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Cave discoveries and speleogenetic features in northeast Greenland

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Abstract: Solution caves situated in the Centrumsø region of northeast Greenland (80°N) were first documented in 1960. Since then, there have been three dedicated caving expeditions to the area that have increased the numbers of cave observations and discoveries substantially. Here, the larger caves, as documented by the Greenland Caves Project during 2015 and 2019, are presented, including surveys and summaries of their key features. Additionally, smaller caves and potential leads, as documented during 2019, are also presented.

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Introduction

Twelve caves located in Silurian limestones (Smith and Rasmussen, 2020) of northeast Greenland were first discovered in 1960, c.20km north of Centrumsø, in a 1km-long tributary valley off the larger Grottedal [valley] (Fig.1, GD) (Davies and Krinsley, 1960). The caves were reported as being short (maximum 60m in length), up to 12m in width, and spanned an elevation range of 490 to 670m above sea level (a.s.l.). In 1960, the passages were all blocked by ice or cave fill, and one was found to contain a c.10cm-thick coarsely-crystalline flowstone.During 1983, the first dedicated caving expedition discovered a more substantial cave with four entrances located 8km south of Centrumsø (Fig.1, GDQ) (Loubiere, 1987). Several decades later, in 2015, the first Greenland Caves Project (GCP) expedition visited the Grottedal caves (Moseley, 2016). The expedition relocated a number of the caves discovered in 1960, but logged 26 caves in total. The most recent expedition, in 2019, investigated one more cave at the site of the 1960 caves, plus four caves on the northern side of Grottedal. In addition, two canyons, each containing tens of cave entrances, were discovered.

At present the Grottedal/Centrumsø region is arid, with less than 200mm of precipitation per year. Furthermore, the environment is also largely devoid of soil cover; hence extensive karstification under modern circumstances is not possible. The presence of remnants of large caves clearly indicates that one or more episodes of extensive karstification occurred during the geological past, though dating to ascertain when this happened has not yet taken place. Most of the cave entrances are situated in the walls of steep-sided canyons, where it is clear that valley incision post-dates cave development. Thus, the now-accessible caves are reduced in size in comparison with their former state. Furthermore, the inner parts of the caves are all blocked either by ice or by cave fill, so it is possible that large parts of these caves remain inaccessible. In some cases, the ice plugs were transparent enough to allow ongoing passages to be seen extending into blackness (Barton *et al*., 2020a). Morphologically, the caves are generally horizontal and occur at several distinct elevations. Most caves show phreatic morphologies, though a few also display signs of vadose modification. Additionally, some caves display evidence of local paragenesis, as well as remnants of cupolas and scallops. One or more extensive phase(s) of speleothem deposition has occurred, though the dominant form of modification nowadays is by frost shattering and gelifraction.

Here a summary is given of the known major cave discoveries and speleogenetic features for northeast Greenland (Davies and Krinsley, 1960; Loubiere, 1987; Moseley, 2016; Moseley, 2020a). Details of smaller caves and truncated caves from the 2015 expedition are provided by Moseley (2016), whereas smaller caves from the 2019 expedition are listed in Table 1. Note that the cave names are not approved by the Language Secretariat of Greenland, and Greenlandic translations might also be subject to change. Locations are given as decimal latitude/longitude and whilst elevations were recorded in the field using a GPS, elevations provided here are from the Arctic Digital Elevation Model (DEM) (Porter *et al*., 2018). Surveyed cave lengths are given to the nearest metre.

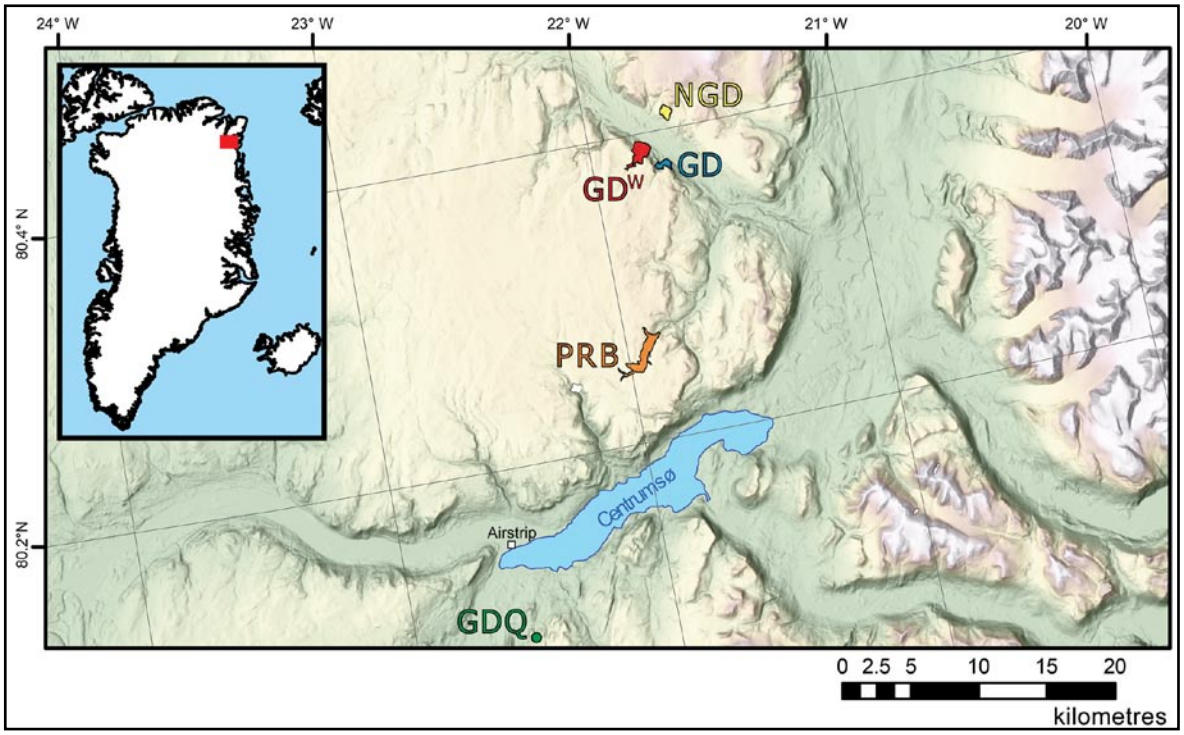

***Figure 1**: Overview map of the locations of the different cave-bearing areas that are discussed in the text.*

GD = *The main focus of the Grottedal cave exploration in 1960 (Davies and Krinsley, 1960).*

GDQ = *Grotte des Quatre.*

GD^{W} = *west canyon on the southern side of Grottedal.*

NGD = *North Grottedal.*

PRB = *PRB Canyon.*

ArcticDEM source data from Porter et al.*, (2018).*

Cave Code	Cave Name	Location (Decimal Lat/Long)	Altitude (m a.s.l.)[1]	Notable Features
GD27	Baby Musk Ox Cave	+80.37657, −21.70607	600	Situated c.60m vertically above Cairn Climb Cave. Accessed via a 100m-long narrowing ledge above exposure that leads to a small scree cone below the cave drip line. Entrance chamber c.4x6m wide, by 3m high. Cave walls have partly preserved phreatic morphology. Small squeeze at the northern end of this chamber terminates in an ice plug after c.1m. The cave was named after skeletal remains of a musk ox calf on the ledge leading towards the cave.
NGD1	None	+80.4119 −21.6783	820	Small phreatic tube
NGD4	None	+80.4129 −21.6801	810	Large alcove, blocked by ice and cave fill
GD^{W}2[2]	None	+80.38695, −21.77809	575	Entrance – two phreatic tubes and keyhole passage (unexplored)
GD^{W}3[2]	None	+80.38573, −21.82598	614	Small phreatic tubes (unexplored)
GD^{W}4[2]	None	+80.38418, −21.82431	566	Phreatic passage (unexplored)
GD^{W}5[2]	None	+80.38315, −21.82756	619	Slot cave (vadose) (unexplored)
GD^{W}6[2]	None	+80.38348, −21.83179	594	Phreatic passage (unexplored)
GD^{W}7[2]	None	+80.38226, −21.83268	631	Four phreatic tubes (unexplored)
GD^{W}8[2]	None	+80.38135, −21.83484	684	Large cave entrance, ice can be seen at base of rear wall (unexplored)
GD^{W}9[2]	None	+80.38341, −21.83601	673	Phreatic passage (unexplored)
GD^{W}10[2]	None	+80.38160, −21.84934	661	Small phreatic tubes (unexplored)
GD^{W}11[2]	None	+80.38183, −21.85311	706	Triangle entrance, c.2m high, breakdown
GD^{W}12[2]	None	+80.38088, −21.85316	685	Large phreatic passage (unexplored)
GD^{W}13[2]	None	+80.38051, −21.83271	715	Triangle entrance, c.1m high, breakdown
GD^{W}15[2]	None	+80.39035, −21.77753	496	Large phreatic passage (unexplored)
PRB1	Pete's Grotto	+80.26014, −21.91781	616	Top of icy scree slope. Large entrance c.5m high, ice wall in back, thick recrystallized flowstone
PRB2	Big Cave	+80.26095, −21.92644	688	High in canyon, large alcove, old meander going off to left
PRB3	Slot Cave	+80.25768, −21.93168	588	Slot cave on bend in river, ice wall at back
PRB3a	Above Slot Cave	+80.25796, −21.93311	638	Small alcove with ice floor
PRB4	Typical Greenland Cave	+80.25784, −21.92455	668	Short cave ending after c.8m
PRB5	Slab Cave	+80.26323, −21.90568	574	Climb up from river level, back and foot up chimney in front of cave (large angled slab to right but tricky to climb)
PRB6	None	+80.24783, −21.9773	685	Triplet entrances. One main one with thick flowstone sequence 4−5m thick. Scree slope full of flowstone. Flowstone *in-situ* in right cave c.5m thick
PRB7	None	+80.24666, −22.00972	676	Small entrances (unexplored)
PRB8	None	+80.25735, −21.95368	729	Entrance inaccessible without rope (unexplored)
PRB9	None	+80.24776, −22.0003	689	Small alcove ending in ice after 5m
PRB10	None	+80.25368, −22.01020	690	Big entrance high in canyon (unexplored)
PRB11	None	+80.25368, −21.91198	700	Small alcove ending in ice after 5m
PRB12	None	+80.27123, −21.91395	708	Small alcove ending in ice after 5m
PRB13	None	+80.26568, −21.92788	720	Flowstone debris exposed on surface above Camp 3

***Table 1**: A compilation of short caves and unexplored karst features as discovered during the 2019 GCP expedition. More-extensive caves are described in the text. [1] Porter et al., 2018. [2] Explored by helicopter; therefore location and elevation may be less accurate.*

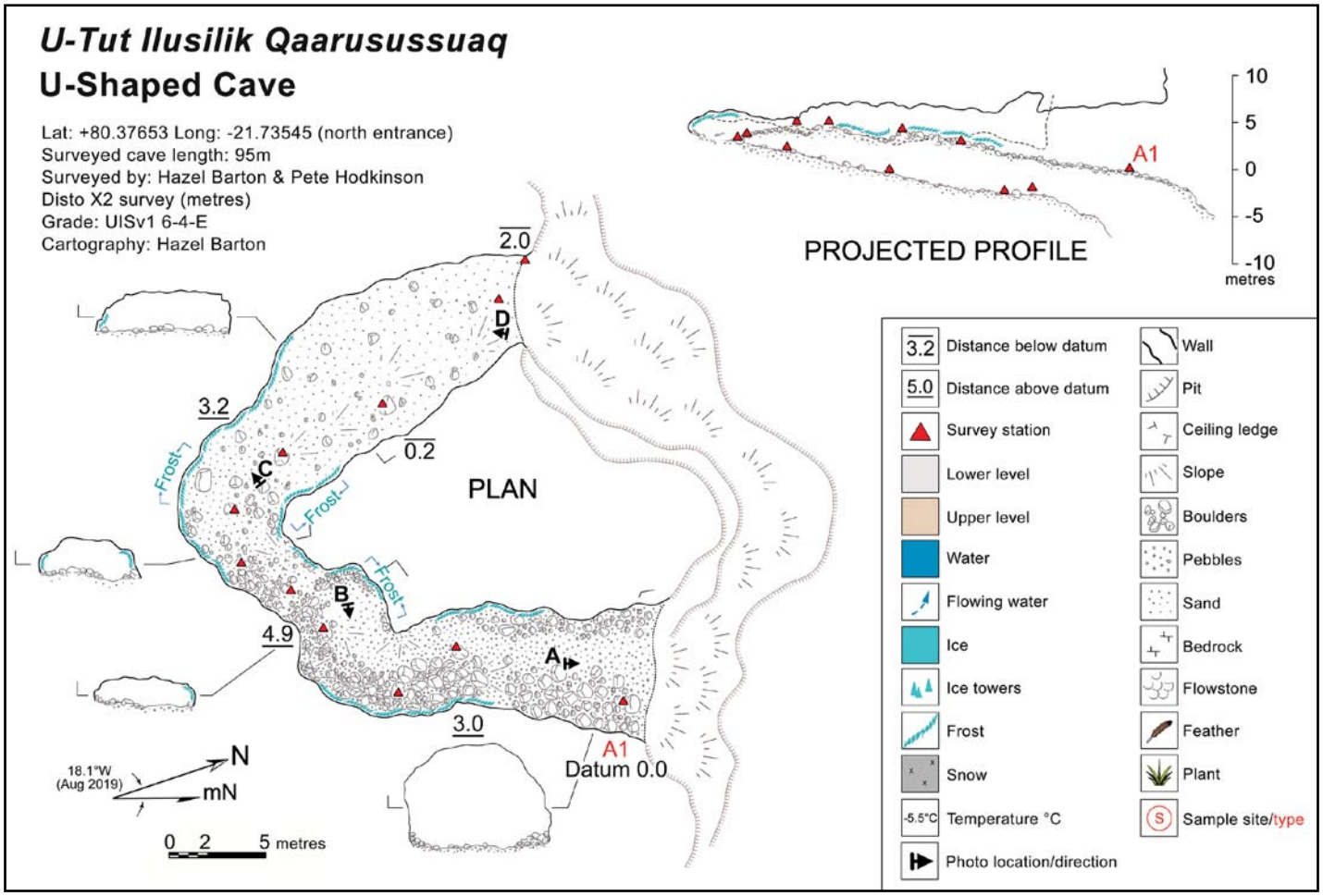

***Figure 2**: Survey of U-Tut Ilusilik Qaarusussuaq (U-Shaped Cave). The **Key** provided is composite, and applies to Figures 2, 4, 5, 6, 7, 9, 10, 11 and 13. [Note: Photo locations/directions relate to additional figures.]*

***Figure 2A**: Looking out across Grottedal from the north entrance of U-Shaped Cave. [Photo: Robbie Shone.]*

***Figure 2B**: Centre of U-Shaped Cave with breakdown material in the background. [Photo: Robbie Shone.]*

Caves discovered in 1960 and 1983

Of the twelve caves discovered in 1960, eleven were situated on the east wall, and one (GD8) on the west wall of the tributary valley on the south side of Grottedal (Fig.1, GD) (Davies and Krinsley, 1960). Two of these caves – U-Shaped Cave and the one on the west wall – were described in detail, whereas the others were not. Thus it has not been possible to ascertain which of the caves discovered in 2015 had already been documented in 1960.

U-Shaped Cave *(U-Tut Ilusilik Qaarusussuaq)*

North entrance: +80.37652, −21.73545, 533m a.s.l.

South entrance: +80.37626, −21.73757, 530m a.s.l.

Surveyed cave length: 95m

The most distinctive and recognizable of all the Greenland caves is the U-shaped cave that was discovered in 1960 (Figs 2–2D). This cave is developed entirely within the Odins Fjord Formation (Smith and Rasmussen, 2020), but is formed along the boundary between a pale grey dolomitic limestone (below), and a dark grey limestone (above) (see Fig.2C). The northern entrance (Fig.2A) is c.13m wide by c.10m high, and the southern entrance is c.8m wide by c.5m high. A c.8m-high chimney is present in the ceiling, c.13m from the northern entrance. The cave floor is generally close to horizontal and covered by sediment (Tischler *et al*., 2020), although breakdown exists locally (e.g. Fig.2B). Ice is present as a thin band along the base of the walls (e.g. Fig.2C). No speleothems were found in the cave, but the walls near the entrances contain patches of a hard, microbiologically-mediated, calcite precipitate. Small photokarren are also observed in the twilight zone of the southern entrance (Barton *et al*., 2020b).

***Figure 2C**: Boundary between pale and dark grey limestone exposed in U-Shaped Cave, with ice at base of wall. [Photo:Robbie Shone.]*

***Figure 2D**: Distinctively bedded pale and dark grey limestone near the U-Shaped Cave southern entrance. [Photo: Robbie Shone.]*

Main Sampling Cave / Kodak Cave

Entrance: +80.37767, −21.74682, 520m a.s.l.

Surveyed cave length: 11m

During 2015, the cave that was reported on the western wall (Davies and Krinsley, 1960) was rediscovered (Fig.3A) and found to contain a 3.8m-wide by 4m-high entrance (Moseley, 2016). Along the southern wall, three notches (Fig.3B) are apparent, containing scallops c.1.5 to 4cm in length (Fig.3C). Because the steeper sides of the scallops are located towards the entrance, the flow direction was probably away from the present-day entrance. At the rear of the cave there is a c.2m-thick sediment sequence, upon which sits a c.20cm-thick *in situ* flowstone deposit (Fig.3D). The floor contains fragments of flowstone concretions that formed in sandy-silty cave sediment and have been partly exhumed by erosion, and a small cairn built by the original explorers, in which they left a note (Moseley, 2020a). The ceiling contains anastomoses (Fig.3E).

***Figures 3A–3E**: Photographs of the Main Sampling Cave / Kodak Cave.*
***3A (top left)**: Overview of the cave (see Figure 3B for more detail).*
***3B (bottom left)**: Three notches present along the southern wall.*
***3C (top right)**: Weathered scallops on the southern wall. [Tape divisions cm/mm.]*
***3D (middle right)**: c.20cm flowstone sequence* in situ *or partly collapsed above a c.2m-thick sediment bank. [Pen (near centre) for scale.]*
***3E (bottom right)**: Remains of anastomoses in the ceiling. Image width c.1m. [Photos: Robbie Shone.]*

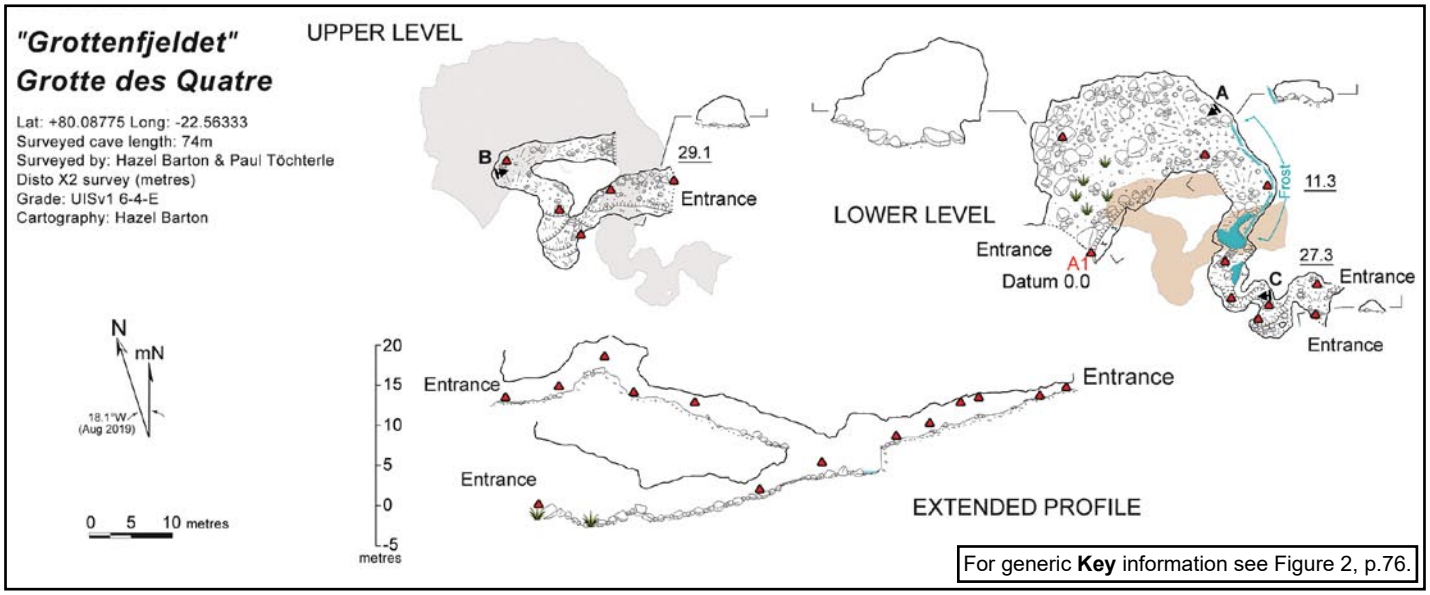

Figure 4*: Survey of Grotte des Quatre ("Grottenfjeldet"). [Note: Photo locations/directions relate to additional figures.]*

Grotte des Quatre ("Grottenfjeldet")

Entrance: +80.08775, −22.56333, 420m a.s.l.

Surveyed cave length: 74m

Grotte des Quatre (Fig 1, GDQ; Figs 4–4C) is the most complex cave yet discovered in the Grottedal/Centrumsø region. Unlike the caves to the north of Centrumsø, this isolated cave, situated south of the lake, is formed within near-vertical bedding and at a low elevation of 420m a.s.l. Despite extensive searching by helicopter and on foot during the regional geological mapping, no other caves were found in the immediate vicinity. The cave has four entrances, the largest of which is c.9m high (indicated as entrance A on the map), the main upper entrance is c.2m high (near B), whereas two small, mid-level entrances are c.40–50cm high (near C). Breakdown material is scattered across the floor of the roomy entrance chamber (Fig.4A). Passages are split over two levels, with the upper passages showing phreatic morphology (Fig.4B) and the lower passage (Fig.4C) displaying meandering vadose entrenchment. Photokarren were found in the twilight zone of some entrances (Barton *et al*., 2020b).

Figure 4A (above)*: Looking out of the main entrance, Grotte des Quatre.*
Figure 4B (below)*: Upper phreatic passage, Grotte des Quatre.*
Figure 4C (right)*: Lower meandering vadose passage, Grotte des Quatre. [Photos: Robbie Shone.]*

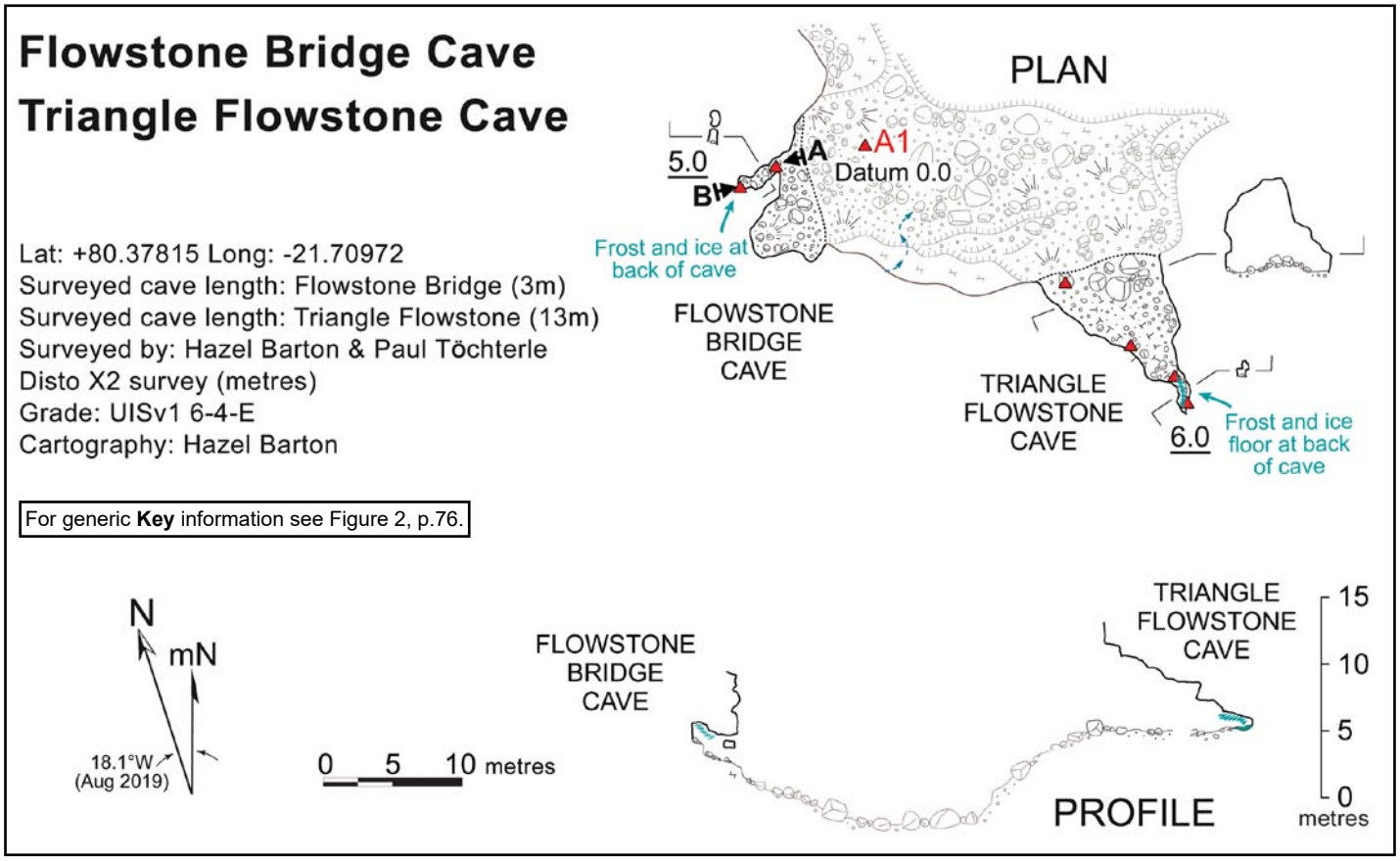

Figure 5*: Surveys of Flowstone Bridge Cave and Triangle Flowstone Cave. [Note: Photo locations/directions relate to additional figures.]*

Greenland Caves Project 2015 and 2019 expeditions

South Grottedal

The following section details the main caves discovered, explored and surveyed by the GCP 2015 and 2019 expeditions. They are situated within the Davies and Krinsley (1960) cave-bearing tributary valley on the south side of Grottedal (Fig.1, GD). It is possible that some of these caves had been explored prior to the GCP expeditions.

Flowstone Bridge Cave and Triangle Flowstone Cave

Entrance: +80.37815, −21.70974, 510m a.s.l.

Surveyed cave length: 3m and 13m respectively

Flowstone Bridge Cave and Triangle Flowstone Cave (Figs 5–5B) are two short caves situated on the edge of what could potentially be a larger collapse feature. They are largely of interest here because the full flowstone sequence from the rear of the cave was sampled in 2019 for palaeoclimate research.

Figure 5A*: Ice samples are collected from Flowstone Bridge Cave. [Photo: Robbie Shone.]*

Figure 5B*: Looking out from Flowstone Bridge Cave, where sampling with an angle-grinder is taking place. [Photo: Robbie Shone.]*

Cairn Climb Cave *(Inussuk Innartooq Qaarusussuaq)*

Entrance: +80.37756, −21.71019, 540m a.s.l.

Surveyed cave length: 19m

Cairn Climb Cave (Figs 6–6D) is located directly above Triangle Flowstone and Flowstone Bridge caves, and is formed at the contact between the Samuelsen Høj and Odins Fjord formations (Smith and Rasmussen, 2020). Accessing the cave involves climbing a steep, c.5m-high, slightly overhanging face. The entrance (Figs 6A and 6B) is c.7m wide by c.5m high, and just inside there is a cairn (Fig.6A) built by previous visitors. Underneath the top stone of the cairn are the remains of a handkerchief with embroidered letters that are barely visible. The walls of the cave contain an iron oxide coating (Fig.6C) and photokarren (Barton *et al*., 2020b). The rear of the cave is blocked by a wall of ice (Fig.6D), and nearby is one of the best displays of 'cryogenic frostwork' observed in any of the studied caves (Barton *et al*., 2020a).

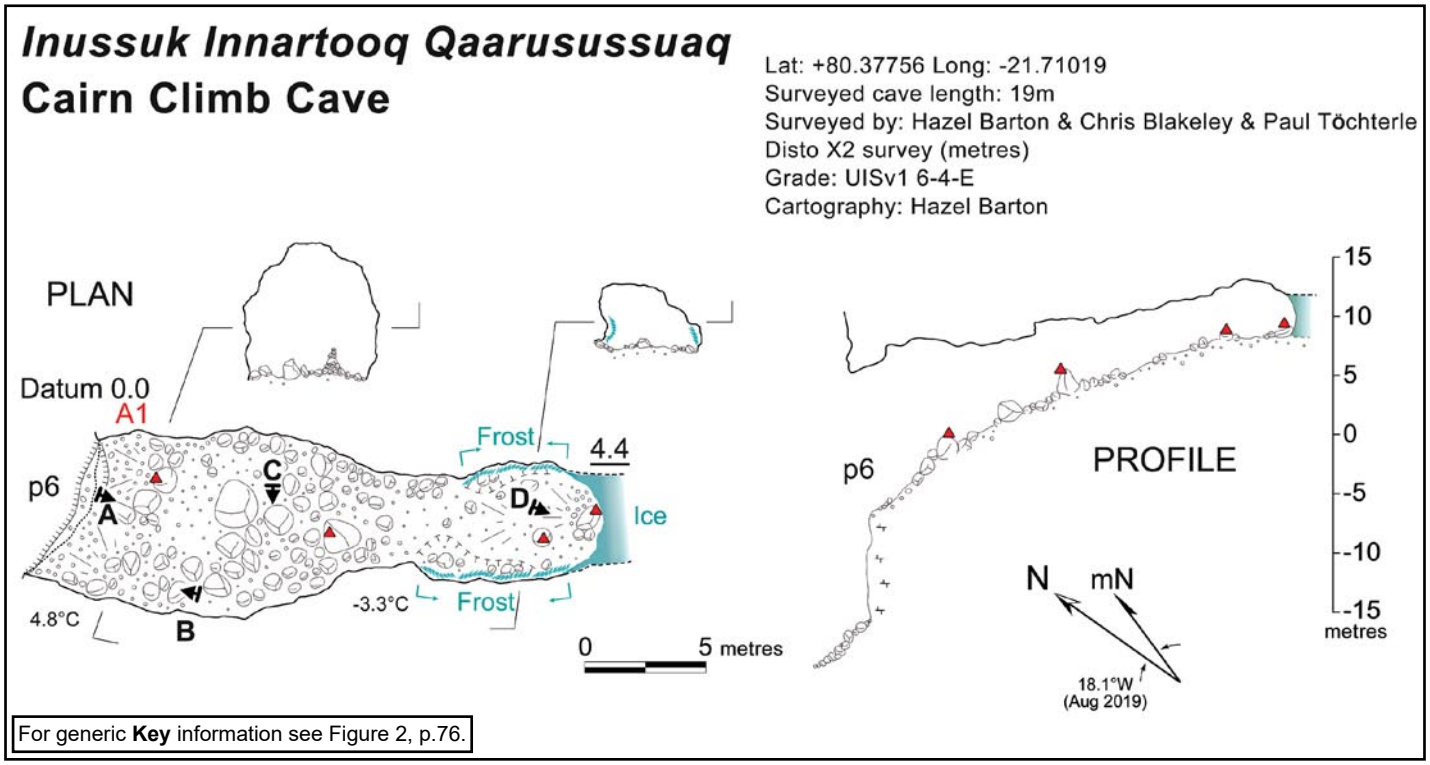

Figure 6: Survey of Inussuk Innartooq Qaarusussuaq (Cairn Climb Cave). [Note: Photo locations/directions relate to additional figures.]

***Figures 6A–6C**: Photographs showing aspects of Inussuk Innartooq Qaarusussuaq (Cairn Climb Cave).*
***6A (above left)**: Examination of the cairn in the entrance; **6B (below left)**: Looking out of the entrance across Grottedal; **6C (above right)**: Patches of brown iron oxides on the west wall.*
***6D (below right)**: Ice plug at rear of cave. [Photos: Robbie Shone.]*

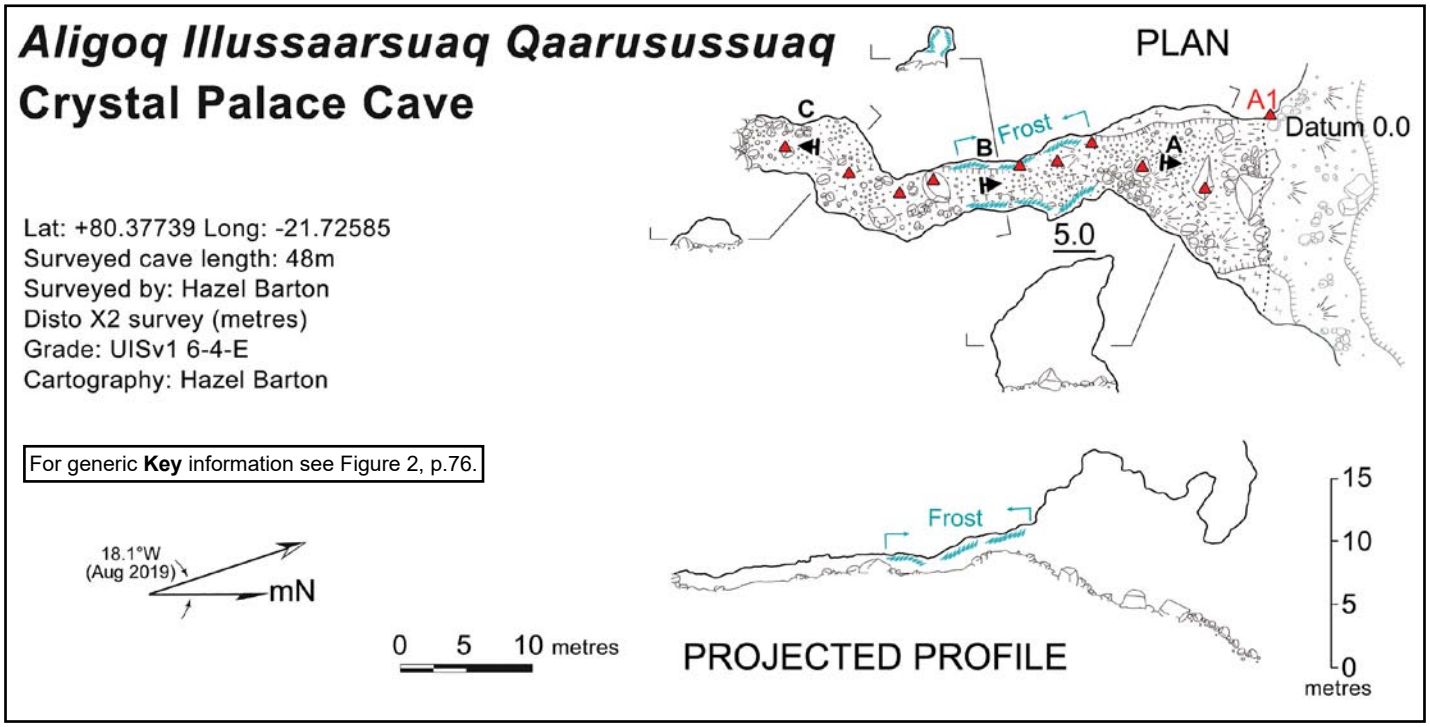

***Figure 7**: Survey of Aligoq Illussaarsuaq Qaarusussuaq (Crystal Palace Cave). [Note: Photo locations/directions relate to additional figures.]*

Crystal Palace Cave *(Aligoq Illussaarsuaq Qaarusussuaq)*

Entrance: +80.37739, −21.72585, 604m a.s.l.

Surveyed cave length: 48m

Crystal Palace Cave (Figs 7–7C) is a high-level cave formed along the boundary between the Samuelsen Høj and the Odins Fjord formations (Smith and Rasmussen, 2020). The large entrance (Fig.7A), which is c.13m wide by c.8m high, is surrounded by tafoni. From the spacious entrance chamber, a steep sediment ramp leads to a narrow crawl containing ice stalagmites and hoar frost (Fig.7B), as well as 'cryogenic frostwork' (Barton *et al*., 2020a). Beyond the crawl, the walls and ceiling of the stooping-size chamber are covered in hoar frost. Large breakdown blocks are present at the back of the chamber, which must be climbed over to reach the final small chamber. The floor of the rear two chambers is covered in a fine-grained sediment (Fig.7C), which in places contains runnels or scours close to bends in the wall. White calcite stalagmites c.8cm tall, and a c.10cm-thick flowstone sequence are buried beneath the sediment in the rear chamber, whereas in the entrance chamber there are sequences of brown flowstone up to c.80cm thick, some of which are fractured and buried beneath the sediment bank. Relics of cemented cave fill are found on the walls in places, and Barton *et al*. (2020b) note fossilized biofilms.

***Figure 7A**: Looking out from the entrance of Crystal Palace Cave and across Grottedal. [Photo: Robbie Shone.]*

***Figure 7B**: Hoar frost in the crawl between the entrance and middle chamber in Crystal Palace Cave. [Photo: Robbie Shone.]*

***Figure 7C**: Rear chamber in Crystal Palace Cave, with breakdown and sediment-covered floor. [Photo: Robbie Shone.]*

***Figure 8**: Cave-bearing canyon (for location see Figure 1 – code GD[w]) on the southern side of Grottedal, some 1.5km to the west of the canyon first explored by Davies and Krinsley (1960). [Photo: Robbie Shone.]*

South Grottedal (west canyon)

During the 2019 GCP expedition, a tributary canyon on the south side of Grottedal (Fig.1, GD[w]; Fig.8), situated c.1.5km to the west of the Davies and Krinsley (1960) canyon, was explored. It was found to be rich in cave entrances (Table 1), two of which yielded substantial cave. Because of time constraints, most of the cave entrances in this canyon were neither explored nor way-pointed.

Lemming Cave *(Narlumukaap Qaarusussuaq)*

Entrance: +80.38586, −21.81800, 526m a.s.l.

Surveyed cave length: 54m

Also known as ***Stig Strikes Again***

Lemming Cave (Figs 9–9C), situated on the northern side of a bend in the canyon, is reached at the top of a c.15m-high scree slope, though the scree slope continues into the entrance chamber.

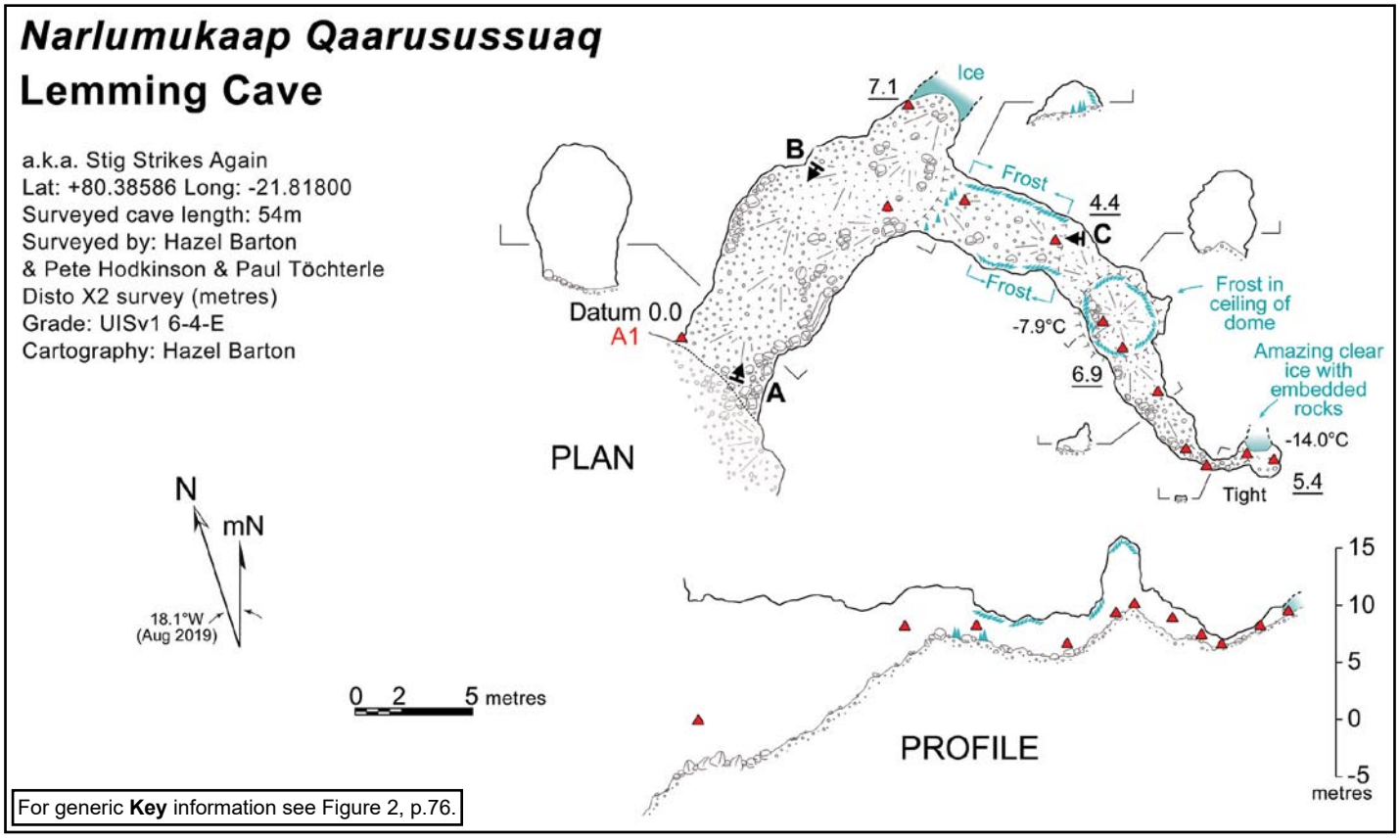

***Figure 9**: Survey of Narlumukaap Qaarusussuaq (Lemming Cave; also known as Stig Strikes Again). [Note: Photo locations/directions relate to additional figures.]*

Figures 9A, 9B and 9C: *Photographs of Lemming Cave.*
Figure 9A (above-left)*: Entrance chamber with pale and dark grey limestone bedding.*
Figure 9B (below)*: Looking out from the entrance chamber, with the helicopter in the distance below.*
Figure 9C (above-right)*: Hoar frost crystals in the ceiling of the crawl.*
[All photos: Robbie Shone.]

The west wall of the entrance chamber displays prominent alternating beds of highly fossiliferous, pale and dark grey limestone (Figs 9A and 9B). Ahead, the continuation of this passage is blocked by an ice wall, but a smaller, c.10m-long, crawling-size phreatic passage with the hoar frost/ice floor horizon in its entrance leads on from the top of the breakdown slope on the right. There are cryogenic cave carbonate deposits spread across the floor at the entrance of this passage. Beyond, the passage is surrounded by hoar frost for c.10m (Fig.9C), then it breaks into a small, c.4m-high, aven. The cave continues for c.10m through a tight constriction, c.30cm high, that was dug open, before ending in a small chamber completely blocked by a transparent ice-plug that holds a c.15cm-diameter cobble in its base. Laminated fine-grained clastic sediments were found beneath the ice plug (Tischler *et al*., 2020).

Swirly Cave *(Sangujoraartoq Qaarusussuaq)*

Entrance: +80.38846, −21.78788, 554m a.s.l.

Surveyed cave length: 96m

The entrance to Swirly Cave (Fig.10) is situated on a ledge system on the eastern sidewall of the valley that was accessed by helicopter. After a short and easy c.1.5m climb, the entrance shows similar shelf ice and hoar frost formations to those met in all the larger caves in the area. From there on, a walking-size vadose canyon descends steadily as far as a collapse of two large boulders, beyond which the cave narrows and drops down a too-tight slot. Abundant remnant phreatic features, including scallops and small tubes, appear to indicate a former upward flow direction, and signs of paragenesis are preserved locally. Scour marks in solidified sediment, as well as prominent scratch marks on protruding parts of the rock walls, are common. Passage continues beyond the tight slot that terminated the exploration, but access would require a significant digging effort.

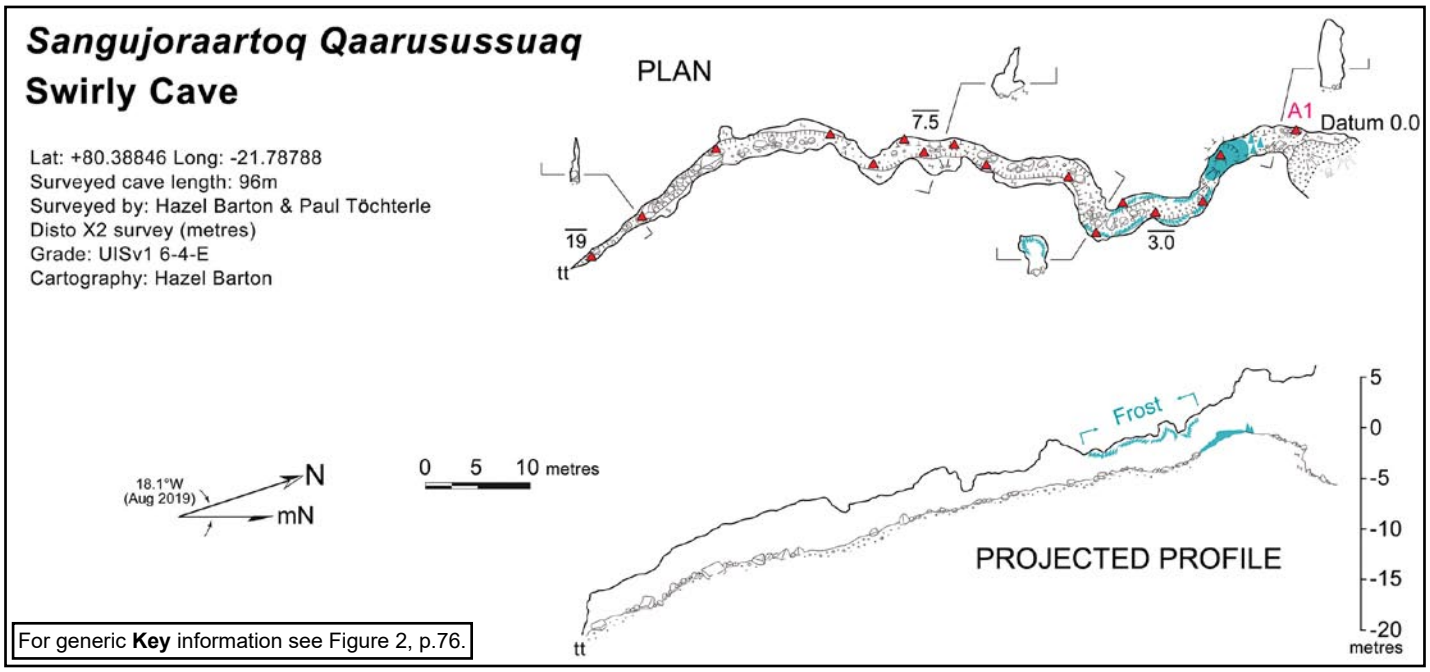

Figure 10*: Survey of Sangujoraartoq Qaarusussuaq (Swirly Cave).*

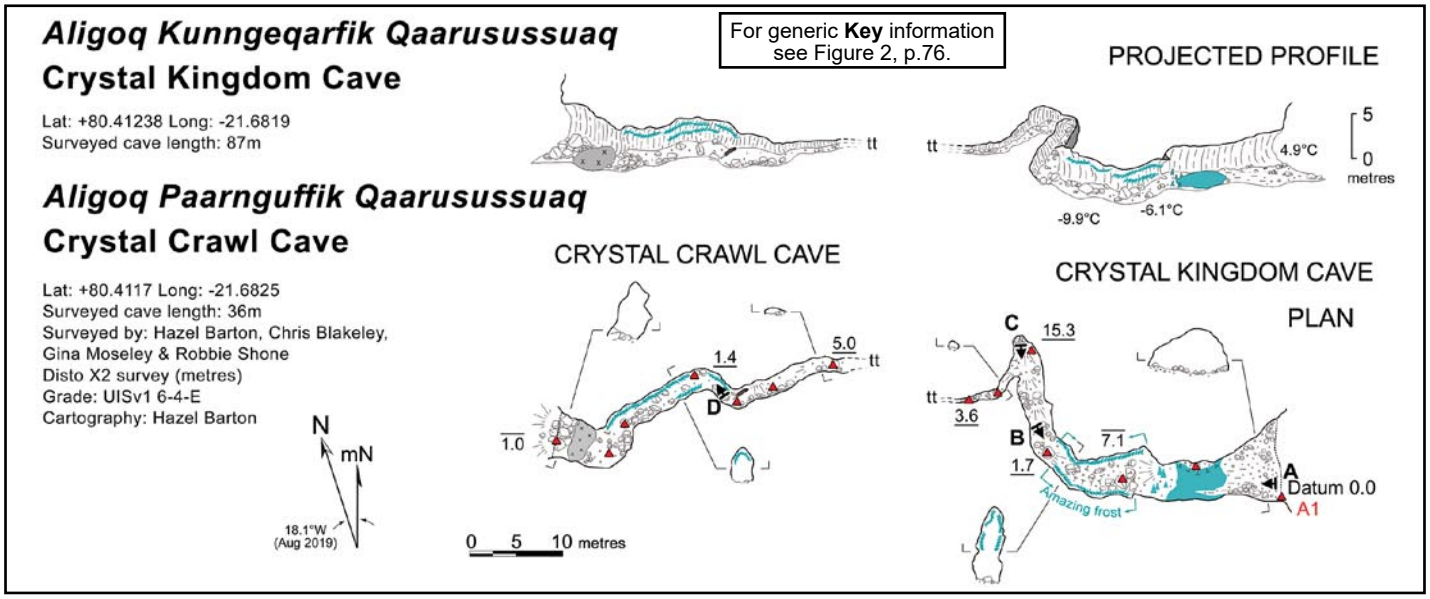

***Figure 11**: Surveys of Aligoq Kunngeqarfik Qaarusussuaq (Crystal Kingdom Cave) and Aligoq Paarnguffik Qaarusussuaq (Crystal Crawl Cave). [Note: Photo locations/directions relate to additional figures.]*

North Grottedal

In 2015, a possible large cave entrance on the north side of Grottedal was viewed through binoculars. In 2019, with the aid of a helicopter, the team had the opportunity to explore northern Grottedal (Fig.1, NGD), where they found one isolated hilltop, capped by reefal limestones of the Samuelsen Høj Formation, containing four cave entrances. Two of these yielded significant length passages, the third was a small phreatic tube, and the fourth was a large alcove blocked by ice and sediment (Table 1).

Crystal Kingdom Cave *(Aligoq Kunngeqarfik Qaarusussuaq)*

Entrance: +80.41238, −21.6819, 825m a.s.l.

Surveyed cave length: 87m

Crystal Kingdom Cave (Fig.11) contains the distinctive ice floor/hoar frost boundary in the entrance (Fig.11A) (Barton *et al*., 2020a). The main passage develops into a c.2–3m-wide by c.5m-high vadose canyon, with a fine-grained sediment on the floor and large, dinner-plate-size, hoar frost crystals (Fig.11B) on the walls and ceiling. Several calcite stalagmites are present on the walls, as well as thick flowstones. The main passage rises to a bend from which a crawling-size phreatic tube descends westwards (Fig.11C), heading directly towards the end of Crystal Crawl, some 15m away. Crystal Kingdom and Crystal Crawl are separated from each other by constrictions, but there might be an air connection. On the bend between the phreatic passage and vadose passage, scour marks similar to those found in Crystal Palace Cave are present in the sediment.

***Figure 11A**: Looking into the entrance of Crystal Kingdom Cave. [Photo: Robbie Shone.]*

***Figure 11B**: Hoar frost crystals, some of which are the size of dinner plates, in Crystal Kingdom Cave. [Photo: Robbie Shone.]*

***Figure 11C**: Looking down the main passage (left) and descending phreatic tube (right) in Crystal Kingdom Cave, with fine-grained sediment floor. Scour marks are seen in the floor around the bend. [Photo: Robbie Shone.]*

***Figure 11D**: Phreatic tube of Crystal Crawl Cave, covered in hoar frost and scattered with massive, broken, flowstone on the floor. [Photo: Robbie Shone.]*

Crystal Crawl Cave *(Aligoq Paarnguffik Qaarusussuaq)*

Entrance: +80.4117, −21.6825, 812m a.s.l.

Surveyed cave length: 36m

Crystal Crawl Cave (Figs 11 and 11D) is a winding, crouching-size phreatic tube. The entrance contains a distinctive ice floor and hoar frost, indicative of 'going' cave passage in Greenland (Barton *et al*., 2020a). Massive flowstone sequences, broken presumably by gelifraction processes, are scattered across much of the floor. Feathers were found inside the cave. The tube narrows to the point that it becomes too tight, heading in the direction of Crystal Kingdom Cave.

PRB Canyon

PRB Canyon, named in memory of Peter Rodney Blakeley (Moseley, 2020a), was discovered as another cave-bearing canyon (Fig.1, PRB; Fig.12) during reconnaissance with the helicopter. Most of the cave entrances did not yield accessible passage, but nevertheless they display extensive karstification, with sizeable entrances (c.5 × 5m) and metres-thick flowstone sequences. In similar fashion to those in the GD^{W} canyon, numerous cave entrances remain unexplored and not way-pointed.

[Kate's] Cove Cave *(Eqik Qaarusussuaq)*

Entrance: +80.25346, −21.93311, 660m a.s.l.

Surveyed cave length: 103m

Cove Cave (Figs13–13E) is the longest cave yet explored in Greenland, with 103m of surveyed passage. It extends linearly in a W–E direction, trending generally downwards from the entrance over an elevation range of c.15m. The entrance (Figs 13A and 13B) contains a wall-to-wall ice pond, which is difficult to bypass. Beyond the ice pond, a small ramp composed of breakdown leads to a hoar frost-covered ceiling (Fig.13C) from which the phreatic passage (Fig.13D) then descends. Breakdown material and shattered flowstone blocks cover the floor, and in places there are cryogenic cave carbonates, both on and within the entrance ice and lying on boulders within the cave. Near the eastern end of the cave there is a c.5m-deep vadose canyon (Fig.13E) that is covered in flowstone on both walls, beyond which the cave is blocked by ceiling-to-floor flowstone. The coldest cave temperature (−17.1°C) yet measured in Greenland was recorded at the base of the vadose slot, which continues as a too-tight passage that could possibly be enlarged by digging.

***Figure 12**: Looking down into PRB Canyon, with the entrance of PRB1 (Pete's Grotto) in the top-right corner. [Photo: Robbie Shone.]*

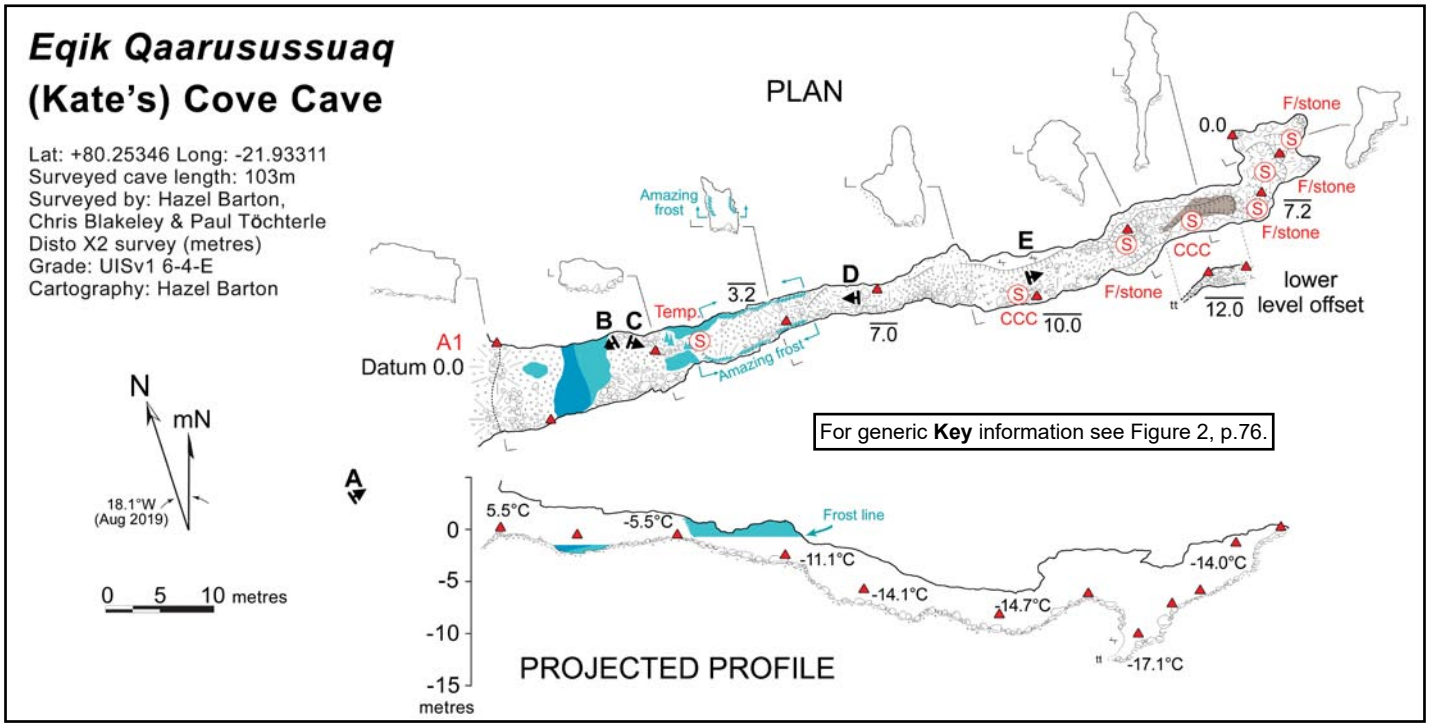

Figure 13: *Survey of Eqik Qaarusussuaq ([Kate's] Cove Cave). [Note: Photo locations/directions relate to additional figures.]*

Figure 13A (above): *The entrance of [Kate's] Cove Cave, in a cove with a waterfall.*
Figure 13B (below): *Looking out of the [Kate's] Cove Cave entrance across the ice pond.*
Figure 13C (top right): *Hoar frost and ice stalagmites close to the entrance of [Kate's] Cove Cave.*
Figure 13D (middle right): *Phreatic tube descending from the entrance of [Kate's] Cove Cave.*
Figure 13E (bottom right): *Vadose trench with keyhole profile at the rear of [Kate's] Cove Cave.*
[All photos: Robbie Shone.]

Summary

Northeast Greenland contains highly karstified terrains, though nowadays this karstification is primarily observed largely in the form of trubcated caves. To date, GCP team members have explored 43 cave entrances, and logged 16 others, though many unlogged features exist, specifically in PRB Canyon and South Grottedal 'west canyon'. Of the 43 explored caves, 28 are less than 10m long, four are between 10 to 20m in length, four are between 30 to 60 metres in length, two are 70 to 90 m in length, and five are between 90 to 110m in length. Based on these statistics, c.1 in 10 caves is over 90m in length, whereas the majority (c.6 in 10) are less than 10m long. Such short caves were so numerous that they were given the name 'Typical Greenland Cave' or 'TGC' but they are indicative of widespread passage development, predominantly phreatic, much of which took place prior to later incision. The longer caves generally contain an ice floor and hoar frost ceiling close to the entrance, as recognized in Barton *et al.* (2020a).

Generally, the caves in the two canyons on the southern side of Grottedal, as well as those in PRB Canyon, are spread over an elevation range of 500 to 700m a.s.l., whereas the four caves on the northern side of Grottedal are between 810 to 825m a.s.l. The elevation of the isolated cave, *Grotte des Quatre*, south of Centrumsø, is the lowest yet recorded in the region, at 420m a.s.l.

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References

Barton, H A, Breley, G J, Töchterle, P and Moseley, G E, 2020a. Cryogenic features of the permafrost ice caves of Grottedal, northeast Greenland. *Cave and Karst Science*, Vol.47(2), 93–99.

Barton, H A, Breley, G J and Smith, M P, 2020b. Microbiological observations in the caves of Grottedal, Kronprins Christian Land, northeast Greenland. *Cave and Karst Science*, Vol.47(2), 88–92.

Davies, W E and Krinsley, D B, 1960. Caves in northern Greenland. *Bulletin of the National Speleological Society,* Vol.22, 114–116.

Loubière, J-F, 1987. Observations préliminaires sur les cavités de la région du lac Centrum (NE Groenland). *Karstologia,* Vol.9(1), 7–16.

Moseley, G E (Ed.), 2016. *Northeast Greenland Caves Project Expedition Report, July–August 2015.* [Innsbruck: Northeast Greenland Caves Project.]

Moseley, G E, 2020a. History of exploration in northeast Greenland. *Cave and Karst Science,* Vol.47(2), 55–59.

Moseley, G E, 2020b. Greenland Caves Project expedition sponsors [Appendix 10]. *Cave and Karst Science,* Vol.42(2), p.116.

Porter, C, Morin, P, Howat, I, Noh, M-J, Bates, B, Peterman, K, Keesey, S, Schlenk, M, Gardiner, J, Tomko, K, Willis, M, Kelleher, C, Cloutier, M, Husby, E, Foga, S, Nakamura, H, Platson, M, Wethington, M, Jr, Williamson, C, Bauer, G, Enos, J, Arnold, G, Kramer, W, Becker, P, Doshi, A, D'Souza, C, Cummens, P, Laurier, F, Bojesen, M, 2018, "ArcticDEM" [Harvard Dataverse, V1]: **doi.org/10.7910/DVN/OHHUKH** [Accessed 25 June 2020].

Smith, M P and Rasmussen, J A 2020. The geology of the Centrumsø area of Kronprins Christian Land, northeast Greenland, and lithological constraints on speleogenesis. *Cave and Karst Science,* Vol.47(2), 60–65.

Tischler, J, Töchterle, P, Moseley, G E, 2020. Characterization of northeast Greenland cave sediments. *Cave and Karst Science,* Vol.47(2), 100–103.

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