going through it myself.

Fast forward 26 years later and there I was, stepping foot on Mulu ground to embark on the same journey my dad had been on. Living the stories he told us, to experience in person what the hype was all about. Frankly, I did not know what to expect. I have been caving with my dad since I was a child, but nothing crazy. On weekends we would bring uni students caving in our city to show them the underworld.

This was definitely a once in a lifetime experience, meeting experts from completely different backgrounds; from doctors to businessmen and scientists, and I am a research analyst myself. All took their time off to be in Mulu for their love for the unknown and the underground, all in the name of speleology.

I took this opportunity, as a novice myself, to join in as much as I could with everyone who had their own mission. I spent time in Stone Horse Cave learning the ecosystem and biology native to Mulu with a couple of photographers, Chris and Judith. The undisturbed nature of the caves just shows how fascinating nature is, with little creatures appearing and hiding as soon as we entered the caves. Few of the things that come to our minds when one mentions caving are crawling, squeezing and specifically what most would fear: claustrophobia. But, Mulu is probably one of the most unique caving areas in the world. It is massive and it made me wonder: if these are the explored systems, how much more is out there still waiting for us to discover?

I started my adventure with a mission to find a connection between two caves, which we believe does exist. We had a chisel and shovel to dig a hole in search for the said connection. We took a couple of hours digging, taking turns, which was a new challenge to me as I found out that digging horizontally and vertically was not as easy as I thought. As a petite person, we dug just enough for me to squeeze myself in, only to find out we felt no draught after all our hard work; we were left with a dead end. No hint of disappointment was seen in any of our faces, just an indication that we were not at the right place, a spirit I found fascinating in these cavers: patient yet inquisitive.

Coming from a mathematical background, I joined a friend of mine, Roo in surveying the cave systems. He of course, does it for a living, whilst I was there observing his work and the technology that comes with it. Imagine walking in pitch blackness, with only a light on your helmet and a sense of memory; these cavers have mapped out the whole of Mulu by hand. These surveys were up on the science centre wall as guides to allow cavers to find their way, like our own bible based on the years of expeditions since 1978. Yes, we made wrong turns, were lost for nearly two hours following these maps, as no



Rida Rambli in Stone Horse Cave
Photo: Chris Howes



A huntsman spider in Stone Horse Cave
Photo: Chris Howes

Google map could help you find your final destination. Most of the time, you only know the route once you find it. But, with the advancement of technology, which has progressed exponentially over the years, the laser scanner was implemented to project the structure of the caves and create a new representation which could be used to show the real embodiment of Mulu caves. Sounds easy? Well, not with heavy equipment, rough terrains and unpredictable weather which brings so much uncertainty to whether we could get the data we wanted on the day. However, it shows the work put into discovering the hidden gems of the caves by these passionate people travelling thousands of miles to reach Mulu.

On day 5, five of us went underground camping at Scumring to change some old rigs. Whilst other teams were on a mission deep underground somewhere else, I had the opportunity to explore with Andy Eavis, the expedition leader, and his son Rob. It fascinates me how this has come to be a tradition for some of them, a really unique family holiday indeed.

Our journey to our base camp at Scumring included one of the best views I had ever laid my eyes on. Forget blue beaches and green mountains, but formations of stalagmites and cave creatures that can only be found deep in a cave, with waterfalls and beautiful ponds serenaded by swiftlets and bats around you. Andy and I were looking for some old ropes to replace, but instead we found ourselves going around in circles and were lost for a couple of hours, with only a survey in our hands. Alas, no ropes were in sight, but to my amazement we were knee-deep in what seemed like white snow, which turned out to be old guano. It was a unique experience, which one could only encounter underground.

At the same time, half of the team was away changing rigs, and Andy and I were starting to worry as they took a while to return to base. With smiles on their faces, they were excited to tell us they may have explored a new connection. This exploration would be significant as the real size of Mulu caves is still unknown. Any new discovery was a celebration for all of us.

It broadened my perspectives on Mulu, especially when my own father would be on expeditions every year, with no phone signals for us to contact him, although this has changed after the pandemic and I was able to send pictures when we were there to our loved ones, instead of waiting to see them only once they are back home. With the help of technology, research and a bunch of passionate people, we are another step closer to discover the mystery of Mulu. Being in a place only a handful of people have stepped foot on, it was a privilege to be invited to this expedition, to explore what my own country has to offer. Was the hype worth it? Absolutely.



Tim Kent (left), Andi Smith, Andy Eavis and Rida Rambli at the Scumring Camp
Photo: Rob Eavis

Expedition Foods

Andy Eavis

WE are very grateful to Expedition Foods Ltd for providing at a very good discount 200 man-days of freeze dried food, consisting of breakfast, dinner main course and desert plus snacks. This was used as the mainstay of our underground camping rations and worked well, the quality of the product was excellent, nutritious and tasty.

We struggled a little bit with our logistics. Most of the breakfasts were in single portions; the double portion packs were a mistake for us to take. People tended to eat one each, which not only reduced the number of meals available but also meant that the main courses filled people up and then they didn't eat the desert afterwards. Main courses ran out more quickly than expected, as did double portion breakfasts, and deserts were left over in excess. The food was universally declared by everyone to be very good quality and delicious.

Surprisingly, the cave crickets could eat through the tinfoil packaging, something that amazed us, but they are substantial creatures, clearly very hungry and capable of smelling food through aluminium foil.

In addition, there is now no marks on the bags to indicate the level to fill to; we understand the fill markings have now been reintroduced. Several expedition members marked their cups with felt tip pens so



*Left: Will Pearson brewing up at the scanning camp in Revival (the Snake Track upper entrance camp). Photo: Roo Walters
Below: Judith Calford preparing Expedition Foods meals, and the Revival camp. Photos: Chris Howes*



they could measure the water before adding it to the freeze-dried packs. We recommend that Expedition Foods, as a side line, could sell graduated cups advertising Expedition Foods.

On a future trip we would not hesitate in taking these packs again, but would only take single portions, we would be more careful with their issue and distribution, and we would only use them for 50% of underground rations, the other 50% being made up with locally sourced produce. There are things like freeze-dried noodles, rice, locally grown cereals and other easily cooked produce which give a break from freeze-dried and help the local economy. Now in Mulu we have a number of opportunities for locally sourced food, something that we never had in the past.

Acknowledgements

Andy Eavis

The members of the Mulu Caves 2022 expedition are grateful for the support of the following:

In Sarawak

The Premier of Sarawak

The Sarawak State Secretary

Sarawak Forestry Commission

All of the Gulong Mulu National Park Management,

Particularly Hein Gerstner, the Park Manager, and his wife Andia

Rambli Ahmed and Bracken Tisen our local executive helpers, advisors and friends

Veno Enar, excellent local organiser and foreman

Jimmy Jarau: senior boat organiser

The other porters who were hardworking, cheerful and longsuffering

In the UK

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Mount Everest Foundation – for giving continuing financial help

Expedition Foods – for delicious underground rations

PJ Hayman for expedition insurance

Lilian Eavis for longsuffering (above and beyond) support to the expedition

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Hugh St Lawrence for maintaining the website



Veno Enar and Judith Calford in Daniel's Cave. Photo: Chris Howes

Conclusions

Andy Eavis

MULU Caves 2022 completed most of its objectives. Cave of the Winds was connected to Racer Cave via a 15m cave dive. This added 11.9km to the total length of the Clearwater System. With this new passage and the connection Clearwater is now nearly 260km long, moving it up the world's ranking from ninth in the world to eighth longest cave in the world, overtaking Lechuguilla Cave in the United States.



Unfortunately, the hoped-for connection to Lagang's Cave was not accomplished (maybe Mulu Caves 2023). That would make it the seventh longest cave in the world.

Exploration of new passage during the 2022 expedition surveyed 6.5km. Much of this was done using underground camps a long way into the Clearwater system. Exploration now of course is getting much more difficult with underground distances being very large.

The cave surveying was complimented with laser scanning, in total over 4.0km of gigantic cave passage was recorded. This will enable us to make a digital 3D model which we can use in many ways from flying a small digital aeroplane through the digital cave to studying the detail of the cave passage sides to help towards the scientific interpretation.

Ten days were spent completing this 3D laser scanning traverse and Mulu Caves 2023 can continue this in the future.

Another 5.0km of cave passage was resurveyed to increase the accuracy of the underground survey and help with the scientific interpretation.

In addition to the normal photography survey and detailed recording of the caves an ambitious science programme was led by Dr Andrew Farrant and Dr Hazel Barton. It is now clear that large tropical caves full of organic material continue to be shaped by atmospheric erosion long after the initial water formation has finished.

The huge scallops in the roof of Deer Cave can now be explained. It was very difficult to envisage huge angular boulders on the floor and a smooth phreatic roof. There is a similar situation in many of the other Mulu passages. There are places where you can see angular boulders on the floor and a very rounded matching indent where they have fallen from the ceiling.

Another ground-breaking area of science on the trip is research to understand why the highly chemical-resistant caving ropes deteriorate so quickly when left *in situ* in Mulu caves. Clearly, this deterioration is a very serious and dangerous problem. Chemical and microbiological studies are unravelling this phenomenon.

Finally, current studies of the geology and topography of the limestone mountains of Mulu suggest it is probable that less than half of the caves have so far been explored, there is much more to do in the future. It is getting more difficult, the law of diminishing returns, we are now further into the mountain both underground and on the surface.

On this trip we had a number of local Malaysian cavers participating and, we hope to continue this collaboration in the future.

MULU contains a history of what was occurring on the surface up to over 5 million years ago and remarkably accurate dates can be calculated for different factors, but further work is required. On the science recording and exploration fronts, the future of Mulu looks very exciting: there is a lot more to do.



Chris Blakeley (left), Kevin Munn, Colin Boothroyd, Zarris Kem and Moose Nixon at the research centre. Photo: Chris Howes



the **MULU** Caves
Project

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Front cover: Dave 'Moose' Nixon embarking on the long bolt climb up the 37m pitch from No Justice into Sandstorm Passage. Photo: Colin Boothroyd

Rear cover: A cave racer snake hunting from the top of a stalagmite in Snake Track. Photo: Chris Howes

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