Preliminary Expedition Report of the Northeast Greenland Caves Project

26th July to 18th August, 2015

Scientific Background and Rationale

Multiple lines of evidence currently exist that demonstrate the climate is changing across our planet (Cubasch et al., 2013). Understanding how the climate will develop in the future and its subsequent effects is thus a major concern. One way of trying to predict what scenarios are possible in a future warmer climate is to use palaeoclimate records from past periods of warmer climate in order to improve understanding of the Earth's response to changes in atmospheric composition and external forcings. Some of the highest quality palaeoclimate records are available from the Greenland ice cores, and our understanding of climate has been revolutionised by drilling into these high-latitude ice sheets (e.g., Johnson et al., 1992; Alley et al., 1993; Dansgaard et al., 1993; Grootes et al., 1993; Obrien et al., 1995; Johnsen et al., 2001). 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 (Bekryaev et al., 2010). This is of major concern because future warming will likely have drastic consequences for ice-sheet stability, global sea levels and carbon-cycle feedbacks. One of the limitations of the Greenland ice-core records is that the high-quality continuous record is limited to the final stages of the last interglacial (123 ka, NGRIP ice core)(NGRIP project members, 2004). The NEEM ice core extends to the early stages of the last interglacial(128.5 ka, NEEM Community members, 2013), but the basal ice is folded and incomplete, making stratigraphic interpretation difficult. Other palaeoclimate archives of long duration that capture previous interglacials do exist from other regions, however, such records often display poor chronological control, and either contain numerous hiatuses, or are continuous but orbitally tuned. In order to facilitate understanding of how the present interglacial may develop, the requirement for good-quality independently-dated palaeoclimate records from past naturally forced interglacials is becoming increasingly important.

Main 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 stable-isotope palaeoclimate record for Greenland. It is expected that the new record will be older than the 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.

Strategy and Goals

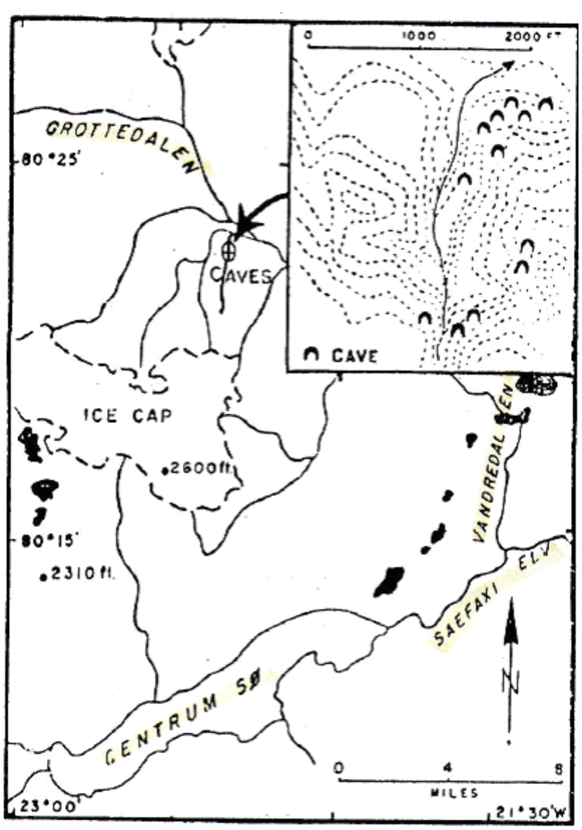
The strategy for this project involves: 1. visiting known speleothem sites in Northeast Greenland, and searching for new sites in the large Centrum limestone massif in cooperation with CASP of Cambridge University, UK; 2. sampling of speleothems in a conservative manner so as to cause minimal damage; 3. production of the first radiometrically-dated speleothem archive for Greenland using either U/Th analyses, or U/Pb analyses at the University of Minnesota, USA; 4. high-resolution stable-isotope analysis for palaeoclimate reconstruction at the University of Innsbruck (UIBK), Austria; 5. establishment of independent chronologies based on lamina counting at UIBK; 6. interpretation of results in cooperation with the Centre for Ice and Climate, University of Copenhagen, Denmark; 7. dissemination of the results of the project.

Caves

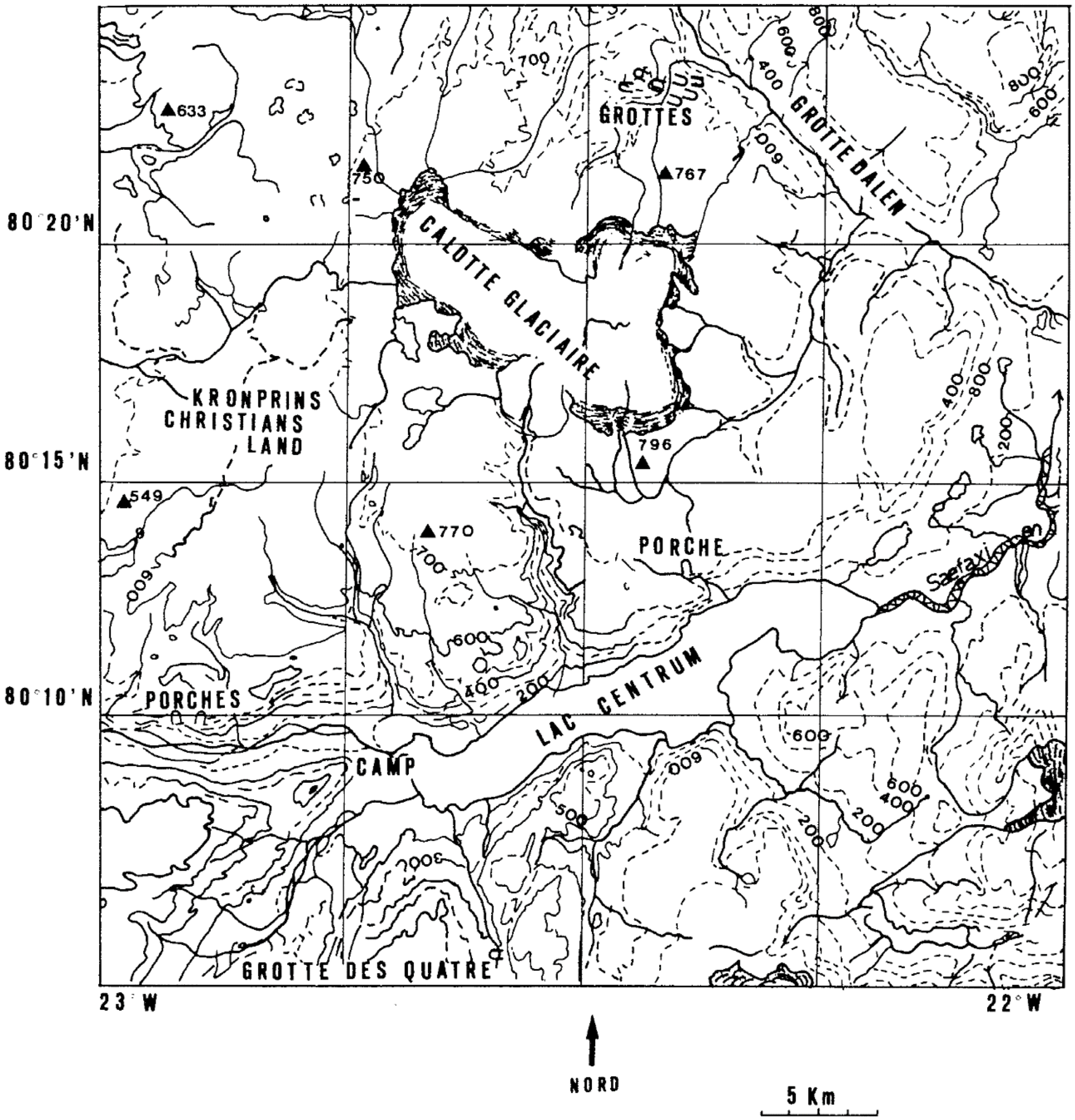
Solutionally-formed caves (80°24’ N, 21°56’ W) at three elevations (490-520, 610-625, and 670 m asl) were first discovered in the Ordovician-Silurian Centrum limestone of Kronprins Christian Land, Northeast Greenland, in 1960 by William E. Davies and Daniel B. Krinsley of the US Geological Survey (Davies and Krinsley, 1960). Davies and Krinsley discovered 12 caves on 29th June, 1960, in a north-south tributary valley to the larger northwest-southeast trending Grottedalen valley. In 1960 and the late 1980s, the caves terminated in cave infill and ice crystals (Davies and Krinsley, 1960; Loubiere, 1987). The cave infill was best exposed in the singular mid-level cave of the west wall, and was present as a 2-m thick orange-yellow silt that was capped by a 10-cm thick coarsely crystalline calcite flowstone. In addition, stalagmite stubs up to 3-cm high were documented as being present on top of the flowstone, and also on the floor of the cave (Davies and Krinsley, 1960). Speleothems have since been reported from at least three caves in the area (Davies and Krinsley, 1960; Loubiere, 1987). The presence of these caves in the currently arid (<250 mm a^{-1}), permanently frozen Northeast Greenland, indicates extensive limestone dissolution has previously occurred. The deposition of a thick flowstone cap, thus requiring groundwater, indicates a previous warmer and milder climate.

According to Davies and Krinsley (1060), Grottedalen is c. 1km (3000 ft) wide, 450-600 m (1500-2000 ft) deep near the caves, and is floored with morainal deposits. The walls are steep with the lower 150 m (500 ft) comprising moraine and talus, whilst the upper parts consist of Ordovician-Silurian limestone and form a steep cliff along the face of the plateau. The plateau is 640-730 m asl (2100 to 2400 ft asl), whilst the thickness of the limestone is c. 2300 m (7500 ft). 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.

The valley of the caves runs north-south off the southern side of Grottedalen. The valley is c.1 km (3000 ft) in length, 60-150 m (200-500 ft) wide at its mouth, and 450 m (1500 ft) deep. There are 11 caves along the east wall and, 1 cave in the west wall. The passages are 5-12 m wide (15-40 ft), and 10 to 60 m in length. The largest cave (12m wide x 12 m high) is on the east side of the valley at the north end, at 610 m asl (2000 ft). It is U-shaped with 2 openings and according to Loubiere (personal communication), contains speleothem deposits, though not in their original position. This is the best documented of the caves. The lower caves are partly filled with glacial moraine, whilst the upper two levels do not contain moraine and are blocked by cave fill and ice crystals.



Map of Grottedalen and the caves from Davies and Krinsley, (1960)



Map of Grottedalen and the caves from Loubiere (1987)

Expedition

The main objective of the expedition was to collect speleothem samples from known cave sites in Northeast Greenland. Secondary to the speleothem collection, we attempted to document the caves through surveying and photography, and aimed to explore new cave sites where possible.

Team members and their primary roles

Scientific work – Gina Moseley, Christoph Spötl
Expedition documentation and public outreach – Robbie Shone
Support team - Chris Blakeley, Mark Wright
Remote logistics organisation – Clive Johnson

Advice collected from:

- Clive Johnson (Polar logistics organiser and leader of many expeditions to Greenland);
- Prof. Paul Smith (Head of the Museum of Natural History, University of Oxford. He has been on several geological mapping campaigns in Kronprins Christian Land and published papers about the geology)
- Jean-Paul Loubiere (Leader of the French 1983 expedition)

Brief Expedition Diary

26th July 2015

The team members travelled from their respective homes to Akureyri, Iceland.

27th July 2015

The team flew from Akureyri, Iceland, to Constable Point and then Mestersvig, Greenland. They began sorting out equipment with Clive Johnson.

28th July 2015

The team continued to sort and pack equipment. During the evening, Gina gave a talk to the personnel working on the base about the project.

29th July 2015

The team flew to Danmarkshaven for refuelling and then onto Centrum Sø. After a few problems with the boat and shallow water, the team decided to spend the night at the end of the landing strip. A (long) dead polar bear was also found nearby.

30th July 2015

The team crossed Centrum Sø with no further difficulties. Gina, Robbie and Christoph set up base camp on the eastern shore, whilst Mark and Chris did a further shuttle run across the lake to collect the remaining equipment.

31st July 2015

The team began the hike to the caves. After 11 km, the team deposited some kit. Gina, Robbie and Christoph continued to 20 km and set up an intermediate camp. Mark and Chris went back to base camp at Centrum Sø to collect the remaining equipment.

1st August 2015

Gina, Robbie and Christoph returned to the kit drop at 11 km from base camp. There they met a musk ox. Mark and Chris walked up to the kit drop with the remaining equipment. Equipment loads were shared out and all five team members continued to the 20 km camp.

2nd August 2015

The whole team continued to the caves where another camp was established. It took the majority of the day to reach the caves due to some navigational issues.


3rd August 2015

Mark and Chris did the final shuttle run to the 20 km camp and back to the caves camp. Gina, Robbie and Christoph began looking at the caves in the east wall. A few calcite samples were collected and many more were observed. Some water and sediment was also collected.

4th August 2015

Mark, Chris and Robbie explored, mapped and documented the most northerly caves on the east wall. Chris climbed up into a large entrance but found a cairn inside the passage, possibly from the French team in 1983. Some other smaller caves were entered that were further north. Perhaps these are the most northerly explored caves on the planet? Gina and Christoph worked in the few caves on the west wall, and collected further samples. They later moved to the east wall to join the other team members in exploring the high-level caves that we believe no one had entered before.


5th August 2015

The team explored the high-level caves in the west wall. A large dead bird was found frozen into the ice. Samples of bone and feather were taken for radiocarbon dating. Christoph explored the top of the plateau. We also discovered a note in an old Kodak film box written by the original explorers.

6th August 2015

Mark, Chris and Christoph did a shuttle run in the morning to the 20 km camp, whilst Robbie and Gina took some photographs of important sampling sites. During the evening, all team members were at the 20 km camp.

7th August 2015

The whole team walked about 10 km together and stored some equipment at “erratic rock”. Mark and Chris returned to the 20 km camp. Gina, Robbie and Christoph continued to base camp at Centrum Sø.

8th August 2015

The team met again at the equipment store and returned together to Centrum Sø.

9th August 2015

The team had a well-earned rest day.

10th August 2015

The team took the boat out to look for caves in the cliffs running along the northern side of the lake.

11th August 2015

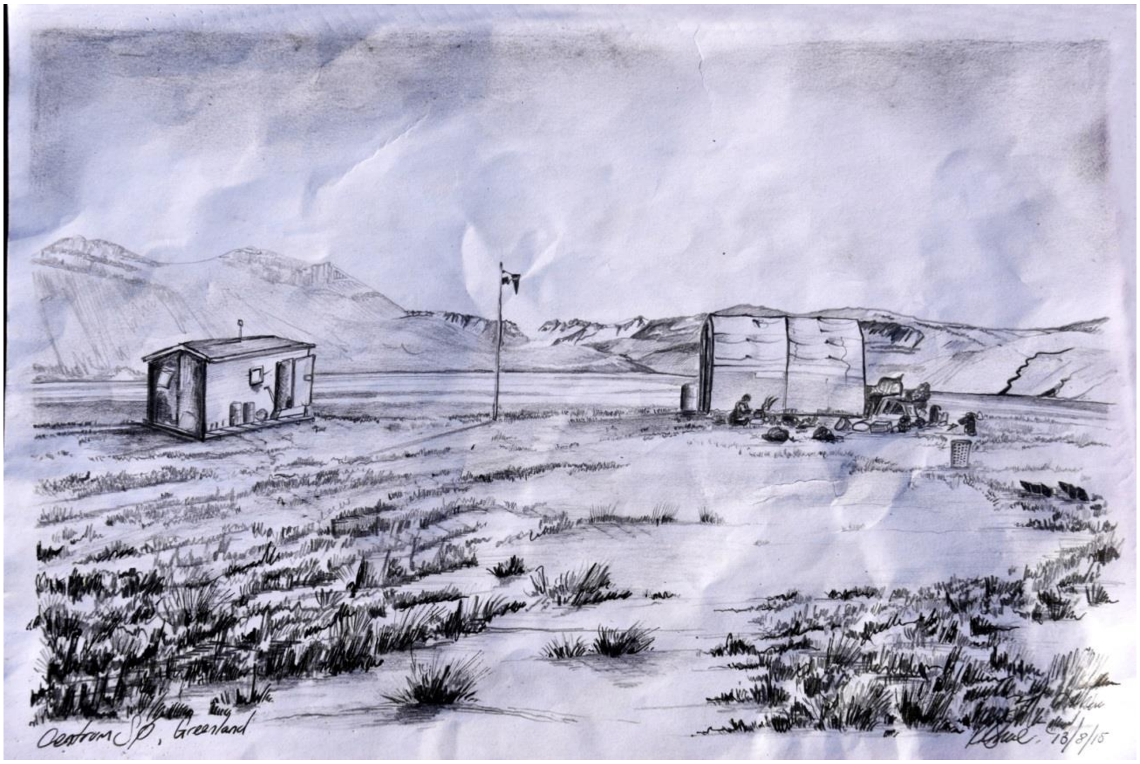
Christoph went on a hike up a nearby hill to look at the geology. Gina, Robbie, Mark and Chris went out in the boat to look for the “porche” discovered by the French team in 1983. No caves were found, but later that night at base camp, Chris discovered a US army ration pack with a best before date of 1955. We opened some tins and they tasted great!

12th August 2015

We were told that the plane would likely come and collect us the next day. We decamped and then took the boat out towards the far eastern end of the lake where we found lake sediments up to 30 m higher than the lake. We spent the remainder of the day moving camp to the end of the landing strip on the western end of the lake.

13th August 2015

At 11 am, we received the word that the plane could not reach us. Due to bad weather along the east coast, it was not capable of taking off, or refuelling along the way. Christoph went for a hike up the nearby hill, whilst the rest of us kept ourselves busy at the end of the airstrip.



14th August 2015

The plane arrived around 2.45pm and was refuelled by hand. We left Centrum Sø around 4.15pm. The equipment that had been rented from CASP was returned to Mestersvig, and then the whole team carried on to Akureyri in Iceland, arriving around midnight.

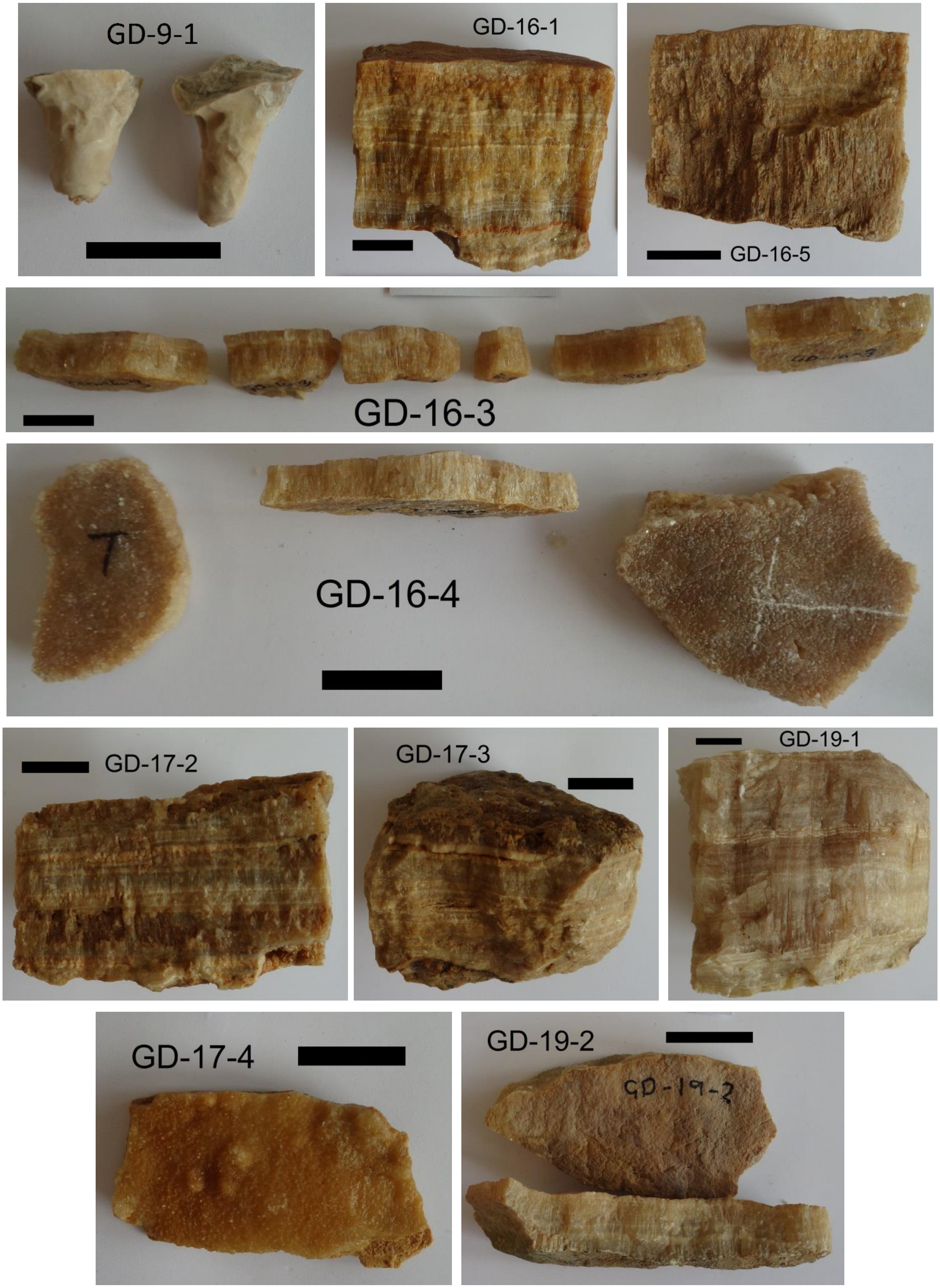
Caves and samples

Originally our plan was to identify each cave by code, rather than by name. We made this decision because we felt it inappropriate to subsequently name caves that other people had discovered. However, we found far more caves than we ever expected to, and for the sake of clarity, gave the caves names based on recognisable features.

The Davies and Krinsley (1960) paper referred to one c. 10cm thick flowstone sequence above a c. 2m thick sediment sequence. It was because of this discovery that our expedition took place. Again, in this very arid environment we did not expect to find all that many more samples. We were very pleasantly surprised and found far more calcite deposits than we ever expected to. In the end the samples we took represented a wide cross-section of the material available.

Code	Name	Latitude / Longitude	Speleothem	Water	Sediment	Bone	Feather
GD-1	River Ice Cave	80.37984 N, 21.73594 W	X	GD1	X	X	X
GD-2	The Tube (South)	80.37881 N, 21.72641 W	GD-2-1	X	GD-2-2	X	X
GD-3	The Tube (North)	80.37883 N, 21.72596 W	X	X	X	X	X
GD-4	U-Shaped Cave	80.37653 N, 21.73545 W	GD-4-2 GD-4-3	X	GD-4-1	X	X
GD-5	Flowstone Tube	80.37712 N, 21.73484 W	GD-5-1	X	X	X	X
GD-6	Skylight Cave	80.37712 N, 21.72787 W	X	X	X	X	X
GD-7	Bubbly Ice Cave	80.37689 N, 21.47422 W	X	GD-7	X	X	X
GD-8	Main Sampling Cave	80.37767 N, 21.74682 W	GD-8-1	X	X	X	X
GD-9	Canyon Ice Cave	80.37846 N, 21.74943 W	GD-9-1	GD-9	X	X	X
GD-10	Triangle Cave	80.37559 N, 21.73677 W	X	X	X	X	X
GD-11	Multi-level Cave	80.37537 N, 21.73769 W	X	X	X	X	X
GD-12	Lens Shaped Cave right	80.37548 N, 21.73704 W	X	X	X	X	X
GD-13	Lens Shaped Cave left	80.37559 N, 21.73633 W	X	X	X	X	X
GD-14	Thick-Flowstone Corner	80.37572 N, 21.73047 W	X	X	X	X	X
GD-15	My Cave	80.37768 N, 21.70736 W	GD-15-1	X	X	X	X
GD-16		80.37970 N, 21.71346 W	GD-16-1 GD-16-2 GD-16-3 GD-16-4 GD-16-5	X	X	X	X
GD-17	Flowstone Bridge Cave	80.37815 N, 21.70974 W	GD-17-1 GD-17-2 GD-17-3 GD-17-4	X	X	X	X
GD-18	Cairn Climb Cave	80.37906 N, 21.71592 W	X	X	X	X	X
GD-19	Crystal Palace	80.37740 N, 21.72585 W	GD-19-1 GD-19-2	X	X	X	X
GD-20	Dead Bird Cave	80.37719 N, 21.74764 W	X	X	X	GD-20-2	GD-20-1
GD-21	Triplet Cave Arch	80.37689 N, 21.74640 W	X	X	X	X	X
GD-22	Triplet Cave Arch	80.37689 N, 21.74640 W	X	X	X	X	X
GD-23	Triplet Cave Arch	80.37689 N, 21.74640 W	X	X	X	X	X
GD-24		80.37460 N, 21.73559 W	X	X	X	X	X
GD-25		80.37537 N, 21.73947 W	X	X	X	X	X
GD-X	Hypogene Cave	80.37369 N, 21.72854 W	GD-X-1 GD-X-2 GD-X-3	X	X	X	X

Photographs of the cave calcite samples that were collected in Northeast Greenland. Black horizontal scale bars = 2 cm. The first oxygen and carbon samples have been prepared and will be analysed during the week following 26th September, 2015.


GD-9-1
GD-16-1
GD-16-5
GD-16-3
GD-16-4
GD-17-2
GD-17-3
GD-19-1
GD-17-4
GD-19-2

CASP Samples

We were asked by Adam Szulc from CASP to collect some samples of bedrock for him. We 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	

Weather Measurements

Some basic weather measurements were taken once per day using a Kestrel 4500 Pocket Weather Meter. The highest recorded temperature was 18.9 °C at 14.44 on 13th August, 2015 at 80.15099 N, 22.50634 W. The lowest recorded temperature was 6.1 °C at 10.01 on 7th August, 2015 at 80.34111 N, 21.49784 W.

Carbon Footprint

The carbon footprint of the expedition and wider project will be calculated in the coming months and very kindly offset by Celestial Green Ventures.

Future Scientific Analyses

Identification of past intervals of time when Northeast Greenland was significantly warmer that today will be achieved through U-series dating of speleothem growth periods. Initially, we will trial the most modern, state-of-the-art techniques for U-Th dating at the University of Minnesota (Shen et al., 2012; Cheng et al., 2013), where current dating precision is of the order of 2‰. If successful, we will aim for 10-20 ages per 10 cm flowstone core. U-Pb dating of speleothems is still in its infancy, however, the field offers an exciting and promising avenue of research for dating speleothems older than the limit of U-Th methods (c.600 ka). We shall adopt this method if necessary. Ideally, I will continue to undertake this work with the University of Minnesota, where it is currently in development.

Stable-isotopes will be analysed in order to characterise the climate during the former warm period(s). The Innsbruck Quaternary Research Group hosts one of the leading facilities for stable-isotope analysis of speleothems and has the capabilities for high sample through-put (Spötl, 2011). All stable-isotope analyses will be performed here and will be sampled using a micromill at a resolution of 100-250 µm. Preliminary analyses with a resolution of 2-5 mm are currently underway.

$\delta^{18}O$ is the most commonly used proxy for climate change that is analysed in speleothems, and is greatly influenced by the $\delta^{18}O$ composition of the input water (Fairchild and Baker, 2012). $\delta^{18}O$ of precipitation varies as a result of temperature, altitude, latitude, and distance from oceanic source. Ice-core stable-isotope profiles show that throughout the last glacial cycle, the $\delta^{18}O$ of precipitation in Greenland was highly dependent on temperature (e.g., Wolff et al., 2010). If this relationship also existed during the time of speleothem deposition, then the $\delta^{18}O$ of speleothem calcite may be used as a proxy for warming or cooling of the climate in the past.

Variation in $\delta^{13}C$ of the speleothem calcite occurs as a result of soil processes and modification in the cave system. In arid environments, large shifts in the $\delta^{13}C$ of speleothem calcite have been associated with palaeovegetation changes (McDermott, 2004), however, short residence-times mean that cave dripwaters may also retain an element of isotopically heavier atmospheric CO_2. Analysis of $\delta^{13}C$ will hopefully yield information about moisture and palaeovegetation changes.

Expedition Costs

Receipt #	Type	Date	Description	EUR	GBP	Account
			TRAVEL			
1	Shuttle	26.7.15	Innsbruck – Munich (Return) (GM, RS) - 184 EUR		139.47	Greenland
2	Shuttle	26.7.15	Innsbruck – Munich (Return) (CS) - 92 EUR		69.73	Greenland
3	Taxi	26.7.15	Keflavik – Reykjavik (GM, RS, CS) - 13500 ISK		67.22	GM CC
4	Taxi	26.7.15	Akureyri Airport– Gula Vilan Guesthouse (All) – 3000 ISK	22.80		GM Cash
5	Taxi	27.7.15	Gula Vilan Guesthouse - Akureyri Airport – 1900 ISK	14.44		GM Cash
6	Taxi	14.8.15	Akureyri Airport – Hotel-1600 ISK	12.16		GM Cash
7	Taxi	15.8.15	Hotel-Akureyri Airport – 2000 ISK	15.20		GM Cash
8	Taxi	15.8.15	Reykjavik Airport – Hotel Cabin – 3750 ISK	28.50		GM Cash
8a	Taxi	17.8.15	Hotel Cabin – Keflavik airport (GM, RS, CS) – 14750 ISK			GM CC
9	Flight	26.7.15	Munich - Reykjavik (Return)(GM)	799.61		UIBK QRG
10	Flight	26.7.15	Munich - Reykjavik (Return)(RS)	799.61		UIBK QRG
11	Flight	26.7.15	Munich - Reykjavik (Return)(CS)	799.61		UIBK QRG
12	Flight		Munich – Reykjavik flight changes	400.00		CS CC
13	Flight	26.7.15	Manchester – Reykjavik (MW)	255.46		UIBK QRG
14	Flight	14.8.15	Copenhagen – Manchester (MW)	93.98		UIBK QRG
15	Flight	26.7.15	Manchester – Reykjavik (CB)	255.46		UIBK QRG
16	Flight	14.8.15	Copenhagen – Manchester (CB)	93.98		UIBK QRG
17	Flight	14.8.15	Reykjavik – Copenhagen (MW)		195.94	UIBK QRG
18	Flight	14.8.15	Reykjavik – Copenhagen (CB)		195.94	UIBK QRG
19	Flight	14.8.15	Reykjavik – Akureyri (Return)(All)	1295.00		UIBK QRG
20	Flight		Flight change – 6 EUR		4.42	GM CC
21	Flight		Excess baggage (CS, RS) - 32 EUR		23.31	GM CC
22	Flight		Excess baggage (GM) – 24 EUR		17.66	GM CC
23	Flight	17.8.15	Excess baggage (CS, GM)(19600)		97.12	Greenland
24	Flight	16.8.15	Reykjavik-Manchester (CB, MW) – 351.88 EUR		258.93	GM CC
			Travel sub-total	**4885.81**	**1069.74**	

Receipt #	Type	Date	Description	EUR	GBP	Account
			ACCOMMODATION			
25	Akureyri	26.7.15	Gula Vilan Accommodation – 30330 ISK		149.95	Greenland
26	Akureyri	14.8.15	Hotel Kjarnalundur – 61689 ISK		309.88	Greenland
27	Reykjavik	15.8.15	Hotel Cabin – 68214 ISK		342.65	Greenland
28	Reykjavik	16.8.15	Hotel Cabin – 35630 ISK		178.98	Greenland
			Accommodation sub-total		**981.46**	
			MEALS			
29	Meal	26.7.15	Evening meal for team in Akureyri – 21300 ISK		105.31	GM CC
30	Breakfast	27.7.15	Breakfast from bakery – 3349 ISK		16.67	GM CC
31	Snacks	27.7.15	Snacks at airport for team – 1200 ISK	9.12		GM Cash
32	Snacks	27.7.15	Snacks at airport for team – 1000 ISK	7.60		GM Cash
33	Meal	15.8.15	Lunch for team in Reykjavik – 13320 ISK		66.91	GM CC
34	Meal	15.8.15	Evening meal for team in Reykjavik – 21220 ISK		106.59	GM CC
35	Meal	16.8.15	Evening meal for team in Reykjavik – 6460 ISK		32.23	GM CC
			Meals sub-total	**16.72**	**327.71**	
			LOGISTICS			
36	Logistics	24.3.15	Logistics organisation 5503 GBP plus VAT (50% contract)	9,224.20		UIBK NF
36a	Admin	24.3.15	University administration fee	59.48		UIBK NF
37	Logistics	7.7.15	Logistics organisation 3340 GBP plus VAT (30% contract)	5,663.41		UIBK NF
37a	Admin	7.7.15	University administration fee	39.98		UIBK NF
			Logistics sub-total	**14,987.07**		
			EXPEDITION			
Waiting invoice			4x 20-man day sledge boxes		2300.00	
Waiting invoice			Insurance		1000.00	
			Expedition sub-total		**3300.00**	
			Total expenditure so far	**19889.60**	**5678.91**	

EXPEDITION COSTS – Still To Be Paid				
	Description	**EUR**	**GBP**	**Account**
	Freight		1600.00	
	Fuel		500.00	
	Charter flight Greenland*		40000.00	
	Meals at Mestersvig		400.00	
	Equipment rental		4000.00	
	AEY-MVG		3100.00	
	Polar bear defense course		540.00	
	Sat phone rental		695.00	
	Logistics organisation 2200 GBP plus VAT (20% contract)		2640.00	
	Expected expenditure sub-total		**53475.00**	

*As mentioned in the original budget, there was a chance of sharing the charter flight with other passengers. We were successful in achieving this, hence the charter flights were approximately 50% of the cost in the original budget.

Based on the current exchange rate of 1 GBP = 1.4 EUR

Total expenditure so far (GBP)	**5678.91 GBP**
Total expenditure so far (EUR) (19889.60 EUR = 27845.44 GBP)	**27845.44 GBP**
Expected expenditure sub-total (GBP)	**53475.00 GBP**
Total cost of expedition	**86999.35 GBP**

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Kate Newton

Lindsey Nicholson

Phil & Lin Shone

Jonathan Vetterlein

Jeff Wade

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