



History of exploration in northeast Greenland

Gina E MOSELEY

Institute of Geology, University of Innsbruck, Innrain 52,
6020 Innsbruck, Austria
E-mail: gina.moseley@uibk.ac.at

Abstract: Solution caves in Greenland were first discovered in 1960 at Lat: +80° during Operation Groundhog – a programme to investigate emergency landing sites for aircraft, run by the United States Air Force Cambridge Research Laboratories Ice-Free Land Program and US Geological Survey. Subsequently, the first dedicated caving expedition to northeast Greenland took the form of a four-man land-based team in 1983. The next dedicated caving expeditions to the area were those of the Greenland Caves Project in 2015 and 2019, though there were attempts to locate a new cave region at Lat: +70° in 2018. In this report, the caving expeditions are put into context of the history of exploration in northeast Greenland, from the beginning – with the pre-Inuit people – to the present day.

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Introduction

Greenland (*Kalaallit Nunaat* in Greenlandic, meaning land of the Kalaallit) is the world's largest non-continental island, with its mainland covering an area of approximately 2,130,800 km². Contrasting with its large size, the population of Greenland is exceptionally low, with an estimated 56,770 inhabitants in 2020 (Worldometer, 2020). Consequently, it has the lowest population density in the world, at just 0.027 people per km². Perhaps inevitably, with so few people and such a vast area, and with a combination of harsh environments and remote locations, exploration of much of Greenland has been limited.

Nowadays, Greenland is an autonomous territory of the Kingdom of Denmark, divided into five municipalities plus the Northeast Greenland National Park (*Kalaallit Nunaanni nuna eqqissisimatitaaq*), the latter having been the focus of cave exploration by the Greenland Caves Project (GCP) since 2015. The National Park, which was established in 1974, is the largest in the world. It has no permanent indigenous population, but several sites are inhabited throughout the year for scientific and military purposes.

A detailed account of the history of exploration in East Greenland until 2010 is provided by Higgins (2010). The present account describes exploratory activities in northeast Greenland, in particular in the Centrumso region (Fig. 1), which has been the focus of the 2015 and 2019 Greenland Caves Project expeditions (Lat: +80.1, Long: -22.5° to Lat: +80.4°, Long: -21.7°).

Pre-modern to early-modern Greenland

Greenland's earliest known settlement is dated to 2500 B.C.E. (Before the Common Era). From 2500 to 800 B.C.E., South and West Greenland were inhabited by the Saqqaq culture, whilst simultaneously, between 2400 and 1300 B.C.E., the Independence I culture lived in North and northeast Greenland (Bennike *et al.*, 2008; Higgins, 2010; Grønnow, 2016, 2017; Greenland Research Centre, 2020). By about 800 B.C.E. the Saqqaq culture had disappeared and at about the same time the Early Dorset culture emerged in West Greenland, extending

eventually through the coastal areas to East Greenland (Higgins, 2010; Greenland Research Centre, 2020), where many tent rings from the culture survive (Higgins, 2010). Whilst the Dorset culture inhabited the West and South, the Independence II culture lived in northeast Greenland (Greenland Research Centre, 2020). Norse people settled South and West Greenland between 986 C.E. (Common Era) and the 15th century (Rafn, 1845; Higgins, 2010; Greenland Research Centre, 2020). Their presence in East Greenland north of Lat: +69° can be deduced, based on the evidence of an ornamented bone comb (Thalbitzer, 1909; Higgins, 2010) and silver buttons and beads discovered in Inuit graves at Scoresbysund (Fig. 1) (Storgaard, 1926; Higgins, 2010). Modern Greenlanders are descended from members of the Thule culture, which settled Greenland from Alaska around 1300 C.E. (Higgins, 2010; Greenland Research Centre, 2020), also extending into northeast Greenland (Grønnow and Jensen, 2009). In 1823 C.E., Douglas Clavering encountered twelve of the Thule at Clavering Ø (Lat: +74°; Fig. 1) (Clavering, 1830). Some consider that this small population was the last of the Thule living north of Lat: +69° (Higgins, 2010).

Exploration in the early to mid-20th century

From the 17th century onwards, numerous exploratory voyages and whaling expeditions visited East Greenland though, based on the accounts in Higgins (2010), none appear to have reached as far north as Lat: +80° until the Danmark Expedition between 1906 to 1908. The Danmark Expedition aimed to explore and map the vast area of northeast Greenland between Cape Bridgman (Fig. 1) on the north coast (Lat: +83.417°, Long: -26.7°) and Cape Bismarck (Fig. 1) in the east (Lat: +76.699°, Long: -18.553°) (Higgins, 2010). Until then, this region had remained unmapped due to the harsh climate and difficult sea-faring conditions. Initially the Danmark Expedition endured difficulties with sea ice, but was finally able to set up base for two years at Danmark Havn (Fig. 1) (Lat: +76.77°; the meteorological station Danmarkshavn used by the GCP 2019 expedition (Moseley, 2020a) is on the north of Danmark Havn).

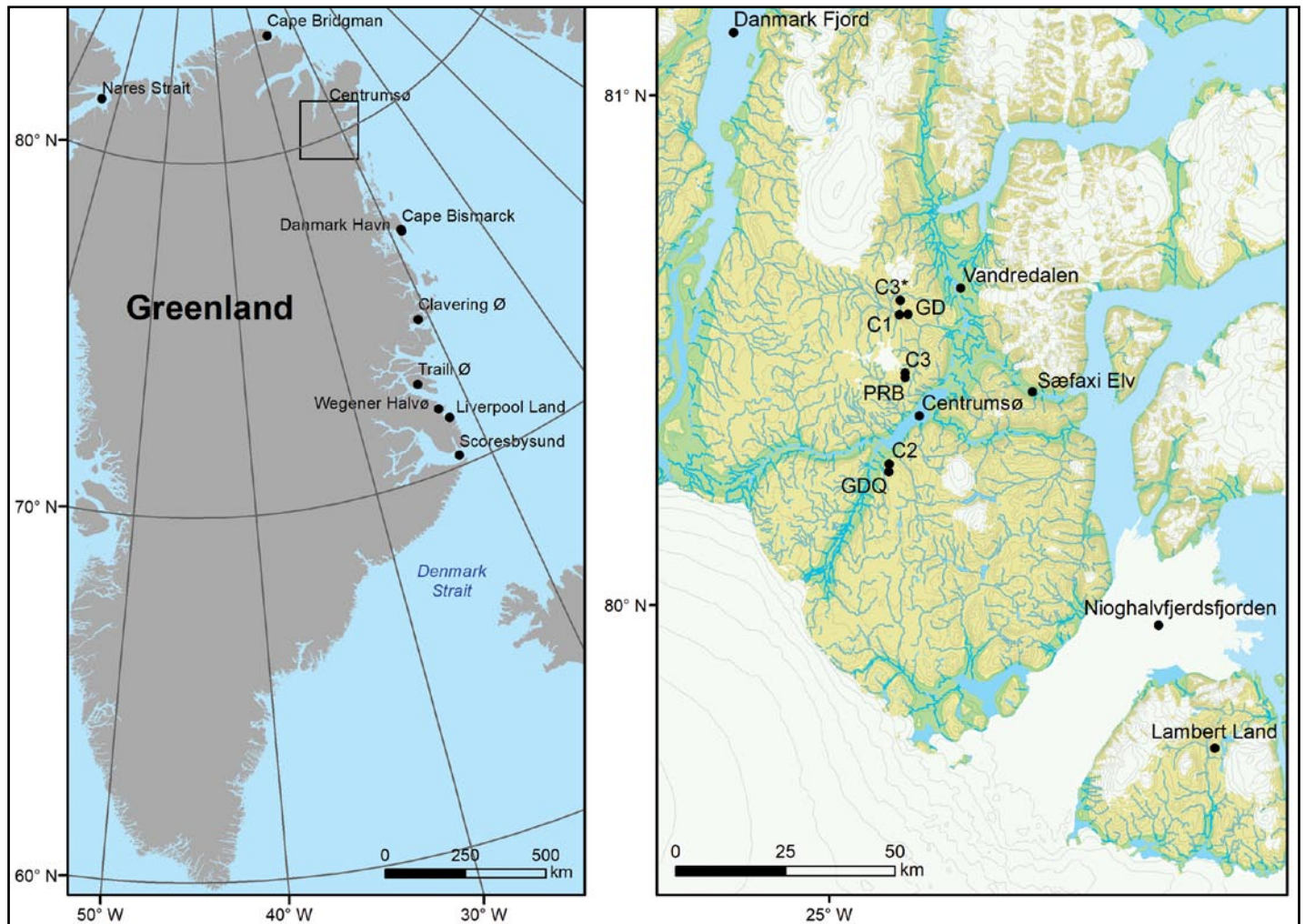


Figure 1: Maps showing locations discussed in the text:

C1 = Camp 1; C2 = Camp 2; C3 = Camp 3; C3* = original (unused) site for Camp 3; GD = Grottedal; PRB = PRB Canyon; GDQ = Grotte des Quatre. [Left-hand map based upon: EuroGlobalMap 2019 (©EuroGeographics. Original product is available for free at eurogeographics.org/maps-for-europe/open-data/topographic-data/). Right-hand map contains data from Styrelsen for dataforsyning og effektivisering, "Topografiske kort i målforhold 1:250.000. Datasættet er produceret i perioden 1990–2000.", May 2020.]

Nearly 200 journeys were made from Danmark Havn as part of the expedition, including four parties of ten men and 86 dogs that departed on 28th March, 1907, heading north (Higgins, 2010). All parties reached the latitude of the GCP 2015 and 2019 expeditions, with two parties turning back at Lat: +80.5°. The other two parties departed company at Lat: +81.7°. The party led by J P Koch, reached the target of Cape Bridgman on the north coast and then returned southwards, meeting-up unexpectedly with the other party, led by Mylius-Erichsen, on 27 May 1907 (Higgins, 2010). Koch's party reached Danmark Havn on 23 June 1907. Mylius-Erichsen's party, however, headed westwards where open water forced them to spend the summer at Lat: +81.5° in Danmark Fjord (Fig.1). They endured difficult times due to a lack of hunting opportunities. In mid-October they were finally able to begin the return journey, but unfortunately all three members perished along the way. The body of one team member, Brønlund, and his diary were found in east Lambert Land (Lat: +79.15°; Fig.1) by a relief party in March 1908. The bodies of Mylius-Erichsen and Høeg-Hagen have never been recovered, but it is thought that they died farther north near Nioghalvfjærdssjorden (Lat: +79.6°; Fig.1) (Brønlund, 1907; Mikkelsen, 1913; Higgins, 2010). An attempt to find and recover the bodies was made by the 1909–1912 'Alabama' Expedition (Mikkelsen, 1913). Whereas they were successful in relocating Brønlund's body, no new leads as to the location of Mylius-Erichsen or Høeg-Hagen were discovered (Higgins, 2010). Attempts were also made to retrace the footsteps of Mylius-Erichsen's team from Danmark Fjord, leading to the discovery of two report cairns but no bodies.

In the following decades, many expeditions were undertaken to East Greenland, but few reached as far north as Lat: +80° in the Centrumso region (Schmidt Mikkelsen, 1989; Higgins, 2010).

Aerial reconnaissance of northeast Greenland, including both topographical and geological observations, was made during 1933 as part of the Three-Year Expedition (*Treårsekspeditionen*) to East Greenland led by Lauge Koch (Koch *et al.*, 1935a, b, 1936). It was not until 1938–1939, however, that ground-level expeditions to the region took place once again. This included the Danish Dog-Sled Expedition and the Mørkefjord Expedition. The former explored the fjords of Kronprins Christian Land and reached Vandredalen (Fig.1) to the northeast of Centrumso (Nielsen, 1941; Drastrup, 1945; Higgins, 2010; Rasmussen, 2013), whereas the latter aimed to traverse between Lat: +76° and Lat: +82°, something that had otherwise been achieved only by the Danmark and Alabama expeditions (Knuth 1940, 1942; Higgins, 2010).

Exploration in the mid to late 20th century

Expeditions to East Greenland led by Lauge Koch resumed between 1947 to 1958 (Higgins, 2010). They were predominantly geological in nature (Koch, 1961), with six to eleven teams active each year. Initially the scientists overwintered, but this ceased in 1953. Of note to the speleological community is that Desmond D Donovan, a lifetime University of Bristol Spelæological Society member (Donovan-Beermann and Mullan, 2020), was part of the 1949–1950 campaigns to Traill Ø (Fig.1) (Higgins, 2010). Donovan is credited with naming a number of geomorphological and geological features including Bath Elv and Bristol Elv after his home city and university respectively. The Koch expedition in 1952 (expedition no.49) consisted of two geological parties that were based at Centrumso (Higgins, 2010) mapping the folded zone east of Centrumso (Fränkl, 1954, 1955) as well as the region between Danmark Fjord and Centrumso (Adams and Cowie, 1953).

In 1953, two geological parties of the Koch expedition again used Centrumso as a base, but were primarily interested in working in North Greenland (Higgins, 2010). Three years later, ‘Operation Defrost’ led by S M Needleman undertook four days of reconnaissance during August 1956 in the Centrumso region as part of investigations into aircraft landing sites for the United States Air Force Cambridge Research Laboratories (AFCRL) Ice-Free Land Program (Davies and Krinsley, 1961; Needleman, 1962; Higgins, 2010). Subsequently, in 1959, field caches of food and fuel were air dropped to nine locations, in preparation for a field study in 1960 as part of Operation Groundhog (Davies and Krinsley, 1961). These 1960 investigations would go on to become important for Greenland cave exploration.

In 1978–80, Niels Henriksen led members of the Geological Survey of Greenland (GGU) and Geodetic Institute in a three-year programme of geological and topographical surveying (Higgins, 2010). This included wide-angle aerial photography between Lat: +76° to Lat: +82° and the positioning of control points between Lat: +76° to Lat: +81°. Later, between 1993–95, Henriksen led another three-year geological campaign for the GGU, with the aim of producing a map at 1:500,000 scale between Lat: +78° to Lat: +81° in Lambert Land and southern Kronprins Christian Land (Higgins, 2010). Centrumso was used as the base camp for the 1993–1995 expeditions. In 1995, the velocity of the inland ice southwest of Centrumso was investigated by the Alfred Wegener Institute for Polar and Marine Research (AWI) (Henriksen, 1996; Higgins, 2010), and since 2008, two weather stations of the Programme for Monitoring of the Greenland Ice Sheet (PROMICE) have been operational c.40km and c.60km southwest of Centrumso (Geological Survey of Denmark and Greenland, 2020). The University of Copenhagen led an expedition in 2009 to carry out further investigation of the Ordovician – Silurian limestones west of Centrumso (Rasmussen *et al.*, 2013; Harper *et al.*, 2014; Smith and Rasmussen, 2020) and, in 2016 and 2017, offshore expeditions led by the AWI were conducted offshore of Lat: +79° to investigate the Northeast Greenland Ice Stream and its controls on ice flux into the northeast Atlantic (Kanzow, 2017; NEGIS, 2020).

One final point of importance before considering caving expeditions is that of the Sirius sledge patrol, which was established in 1950, originally under the name Operation Resolut (Schmidt Mikkelsen, 2020). The main aim of Sirius is to undertake military surveillance and instil sovereignty through patrol of the uninhabited coastline between Liverpool Land in East Greenland and the Nares Strait in North Greenland (Fig.1). They also act as civilian police, and supervise expeditions. During the winter months they travel by dog sled, and during the summer months by sailing (Schmidt Mikkelsen, 2020).

Northeast Greenland cave exploration

In June and July 1960, the US AFCRL and the US Geological Survey continued investigations into emergency landing strips in North and northeast Greenland (Davies and Krinsley, 1961). In total, eight sites were investigated with the main focus of the study being on unconsolidated surface deposits and related ground features (Krinsley, 1960; Needleman, 1960; Davies, 1961; Davies and Krinsley, 1961). Between 14 June to 2 July, operations were centred around Centrumso (Fig.2) (Davies and Krinsley, 1961), leading to the first-known discoveries of solution caves in limestone in Greenland (Davies and Krinsley, 1960). The caves were found to be c.20km north of Centrumso, and located in a c.1km-long north–south-trending tributary valley (Lat: +80.38°, Long: –21.74°; Fig.1), which extends from the southern side of the much larger Grottedal (Fig.1). Davies and Krinsley reported the presence of twelve caves; eleven are located in the east wall and one in the west wall. They were described as being at three elevations (490 to 520, 610–625, and 670m above sea level), 5 to 12m in diameter, and 10 to 60m in length. Of interest



Figure 2: The Twin Otter lands at Centrumso in August, 2015, next to an old US Army hut left from the 1960s. [Photo: Robbie Shone.]

to palaeoclimate studies, was the presence of sediment fill and coarsely-crystalline calcite deposits in the one cave of the west wall indicating a previously milder climate (Davies and Krinsley, 1960; Moseley, 2016; Moseley *et al.*, 2016).

The next caving expedition to the area was a four-man expedition led by J F Loubière during 1983 (Loubière, 1987). Working from Centrumso, the team undertook several extended foot traverses. Team members visited and explored the Grottedal caves discovered in 1960, but also reported a ‘porch’ on the plateau just a couple of kilometres north of the lake. Most significant, however, was the discovery of the Grotte des Quatre (*Grottenfjeldet*), which is situated some 8km south of Centrumso (Fig.1). Compared to other known Greenland caves, Grotte des Quatre is more complex morphologically, containing four entrances (one of which is up to 9m high) and including meandering cave passages at different elevations (Moseley *et al.*, 2020). Attempts to recover flowstone from Grotte des Quatre were successful, but attempts to date them using electron spin resonance (ESR) were unsuccessful (Loubière, 1987). The expedition also contributed to studies of the active layer in a terrace to the west of Centrumso (Chiron and Loubière, 1988).

As far as is known, the next dedicated caving expedition was that of the 5-man 2015 Northeast Greenland Caves Project (Moseley, 2016; Moseley *et al.*, 2016). The team, including Christopher Blakeley, Gina Moseley, Robbie Shone, Christoph Spötl and Mark Wright, operated from Centrumso (Fig.3), where they used a Zodiac inflatable to cross the 20km-wide lake from west to east. They then took three days to travel on foot to the caves discovered in 1960, where they had three and a half days of exploration. In total, 26 caves or cave relics were explored including the distinctive U-Shaped Cave (described in 1960) and the calcite-bearing cave on the west wall (Davies and Krinsley, 1960; Moseley, 2016).



Figure 3: Members of the 2015 expedition take shelter in a US Army hut left at Centrumso from the 1960s. L–R: Chris Blakeley, Mark Wright, Gina Moseley, Christoph Spötl. [Photo: Robbie Shone.]



Figure 4: Note left by the original explorers in 1960, discovered during the 2015 expedition.

Besides exploration and documentation of the caves, the main purpose of the expedition was to collect samples of speleothem for pilot palaeoclimate research. This proved to be highly successful, because a sample of the 1960-described calcite was collected, along with 15 other calcite samples from other caves, thus demonstrating that there was extensive speleothem deposition during a time of milder climate in northeast Greenland (Moseley *et al.*, 2016). Additionally, the carcass of a gyrfalcon dated to 1,000 years ago was discovered in the rear of a short cave (Moseley *et al.*, 2019). The highlight of the expedition, however, was finding a note written by the original explorers (Fig.4), which had been left underneath a small cairn in the cave of the west wall. The note was so well preserved that it had the appearance of being written “only yesterday”. It was protected inside light-sensitive foil film packaging and placed inside a yellow Kodak film box dated ‘develop before Dec. 1961’ (Fig.4).

In a departure from northeast Greenland, Christopher Blakeley, Gina Moseley, and Robbie Shone visited the Wegener Halvø peninsula (Lat: +70°; Fig.1) during 2018, as part of the EAGRE18 (EAsT GREenland) Greenland Caves Project expedition. In order to reduce the carbon footprint of the expedition, the team sailed from Iceland to Greenland with the Top to Top Global Climate expedition. Unfortunately, a difficult year with sea ice meant that the team swapped to helicopter for the final part of the journey; something that they had hoped to avoid. Already tired from the many days on the boat, which included continuous iceberg watches in rotations, the sleep-deprivation continued as they undertook watches for polar bears. Given the delays in travel, they managed only two full days of surface exploration in search of caves. Details of specific targets had been provided by a geologist who had previously worked on the peninsula. Unfortunately, the potential leads yielded no caves (Moseley and Blakeley, 2020).

Funded by a substantial grant from the Austrian Science Fund (project no. Y 1162-N37), the Greenland Caves Project returned to the Centrumso region in 2019 (Fig.5) (Moseley *et al.*, 2020). The interdisciplinary team included: Hazel Barton (geomicrobiologist), Christopher Blakeley (rigging expert), Peter Hodgkinson (doctor), Adam Ignéczi (glaciologist), Gina Moseley (leader and palaeoclimatologist), Robbie Shone (photographer and filmographer), Paul Smith (geologist), Andrew Sole (glaciologist), and Paul Töchterle (geologist). Additionally, extensive in-field support was provided by Stig Erick Bjerkenås (pilot) and Hans Christian Sivertsen (mechanic).

The main objectives of the 2019 expedition were to: (1) collect speleothem samples for use in palaeoclimate reconstruction; (2) measure sedimentary sections across the Ordovician–Silurian boundary and collect stable-isotope samples to improve

understanding of the end-Ordovician glaciation and extinction event, 445 million years ago; (3) improve the detailed geological mapping around the caves to elucidate the speleogenetic constraints; (4) investigate the former ice sheet extent through dating of glacial erratics and eroded bedrock; (5) investigate the geomicrobiology of the caves to help determine the mechanisms that allow microbial survival in these cold and dry caves; (6) undertake the first entomological study of this region; (7) survey the larger caves using the latest digital techniques, including photogrammetry; (8) explore the area for previously undiscovered caves and investigate and map them where found. The team operated from three consecutive basecamps (Moseley, 2020a). Camp 1 (Lat: +80.38°, Long: –21.74°; Fig.1) was established on 04 July, 2019, in the vicinity of the south Grottedal caves explored in 1960, 1983 and 2015 (Davies and Krinsley, 1960; Loubière, 1987; Moseley, 2016; Moseley *et al.*, 2020). Because extensive exploration of these caves had previously been undertaken, only one additional cave was explored in this area during 2020 (Moseley *et al.*, 2020). The cave team otherwise focussed on speleothem collection from Crystal Palace Cave (GD-19) and Flowstone Bridge Cave (GD-17), in addition to several other objectives. Ignéczi, Smith and Sole worked on geological mapping and glacial geomorphology.

On 08 July 2019, Camp 1 was dismantled, and the team remobilized to Camp 2 (Lat: +80.10°, Long: –22.52°; Fig.1) via helicopter. Camp 2 was established southwest of Centrumso in the vicinity of a former camp used by the geological mapping campaign in 1994 and 1995. This camp allowed access to Grotte des Quatre (Loubière, 1987; Moseley *et al.*, 2020) and the surrounding area for further investigation. No other caves were discovered near this locality, despite utilizing air support to cover more ground. From Camp 2, the helicopter was used to make a day trip to a cave-bearing canyon that had been discovered by Smith and Bjerkenås during the initial Camp 1 mobilization. Specifically, some members explored Cove Cave (*Eqik Qaarusussuaq*; Lat: +80.25°, Long: –21.93°) that had been spotted from the helicopter and shown to have a large entrance with an ice floor (Moseley *et al.*, 2020). While exploration of Cove Cave took place, Ignéczi and Sole, and Smith and Hodgkinson used the helicopter to reach distant field sites located at north Centrumso and Sæfaxi Elv (Fig.1) respectively. On 12 July 2020, Camp 2 was dismantled, Camp 3 established, and Ignéczi, Smith and Sole departed from the expedition. The location of Camp 3 was revised from the original plan of placing it on the north side of Grottedal (Fig.1); instead, Camp 3 (Lat: +80.26, Long: –21.91; Fig.1) was established within the newly-discovered canyon that hosts Cove Cave. Several tens of cave entrances had been observed during aerial reconnaissance in this canyon, thus it appeared to be a more promising base for the final few days of the expedition.

During the expedition, the father of one of the team members died; hence the newly discovered canyon was named PRB Canyon, in memory of Peter Rodney Blakeley (Fig.1). Two days were spent on foot exploring PRB Canyon. The first day, exploration took place from river level, which proved extremely difficult because it was difficult to see cave entrances from below. The second day, the remaining six expedition members split into two teams with Barton, Hodgkinson and Töchterle exploring from the top, whilst Blakeley, Moseley and Shone explored from the bottom. The primary focus of the latter team was to photograph Cove Cave, which (despite having GPS coordinates) proved extremely difficult to locate on foot, resulting in the loss of several hours. It was 6pm by the time it was relocated. PRB Canyon was left with many potential leads; there simply was not enough time for investigation of the many entrances that open out into this canyon. On two other days, the helicopter was again utilized for aerial reconnaissance, resulting in the discovery of several caves on the north of Grottedal (close to the original planned site for Camp 3), as well as yet another canyon riddled with caves, this time to the south of Grottedal, c.1.5km west of Camp 1. Like PRB Canyon, this as-yet unnamed canyon was left with tens of unexplored cave entrances.

Summary

Northeast Greenland is an extremely remote and hostile land that now has no indigenous population. Because of the difficulties in mounting expeditions to this region, the coast of northeast Greenland remained the last part of Greenland to be mapped – finally completed only at the start of the 20th century. Since then, the legacy of the ill-fated Danmark Expedition has left Arctic explorers with many questions and a continuing sense of admiration and wonder. Geological mapping was the central focus of most expeditions in the Centrumso region during the mid to late 20th century, leading in 1960 to the first discovery of limestone solution caves (Davies and Krinsley, 1960). A return expedition to the caves in 1983 led to the discovery of an isolated but comparatively complex cave southwest of Centrumso (Loubière, 1987). Loubière also attempted palaeoclimate studies but found that the speleothem is too old to date using ESR methods. The most recent dedicated caving expeditions to the region were in 2015 (Moseley, 2016) and 2019 (Moseley *et al.*, 2020). In 2015, the caves that were discovered in 1960 were investigated and a further fourteen caves or cave relics explored. The 2019 expedition added to the knowledge of Greenland's caves through the discovery of several passages on the northern side of Grottedal, plus two previously unknown cave-bearing canyons that are riddled with caves and full of unexplored leads.

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Figure 5: In 2019, Paul Smith looks at the remains of the 1960s US Army hut at the end of the Centrumso landing strip. [Photo: Robbie Shone.]