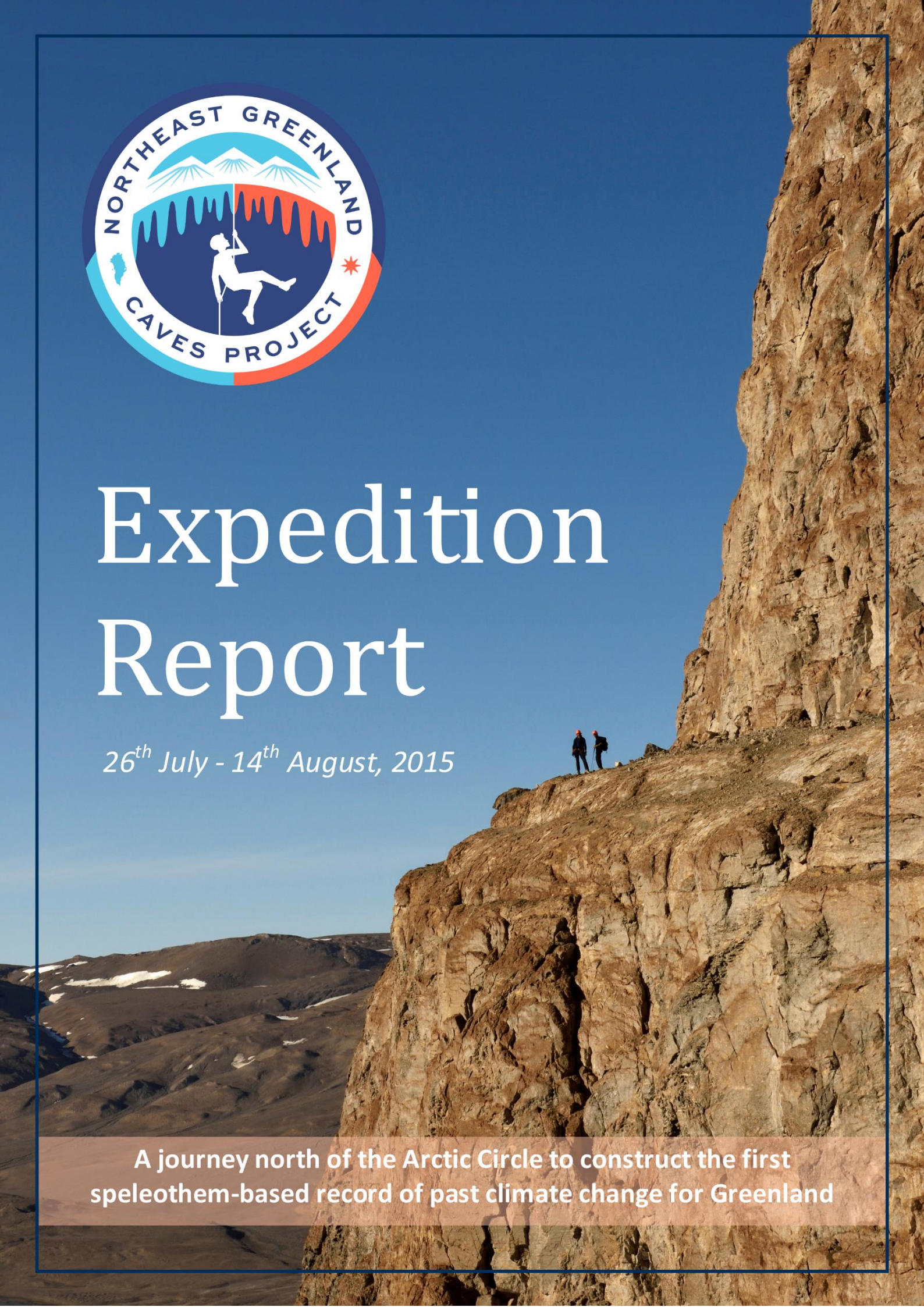

Expedition Report

26th July - 14th August, 2015

A journey north of the Arctic Circle to construct the first speleothem-based record of past climate change for Greenland

In memory of Charlie Self

Report on the findings of the

Northeast Greenland Caves Project

2015 expedition to

Kronprins Christian Land, Northeast Greenland

July-August, 2015

Project & Expedition leader: Dr. Gina Moseley

Written & edited by Dr. Gina Moseley with additional contributions from: Chris Blakeley, Robbie Shone, Prof. Paul Smith, Prof. Christoph Spötl, Dr. Adam Szulc, and Mark Wright

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Forward

We did it, we finally did it!

After several years of planning, and many more years of dreaming, our team of five people set off for Greenland on 26th July, 2015. Our aim was to collect samples of cave calcite for use in construction of the first record of climate change from caves in Greenland. We were successful, and came back with many more samples than we ever expected to find, not to mention the documentation of twenty-six caves. This report is our story, right from the beginning when I was first introduced to the idea, through to the highs and lows of the expedition itself, and on to today, where we are now deep in the throes of the scientific analyses. Many people and organisations made this possible, and I can't thank you all enough. Special mention, however, should be given here to: Clive Johnson, our fantastic polar expert and logistics organiser; Andy Whitham and the team at CASP who supported us logistically throughout the whole project; the Danish military and ground staff at Mestersvig who were extremely welcoming and supportive of our expedition; and finally, Jean-François Loubiere, leader of the 1983 expedition, and Prof. Paul Smith of the Museum of Natural History, University of Oxford, both of whom have visited the caves before and offered us lots of advice. I hope that you enjoy reading about our journey and looking at the fantastic photographs of one of the most remote places on Earth.

Gina x

5th May, 2016

"Look deep into nature, and then you will understand everything better."
Albert Einstein

Contents

The Beginning

This project began in a pub in Bristol, UK, some time between 2005 and 2009. Gina was (and still is), a member of the University of Bristol Spelæological Society. In chatting to Charlie Self and Graham Mullan, she learnt of limestone caves in Greenland. Charlie was kind enough to share with her all of his literature on caves in Greenland. He mentioned "some small holes" in Northeast Greenland, which didn't sound too inviting, at least from a sport caving and exploration point of view. Gina tucked the literature away for a few years, but always kept Greenland in the back of her mind. In the following years, she would bring out the folder every so often and browse through the literature. Finally, two sentences in the Davies and Krinsley (1960)[1] paper struck her as important and interesting…

> "The fill is capped by a flowstone deposit 4 inches thick formed of coarsely crystalline calcite. On top of this are stubs of stalagmites about an inch in diameter and ½ to 1 inch high."

For the caves and the sediment and calcite deposits to have formed, this currently arid region must have had a warmer and wetter climate at some point in the past. The deposits might therefore hold clues to when in the past Greenland was warmer than today, and could also be used to construct a climate record. The climate record in turn may be used as an analogue for Greenland in future warmer and wetter years.

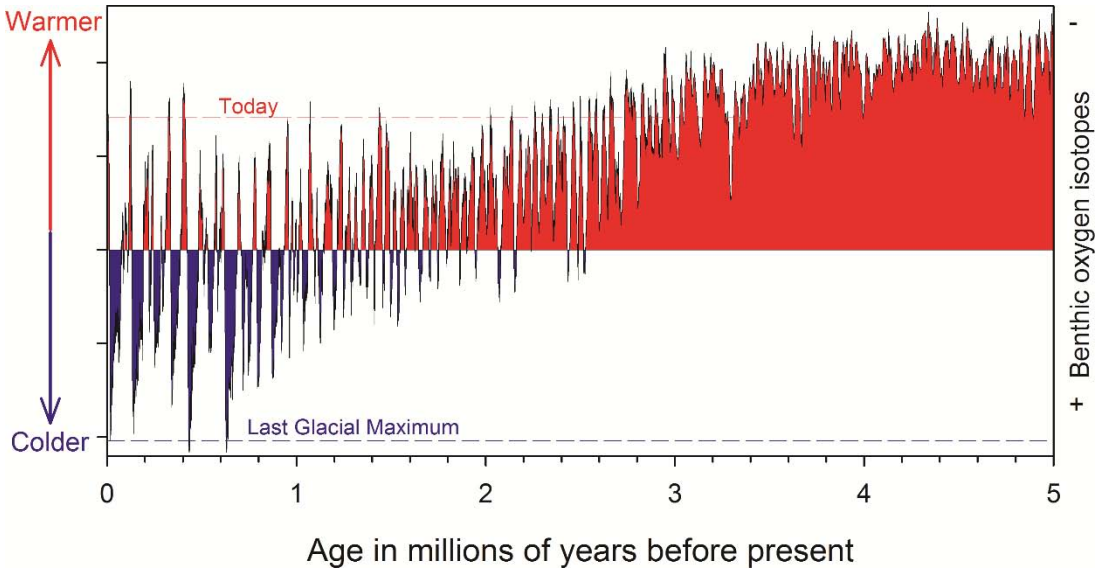
In the autumn of 2013, Gina started making enquiries with colleagues that work in Greenland, the Danish Geological Survey, and a number of polar logistics companies. Unfortunately the cost of such an expedition appeared to be far beyond reach; she was quoted up to £140,000 at one point. Raising such funds for a scientific programme is virtually impossible when there is no preliminary data to prove the concept, and raising such funds solely for a cave exploration expedition is unheard of. Finally, Clive Johnson of Polarsphere, and recipient of the Polar Medal (2001), became involved with the project in January, 2014. He planned the most cost and research-effective way to undertake the work. His budget seemed achievable with some hard work, so Gina began the lengthy process of writing grant applications and sponsorship letters. It soon became apparent that the summer of 2014 would be too soon for the expedition, but 2015 might be a possibility.

Scientific Background and Rationale

The Earth's climate is changing[2]. Understanding how it will develop in the future and its subsequent effects is one of the biggest environmental and socio-economic concerns of our time. In order to predict what the climate will be like in a warmer world, scientists look to past periods of warmer climate, to improve understanding of how the earth system behaves under such conditions.

Some of the highest quality records of past climate change are available from the Greenland ice cores, and our understanding of climate has been revolutionised by drilling into these high-latitude ice sheets[3-8]. The Poles in particular are highly sensitive to climate change and since 1875, the Arctic north of 60°N has warmed at a rate almost twice as fast as the global average[9]. This is a major concern because future warming will likely have drastic consequences for ice-sheet stability and global sea levels.

During the last 2.6 million years, known as the Quaternary period, the Earth's climate has oscillated between warm periods (interglacials) such as today, and cold periods (glacials). The last interglacial period took place about 130,000 to 118,000 years ago, and during this time, air temperature in Greenland was about 3-5°C higher than today. Deep ice-core climate records drilled from the Greenland ice sheet extend back continuously 123,000 years, to the final stages of the last interglacial (NGRIP ice core)[10]. The NEEM ice core[11] extends back 128,500 years, to the early stages of the last interglacial, but the basal ice is folded and incomplete, making interpretation difficult. The need for information about climate dynamics during past interglacials is thus still a major and increasingly important concern.



Temperature change over the last 5 million years. Adapted from 12.

Project Objectives and Approach

The main objectives of this project are to establish: 1. when in the geologically recent past was Greenland warmer than today? And 2. what was the nature of the climate during those warm intervals? In order to answer these fundamental questions, this project aims to develop the first speleothem-derived palaeoclimate record for Greenland. It is expected that the new record will be older than the current limit of the Greenland ice cores and will cover a period when conditions at the site were warmer and wetter than today. The record will thus be used to extend our knowledge about changing climates in a highly sensitive region of the globe, and will assist with improving our ability to make projections for future climate change.

Cave knowledge Pre-2015

Solutionally-formed caves (80°24' N, 21°56' W) at three elevations (490-520, 610-625, and 670m above sea level (a.s.l.)) were first discovered in the Silurian Centrum limestone of Kronprins Christian Land, Northeast Greenland, in 1960 by William E. Davies and Daniel B. Krinsley of the US Geological Survey[1].

Looking northwest along the valley of Grottedalen. Robbie Shone

Twelve caves were discovered on 29th June, 1960, in a north-south tributary valley to the larger northwest-southeast trending Grottedalen valley. In 1960 and 1983, the caves terminated in cave infill and ice crystals[1,13]. The cave infill was best exposed in the singular mid-level cave of the west wall, and was present as a 2m thick orange-yellow silt that was capped by a 10cm thick, coarsely crystalline calcite flowstone. In addition, stalagmite stubs up to 3cm high were documented as being present on top of the flowstone, and also on the floor of the cave[1]. The presence of these caves in the currently arid (<250mm a^{-1}), permanently frozen Northeast Greenland, indicates extensive limestone dissolution has previously occurred. The deposition of a thick flowstone cap, thus requiring groundwater, suggests a previous warmer and milder climate.

Panoramic view looking at the east wall of the tributary valley containing the caves. The larger valley containing the river in the background is Grottedalen. Here, the higher-level entrances to GD19 (left) and GD6 (right) can be seen, as well as the two lower-level entrances to the U-shaped cave (GD4). A person can just be made out standing in the far right entrance for scale. *Robbie Shone*

Grottedalen is c. 1km (3000ft) wide, 450-600m (1500-2000ft) deep near the caves, and is floored with morainal deposits[1]. The walls are steep with the lower 150m (500ft) comprising moraine and talus, whilst the upper parts consist of Ordovician-Silurian limestone that forms a steep cliff along the face of the plateau. The plateau is 640-730m a.s.l. (2100 to 2400ft a.s.l.), whilst the thickness of the limestone is c. 2300m (7500ft). The bedrock in Grottedalen is limestone. In the vicinity of the caves the limestone dips gently westward. It is grey to black and intercolated with layers of chert and dolomite[1].

The valley containing the caves runs north-south off the southern side of Grottedalen. The cave valley is c.1km (3000ft) in length, 60-150m (200-500ft) wide at its mouth, and 450m (1500ft) deep. Davies and Krinsley[1] noted eleven caves in the east wall and one cave in the west wall, with passages up to 5-12m wide (15-40ft), and 10-60m (30-200ft) in length. The largest cave (12m wide x 12m high), which is U-shaped with two entrances, was found at the northern end of the east wall at 610m a.s.l. (2000ft). Only the lowest level of caves was found to contain glacial moraine[1]. All caves terminated in cave fill and ice crystals[1].

Expedition Aims

The main aim of the expedition was to collect speleothem samples from known cave sites in Northeast Greenland. Secondary to the speleothem collection, the caves were documented through surveying and photography, and new cave sites were explored where possible.

Permissions

The expedition was conducted under Greenland MLSA prospecting licence number 2012/18. In addition, permission was granted by the Danish military to use Mestersvig as a point of entry to the national park; a radio permit was obtained from the Greenland Government to use certain radio transmitters, including satellite phones (VHF); and a firearms permit was issued by the Greenland Police to use CASP rifles in Greenland.

Team members

Dr. Gina Moseley

Prof. Christoph Spötl

Mark Wright

Chris Blakeley

Robbie Shone

Advisors

Clive Johnson
Polar logistics organiser
Polarsphere

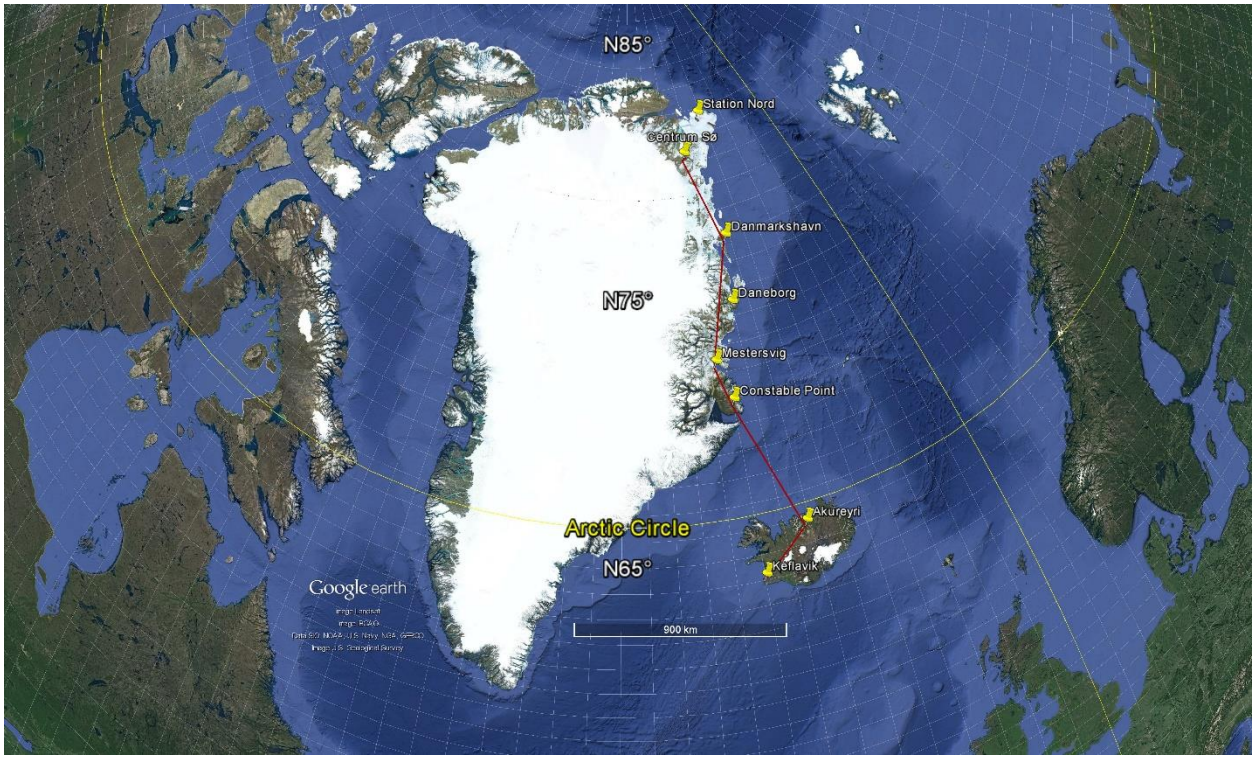
-

Prof. Paul Smith
Museum of Natural History
University of Oxford

-

Jean-François Loubiere
Leader of the 1983 expedition

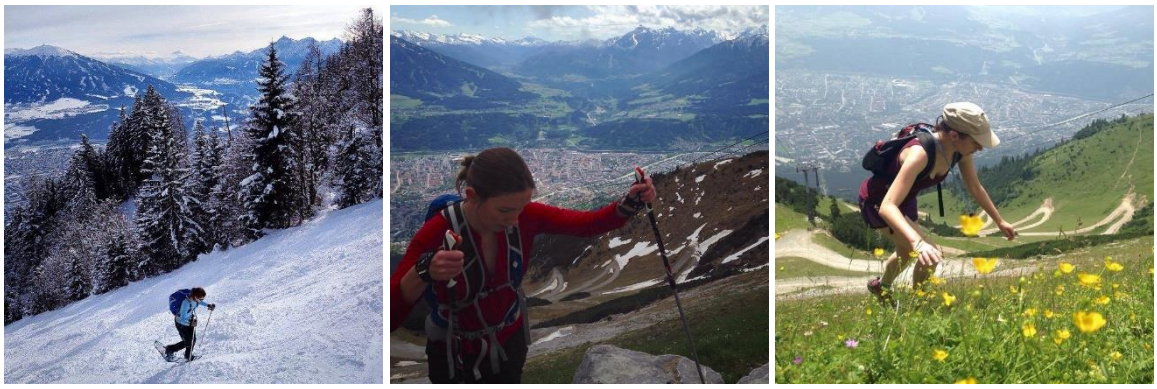
Route



Yellow - Gina, Robbie, and Christoph
Blue – Chris
Black - Mark and Chris
Red – Everyone

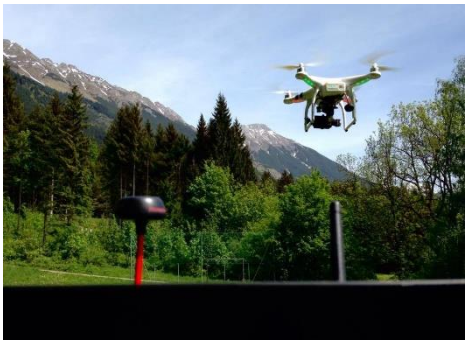
Diary

Pre-expedition



Training for the expedition during winter, spring and summer. Robbie Shone

Equipment sponsorship and testing. Left: Petzl. Right: Voltaic Systems. Robbie Shone



Practising flying the drone. Robbie Shone

Meetings in cyberspace. Robbie Shone

Minimising equipment and packing. Chris Blakeley

26th July, 2015

Akureyri. *Gina Moseley*

All of the team left their respective homes in the early hours of the morning to travel to Iceland. They met in Reykjavik and then travelled together to Akureyri, finally arriving at Gula Villan Guesthouse where they spent the evening.

The flight to Greenland the next day was a charter flight provided by Norlandair. Consequently, the time of departure was not firmly fixed. Gina checked with the airport staff at Akureyri and was told that it would be about 12pm. Previously, the group had been told that it should be mid-morning, so the change of schedule led to some nerves about missing the flight. Clive assured them via sms that the new plan should be fine, and that this was simply the way of the Arctic.

27th July, 2015

The team fly to Greenland. *Robbie Shone*

With the new, later departure time, the team had a leisurely morning in a busy guesthouse before making their way to the airport by taxi. It turned out to be a hive of activity for such a small place. They met up with geologists Dr. Adam Szulc and Dr. Audrey Decou from CASP (casp.cam.ac.uk) who were also on their way to Greenland for a field season.

The charter plane, a Twin Otter, was called Siorarsiooq (Greenlandic for Sandpiper). From Akureyri, the team flew to Constable Point, Greenland, where the plane refuelled and picked up their logistics organiser Clive Johnson. From there, the team continued north to the Danish military base, Mestersvig. The ground staff that greeted them were extremely welcoming, and informed them that they hadn't seen a polar bear in one and a half months. It was meant to settle the nerves, but to newcomers in the Arctic, one and a half months didn't seem so long ago. During the evening, the team sorted kit, inflated the boat to check for leaks, checked the engines were working, and discussed further options for the expedition. This was their first experience of 24-hour sunlight.

Left page: Views from the Twin Otter on the flight from Iceland to Constable Point to Mestersvig
Right page: Sorting through the kit at Mestersvig
Robbie Shone

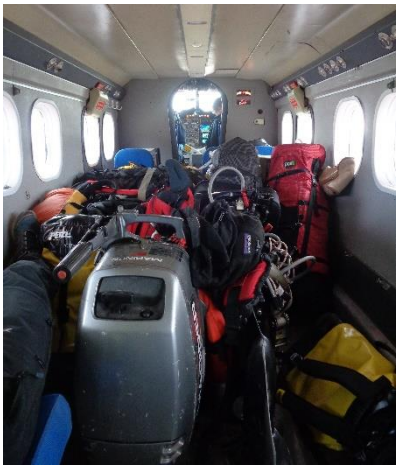
28th July, 2015

The clouds lifted, the sun came out, and so did the mosquitoes. Thankfully the boat remained inflated throughout the night so no repairs were necessary. The day was spent further sorting kit and loading the Twin Otter. In the evening Gina gave a talk to the personnel on the base about the project and the expedition. They were really interested and supportive, and even offered to come along to help!

Mark Wright sorts through the equipment at Mestersvig amongst many mosquitoes. *Robbie Shone*

29th July, 2015

The team left Mestersvig shortly after 8am. After a couple of hours they landed at Danmarkshavn for refuelling. In the strong winds the pilot had to abandon the first attempt at landing when just a few metres off touching down. The second attempt was uneventful. Ground staff greeted the team wearing full anti-mosquito attire and informed them that they hadn't seen a polar bear in six weeks, but when it had visited, it had returned about ten times. As the team continued further north, the snow and ice slowly disappeared, eventually being replaced by brown mountains and milky blue rivers. With time, a large lake came into view and at 1pm the team landed on the airstrip at the southwestern end of Centrum Sø. They watched and



The gear inside the Twin Otter for the flight to Centrum Sø.
Gina Moseley

listened as the Twin Otter flew off into the distance, leaving them on their own for several weeks. The last thing one of the pilots said was “watch out for the dead polar bear over there”.

The airstrip is located on a sandy spit of land, sandwiched between rivers to the north and south. The plan had been to put the boat in the northern river, since the southern river appeared very shallow on satellite images. However, in their haste to get going, and given that the kit had been unloaded near the southern river, which at that time was quite high, the team abandoned their original plans and launched the boat into the southern river. They hadn’t gone far after pushing off before they grounded in shallow water on a sandy bank. Mark jumped into the cold water wearing waders and pulled the boat into deeper water. They went no more than a couple of metres and then grounded again. Mark pulled the boat into deeper water once more, and they grounded again. Heavily loaded, the boat was difficult to move so the remaining four removed their boots and socks and joined Mark barefoot in the water. It was cold but at least the bottom was soft and sandy. After c. 20 minutes of dragging the boat around and not finding a deep enough channel, despite there being an 80m deep lake nearby, Mark went in search of deeper water. His apparent ability to walk on water for half a kilometre told the team that it wasn’t going to be easy to come by. They made the decision to empty what they could out of the boat, pull it back to shore, and to take a look at the northern river as had been the original plan. It turned out to be the best strategy, and Mark and Chris were soon out on the lake whilst the other three moved equipment to the northern shore.

The flight from Mestersvig, along the east coast of Greenland to Centrum Sø. *Robbie Shone*

Mark Wright searches for deeper water for the boat. *Robbie Shone*

Tired from the long journey and also a little cold, the team decided to stay the night at the end of the landing strip. They warmed up in an old canvas US military hut, before carrying all the gear the few hundred metres to the northern river in preparation for the next day. They used the spare time that evening for some rifle practice, using a popular red and white drinks can that they were disgusted to find on the floor as the target. They also tested the bear fence, took some weather measurements, and watched an Arctic stoat scuttling about. Despite the setback they were still optimistic about what lay ahead. The itinerary allowed them the time to have a few setbacks, though they were hoping that there wouldn't be many more.

Left : Dragging the boat back to shore. Right : Resting in the US army military hut. *Robbie Shone*

GPS plotting whilst finally crossing the lake! *Robbie Shone*

30th July, 2015

Base camp on the eastern end of Centrum Sø. *Robbie Shone*

The team were more successful today and all headed across Centrum Sø without any further difficulties. The cove that had been identified on the satellite images as being a possible place to locate base camp was found easily. It turned out to be a good place for getting the boat in and out of the water. Gina, Robbie and Christoph prepared camp, whilst Mark and Chris returned to fetch the last of the equipment from the landing site. Base camp was set up so that the food and communal cook tent were downwind of the sleeping tents (at the time of pitching). A bear fence was set up around the sleeping tents. The remainder of the day was spent preparing for the walk to the caves. The morning of the 30th July was the only time they experienced any rain and it was a very light drizzle.

Hiking past multi-coloured scree slopes created on the slopes of Neoproterozoic sedimentary rocks. *Robbie Shone*

Mark Wright and Chris Blakeley hike along Vandredalen. *Robbie Shone*

31st July, 2015

Top : Walking in the night sun.
Bottom : Patterned ground.
Robbie Shone

It was agreed that the best approach to get all of the gear and 45 man-days of food to the caves would be to do shuttle runs. The decision was made to leave the drone at base camp in order to reduce some of the weight and bulk that needed to be carried. Despite cutting back as much as possible, everyone began the hike with bags weighing 25+ kg. The weather was good, if a little warmer than expected. They saw one large musk ox that didn't seem too bothered by their presence. A military C130 flew past them at low level.

After 11.5km of walking through Vandredalen, they stored some kit and separated. Gina, Robbie and Christoph continued and set up camp within Grottedalen next to a river, 19.5km from base camp. Mark and Chris returned to base camp on the eastern shore of Centrum Sø, seeing the musk ox once more en-route. Grottedalen was much easier going under foot than the main valley of Vandredalen and contained a spongy polygon-patterned floor typical of permafrost environments.

River camp. *Robbie Shone*

GPS tracks and main waypoints for boat crossing and the hike to the caves.

1st August, 2015

Midnight sun at river camp. *Robbie Shone*

Gina, Robbie and Christoph had an easy morning, returning with relatively empty bags to the kit dump. When they arrived, a musk ox was drinking nearby from a stream. It appeared curious rather than threatened, and after a while wandered uphill to keep watch from higher ground. Mark and Chris walked from base camp with the remainder of the equipment to the kit dump where the gear was separated into more manageable loads. All five members of the team were at the river camp on this evening.

2nd August, 2015

Today the team had the last 12km of the hike to do to reach the caves. They began by crossing the river, which thankfully was at its lowest during the morning despite the 24 hour sunlight. During the journey, caves were spotted on the south side of Grottedalen after c. 6km, but were noted as something to take a look at upon return. The last part of the walk to the valley containing the caves was pretty tough. Unfortunately, upon reaching the target valley, the team found no caves, and after three days of walking in the heat of the sun, carrying 25+ kg loads, it was a rather disappointing moment. Robbie and Gina looked around the local area for caves but none were to be seen. Transferring the hand sketched maps from Loubiere (1987)[13] onto satellite images simply hadn't worked.

Following some discussion, the team decided to return to the caves they had seen previously. They would be a good place to start. However, approaching these caves from the opposite direction showed them in a new light, and they were exactly the caves that the team had been looking for all along. It was a classic case of relying on satellite imagery and hand drawn maps instead of concentrating on the terrain. Actually, it only resulted in another 10kms and gave the opportunity to check out another side valley for caves. The team was pleased to reach 'their' valley, and were happy to set up camp in such a magnificent setting.

Crossing the river. *Robbie Shone*

Camping beneath the caves. *Robbie Shone*

Chris Blakeley and Mark Wright on the final shuttle run. *Chris Blakeley*

3rd August, 2015

Mark and Chris undertook a final shuttle run to collect the remaining food and equipment left at the river camp. Thanks to the geographical embarrassment of the day before, the walk was now much less than had been anticipated. By the time Mark and Chris returned to the caves, they had hiked 72km. On the way they discovered the remains of a former camp (human faeces and toilet paper), and elsewhere some pellets, possibly from an owl. They also looked at the possibility of crossing the river to get to the other side of the valley.

Looking down on camp and Grottedalen from the high-level caves in the east wall. Robbie Shone

Christoph, Robbie and Gina began looking at the caves. They started with a small rock shelter (GD1) at river level from which they collected some ice. They then moved up to the terraces on the east wall, aiming for the large U-shaped cave. On the way they discovered a small phreatic tube (GD2) and a rock shelter (GD3) that contained fine-grained sediment and breakdown. Sliding on her stomach over the sediment at the back of GD2, Gina found some breakdown covered in a thin (c. 5mm thick) slither of flowstone. Whilst only small, finding this thin piece of flowstone was a significant step and enabled the first speleothem sample to be collected. Christoph, Robbie and Gina then made their way southwards along the terrace to the U-shaped cave (GD4). They were disappointed not to find any speleothem deposits inside, but did manage to collect some sediment for grain-size analysis. Robbie and Gina took photos whilst Christoph went to explore the area further. Nearby, he found another small tube (GD5) containing a notch and a thick, broken sequence of flowstone before heading up the steep scree slope. Near the top he found a several metre-thick flowstone sequence in a wall with no cave left around it. He also managed to gain access to one of the large, higher-level entrances (GD6) that could be seen from the valley floor. Jean-François Loubiere had previously indicated that his expedition had not managed to get into these higher-level entrances, and suggested abseiling from the top of the cliff into these caves. The cave Christoph entered has a steep passage leading up to a skylight. He found many more large broken pieces of flowstone, and returned to Robbie and Gina with the good news. Since GD5 was relatively close, they decided to sample the flowstone from there, but leave the high-level caves for another day. The flowstone sequence in GD5 turned out to be rather thicker (c. 20cm) than anything they were expecting to find, however, the material was very friable and crumbly, and they suspected it might have been subject to post-depositional diagenesis. Consequently, only a small piece of the flowstone was sampled for pilot studies because they thought it might not be suitable for analysis. Nonetheless, it was a good sign as it meant there might be other thick flowstone sequences to be found, but hopefully of better quality.

Bagging a sample in GD5 (Flowstone Cave). Robbie Shone

Upon returning from the shuttle run, Chris had a look at the northern side of the east wall and noted some entrances for the next day.

4th August, 2015

The team split up today. Robbie, Mark and Chris targeted the most northerly caves in the east wall, whilst Christoph and Gina went to the west wall in search of the flowstone described in 1960[1].

Mark Wright and Chris Blakeley are silhouetted inside GD15 (My Cave). *Robbie Shone*

The east-wall team headed straight to the most northerly cave (GD15) that they could see. It was a small triangular-shaped cave (GD15) and contained a number of broken flowstone deposits that were sampled. GD15 isn't the most northerly cave on the planet, but it could be the most northerly explored cave on the planet. Had people from the other expeditions been inside GD15 already? There was no evidence to suggest so.

After GD15, Robbie, Mark and Chris discovered two other small caves (GD16 and GD17) within several metres of each other containing in situ flowstone. Surprised and excited to find such thick flowstone sequences, they collected yet more samples before targetting a large entrance that required some climbing to get into. Once inside they discovered a cairn, presumably left by the 1983 expedition. No further speleothem formations were found.

On the west wall, Christoph and Gina first documented a small rock shelter with an ice floor (GD7) that had been viewed from the other side of the valley on the previous day.

The team scramble up the scree slope to the higher level caves in the East Wall. Robbie Shone

They were looking specifically for cryogenic cave calcites (CCCs), an interesting type of speleothem that precipitates out of solution as water freezes to ice. They didn't find any CCCs, but did collect some ice for isotope studies. They then visited the cave (GD8) that was described in 1960 as having a four-inch-thick flowstone deposit. It was the whole reason that the expedition was taking place. It was easy to find and recognise, even from the grainy black and white photographs in the original print[1]. The cave proved to be the most interesting in terms of development, containing scallops, anastomosis, notches, sediments, concretions, and the flowstone. There was a lot of evidence for previous human activity, with large broken chunks of flowstone on the floor. A sample was collected from the broken material, rather than from the in situ material. The final cave they visited that day on the west wall was up a steep climb in a small canyon-type feature. At the top, they found a cave (GD9) with the walls and floor covered in ice. It also contained ice stalagmites. They didn't venture to the very back as they didn't want to muddy the floor. No flowstone was found, but they did observe a number of small stubby dripping stalactites in the entrance. A couple were taken for analysis, and some were sampled for drip water.

The team reconvened late in the afternoon outside the U-shaped cave (GD4) where they swapped stories and samples. Without the pressure of daylight running out, they scrambled

The team outside GD19 (The Crystal Palace).
L-R: Robbie, Christoph, Chris, Gina and Mark. *Robbie Shone*

up the scree slope to the higher level caves. Mark and Chris rigged a hand-line across a scree slope that was perched above a steep drop. The cave discovered by Christoph the previous day (GD6) was surveyed by Mark and Chris, Christoph assessed the suitability of some flowstone samples, and Gina and Robbie targeted a large entrance (GD19) that could be seen easily from the other side of the valley. They were very pleased to find several thick flowstone sequences in situ and ex situ that appeared dense and compact. Unfortunately, the sequences were far too large to sample in completeness, bearing in mind the team still had to carry any samples (along with all the gear) back to base camp. By this time, they had come round to the idea that this might be a pilot study only. They had found so much more flowstone than they had expected to, they simply couldn't sample it all without the help of some transport closer to the caves. Once again, they took a small sample for preliminary studies from GD19. There was still a good chance that none of the samples would be suitable for palaeoclimate reconstruction. In the meantime, Chris, Mark and Christoph had joined Gina and Robbie in GD19 and gone exploring at the top of the sediment bank. Through a small hole they found a chamber filled with hoar frost and ice crystals. It was a stunning find and certainly in need of a photograph!

Chris Blakeley admires the hoar frost in GD19 (The Crystal Palace). Robbie Shone

5th August, 2015

With all the entrances in the east wall explored, the whole team decided to try and get into the high-level caves in the west wall. Now that they were used to moving up and down the scree slopes, getting access to the first of the high-level caves was quite simple. It involved scrambling up a scree slope onto a ledge and then round into the entrance (GD20). The cave didn't go far or contain any speleothem deposits, so Gina stayed to complete the survey and make some notes, whilst the guys tried to get into some other more difficult-to-reach entrances. Using climbing techniques and belayed by Mark, Chris managed to get into the entrances, but found that they were just rock shelters (GD21, 22, 23).

The team moves across the scree slopes on the west wall. Robbie Shone

Whilst sat at the back of GD20, however, Gina noticed a clump of beige-green material amongst the rocks in the floor. She prodded it and it gave off a strange smell, so she prodded it again to check, and yes it definitely smelled. She realised it must be something dead but couldn't work out what it was. As she looked closer she realised there was more of the beige material in a hole in the ice, and it contained black and white feathers! It was a bird, and closer inspection showed that its skull was frozen into the ice on the floor. When the guys returned, they photographed the cave and the bird, and took samples of the bone for radiocarbon dating.

Christoph scrambled up to the top of the cliff, onto the plateau, and back down the east wall to some other small, high-level entrances (GD10, 11, 12, 13, 14, 24, 25, X). He reported finding coarsely-crystalline flowstone present as sub-rounded fragments on the plateau, together with glacial erratics (including conspicuous red granite that was repeatedly seen in the valley). These fragments of flowstone clearly stem from cave passages eroded by the glacier and demonstrate that speleothem-bearing cave passages are not confined to the shallower levels that are present today.

Walking along the flood plain of Grottedalen. Robbie Shone

In the meantime, Gina, Robbie, Chris and Mark tidied up the remaining photography work on the west wall. In particular, they wanted to photograph the main sampling cave described in 1960 (GD8) since it was so important to the history of the expedition and also displayed many features of speleological interest. Whilst taking the photograph, Gina noticed a piece of yellow cardboard stored beneath some rocks.

She pulled it out to remove the litter, but found that it was an old Kodak black and white film box with a note inside from the original explorers. It was a very exciting find, and definitely one of the highlights of the expedition.

6th August, 2015

With all the caves now explored, Chris, Mark and Christoph took the first of the equipment back to the river camp, whilst Robbie showed Gina the small caves containing in situ flowstone (GD16 and GD17) that had been found two days previously. Further samples and photographs were taken. The Grottedalen camp was then dismantled, and all of the team moved the remainder of the gear to the river camp that evening.

Sample collection. Robbie Shone

The team rest near a large metamorphic conglomerate boulder. Robbie Shone

7th August, 2015

Now on the home straight, the whole team began the walk towards base camp on the edge of Centrum Sø. The team dumped kit near a distinctive conglomerate boulder and separated: Mark and Chris went back to the river camp, and Christoph, Gina and Robbie continued to base camp.

Robbie, Chris and Christoph enjoy soup back at base camp. Gina Moseley

8th August, 2015

Today the team finished the last day of hiking. Robbie, Gina, and Christoph walked from base camp to the kit dump at the conglomerate rock, collecting bedrock samples for Dr. Adam Szulc from CASP on the way. Chris and Mark walked from the river camp and met the other three, where the kit was once again divided amongst everyone. They then retraced their steps over the sharp-rocked scree slopes, onto the flat land nicknamed Mars because of its barren, red appearance, and finally onto the spongy soft soils surrounding Centrum Sø. On the final approach to base camp, Mark noticed some empty old green tins lying on the floor indicating that an army camp must have been located nearby. It was also noted that the lake had risen a few cm over the last eight days. That evening, instead of the freeze-dried meals, the team enjoyed "Centrum Sø Special Fried Rice" containing spam, freeze-dried onions, sweetcorn, and peas mixed with brown sauce. It was really quite delicious, honestly!

9th August, 2015

The team enjoyed a very well earned rest day and didn't venture very far. They wandered the few kilometres back up to Mars so that Robbie could use the drone to capture some aerial shots.

10th August, 2015

Surface bashing by boat for cave entrances. *Robbie Shone*

With the feeling that the team had achieved what they set out to do, and having not had any major accidents or health issues, today was spent having a leisurely look for cave entrances. Since a couple of the team had thought that they had spotted some entrances on the journey over the lake, surface bashing was done by boat. The team journeyed the full length of the lake and had a look at a couple of potential sites, but all turned out to be shadows or rock shelters only.

Christoph looking out over Vandredalen.
Christoph Spötl

11th August, 2015

Based on the original schedule, the team were meant to decamp and cross the lake today in preparation for the pick-up tomorrow. However, when Gina had made the daily check-in with Clive the previous night, she was informed that there was terrible weather along the east coast of Greenland and that no aircraft were taking off. It meant that their pick-up would be delayed, possibly for four days when the next good weather window was forecast. The team agreed that base camp on the eastern end of Centrum Sø was a more desirable place to be than the end of the landing strip at the western end of the lake, so decided to delay decamping until further notice. Christoph hiked up to one of the nearest peaks, whilst the other four attempted but failed to find a rock shelter that was marked in the Loubiere (1987) report.

In the evening, Chris found the remains of a former US army camp, complete with a box of twelve green tins of army rations dated to best before 1955, making them 60 years out of date!

12th August, 2015

The team were informed that the Twin Otter would likely pick them up the next day so they decamped, left the tents out to dry, and took the boat out during the morning to the far eastern end of the lake to look at the glacier and 30m-high lake sediments.

Getting all the equipment across the lake once again took two runs. The team then worked hard to dry the boat and get the equipment and engines across to the landing strip.

Carrying the heavy boat engine across to the landing strip. *Gina Moseley*

13th August, 2015

Unfortunately, when Gina rang the aviation officer at Constable Point he informed her that the plane couldn't take off after all, and that she would have to phone again the next day to check for an update. With everything packed away, the team didn't want to get the boat wet again, so they decided to stay where they were. The weather at their location was absolutely wonderful: clear blue skies, warm temperatures, and a little breeze to keep the mosquitoes away. Christoph went for a hike up the nearest peak, whilst the others kept busy around the landing strip by building a solar shower, drawing sketches, and generally soaking in the atmosphere and enjoying their surroundings.

Lake sediments up to 30m high at the eastern end of Centrum Sø. *Robbie Shone*

14th August, 2015

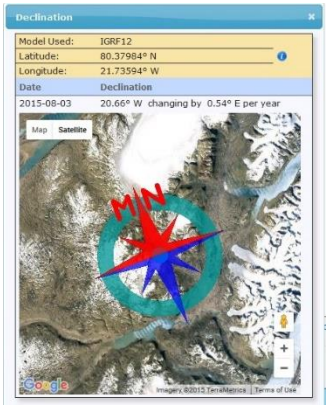
Gina rang at 9am for an update on the weather and pick-up situation. She was told that the plane would likely be coming, but she would have to call back at 11am to find out if it had taken off or not. At 11am she was told it was on its way and would be a few hours. The team packed away the last few items, and with a couple of hours to spare, had some fun by building an oven in the sand and making flapjacks from the remaining oats, sugar, butter and chocolate. They tasted terrible, but it was an enjoyable experience nonetheless.

With time, a faint engine sound could be heard in the distance. The team thought it too early to be the Twin Otter, but actually with a relatively empty load it had made good progress and it was indeed their pick-up. The weather had been too bad for the plane to refuel along the way, so the pilots brought six barrels of fuel with them, which took about an hour to hand pump into the plane for the return journey.

The pilots were keen to get home to Iceland for the weekend, so the stop at Mestersvig was brief. The cook kindly provided the team with a delicious take-away meal of potatoes and chicken to eat on the flight to Iceland. It really tasted amazing! At roughly midnight the whole team touched down in Iceland, back into the first darkness they'd seen for four weeks. The expedition and amazing once-in-a-lifetime experience was at an end. The team was unharmed and they had a precious collection of speleothem samples in their hands for the next generation of Greenland climate research!

The team land in Akureyri, Iceland. Robbie Shone

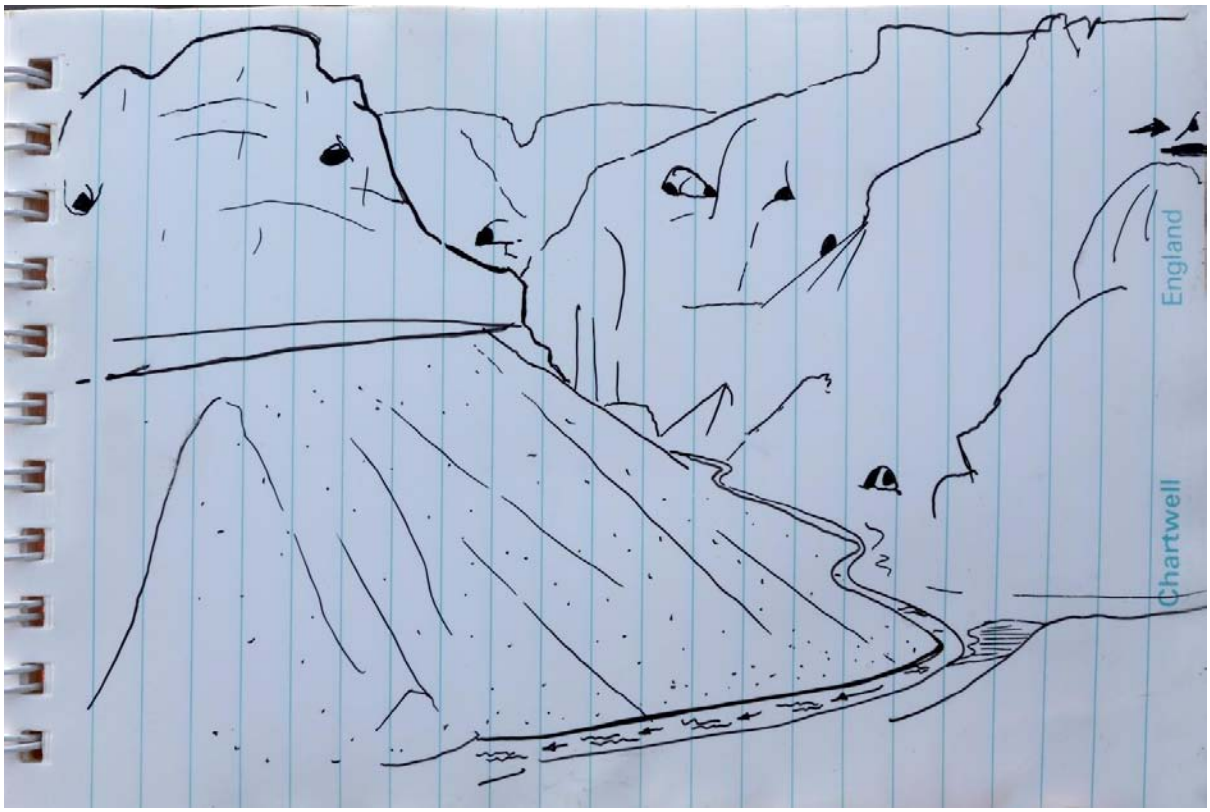
Surveying



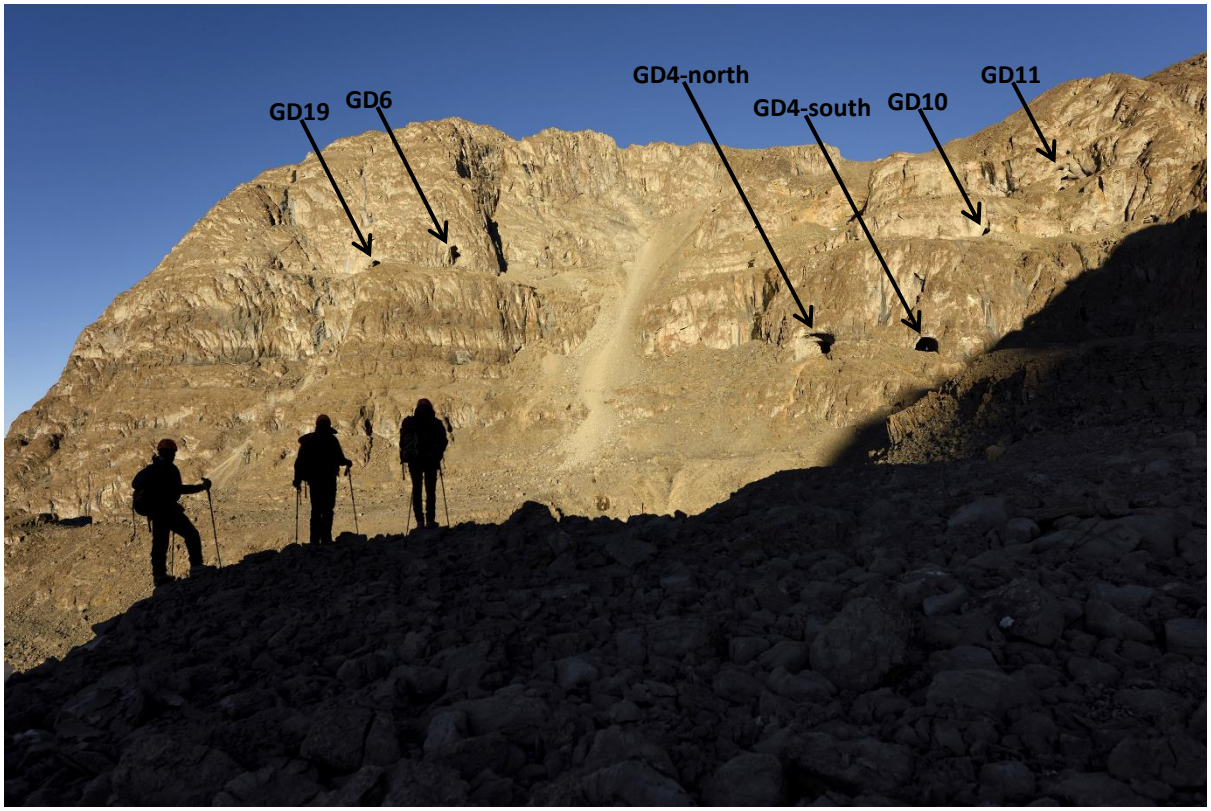
Caves were surveyed with a Suunto KB-14/360R DG compass and a Suunto PM-5/360 PC clinometer along with a Leica Disto D2, or alternatively with a Leica DistoX adapted to take compass and inclination readings. Declination was 20.66° W at the time of measurement[14]. GPS points are based on the WGS-84 grid and elevations are determined by barometric pressure. Caution should thus be used when referring to cave elevations. Surveys are not provided in this report but are available upon request.

Caves – 2015 Expedition

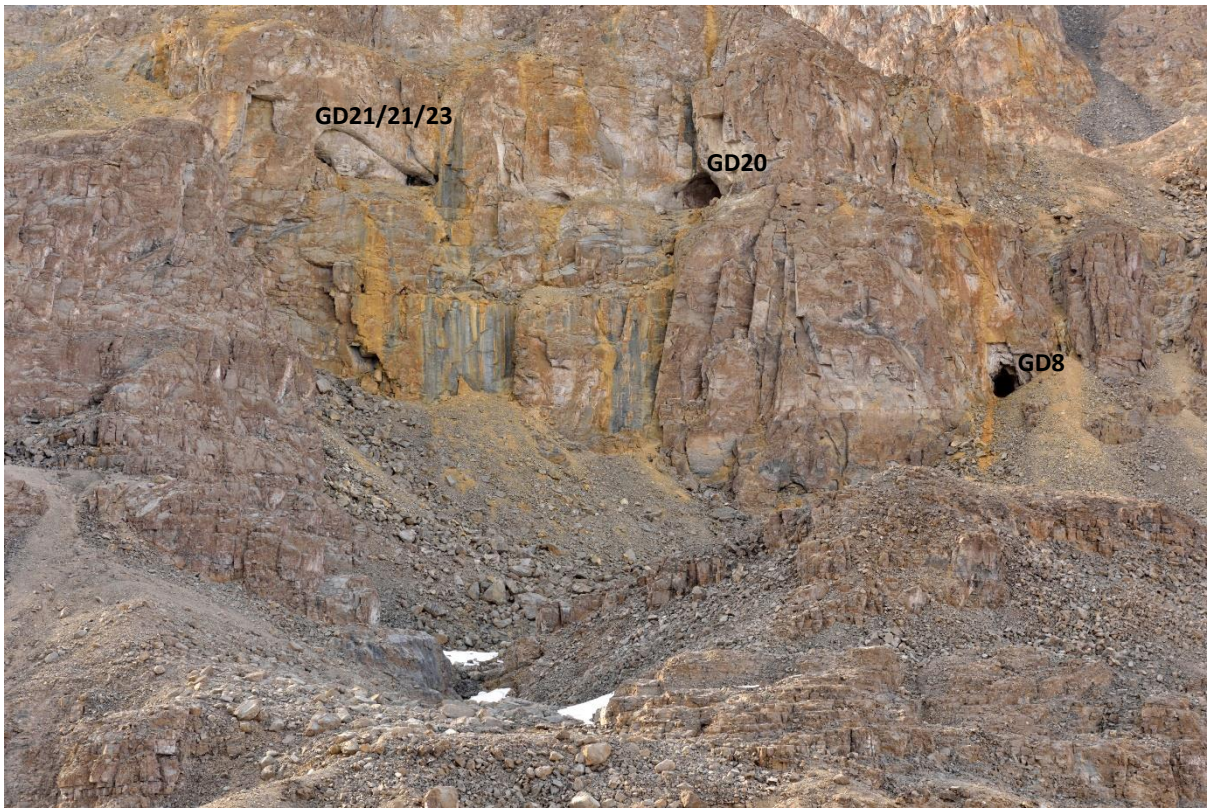
Originally each cave was to be identified by code (GD for Grottedalen and then sequential numbering), rather than by name because we considered it inappropriate to subsequently name caves that other people had discovered. However, far more caves were found than was expected, thus, for the sake of clarity it became necessary to start referring to the caves based on distinguishing features.



Field sketch of some visible cave entrances. Robbie Shone



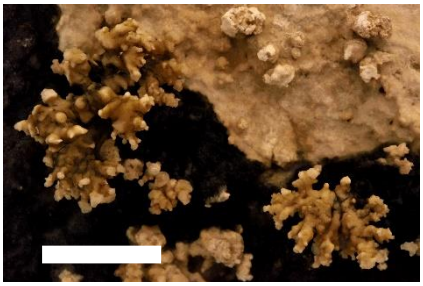
Various cave entrances in the east wall. Christoph Spötl stands in GD4-south for scale. *Robbie Shone*



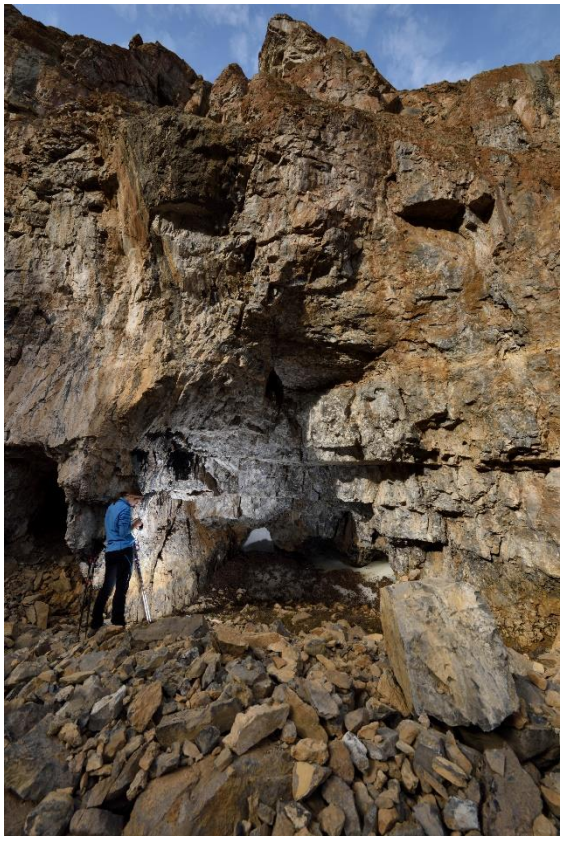
Various cave entrances in the west wall. *Robbie Shone*

GD1 – River Ice Cave

80.37984 N, 21.73594 W
8m accuracy
357m a.s.l.
Team: GM, RS, CS
Description: Rock shelter with a 0.7m thick floor of ice. The entrance is 4.9m wide by 3.7m high, and the cave length is 5.3m. The shelter narrows at the back to a chimney that is blocked by ice. Several chimneys can be seen coming down near the front of the cliff above the cave. Popcorn is present on the side walls.



Popcorn on the side walls of GD1. Scale bar = 2 cm. Robbie Shone



GD1 and the cliff containing chimneys above it. Robbie Shone

Looking out of GD1 with the east wall in the background. Robbie Shone

GD2 - The Tube South

80.37881 N, 21.72641 W
4m accuracy
452m a.s.l.
Team: GM, RS, CS
Description: The entrance is 1.5m wide by 0.9m high, and the cave length is 3.5m. The tube contains fracture-filling calcite and fine-grained sediment at the rear, which eventually blocks the passage. Breakdown covered in thin, c. 5mm thick flowstone, lies on the sediment at the back of the cave. No ice was observed.

The entrance to GD2. Robbie Shone

GD3 - The Tube North

80.37883 N, 21.72596 W
6m accuracy
454m a.s.l.
Team: GM, CS
Description: The entrance is 1.3m wide by 0.5m high, and the cave length is 3.6m. Popcorn is found in the entrance, whilst a c. 1m thick, orange-coloured fine-grained sediment is at the back of the cave. Ice is on the walls.

Left : The entrance to GD3. Right : Sediment and ice at the back of GD3. Gina Moseley

GD4 - U-Shaped Cave

North entrance
80.37653 N, 21.73545 W
4m accuracy
501m a.s.l.

South entrance
80.37626 N, 21.73757 W
7m accuracy
514m a.s.l.

Sediment-filled passage in GD4. Robbie Shone

Team: GM, RS, CS
Description: The cave is 100m in length, shaped like a U, and has two entrances. The northern entrance is 13m wide by 10m high, and the southern entrance is 8m wide by 5m high. An 8m high chimney is present in the ceiling, c. 13m from the northern entrance. The cave appears to have formed along an unconformity between a light grey limestone (bottom), and a dark grey limestone (top). Ice is present in a thin band along the base of the walls. No stalagmites or flowstones were found, but the walls near the entrances were covered in hard moonmilk-type crusts. The floor of the cave is mostly covered in sediment and breakdown.

The unconformity between the two limestones and ice around the base of the wall. Robbie Shone

Hard, moonmilk-type crusts on the entrance walls of GD4. Gina Moseley

Collecting sediment. Robbie Shone

Southern entrance. Paul Smith

Christoph Spötl walks past a stripy, thinly-bedded wall near the southern entrance. Robbie Shone

Looking out of the northern entrance of the U-shaped cave (GD4). Robbie Shone

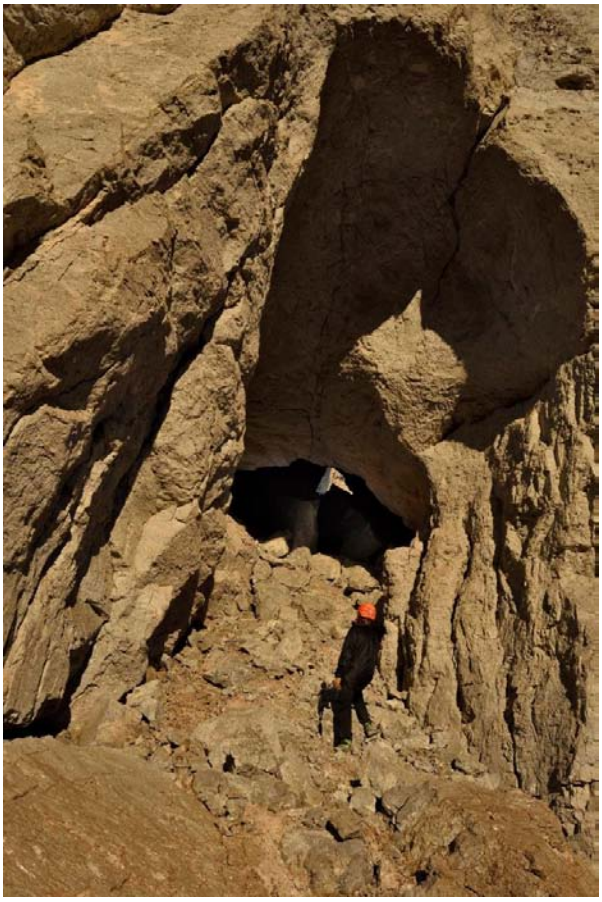
GD5 - Flowstone Cave

80.37712 N, 21.73484 W
8m accuracy
634m a.s.l.
Team: GM, RS, CS
Description: The entrance is 1.5m wide by 2m high, and the cave length is 4.4m. The floor is covered by sediment and breakdown boulders, and the back wall is covered in ice and hoar frost. A 30cm deep notch is present in the north wall, which contains in situ flowstone. Much larger, friable flowstone sequences are broken and scattered over the floor, inside and outside of the cave.

Above: The entrance to GD5.
Left: Large, friable flowstone found outside GD5.
Below: The notch on the left of GD5. Robbie Shone

GD6 - Skylight Cave

80.37712 N, 21.72787 W
5m accuracy
669m a.s.l.
Team: CS, MW, CB
Description: The lower entrance is 3m wide by 9m high, and the cave length is 54m. The cave rises steeply (c. +30°) to a c. 5m high chimney at the end that opens to daylight.



The lower entrance to GD6. Robbie Shone

GD7 - Bubbly Ice Cave

80.37689 N, 21.74219 W
5m accuracy
512m a.s.l.
Team: GM, CS
Description: Rock shelter containing an ice floor and hoar frost on the walls. The entrance is 1.8m wide by 2.0m high, and the cave is 2.8m in length. Breakdown is on the floor around the entrance.

Ice on the floor of GD7. Gina Moseley

Bubbles in the ice of GD7. Gina Moseley

GD8 - Main Sampling Cave

80.37767 N, 21.74682 W
9m accuracy
520m a.s.l.
Team: GM, CS
Description: The entrance is 3.8m wide by 4m high, and the cave length is 11m. Three notches are present in the left wall, which also contains scallops between 1.5 to 4cm in length. The steeper side of the scallops is located towards the entrance i.e., suggesting the flow direction was from the present entrance into the cliff. At the rear of the cave, there is a 2m thick sediment sequence, upon which there is a 20cm thick in situ flowstone deposit. This sediment/flowstone sequence is the same one that was described in 1960[1]. Ex situ pieces of the flowstone are scattered on the floor. The ceiling contains anastomosis, and concretions are present on the floor.

GD8, showing the three notches on the left side and the sediment sequence at the rear of the cave.
Robbie Shone

Scallops in GD8. Water-flow direction is left to right. Robbie Shone

Anastomosis in GD8. Gina Moseley

Flowstone and sediment at the rear of GD8. Robbie Shone

Concretions in GD8. Gina Moseley

GD9 - Canyon Ice Cave

Breakdown in the entrance of GD9.
Gina Moseley

80.37846 N, 21.74943 W
6m accuracy
530m a.s.l.
Team: GM, CS
Description: The entrance is 3.6m wide, by 1.7m high, and the cave length is 8.5m. Breakdown is found in the entrance, but the floor at the rear of the cave is covered in a sheet of ice. At the rear of the cave, there is a hole in the ice that drops down to a small pit containing ice stalagmites. Hard, moonmilk-type encrustations are on the walls around the entrance. Small stalactites, which were dripping at the time, are found in the entrance. These are the only stalactites that were observed during the entire expedition.

Top left : Stalactites in the entrance of GD9.
Top right : Patterned ice along the walls of GD9.
Bottom left : icy floor of GD9.
Bottom right : Shallow pit in the ice containing ice stalagmites.
Gina Moseley

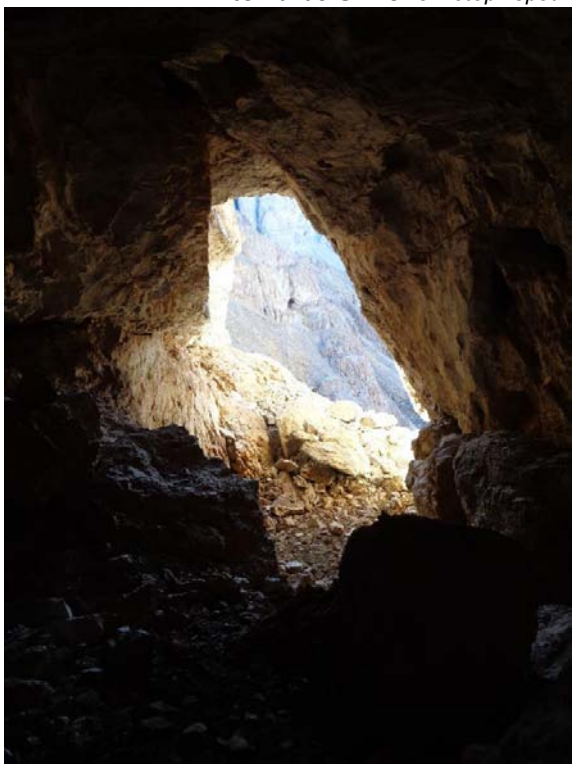
GD10 - Triangle Cave

80.37559 N, 21.73677 W
10m accuracy
557m a.s.l.
Team: CS
Description: Triangle-shaped cave above GD4, 5m in length. Contains coarse crystalline flowstone c. 10cm thick to the right of the entrance. Remnants of cupolas are on the ceiling. Ends in ice and hoar frost.

Looking in to the entrance of GD10.
Christoph Spötl

Dissolution niche containing speleothems in GD10.
Christoph Spötl

Looking out of the entrance to GD10 towards GD20. *Christoph Spötl*



Ice and hoar frost at the end of GD10.
Christoph Spötl

GD11- Multi-Level Cave

80.37537 N, 21.73769 W
10m accuracy
577m a.s.l.
Team: CS
Description: Cave over four levels. Lowest level is c. 4m in length and c. 1m high. The floor is covered in ice. The second level contains sediment and some ice. The third and fourth levels are difficult to reach above an overhang.

Lower three levels of GD11. Christoph Spötl

GD12 - Lens-Shaped Cave - right

80.37548 N, 21.73704 W
12m accuracy
578m a.s.l.
Team: CS
Description: Lens-shaped cave c.4m wide, c.1m high, and c.4m long. Contains ice but no hoar frost

Left : Entrance to GD12. Right : ice at the back of GD12. Christoph Spötl

GD13 - Lens-Shaped Cave - left

80.37559 N, 21.73633 W
12m accuracy
584m a.s.l.
Team: CS
Description: Same as GD12.

Left : Entrance to GD13. Right : ice at the back of GD13. Christoph Spötl

GD14 – Thick Flowstone Corner

80.37572 N, 21.73047 W
4m accuracy
594m a.s.l.
Team: CS
Description: Ruin of a cave over two levels. The lowest level contains a thick flowstone sequence that is c. 90cm thick. The upper level is c. 2m deep with ice on the floor.

The thick flowstone sequence of GD14, with no cave left around it.
Robbie Shone

GD15 - My Cave

80.37768 N, 21.70736 W
10m accuracy
490m a.s.l.
Team: MW, CB, RS
Description: The entrance is 3.7m wide by 1.5m high, and the cave length is 10m. The floor of the cave is covered in sediment, and ice is present on the rear wall.

Mark Wright at the back of GD15. *Robbie Shone*

Looking out of the entrance of GD15. *Robbie Shone*

GD16 – Triangle Flowstone Cave

80.37815 N, 21.70974 W
20m accuracy
567m a.s.l.
Team: MW, CB, RS
Description: Vadose trench containing a notch on the left wall. Thick (c. 20cm) pieces of porous brown-looking flowstone lie broken on the floor, whilst a c. 10cm thick flowstone is present inside the notch, and a thin layer of flowstone drapes down the left wall. The rear of the cave contains ice.

Thin layer of flowstone draped in situ down the left wall. Gina Moseley

Flowstone c. 10 cm thick in situ in the notch. Gina Moseley

The vadose passage of GD16 showing the notch on the left wall and the thin layer of in situ flowstone draped over it. Gina Moseley

GD17 – Flowstone Bridge Cave

80.37815 N, 21.70974 W
20m accuracy
563m a.s.l.
Team: MW, CB, RS
Description: Keyhole shaped passage that is 4m long. The left wall contains a notch that is 20cm deep and 40cm high. The entrance of the cave contains an in situ flowstone bridge, whilst the complete wall of the rear of the cave contains a flowstone sequence that is 2m thick and covered in hoar frost.

Above: Robbie Shone holding a thick piece of flowstone outside the entrance of GD17. Gina Moseley

Left: Gina Moseley looking out over the flowstone bridge in GD17. Robbie Shone

Below: Flowstone in situ at the back of GD17.
Robbie Shone

GD18 - Cairn Climb Cave

80.37906 N, 21.71592 W
20m accuracy
740m a.s.l.
Team: MW, CB, RS
Description: The entrance is c. 7m wide by 5m high, and the cave is c. 15m in length. Inside the entrance is a cairn, presumably built by the explorers in 1983. The rear of the cave narrows to 2.5m high, and ends in a wall covered in ice.

Cave GD18 (Cairn Climb cave). Top left : Chris Blakeley climbs into the entrance, spotted by Mark Wright. Top right : Chris Blakeley coils rope in the entrance. Bottom : Mark Wright admires a large ice formation at the rear of the cave. Robbie Shone

GD19 -
The Crystal Palace

80.37740 N, 21.72585 W
6m accuracy
605m a.s.l.
Team: GM, CS, MW, CB, RS
Description: High-level cave with a large entrance that is 13m wide by 8m high. Tafoni can clearly be seen around the entrance. Thick flowstone sequences, at least 1m thick, are found in situ and ex situ near the entrance on both the left and right wall. In addition, a thin flowstone sequence with runnels is present on the right wall above the thick flowstone sequence. From the entrance, a steep ramp leads to a narrow crawl containing ice stalagmites and hoar frost. Beyond the crawl, the cave opens up to a stooping size chamber that has a temperature of -6°C. The walls and ceiling are covered in hoar frost. Large breakdown blocks are present at the back of the chamber, which one needs to scramble over and around. The cave ends in another small chamber that does not contain ice or hoar frost.

Tafoni around the left side of the entrance to GD19. *Robbie Shone*

Gina Moseley and Chris Blakeley in the rear chamber of GD19. *Robbie Shone*


Flowstone to the right of the entrance in GD19. *Robbie Shone*


Flowstone to the left of the entrance in GD19. *Thin flowstone containing runnels in GD19.*

Robbie Shone


Hoar frost in the middle chamber of GD19. *Robbie Shone*

GD20 - Dead Bird Cave

80.37719 N, 21.74764 W
10m accuracy
510m a.s.l.
Team: GM, CS, MW, CB, RS
Description: High-level cave that ends after 15m in ice and breakdown. The entrance is 6m wide by 5m high. Breakdown blocks featuring anastamosis are present on the floor. A dead bird was found at the back of the cave, partly frozen into the ice on the wall, and partly frozen into the ice on the floor.

Top: The entrance to GD20.

Middle: The rear of GD20.

Bottom: Looking out of the entrance of GD20.

Robbie Shone

GD21_22_23
Triplet Cave Arch Cave

80.37689 N, 21.74640 W
6m accuracy
553m a.s.l.
Team: MW, CB
Description: High-level rock shelters.

Chris Blakeley accesses GD21-22-23. Robbie Shone

GD24

80.37460 N, 21.73559 W
5m accuracy
630m a.s.l.
Team: CS
Description: Short, 6m long cave with an entrance that is 1.5m wide by 2.5m tall. The back wall is covered in ice. No speleothems, karstic morphologies or loam were observed.

GD24. Christoph Spötl

GD25

80.37597 N, 21.73947 W
5m accuracy
554m a.s.l.
Team: CS
Description: The entrance is c. 5m wide by c. 2m tall, and the cave length is c. 9m. The rear of the cave contains a small skylight. Ice is present on the back wall, but no speleothems are present.

GD25. Christoph Spötl

GDX - Hypogene Cave

80.37369 N, 21.72854 W
5m accuracy
683m a.s.l.
Team: CS
Description: Horizontal tube c. 30-35cm in diameter filled with dense, laminated calcite, followed by coarse calcite and loam. The tube can be traced c. 3m.

Hypogene tube. Christoph Spötl

Further Cave Exploration

By Mark Wright

The cave entrances seen to the north of the large glacial river running down the Grottedalen valley looked tantalizingly close. Upon closer inspection of photographs we took through a pair of binoculars when we first entered the valley, they appeared to be very large cave entrances.

During the final shuttle run of equipment between the river and cave camps on the 3rd August, Chris and I followed the main glacial river for nearly the entire 6km between the camps. We were sure we would find somewhere over this distance where a safe crossing could be made, it was less than 15m wide in a few places……We were wrong.

Even when the river was at its lowest, in the morning, the force of the fast, deep flowing water would preclude any chance of a safe crossing on foot, even with a lifeline. The sound of large boulders in constant movement below the water surface, a warning of what could happen to anyone who dared attempt it.

Chris and I discussed the possible options, a rocket launched grappling hook, being one of them. This type of system had been used very effectively in one of the world's largest underground rivers, the Nare in New Britain. In that cave there was plenty of solid rock either side of the vast river for the hook to become attached to, here there was nothing. The sediment riverbanks were in a constant state of collapse and there were a few hairy moments as we got a bit too close to the edge on occasions.

Chris and I are both proficient paraglider pilots and a mutual friend of ours, Mike O'Shea, another arctic explorer, is also very proficient with a paramotor, which is a paraglider with a back mounted power unit and propeller. Mike recently made the first paramotor flight between Ireland and the UK mainland.

This got us thinking. The weather conditions we had witnessed during our stay in the Grottedalen valley would have been perfect for flying and the soft, flat ground would have made for an excellent landing and take-off zone. With a couple of tandem paramotors, easily transported in a Twin Otter, not only would we have been able to fly over the river and directly to the cave entrances visible to the north, but we could have flown ourselves and all of our equipment to the main Grottedalen camp within a day of reaching the airstrip at Centrum Sø.

Maybe next time.

Samples

Davies and Krinsley (1960)[1] documented only one 4-inch-thick (c. 10cm) flowstone sequence above a c. 2m-thick sediment sequence, and other visitors to the caves didn't recollect finding much more. Finding so many flowstone deposits in 2015 was thus both a pleasant surprise and a disappointment because everything couldn't be sampled in completeness with such limited resources. In the end the samples that were collected represented a wide cross section of the material available and will hopefully yield information that a bigger project can be built on.

Cave		Sample				
Code	**Name**	**Speleothem**	**Water**	**Sediment**	**Bone**	**Feather**
GD1	River Ice Cave	X	GD1	X	X	X
GD2	The Tube (South)	GD2-1	X	GD2-2	X	X
GD3	The Tube (North)	X	X	X	X	X
GD4	U-Shaped Cave	GD4-2* GD4-3*	X	GD4-1	X	X
GD5	Flowstone Tube	GD5-1	X	X	X	X
GD6	Skylight Cave	X	X	X	X	X
GD7	Bubbly Ice Cave	X	GD7	X	X	X
GD8	Main Sampling Cave	GD8-1	X	X	X	X
GD9	Canyon Ice Cave	GD9-1	GD9	X	X	X
GD10	Triangle Cave	X	X	X	X	X
GD11	Multi-Level Cave	X	X	X	X	X
GD12	Lens Shaped Cave right	X	X	X	X	X
GD13	Lens Shaped Cave left	X	X	X	X	X
GD14	Thick Flowstone Corner	X	X	X	X	X
GD15	My Cave	GD15-1	X	X	X	X
GD16	Triangular Flowstone Cave	GD16-1 GD16-2 GD16-3 GD16-4 GD16-5	X	X	X	X
GD17	Flowstone Bridge Cave	GD17-1 GD17-2 GD17-3 GD17-4	X	X	X	X
GD18	Cairn Climb Cave	X	X	X	X	X
GD19	Crystal Palace	GD19-1 GD19-2	X	X	X	X
GD20	Dead Bird Cave	X	X	X	GD20-2	GD20-1
GD21	Triplet Cave Arch	X	X	X	X	X
GD22	Triplet Cave Arch	X	X	X	X	X
GD23	Triplet Cave Arch	X	X	X	X	X
GD24		X	X	X	X	X
GD25		X	X	X	X	X
GDX	Hypogene Cave	GDX-1** GDX-2** GDX-3**	X	X	X	X

*Moonmilk; **Hypogene samples

Ongoing Scientific Analyses

The main aim of this project is to find out when Northeast Greenland was warmer and wetter than today, and to characterise the climate during those periods. The expedition was extremely successful in collecting sixteen speleothem samples that will be used to address these issues. Within a couple of weeks of returning from the expedition, the samples were drilled at 2 to 5mm resolution for stable isotope analysis (carbon and oxygen) using a handheld dentist drill and analysed at the Quaternary Research Group, Institute of Geology, University of Innsbruck (UIBK), Austria. The initial results look very promising, and show that the samples retain a record of changing oxygen and carbon isotopes. The interpretation of these changes will require further work.

Water and ice samples have also been analysed for oxygen and deuterium isotopes at the UIBK. The results are as follows:

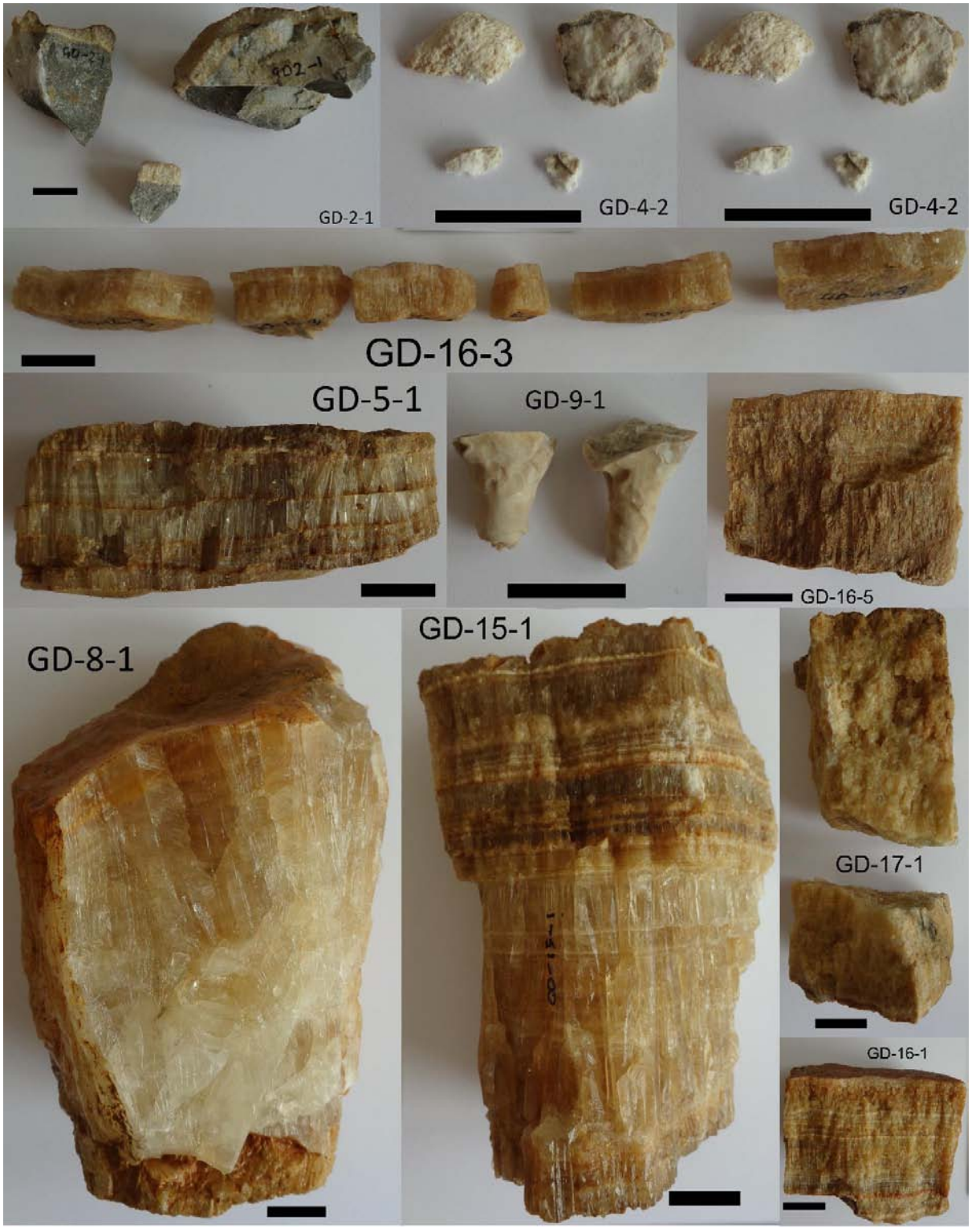
Location	$\delta^{18}O \pm 2\sigma$ (‰)	$\delta D \pm 2\sigma$ (‰)
Cave Ice (GD1)	-25.23 ± 0.04	-189.60 ± 0.4
Centrum Sø Lake Water	-26.17 ± 0.2	-198.51 ± 0.9
Cave Ice (GD7)	-24.16 ± 0.1	-185.45 ± 0.2
Stalactite Drip Water (GD9)	-22.43 ± 0.1	-172.08 ± 0.9

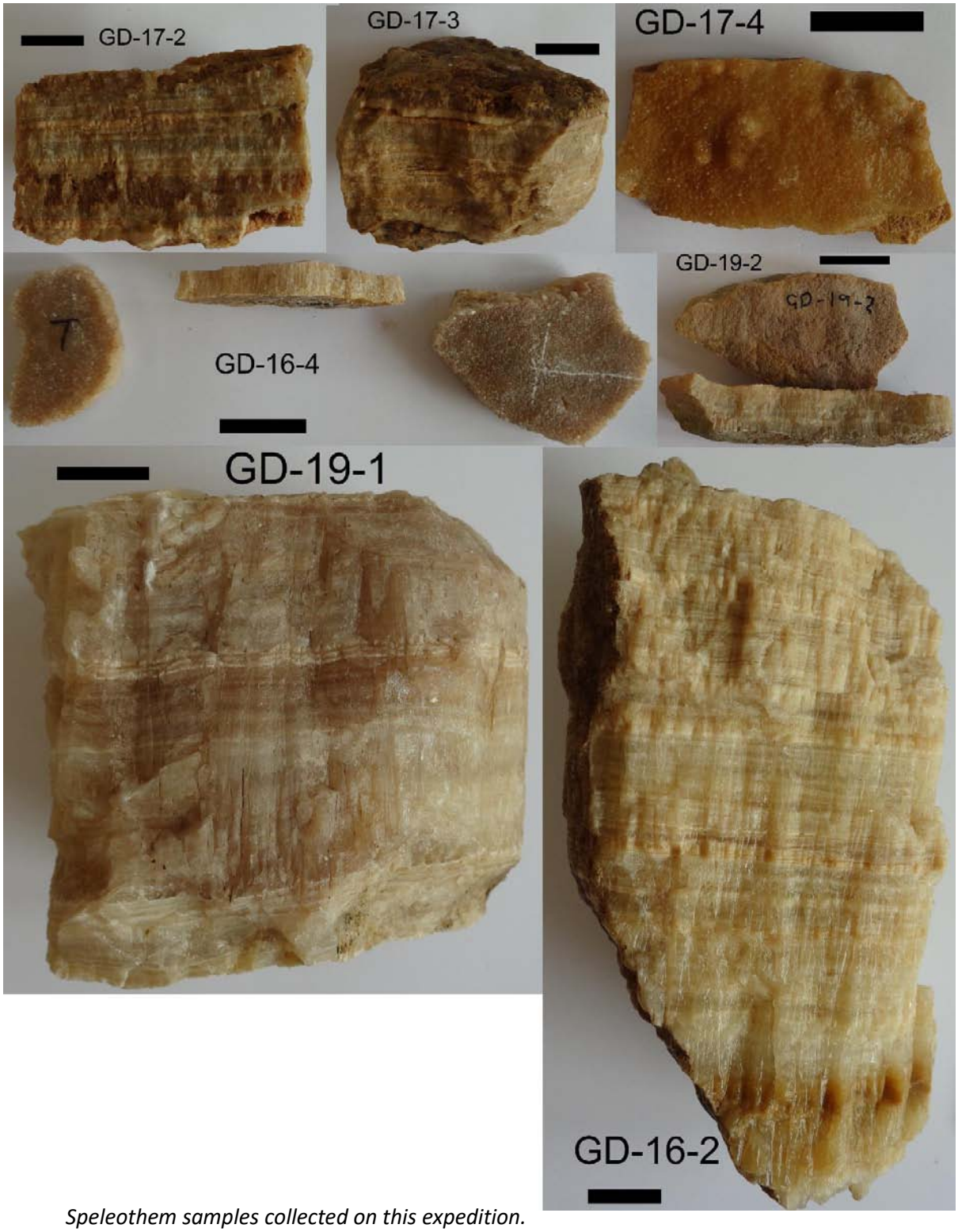
Stable isotope analysis of the bedrock that the caves are formed in yielded the following results:

Sample	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)
GD2-1-B1	0.05	-9.17
GD2-1-B2	-0.03	-9.64
GD2-1-B3	-0.12	-7.22

In September, 2015, sixteen pilot U-Th samples were dated at the University of Minnesota, USA, in the Trace Metal Isotope Geochemistry laboratory of Prof. R. L. Edwards. Powdered sub-samples of up to 100 mg were hand drilled by Gina Moseley from the top and base of the most interesting samples, or alternatively from just one growth layer in the less interesting samples. Dr. Yanbin Lu performed the chemical separation and purification procedure and analytical measurements[15-17]. A second set of pilot samples was analysed in February, 2016, by Gina Moseley. The initial results have provided a grounding for further study. In June, 2016, Gina Moseley targeted a select few samples for climate reconstruction. The results will hopefully be released in peer-reviewed journals.

In July, 2016, a 24.7g piece of GD8-1 was cut into three samples for preliminary pollen analysis. Each sample was cleaned in distilled water in an ultra-sonic bath and left to dry in a clean air laminar flow hood. The samples were prepared and analysed by Dr. Daniela Festi of the Institute of Botany, University of Innsbruck, Austria, but not found to contain any pollen or other non-pollen palynomorphs or charcoal.


GD-2-1
GD-4-2
GD-4-2
GD-16-3
GD-5-1
GD-9-1
GD-16-5
GD-8-1
GD-15-1
GD-17-1
GD-16-1



Speleothem samples collected on this expedition.
Black bars = 2 cm

CASP Samples

Dr. Adam Szulc from CASP asked the team to collect some samples of bedrock for him. They were happy to oblige. The following samples were collected. KC=Kronprins Christian Land. VD=Vandredalen. CS=Centrum Sø.

Location	Sample	Location	Description
Adam 1	KC-VD-1	80.24977 N, 21.36923 W	Sandstone
Adam 2	KC-VD-2a	80.25542 N, 21.34889 W	Sandstone
Adam 2	KC-VD-2b	80.25542 N, 21.34889 W	Shale
Adam 3	Centrum Sø landing strip	80.15099 N, 22.50634 W	Sand
Adam 4	KC-CS-1	80.17233 N, 22.24165 W	Sandstone
Adam 5	KC-VD-3	80.22694 N, 21.63806 W	
Adam 6	KC-VD-4	80.22213 N, 21.60386 W	
Adam 7	KC-CS-2	80.14629 N, 22.69560 W	

By Adam Szulc - Six bedrock samples at various elevations and one sand sample provide a good general coverage of the area around Centrum Sø. The sand will be used for provenance analysis in order to define source areas of sediment in the region. If they contain the appropriate minerals, the bedrock samples can potentially be used for thermochronology to shed light on the thermal and tectonic history of the region. Additional potential analyses include petrography and heavy mineral description of the bedrock samples in order to accurately define the rock types and provide insights into their provenance.

Weather Measurements

Some basic weather measurements were taken on average once per day using a Kestrel 4500 Pocket Weather Meter, which was loaned to the expedition by Dr. Iva M. Stiperski of the University of Innsbruck. The highest recorded temperature was 18.9 °C at 14.44pm on 13th August, 2015, at 80.15099 N, 22.50634 W. The lowest recorded temperature was 6.1 °C at 10.01am on 7th August, 2015, at 80.34111 N, 21.49784 W. During July 1960, mean daily air temperatures at Centrum Sø ranged from 12-14 °C[18].

Gina Moseley takes weather measurements.
Robbie Shone

Date	Latitude / Longitude	Time	Air Temperature °C	Wind Chill °C	Relative Humidity %	Heat Index °C	Dew Point °C	Wet Bulb Temperature °C	Head Wind m s^{-1}	Cross Wind m s^{-1}
29.7.15	80.15099 N 22.50634 W		10.4	7.4	63.5	8.9	3.1	6.2	4.0 @ 149°	2.9
30.7.15	80.20691 N 21.57293 W	1350	13.0	13.0	63.0	12.3	6.1	9.5	0.4 @ 210°	0.0
01.8.15	80.34111 N 21.49784 W	0930	16.3	16.1	46.3	15.6	4.6	10.1	2.1 @ 143°	1.0
02.8.15	80.34111 N 21.49784 W	0919	14.4	14.0	46.2	13.4	2.9	8.6	2.6 @139°	0.0
04.8.15	80.38235 N 21.70724 W	0755	12.2	12.2	53.9	10.9	2.4	7.1	0.0	
06.8.15	80.38235 N 21.70724 W	1100	7.5	5.7	63.0	7.3	1.1	4.5	3.3 @ 205°	1.0
07.8.15	80.34111 N 21.49784 W	1001	6.1	4.6	75.6	7.8	3.6	5.7	2.1 @ 197°	0.5
10.8.15	80.20691 N 21.57293 W	1137	7.4	5.8	84.6	6.9	4.6	5.8	1.8 @ 270°	1.0
10.8.15	80.17169 N 22.23907 W	1607	17.4	17.4	67.9	17.1	11.2	13.8	0.4 @ 269°	0.4
11.8.15	80.20124 N 21.94745 W	1555	13.1	8.9	60.4	9.5	2.4	5.7	2.4 @ 203°	1.5
12.8.15	80.15099 N 22.50634 W	1835	13.7	11.1	58.0	10.9	3.8	7.7	2.0 @ 220°	1.3
13.8.15	80.15099 N 22.50634 W	1444	18.9	13.5	64.5	13.5	7.4	9.8	1.4 @ 180°	0.3
14.8.15	80.15099 N 22.50634 W	1045	9.7	8.7	71.1	9.3	4.5	7.1	1.6 @ 140°	1.0
Weather measurements taken with a Kestrel 4500 Pocket Weather Meter in Kronprins Christian Land, Northeast Greenland										

Dead Bird (GD20)

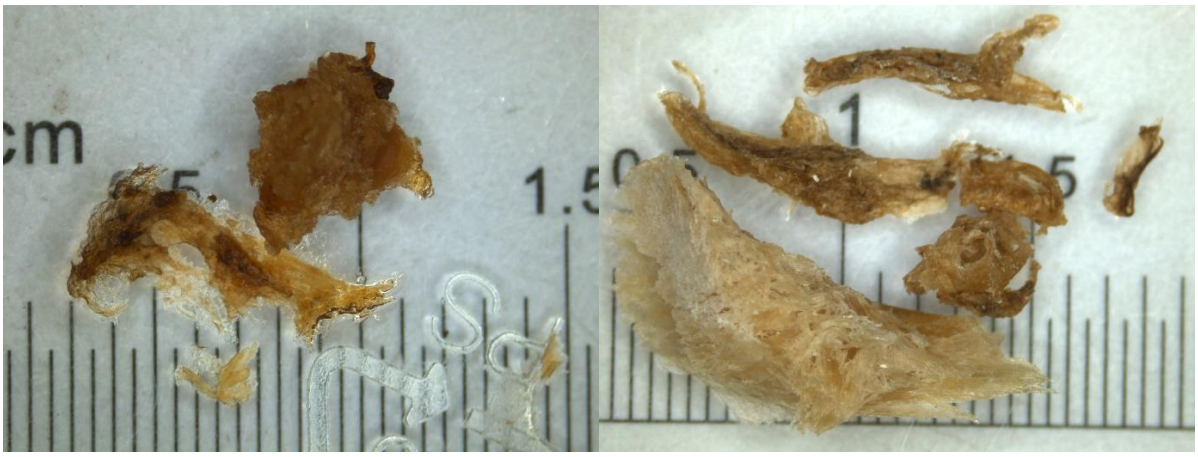
Samples of bone and feather were taken from the dead bird found in GD20 for use in radiocarbon dating and identification. Assuming it was the same bird, the wings were in a hollow amongst the hoar frost on the wall of the cave, whilst the body and skull were found on the floor. The parts on the floor were found frozen into the ice, indicating that at least some of the ice formation had taken place since death. The torso was covered in a green mould.

The bone samples were sent to Dr. Irka Hajdas at the Laboratory of Ion Beam Physics ETH Zurich, during October, 2015. The staff found skin and flesh on the bones, which were used in the radiocarbon analysis, meaning that the bones did not have to be destroyed. The results were received one month later and show that the bird is not modern. Specific results will be published with time in a peer-reviewed journal.

Gina has also been liasing with Dr. Olivier Gilg, of the Groupe de Recherche en Ecologie Arctique (GREA). Dr. Gilg is confident in his identification of the bird, however, we hope to perform DNA barcoding on the sample some time during 2016.

Top and bottom: The remains of the dead bird found in situ in GD20. Robbie Shone

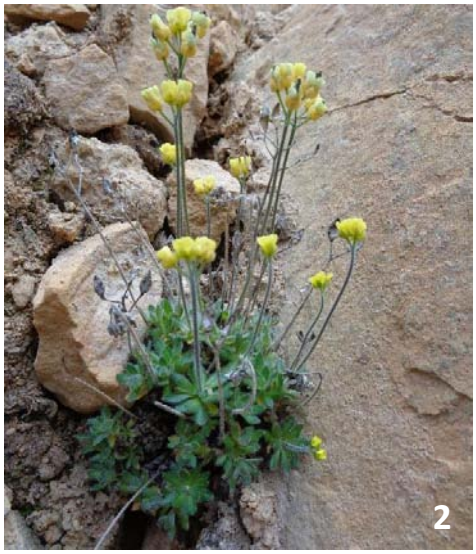
The samples of feather and bone collected from GD20. White bar = 2cm. *Robbie Shone*



Flesh and skin found on the bone sample sent for radiocarbon dating.
Laboratory of Ion Beam Physics, ETH Zurich

Flora

Presented here is a collection of photographs of the flora that was observed in Kronprins Christian land during the expedition. We would like to thank Prof. Brigitta Erschbamer from the Institute of Botany at the University of Innsbruck for assistance with identification.



Photos: 1. *Saxifraga oppositifolia* (purple mountain saxifrage) 2. *Draba alpina* (alpine draba) 3. *Papaver radicatum* (Arctic poppy) 4. *Saxifraga cernua* (nodding saxifrage) 5. *Minuartia sp.* (stitchwort) 6. Unknown 7. *Salix phylicifolia* (willow) 8. Poaceae 9. *Dryas octopetala* (mountain-avens) 10. Either *Eriophorum angustifolium* (tall cottongrass) or *Eriophorum scheuchzeri* (white cottongrass) 11. *Silene acaulis* (moss campion) 12. *Rumex sp.* (docks and sorrels). *1-10 Gina Moseley. 11-12 Robbie Shone*

Fauna

Presented here is a collection of photographs of the fauna that was observed in Kronprins Christian land during the expedition. A bee was also observed and a live musk ox, though no photographs were taken of these.

Photos: 1 & 2. Ovibos moschatus (musk ox*) skeleton* 3. *Sterna paradisaea* (Arctic tern) 4. *Scolopacidae* (sandpiper) 5. *Vulpes lagopus* (Arctic fox) 6. Bear footprint 7. *Ursus maritimus* (polar bear) 8. *Ursus maritimus* (polar bear) mouth. *1-3, 7 Robbie Shone, 4 Gina Moseley, 5-6, 8 Chris Blakeley*

1950s US Army Food Rations

Chris Blakeley discovered a box of US army food rations stored half sheltered beneath some rocks close to base camp. The box read “Ration Combat Individual” and contained rusty green tins stamped with a month followed by 1955. Each tin contained a can opener. A couple of the tins were opened up and found to contain either meatballs and beans, or grape jam, five biscuits, and cocoa powder or vanilla crème. Despite being 60 years out of date, everything smelled fine, so the team ate them. Delicious!

Top : The US army rations as they were found near base camp. Middle : The opened tins. Bottom : Eating the 60 year old rations.
Middle left : Robbie Shone. Bottom left : Chris Blakeley. All others : Gina Moseley.

Note from the Original Explorers (GD8)

Whilst photographing GD8, a small piece of yellow cardboard hidden underneath a pile of rocks caught Gina's eye. It turned out to be a black and white Kodak film box with a develop-before date of December 1961. The foil film wrapper was inside the box, and inside that was a note dated June 29, 1930. The note was written by W.E. Davies, the first author of the paper published in 1960[1] in the NSS Bulletin. It was because of that paper that this expedition took place. The date on the note didn't make sense though. In 1930, Davies would have only been 13 years old[19]. The note also wasn't written by Davies's father, whose name was William R. Davies[19]. The date on the note remained a mystery for several months, until Gina managed to contact Daniel B. Krinsley, the co-author of the 1960 NSS Bulletin paper[1]. He replied to say that the date of 1930 is clearly a mistake.

The Kodak film box, foil wrapper and note found in GD8. Robbie Shone

Equipment and Access Methods used during the Expedition

By Chris Blakeley

We were very fortunate to have the expertise of Clive Johnson, but also his agreement to use some equipment stored at Mestersvig. This offer and Clive's knowledge had effectively made the expedition possible, and so we made good use of it, by borrowing a boat, stoves and tents.

Our first technical concerns of the project related to accessing the high-level caves described by previous expeditions to the valley. We took with us sufficient lightweight material to be able to use natural anchors, such as large blocks or protruding spikes of bedrock. We also had a small number of bolts with us in case natural features weren't ideally placed or suitable. The bolts could be placed with hand tools or by drill. Hilti had provided a lightweight TE4 A22 drill for any core sampling that may have been required, so we had both options open to us.

In terms of personal equipment for accessing areas with a potential fall risk or risk of stone fall, we had an ultra-light mountaineering helmet each and two caving harnesses with lanyards. We also took two descending devices that could be used for belaying, hauling in rescue scenarios, and two sets of rope ascending equipment. Along with low stretch rope this gave us an all-round 'kit' for accessing areas quickly to assess their potential and then equipping them so that Gina, Christoph and Robbie could access if needed. Being able to protect exposed edges or steep scree couloirs was particularly important considering the size of our team and the remoteness of the locations. We all had walking poles and leather gloves, both of which were invaluable whilst carrying loads of up to 28kg over such sharp and untouched rocky terrain.

During the course of the trip, we protected a very exposed scree chute over a 150m-high cliff, climbed up into a cave entrance and abseiled out after surveying and photographing, and made a loose and exposed traverse to three promising looking entrances which, on arrival, were shallow rock shelters. We were able to use natural anchors everywhere and didn't need to place a single bolt. This meant we left minimal trace.

In order to traverse Centrum Sø we needed an ice free passage. Amazingly, the weather provided a window, which opened two weeks before our arrival, and closed two weeks after our departure. I must admit that navigating between the shore and remaining ice would have been beautiful, but we had a lake of open water. Clive had a small fleet of inflatable Zodiacs in his store, of which we selected the one that stayed inflated the longest. We briefly discussed using two boats, towing one behind the other to transport all of our equipment to base camp in a single passage. However, towing loaded boats with outboards, ropes in the water, remote terrain and potential inclement weather led to a simpler solution; a single boat with one pass if possible, or two if necessary.

Assembling and inflating the boat gave the team a chance to see how to fit the decking, stringers, pump, and engine, etc. The engines were treated to new spark plugs, the cranks turned, and the electrics, fuel priming bulbs and mixes checked. Three Zodiacs were rigged and left inflated overnight to check for any leaks. A test load of the boat with our equipment

on dry land left little space for the team, and marginal freeboard so we considered taking only tools and minimal spares instead of a spare engine, and less fuel to reduce the load. But ultimately, we opted for a complete spare engine, parts, fuel, and two passages. This gave us more time on the lake and exposure to the weather, mechanical issues and navigation. It was also another period where our team would be split. This meant considering bears, incidents or injuries and perhaps overnighting in different locations. We had two radios, two sat phones, flare gun or rifle, food, stove, water, clothing and first aid kit with each team whenever we separated. The boat always had spare fuel, spare engine, parts, anchor and chain and paddles on board. When we left the boat and headed to the sampling site, we deflated the keel and dropped pressure in the tubes to reduce the chances of it blowing away or flipping, and of overexpansion in the 24-hour sun. It was also pinned down with the two engines and the fuel laid inside. It was dragged up the beach and its anchor buried. Apparently bears can have a taste for boat rubber. We had a couple of large patches, but I'm pretty sure they would have been a token gesture if an interested bear took a real shine to a Zodiac meal.

Usually, boat handling this far north would require survival suits for the whole team. With the weather forecast, no ice and the fact that we were not on the open sea we assessed that for this trip they weren't a necessity. We all wore PFDs anytime we were on the water. This reduced bulk and weight significantly. We took only one pair of waders for launching and maneuvering. As explained elsewhere in the report, we did drag the loaded boat in shallow water whilst searching for a deeper channel, and a second pair of waders or two survival suits would have been more appropriate than entering the lake in our underwear at 80°N.

For all cooking we used two MSR Dragonfly stoves, with white gas fuel and meths for priming. Our fuel estimations were accurate both for the boat and cooking, and the stoves performed as expected. We were a bit thin on meths by the end of our wait for the return flight from Centrum Sø to Mestersvig, and we had consciously used the last of the little generator fuel for camera and drone battery charging for some final flights and photos. The solar panels had been used for all other charging requirements.

There were two Garmin handheld GPSs with us, so tracks could be plotted and the location of all cave entrances and sampling sites recorded. One GPS was used to plot the location of the landing strip at Centrum Sø and the deeper water channel out into the main lake. It also held the coordinates of our base camp, route to River camp via the shuttle run stops, and also to Grottedalen camp. This meant that in foul weather or low visibility the team could navigate using a combination of GPS and our laminated satellite images with latitude and longitude overlays.

Considering the latitude of the expedition, proximity to the Greenland icecap and recent seasonal melt, the conditions we encountered were very mild. The team was prepared for very cold conditions with good quality down clothing, insulated footwear and headwear, gloves and thermal underwear. Air or synthetic filled mattresses and four season down sleeping bags were used by everyone inside three two-person mountain tents equipped with snow/rock valences. Actually we were over-equipped as far as temperatures were

concerned. For the most part we were able to camp, cook and operate in the sun 24 hours of the day in mid-weight outdoor clothing. Occasionally, in the shadow the cool arctic air made its presence known, and down jackets were appreciated for some of the longer photography and sampling sessions. We even managed a comfortably warm solar shower at Centrum Sø airstrip before the flight south to Mestersvig.

Photography, Filming and Power

By Robbie Shone

Recording the team's discoveries inside the caves and in the remote wilderness this far north and away from civilisation was one of the aims of the expedition. It was vital to the success of the expedition that we returned with a large number of good quality photographs and enough video footage to produce a short film all about the expedition. This was necessary not only for ourselves but also for our many sponsors who had generously supported us with funds or equipment. It was my role to carry this out.

Before the expedition began, we established all the main challenges and technical difficulties we were likely to face working in the field. Arguably, the main issue was going to be charging batteries for cameras, laptops, the aerial drone, satellite phones, GPSs and the cordless drill for coring samples. We had a small generator at base camp that we could use to charge batteries before leaving for the hike, however, we would be gone from base camp for 9-10 days, hence we needed something more portable so that we could charge on the move. In August at 80° N, the sun circles overhead all day, never dropping below the horizon. This meant that we could potentially use solar panels to generate and store enough energy to re-charge all the batteries for all of our equipment. However, this relies upon 'good' weather conditions.

We reached out to Voltaic Systems in the USA who manufacture portable solar panels ideally suited for our needs. They were very generous and very supportive and kindly donated two Arc 20W solar charging kits and a V44 USB battery. This proved more than enough and with the 24-hour sunlight we successfully managed to keep everyone's batteries topped up with energy.

With our limited time in the field and our plan to reach the caves from the landing strip at Centrum Sø, it was painfully clear that photographic and video equipment had to be reduced down to the very bare minimum. With a 20km lake to cross by boat, followed by a 3-day hike (each way), everything had to be carried on our backs in rucksacks and that included the samples from the caves that we were hoping to find on the return leg. We therefore decided to leave the team's laptop at base camp on the shores of Centrum Sø and rely solely on memory cards to store all the footage. Thankfully the Nikon D810 DSLR that we used as our main operating system has two memory card slots, so we could make two copies of each file; one on the CF and one on the SD card. Getting all this equipment over the lake was relatively easy because we used a Zodiac 3 inflatable boat. However, we still had to keep it all dry. We used portable waterproof plastic barrels that cavers have used for

Mark Wright and Chris Blakeley repair the drone after it crashes into a Danish flag pole.
Robbie Shone

years known as ‘darren drums’. These barrels are suitably shaped to carry inside bags and most of all they are lightweight, especially compared to their competition, the Peli Case.

On the drone’s first flight close to the end of the landing strip next to Centrum Sø, we managed to fly it straight into the Danish flagpole. Even though the on board display said that the built-in GPS system had successfully locked on to 8-11 satellites, there was still a time shortly after initial take-off where the drone had a mind of its own and flew around before we gained complete control. This was extremely worrying and was the case on every flight we had with it. Unfortunately the gimbal took the main impact and as a result of this the horizon line in the frame appeared slightly slanted. Thankfully it could be straightened with the aid of a pair of pliers, a leatherman multi tool, and three patient pairs of hands.

Unfortunately, after the efforts to fix it, it was decided that the aerial drone would be left behind at base camp as it was big and cumbersome and only added to the already monstrous hike. We thought the best and most photogenic shots gained from the drone would be around the lake and Vandredalen (valley) anyway, which we could make on our return.

Once the team had setup camp at the mouth of Grottedalen and blessed with good weather, the solar panel kits were laid out on the soft spongy floor absorbing all the rays from the 24-hour sunshine, whilst the team headed off to explore the caves. We tried to maximise our time here by shooting stills and video footage together, one after the other. Thankfully the caves were not too big and mainly always within sight of daylight, which played into the hands when shooting video. Without the drone batteries and the LCD portable screen to re-charge, the Voltaic solar kits were never stressed and easily managed

Robbie Shone sorts through his camera gear.
Gina Moseley

to re-charge the remaining few batteries

For the stills, we shot every photograph in RAW format and each file was processed to each of the two memory cards inside the camera. The storage in the memory cards was plentiful and we never reached the limit.

For the video footage on the DSLR, we shot in 1080 HD and used a Røde shotgun mic the majority of the time, picking up general sounds and any voices in conversation. When I performed more formal interviews, I used a Hama lapel mic.

We shot the aerial drone footage on a GoPro at 2.7k at 25 frames per second.

To conclude, we got lucky with the weather! Without constant 24-hour blue skies and bright sunshine we would have struggled to re-charge all the batteries we needed to. Astonishing really. After all, this is the Arctic!

Photographic equipment list

Nikon D810 DSLR camera
Nikon D800 DSLR camera
Nikon 16-35mm F4 lens
Nikon 24-70mm F2.8 lens
Nikon 60mm MACRO F2.8 lens
3 Legged Thing BRIAN portable travel tripod with Acratech tripod head
5x Nikon DSLR camera batteries
4x Motorola PMR walkie talkie radios
2x LED panels
3x Sunpak 120J flashgun/Strobe
5x Pocket Wizard Plus II radios
Portable Røde shotgun hotshoe microphone
Hama lapel microphone on a 6m cable.
GoPro Hero 4 camera
DJI Phantom 2 aerial drone
2x Lexar Professional 128gb CF memory cards
2x Lexar Professional 128gb SD memory cards
2x Lexar Professional 64gb CF memory cards
2x Lexar Professional 64gb SD memory cards
1x Lexar Professional 64gb Micro memory card (Go Pro)

Medical, Hygiene and Safety

Thankfully, injuries and health issues were relatively minor, and besides a little weight loss the team all came back in one piece.

Prior to the expedition, the Danish authorities required insurance coverage to be in place for Search and Rescue at a level of 1,000,000 Danish Krona, and personal/medical/repatriation cover at a level of 280,000 DKK per person. CASP kindly allowed the team to be included on their insurance. In addition, Mark Wright, Robbie Shone and Gina Moseley all attended a polar bear defence training course in the UK. Christoph Spötl had previously attended such a course in Svalbard.

During the expedition, calls were made daily to Clive Johnson on the sat phone at 7pm. In the event that contact could not be made, a back-up call time of 7am was also arranged. SMS messages were also sent relatively frequently back to the UK for social media purposes, and had the advantage of keeping the team in touch with additional people.

Minor medical issues. *Top & middle: Robbie Shone. Bottom : Gina Moseley*

All team members were first aid qualified to varying degrees and several first aid kits were taken so that in the event that the group split, each sub-team could carry a first aid kit. Two satellite phones were also carried so that each sub-team could call for emergency if needed, and walkie talkies were carried for communication between sub-teams. Each first aid kit contained a list of medical conditions, allergies, current medication, blood-type (where known) and emergency contact details for each person. In case of an attack, a .308 calibre rifle and pencils flares were carried.

Several members of the team suffered from minor medical issues during the course of the expedition. After three days of hiking with heavy bags, Mark's ankle started to become painful, though there were no visible marks or swelling on the surface. Chris applied a doughnut bandage to the area to help relieve pressure from the inner boot cuff and this helped but didn't completely solve the problem. Gina also suffered from mosquito bites. Despite wearing long-sleeve clothing and using 100% Deet, she was severely bitten. After two days of hiking, 223 bites were counted on her left arm alone. She treated the bites with Insecticum and made a conscious effort not to scratch them. In the final days of the expedition, Robbie's hand also became swollen and itchy. The reason for the reaction was never found, but it was treated with antihistamine, regular washing, and changing to another base-layer top.

In terms of hygiene, each camp had a designated toilet area that was built at a safe distance from the camp. Toilet waste was burned during each visit and hand sanitizer was used to kill germs. Nobody on the team became ill during the expedition.

Food Rations

Gina and Christoph sort through the remaining rations back at base camp. *Robbie Shone*

The expedition used four 20 man-day sledge boxes of food rations each containing:

20 Assorted freeze dried meals.
20 Sachets Alpen cereal.
1 500 g bag of quick oats.
40 Sachets coffee.
80 Tea bags.
1 Bag of assorted condiments.
1 Pack of potato powder.
1 Bag of dried onion slices.
1 Tin of freeze dried garden peas.
1 Tin of freeze dried sweet corn.
1 Tin of Spam.
15 Twin packs of biscuits.
2 400 g tins full cream milk powder.
20 110 g bars of chocolate.
4 500 g tins of butter.
2 Tins of processed cheese.
2 Packs of boil-in-the-bag rice
20 Assorted sachets of cuppa soup.
2 500 g packs of cube sugar.
1 250 g jar of Marmite.

Meatballs and beans, 60 years out-of-date, being warmed up on the stove.
Chris Blakeley

Public Outreach

The Project has been involved in a number of public outreach activities in order to educate people about the science, the expedition, and most importantly the wider issues of climate change. These outreach activities include:

- Website: northeastgreenlandcavesproject.com
- Instagram: instagram.com/negreenland_caves/ (16.8.16 – 22,300 followers)
- Facebook: facebook.com/NortheastGreenlandCavesProject (16.8.16 - 965 followers)
- Twitter: twitter.com/Greenland_Caves (16.8.16 – 1,102 followers)
- Crowdfunding campaign: http://northeastgreenlandcavesproject.com/crowdfunding/
- Promotional film (premiered at Kendal Mountain Film Festival; youtu.be/849WXWQiyds)

In the media:

- BBC Radio 3 Cornerstones Lecture Series – Aired 9.12.15 (tinyurl.com/j74dzwg)
- National Geographic News: English (tinyurl.com/qzn6mkz); Spanish (tinyurl.com/jp8fpmj)
- National Geographic Best Job Ever (https://youtu.be/ZQxoCBdK0m4)
- National Geographic Food Blog (tinyurl.com/jn44aw9)
- Outdoor Women's Alliance pre-expedition article (tinyurl.com/jnmhzgz)
- Outdoor Women's Alliance post-expedition article (tinyurl.com/jfdrujg)
- Science Nordic (http://tinyurl.com/zzw47vl)
- Adam Hartland's Blog
- Newspapers – Der Standard; Bezirks Blätter; Buxton Advertiser; Northwich Guardian; Cannock Chronicle; Express & Star

Lectures and presentations:

- Irish Union of Speleology Conference (29.10.2016)
- Combined Services Caving Club AGM (12.03.2016)
- Wilderness Lecture Series (17.02.2016)
- CASP (12.11.2015)
- Downend Air Training Corps (28.09.2015)
- Hidden Earth (27.09.2015)
- Lake Fellowship of Unitarian Universalists (24.01.2016; 18.01.2015)

Conference attendance:

- EGU General Assembly (April, 2016)
- Comer Abrupt Climate Change Conference (October, 2015)

Papers (Non-peer reviewed)

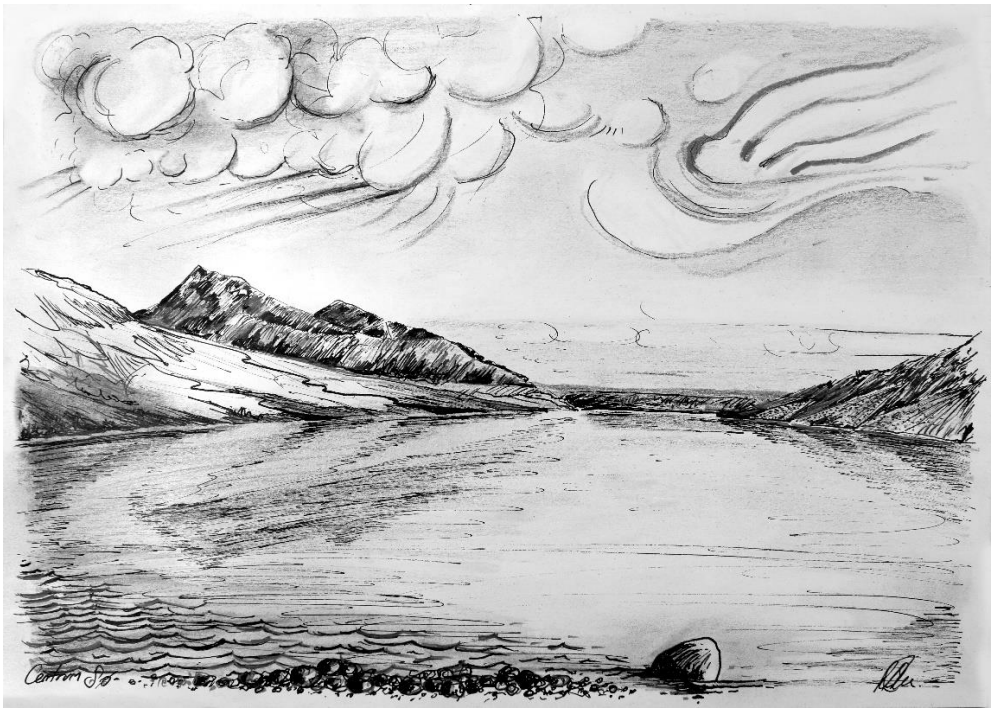
- Moseley, G.E., Lawrence Edwards, R.L., Cheng, H., Spötl, C. 2016. Northeast Greenland Caves Project: Constructing a speleothem-derived record of climate change for the Arctic. *Quaternary Newsletter 139*, 35-38.

Acknowledgements

The members of the Northeast Greenland Caves Project are extremely grateful for all of the wonderful support that they have received from all around the world. In particular, we would like to thank all of those who have offered us advice, scientific support, logistical support, and sponsored us, without you, the expedition and the project would never have happened.

Project and Expedition Support

Clive Johnson – Polarsphere, logistics organiser
Prof. Paul Smith – Museum of Natural History, University of Oxford, previous visitor to the caves
Jean-François Loubiere – Leader of the 1983 expedition, previous visitor to the caves
Charlie Self – Knowledge and literature on Greenland caves
CASP – Logistical support
Captain Jan Lyngsø Jensen – Operations & Logistics Division
Master Sergeant Kim Hansen – Arctic command
Ground staff at Mestersvig and Danmarkshavn - Logistical support
Prof. Larry Edwards – University of Minnesota, U-Th dating support
Prof. Hai Cheng – University of Minnesota and Xi'an Jiaotong University, U-Th dating support
Prof. Christoph Spötl – University of Innsbruck, stable-isotope analysis
Prof. Brigitta Erschbamer – University of Innsbruck, flora identification
Dr. Daniela Festi – University of Innsbruck, pollen analysis
Dr. Irka Hajdas – ETH Zurich, radiocarbon dating
Dr. Andy Harp – First aid and medical advice
Dr. Olivier Gilg – Dead bird identification, Groupe de Recherche en Ecologie Arctique, France
Dr. Iva Stiperski – University of Innsbruck, loan of the Kestrel 4500 Pocket Weather Meter
Dr. Yanbin Lu - University of Minnesota, U-Th dating support
Charlie Boscoe – Short film editorial advice
Andy Eavis – Loan of the satellite phone



Field sketch by Robbie Shone looking across Centrum Sø from base camp.

Financial Sponsors

University of Minnesota
Xi'an Jiaotong University
National Geographic Society
University of Innsbruck Nachwuchsförderung
Comer Family Foundation
Petzl Foundation
Phil & Lin Shone
Innsbruck Quaternary Research Group
Go Balance *(formerly Celestial Green Ventures)*
Gina Moseley
Mount Everest Foundation
Austrian Academy of Sciences
British Cave Research Association
Transglobe Expedition Trust
Robbie Shone
Sue & Pete Moseley
National Speleological Society
Quaternary Research Association
Wilderness Lectures
Ghar Parau Foundation
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Chris Blakeley
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Easyfundraising
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Jonathan Vetterlein
Amy Hinkle
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Kate Newton
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Per Ellingson
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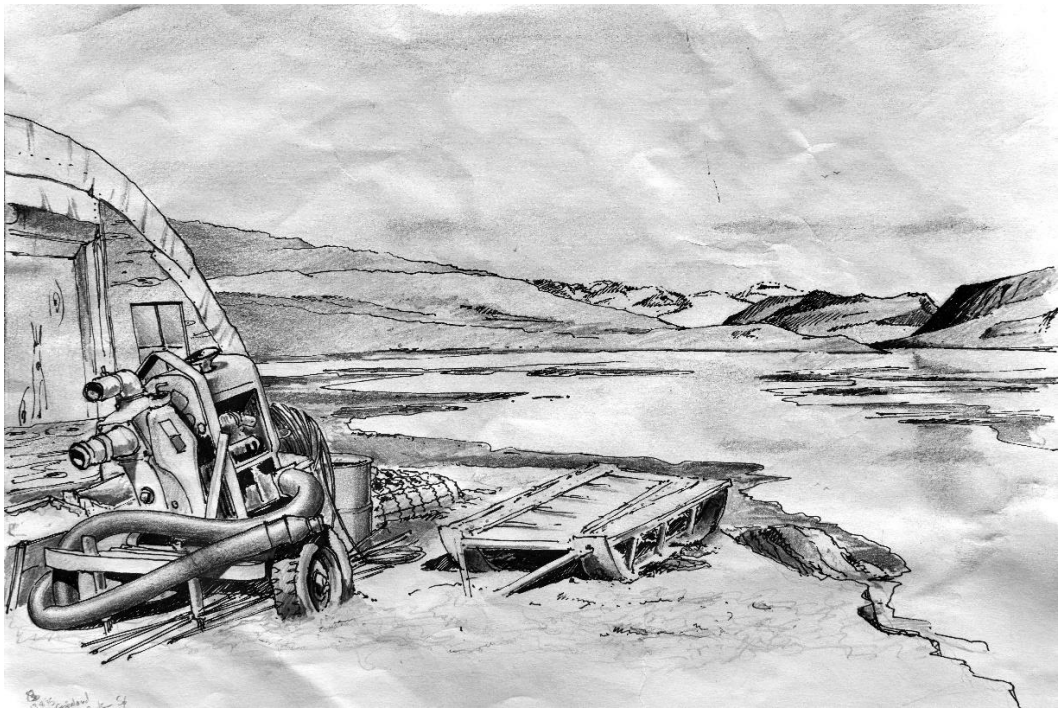
Gouffre Berger Book Project



Field sketch by Chris Blakeley looking across Centrum Sø from the landing strip.

Equipment Sponsors

Bellroy

5x Elements Pocket wallet *(for use in fundraising)*

FIA Formula E Championship

The FIA Formula E Championship kindly donated two 2015 Monaco ePrix exclusive hospitality tickets to the Project for use in fundraising. Unfortunately, we could not find anyone interested in giving us a donation in exchange for the tickets, consequently they were returned to the FIA.

Joe Immen

Logo design

Hilti Austria

1x TE 4-A22 cordless rotary hammer drill
3x batteries

Thomas Arbenz, Netopyr Products

1x Megha bag

Ortlieb

1x 5L folding bowl
1x 10L folding bowl
4x 42L short dry bag liner PS10
4x 75L long dry bag liner PS10
1x PS10 compression dry bag with valve and belt
1x 40L duffle bag
1x A5 document bag
5x Ortlieb multi-function buff
1x Ortlieb t-shirt M
4x Ortlieb t-shirt L
5x Ortlieb catalogues
1x T-Pack
3x 10L water sack

Red Bull

48x cans of Red Bull
(for use in fundraising)

Petzl

5x SIROCCO helmets
5x TIKKA RXP headlights
15x ACCU RXP batteries
4x pairs of CORDEX gloves
2x 30l PORTAGE sacks
1x 45l TRANSPORT sack
2x DUAL CONNECT ADJUST lanyards
4x SPIRIT SCREW-LOCK carabiners
1x PUSH 9mm x 100m low stretch rope
20x ANGE S carabiners
20x 120cm slings
15x anchors and alloy hangers

Scanlico Denmark

5x merino wool Buffs

Suunto

Suunto KB-14/360R DG compass
Suunto PM-5/360 PC clinometer

Swarovski Optik

1x CL Pocket 8x25 B binoculars

Virgin Balloon Flights

2x pairs of Virgin Balloon Flights National 7 Day Anytime Vouchers
(for use in fundraising)

Voltaic

2x Arc 20W solar charger kit
1x Arc 7W solar charger kit

Carbon Footprint

Pre-expedition		***t CO_2***
Polar bear defence	Return train, Innsbruck-Munich, GM, RS	0.000*
Polar bear defence	Return flight, Munich-Manchester, GM, RS	0.987
Polar bear defence	Single small car, petrol, Manchester to Mildenhall, GM, RS	0.064
Paul Smith meeting	Single small car, petrol, Mildenhall to Oxford, GM, RS	0.034
Polar bear defence	Single small car, petrol, Oxford to Manchester, GM, RS	0.048
Polar bear defence	Return minivan, diesel, Oughtibridge to Mildenhall, MW	0.208

Expedition

Single small car, petrol, Theys to Nantes, CB	0.163
Single flight, Nantes-Manchester, CB	0.178
Single train, Manchester-Oughtibridge, CB	0.000*
Return small car, petrol, Oughtibridge-Manchester, CB, MW	0.028
Return flight, Manchester-Keflavik, CB, MW	1.338
Bus, Keflavik-Reykjavik, CB, MW	0.010*
Return minivan, diesel, Innsbruck-Munich, GM, RS	0.173
Return minivan, diesel, Kolsassberg-Munich, CS	0.163
Single flight, Munich-Stockholm-Keflavik, GM, RS, CS	2.111
Single flight, Keflavik-Copenhagen-Munich, GM, RS, CS	1.872
Single small car, petrol, Keflavik-Reykjavik, GM, RS, CS	0.010
Return flight, Reykjavik-Akureyri, All	1.100
Single minivan, diesel, Akureyri airport-Gula Vilan, All	0.002
Single small car, petrol, Gula Vilan- Akureyri airport, GM, RS, CB	0.001
Single small car, petrol, Gula Vilan- Akureyri airport, MW, CS	0.001
Single flight, Akureyri-Constable Point, All	0.819
Single flight, Constable Point-Mestersvig, All	0.230**
Single flight, Mestersvig-Danmarkshavn, All	0.400**
Single flight, Danmarkshavn-Centrum Sø, All	0.870**
Single flight, Centrum Sø-Mestersvig, All	1.210**
Single flight, Mestersvig-Akureyri, All	1.050**
Single small car, petrol, Akureyri airport-Hotel Kjarnalunder, GM, RS, CB	0.001
Single small car, petrol, Akureyri airport-Hotel Kjarnalunder, MW, CS	0.001
Single minivan, diesel, Hotel Kjarnalunder-Akureyri airport, All	0.001
Single minivan, diesel, Reykjavik airport-Hotel Cabin, All	0.002
Single small car, petrol, Hotel Cabin to Keflavik airport, CB, MW	0.010
Single small car, petrol, Hotel Cabin to Keflavik airport, GM, RS, CS	0.010
Single small car, petrol, Manchester-Theys, CB	0.277
Single small car, petrol, Manchester-Oughtibridge, MW	0.028

Post-expedition

Hidden Earth/ATC	Return flight, Innsbruck-Gatwick, GM	0.435
Hidden Earth/ATC	Small car, petrol, Gatwick - Churchill-Filton-Gatwick, GM	0.095
Comer Meeting	Return flight, Innsbruck-Frankfurt, GM	0.257
Comer Meeting	Return flight, Frankfurt-Chicago-Madison, GM	2.795
KMF	Return flight, Innsbruck-Frankfurt-Manchester, RS	0.658
KMF	Small car, electric, Manchester-Kendal-Manchester, RS	0.042
CASP	Return minivan, diesel, Innsbruck-Munich, GM	0.173
CASP	Single flight, Munich-Luton, GM	0.219
CASP	Single flight, Manchester-Munich, GM	0.247
LW/LFUU/WA	Return flight, Innsbruck-Gatwick, GM	0.435
LW/LFUU/WA	Return flight, Heathrow-Minneapolis, GM	2.395
CSCA	Single flight, Innsbruck-Gatwick, GM	0.217
CSCA	Single flight, Bristol-Innsbruck, GM	0.245
EGU	Return train, Innsbruck-Vienna, GM	0.000*
LW	Return flight, Innsbruck-Frankfurt, GM	0.257
LW	Return flight, Frankfurt-Chicago Minneapolis, GM	2.907
LW	Return flight, Innsbruck-Frankfurt, GM	0.257
LW	Return flight, Frankfurt-Chicago Minneapolis, GM	2.907
LW	Return flight, Innsbruck-Frankfurt, GM	0.257
LW	Return flight, Frankfurt-Chicago Minneapolis, GM	2.907
Total		**31.105**

CB – Chris Blakeley; CS – Christoph Spötl; GM – Gina Moseley; MW – Mark Wright; RS – Robbie Shone

ATC – Air Training Corps; CSCA – Combined Services Caving Association; EGU – European Geosciences Union General Assembly; KMF – Kendal Mountain Festival; LFUU – Lake Fellowship Unitarian Universalists; LW – Lab Work, Minnesota; WA – Wilderness Award

All calculated using myclimate.org carbon footprint calculator, with the exception of activities marked *, which were calculated using carbonfootprint.com. ** denotes that the carbon footprint has been calculated using 0.0014 t km^{-1} based on the Akureyri-Constable Point (600 km) footprint of 0.819 t.

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The Old Printworks, Suite 29, Commercial Road, Eastbourne, East Sussex, BN21 3XQ, England
www.go-balance.com
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+44 (0)208 123 3479

Dr Gina Moseley
Northeast Greenland Caves Project
Institute of Geology
University of Innsbruck
Austria

8th August 2016

Dear Gina,

I am pleased to hereby confirm that Go Balance Ltd have retired 35 Natural Capital to fully offset the calculated carbon footprint of the Northeast Greenland Caves Project carried out in July-August 2015.

The details of the retirement are as follows:

Retirement Date:	08/08/2016
Project Name:	Trocano Araretama REDD+ Project
Project Location:	Municipality of Borba, Amazonas, Brazil
Number of NCCs Retired:	35
Transaction Reference:	e902debf-f51c-4794-9c13-fb75cb1c620

I would like to also take this opportunity to congratulate you and your team on success of this expedition and I wish you all the best for your future endeavours.

Yours sincerely,

Ciaran Kelly
Director, Go Balance Ltd

Finances

Expedition Costs (Outgoing)

Exchange rate used: 1 EUR = 0.749 GBP	**GBP**
Transport	62,712
Accommodation	1,608
Freight & excess baggage	477
Equipment	3,269
Food	1,600
Logistics and administration	13,389
Sat phone rentals and calls	492
Polar bear defence	1,118
Search and rescue insurance	1,060
Radio licence	30
Total	**85,755 GBP**

Expedition Sponsorship (Incoming)

Austrian Academy of Sciences	5,000 EUR
BBC Radio 3 Essay Fee	450 GBP
Bellroy Wallets	39 GBP
British Cave Research Association	2,160 GBP
Comer Family Foundation	14,000 USD
Easyfundraising	87 GBP
Ghar Parau Foundation	600 GBP
Go Balance (formerly Celestial Green Ventures)	3,000 GBP
Interest	92 GBP
Lake Fellowship Speakers Fee	250 USD
Mount Everest Foundation	2,700 GBP
National Geographic Society	20,000 USD
Neotypr. Products of Switzerland	100 GBP
National Speleological Society	1,400 USD
Petzl Foundation	8,000 EUR
Private Sponsorship	11,333 GBP
Quaternary Research Association	700 GBP
Red Bull Drinks	50 EUR
Transglobe Expedition Trust	2,000 GBP
UIBK Nachwuchsförderung	15,000 EUR
UIBK Quaternary Research Group	4,916 EUR
University of Minnesota	25,000 USD
Wilderness Award	650 GBP

Additional Project Costs

Radiocarbon dating of bird bone*	350 EUR
Website running costs (Jul 14 – Sept 16)	157 EUR + 83 GBP
Logo design	8 GBP
Advertising	47 GBP
Business cards	21 GBP
Photographic prints	7 GBP
Expedition T-shirts	172 GBP
Expedition Report Printing**	434 GBP
ISBNs	180 EUR

*Funded by the Austrian Academy of Sciences. **Funded by the Innsbruck Quaternary Research Group. All other costs paid privately by GM & RS

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