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# Northern Caves 2023
# Expedition Report
## Wulff Land, Kalaallit Nunaat / Greenland

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# Report on the findings of the Greenland Caves Project 2023 expedition to Wulff Land, Kalaallit Nunaat/North Greenland July-August, 2023

## Project & Expedition leader: Prof. Dr. Gina Moseley

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**Dr. Nathan Hudson-Peacock**
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Cover Photo: Looking east out of the entrance of WUL-8, 'The Cold War Cave', Wulff Land, North Greenland.
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## Abstract

Caves offer one of the last remaining realms on Earth for original exploration. It is not possible for satellites to see inside the Earth, or for robots to map underground labyrinths. Learning about the world beneath our feet therefore requires humans to physically enter the underworld. Due to the harsh environment, remote location and difficult logistics, the most northerly-known caves in the world, located in North Greenland at c.82°N, remain largely unexplored.

This project aimed to rectify this situation by mounting the first dedicated cave-exploration expedition to North Greenland where the team accessed, explored, documented and mapped a number of previously unexplored caves. The caves were assessed for their potential to be used in Arctic climate change research. Through exploration of the caves, it was possible to establish whether cave mineral deposits (speleothems) were present from which records of past climate change can be constructed. Such records are critically important for placing present Arctic climate change in the context of natural variability, and for providing information about the Arctic response to a warmer world. Furthermore, speleothem records are likely to cover time periods beyond the limit of the Greenland ice cores, thus providing completely new knowledge about past Arctic climate. In addition to the exploration and palaeoclimate research, the project also conducted a number of interdisciplinary projects including modern palynology, entomology and microbiology.



## Abstrakt

Huler tilbyder en af de sidste tilbageværende riger på Jorden til original udforskning. Det er ikke muligt for satellitter at se inde i Jorden, eller for robotter at kortlægge underjordiske labyrinter. At lære om verden under vores fødder kræver derfor, at mennesker fysisk kommer ind i underverdenen. På grund af det barske miljø, afsides beliggenhed og vanskelige logistik er de nordligst kendte grotter i verden, der ligger i Nordgrønland ved c.82°N, stort set uudforskede.

Dette projekt havde til formål at rette op på denne situation ved at montere den første dedikerede hule-udforskningsekspedition til Nordgrønland, hvor holdet fik adgang til, udforskede, dokumenterede og kortlagde en række hidtil uudforskede huler. Hulerne blev vurderet for deres potentiale til at blive brugt i arktisk klimaændringsforskning. Gennem udforskning af hulerne var det muligt at fastslå, om der var grottemineralforekomster (speleothems) til stede, ud fra hvilke optegnelser om tidligere klimaændringer kan konstrueres. Sådanne registreringer er af afgørende betydning for at placere de nuværende arktiske klimaændringer i sammenhæng med naturlig variabilitet og for at give information om den arktiske reaktion på en varmere verden. Desuden vil speleothem-registreringer sandsynligvis dække tidsperioder ud over grænsen for de grønlandske iskerner, og dermed give helt ny viden om tidligere arktisk klima. Udover udforskningen og palæoklimaforskningen gennemførte projektet også en række tværfaglige projekter, herunder moderne palynologi, entomologi og mikrobiologi.

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## 1.0 Introduction

During the 1950s and early 1960s, in the height of the Cold War, the US Air Force Cambridge Research Laboratories undertook an extensive campaign to evaluate emergency ice-free landing sites in North and Northeast Greenland (Davies and Krinsley, 1961). The campaign was successful and significantly improved our knowledge of Greenland's glacial and geological history in one of the remotest parts of the planet. As part of those investigations, the first Greenlandic caves in limestone were discovered, including twelve caves in the Centrumsø region (80.2°N) of Northeast Greenland, plus one cave in Wulff Land (81.8°N) in North Greenland (Davies and Krinsley, 1960) which, at the time, was the most northern-known cave in the world.

The caves in the Centrumsø region were partly explored in 1960 and since then have only been visited by three dedicated caving expeditions, of which the most recent two in 2015 and 2019 were led by the Principle Investigator (PI) Gina Moseley as part of the Greenland Caves Project (Loubiere, 1987; Moseley, 2016; Moseley, et al., 2020). In contrast, the cave in Wulff Land was photographed in 1958 by W E Davies as part of aerial reconnaissance, but it was never explored.

Over the years, numerous explorers have dreamed of accessing the cave in Wulff Land. The original 1958 photo of the Wulff Land cave was passed on to Prof. John Peel, formerly of the University of Bristol Department of Geography, hence through this connection, speleologists within the University of Bristol Spelaeological Society (UBSS) came to be involved in the story. In the late 1980s, members of UBSS attempted to mount an expedition to the cave, but due to logistical and budget constraints, they were never successful in leaving British shores. Later, in 1992, the Oxford University Officers Training Corps also played with the idea of exploring the cave in Wulff Land, but they too came upon the same problems. Gina Moseley learnt about the Wulff Land cave from Charlie Self of UBSS in c.2008 and he was kind enough to provide her with his collections of literature and correspondence on Greenlandic caves.

The Wulff Land cave was described as being located in a 'mesa' comprised of Ordovician limestone. The iconic entrance photographed from the air was described as being within a c.150m-high escarpment on the east side of the 'mesa', overlooking a lake that later was named Apollo Lake.

Correspondence written by W E Davies to various speleologists over the decades following the photograph stated that:

*1) "The one in Wulff Land has not been explored. To enter it would require roping down an escarpment about 100m high. There appears to be another entrance to it on the upland to the west that would not require so much rope work. The cave appears to be very large with the opening on the scarp having a diameter of 10m." (correspondence to J-F Loubiere, 1981)*

*2) "As far as I know, no one has entered the cave on Wulff Land. It would be difficult to enter on the east side. Here the entry is in a cliff on the west side of what we call East Lake. The entry is near the north end of the lake. The cliff is about 150 m high and extends to the top of the 'mesa'. At the bottom of the cliff is a steep rock slope cut by a few equally steep but shallower ravines. In the lower half of the slope is the usual accumulation of talus and rocky fans. The cave entrance is about halfway up the cliff face. The top of the mesa is in the order of 600m above the valley floor lake. There appears to be a depression or sinkhole on top of the mesa, near its center, WSW of the cliff entrance. The upland is approachable on the west side of the mesa where slopes are gentler and there is a break in the cliffs" (correspondence to C Self, 1986)*

Personal communication with Prof. Paul Smith (University of Oxford), who undertook extensive geological mapping campaigns in the area in the 1990s, additionally indicated that the cave entrance was so large that a helicopter pilot once contemplated trying to land inside it. Unfortunately, the back draft was too much and nerves were too tested and the attempt was aborted. Nevertheless, such observations indicated that the Wulff Land cave entrance is much larger than any of the caves in the Centrumsø region (Moseley, 2016; Moseley et al., 2020). Smith also provided Moseley with his own photographs of the cave, which clearly showed the large entrance in the eastern face, as well as other caves in the region, indicating that the large entrance is not an isolated feature.

In 2021, Moseley received the Rolex Award for Enterprise to explore the cave in Wulff Land. This provided motivation to research further afield, and thanks to aerial photography from the geological mapping campaigns of the 1990s, numerous potential cave entrances were discovered throughout North Greenland, many of which were reported in Smith and Moseley (2020).

For the expedition to take place, a significant amount of planning and further funding was required. Sebastian Rasmussen of the Polog Polar Logistics Company invested countless hours in the logistical plan. In summer 2022, 20 drums of A1 jet fuel were sent by ship to Qaanaaq in northwest Greenland, where they were stored in a shipping container. The

plan was that a ski-equipped DC3 would transport the fuel to a depot in Hall Land, North Greenland, in winter 2023. The fuel would then be retrieved with a Twin Otter in summer 2023 and brought to the Northern Caves basecamp. Unfortunately, and unpredictably, after the fuel was deposited in Qaanaaq, the runway was reclassified and deemed too short for the DC3 to land. This meant that the option for a winter fuel dump to North Greenland was no longer viable. Rasmussen devised a new plan that involved chartering a Robinson R66 from Iceland. The R66 is more fuel efficient than the helicopter in the original plan, therefore reducing the fuel requirements of the expedition.

Further set-backs came in spring-summer 2023 when it was announced that there was only one operational Twin Otter presently servicing East Greenland. Parts were needed for two others that were grounded, but due to knock-on effects of COVID, there were production and shipping delays of unknown duration. Making final logistical plans was almost impossible, which caused further issues for making permit applications and buying compulsory expedition insurance. One project partner that was due to share mobilisation and demobilisation costs of the Twin Otter and helicopter decided about one month before the expedition to postpone their field season until 2024. This added a substantial financial burden to the expedition. Further complications came when the Fagradalsfjall volcano erupted in Iceland in the days before the expedition, and when the team members finally arrived in Iceland, they were still without the final expedition permit. Thankfully the expedition did continue and all the small hiccups were ironed out. The Expedition Log provides details specific to the execution of the Northern Caves 2023 Expedition.

### *1.1 Northern Caves 2023 Participants*

**Prof. Dr. Gina Moseley**, University of Innsbruck
Leader, palaeoclimatologist, speleologist

**Chris Blakeley**, Petzl
Rope-access specialist

**Dr. Nathan Hudson-Peacock**
Medic

**Dr. Gabriella Koltai**, University of Innsbruck
Palaeoclimatologist, speleologist

**Robbie Shone**, National Geographic
Expedition photographer

**Matthias Vogt**, Volcanoheli
Helicopter pilot

**Hans Erik Lange,** Greenland National Museum and Archives Archaeologist
Unfortunately travel cancellations prevented him from joining the expedition

**Sebastian Rasmussen**, Polog
Logistics organiser, not present on expedition

Figure 1: Expedition Team, left to right. Nathan Hudson-Peacock, Matthias Vogt, Gina Moseley, Chris Blakeley (back), Robbie Shone (front), Gabriella Koltai.

## 2.0 Expedition Location

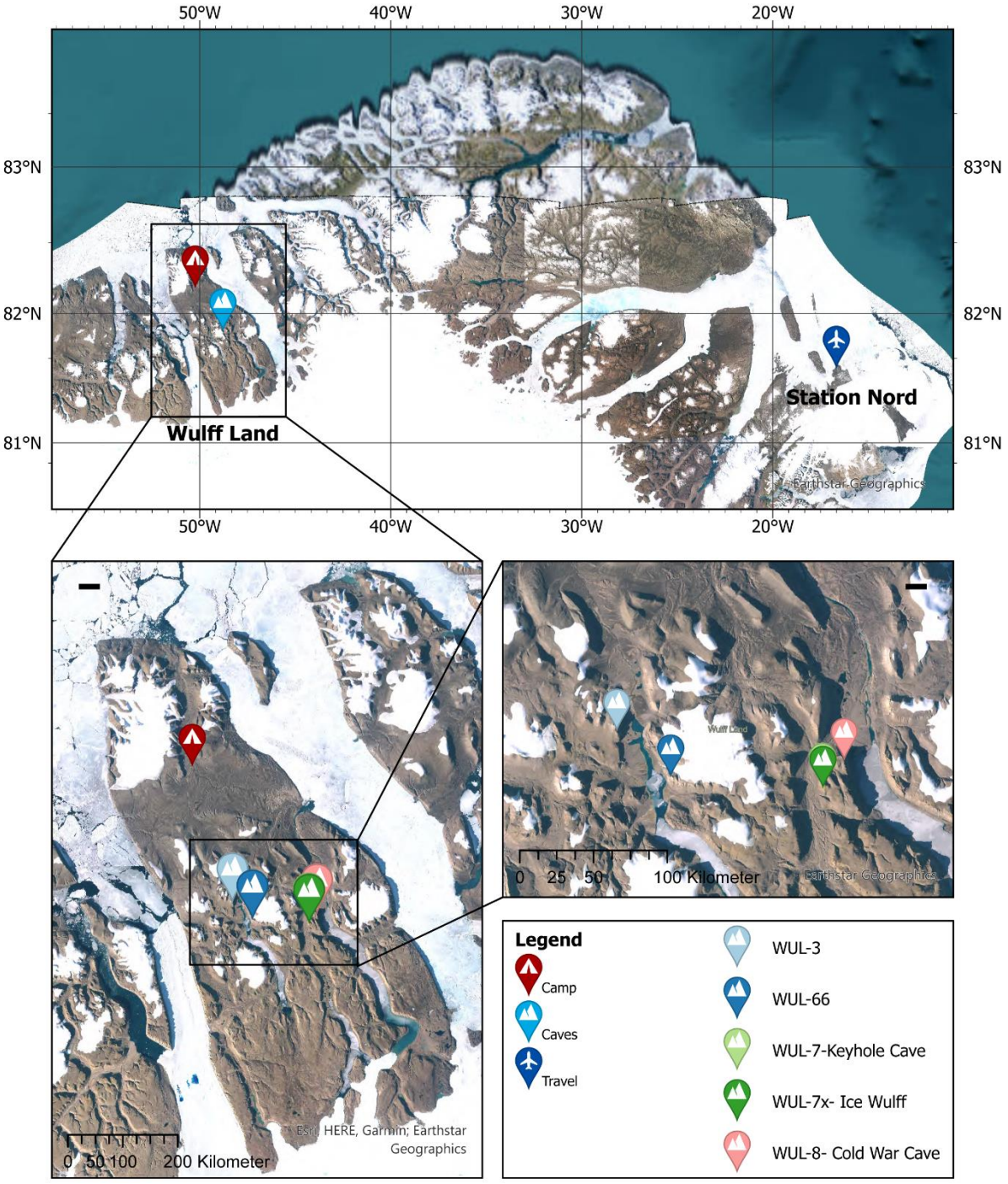


Figure 2: Map of the expedition location and key locations discussed in text.
Designed and produced by Lena Friedrich.

## 3.0 Administration and Logistics

### *3.1 Permits and Insurance*

The following permits were obtained:

KNNO Expedition Permit C-23-11
Genetic Resources G23-030 and G23-087
General Scientific Research Permit GSR-1-2023-03
Rifle Permit C-23-11
Radio Permit 2023-6569
Insurance SP5035702.1.7
Export Permit 2023-97

Further, the Mineral Licence and Safety Authority (MLSA) assessed the activities of the project and concluded that the activities fell beyond the scope of the Mineral Resources Act. The expedition therefore did not require a Scientific Permit from the MLSA.

### *3.2 Camp and General Equipment*

Figure 3: Twin Otter landing site in Wulff Land.

The base camp was established at the same location as the Twin Otter Landing strip (Fig.3) in the north of Wulff Land, approximately 35 to 50 km to the investigated caves (Fig.2). The camp included five 2-man sleeping tents (four Terra Nova Quasars and one MSR tent). The Quasars were equipped with an entrance and porch at each end, which was useful both for storing equipment and also a quick exit in the right direction when the bear fence was triggered (Fig.4). The Quasars were all modified with valences for rocks and snow. They stood up to the strong gusts and winds well. Unfortunately, one of the poles on the MSR tent snapped in the strong wind and pierced the tent. It severely damaged the integrity of the structure of the tent meaning that it had to be moved to a move sheltered location outside of the protected sleeping area.

Base camp also had an 8-10-man communal tent with porch, however, due to weight limitations, only the outer was sent all the way to Wulff Land (Fig.5). Whilst this made it harder to warm up on cold days, it had the advantage that footwear did not need to be removed upon entering the tent.

Figure 4: Four Terra Nova Quasars in the snow.

Figure 5: The communal base camp tent with porch and no inner.

Figure 6: Gina Moseley and her 2-year-old daughter Madeline preparing freight prior to the expedition.

It took three months to prepare the freight prior to the expedition (Fig.6), which was largely sent in aluminium transport boxes. The main components of the freight included: tents, food, kitchen equipment, scientific equipment, medical equipment, cave access equipment, power generation, safety, and rescue equipment.

### *3.3 Cave-Access by Chris Blakeley*

Figure 7: Chris Blakeley and Gabriella Koltai sort through gear needed to access caves.

In terms of equipment for this expedition, the focus was turned towards the access and exploration of Wulff Land 'Cold War' cave (which became 'WUL-8' during pre-expedition planning) and, of course, the need to travel as lightweight as possible.

It is always a compromise, particularly when trying to estimate how much rope will be needed. Rope is certainly the heaviest of the rigging equipment, especially considering the scale of the objectives.

Once underground, and with experience of previous Greenland caves, rope lengths - depending on the extent of underground cave development - are a little easier to manage. However, imagining what terrain may need to be protected whilst accessing the caves is more difficult. In the case that insufficient rope is taken, then the cave entrances may not be accessible at all. Steep and 'high consequence' ground on the route to the entrance can very easily require hundreds of metres of rope and numerous anchors.

Concentrating on WUL-8, the most likely access was from above (Fig.7). Hoping that the team could be dropped by helicopter with all equipment directly above the entrance actually paid off in the event. Ideal aerological conditions for the helicopter and a suitable landing zone identified on the approach, as well as just a couple of short minutes to look at the face either side of the entrance, gave reassurance that in terms of equipment and the terrain, there was a very good chance of accessing the cave.

Stone-fall was the biggest hazard identified, which wasn't helped by the primarily vertical gully and linked crack system that was followed from the cliff top (Fig.8). A judicious amount of time-consuming 'cleaning' of the route was performed whilst rigging in order to limit stone-fall onto the team and the rope. However, it's simply not possible to remove every loose rock in this shattered environment, and so particularly on this route a priority was to avoid sending material onto those members of the team below, or onto themselves as they passed beneath ledges and loose rock.

In the case of WUL-8, all the rope and every removable anchor that the team had available that day were used just to reach the entrance. A mix of obstacles were encountered, requiring competencies and confidence in single rope technique from the whole team in order to descend to the cave. Delicate and sometimes unwieldy photographic and scientific equipment such as tripods and 3D laser scanning equipment were brought down the route and then up a short, steep, and very mobile slope and into the main cave. A lightweight first aid kit, food and simple emergency equipment was also brought down, with the main first aid and rescue equipment remaining at the top of the nunatak with Nathan the team doctor, who's rope experience was too limited for such a delicate descent. Within the cave itself, there was no further rigging or ropework required. Although a couple of interesting leads higher up in the walls were seen, the potential for scientific benefit from further exploration was very minimal and time was too limited for bolting up to them.

Keyhole Cave (WUL-7) was generally more horizontal to access, and again, the approach was made from a helicopter transfer and landing zone above and to the south. The descent towards the cave was relatively straightforward, albeit including one very exposed-feeling traverse sloping 20m on hollow and corroded rock. A slip here would have resulted in an awkward slide down to another lower platform, but this lower level wasn't visible during the traverse and so gave the impression that a fall would be all the way to the valley floor some 800m below. From here, the route went on to cross an exposed scree slope, which was protected with a steeply angled descending rope, giving access to a couple of horizontal platforms. These were actually massive detached flakes (Fig.9); huge pieces of the cliff. In fact, as it was possible to see between them and the cliff and also around their sides, it was difficult to know how they remained in place. The rope could now be rigged horizontally, with removable bolts placed into the rare solid parts of the main cliff, just in case it was the flakes which chose to break away whilst the team were walking along them. At the very end of this traverse a beautifully round, person-sized window looked into the cliff and down an 8m pitch. Two anchors placed just outside this window made for a straightforward drop into WUL-7, and direct access to its truncated main benched passage which had been seen from the helicopter only a few days earlier, earning it its name. The cave.

Figure 8: Gina Moseley climbs the rope from WUL-8. The loose, shattered, thinly-bedded nature of the limestone is clearly visible.

Figure 9: Gina Moseley and Chris Blakeley walk along the detached flakes outside WUL-7 (Keyhole Cave) with the protection of a traverse line.

included a short, loose climb up into a small aven at its inner extremity, but nothing that required rigging

The Petzl PUSH 9mm rope has proven to be reasonably robust and yet light enough to transport, although clearly the heaviest component of the access equipment in total. It has been used for climbing, single rope technique and regularly for handlines.

Using Petzl PULSE 8mm removable anchors has changed the face of expedition style rigging. Knowing that an anchor can simply be removed after use means that rigging for prospecting, or to protect an area quickly, will not 'waste' a precious bolt that could be a limitation later on. It's only drill battery power that limits progress in this respect. And, of course, nothing is left in the environment apart from an 8mm diameter hole.

On the subject of the drill, the team took the excellent little HILTI TE2 A22 hammer drill as used in 2019, along with 8mm HILTI SDSplus bits. Although the batteries were charged fully prior to each day's activities, the rigging for the entire expedition could probably have been completed on only one battery such is the efficiency of the bits and the drill.

### *3.4 Surveying Methods by Gabriella Koltai*

A variety of methods were used to document the newly accessed caves, including standard cave surveying to state-of-the-art 3-dimensional laser scanning and photogrammetry. Given the limited time in the field, only WUL-8 was surveyed with all methods, whilst other caves were surveyed only with traditional cave surveying methods.

Standard cave surveying involved using a DistoX laser range finder coupled to a smartphone running the Sexytopo cave surveying software (Fig.10). The two DistoXs were calibrated inside WUL-8 and yield values less than 0.5. Chris and Gabriella refined the field sketches whilst sat in base camp on poor weather days. Gina later drew up the surveys using Adobe Illustrator.

Figure 10: Chris Blakeley and Gabriella Koltai survey WUL-8 using standard cave surveying equipment.

The photogrammetry of WUL-8 included Gina taking over 1000 photographs of all views of the cave using a Nikon Z7ii mirrorless camera. Because of the daylight throughout most of the cave, additional flashes were not needed. It was important to have a good overlap between adjacent photographs. Photogrammetry targets were incorporated into the main cave survey so that scale could later be added to the photogrammetry model. Attempts were made to produce a low-resolution photogrammetry model in the field but this did not prove successful and the cave appeared as a canyon. The main high-resolution model was produced at the University of Innsbruck using Metashape Agisoft.

The 3D laser scanning was performed by Gabriella using a handheld laser scanner (Fig.11; LiDAR ZEB Horizon, GeoSLAM Inc.). The scanning involved doing a maximum 15-minutes-walking around in the cave many times and returning back to the same point. We selected some of the cave survey stations as a start point for the laser scanning. A key for a successful laser scan is to have a large spatial overlap (~30%) between the loops that allows to merge the numerous scans into one 3D model. The main high-resolution model is currently being produced at the University of Innsbruck using Connect.


Figure 11: Gabriella Koltai surveys WUL-8 using the LiDAR ZEB Horizon, GeoSLAM. The Cardo Outdoor communication device can be seen on the helmet.

### *3.5 Media Documentation by Robbie Shone*

Figure 12: Robbie Shone carrying his standard expedition photo gear.

As always, documenting the team's journey and discoveries in the arid and remote wilderness of Wulff Land and any neighbouring peninsulas across Greenland's northern territory was one of the major aims of the expedition. It was an important goal for the success of the expedition that the team returned with many good quality photographs and video footage for the major sponsors.

As a professional photographer, Robbie Shone had the primary role in the field to shoot the RAW photographs and capture the video footage (Fig.12). Before the expedition, the team recognized several main challenges and technical difficulties that they were likely to face working in the field. Thankfully, after three previous expeditions, they knew more about what was involved, meaning they knew what not to do and what not to take all the way to the northern peninsulas of Greenland. Nevertheless, the team had never been this remote in Greenland and this isolated. Arguably the main issue was going to be charging batteries for the electrical items, so everything ran smoothly. These were: cameras, laptops, the aerial drone, satellite phones, GPSs, battery-operated grinder, and the cordless drills for coring samples and installing the Petzl PULSE anchors.

Unlike the 2015, 2018 and 2019 expeditions, the weather was poor. After only a couple of days it turned against the team. The sun never really shone and they were forced to spend over six days tent bound. Any chance of using solar power was almost impossible. This was something that thankfully the team had considered prior to departure and during their trip up the east coast, they stopped off at Constable Point and picked up a second small Honda generator from the shipping container belonging to POLOG (the team's logistics organiser). This second generator was never used, but acted as the team's only back-up to their own small Honda generator which performed perfectly well and provided enough output to re-charge all power demands. As a precaution though, the team brought plenty of petrol/gasoline (20 litres) and two spare NGK spark plugs for the generator which were also never used.

As is typical with remote expeditions to far flung parts of the world, there is always limited time in the field. The ambitious plan to reach many different cave sites along the northern coast of Greenland's peninsulas and spend enough time at each site to study the landscape and explore the caves was always going to be a challenging one. During the 2023 expedition, the weather was bad for flying the helicopter, so when the team eventually reached a cave site, they had the bare minimum of time available to carry out all objectives or as many as they could achieve.

As is a common thread now, Robbie had the twofold challenge of shooting still photographs and capturing video footage. However, what helped reduce his workload was that Nathan was tasked with capturing vertical video content on his smartphone for all social media requirements for NGP. He embraced this and began gathering content even before leaving his home.

During the preparations and planning, the team had observed dozens of key and exciting locations where they wanted to visit. However, due to either the bad weather or the scale of the landscape, several were crossed off the list almost immediately. For the story of the expedition, it was important to record everything that was happening, including all the off days confined to the main base camp. When the weather allowed, the team visited the giant 'Cold War' cave they named WUL8. This was an amazing story in itself and offered amazing visuals from atmospheric vistas stretching for miles and miles over several fjords, to vertical cliff abseils over hundreds and hundreds of metres of empty space, culminating in a huge cave portal containing an ice lake and great acoustics. Further stunning photographic opportunities arose whilst flying in the helicopter or from flying the small DJI drone. These included flying over low-lying lake shores, braided rivers of turquoise/brown waters, deep ravines and canyons, to high-level hillsides.

Figure 13: Robbie Shone photographing camp after the light snowfall.

On one occasion - the last day of exploration before the weather turned, both Gina and Robbie had separated from Chris, who was left to rig ropes into what proved to be the only cave the team discovered that contained calcite samples. Gina and Robbie discovered a stunning cave, with several passages, one with walls fully covered with ice and ice crystals. Another passage led to a giant ramp of boulders terminating in the most unusual of ice plugs. The ice was crystal clear, like glass but with huge crystals decimetres in size. Although Robbie was armed with his photographic equipment, time proved the most precious thing of the day. As they were about to spend a few hours documenting the cave they had named Ice Wulff, Chris broke through on the Cardo device that his cave that he had just successfully rigged down into, did in fact contain the elusive calcite samples that Gina was missing and unfortunately Ice Wulff didn't! That meant that Gina and Robbie had to put all the photographic and surveying equipment back into their bags and race back up the 200m steep scree slope to meet Chris in time to obtain the calcite samples. They only had a little over two hours before the planned helicopter pickup. Needless to say, Ice Wullf remains undocumented although it may be Greenland's most spectacular cave 'ever discovered'.

For lighting in the caves, Robbie mostly used battery-powered flashguns (strobes) and StellaPro REFLEX lights which were a very recent sponsorship deal. Thankfully, the caves that the team explored were not too big and overwhelming for the lighting capacity that had been brought into the field. Ice is very reflective! All photo/video material was downloaded at the end of each day and backed up three times onto three small portable LaCie 1TB hard drives.

The team didn't carry out any social media posts whilst in the field.

Photographic and communication equipment included:

Nikon Z8 Mirroless camera - courtesy of Nikon Europe
Nikon Z8 Mirroless camera - loan from NGP
Nikon Z7ii Mirrorless camera
Nikon Z 24-70mm F/2.8 S lens
Nikon Z 14-24mm F/2.8 S lens - loan from NGP
Nikon Z 70-200mm F/2.8 lens - loan from NGP
Nikon Z 105mm Macro lens - loan from NGP
Nikon Z Nikkor 2.0x Teleconverter - loan from NGP
5× Nikon camera batteries
3 Legged Thing Pro LEO 2.0 portable carbon fibre travel tripod
Acratech tripod ball head
3× Sunpak 120J flashgun/strobe
5× Pocket Wizard Plus II Transceiver radios
2x StellaPro REFLEX lights for filming (single LED)
4x StellaPro REFLEX batteries
2x GoPro HERO11 Black with Volta hand grip.
1x DJI Mavic 3 Classic drone with Hasselblad 20MP camera
3x DJI Mavic 3 Classic drone batteries
2× Lexar Professional 128gb CFexpress memory cards
2× Lexar Professional 128gb SD memory cards
2× Lexar Professional 64gb CF memory cards
2× Lexar Professional 64gb SD memory cards
2× Lexar Professional 64gb Micro SD memory card
5x Cardo Systems Packtalk Outdoor units – sponsorship deal
4× Motorola PMR walkie talkie radios (never used)

### *3.6 Medical*

Prior to Northern Caves 2023, Nathan invested a significant amount of time into preparing for the expedition. This included assessing the different options for the quickest medical evacuation possible, whilst however planning for the longest evacuation that might take place (i.e., weeks in the case of a bad weather window). Nathan prepared a comprehensive medical kit that stayed at base camp, multiple small first aid kits to be carried by teams, plus an intermediate kit that he carried with him in the field. Prior to the expedition, everyone filled out a very comprehensive medical screening questionnaire and Nathan followed up where needed. He recommended vaccinations, and suggested everyone get dental checks with enough time for any necessary work. Gina and Gabi attended a wilderness first aid course prior to the expedition whereas Chris already held advanced first aid training skills in relation to his work.

During the expedition, a couple of issues required attention. Robbie once again experienced itchy swollen hands, the same as he had experienced on the three previous Greenland Caves Project expeditions. This time, Robbie felt the itching within half a day of

digging in the soil without gloves and informed Nathan immediately. Nathan successfully managed to keep it under control and prevent it from blistering (unlike the previous expeditions) with the aid of steroid cream and moisturiser.

Gina additionally experienced an issue on her left wrist, which started as a pain in the wrist but progressed so that it was difficult to grip and climb the rope). Nathan used a portable field ultrasound (Fig.14) and identified the issue. It was treated with compression and pain killers.

Figure 14: Nathan Hudson-Peacock uses the portable ultrasound on Gina Moseley's wrist.

### *3.7 Communication*

The expedition communication devices were largely governed by the permit requirements, which stated 'Please note that all expeditions are required to bring a PLB, maritime VHF and satellite telephone. In case the expedition will split up into several groups, all sub-groups will need to be equipped with PLB, VHF and satellite phones.'

The expedition carried:

- 2x Ocean Signal RescueMe personal locator beacons
- 2x Uniden MHS75 waterproof handheld 2-way VHF marine radios
- 4× Motorola TLKR T80 Extreme walkie talkie PMR radios
- 5x Cardo Packtalk Outdoor bluetooth communication devices, which proved extremely valuable when team members wanted to keep in contact with one another (e.g. talking on the descent of the wall to WUL-8). These devices require line of sight, but when multiple devices are in operation then a mesh enables communication over greater distances and beyond line of sight.
- 2x Iridium 9555 satellite phones
- 1x Iridium Go! with SOS function
- 1x Garmin Inreach Explorer+ with SOS function

Daily messages were sent to the expedition logistics organiser, Sebastian Rasmussen, as well as Disney Global Security Team. It was found that the Garmin Inreach Explorer+ connected to the Garmin Earthmate app on a smartphone was the most efficient way to send and receive messages, while we experienced some problems with the satellite phones. The Cardo Packtalks (Fig.11) worked perfectly and allowed smooth communication when the team members were out of voice range.

### *3.8 Weather*

'Premium' weather forecasts were obtained using the Garmin Inreach Explorer+. This service provided 7-day forecasts reported in varying intervals (1-2 hour intervals for the first day, 3-6 hour intervals for the next day, and 12-hour intervals for the remaining 5 days). Unsurprisingly, the forecasts for such a remote region that is hard to model were not perfect. They were, however, fairly accurate with the temperature and wind speeds. Rain and snow were not always as projected in the long-distance forecast, but did improve substantially for the short-term forecast.

Specific details regarding the weather are found in the expedition log but in general the expedition began with warm temperatures, clear blue skies and no wind. On day two, the sky became overcast and then over the course of the next days, the weather gradually deteriorated. Temperatures approached 0°C, the wind increased with gusts over 25 kts, it rained lightly on some days and there was one light snow storm that left a thin covering of snow (Fig.15). By lunchtime the snow in the valley bottom had already melted (Fig.16).

### *3.9 Waste Disposal*

All waste was dealt with according to the regulations specified in 'Rules for field work and reporting regarding mineral resources in Greenland', issued by the Government of Greenland Bureau of Minerals and petroleum (Ref no.69-03-20+01). This included:

1.07.01. Treatment and storage of waste products took place in such a way that it was not scattered by the wind or accessible to wildlife.

1.07.02 Combustible waste products were burned in a steel drum or transported to Station Nord for further handling.

1.07.06 Non-combustible waste products were transported to Station Nord for further handling.

1.07.09 Small quantities of waste water were produced from cleaning kitchen utensils with a soap carrying an eco-friendly label. Human waste was buried in such a manner that did not lead to fouling up of the surroundings.

Figure 15: Wulff Land base camp after the light snowfall.

Figure 16: Chris Blakeley walks through base camp after the sun has quickly burnt off the light snowfall.

1.08.03 All equipment and empty fuel containers were removed from base camp and transported to Station Nord.

### *3.10 Safety by Chris Blakeley*

Figure 17: Chris Blakeley prepares to rig into WUL-8.

As already experienced during previous Greenland Caves Project expeditions, and in similar group situations in the mountains, one of the most useful items to carry is a short length of rope and a couple of slings and carabiners. This lightweight equipment is often all that is needed to effectively protect an exposed step, haul or lower equipment, enable a group member to progress without their heavy rucksack, or even for a simple descent or to protect a climb. In a couple of situations during this expedition these methods were used very successfully, avoiding much more time consuming and potentially hazardous routes.

The team took the decision prior to the expedition to equip themselves with a lightweight technical stretcher. The Petzl NEST was chosen for a few reasons. Chris is very familiar with the device, it can be transported simply, is ideal for confined spaces and includes an integral casualty harness that is perfect for horizontal and vertical rope rescue. Additionally, one had been sourced at no charge to the expedition! A 2m-long tube with the four stiffening lattes and one bag with the rolled-up stretcher made transport a lot simpler than a basket-style equivalent. It was certainly extra weight to consider though, especially during the discussions at Station Nord when the team were suddenly tasked with potentially leaving 200kg of equipment behind. However, it made it to base camp where it was stored for the duration. Although it wasn't needed, a stretcher can certainly make a huge difference - potentially critical - in even simple cases of casualty evacuation on difficult terrain so it did add a level of confidence for Nathan and the rest of the team.

A stretcher is very useful for many evacuation cases, but this expedition aimed to access some specific cave entrances and potentially explore further underground. In addition to the equipment for personal progression on ropes, the team also had a dedicated and compact hauling system for deployment should the need arise to haul a casualty any distance vertically. The system could be used with or without the stretcher and included another two removable anchors.

Working with helicopters can lead to potential hazards quickly escalating into higher consequence situations. This expedition in particular, in comparison to the previous Greenland Caves Project expeditions, relied exclusively on the presence of the helicopter and its ability to fly.

Ensuring that the helicopter had sufficient fuel for its operations, weight capacity for the team and equipment, visibility, appropriate wind speed and as mentioned elsewhere, pilot daily flying time were all components of the team's daily discussions and safety planning. Mattias was careful to complete a thorough explanation of the Robinson R66 helicopter's specific hazards, how the team should get in and out, loading, unloading and rotor running (hot) drop offs. Handling of rifles, distress flare pistols and ammunition was also strictly managed by the team during all fixed wing and helicopter operations.

Firearms, flare pistols and ammunition are equipment not regularly handled by the members of the expedition other than whilst in Greenland. At the beginning of each expedition, the team has therefore dedicated some time to familiarise themselves with the weapons, types of ammunition, loading, unloading, presenting and carrying. Finally, a little target practice to ensure that each member of the team had at least some experience in how the weapon would feel, aim and respond whilst firing. No pencil flares were taken on this occasion, and the team took the opportunity to practice discharge a flare pistol whilst at base camp. An important concern is to avoid a flare landing behind a bear or other threat, and so potentially driving it towards the gun. It was very useful for the whole team to see just how far the flare was launched. It would be very easy to 'overshoot'.

In order to limit attraction of muskox, wolves (this expedition making its basecamp in Wulff Land) and principally polar bears, the kitchen tent with its associated enticing smells and food storage was sited about 300m downwind of the sleeping tents. On arrival at basecamp, the prevailing wind was northerly; driven by cool air coming from the sea ice. It was also felt that this would be the likely route taken by any bears heading away from the sea. During the next couple of weeks, the wind would change with the unstable weather, and southerlies were also encountered. The team were really careful to store all food in the closed aluminium containers, sealing waste in knotted bags, and burned anything tempting to

wildlife, in order to limit visits to the camp. Whilst the team were confined to the basecamp tent for more prolonged periods, they did keep a regular lookout for local wildlife, taking a weapon whilst collecting river water, visiting the toilet, exploring locally, and when accessing the sleeping tents. There was often poor visibility due to low cloud, which meant staying more alert for short notice sightings and a heavier reliance on the bear fence alarms. The 'bear fence' was erected around the sleeping tents with as much distance as possible between the tents and the perimeter (Fig.17). The fence was as lightweight as possible, with the posts made of wooden broom handles, a loud personal attack alarm on every second post, and 2mm dyneema cord running between the posts that would pull out the pin on the alarm if the fence was disturbed. Over the years, the team has had many discussions regarding the usefulness of such a fence with questions centred around whether there would be time to act in a serious attack. On this expedition, the fence was triggered three times whilst members were sleeping; first by a hare, second by a musk ox, and thirdly by a wolf. All of these instances would have gone unnoticed if the fence had not been installed. It was clear that the loud noise scared the animals and it woke the team members such that it would have been possible to act if attention was needed.

In line with most expeditions, the more likely incidents are those related to simpler activities as that can be where attention is least focussed. Relatively simple tasks such as refilling the generator with petrol, lighting the MSR Dragonfly stoves, burning rubbish, cutting and flattening empty Jet A1 fuel drums for onward transport, carrying fresh water from the river and so on were therefore discussed and noted. Even a straightforward incident such as a sprained ankle, a burn or a deep cut could have serious consequences for the individual, but also for the expedition, due to the small team size and the extremely remote location.

Figure 18: Chris Blakeley, Gina Moseley and Gabriella Koltai install the 'bear fence'

### *3.11 Fauna*

Figure 19: Arctic Wolf Spider.

Figure 20: Unidentified bird.

Figure 21: Arctic Stoat.

Figure 22: Arctic Jaeger.

Figure 23: Unidentified butterfly.

Figure 24: Arctic Hare.

Figure 25: Musk Ox gather close to base camp on the opposite side of the river.

## 4.0 Expedition Log

***Monday 17th July, 2023***

The Iceland Team (Chris Blakeley, Nathan Hudson-Peacock, Gabriella Koltai, Gina Moseley, Robbie Shone) arrived in Keflavik from various departure points in Europe. Hans Lange was en-route along the west coast of Greenland to Qaanaaq but had difficulties due to weather. The Iceland Team spent the night in Reykjavik (Fig.26).

Figure 26: Left to right, Nathan, Gabi, Gina, Robbie and Chris meet in Reykjavik.

***Tuesday 18th July, 2023***

The Iceland Team had interesting discussions at breakfast with a Swiss geologist who was staying in the same hotel. He'd seen the expedition t-shirts and was interested in the project. The Iceland Team flew by scheduled flight from Reykjavik to Akureyri where they then spent the afternoon going over the various communication devices and the content and uses of equipment in the small field kits (Fig.27). They bought food for the journey to Station Nord and had email discussions with Sebastian over the final expedition permit, which still hadn't arrived but was in process. As the hours ticked on, it looked less and less likely that the expedition would take place, but finally it arrived c. 1925 whilst sat at dinner the night before the expedition was due to start.

***Wednesday 19th July, 2023***

The Team departed Akureyri c.1015 in a King Air charter from Norlandair and arrived at Constable Point (Nerlerit Inaat Airport) c.1150. The pilots refuelled whilst The Team collected a spare generator, petrol, white gas, rifles, flare guns and ammunition from the Polog store. Unfortunately, some of the rifles and flare guns that were listed on the permit could not be found. Gina phoned Sebastian but he could not provide any further

Figure 27: Nathan Hudson-Peacock goes through the contents of the emergency field first aid kits.


Figure 28: Nathan, Gabi and Gina at Station Nord.

details. The pilots were eager to get going so The Team took alternative weapons instead. Gina and Gabi also collected soil samples for a modern palynology study. They departed Constable Point (Nerlerit Inaat Airport) c.1300 and arrived at Station Nord, c.1600 (Fig.28). The head of the base (Christian) and the Twin Otter pilots met The Team off the King Air and went straight into discussions regarding weight and concerns regarding the flight the next day. The pilots had different information regarding the weight of the equipment compared to what was actually present (350 kg vs. 385 kg of freight plus an extra 260 kg in personal gear, rifles, generator and other miscellaneous items collected en-route). They announced that they needed to take two drums of fuel with them (2x 200 kg) in order to get back. This pushed the total weight to 1400 kg, which was 400 kg over the payload and therefore not possible. They indicated that they might have to do two runs to Wulff Land, which set alarm bells ringing as to the extra cost. The budget had very little capacity for extra expenses, and looking at the figures it was estimated that an extra return flight to Wulff Land would be on the order of 20,000 to 25,000 EUR. It was a stressful situation and some discussions were had about not continuing any further. The Team were taken to the Villum Research Station where they were met by the manager (Jan). Jan showed them around the facility, which was very comfortable, kitted out with bunk beds, a kitchen, lounge area, and basic laboratory facilities. There wasn't much time to get comfortable, as The Team immediately went to find the freight that had been sent in advance to check that there wasn't anything amiss. It turned out everything was present as should be (and importantly there was nothing extra either). They enjoyed a light-hearted moment in the Station Nord souvenir shop, where it was indeed possible to get a passport stamp! Gabi and Nathan prepared dinner, whilst Chris and Gina looked over the logistical plan for the fuel requirements so that the Twin Otter pilots could be given a definitive answer on where to make the fuel dumps. After dinner, Christian and a representative of the Sirius patrol checked over the permit paperwork. The issue of having different weapons compared to those on the permit came to light, but it was a simple fix and they simply made a note. They wanted to check which communication devices the expedition had and what the numbers were and made it absolutely clear that The Team was not permitted to make use of any military installations that they might come across during the expedition, except in an emergency. The issue of too much weight came up once again. Christian tried to get in touch with the helicopter pilot (who was en-route up the east coast) to see if he could take some of the freight, and the Twin Otter pilots tried to establish whether there was a spare drum of fuel stored at Wulff Land. After a few drinks in the bar and a game or two of 'knocking a nail into a piece of wood', The Team retired to bed none-the-wiser as to the status of play the following day and had also received the news that Hans Lange had returned to Ilulissat due to navigational issues.

***Thursday 20th July, 2023***

Breakfast at 0800. Found Christian at 0830 who still didn't have an update. Gina and Robbie started separating out 200 kg of freight that might be able to come a day late on the helicopter. This included spare fuel, scientific equipment, the spare generator etc. Within 10 minutes, Christian arrived with the news that Matthias, the helicopter pilot, could take 120 kg. This was great news, then the Twin Otter

Figure 29: Inside the Twin Otter going to Wulff Land.

pilots arrived and they had found out that there was a spare drum at Wulff Land that they could use, meaning they only needed to transport one drum with them. With 120 kg going on the helicopter and one fuel drum (200 kg) removed, they were happy to do just the one run to Wulff Land. The new problem was that they wanted to leave immediately and didn't appreciate that some time was needed to decide what could stay behind and what could come the next day.

The Twin Otter departed Station Nord at c. 0935 and landed on a very bumpy landing strip at Wulff Land at c.1135 (Figs.29-33). It was a quick turn-around. The freight was removed, the plane was refuelled, and the pilots departed, continuing further west to the fuel dump in Qaanaaq. The Team was finally alone on a beautiful warm sunny day, with crystal clear blue skies in the wilderness of North Greenland; alone that was except for the millions of mosquitoes that buzzed around taking every opportunity to enjoy the new food source that had arrived. At times it was impossible to breathe in without swallowing a few unfortunate mosquitoes.

The Team immediately began planning how to set up base camp, the critical point being what was upwind and downwind, so that the sleeping tents and cook tent could be separated accordingly. Ultimately the camp was set up on a raised river terrace (in case the river rose), but not so far away from the edge in order to reduce the blind spot (Figs.34-35). There were lots to do, and it was easy to get distracted and just keep going. In the end, a much-needed break was had and the first cups of tea and lunch. Afterwards, Chris, Gabi and Gina installed the bear fence, and Robbie and Nathan built the toilet. The evening was spent doing a bit of rifle and flare gun practice.

***Friday 21st July, 2023***

The Team stayed around camp all day and continued fettling gear and equipment (Fig.36). The Twin Otter arrived c.1430 with five drums of fuel. They brought the sad news that Hans Lange had not been able to get to Qaanaaq (he had started travelling on 15th July), and he would therefore not be joining the expedition. This was a huge blow to all of us. The Twin Otter left at c. 1440 and returned to Hall Land, where it picked up another five drums, dropped them at Warming Land, and then continued back to Station Nord. In c.1715, Matthias Vogt and the helicopter arrived at Wulff Land (Fig.37).

***Saturday 22nd July, 2023***

The Team had breakfast together. Gina, Chris and Robbie took the first flight to WUL-8. They tried to fly via the potential WUL-7 caves to check them out, but this was decided spontaneously and the correct coordinates were not known. They did not waste time and headed to WUL-8, which Matthias approached from the south so that the cave entrance emerged on the left of the helicopter. Scale is hard to judge in a vast landscape without recognisable features such as trees or buildings, which meant that from the air, WUL-8 looked somewhat of an anti-climax. Matthias landed the helicopter on the surface, the three jumped out with the gear and he flew off to collect Gabi and Nathan. Chris began rigging straight away and from the top of the plateau (Fig.38), the valley bottom did indeed look a long way off. With time, the helicopter returned, shut down, and out popped the other three. After some time without communication from Chris, Robbie managed to shout down to him and found that he would need the next rope. Chris was trying to communicate that we should turn on the Cardo communication devices, but in the excitement, they hadn't all been 'grouped' and did not yet work as they should. Robbie took rope down to Chris and was also gone for some time. Those remaining on the top kept themselves busy (Fig.39). Gina and Gabi looked at rocks and found lots of granites and other 'exotic' specimens. They all scouted the surrounding cliff faces in the binoculars for cave entrances, but in reality, it looked like Swiss cheese and there were lots of small holes everywhere. Another potential large entrance was spotted on the same side as WUL-8 but on the next buttress to the south. Gina, Gabi and Nathan collected some samples for a palynology study, then Nathan walked up to the peak of the mountain, whilst Gina and Gabi headed down the west side of the plateau to look at some potential cave features, but they all turned out to be water marks or rock shelters. After some hours, Chris and Robbie reappeared. They were excited and reported that they'd used all the rope just to access the entrance slope but hadn't entered the cave yet. At one point, Chris had traversed over towards the cave (Fig.40), only to find out he was still far too high up. The entrance was absolutely huge!

Figure 30: Chris and Gina discuss the landscape.

Figure 31: Icy fjords in North Greenland.

Figure 32: Elephant foot glaciers in North Greenland.


Figure 33: The expedition arrives at Wulff Land.

Figure 34: Establishing base camp in Wulff Land.

Figure 35: Dead musk ox skeleton.

Figure 36: Sorting gear inside the base camp tent.

Figure 37: Helicopter arrives.

Figure 38: Chris Blakeley begins the descent from the plateau into WUL-8.

Figure 39: Looking south along Apollo Lake from the plateau above WUL-8.

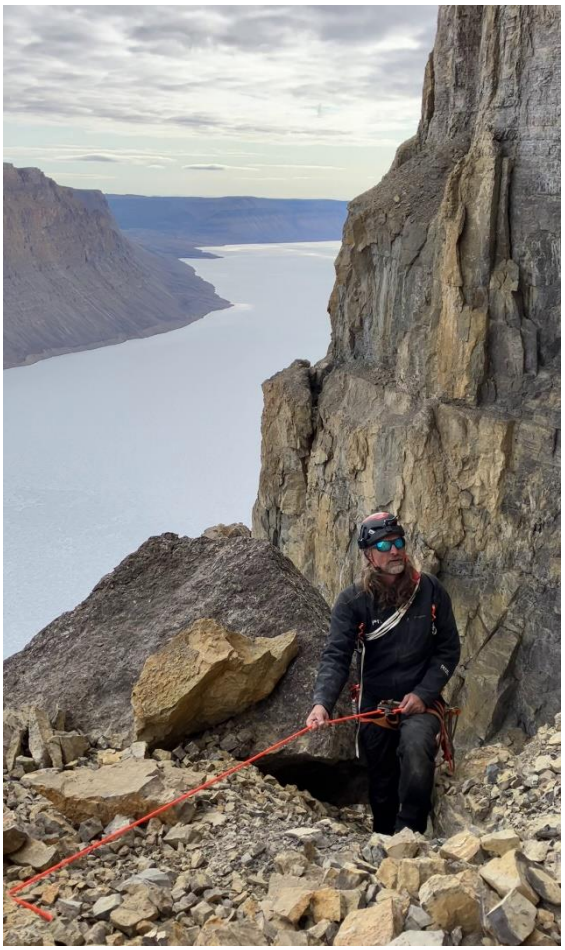

Figure 40: Chris Blakeley rigs into WUL-8.

After lunch, Chris, Gina, Robbie and Gabi descended the gully to WUL-8 (Fig.41). Chris had rigged it wonderfully for those who were not so experienced on ropes. Unfortunately, the rock remained extremely loose and Gina dislodged a rugby-ball-sized rock onto Chris, who was hit in the chest despite pulling himself close to the wall after hearing 'BELOW'. Robbie in turn was hit on the shoulder by a tennis-ball-sized rock dislodged by Gabi. Thankfully, no one was seriously hurt but it served as a serious reminder to the dangers and remoteness of the expedition. Chris waited before the final pitch to let Gina descend the last rope first, she waited at the bottom for Chris to join and they scrambled up the final scree slope up to the towering entrance together where they took in the magnificent view and waited for Robbie and Gabi to join. Several birds who used the ledges high up in the cave for nesting flew about. Once reunited, they explored the cave together, impressed by the grand size of the place and hoping it wouldn't end too soon. The walls were very thinly-bedded and completely full of fossils. Huge breakdown boulders were scattered throughout the chamber, and a watery-icy pond was just beyond the entrance. Looking at the 1990 photo from Paul Smith, the pond was also present then. Towards the back of the chamber, the boulders descended down underneath a wall covered in hoar frost.

Figure 41: Gina Moseley follows Chris Blakeley down the gully into WUL-8 once it had been rigged.

They tried to find ways on through the boulder choke, but in this environment, it wasn't the place to push hard. After some time, they called it quits in trying to find a way on. High up in the walls of the chamber it was clear that there were potential passages, but this would also require some serious bolting work. Time was ticking on. The underground team had been out of contact with the surface for some hours, Matthias's work hours were quickly closing in and four people still needed to climb the ropes. It was clear that they would have to come back the following day to do the documentation, however, it was clear no speleothem samples were present hence tomorrow would be the last day dedicated to this cave.

Gina departed up the ropes first. She contacted Nathan over the Cardos and relayed the findings. Nathan had had a long day of waiting on the surface but he'd taken the opportunity to learn the concept of flying a helicopter and enjoy the surroundings. Gina and Nathan departed with the first helicopter, then Matthias returned to collect Chris, Robbie and Gabi who had ascended in the meantime. It had been a special day. WUL-8, which was photographed in 1958, had finally been explored after 65 years. It was also a special day for Chris, who enjoyed a milestone birthday (Fig.42) being the first person to rig into the cave. At basecamp, everyone was generally in good spirits. The Team enjoyed some cake, whisky, and Chris opened cards and presents.

Figure 42: Happy Birthday Chris.

***Sunday 23rd July, 2023***

All the documentation for WUL-8 needed to be achieved today so that The Team could redirect their attention to other caves. Robbie needed his big aerial photographs. Chris, Gabi and Gina departed first so that they could get in position on the wall. En-route they checked out 'WUL-7' as they now had the coordinates. These turned out to be a series of smaller caves including one in particular that was a keyhole shaped passage. This observation would later become important as it indicated that the cave maintained its original morphology, unlike WUL-8, which was a large breakdown chamber. If WUL-8 ever contained any speleothem deposits, they would be underneath the boulders.

Robbie and Nathan arrived in the second helicopter, but since the descent of the other three was ongoing, the helicopter waited idling in the valley bottom. Robbie was given the word that the team on the wall would be ready in 2 minutes. The helicopter took off and classically, progress on the wall stalled, which meant the helicopter burnt precious fuel for minute upon minute, whilst Robbie also got increasingly nervous as the light got worse and worse. Eventually the photo shoot got going, but the light was fairly drab and, in the end, Robbie rather disappointingly called the end.

One limitation that had not been fully accounted for was the limit on the helicopter pilot's working hours (c. 8 hours per day, maximum 10 hours). In the past on other expeditions, the 24-hour sunlight has been an advantage, as it has meant that the team can work late in the cave and safely return to camp when needed. Since this expedition required the helicopter to return to camp, the work had to be completed within the cave with enough time to get people and equipment back up the ropes, de-rig, and the helicopter do two shuttle runs with a refuelling stop included. This added considerable time pressure that The Team had not experienced previously. Looking at their watches in the cave, everyone realised they had to work fast. Robbie also arrived with the news that Matthias had made a point of saying he could not work another long day, or if he did then he would need a full day off the next day. This news wasn't particularly well received (even if it was known); everything became rushed and the chances of an accident seemed heightened. Gina and Gabi calibrated the distos, which took time. It had to be done in a cave hence the reason it was only achieved now. Robbie and Chris started some photography, but Robbie needed more assistance and wasn't quite getting what he needed. Gina and Gabi then began the microbiological sampling, but since they are not microbiologists it took some time to reacquaint themselves with the correct sampling process for four different studies. They still had a 3D laser scan and photogrammetry survey to do, the latter of which needed a regular survey for scale. In the end, Chris and Gabi worked quickly on the regular survey, Gina did the photogrammetry alone, then Gabi did the 3D laser scan which was challenging when people needed to continue working on other tasks thus interrupting the scanning process. Robbie and Chris continued the photography and also enjoyed a spot of twitching, including watching a fledgling take its

first flight from a ledge high up in the cave. As they all worked as quickly as possible, the weather turned worse and worse outside. In the end they had to call an end to their time in the cave and get people and gear up the ropes. It was miserable climbing back up in the cold drizzle and Matthias wanted to get going asap.

Under a dark grey sky, the helicopter approached basecamp (Fig.43). The high spirits of the day before were gone, this was now a mission. At first nothing seemed amiss, then Matthias said 'uh-oh, the

Figure 43: Grey skies and a rainbow after a rain shower in Wulff Land.

shelter is down'. Indeed, it was down. Not just down, but torn from two of its anchor points and flapping around in the wind. The basecamp tent looked like it might take off too. Gina and Nathan got out so that Matthias could return as quickly as possible. As they knelt in front of the helicopter, waiting for it to leave any moment now, Matthias started making a cutting symbol across his throat. What did it mean? Were Gina and Nathan in danger if they stayed in that position? Was something else wrong? Then the engine turned off. Was it too windy to collect Chris, Gabi and Robbie? The rotors squeaked to a stop, Matthias got out and said he had to refuel. This was a relief but the wind seemed to be getting stronger and stronger, and the chances of picking up the others seemed to be getting less and less. Nathan and Gina set about sorting out camp. The plus side to all this wind was that the mosquitoes had gone. Wind and dust howled through the basecamp tent, the valences flapped around and every pin in the bear fence had been pulled out. Even so, in the noise of the wind it was difficult to hear the siren of the 10 alarms going off until one was up close. The tarpaulin over the generator and electrical equipment had ripped off the wooden shed and was just being held with a couple of pegs in the ground. It took both Nathan and Gina to tame it. Matthias took off to fetch Chris, Gabi and Nathan. One of the poles on Matthias's tent had snapped and was poking through the outer. Nathan and Gina collected bigger rocks for the basecamp valences and cleared as much dust from the gear inside the tent as possible. They tried re-establishing the bear fence but it was a fool's errand and by the time they had gone around the whole perimeter they were all screeching once again. The helicopter returned with the others, who also jumped into sorting out camp. Chris and Robbie brought fuel drums over to make a windbreak in front of the basecamp tent, and Matthias moved his tent next to the shed for better protection from the elements, but unfortunately outside of the bear fence. Once everything was repositioned and tied down as much as possible The Team retired to the basecamp tent where the mood was a lot more subdued compared to the previous evening. Matthias was on tenterhooks all evening, worried that the gusts might get up to 35 knots, which would not be good for the helicopter.

***Monday 24th July, 2023***

Figure 44: Low cloud and fog surround base camp.

The winds had died down but it rained and there was poor visibility (Fig.44). The Team were forced to have a rest day and were confined to basecamp all day, which after two intense days in WUL-8 was not that unwelcome. Gina and Gabi took the opportunity to do an hourly isotope rain study and in case things should change in the afternoon, The Team planned for cave prospecting. Given the high humidity, Matthias was only prepared to fly one team as the risk was too high that they would not be picked up again if he should leave them. It was decided that Chris as rigger, Robbie as photographer, and Gabi as scientist should go. They prepared their gear in case the opportunity arose and a plan was made to visit 'WUL-3' first as it looked relatively easy to access, not requiring many hours of rigging for access. 'WUL-6' was identified as another potentially easy-access entrance. In the meantime, over many cups of tea and coffee, Matthias and Gina received independent weather forecasts and both confirmed that today and tomorrow were the best days weather-

wise. Afterwards snow was expected and it did not look promising for the rest of the expedition. Matthias suggested thinking about 'an emergency response plan' if the weather turned as forecast. As the hours ticked on, the weather did not improve sufficiently enough for flying and in the end the whole day was spent at basecamp. Gina produced a first trial of a photogrammetry model of WUL-8. It didn't work out well. The software turned it into a canyon. It would need a bit more work!

***Tuesday 25th July, 2023***

Brighter weather in the morning compared to yesterday. New forecast suggested today and tomorrow would be the best days, and then the bad weather would close in on Thursday until Tuesday next week (a day after the scheduled pick-up). At this point, it looked as if The Team would be staying longer than planned in Greenland but it would mostly be spent at basecamp. Matthias was prepared to fly, so once again Chris, Gabi and Robbie prepared to depart. Then the weather turned once again and visibility was too poor. The departure was called off. The Team got word that a Twin Otter would arrive to refuel (Fig.45), so they waited for news from the pilots as to the state of the weather around the peninsula. The plane arrived at c.1230 en-route to Washington Land. One of the pilots had dropped Chris, Robbie and Gina at Centrum Sø during the first expedition in 2015. The pilot remembered them too, or specifically 'boats' and 'caves'. It was certainly a welcome, warm and unexpected meeting in North Greenland.

Figure 45: Chris Blakeley and Gabriella Koltai help the visiting Twin Otter with refuelling.

Chris, Gabi and Robbie departed c.1315. Gina and Nathan stayed at basecamp providing regular weather reports to Matthias and worked on the WUL-8 photogrammetry model. En-route to WUL-3, a promising canyon with several caves was spotted but not explored at this stage. The helicopter landed at a lower elevation than WUL-3 and Chris, Gabi and Robbie hiked up to the cave (Figs.46-47) whilst Matthias went down to the valley bottom to wait (Figs.48-49). It was too risky to wait at elevation due to the high humidity and risk of instantly being in the cloud. They surveyed and photographed the cave and took samples for microbiology. The cave air temperature was logged for 2 hours and a fine-grained powder (possibly cryogenic cave carbonates) was sampled from the ice. There were otherwise no speleothem samples discovered.

The next target was WUL-6, however, on the way a large entrance that hadn't previously been identified from the aerial reconnaissance was observed. Matthias was able to do a 'hot drop-off' and then land in the valley (Figs.50-51). Chris, Gabi and Robbie surveyed and photographed the cave that became known as WUL-66. The temperature was logged too but then time was cut short due to bad weather approaching base camp and the three had to leave.

***Wednesday 26th July, 2023***

The north end of the bear fence was triggered at 0830 whilst everyone was still asleep in the tents. An inquisitive Arctic Hare hopped about in the sights of two rifles before retreating to the west, seemingly stressed a little by the noise of the alarm. In four expeditions, this was the first time the bear fence had been tested and we were pleased to see it worked.

Again, poor visibility meant the day was spent in camp (Figs.52-53). The weather forecast suggested tomorrow (Thursday) would be the last chance to fly and explore caves, which was unfortunate given that the expedition was still planned to run until Monday. So far, despite exploring three caves, no speleothem samples had been sampled, though a flowstone had been observed in the gully at WUL8. At the time it had not been sampled because it was no longer in a cave and had likely been subjected to diagenesis. It had been expected that more suitable samples would be discovered in other caves over the course of the expedition (unfortunately that hadn't happened due to a lack of productive field days).

Over the course of the day, a large single male musk ox made his way slowly from the north, down the east side of the river towards camp (Fig.54). About 1630 he came directly into camp, broke through the bear fence not far from where Chris stood and became spooked in front of the tents. Chris retreated from the area whilst the others looked on from a short distance away. The musk ox also retreated, he ran through the bear fence in another location, west and into the river where he was washed downstream

Figure 46: Chris Blakeley and Gabriella Koltai hike up from the helicopter drop-off to the entrance of WUL-3.

Figure 47: Chris Blakeley and Gabriella Koltai look out over the foggy valley close to WUL-3.

Figure 48: Gabriella Koltai descends down the scree slope from WUL-3 to the helicopter pick-up point. Note the helicopter in the valley bottom for scale.

Figure 49: The helicopter emerges from the mist as it flies up to collect Chris Blakeley, Gabriella Koltai and Robbie Shone after exploring WUL-3.

Figure 50: Chris Blakeley and Gabriella Koltai depart the helicopter after a hot drop-off by Matthias Vogt close to WUL-66.

Figure 51: The helicopter waits in the valley bottom whilst Chris Blakeley, Gabriella Koltai and Robbie Shone explore WUL-66.

Figure 52: Gina Moseley washing up in the cold rain.

Figure 53: Gina Moseley, Gabriella Koltai and Robbie Shone collect water from the river.

Figure 54: The lone male musk ox that visited camp.

in the full flow for some distance. Eventually he found his footing and climbed out on the other side where he spent the night. In the evening The Team debriefed about the events of the day with the hare and musk ox. They made plans and packed for what would likely be the final day of the expedition.

***Thursday 27th July, 2023***

Cooler weather and there had been some light rain overnight. It was still overcast with low fog in the south, but some patches of blue sky in the north. Mattias was optimistic about flying later on and final plans were made. The rough plan was Gina, Robbie and Gabi would go to 'the canyon' spotted on Tuesday to quickly assess its suitability. If it looked promising then Chris and Nathan would join them and they would all spend the day there. If not, then Nathan would stay with Gabi in 'the canyon' to do a thorough check in an environment more suitable for a beginner caver, and Chris, Robbie and Gina would head to WUL-7. Once the teams were in position, Matthias needed to sling a drum of fuel from the other depot on Warming Land to Wulff Land.

The first team departed at 1230, though even at that point it was not clear if they would make it due to the low cloud. Initially they went to WUL-8 to pick up some of the 'gully' flowstones in case these would be the only speleothem samples collected on the expedition. On the plateau above WUL-8 it was clear enough to land for a moment whilst Gabi and Robbie retrieved some samples, though the visibility changed quickly and had they been any longer it would have been a different story. They flew on to 'the canyon' but first went via a cave that had opened up at the end of a retreating glacier. It did not seem to go far, so they continued. At 'the canyon' there was some confusion with Robbie and Gabi as to whether it was the correct place, but Matthias checked his flight log and it turned out to be correct. The three jumped out, Matthias flew off, they cleared some large rocks so that Matthias could land better when he came back, then headed off down the canyon. They worked as quickly as possible, checking each potential cave entrance but all closed down quickly and without speleothem. When they heard the helicopter returning, they headed back up to the plateau and made a quick exchange. Nathan stayed with Gabi and they explored the canyon properly, whilst Chris, Gina and Robbie departed for WUL-7.

Gabi and Nathan sorted gear and headed off down the canyon (Figs.55-56). It was bitterly cold in the wind so they had lunch in an alcove before setting off further. There were lots of potential leads in the canyon, so they split up and communicated via Cardo. Nathan explored his first Greenland cave! It

Figure 55: Gabriella Koltai heads down ‘The Canyon’.

Figure 56: A small cave and meltwater pond in ‘The Canyon’.

was a small alcove with ice at the back. Gabi rushed from cave to cave, clambering up to the small chambers and digging in the floor for speleothems. They came across two waterfalls and a beautiful small icy pond (Fig.56). At one-point Matthias flew overhead slinging his fuel drum (he'd had to take a detour due to bad weather). On the return flight to camp, Gabi and Nathan noticed a clear river not far from base camp. They went for a walk and filled up the water sacks, which turned out to be much clearer and less silty than the river close to camp. Whilst awaiting the return of Chris, Robbie and Gina, they did a stretching session to jazz music!

Meanwhile, Chris, Robbie and Gina hovered in front of the knobbly lump of rock hosting WUL-7 and looked at it in further detail. Many relatively small entrances were observed within the buttress of rock, as well as a single, much larger, entrance several hundred metres down the scree slope. Matthias dropped the three off on the plateau, then left to refuel on Warming Land and sling a drum (plus the empty) to Wulff Land. Chris began rigging to WUL-7 'Keyhole Cave' (Fig.58), whilst Gina and Robbie made their way down the scree slope to the large entrance (Fig.59). The scree slope was a new experience for them: In addition to the rocks, it was intermixed with fine-grained sediment, plants and in places a thin stream of water ran underneath.

Figure 57: Nathan Hudson-Peacock exploring his first caves and Gabriella Koltai in 'The Canyon'.

Figure 58: Chris Blakeley begins the traverse to WUL-7 (Keyhole Cave).

Figure 59: Gina Moseley heads down the scree slope to ‘Ice Wulff’.

Figure 60: Chris Blakeley communicates to the drone that there are speleothem samples in WUL-7 (Keyhole Cave).

Figure 61: Gina Moseley and Chris Blakeley discuss the weather forecast with Matthias Vogt.

It took quite a while to get there, as it turned out to be lower down the slope than anticipated (appreciating scale in this landscape was a continuous problem). The cave turned out to be one of the most speleogenetically advanced that The Team had yet discovered in Greenland, with multiple breakdown chambers containing car-sized boulders, avens in the ceiling and an ice-covered passage that led to a shaft. At the top of a breakdown slope, a huge ice plug with large clear ice crystals was found. No speleothem samples were found but it was the classic experience of finding an amazing cave on the last day of an expedition. With only two people, they did not have enough resources for photography and surveying so they contacted Chris on the Cardo communication devices. It was patchy and hard to get a good signal. Robbie flew the drone to see what was going on and Chris managed to communicate that there were speleothem samples inside the cave (Fig.60). It was a bittersweet experience leaving the beautiful cave, later named Ice Wulff, completely unphotographed, un-surveyed and unsampled. However, time was running short; Matthias would be back in three hours to collect them, and until this point they had still not managed to collect speleothem samples. Gina and Robbie climbed back up the scree slope, with heavy bags laden down with drilling and photographic gear. It took an hour climb the 200m vertical difference back up to where they had started. Chris directed Gina and Robbie down the very exposed slope and across a ledge with a massive crack running next to the wall (Fig.9). Chris had rigged down a skylight that led into the main passage. It took Gina a while to find the flowstone that Chris had seen, it was heavily recrystallised. They decided not to take samples of this and instead descended into the cave, which was mostly a stooping size passage, covered in hoar frost with a few avens and the all-important speleothem samples! Matthias was due in just over an hour. Samples were quickly taken of flowstone and sediment. Gina drew a rough sketch survey and Chris and Robbie took photographs. It was rushed but successful. After derigging they arrived back at the helicopter about 20 minutes late (Fig.61), but Matthias didn't seem to mind.

Matthias relayed the news that he'd been on the phone to the met office for 30 minutes. They'd informed him that a big storm was coming of a magnitude that they'd never seen before at this time of year in the area. They had advised him to leave otherwise he would likely be stuck. He planned to leave that evening as soon as they were back.

At basecamp everyone rallied around to get Matthias's things together. Some took down the tent, others gathered his belongings and made him a warm meal whilst he refuelled and prepared the helicopter. It was a sad moment, and everyone felt his departure (Fig.62). It was the beginning of the end of the expedition.

Figure 62: Matthias Vogt departs in the helicopter.

***Friday 28th July, 2023***

Gina received a text from Matthias about 0345. He had flown through difficult weather and set up camp about 1 hour from Station Nord. She received another message about 1030 to say that he was already on his way south. It had snowed heavily at Station Nord overnight. Sebastian also checked in on the Team. At the Wulff Land base camp, it was slightly drizzly but definitely not as bad as forecast. Everyone stayed around camp. Robbie and Gabi fetched water. Chris and Gabi packed boxes outside, and Gina packed boxes inside. Nathan sorted through the medical kit (Figs.63-66). Gina did a food inventory and The Team discussed how to proceed the next days. It was clear they didn't need to stress about food rations. They had enough for 12 days eating a normal rate. They spent a lot of time in the communal tent having interesting scientific discussion between North and Northeast Greenland. They discussed the lack of speleothems in North Greenland, and whether that was a product of the past climate or sampling bias.

***Saturday 29th July, 2023***

The Team woke up to a light dusting of snow (Fig.15) but the sun was shining and there was blue sky. Gina and Robbie flew the drone whilst waiting for the others to surface. Everyone enjoyed the warmth of the sun after a cloudy grey cold wet week (Fig.67). By late morning, the weather had turned again and it got colder. Light snow fell on and off for the rest of the day. The Team mostly sat in the base camp tent (Figs.63-66,68-69). Gabi and Nathan went for a walk on the little ridge behind camp. Chris and Robbie photographed birds. Gina and Gabi collected hare and musk ox faeces for microbiologists as well as soil from beneath a musk ox carcass (Fig.70). The malaise trap was taken down and everyone enjoyed looking at the various bugs that had been caught.

***Sunday 30th July, 2023***

The Team woke to a low cloud base and poor visibility (<2km with 200m cloud base). It was damp and cold all day and was snowing again by 2pm with a sustained northerly wind covering the ground with 2-3cm on all north facing surfaces.

The Team stayed local to base camp and did more packing and organising of the freight in anticipation of the Twin Otter pick-up the following days. The forecast and information from Sebastian were uncertain about the pick-up, however, both confirmed poor visibility and precipitation in North Greenland.

***Monday 31st July 2023***

Gina sent weather reports to Station Nord at 0800. The pilots wanted to know the state of the runway (hard or oft, wet or dry?). They reported it was hard and dry. The Team hadn't experienced the bad weather that had hit other parts of North Greenland. They decamped up to the point of taking down the tents until they had definitive word of the pick-up. They received word that the Twin Otter was having difficulty with weather and would first go to Midsommer Sø to collect the Korean team. At base camp it was dry, which made it relatively easy to do the final packing. Chris and Robbie collapsed the empty fuel drums, which turned out to be quite a dangerous operation (Fig.71), and Chris and Gabi sliced open the speleothems ready for transport (Figs.72-73). The weather did get worse during the day but not so bad as to prevent a pick up. The Team got word that the Twin Otter would arrive about 1700, which it did, though it had had to fly via the north coast in order to avoid bad weather. On arrival. The Team were ready and waiting (Fig.74). It refuelled with The Team's last drum at Wulff Land. They loaded and departed at 1800 but flew a direct route overland back to Station Nord. At Villum Research Station they welcomed the showers and sorted once again through gear. Some had to go to Constable Point, and the rest to Svalbard. The final freight manifest was prepared and all boxes weighed with 295 kg going to Svalbard and 80 kg to Constable Point. The Team visited the Station Nord souvenir shop, stamped their passports, bought various souvenirs and visited the bar for a few celebratory drinks.

Figure 63: Life inside the communal tent during the last few days at base camp in Wulff Land.

Figure 64: Chris Blakeley and Gabriella Koltai pack the rigging equipment.

Figure 65: Gina Moseley packs the scientific equipment.

Figure 66: Nathan Hudson-Peacock prepares the medical inventory.

Figure 67: Nathan Hudson-Peacock enjoys a brief moment of sunshine.

Figure 68: Chris Blakeley, Gabriella Koltai and Nathan Hudson-Peacock keep busy whilst tent bound.

Figure 69: Being tent bound took its toll after a while.

Figure 70: Musk ox carcass.

Figure 71: Chris Blakeley and Robbie Shone collapse the empty fuel drums ready for further transport.

Figure 72: Chris Blakeley and Gabriella Koltai slice open the first speleothem samples from North Greenland.

Figure 73: Chris Blakeley and Gabriella Koltai holding the first speleothem samples to be sliced open from North Greenland.

Figure 74: The Twin Otter arrives to collect The Team.

## 5.0 Fieldwork and Research

### *5.1 Caves Explored*

# WUL-8

81.846631°N, 48.194972°W

Explored by: Gina Moseley, Christopher Blakeley, Robbie Shone, Gabriella Koltai

Surface support: Nathan Hudson-Peacock, Matthias Vogt

Figure 75: Aerial reconnaissance photograph of WUL-8. Source: Geological Survey of Denmark and the Ministry of Mineral Resources.

**Access**

Access to WUL-8 was achieved from the plateau above the cave where the helicopter was able to land and shut down. Chris Blakeley rigged down the gully and wall system, 12m to climbers right to the north of the cave. The equipment included 150m of rope, 4 rope protectors, 9 rebelays, and 1 deviation. Beware of loose rocks.

**Appearance, Geomorphology, Tectonics and Deposits**

Large breakdown entrance with boulders spread throughout the floor. Original solutional morphology can be seen only in a few places, because breakdown dominates the cave morphology. Solutional morphology is visible on the left wall (looking in) as three channels c.10 to 15m above the floor and as several high-level phreatic passages at the rear of the cave. Entrance contains a pool of water with ice at the base. The rear of the cave descends into a boulder choke (not drafting) surrounded in hoar frost. Fractures and large-scale tectonic features not observed. Speleothems not present.

**Biology**

Small plant present in sediment (soil?) between boulders at entrance. Birds living (and nesting) high up on ledges in cave. Bacterial/algal activity in the the entrance pool.

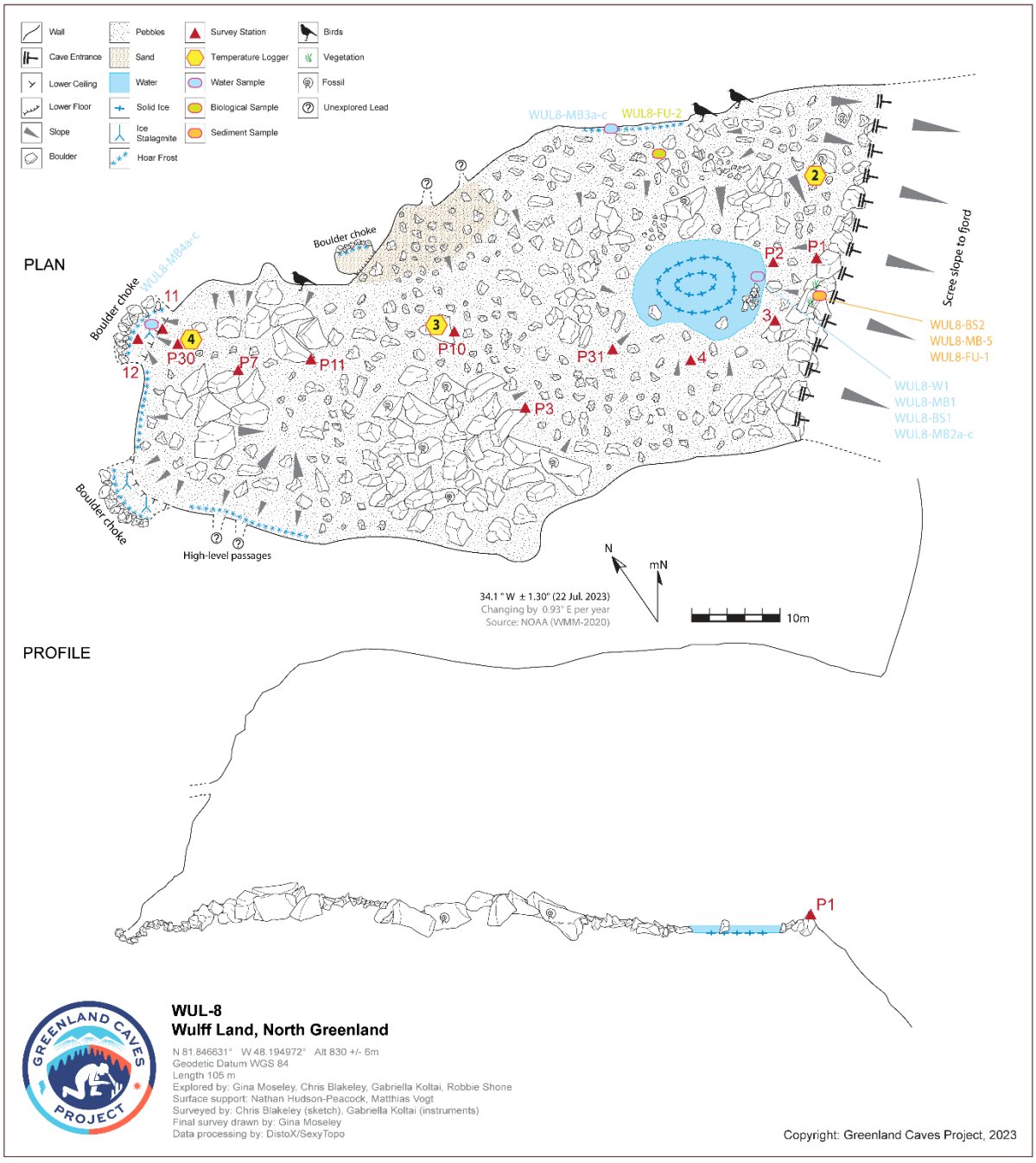


Figure 76: Survey of WUL-8.

Figure 77: Aerial photograph of WUL-8.

Figure 78: Aerial photograph of WUL-8. See persons for scale.

Figure 79: Looking out of WUL-8 across the icy entrance pool.

Figure 80: The icy entrance pool in WUL-8.

Figure 81: Chris Blakeley, Gabriella Koltai and Robbie Shone ascend the gully of WUL-8 (people inside white circles).

Figure 82: Small speleogenetic features are visible (in white circles) above WUL-8. Chris Blakeley inside dashed circle for scale.

Figure 83: Gabriella Koltai swabs an ice stalagmite for microbiological research.

Figure 84: Gabriella Koltai collecting water from the icy entrance pool in WUL-8.

Figure 85: Gina Moseley and Gabriella Koltai collecting microbiology samples in WUL-8.

Figure 86: Plant growing in between rocks in the entrance to WUL-8.

Figure 87: One of the many birds nesting on ledges high up in WUL-8.

| Cave | Sample Code | Specimen | Details |
|---|---|---|---|
| WUL-8 | MB1 | Water | Entrance pool of water with ice at base |
| WUL-8 | MB2a,2b,2c | Swabs of water | Entrance pool of water with ice at base |
| WUL-8 | MB3a,3b,3c | Swabs of ice | Hoar frost on right side of cave (looking in), in light zone |
| WUL-8 | MB4a,4b,4c | Swabs of ice | Ice stalagmite at rear of cave, at start of boulder choke, in dark/twilight zone |
| WUL-8 | MB5 | Soil | Small patch of soil beneath small plant between boulders, in light zone (not far from drip line) |
| | | | |
| WUL-8 | BS1 | Water | Entrance pool of water with ice at base |
| WUL-8 | BS2 | Soil | Small patch of soil beneath small plant between boulders, in light zone (not far from drip line) |
| | | | |
| WUL-8 | FU1 | Soil | Small patch of soil beneath small plant between boulders, in light zone (not far from drip line) |
| WUL-8 | FU2 | Bird faeces and soil | Collected from top of boulders, on right as looking in, c. 20 m from the entrance in the light zone |

Table 1: Microbiology samples collected from WUL-8.

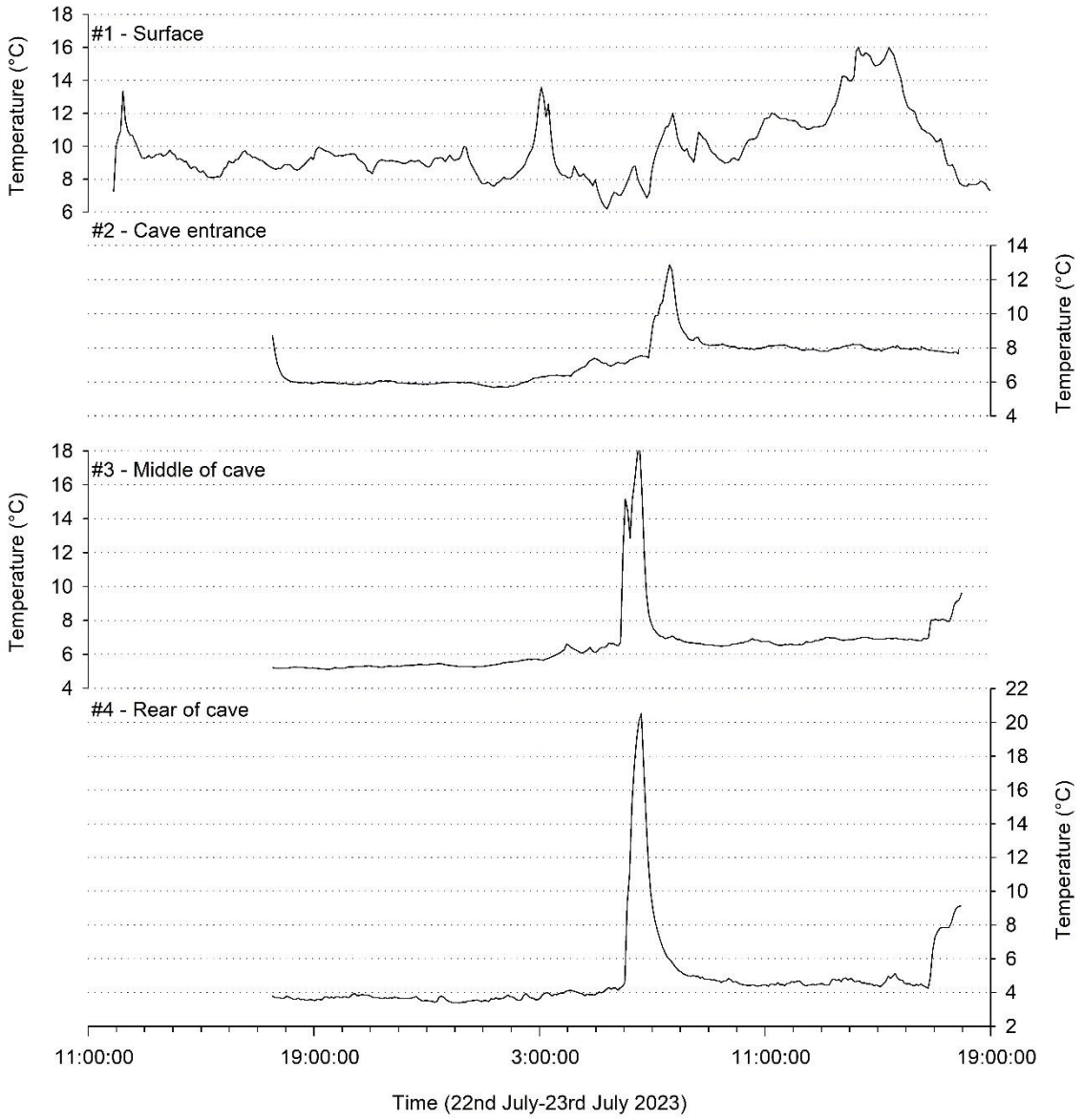


Figure 88: Temperature time series as recorded by four Gemini Tinytag View 2 temperature loggers at 5-minute intervals placed on the surface (plateau) above WUL-8 (#1), in the cave entrance (#2), in the middle of the cave (#3), and at the rear of the cave (#4). See figure 76 for exact positioning. The 1-hour equilibrating interval (as defined during the calibration study) is included in the data shown here.

# WUL-3

81.871673°N, 49.578608 °W, c. 750 m asl

Explored by: Christopher Blakeley, Robbie Shone, Gabriella Koltai

Surface support: Nathan Hudson-Peacock, Gina Moseley, Matthias Vogt

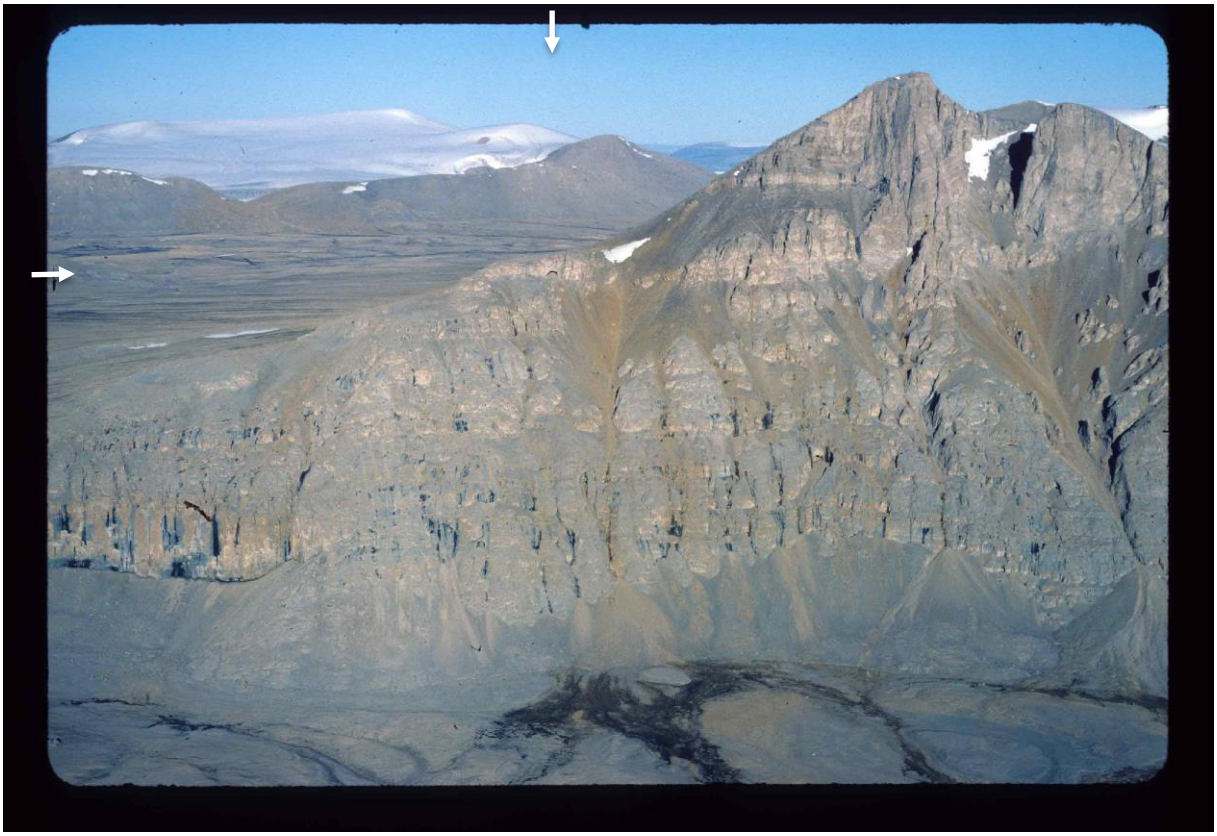

Figure 89: Aerial reconnaissance photograph of WUL-3 (see arrows for guidance). Source: Geological Survey of Denmark and the Ministry of Mineral Resources.

**Access**

Following the drop-off by the helicopter at a suitable location, WUL-3 was accessed by a c. 25-minute hike up and across a ledge. No ropes were required.

Another small breakdown entrance (a few metres in diameter) was discovered on the way to WUL-3, ca. 5 min hike. Floor is covered with ice.

**Appearance, Geomorphology, Tectonics and Deposits**

Large breakdown entrance with some solutional features in the wall and on the ceiling (i.e. cupolas and solutional channels). Ice plugs with large (decimetre-sized crystals) present at end of two passages. Breakdown and rocks throughout cave and in places overlying ice. Fractures and large-scale tectonic features not observed. Speleothems not present though there may be modern cryogenic powders in some of the ice pools. Bird feathers were observed frozen into the ice and lying on the floor at the end of one of the passages.

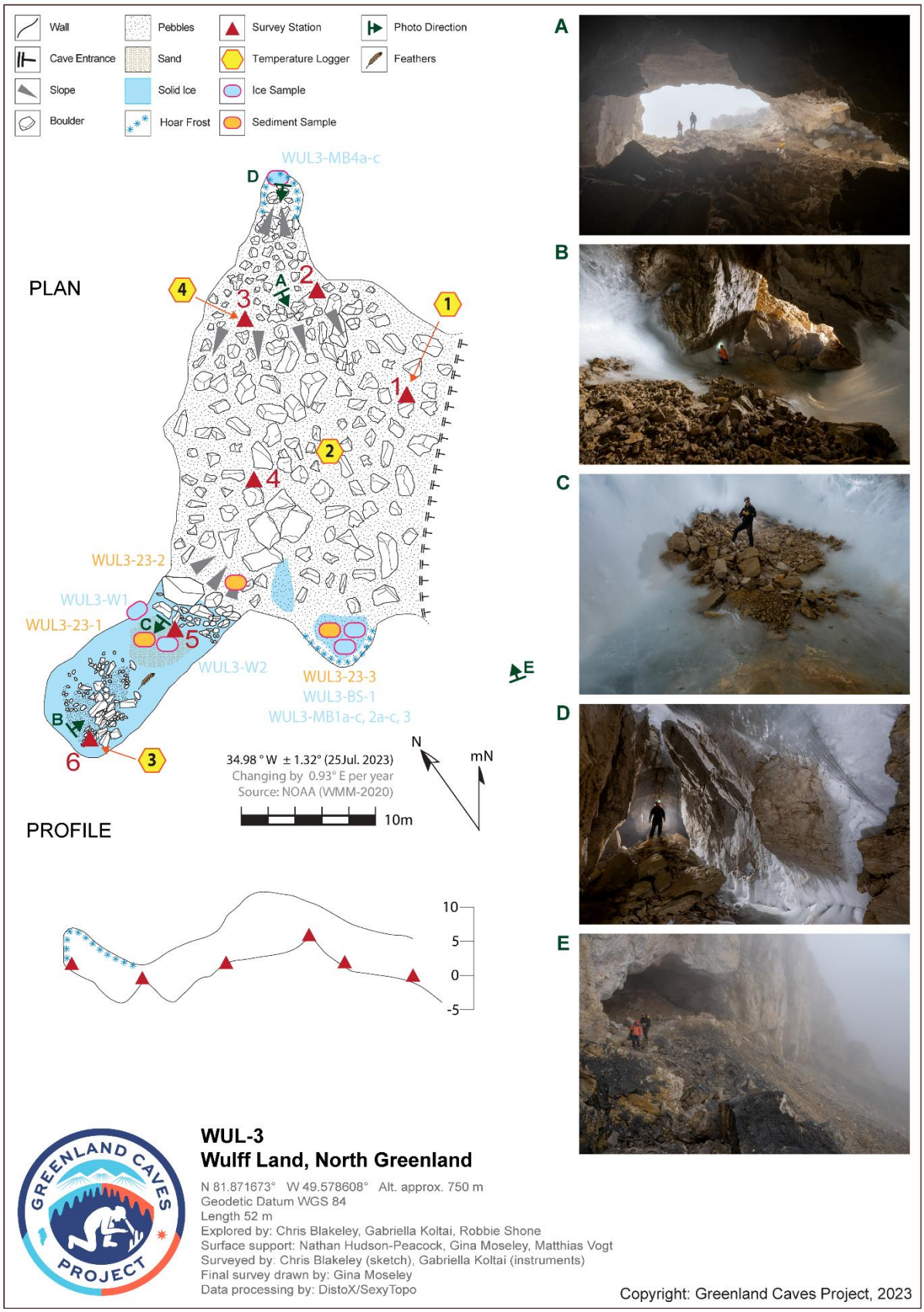


Figure 90: Survey of WUL-3.

Figure 91: Chris Blakeley and Gabriella Koltai in the entrance of WUL-3.

Figure 92: Chris Blakeley and Gabriella Koltai leave the entrance of WUL-3.

Figure 93: Gabriella Koltai collects ice samples in WUL-3.

Figure 94: Feathers in the ice of WUL-3.

Figure 95: Chris Blakeley surveying in WUL-3.

Figure 96: Chris Blakeley admires the ice formations in WUL-3.

| Cave | Sample Code | Specimen | Details |
|---|---|---|---|
| WUL-3 | MB1a,1b,1c | Water | Pool of water with ice at base |
| WUL-3 | MB2a,2b,2c | Swabs of water | Pool of water with ice at base |
| WUL-3 | MB3 | Water | Water sample with preservation liquid inside |
| WUL-3 | MB4a,4b,4c | Swabs of ice | Hoar frost at end of side passage |
| | | | |
| WUL-3 | BS1 | Water | Pool of water with ice at base |

Table 2: Microbiology samples collected from WUL-3.

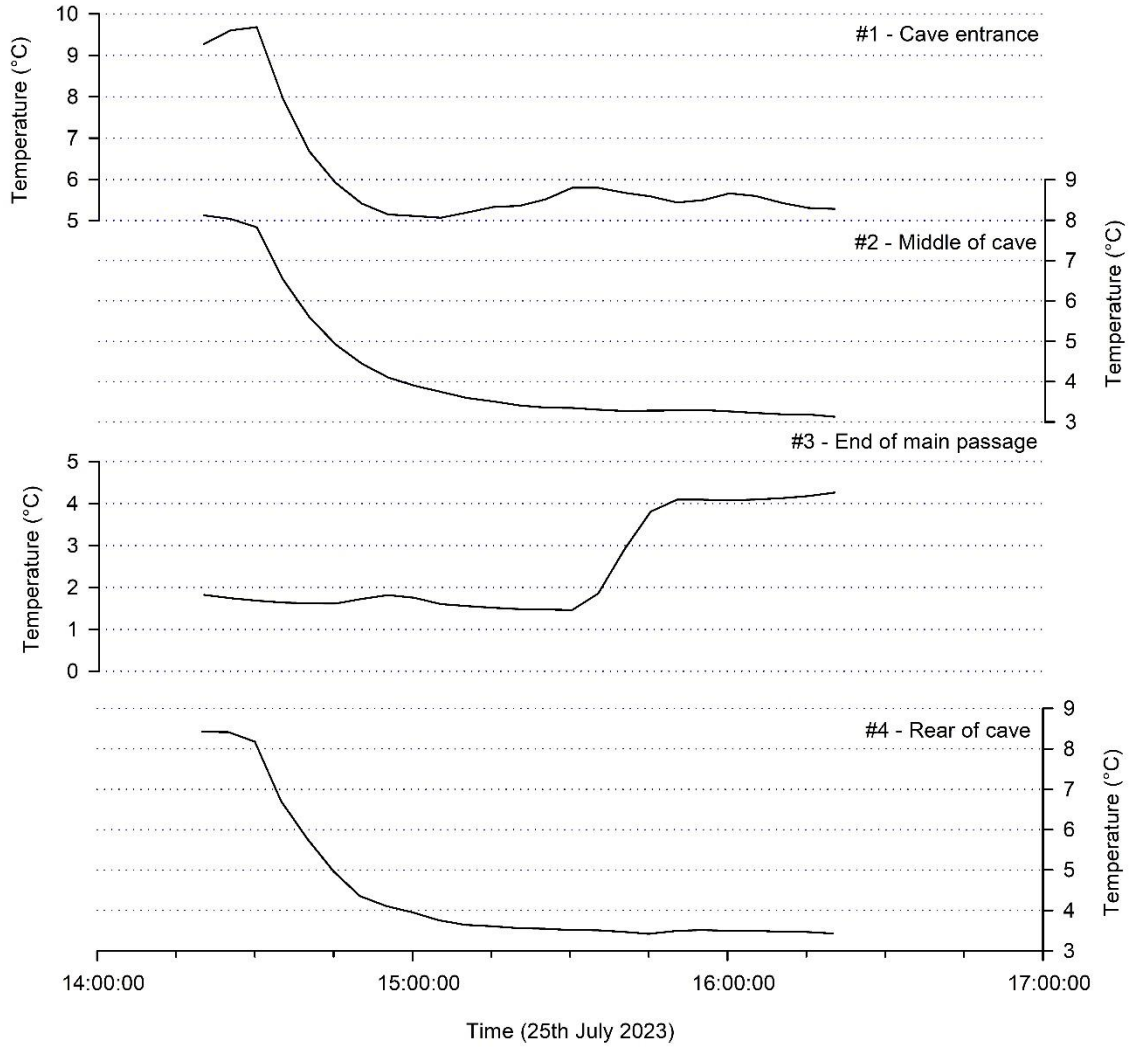


Figure 97: Temperature time series as recorded by three Gemini Tinytag View 2 temperature loggers at 5-minute intervals placed in the WUL-3 cave entrance (#1), middle of the cave (#2), end of main passage (#3) and at the rear of the cave (#4). See figure 90 for exact positioning. The 1-hour equilibrating interval (as defined during the calibration study) is included in the data shown here.

# WUL-66

81.832215°N, 49.250101 °W, c. 750 m asl

Explored By: Christopher Blakeley, Robbie Shone, Gabriella Koltai

Surface support: Nathan Hudson-Peacock, Gina Moseley, Matthias Vogt

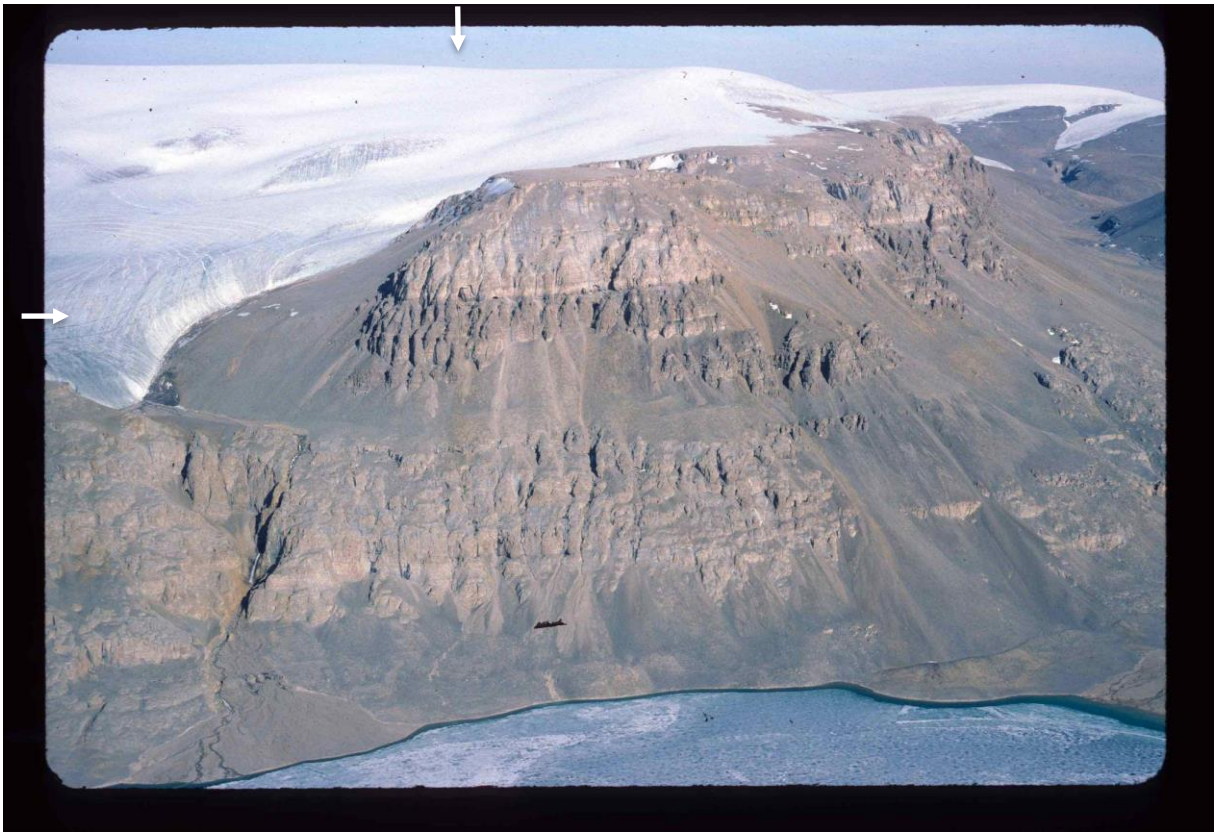

Figure 98: Aerial reconnaissance photograph of WUL-66 (see arrows for guidance). Source: Geological Survey of Denmark and the Ministry of Mineral Resources.

**Access**

Following the drop-off by the helicopter at a suitable location, WUL-66 was accessed by a 3-minute walk up a ledge. No ropes were required.

**Appearance, Geomorphology, Tectonics and Deposits**

Large entrance with large passages (c. 10m wide by 7 to 12 m high). The main passage ends in an ice wall with large beautiful ice crystals (up to few cm). A side passage continues but is too tight to crawl through. Lots of beautiful solutional morphologies on the cave walls and the ceiling. No scallops and walls are often covered in ice. No speleothems were observed but there may be some ‘modern’ CCCfine. One coarsely crystalline calcite was found on the cave floor but this may predate the cave. No biology was observed.

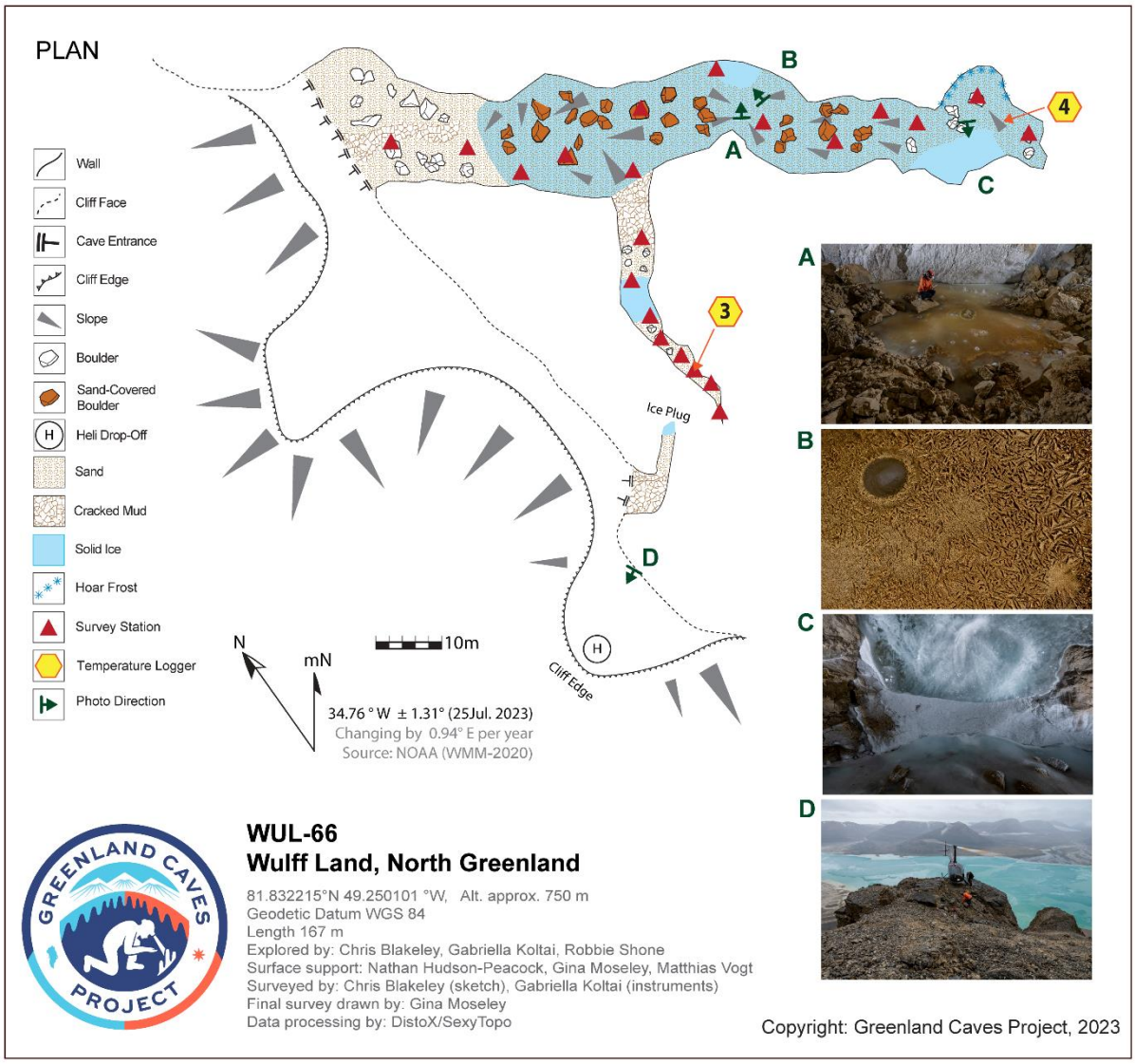


Figure 99: Survey of WUL-3.

Figure 100: Gabriella Koltai looks over the ice pool covered in fine-grained sediment.

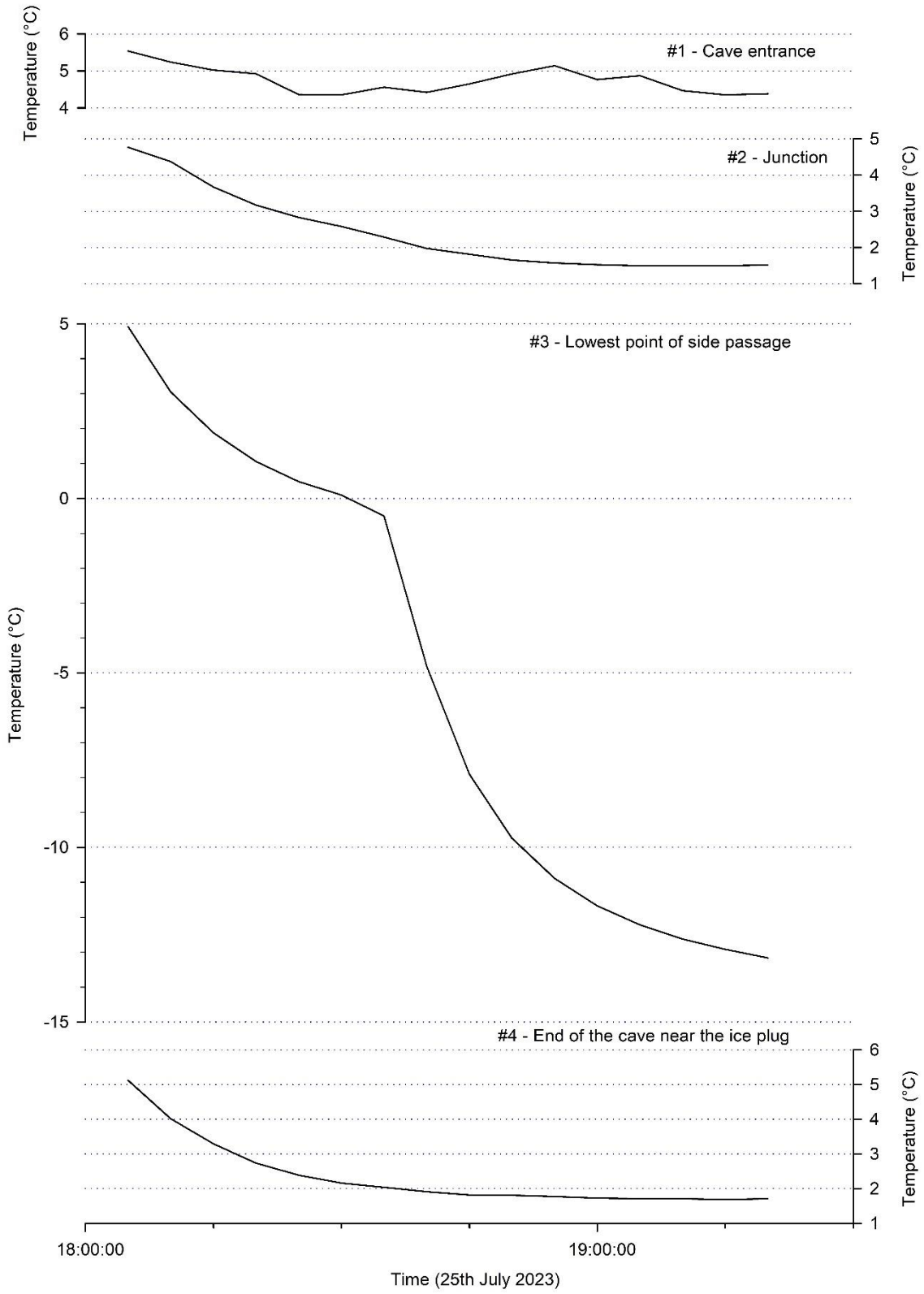


Figure 101: Temperature time series as recorded by four Gemini Tinytag View 2 temperature loggers at 5-minute intervals placed in the WUL-6 cave entrance (#1), at 'the junction' (#2), near the ice lake from 18:10 to 18:34 and then relocated to the lowest point in the side passage at 18:35 (#3), and at the end of the cave near the ice plug. See figure 99 for exact positioning. The 1-hour equilibrating interval (as defined during the calibration study) is included in the data shown here.

# WUL-7

81.825180°N, 48.326654 °W, c. 840 m asl

Explored by: Gina Moseley, Christopher Blakeley, Robbie Shone

Surface support: Matthias Vogt

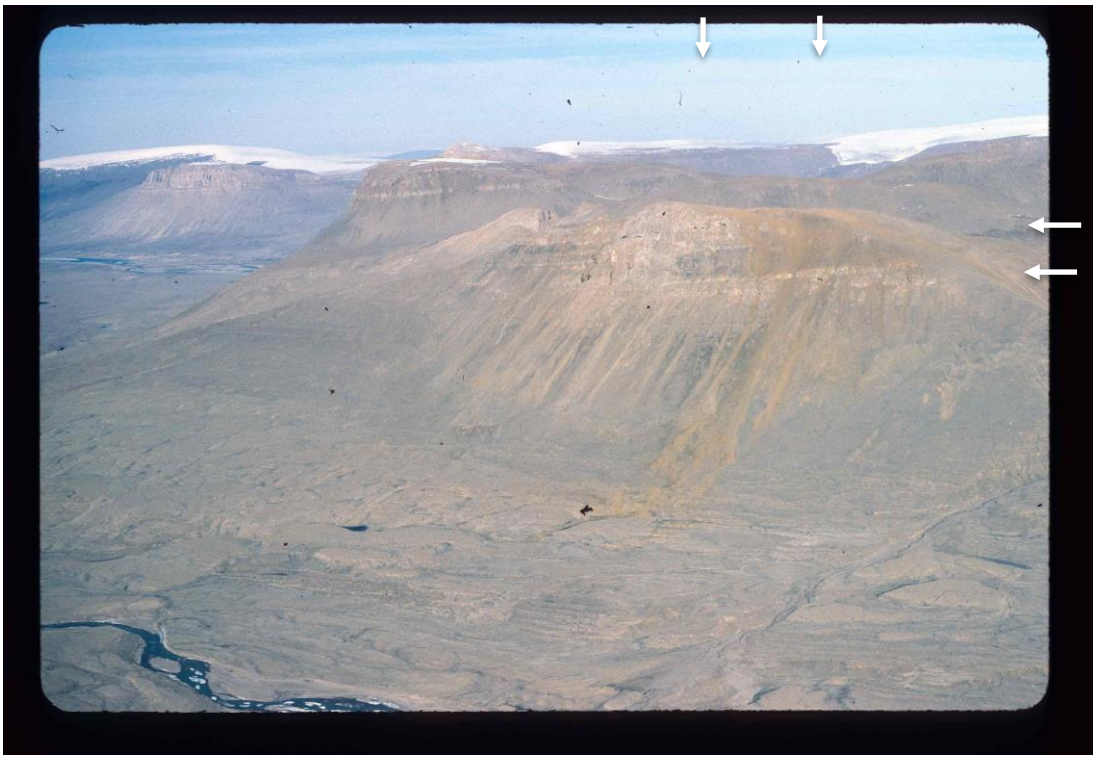

Figure 102: Aerial reconnaissance photograph of a series of caves including WUL-7 (Keyhole Cave; upper caves) and Ice Wulff (lower cave) (see arrows for guidance). Source: Geological Survey of Denmark and the Ministry of Mineral Resources.

Figure 103: Photograph taken from helicopter of WUL-7 (Keyhole Cave).

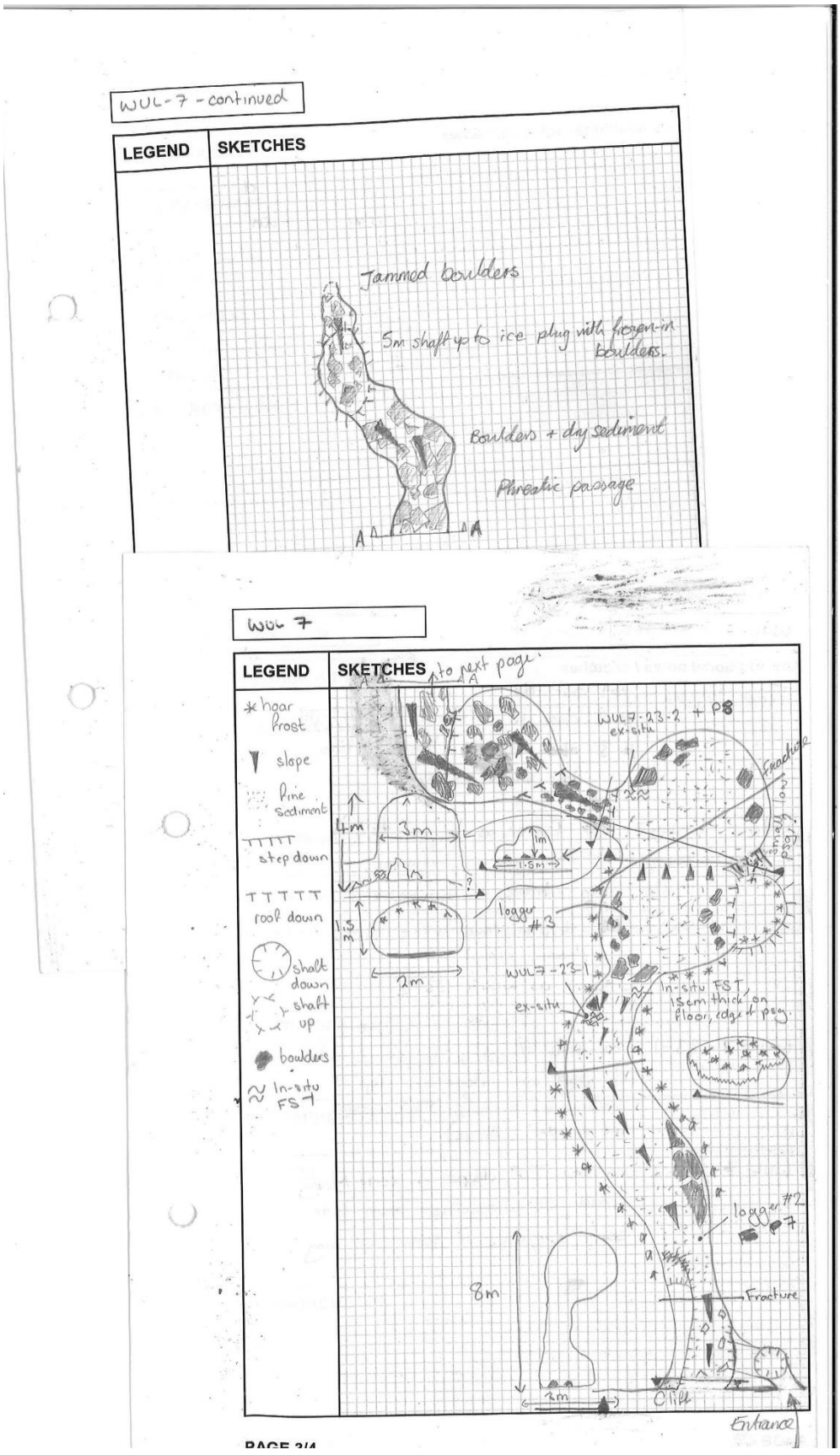


Figure 104: Fieldnote sketch of WUL-7.

Figure 105: Gina Moseley about to enter WUL-7 via the skylight entrance rigged by Chris Blakeley.

Figure 106: Gina Moseley collects flowstone samples from the hoar frost-lined passage in WUL-7.

Figure 107: Chris Blakeley descends through the skylight entrance into WUL-7.

Figure 108: Chris Blakeley in the keyhole-shaped passage of WUL-7. Note the major fracture running through the rock.

# ‘Ice Wulff’

81.8225 °N, 48.32388 °W, c. 660 m asl

Explored by: Gina Moseley, Robbie Shone

Surface support: Matthias Vogt

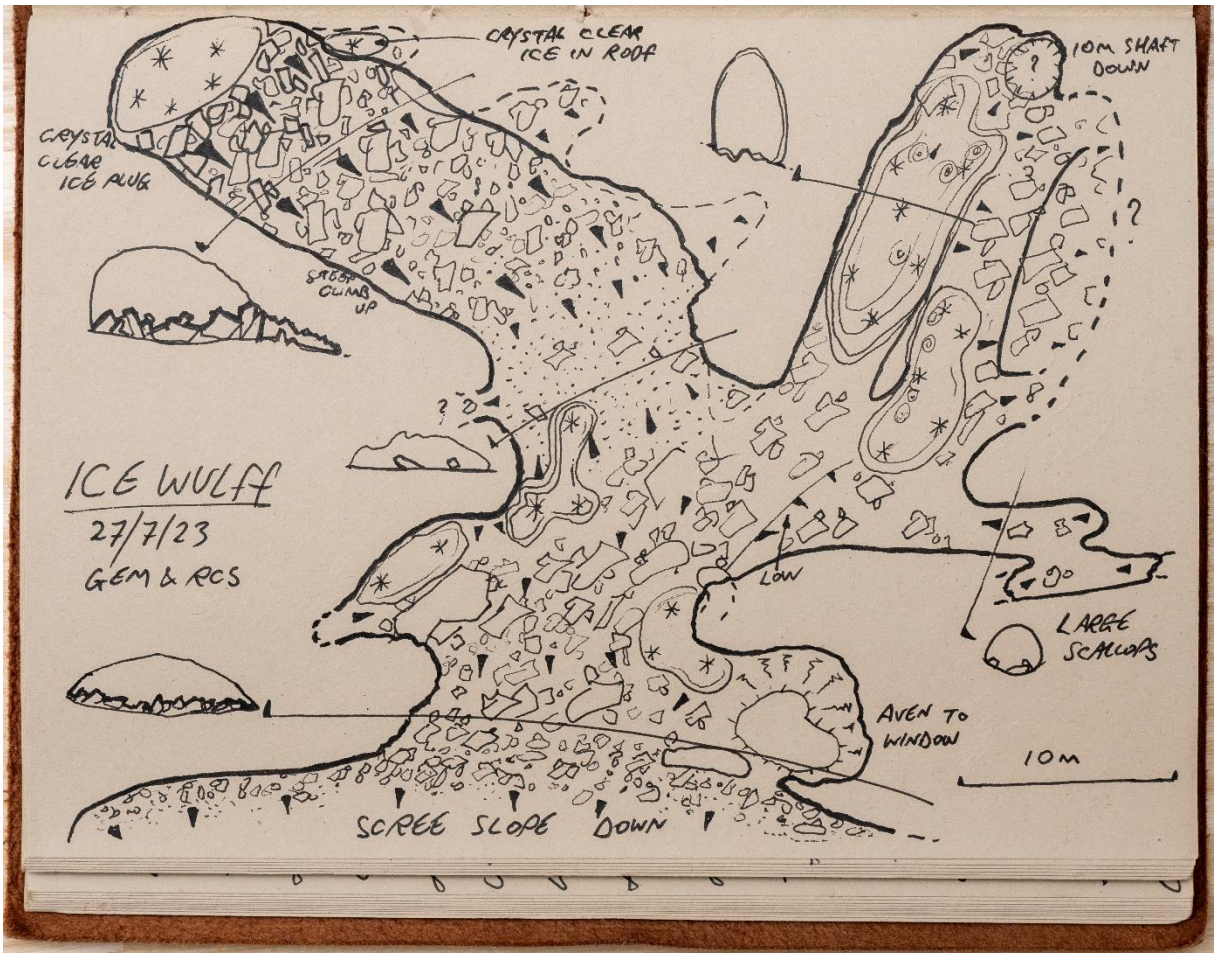


Figure 109: Fieldnote sketch of ‘Ice Wulff’.

Figure 110: Various images from Ice Wulff including the ice-lined passage leading to a shaft.

# ‘The Canyon’ by Gabriella Koltai

81.90083°N, -49.59944°W, c. 578 m asl

Explored by: Gabriella Koltai, Nathan Hudson-Peacock

Surface support: Matthias Vogt

Figure 111: Cave entrances in ‘The Canyon.’

Figure 112: View into ‘The Canyon’ from one of the larger entrances.

On the last day our team split into two groups. Gina Moseley, Robbie Shone, and Chris Blakeley headed to Keyhole Cave, while Gabriella Koltai and Nathan Hudson-Peacock stayed in “The Canyon” to check all the cave entrances. Most of the caves were rather small and were blocked after a few metres. Some of the larger caves were easy to climb, but one had to be careful of the loose rock.

We kept looking for new caves with the hope of finding speleothems and did not take the GPS coordinates of any of the entrances, nor did we survey them.

## *5.2 Interdisciplinary Scientific Studies*

### *5.2.1 Speleothem Samples*

| Cave | Sample Code | Details |
|---|---|---|
| WUL-8 | WUL8-23-1 | Flowstone from gulley to north used to descend to cave. c. 35m below present-day surface. Many broken flowstones lying in gully. Macroscopically looked similar. Collected by Gina |
| WUL-8 | WUL8-23-2 | Flowstone from gulley to north used to descend to cave. c. 35m below present-day surface. Many broken flowstones lying in gully. Macroscopically looked similar. Collected by Robbie |
| WUL-7 | WUL7-23-1 | Ex-situ flowstone lying at side of passage on floor on top of fine-grained sediment. In-situ flowstone nearby (but the team had no grinder). Located after large hanging hoar frost formation and on mild slope before hoar frost aven. Collected by Gina |
| WUL-7 | WUL7-23-2 | Ex-situ flowstone lying on floor just before phreatic crawl. Many small broken block together, seem to be same sequence therefore placed in same bag. Same location as pollen sample P 8. Collected by Gina |

Table 3: Description of speleothem sampling locations


Figure 113: Slabs taken from speleothem samples. Scale bars = 2cm.

### *5.2.2 Water Isotope Samples*

| Location | Sample Code | Specimen | Details |
|---|---|---|---|
| Base camp | BC-W1 | Rain | Rain event 24.7.23; Time 2000-2045* |
| Base camp | BC-W2 | Rain | Rain event 24.7.23; Time 2045-2145* |
| Base camp | BC-W3 | Rain | Rain event 24.7.23; Time 2145-2245* |
| Base camp | BC-W4 | Rain | Rain event 24.7.23; Time 2245-2340* |
| Base camp | BC-W5 | | |
| Base camp | BC-W6 | | |
| Base camp | BC-W7 | Rain | Rain event 25.7.23; Time 1634-1645. Rain stopped shortly after |
| Base camp | BC-W8 | Rain | Rain event 25.7.23; Time 1820-1830. Rain stopped shortly after |
| Base camp | BC-W9 | Snow | Snowfall event 29.7.23; Time 1415. Very little fell |
| WUL8 | WUL8-W1 | Water | Entrance pool of water with ice at base |
| WUL3 | WUL3-W1 | Hoar frost | Wall at rear of cave |
| WUL3 | WUL3-W2 | Congelation ice | Rear of cave |

Table 4: Description of water isotope sampling locations. *It rained all day, on and off. Sampling began in the evening during a 'heavy' rain event.

| Sample | $\delta^{18}O$ | $\delta^{18}O$ (1σ) | $\delta^{2}H$ | $\delta^{2}H$ (1σ) | Departure from Global Meteoric Water Line |
|---|---|---|---|---|---|
| BC-W1 | -21.12 | 0.07 | -163.62 | 0.33 | no |
| BC-W2 | -21.22 | 0.01 | -164.82 | 0.10 | no |
| BC-W3 | -20.47 | 0.03 | -158.52 | 0.11 | no |
| BC-W4 | -21.44 | 0.06 | -167.68 | 0.51 | no |
| BC-W5 | -20.44 | 0.06 | -159.56 | 0.64 | no |
| BC-W6 | -20.33 | 0.02 | -160.70 | 0.15 | yes |
| BC-W6* | -20.33 | 0.05 | -159.93 | 0.46 | no |
| BC-W7 | -17.78 | 0.05 | -141.11 | 0.19 | yes |
| BC-W8 | -19.01 | 0.03 | -145.37 | 0.03 | no |
| BC-W9 | -21.30 | 0.04 | -167.71 | 0.12 | no |
| WUL3-W1 | -23.43 | 0.06 | -167.61 | 0.34 | yes |
| WUL3-W2 | -23.48 | 0.03 | -170.31 | 0.07 | no |
| WUL8-W1 | -28.10 | 0.09 | -223.68 | 0.77 | yes |

Table 5: Water isotope results. *Repeat measurement. Analysed by Leonie Leitgeb at the Institute of Geology, University of Innsbruck, on a Picarro L2140-i CRDS.

### *5.2.3 Surface Microbiology Samples*

| Location | Sample Code | Specimen | Details |
|---|---|---|---|
| Base camp | FU3 | Soil | Soil beneath dead musk ox |
| Base camp | FU4 | Faeces | Musk ox faeces |
| Base camp | FU5 | Soil | Soil beneath musk ox faeces |
| Base camp | FU6 | Faeces | Hare faeces |
| Base camp | FU7 | Soil | Soil beneath hare faeces |

Table 6: Description of microbiology sampling locations around basecamp.

Sample site FU3.

Sample site FU4 and FU5.  Sample site FU6 and FU7.

Figure 114: Images of basecamp microbiology sampling sites.

### *5.2.4 Pollen Samples*

Samples were collected for investigation of pollen found in Greenlandic top soils in order to determine whether exotic species are present or not. To collect the samples, a metal teaspoon was cleaned with an alcoholic wipe and 'dipped' several times in the soil being sampled. Soil was then sampled using the teaspoon in each of the corners as well as the centre of a $1m^2$ area.

| Location | Sample | Specimen | Details |
|---|---|---|---|
| Constable Point | P1 | Soil | Soil from behind containers on side of fjord. Tried to sample undisturbed ground and an area away from traffic. |
| Plateau above WUL-8 | P2 | Soil | Soil from directly above cave on plateau, rocky ground, including granites brought from elsewhere, and thin soils in places. |
| Plateau above WUL-8 | P3 | Plant | 'Moss-like' plant from same location as P2 |
| Plateau above WUL-8 | P4 | Plant | 'Moss' from same location as P2 and P3 |
| Base camp | P5 | Soil | North bank of river terrace. Permafrost patterned soil. |
| Base camp | P6 | Plant | Moss head from same location at P5 |
| WUL-7 | P7 | Cave sediment | Sample of fine-grained sediment from floor of cave, c.10 m from entrance, in daylight. Same location as temperature logger #2 |
| WUL-7 | P8 | Cave sediment | Sample of fine-grained sediment from floor of cave, just before phreatic crawl, in darkness. Same location as WUL7-23-2 |

Table 7: Description of pollen sampling locations

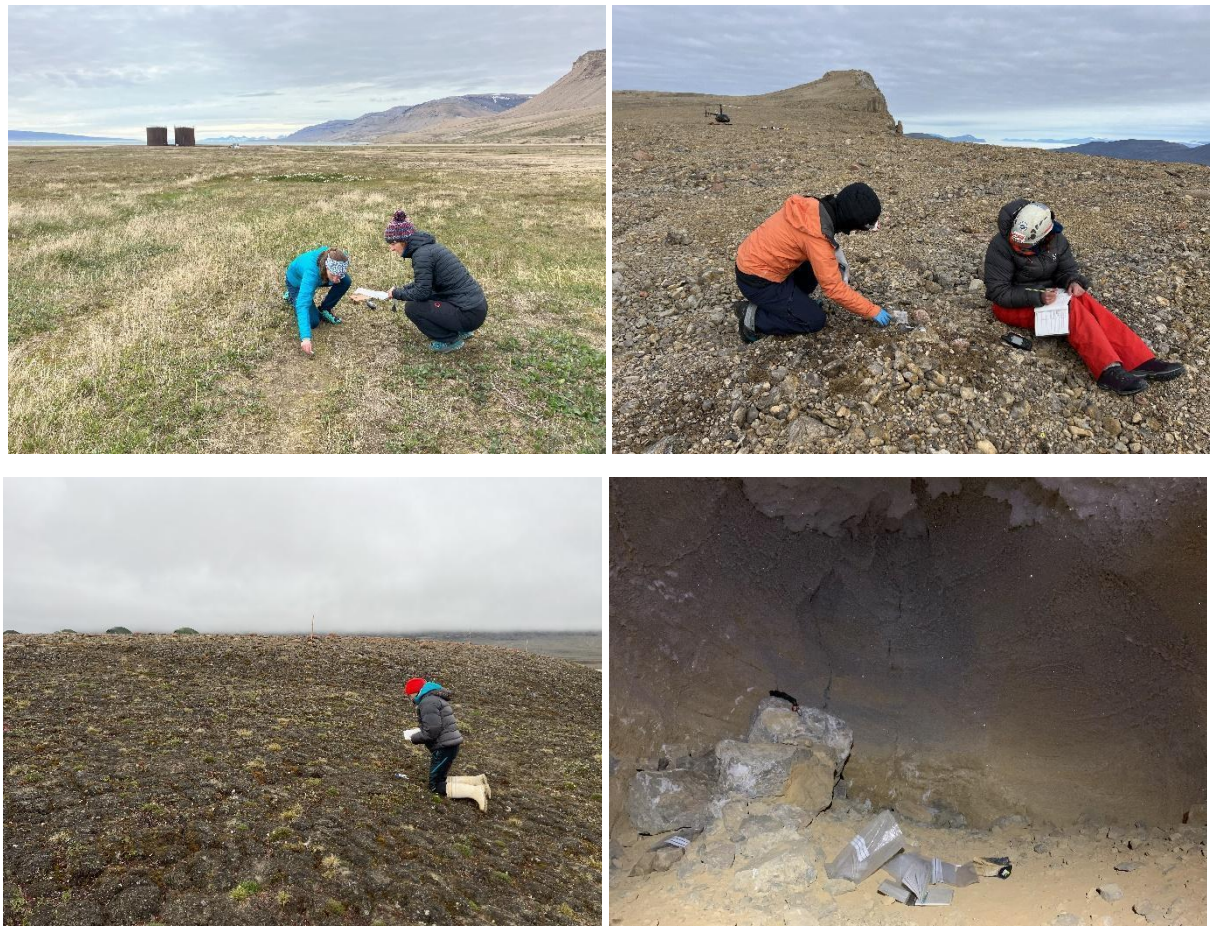

Figure 115: Images of various pollen sampling sites.

### *5.2.5 Surface Microclimate*

Gemini Tinytag View 2 temperature loggers (resolution 0.02°C over -40 to 125°C) were deployed on the surface and at selected intervals in the caves. Prior to the expedition, the performance of one of the loggers (Tinytag Plus 2 TGP-4205 with PT1000 Probe) was tested using an ice melting point check in an ice bath at the University of Innsbruck. Another calibrated logger was used for comparison. Before the expedition, all the loggers were placed in a refrigerator overnight to compare their performance. It was found that the loggers took approximately one hour to reach equilibrium with the temperature of the environment in which they were recording. At each field site, the loggers were set to record at 5-minute intervals with the exception of the basecamp logger which recorded at 1-hour intervals (Fig.116).

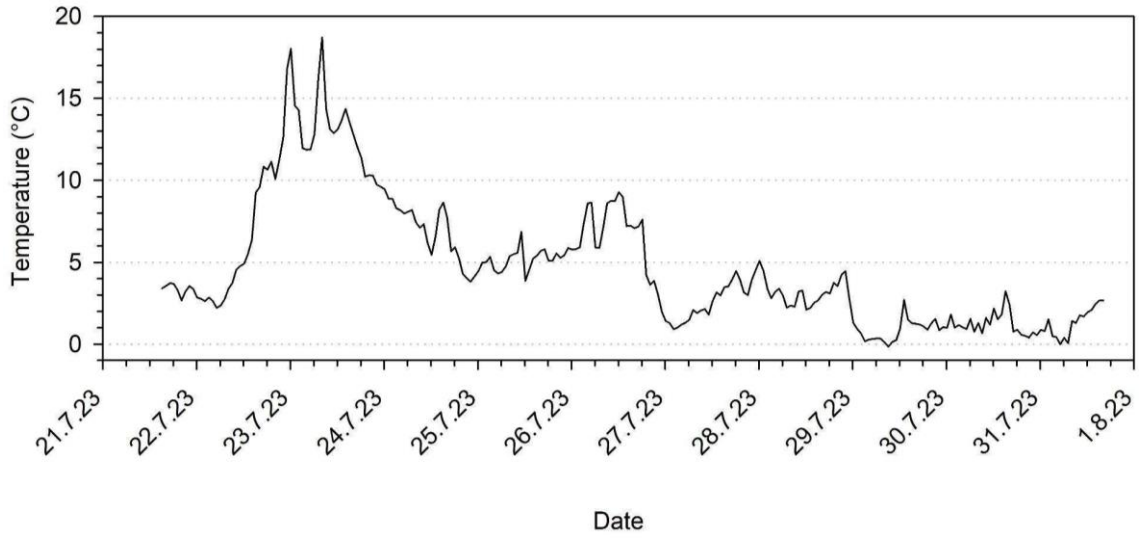


Figure 116: Temperature variability as recorded at 1-hour intervals at 2m-surface height at the basecamp.

### *5.2.6 Entomology Samples*

On the second day of the expedition, the malaise trap was set up to collect entomology samples. Ethanol was poured in a bottle at the top of the tent to capture the insects. The tent was dismantled after a week due to strong winds.

Figure 117: An entomology sample was collected at the base camp using a malaise trap. The sample is being analysed by the University of Oxford Museum of Natural History.

## 6.0 Finances

### *6.1 Expenditure*

| Item | Original Currency | EUR |
|---|---|---|
| **Travel** | | |
| Commercial Flights (Europe to Iceland - One Way) | 60,000 DKK | 8,070 |
| Commercial Flights (Svalbard to Europe - One Way) | 3,612 EUR | 3,612 |
| King Air Mob AEY - NOR - AEY (19JUL) | 225,000 DKK | 30,265 |
| Twin Otter Mob and Fuel Retrieval/Dumps | 897,400 DKK | 120,700 |
| Twin Otter Demob | 232,400 DKK | 31,260 |
| Dornier Demob | 135,000 DKK | 18,160 |
| Helicopter | 706,000 DKK | 94,960 |
| Helicopter Fuel and Storage | 18,552 EUR | 18,552 |
| Taxis | 396 EUR | 416 |
| Accommodation | 7,694 EUR | 7,694 |
| **Communication and Safety** | | |
| Satellite phone and InReach Rental | 1,685 EUR | 1,685 |
| Weapons Rental | 5,000 DKK | 675 |
| First aid courses, shooting course, pre-expedition meeting | 1,930 EUR | 1,930 |
| **Food and Equipment** | | |
| Expedition Food | 1,902 EUR | 1,902 |
| Meals | 1,265 EUR | 1,265 |
| Freight | 7,090 EUR | 7,087 |
| Power | 1,327 EUR | 1,327 |
| Scientific Equipment | 575 EUR | 575 |
| Camp Equipment | 456 EUR | 456 |
| Laser Scanner Insurance | 189 EUR | 189 |
| T-Shirts | 380 GBP | 450 |
| Medical | 4336 EUR | 4,336 |
| **Organisation** | | |
| Banking | 1,129 EUR | 1129 |
| Permits | 724 EUR | 724 |
| Logistics | 6,000 EUR | 6,000 |
| Expedition Insurance | 5,144 EUR | 5,144 |
| | | |
| **Total** | | **368,524 EUR** |

Table 8: Expenditure for Northern Caves 2023 Expedition.

### *6.2 Funding and Sponsorship*

| **Funding Body** | **Financial Support (Original Currency)** | **EUR** |
|---|---|---|
| Rolex Award for Enterprise | 200,000 CHF | 184,247 |
| Transglobe Expedition Trust | 10,000 GBP | 11,535 |
| Mount Everest Foundation | 12,500 GBP | 13,513 |
| University of Innsbruck Stiftung | 15,000 EUR | 15,000 |
| Austrian Academy Sciences | 10,000 EUR | 10,000 |
| Petzl Foundation | 12,500 EUR | 12,500 |
| Austrian Science Foundation | 26,147 EUR | 26,147 |
| British Cave Research Association | 1,000 GBP | 1,092 |
| Comer Global Climate Change Foundation | 40,000 USD | 36,420 |
| National Geographic Partners | 52,850 USD | 50,152 |
| Wings Worldquest | 1,000 USD | 893 |
| Institute Geology, UIBK | 450 EUR | 450 |
| Gina Moseley | 5,828 EUR | 5,828 |
| Robbie Shone | 608 EUR | 608 |
| Banking | 139 EUR | 139 |
| **Total** | | **368,524 EUR** |

Table 9: Funding sources for Northern Caves 2023.

## 7.0 Acknowledgements

We would like to thank the following organisations and individuals for supporting and funding this project: Rolex Awards for Enterprise, National Geographic Magazine, Comer Global Climate Change Foundation, Austrian Science Foundation, Petzl Foundation, Mount Everest Foundation, Transglobe Expedition Trust, Austrian Academy of Sciences, Gina Moseley, British Cave Research Association, Wings Worldquest. Additionally, we would like to thank Petzl, Cardo Outdoor, Grayl and Stella Prolights for equipment sponsorship. Expedition participants Gina Moseley, Robbie Shone, Chris Blakeley, Gabriella Koltai, Nathan Hudson-Peacock also invested in personal equipment. Thanks are also extended to Sebastian Rasmussen of Polog for logistical planning and support, Norlandair for Twin Otter flights, Matthias Vogt at Volcano Heli for helicopter support, the team at Villum Research Station and Station Nord for welcoming and hosting the expedition members prior to and after the expedition.