RETURN TO

VATNAJÖKULL

1932 · 2019

Expedition Report

Oliver Vince, Glen Gowers and John-Henry Charles

www.sledgereport.com

Into the unknown. John-Henry and Glen push on through whiteout conditions during our first traverse of the Vatnajökull Icecap.

John-Henry, Oliver and Glen on the summit of 'Dome 1' on the Northern side of the Vatnajökull icecap. The cairn in the foreground is where the handwritten note from the 1932 expedition was found.

Our camp seen from above. This tent served functioned as a fully functioning laboratory for the first ever example of fully off-grid DNA sequencing.

The team relaxing at basecamp after achieving our historical, scientific and mountaineering objectives.

Our camp on the coldest night of the expedition: mid-way through the return icecap traverse.

The final sunset of the expedition. The sun barely dipped below the horizon before rising 20 minutes later.

The darkest that it got on the final night of the expedition

Contents

1 Introduction

Early in 2018, we discovered the diary of the 1932 Cambridge Expedition to Vatnajökull. This diary contains a superbly written and entertaining account of an incredible adventure undertaken by a team of undergraduates during the summer of 1932. Against the odds, and with no prior polar experience, this team of six completed the first double crossing of Europe's largest icecap unassisted and unguided. Soon after the discovery of the diary, we found their scientific publications, their maps and their photographs from the expedition.

These discoveries sparked an idea that, through a combination of long hours, determination and luck, led to the most formative project that any of us has been a part of.

Due to the inaccessibility and hostile conditions on the Vatnajökull, the area that the 1932 team studied is visited extremely rarely. Our plan was to repeat the 1932 expedition as closely as practically possible in 2019. Among other aims, we planned to follow their route unguided and unsupported, rediscover evidence that they left behind and push the boundaries of expedition science as they did. Retaking their photographs and resurveying their basecamp would also give us an insight into any long-term changes taking place in this unique environment.

We are proud of our expedition results. Our scientific programme represented a step-change in the field of remote DNA sequencing, with our findings published in the scientific journal '*MDPI Genes*'. Amongst other successes, our historical programme re-discovered a handwritten note that the 1932 team had left in a cairn at their basecamp on the northern edge of the icecap. Most importantly, we all returned safe and happy.

This expedition was much more than the highs and lows of our time on the ice. The training, fundraising, promotion, logistics and research challenged us in multiple dimensions. These challenges have developed us all as individuals and as a team.

This expedition would not have been possible without a great number of people, to whom we are truly grateful. A full list of these people can be found later in this report.

This report is intended to provide the reader with a comprehensive overview of the Return to Vatnajökull Expedition 2019. We hope that it also provides a flavour of the journey that we were incredibly fortunate to experience, along with an idea of the time and effort required to organise a successful expedition on this scale.

If you are using it as a basis for planning your own expedition or have any other feedback, please do not hesitate to get in touch. We would be happy to provide as much advice and assistance as we are able to.

2 Expedition Overview

2.1 Aims and objectives

This expedition set out to repeat both the physical route and the scientific expedition spirit of the 1932 Cambridge expedition to the Vatnajökull icecap in Iceland. Our expedition had three key aims.

2.1.1 Historical aims

The 1932 team spent 7 weeks on the icecap, plus several weeks either side on the south coast of Iceland. During their time in Icelandic civilisation, they met with many local people and took a diverse range of photographs that show the livelihoods of the Icelanders in the 1930s. Whilst on the icecap, they took many more photographs and recorded their adventures in their diaries. Our expedition's first aim was to repeat their route as closely as possible and visit the key locations of the 1932 expedition. We aimed to discover any records of their visit that remained both on the south coast and at their basecamp. We also aimed to connect with the environment and retake as many of their photographs as possible.

2.1.2 Scientific aims

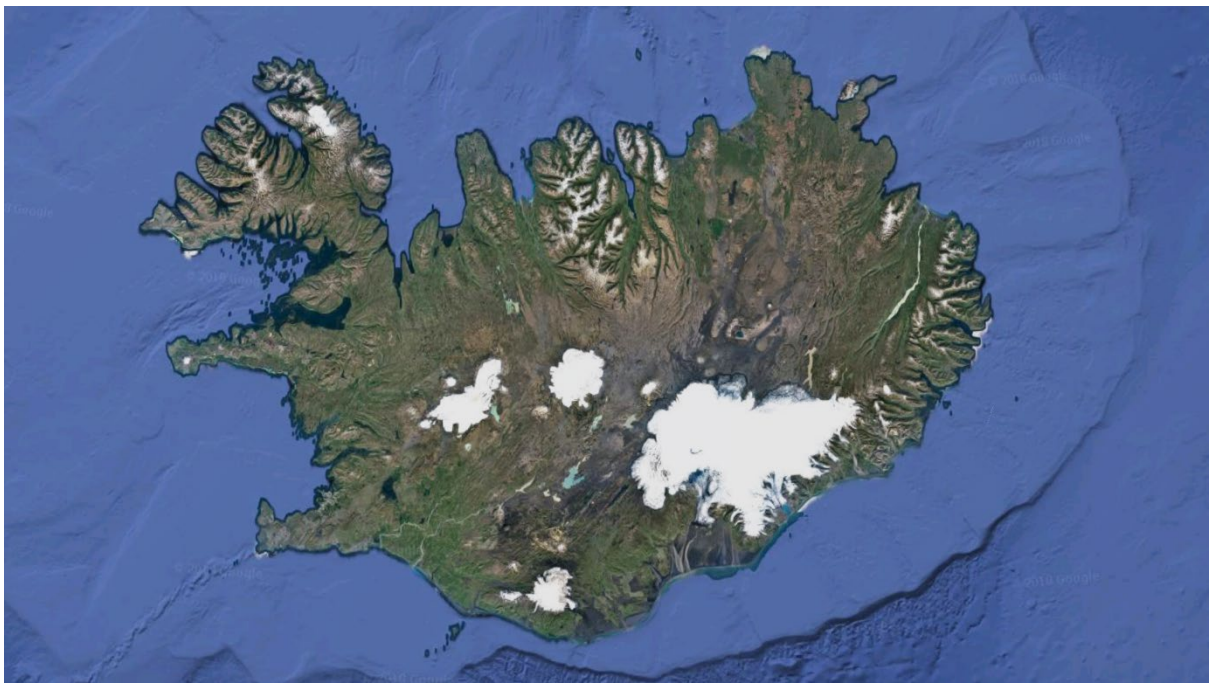
A major focus of the 1932 expedition was scientific data collection. At their basecamp on the northern edge of the icecap, they conducted detailed botanical, ornithological, glaciological and geological surveys. They also drew detailed maps of this unique location. Our expedition aimed to conduct environmental surveys that would provide an insight into any long-term changes taking place in this rarely visited landscape. We also aimed to push the boundaries of expedition science by becoming the first team to conduct fully off-grid microbial DNA sequencing. Developing this technology opens the door to increasing our understanding of the vast range of life forms that exist in the most remote corners of our planet. Over 99% of the microbes that exist on this planet have yet to be discovered. This technology has the potential to change that.

2.1.3 Adventure and personal development aims

Before we began the expedition planning process, our team possessed limited relevant experience for independent polar travel. Our aim was to travel unassisted and unguided in one of the planet's most hostile environments as the 1932 team did before us. This presented enormous personal and team challenges in almost every way.

2.2 Location

The Vatnajökull Icecap forms an 8000km^2 frozen plateau between Iceland's two highest mountain ranges. Due to Iceland's position in the Atlantic Ocean and the icecap's proximity to the coast, the Vatnajökull is associated with unpredictable weather including extremely high winds and heavy snowfall. As we discovered on our expedition, it can also rain heavily, even in the middle of the icecap. Situated in the south eastern corner of Iceland, the Vatnajökull is Europe's largest icecap.



A satellite image of Iceland. The Vatnajökull Icecap can be seen in the south eastern corner of the country. The icecap occupies almost 10% of the surface area of Iceland.

The Vatnajökull provides an ideal location for expedition teams looking for an affordable place to develop their experience of polar environments. It has many of the environmental characteristics of the polar regions, but it is much cheaper to access. Additionally, the presence of an excellent search and rescue (SAR) service and a lack of polar bears makes travel gaining experience significantly safer than elsewhere.

2.3 Overview of expedition findings

2.3.1 Historical findings

Our historical rediscovery began in the town of Höfn on the south eastern corner of the icecap. This was where the 1932 team landed in Iceland - we found records of their visit in the local museum and library, along with the buildings that they stayed in pre-icecap.

Note from 1932 team, found inside a tin in the cairn on Dome 1

Our guide onto the icecap was the grandson of 1932 team's guide. During our expedition, we read their published diary "An Iceland Adventure" in real time as we experienced the same locations.

On the northern edge of the icecap, we scaled 'Dome 1', a totem looming over the 1932 basecamp. In a cairn on the summit we found fuel cans and, inside, a sealed tin containing a handwritten note from the 1932 team. This was a historical artefact that had never been seen before (confirmed by the National Park). We were also able to retake several of their photographs and re-map the glacial lake, Thorbergsvatn.

2.3.2 Scientific findings

Our microbial sequencing effort saw us shrink a DNA sequencing laboratory into a lightweight and small enough form to fit into the back of a sledge. This was designed as a modern twist on the flora and fauna surveys conducted by the 1932 team. We

achieved over 24 hours of microbial DNA sequencing on the ice cap, comparable to what would be expected in a full-size laboratory. All power for this was derived from solar energy ensuring this kind of experiment could be run repeatedly during the expedition. This work has resulted in a peer-reviewed publication (Appendix VIII). This can be found at: https://www.mdpi.com/2073-4425/10/11/902

All microbial sequencing was conducted within the confines of this tent. Prior to this, the laboratory had been transported across the entire icecap in the back of Glen's pulk.

2.3.3 Adventure and personal development

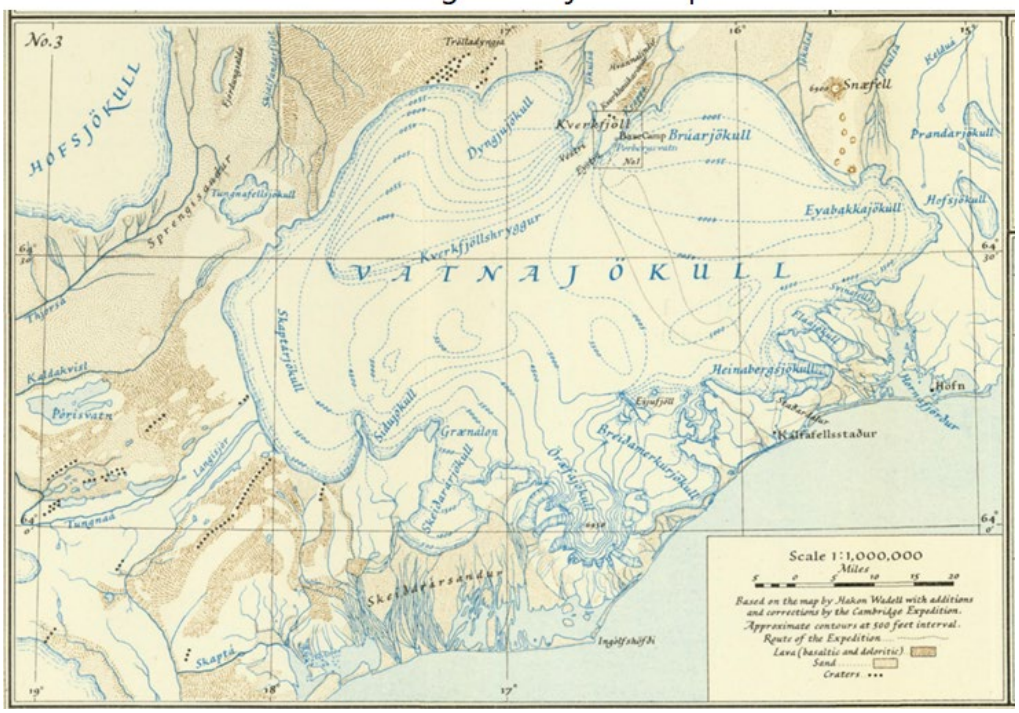
This expedition tasked us with organising a project on a much greater scale than anything we had experienced before. Prior to the expedition, sourcing sufficient funding, adequate training, and logistical arrangements proved a steep but invaluable learning curve. During our time on the icecap, fresh challenges developed minute by minute and forced us to respond accordingly. Having no guide or team member experienced in polar travel meant that this placed a sizable mental strain on the whole team. Kudos goes to the whole team for channelling this strain into problem solving and a constant cheerful, 'can-do' attitude. Protecting the delicate scientific equipment from the elements meant that we developed a conservative approach to progress – keeping ourselves well fed and well rested took priority over distance covered. In the end, this enabled us to achieve every single expedition objective and allowed us to live safely and without mishap for an extended period of time.

Living in such close proximity for an extended period of time whilst dealing with the mental strains of life on the icecap could have created friction between team members. However, our time in the tent was thoroughly enjoyable due to the constant good humour of the team.

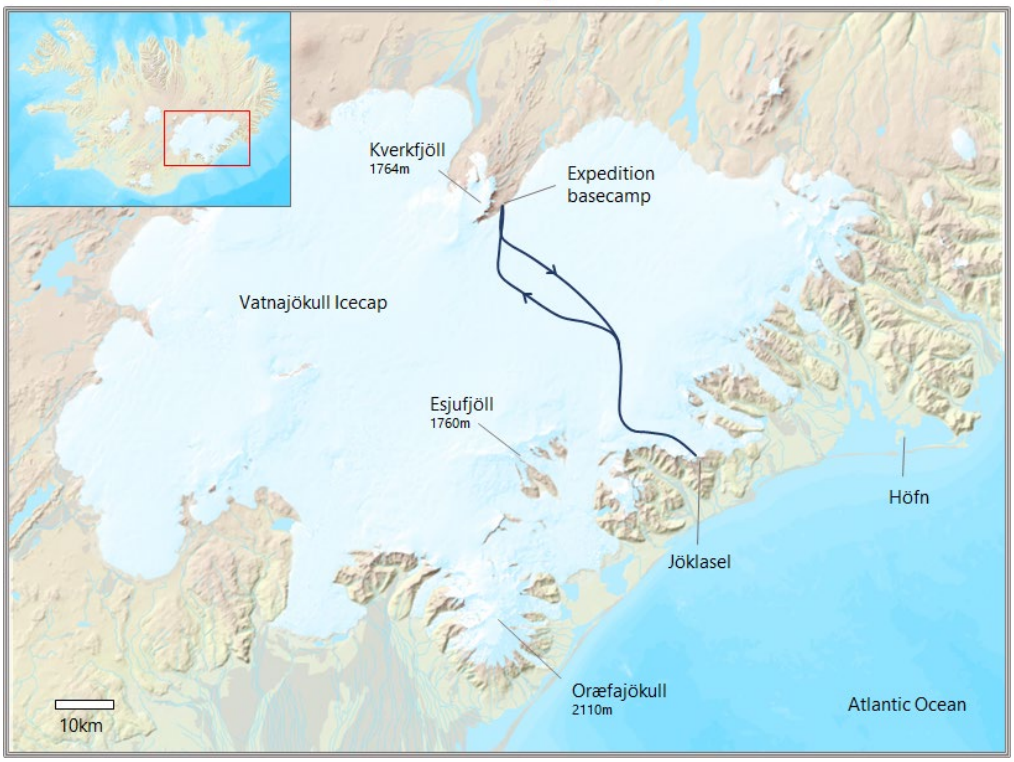
3 Expedition maps

3.1 Whole route maps

Route of the Cambridge Vatnajökull expedition 1932

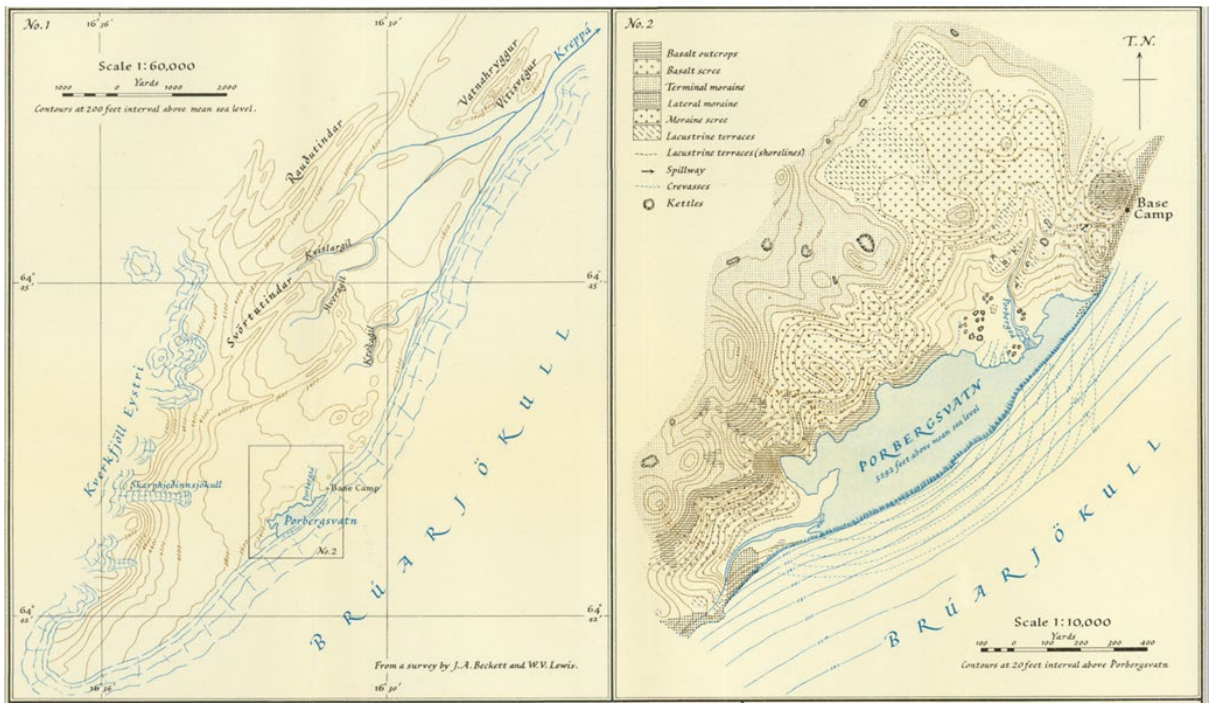


Route of the Return to Vatnajökull expedition 2019



3.2 Basecamp maps

Basecamp of the Cambridge Vatnajökull expedition 1932



Basecamp of the Return to Vatnajökull expedition 2019

4 Team

Our team consisted of three friends with a passion for the outdoors who met whilst studying together at University. The complementary strengths and good-humoured, competent nature of the team was the bedrock upon which this expedition's successes were built.

4.1 Oliver Vince - Expedition Leader

Oliver's aims were to travel and live safely and comfortably in the harsh environment of an icecap. Before starting the expedition, Oliver had experience leading climbing and mountaineering expeditions in the UK and Alps, as well as expedition experience in the Atlas Mountains and the Malaysian Rainforest. More broadly, Oliver had led a wide range of projects, experience that became invaluable during the organisation and fundraising parts of this project.

Oliver was primarily responsible for the overall logistics and fundraising of the expedition, along with the historical research elements and the 3D aerial mapping. As adventure filmmaking is a personal passion, Oliver also took primary responsibility for the film and photography aspects of the expedition. Oliver graduated with a degree in Engineering Science in 2016 and is currently finishing his PhD in cancer research.

4.2 John-Henry Charles - Technical Lead

John-Henry's primary aim for the expedition was to develop his polar experience, to build a platform for further expeditions in the future. John-Henry is also interested in guiding and wanted to continue to develop some of the technical skills for this profession. John-Henry took responsibility for route-planning, cooking, and safety - basically trying to ensure there were no major worries to distract Glen from his science and Oli from his filming.

Having previously completed an unsupported ski crossing of the Hardangervidda, with time spent on two Arctic expeditions (to Svalbard and the Canadian High Arctic), John-Henry had the most polar travel experience of the team. He also has extensive climbing and mountaineering experience across Europe, Middle East and North Africa, leading up to E1 Trad and IV Scottish Winter. He had also completed long-distance cycles (including UK to Istanbul and the length of Norway). He completed his Earth Sciences Degree in 2016.

4.3 Glen Gowers - Scientific Lead

Glen sought to combine his two major interests; the outdoors and biochemistry to execute a scientific programme inspired by the 1932 expedition. Using skills developed during his PhD in Biotechnology, he aimed to identify microbial communities at the 1932 basecamp, using a miniaturised solar-powered DNA sequencing laboratory.

Glen has previous experience on offshore sailing expeditions and other expedition experience in the UK, Alps, and Tanzania. In addition to the scientific work, Glen was determined to upskill his polar skills including nordic skiing, pulk pulling, and snow campcraft.

5 Acknowledgements

This expedition could not have been a success without the support of the following individuals.

Firstly, we would like to thank our respective partners, Jojo, Khristy, and Sian, for their support during the planning and expedition phases.

After landing in Iceland, Sam Cornish, Joe Cornish, and Daniel Bergmann offered unrivalled logistics support in the most oversized (but entirely appropriate) vehicles. Such good-humoured friends were very welcome for calming our nerves in the days immediately before departure onto the icecap.

We are extremely grateful to the whole team at Glacier Jeeps for their patience when providing us with advice prior to our arrival in Iceland and their reliability and competence when guiding us onto and away from the expedition start point. We owe particular gratitude to Bjarni and Bjarney (especially for being willing to appear on camera!). The team at the Höfn Glacier Museum were very helpful in digging through their archives for records from 1932. The filming and scientific programmes of this expedition would not have been possible without the support and permits from the Vatnajökull National Park, for which we are also extremely grateful.

We are very grateful to Harris for his efforts towards this expedition early on, including on our Chamonix training trip. Richard Mansfield deserves special thanks for putting up with us in Chamonix and providing us with crucial glacier travel training. Declan and Phillipa from the Alpine Ski Club offered fantastic advice on the practicalities of the Vatnajökull. We are extraordinarily grateful (in hindsight!) for suggesting camping on the cairngorm plateau in a storm in January as an adequate proxy for the Vatnajökull. This turned out to be the most valuable training trip we could have had.

Our scientific microbial sequencing work could not have been possible without the help and support of Arwyn Edwards who from day one offered invaluable advice for converting a laboratory to something that could be carried on a sledge. Special thanks to Sara Rassner and Andre Soares for their help during a scientific training trip to Abersytwyth. Ingeborg offered fantastic local scientific knowledge before and after the

expedition, for which we are extremely thankful. And finally, a thank you to Tom Ellis who allowed us to borrow his laptop and for continued scientific support.

We are enormously grateful to all of the funding bodies that supported to this expedition (see section 12) - without this support, nothing in this report would have been possible. A particular note of thanks should go to Lorraine Craig, of the Imperial Exploration Board, who was an early advocate for this expedition and offered regular and invaluable advice throughout the planning phase.

Mark Walker from Exped Adventure taught John-Henry how to camp on snow and ice during his traverse of Hardangervidda in Norway, and gave all sorts of tips on how to engage and survive in very cold places.

Additional thanks to Nick Putnam, Mark Walker, James Lam, Will Hartz and Mike Searle for their combination of advice and advocacy.

We would additionally like to offer a note of thanks to previous expeditions that provided detailed reports. It cannot be overstated how helpful detailed reports of similar expedition can be to avoid reinventing the wheel at every turn. Particular acknowledgement to Spitsbergen Retraced 2016 and the British Stauning Alps expedition 2017. We sincerely hope that this report can prove as useful a resource as we found these previous expedition reports.

6 Historical discovery

6.1 1932 Expedition

In July 1932, 6 undergraduates from the University of Cambridge with no prior polar experience made the first double crossing of the Vatnajökull icecap in the south eastern corner of Iceland. In just over a month, the team used pack ponies, skis and their feet to travel unsupported over 120km on the icecap and then a further 60km into the volcanic desert to the north of the glacier.

Storms, the summer melt and failing equipment made their journey incredibly tough going and prevented them from achieving all of their original expedition goals. Despite this, they were the first team to spend any length of time in this area and subsequently returned with a wealth of geological, glaciological, ornithological and botanical information along with the first accurate maps of the area and a collection of over 200 stunning photographs of their expedition. Their published account of the expedition describes their journey in graphic detail.

The 1932 team consisted of explorers who went on to excel in all walks of life. The team was led by Brian Roberts, an explorer and diplomat who played a key role in the conception and development of the Antarctic Treaty. The team also included William Launcelot Scott Fleming, an explorer who went on to be a director of the Scott Polar Research Institute and Chaplain to the Queen. Both men were recipients of the Polar Medal for their roles on the British Graham Land Expedition.

6.2 Bibliography

Before departing on the expedition, we consulted a variety of sources related to the 1932 expedition. This included visiting the Scott Polar Research Institute in Cambridge where all of the original correspondence, news articles and diaries from 1932 are held.

Sources of information on the 1932 expedition include:

- The original expedition diary of B. B. Roberts, the expedition leader, held at the SPRI in Cambridge.
- An Iceland Adventure, J. A. Beckett (the team's personal account of the expedition, published as a book). We took a copy of this on the expedition and read it in the same locations.

- The Cambridge Expedition to Vatnajökull, 1932, B. B. Roberts, J. A. Beckett, W. V. Lewis, F. W. Anderson, W. L. S. Fleming and P. Falk, The Geographical Journal, Vol. 81, No. 4 (Apr., 1933), pp. 289-313 (the scientific papers of their expedition plus a transcript of a discussion at an evening meeting of the Royal Geographical Society about the expedition with Admiral Sir William Goodenough)
- The Cambridge Expedition to Vatnajökull, Emmanuel College Magazine 1931-32 28(1) 13-17, held at the SPRI
- Iceland papers Volume 1. Scientific results of Cambridge Expeditions to Iceland 1932-38, B. B. Roberts

The full collection of photos taken by the 1932 expedition can be found here: https://www.spri.cam.ac.uk/picturelibrary/catalogue/cev1932/gallery/

6.3 Pre-icecap findings

We met several people in both Höfn (at the Glacier museum and in the library) and Vagnnstadir who knew of the 1932 expedition. Most notably, the team at Glacier Jeeps (Bjarni and Bjarney). Bjarney was, in fact, the grandson of Skarpajeddin, the guide for the 1932 team. We had the pleasure of interviewing Bjarney and looking at old photographs and incredibly, skis left behind by the 1932 team. We were dropped off on the ice-cap by a living connection to the 1932 team, making for quite a special expedition start.

6.4 Icecap

Our main reflection from our time on the Icecap with regards to the 1932 team is that they must have had a much tougher experience than us (and were probably just much tougher people). Their equipment paled in comparison to what we were fortunate enough to bring (notably food, navigation, safety communications, tent, waterproofs).

In addition, satellite imagery and access to accounts from people who have previously visited the icecap allowed us to make better preparations than they ever could have done. Decades of climate measurements advised us to conduct our expedition in April, thus avoiding both the summer melt and the worst of the winter storms. The 1932 team went in July/August during the worst of the summer melt and had to travel by night to avoid falling into pools of meltwater. Nowadays, no-one ventures into the middle Vatnajökull during the summer. We hardly saw any crevasses, whereas they

record multiple incidences where they nearly lost either team members or critical equipment into cavernous crevasses.

6.5 Cairn

In the 1932 diary, they mention that they left a 'record of their visit' in the Cairn on the top of 'Dome 1'. Before departing, we weren't sure of the exact location of Dome 1 - it is not apparent in satellite imagery nor is it marked on any subsequent maps of the area. We arrived at the northern side of the ice cap in thick fog and set up camp for the night. When the skies cleared in the following morning, we happened to be camped only 2km from a large dome, unmistakably resembling the photos from 1932.

The 2019 team on top of the 'Dome 1' (named by the 1932 team).

We scouted a route off the ice cap (probing for crevasses as we went) and scaled the dome. To our amazement a noticeable cairn was clearly visible. Moving aside a few of the rocks, we found a pile of weathered fuel cans. Though we were nearly certain this was from the 1932 team we didn't want to get our hopes up until we had good proof. After some careful excavation, we found a sealed "24-hour ration Horlicks Malted Milk Tab" tin, caked in rust. Gently removing the rubber sealing we found a waxed note

inside. This note contained a record of the names, college affiliations, and expedition roles of each of the 1932 members. Fantastically, though, a handwritten sentence survived at the top of the note reading "Camp on lateral morraine below this point from July 14th-28th 1932".

A Horlicks tin in which a note was stored

The note. The handwriting at the top reads 'Camp on lateral moraine below this point from July 14th-28th 1932'.

6.6 Re-photography

We were able to repeat many of the 1932 team's photos. These include photographs of the landscape and of their day-to-day experiences during the expedition. A few of our best repeats are included here.

Unpacking the tent

Resting on the approach to Kverkfjöll

'Chilling'

'Posing'

The cairn containing the note from the 1932 team (on 'Dome 1')

Skarpjedinsjokull: the glacier that the 1932 team named after the guide who showed them the way onto and away from the icecap on the south coast. This glacier tumbles almost vertically from the summit of Skarphedinstindur (also named after their guide), Iceland's second highest peak (at 1936m). This peak is the highest in the Kverkfjöll range. As the 2019 photograph is taken in April (not July), there is more snow. However, the glacier tongue has still visibly shrunk over the past 87 years.

7 Microbial research

This work has been published in an open access and peer-reviewed journal, MDPI Genes in the '*Metagenomics in situ*' Special Issue (Appendix VIII): https://www.mdpi.com/2073-4425/10/11/902. Research permits are shown in Appendix VII.

7.1 Background

Travelling to the remote northern edge of the Vatnajökull ice cap in 1932, little was known about the flora and fauna of the region.

"Our object was to study all the forms of life, both floral and faunal, inhabiting a given area"

The Cambridge Expedition to Vatnajökull, 1932, The Geographical Journal Vol 81, 4 (1933)

Their inquisitive and thoughtful characterisation of the life in this remote region was a source of inspiration for our expedition. Where they contributed new insights into the types of visible life found in the remote northern region we decided to turn our attention to characterising the little known world of life invisible to the naked eye. Microbes (bacteria, and other single celled organisms) play an enormously influential role in ecosystems. Only recently have we appreciated their abundance and importance in extreme polar environments. Our ability to study these organisms has thus far relied upon taking samples back to a laboratory where DNA sequencing can be conducted to identify species. A major drawback to this approach is the propensity for samples to change and degrade over time. As we aim to study more and more remote corners of the earth the time between sample collection and analysis grows, increasing the chance of sample alteration or degradation significantly. The result of this is well characterised microbial communities in close vicinity to Western research institutions but a lack of data representing the rest of the globe, particularly the most inaccessible regions. Recent developments in DNA sequencing technology has resulted in a handheld device that can plug into a laptop. This step change in technology has allowed researchers to take these devices to remote places and demonstrate that DNA can be sequencing *in situ*, eliminating the need to take samples. To date, however, such endeavours have made use of significant infrastructure, such

as generators and vehicles. We saw an opportunity to demonstrate the ability to conduct DNA sequencing entirely off grid, out of a sledge, using solar power alone. In demonstrating this we hoped to create a blueprint that could mean anyone could sequence, and characterise, any microbial community in any remote corner of the planet. And so, in the spirit of the 1932 team, we aimed to meaningfully contribute to the scientific community by developing the field of expedition science.

7.2 Sequencing off-grid

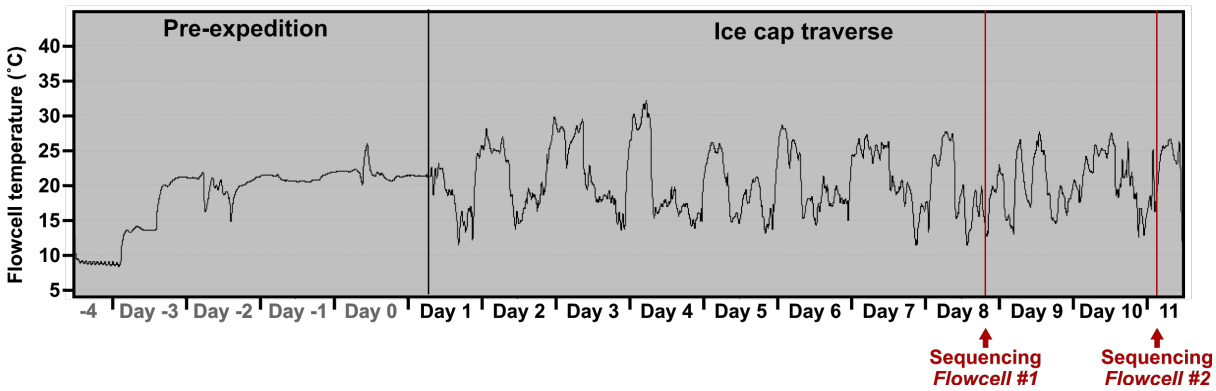
With modifications to our lab equipment we were able to fit the entire laboratory (excluding laptop and solar panel) into 2x 9L boxes that could fit widthways in the back of the sledge. The only pieces of equipment not transported in a sledge were the flowcells, the lab-on-a-chip devices that perform the sequencing. These were carried on our person for the whole traverse to keep them from freezing.

The contents of our 2x 9 litre boxes.

7.3 Preventing flowcells from freezing

A critical requirement for sequencing using Oxford Nanopore devices is to use 'active' flowcells. These devices plug into a laptop and are about the size of a smartphone. Flowcells, containing biological material, can rapidly degrade if allowed to freeze and it was therefore imperative to prevent the flowcells from freezing for 11 days while we

traversed the ice cap and prepared for the experiments at our base camp. During the outbound flight the flowcells were kept in a polystyrene box. This maintained a consistent temperature of 9˚C during transit. During the ski traverse, warm temperatures were achieved by placing the flowcells in a tupperware box and stringing this around Glen's neck. The temperature was monitored continuously using an aquarium thermometer with the probe attached to the outer edge of the tupperware box. Temperature could be regulated by moving the box between layers of clothing and layering more clothing on top. Interestingly, the wind direction and strength was a more significant factor than ambient temperature and windproof clothing layers were essential. At night the flowcells were kept inside the sleeping bag attempting to keep them upright as much as possible. Below is the temperature graph for the entire expedition showing that the temperature never dipped below 9˚C, thus validating this method for keeping them warm. Ambient outside temperatures reached a minimum of -16˚C during the expedition. Interestingly, at night the flowcells got *too* hot and at one point exceeded 30˚C, the limit recommended by Oxford Nanopore, thus validating the impressive thermal retention properties of the Mountain Equipment Lamina Z -30/34 sleeping bag and making for an uncomfortable nights sleep for both Glen and his flowcells.



Data from the temperature logger kept with the 2 flowcells during the expedition

7.4 Conducting solar-powered sequencing (solar-seq)

The final challenge once we could extract and prepare enough DNA was to maintain laptop power long enough to collect a meaningful amount of data. Oxford Nanopore sequencing runs a computationally intensive programme. This poses a problem where a normal laptop battery may only last a few hours in cold conditions. Ideally sequencing runs should continue for 24-48 hrs to obtain sufficiently large datasets. We opted for solar power to generate enough power to achieve this. We pre-charged 3x 20,000 mAh power banks using a Mobile Solar Chargers 90W solar panel which packs down to the size of a thin briefcase. This solar panel could easily achieve 21V, 3A

(~60W) during the long days, even in cloudy conditions. During the sequencing run, the PowerAdd battery was plugged into the solar panel continuously and simultaneously connected to the laptop when required to maintain laptop charge between 60-80%.

7.5 Results

We extracted DNA from a soil sample collected from the Hveragil hot spring gorge just north of the ice cap. Our DNA extraction protocol yielded 6.5 µg of DNA in total, a high enough quantity to perform Nanopore sequencing. We first ran a proof-of-principle sequencing run which aimed to only use the laptop battery power. This allowed us to determine if the run was generating useful and meaningful data rather than just 'junk'. Following this successful run we used a fresh flowcell to perform data collection for as many hours as possible. Using the solar set up described above provided power from 8am – 6pm. We continued our sequencing effort using the remaining power banks for a further 9.5 hours (until 3.30 AM). Combined, these two runs achieved over 24 hours of sequencing, comparable to that expected in a normal laboratory.

7.6 Blueprint for future expeditions

We hope that the work here lays the foundations for future expeditions to add DNA sequencing to their scientific toolkit. We anticipate that in the future performing DNA sequencing should be as easy as taking anemometer readings and amateur expeditions provide a vital resource for scientists to obtain passive data from the most remote corners of the world. We encourage any upcoming expedition with a scientific programme that could accommodate DNA sequencing to contact Glen (glgowers@gmail.com).

8 Other scientific contributions

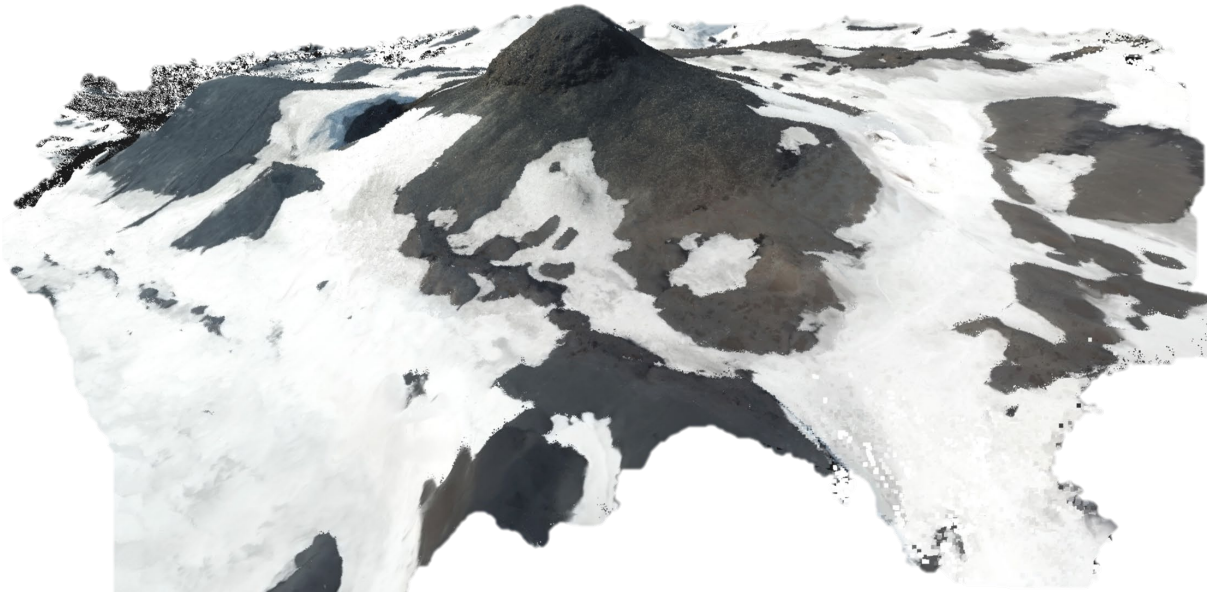
Our permit for the use of UAVs is shown in Appendix VII.

8.1 Drone mapping

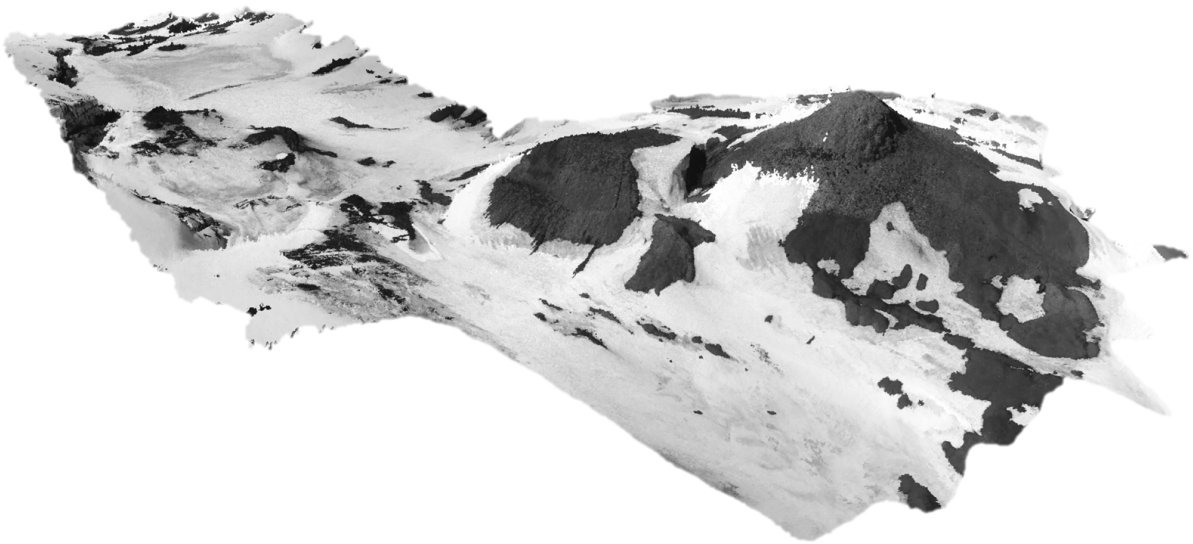
As a modern take on the basecamp surveys completed by the 1932 team, we were able to create 3D maps of several of the key locations around the basecamp; most notably Dome 1 and the Hveragil gorge. We believe that these maps are the first of their kind to be created of the area.

Whilst commercial software is available that can automate the path of drone flights, we preferred to maintain manual control to keep battery usage to a minimum and cope with any sudden changes in the weather. For Dome 1, an orbital flight was flown around the summit with a camera angle of 45° to the horizon. For Hveragil, the drone was flown in a line down the gorge (from above), with the camera pointing straight down. During both flights, the drone filmed continuously in 4K. Filming requires much less battery usage than stopping and taking photos at intervals and still achieved admirable results.

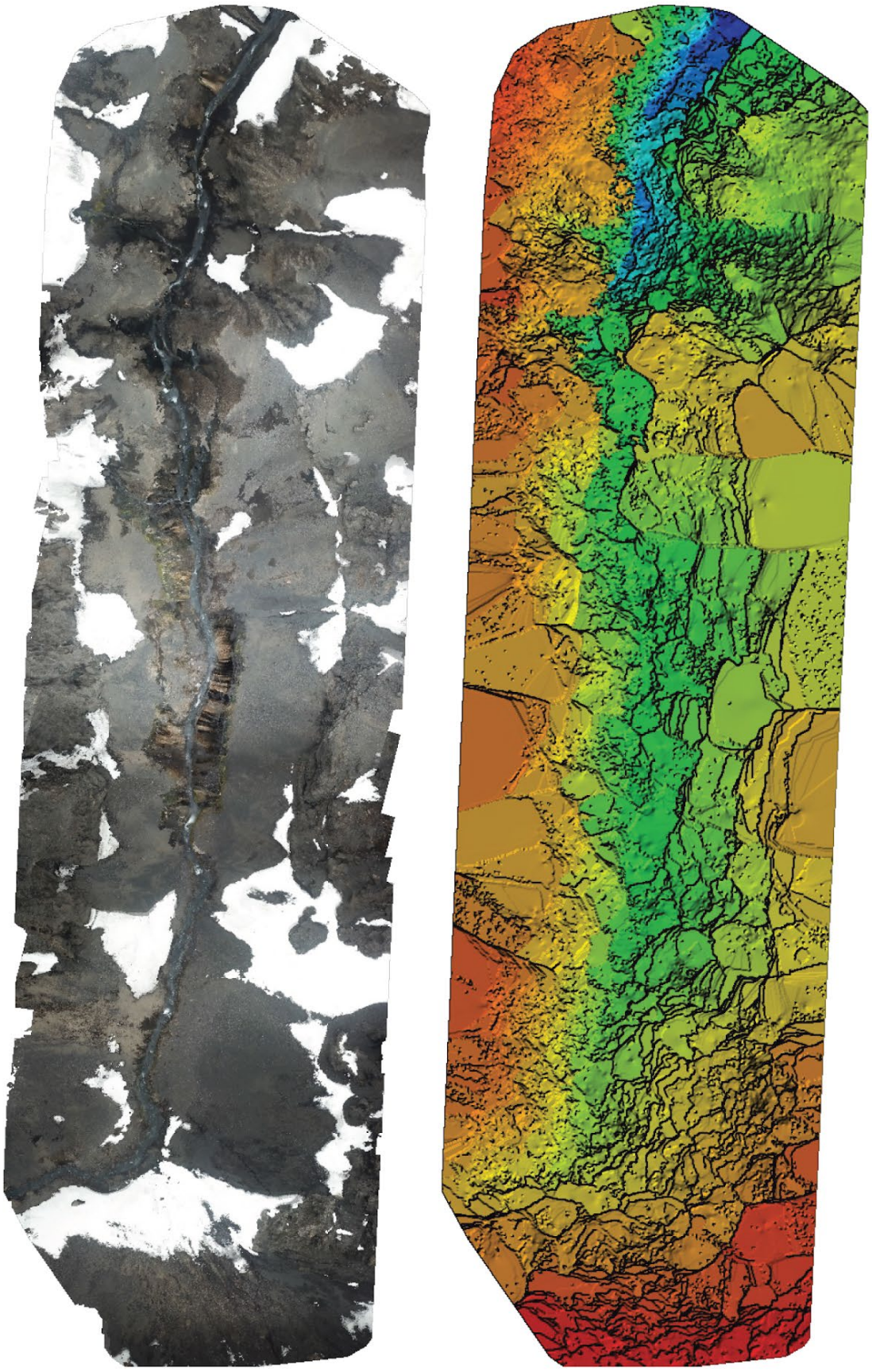
When back in the UK, sequential images (every 5 frames or so) were taken from the videos using Adobe Premiere Pro. These were then loaded into the Pix4d online software which created high resolution 2D, 3D and topological maps of the locations. These 3D maps provide an exciting visualisation of the dramatic locations that we visited and allow an accurate depiction of the site of soil sample collection. As an added bonus, it allows a small model of the locations to be 3D printed.



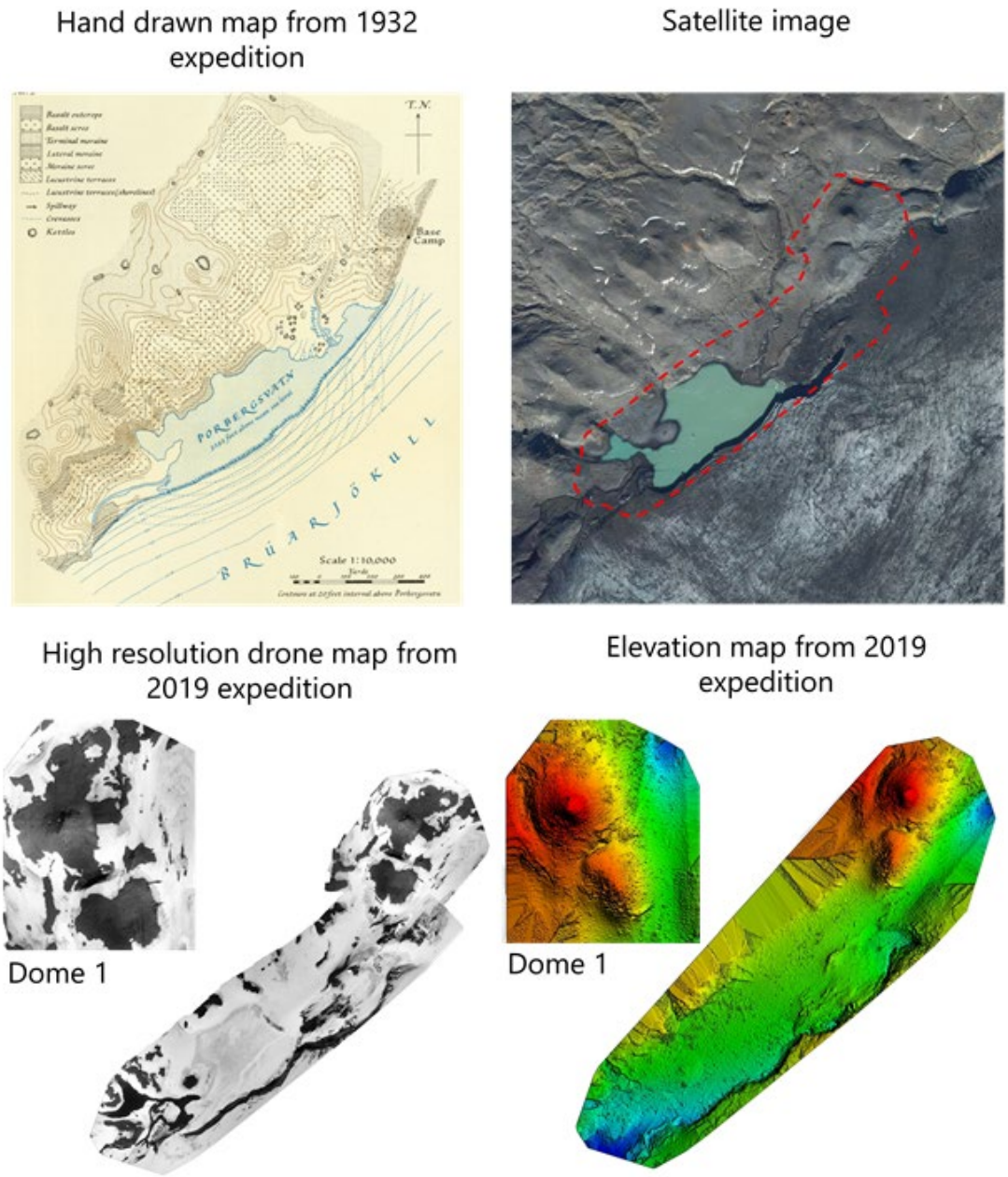
3D map of Dome 1



3D map of Dome 1 and Thorbergsvatn lake



Photographic and elevation maps of the Hveragil Gorge.



Comparison between the maps from the 1932 and 2019 expeditions. Considering that the 1932 maps were hand drawn from manual surveys, they are incredible!

8.2 Psychological surveys

As part of the scientific output of this expedition, we took part in a wider study into psychology on expeditions run as a collaboration between the University of Aberdeen, the University of Manchester, the University of Lancaster and NASA. This entailed each team member filling out a short psychological survey each morning and night of the expedition, along with a longer pre and post expedition survey. We are awaiting the aggregated survey results. To find out more, please follow this link: http://wp.lancs.ac.uk/expeditionpsychology/

9 Mountaineering

9.1 Kverkfjöll

In their 1932 book, the team end a chapter suggesting they are going to climb Kverkfjöll and begin the next chapter by saying they've got other plans. Our 2019 experience was not too dissimilar. Kverkfjöll looks beautiful and majestic from its eastern side but given our lack of experience at serious winter ascents, we decided it would be a challenge too far.

Coming onto the icecap roped up. Dome 1 can be seen in the mid-ground and Kverkfjöll in the background.

All routes up Kverkfjöll from the east appear to entail either engagement with quite heavy crevasses and steep glaciers (e.g. Skarphedinsjokull), or loose and crumbly basalt. That said, its natural beauty and isolation would provide an ideal challenge to more experienced mixed and winter mountaineers.

9.2 Svörtutirdar

From our camp, the clearest mountaineering objective in sight and within a reasonable distance (other than Kverkfjöll) was Svörtutirdar, a feature that the 1932 team named 'The Teeth'.

We spent a morning skiing to the base of the teeth, before John-Henry and Glen ascended to the highest point in two pitches whilst Oli flew the drone. The rock was crumbly and basaltic. We made an ascent up the most obvious line, following a chimney in the central section of the teeth up to the ridgeline, before following the ridge up to the summit.

John-Henry summiting the 'teeth'

The 'teeth' ridge

9.3 Lava domes

We made an effort to ski up many of the lava domes in the area. The results of our ascents and descents were spectacular falls on nordic skis, in addition to 360º photographs of the summits of some of the domes.

The 360º photographs of the dome summits have been uploaded onto Google Maps.

A selection of the 360˚ photos uploaded to Google Maps, allowing everyone to see where the 1932 basecamp was.

10 Filming and photography

From the start of this project, producing a film was a major goal of the expedition. More specifically, the aim of the film was to communicate our scientific findings to a wider audience, whilst maintaining the personal and adventure element that many research films lack. This was a major task; requiring time, patience and focus, particularly when capturing the more stressful times during the trip.

Our camera equipment was comparatively low budget, but allowed all practical camera angles to be captured without much disruption to the flow of expedition life.

10.1 Camera equipment reviews

- **Gopro Hero 6 Black** - waterproof and bombproof, bought for £250, this was the workhorse of the filming. All situations where other cameras would be ruined, it captures high quality (4K) footage - leaving it outside the tent overnight is not a worry. It has in built optical stabilisation (although the Hero 7 Black improves on this) which means that even handheld footage looks good. Due to its 3 microphones and noise cancelling software, it captured excellent voice audio even in the toughest conditions. People also react much more amicably to being filmed with a Gopro when compared to a larger camera.

- **Panasonic Lumix FZ82** - a 4K bridge camera bought for £200. With a lens capable of instantly switching between shooting with a 20mm wide angle to a 1200mm telescopic, this camera has impressive flexibility and capabilities when capturing events. In our experience, it is relatively robust, especially as the inability to swap lenses prevents muck from getting into the working parts of the camera. This also collected great audio without an external microphone and has good optical stabilisation. A highly recommended solution for covering all bases on a budget.

Oliver on top of Dome 1 with the Panasonic Lumix camera

Oliver attempting the photographic biathlon

- **Nikon J5 with a f1.8 prime lens** - allowed capture of footage with bokeh, to add a slightly more cinematic element to some of the footage.

- **Canon G7x** was more than suitable for the conditions we encountered and also captured excellent footage and audio.

- **DJI Mavic Pro** - definitely the most suitable drone for expedition filming due to its long range, stability in high winds and small, folding design. The Mavic is capable of a wide range of intelligent flight modes including 'follow me', 'orbit' and subject tracking, whilst providing 4K capability. Drones definitely add a unique perspective, but come with major cost and power requirements for an expedition. This Mavic was pre-owned by one of the team members who had ~3 years prior experience operating drones in similar environments. The drone batteries used a lot of power, and so were only charged when we had excess capacity. Key considerations are the effect of the cold on the battery performance, the ability of the drone to handle tough weather and obtaining necessary permissions for flights prior to expedition departure.

- **Tripods** - Gorilla pod and Manfrotto Compact Advanced tripod. The former allows flexible, rapid shooting. The latter was an essential for re-photography and more stable shots.

10.2 Tips for future teams

- Get people on camera. Asking questions like 'what are you doing?' or 'where are we?' leads to people behaving naturally on camera and lots of material for filming. People talking makes the most interesting film.

- Film everything, especially events that add to the story. Try and be filming before the event happens, or as soon after it starts as possible. This usually means having a small camera very readily accessible.

- Take lots of sd card space and battery capacity. Camera batteries weigh little, and a 256GB SD card can be bought for less than £50. This will allow you to film everything for months without opening the memory card slots or worrying about camera capacity etc.

- Get lots of different shots such as telescopic, wide angle, selfie, drone, timelapse etc.

- Stability is key. For a film, stable footage is a necessity, not an option. The drone has a gimbal built in, the Gopro and FZ82 both have optical stabilisation.

Gimbals are now relatively low cost, but if they are out of budget, just make you stand still when shooting.

- Cheaper, more robust cameras are better for this kind of environment. The saying goes that 'the best camera is the camera you have with you', but more realistically in extreme conditions, 'the best camera is the camera that you're willing to get out and dangle from your wrist without worrying about it'. Not thinking about the camera allows you to capture real emotions and real conditions.

- Practice. Our team had several years of filmmaking experience in similar environments and so understood the extra requirements that arise from producing professional level content in demanding situations.

Photography in cold temperatures requires commitment

11 Financial overview

Fundraising took place for a period of 12 months from April 2018 – April 2019. Here we summarise the sources of our funding and provide a breakdown of our costs to help guide future expeditions.

11.1 Grant funding

Inevitably expeditions often require a level of external funding to supplement personal contributions. The nature of this kind of endeavour requires significant expenditure in safety equipment, logistical support, technical equipment, and training. These costs can often be inflated and, therefore, inhibitory for young people. For this reason, many grants exist to lower the barrier to entry. We are enormously grateful for the support from these grants, both financial and otherwise. We applied for 23 grants and were successful in 11 of these applications (outlined below). Grant funding accounted for 62% of our total income.

11.2 Personal contributions

In addition to grant funding we met the remaining costs of the expedition through personal contributions. This amounted to almost £8,900 which represents 38% of total income.

11.3 Borrowed equipment

Costs were minimised where possible through borrowing equipment. The most valuable items borrowed or donated were:

- Tent (Hilleberg Keron 4GT with double poles) from the Imperial College Exploration Board
- Oxford Nanopore DNA sequencing kit from Prof Tom Ellis, Imperial College
- Laptop suitable for sequencing from Prof Tom Ellis, Imperial College
- DNA extraction kit and equipment from Dr Arwyn Edwards, Aberystwyth
- DNA quantification equipment and reagents from Thermo Fisher Scientific, UK
- Garmin InReach GPS unit (without subscription) from the Alpine Ski Club

- Avalanche transceivers (x3) from the Alpine Ski Club
- Personal Locator Beacon (PLB) from the Alpine Ski Club

To aid other expeditions in planning we have outlined the estimated value of each of these items in Appendix I should future expeditions want to consider these purchases.

11.4 Expedition finances

Summary	
Outgoings	
Alpine training	£2,676.29
Cairngorms training	£522.44
Peak district training	£61.77
Medical and Safety	£929.52
Group equipment	£4,809.70
Personal Equipment	£8,005.47
Flights	£1,291.84
Filming Equipment	£459.48
Costs in Iceland	£4,055.39
Administration	£595.25
Total	**£23,407.15**
Income	
Grants	£14,550.00
Personal contributions	£8,857.15
Total	**£23,407.15**
Income breakdown	
	Amount
Andrew Croft Memorial Fund	£2,000.00
AC Irvine Travel Fund	£1,400.00
Alpine Ski Club	£250.00
The Jeremy Wilson Charitable Trust	£500.00
Imperial College Exploration Board	£850.00

Leathersellers' Company Charitable Fund	£800.00
Gino Watkins Memorial Fund	£2,500.00
Wallace Watson Award	£4,000.00
CGCA Old Centralian's Trust	£1,000.00
Leathersellers' Company Charitable Fund	£500.00
University College Oxford Overbrook Fund	£750.00
TOTAL	£14,550.00
Personal contributions	£8,857.15
GRAND TOTAL	**£23,407.15**
Outgoings breakdown	
	Grant expenditure
	Personal expenditure
Medical and Safety	
Medical course	£504.00
Medical equipment	£214.85
Insurance	£210.67
TOTAL	**£929.52**
Group equipment	
Sleeping bags	£535.08
Dry bags	£231.75
Solar panels and power packs	£619.20
Miscellaneous scientific equipment	£342.29
Pulks	£1,399.10
Inreach	£463.39
Snowpegs	£73.00
Snowsaw	£44.45
Other group equipment (shelters, probes, tools, mugs, bottles, etc)	£1,101.44
TOTAL	**£4,809.70**
Personal equipment	

Buffalos	£339.22
Snowshoes	£564.00
Skis	£1,010.85
Ski boots	£820.00
GG personal gear (clothing, equipment, boots, etc)	£1,641.15
JH personal gear (clothing, equipment, boots, etc)	£1,495.35
OV personal gear (clothing, equipment, boots, etc)	£2,134.90
TOTAL	**£8,005.47**
Flights	
Outbound flights	£548.16
Return flights	£743.68
TOTAL	**£1,291.84**
Filming equipment	
Lens, cable, tripod	£259.48
OV personal camera	£200.00
TOTAL	**£459.48**
Costs in Iceland	
Costs associated with transport to Hofn	£367.11
Accommodation in Reykjavik	£308.68
Accomodation in Hofn	£179.07
Accommodation at Vagnsstadir	£144.12
Jorfi Hut	£133.77
Food for icecap	£1,338.45
Other food in Iceland	£500.00
Superjeep transport to icecap	£230.36
Superjeep pickup from icecap	£230.36
Car hire	£623.47
TOTAL	£4,055.39
Administration	
Website hosting	£86.40
Inreach subscriptions and rental	£347.95
SAR donation	£103.00

Carbon credits	£57.90
TOTAL	**£595.25**
Alpine training	
Car rental	£469.91
Guide costs	£665.86
Flights	£385.52
AAC memberships	£105.00
Living costs	£1,050.00
TOTAL	**£2,676.29**
Aviemore training	
Food	£152.44
Travel	£282.00
Accomodation	£88.00
TOTAL	**£522.44**
Peaks training	
Fuel	£38.27
Food	£23.50
TOTAL	**£61.77**
GRAND TOTAL	**£23,407.15**

12 Training

All team members are passionate about the outdoors and therefore engaged in independent trips in the years prior to the expedition. Our formal training trips were planned to allow us to put key skills into practice, test out gear and bond as a team before departure. Where these training trips could not meet a development need, expedition members also attended specialized skills courses planned to address key knowledge gaps.

12.1 Group training (whole team)

12.1.1 Technical skills training, Alps - September 2018

Rock climbing, dry glacier travel, wet glacier training with mountain guide on the Vallée Blanche, simulating many of the features of the icecap. Crevasse and avalanche training, mountaineering skills and a summit of Gran Paradiso

Team practicing crevasse rescue on the Mer de Glace, Chamonix

12.1.2 Expedition 'dry' run 1, Cairngorms - January 2019

Camp-craft, navigation, dragging pulks, testing food, snowshoes and tents. A very wet and windy experience camping on the Cairngorm plateau made us take the preparation requirements for Vatnajökull much more seriously. A recommended training trip for any expedition team going anywhere.

Soaked to the skin on the summit of Ben Macdui

12.1.3 Expedition 'dry' run II, Peak District - March 2019

Camp-craft, navigation, finalizing kit-list, testing waterproofs, camping in snow.

Cooking breakfast in the Peak District

12.1.4 Wilderness ITC Level 3 First Aid course, UK - April 2019

Remote medicine training in case of medical emergency.

12.2 Specialized skill training

- **Jonathan Conville Mountaineering Course, Scotland, January 2019 (3 days)**
  Glen did not have as much winter mountain experience as the remainder of the team and therefore joined the JCMC to get some quality mountain days and training.

- **Genome sequencing dry run, Abersytwyth, Wales - February 2019 (3 days)**
  Glen joined Arwyn Edwards on a genome sequencing crash course to ensure our in-field work was as prepared as feasibly possible

- **Hardangervidda crossing, Norway - March 2019 (10 days)**
  John-Henry joined a guided expedition with Mark Walker and Exped Adventure across the Hardangervidda plateau to develop polar skills and camp-craft experience on snow and ice

12.3 Examples of individual training

- Ski touring training with the Alpine Ski Club, Chamonix - April 2018 (4 days) (Oliver)
- Half-Ironman, UK - July 2018 (1 day, plus training) (Oliver and Glen)
- Ski touring in Garmisch Partenkirchen - January 2019 (5 days) (Oliver)
- Ski touring in Serre Chevalier, Alps - January 2019 (7 days) (John-Henry)
- Nordic skiing practice, Swiss Alps - February 2019 (3 days) (John-Henry)

13 Logistics

13.1 To and from Iceland

Prior to leaving for Iceland, we spent 4 days together in London packing, repacking and purchasing food. We flew from Gatwick to Keflavik airport. Our pulks were taken as luggage in the hold.

We booked return flights with Icelandair to Manchester and London airports once we knew which date we would be dropped off on the ice. We used an Airbnb in Keflavik the evening before our flights to re-organize belongings before travel back to the UK.

Laying out all our equipment was a good way to check we hadn't forgotten anything

13.2 To and from Höfn

Daniel Bergmann, a photographer and friend of Sam and Joe Cornish, was kind enough to collect us from the airport, and drive us to Höfn. This was pre-arranged as part of a photography trip for Sam and Joe. We dropped our gear off with Glacier Jeeps before heading to Höfn to wait for a weather window to open up. We took a daily bus service to travel back to Glacierjeeps at Vagnasstadir.

Our gear at Vagnasstadir before departure onto the icecap.

After the expedition, Glacierjeeps dropped us off in Höfn. We rented a car from Europcar in Höfn to drive back to Rekjavik and paid the single direction travel premium. This was the only practical way of transporting the team plus all eleven suitcases.

13.3 From Höfn to the Ice-cap

Glacierjeeps (http://www.glacierjeeps.is/) based in Vagnasstadir, were pre-arranged to drop us off on the ice-cap in an appropriate weather window. We were driven up to the snowline in jeeps, before a snow-cat took us further onto the icecap.

We arranged a flexible pick-up with Glacierjeeps, whereby they agreed to pick us up from a safe location on the icecap on a certain date, based on a GPS location shared via the Inreach. Ultimately, we completed a double traverse, and therefore did not need this icecap pick-up. Instead, we were collected by Jeep from the Jöklasel hut.

13.4 Timings

Our timings were highly flexible, and allowed us to use the 'right' weather window. We had a fixed departure date from the UK, a fixed length of time to be spent on the

icecap (based on food), and only finalized return details once we set our drop-off date on the ice.

13.5 Travelling with scientific material

There are a number of hurdles to transporting scientific equipment to a remote location. First, it is imperative to get approval from the authority responsible for the region you plan to visit. We had to obtain a research permit from the Vatnajökull National Park (Appendix VII). Flying scientific equipment, including reagents and devices often leads to items being stuck at customs. This would have derailed our scientific plans as we didn't have the contingency time to wait for customs to clear. It is important to engage with the airline early and determine which MSDS (Material Safety Data Sheet) forms you need for which pieces of equipment/reagent. We included a printed MSDS form in the hold luggage alongside each item so that, if searched by customs they would be immediately satisfied with exactly what material was there. Due to this planning we had no issues transporting our scientific work.

14 Safety

14.1 Insurance

After some searching for a willing and appropriate insurance provider, the BMC ensured us that their Europe Alpine & Ski standard cover would be sufficient. The cost was roughly £100pp.

We used Austrian Alpine club membership (and therefore insurance) for all training trips in the Alps.

14.2 Safety equipment

The team travelled with:

- 2x Garmin Inreach
    - Main device
        - Owned by team, used on training trips in advance of expedition
        - Used for navigation & to communicate daily with SAR and home
        - Routes and crevasse fields were pre-loaded onto device
        - Never allowed beneath 50% battery level.
    - Back-up device
        - Rented from Alpine Ski Club
        - Used as a reserve device, with limited use in navigation

- 3x Avalanche transceivers
    - Each individual had his own transceiver in case of avalanche
    - Used especially when skiing off the icecap in the lava dome area

- 3x Map (incl. Crevasse maps) and compass
    - Each individual had his own map and compass
        - Use of the compass was occasionally challenging for the person at the lead of the group in white out, and in the future we would recommend using a device allowing hands-free compass use

- 3x Probes and shovels
    - Probes were occasionally used for checking crevasse risk at the edges of the icecap.
    - High-quality shovels and snowsaws are absolutely vital in polar environments for snow-wall creation and porch digging etc.

- 3x Builder's snow bags
    - With variable quality snow on the icecap, by filling the bags with snow we had an easy and reliable method to build a snow-wall in a hurry.

14.3 Engagement with local authorities

We began sharing details of the expedition with Iceland's Search and Rescue team approximately 3 months before our intended departure. Their feedback and support was vital in final kit decisions (i.e. to take all three options of skis, snowshoes and crampons). SAR provided their latest crevasse maps, which were instrumental in pre-defining our route on the Inreach devices. In addition, the knowledge that in the worst case scenario, SAR would be available to support us put our minds at ease in planning. SAR is a fantastic resource in Iceland. After our expedition, we donated $125 to SAR in appreciation of their help.

We made enquiries about the area, and its mountaineering potential on the English language section of Isalp, the Icelandic Alpine Club.

We engaged with local hut owners, and were granted access to Sigurðarskáli, despite the location being closed over Winter/ Spring, which was very generous of the owners. In an emergency, if a return icecap traverse had become impossible, this would have provided a welcome escape route. We also tried to engage JORFI regarding conditions and access to Kverkfjöll, although this source provided less useful information.

Bjarney at Glacierjeeps also provided guidance and support on the phone in advance of our drop-off on the ice. This was especially kind, as they are a commercial service, not an advice or safety hotline.

14.4 Communications

With two Garmin Inreach devices, we were always able to communicate with Icelandic authorities, family in the UK, and the in-built weather function of the InReach. We took two expedition subscriptions on our Inreachs to ensure we could send an unlimited number of messages.

We sent a message to SAR and family in the UK every morning outlining our intentions for the day, and every evening once camp was set up.

We received forecasts on request from the Inreach device, and on an adhoc basis, received forecasts from family interpreting the Icelandic weather forecasts.

15 Kit evaluations

Through plenty of research and personal recommendations we were able to put together a kit list that could put us in good stead for the wide variety of conditions we expected on the Vatnajökull. A full kit list is shown in Appendix I. Here, we wish to highlight the particularly crucial pieces of kit and those that could be improved upon.

15.1 Skis

There are about as many opinions on the choice of ski as there are crevasses on the Vatnajökull (lots). Our first consideration was to opt for the traditional nordic ski or an alpine touring ski. Nordic skis comprise a 'soft' boot that connects to the ski at the toes (either through 3-pin design or 'NN' bindings). There are several advantages of nordic skis. Being very light and minimal in binding design they are an efficient choice for covering large distances. The soft boot can be easily used as a regular comfortable boot when around the camp. The other option we considered was an alpine touring ski. The major differences include a wider ski which allows greater uphill traction but less efficient travel over long distances and a boot with a flexible plastic shell. Crucially an alpine touring ski has the option of the ankle being secured to the ski, making downhill skiing possible. We opted for a nordic ski which was largely a good choice. This resulted in efficient travel on the flat icecap with the pulks, but at the cost of our ability to ski downhill. However, on several days, the surface was hard, icy snow and the nordic skis had a tendency to lose their grip. On these days, alpine touring skis fitted with ski crampons would have been preferable.

We were fortunate to not suffer any major injuries when travelling downhill (around the basecamp and when descending from the icecap) on Nordic skis. Any team spending a reasonable proportion of their time in more varied terrain (with gradients) should seriously consider the trade-off between efficiency on the flat and safety on the descents. Alpine touring boots (e.g. Scarpa Maestrale) can be fitted with C2 crampons for ease of switching between dry and wet glacier. In addition, the ability to remove the boot liners from alpine touring boots would be beneficial when drying them overnight in the tent.

Attempting to downhill ski on nordic skis proves challenging and dangerous in such remote locations

Our choice of ski represented a compromise between cost and quality. We looked into Asnes Nansen skis but these prove a) very expensive and b) required using skins to gain traction. We were then recommended Fischer E99 skis. These proved a good choice. The fishscales on the underside allow sliding forward and ample traction backwards (even up moderately steep inclines) meaning we never actually used the skins.

Boot choice diverged in the group. John-Henry opted for the Alfa Outback boot with Gore-Tex. Though at a higher price tag these proved the perfect boot. Oliver and Glen, unable to source a supplier we could visit in person to try sizes opted for the Fischer BCX 6 from Cairngorm Mountain Supplies. While comfortable and extremely warm, the latter proved more of a hindrance than a help. When skiing overheating resulted in dampness due to sweat which became cold when exercise was over. Additionally the lace of Glen's boot ripped out on day one, which, though not critical, resulted in a very loose shoe for the entire expedition. We would therefore recommend highly the combination of Fisher E99 skis with Alfa Outback boots for efficient travel across flat icecaps.

15.2 Personal Kit

The most crucial pieces of equipment we bought were waterproofs. These not only provided great protection from both rain and snow (which easily melts with body head) but also from wind. Our clothing strategy centred around layering, therefore, we opted for waterproof shells that could go over any warmer down layers we wore. It is pertinent to note that the Vatnajökull has a particularly high level of precipitation (including rain!) and is in stark contrast to many colder but much drier ice caps (e.g. Antarctica). Therefore, a waterproof shell is critical, and many expeditions on the

Vatnajökull have opted for 'Antarctica style' clothing and suffered the consequences. We tried a variety of waterproofs on our training trips and came to the conclusion that you really do get what you pay for. We, therefore, all ensured we had a shell layer (top and bottom) from a reputable supplier (Norrona, North Face, and Mountain Equipment) with Gore-Tex Pro. We quickly learned not all Gore-Tex layers are created equal and the Pro is essential for such testing, multi-day conditions. We ended up wearing these layers practically every single day. Layering is an essential strategy as during a day of ski traversing one can fluctuate from overheating during skiing to rapidly cooling when erecting the tent or eating. Layering allows you to rapidly and effectively respond to changes in your body temperature.

We also recommended the use of a Buffalo Special 6 shirt. This proved to be an incredibly versatile piece of equipment. It seemed to be a 'do-it-all' layer, with a large front pouch and easy ventilation. We all wore it most days. While skiing in mild conditions it can be quite warm but for all other conditions we found it to be a fantastic layer, particularly in and around camp.

We should take the opportunity to sing the praise of Merino Wool. We opted to only wear merino wool in direct contact with our skin. This was primarily for hygiene reasons. Merino, through magic or otherwise, has antimicrobial properties and, despite no deodorant, retains no (perceivable) smell. We used a strategy of changing merino underwear every 3-4 days and changing merino thermals (top and bottom) every 5 days or so. This proved a very successful strategy for keeping tentmates' noses happy.

15.3 Tent

We tested two tents in the Cairngorms, the Mountain Hardwear Trango and the Terra Nova Quasar. While both excellent tents in their own right, we found the lack of a large porch meant it was very difficult to cook in challenging conditions and difficult to manage extreme wetness. We, therefore, sought to borrow a larger tent that we could all stay in, crucially with a large vestibule porch. After much research we settled upon the Hilleberg Keron 4GT. This proved the perfect tent for this environment. The large porch (approx 30% the length of the tent) could be dug out (below), the large size meant our laboratory work could be done with relative ease, and the option to double pole gave us confidence in high winds. We cannot recommend this tent highly enough.

The Keron 4GT porch which can be dug out to provide standing room inside the tent and a lowered platform for cooking.

15.4 Power

This expedition had significant power requirements. During the traverses we would need to power both our Garmin InReach GPS devices (always having redundancy for contacting search and rescue), the two drone batteries for filmmaking, and the selection of other cameras we used routinely. At basecamp we then had to power all our various scientific equipment including a laptop. For small devices (5V power requirement) we used 10,000 mAh waterproof battery packs (AquaTrek - Mobile Solar Chargers). For the laptop and the drone batteries we used larger 20,000 mAh DC power banks (Poweradd x1 and Aceyoon x2). To deliver power to the laptop (Dell XPS) we used the Omnicharge USB-C to DC barrel adapter. After some testing we could power the DJI drone batteries using the DJI car charger and a cigarette lighter DC adapter plugged into the battery packs. The small power banks were charged from either a 10W or 15W flexible solar panel (Mobile Solar Chargers). These were ideal as they could be easily strapped to a pulk or backpack and were extremely robust. For the larger powerbanks we used a 90W solar panel (Mobile Solar Chargers) which could fit nicely on the back of a pulk. Even in cloud cover we were able to generate over 20V from this panel, owing to the reflectivity of the ice.

15.5 Campcraft

Camping on a relatively flat sheet of ice means winds can quickly pick up. It is crucial to protect the tent from prevailing winds. Ordinarily this would involve cutting ice blocks using a snowsaw (we used 2x MSR snowsaws) and constructing a brick-styled wall on the windward side of the tent. We were warned, however, with such high levels of precipitation on the Vantajokull that it may be difficult to cut ice blocks with fresh loose snow present. We, therefore, opted to use 3x industrial garden waste containers that are collapsible. These could be filled with snow and placed at the windward side (below).

Three garden waste bags (left) were filled with snow to form a protective wall.

In addition to a wall, when conditions were windy, we tried to dig a pit for the tent so reduce the surface area exposed to the wind. There was always an physical/ emotional trade-off made between digging and just putting up the tent. The decision was made based on forecasts and energy levels. For the task, and digging out the porch of the tent, a good shovel is crucial. After several breakages of 'cheapish' snow shovels on training trips we opted to purchase more robust models for the expedition (Ortovox Kodiak, Beast, and Black Diamond Evac 7). The Kodiak and Evac proved most effective owing to the larger spoon size.

15.6 Cooking

For cooking (exclusively melting snow) we used an MSR XGK stove (with a backup Whisperlite, though never used) with clean premium liquid fuel. This was lit using a flint. This stove proved enormously reliable and the repair kit we brough remained in its original packaging. We primarily cooked inside the porch on a platform cut into the side of the dug-out porch (a step at about knee height). We brought a solid 'stove board' (literally just a simple piece of plywood) on which to place the stove. Some kind of solid platform is crucial to avoid the stove falling over.

We used a 2L MSR Ceramic Pot which was a good size for fitting in enough ice/snow and melting relatively quickly. We quickly realised that melting was most efficient if about an inch of water is put at the bottom of the pot before snow is added.

We budgeted 1L of fuel per day, this proved far in excess, though due to some spillages and breaking of plastic fuel bottoms in the pulk we were grateful for the redundancy. We used about half the fuel bottles in the end, returning our excess bottles to a supplier in Rekjavik. John-Henry had a habit of really ramming the fuel bottles into his (full) pulk, with the net result of leaks. Some of his lunchpacks were soaked in petrol, which decreased food supplies modestly. Be aware petrol leaks even through multiple plastic bags.

16 Appendix

16.1 Appendix I: Value of borrowed or donated items

Item	RRP value	Status	Source
Hilleberg Keron 4GT tent	£1,233.00	Borrowed	Imperial College Exploration Board
Tent pegs and extra poles	£320.00	Borrowed	Imperial College Exploration Board
Dell XPS 13 1TB SSD 16 Gb RAM laptop	£1,600.00	Borrowed	Professor Tom Ellis
Terralyzer DNA extraction tool	£600.00	Borrowed	Dr Arwyn Edwards
Garmin InReach GPS device	£464.00	Borrowed	Alpine Ski Club
Avalanche transceivers (x3)	£400.00	Borrowed	Alpine Ski Club
Personal Locator Beacon (PLB)	£189.00	Borrowed	Alpine Ski Club
TOTAL	**£4,806.00**		
Nanopore sequencing kit (2x flowcells, 6x reagents)	£1,300.00	Donated	Professor Tom Ellis
QIAGEN Powersoil DNA extraction kit	£126.00	Donated	Dr Arwyn Edwards
Qubit 4.0 fluorometer (DNA quantification tool)	£2,555.00	Donated	Thermo Fisher Scientific
TOTAL	**£3,981.00**		

16.2 Appendix II: Full kit list

Item	Item details	Weight (g)/unit	Weight (g) total	Quantity (total)
PERSONAL				
Ski/walk equipment				
Skis	Fischer E99	1950	5850	3
Ski bindings	Fischer Magnum	530	1590	3
Skins	Madshus Intelliskins	200	600	3
Ski boots 1 (JH)	Alfa Outback APS	1850	1850	1
Ski boots 2 (OV, GG)	Fischer BCX 6	1860	3720	2
Snow shoes	MSR revo ascent	1920	5760	3
Hiking boots	Scarpa Manta (JC), Scarpa Triolet (GG) and La Sportiva Trango Tower (OV)	1600	4800	3
Camp shoes	Nordisk Mos Down slippers	200	600	3
Moon Boots	Decathlon SH500 X-warm	400	800	2
Boot socks	Ortovox, Salewa, etc	100	1500	15
Crampons	Grivel G12	1040	3120	3
Pulk (50kg)	Snowsled	2200	6600	3
Pulk bag	Snowsled	830	2490	3
Pulk Harness	Snowsled	480	1440	3
Pulk hauling ropes	Snowsled	330	1320	4
Pulk straps (incl spare)	Snowsled	480	1920	4
40L backpack	Osprey Stratos 36 or equiv	1500	4500	3
Poles	Black Diamond Expedition	520	1560	3
Dry bags large 40L	OEX	80	240	3
Dry bags small multi pack	OEX	150	600	4
Dry bags large for tent items	Osprey 70-100L	80	240	3
Dry bags large for sleeping bag	Ortileb 59L	150	600	4
Sunglasses	BLOC, Julbo, or equiv. Cat 3 or Cat 4	100	300	3

Ski goggles	Oakley Prizm, Scott Ultimate II, or equiv	100	300	3
Personal rack				
Crevasse PCD	Petzl Microtraxion	85	255	3
Pulley	Petzl Oscillate	42	126	3
Ice screws	Grivel Helix or equivalent	128	768	6
Knife	Petzl Spatha or Victorinox Skipper	183	549	3
Harness	Black Diamond, Simond, or equiv	200	600	3
Screwgate carabiner	Black Diamond, Simond, or equiv	90	1620	18
Slings (60 cm and 120 cm)	DMM, Simond	100	300	3
Helmet	Black Diamond, Simond, or equiv	340	1020	3
Glacier walking axe	Petzl Glacier, Simond Ocelot, Camp	420	1260	3
Belay plate	Simond toucan, or equiv	50	150	3
Shovel	Black Diamond Evac 7, Ortovox Beast, Ortovox Kodiak	700	2100	3
Additional head torches	LE USB-rechargeable head torch	50	100	2
Crevasse probe	Decathlon simond	245	490	2
Avalanche probe	Ortovox ALU 240	245	245	1
Snow saw	MSR Beta Snowsaw	150	300	2
Eating				
Long spoon	Sea to Summit Alpha long spoon	50	150	3
Thermal mugs	Thermos ThermoCafe 450 ml	300	900	3
Thermos	Lifeventure 1L thermos, Primus 0.7L, or equiv	570	1710	3

Nalgene 1.5L	Nalgene 1.5L	50	200	4
Nalgene 1L	Nalgene 1L	50	150	3
Food				
Freeze dried, breakfast/dinner	Expedition Foods	150	28500	190
Snack lunch	Oatcakes/Cheese/Cured meat	100	6300	63
Snack pudding	Chocolate/fruit/hot chocolate	100	6300	63
Starters	Soup	100	6300	63
Drinks	Coffee/hot chocolate	30	1890	63
Vitamins	1 pack of 60 vits - tesco	20	20	1
Clothing				
Expedition underwear	Dilling boxers, 100% merino	50	600	12
Baselayer (top)	Decathlon 100% merino baselayer	50	600	12
Baselayer (bottom)	Decathlon 100% merino baselayer	50	450	9
Fleece	Rab nucleus or equiv	50	150	3
Inner insulated jacket	Buffalo Special 6 Shirt	675	2025	3
Cold hat	Generic	50	150	3
Buff	Generic	50	150	3
Thin working gloves	Black Diamond crag gloves	70	210	3
Think fingered gloves (backup)	North face Vengence GTX Pro or equiv	310	1240	4
Soft inner gloves	Generic	100	300	3
Waterproof overmitts	Extremities Tuff Bags Overmitts	78	234	3
Outer waterproof jacket	North Face Summit Series L5, Norrona Lofoten, Mountain Changabang	500	1500	3

Outer waterproof trousers	Mountain Equipment Karakorum, North Face Summit Series L5, or equiv	440	1320	3
Outer Down/synthetic jacket	Montane 800 fill down jacket or equiv	508	300	3
Inner Down/synthetic jacket	Rab Altus or equiv	438	1314	3
Softshell Trousers	Montane Terra or equiv	340	1020	3
Gaiters	Simond long gaiters or equiv	200	600	3
GROUP				
Camp/sleep equipment				
Tent, pole, pegs	Hilleberg Keron 4GT	5500	5500	1
Snow pickets	6x Hilleberg snow pickets	300	900	3
Spare tent poles	Hilleberg pole for Keron 4 GT	200	600	3
Base thermal mat	Therm-a-rest Z-lite SOL or equiv	410	1230	3
Air structure	Sea to Summit Comfort Light Insulated, Thermarest NeoAir or equiv	1120	3360	3
Air pillow	OEX Traverse Pillow	360	360	1
Sleeping bag	MH Lamina Z -34/-30C	2700	8100	3
Survival shelter	Vango 8 person	1150	1150	1
Survival shelter	Vango 4 person	581	1162	2
Cooking				
Stove 1 + pump	MSR XGK EX stove	490	490	1
Stove 2	MSR Whisperlite stove	400	400	1
Stove board	Generic plywood board	200	200	1
Pot	MSR ceramic pot	200	200	1
Fuel bottle	Primus 1L premium liquid fuel	1000	25000	25
Refillable fuel bottles	MSR 600ml and 900ml	135	405	3

MSR XGK repair kit	MSR XGK repair kit	200	200	1
Fire blanket	Generic	100	100	1
Hardware				
Rope 1	DMM 30 m	2000	2000	1
6 mm cord	Simond 6mm cord	500	1500	3
Navigation and safety				
GPS units	Garmin InReach	213	426	2
Personal Locator Beacon (PLB)	Ocean Signal PLB1	200	200	1
Transceivers	BCA Tracker T2	200	400	2
Maps	Islandskort maps	100	100	1
Compass	Silva Ranger S or equiv	58	174	3
Survival suits/bags	HiGear survival bag or equiv	50	150	3
Misc				
Accessory carabiners	Quechua snap hook	20	240	12
Ziplock Bags	Generic zip lock bags	10	630	63
Antibacterial hand wash	Generic Antibac 100ml	100	300	3
Thermal food pouch	Optimus Heat Pouch	20	40	2
Sunscreen	SPF50+ Ambre Solaire 50 ml	100	600	6
SPF lip protector	Piz Buin Mountain SPF50	100	600	6
Lip balm	Carmex 3 pack	100	100	1
Zip ties	Zip ties (x75 various)	50	50	1
Gaffa tape	3M Duct tape 50 mm x 5 m	50	150	3
Bungee cords	MasterLock x6	50	50	1
Resin	Araldite hard set rapid epoxy	50	50	1
Brush	Dish scrub brush	50	150	3
Tent pole repair sleeve	MSR (JH), Hilleberg (Group), DAC (Glen)	20	60	3
Spare batteries	Generic	100	500	5
Electrical tape	Generic	50	50	1

Snow bags	Generic garden waste bags (300L)	390	1170	3
Flint	Light My Fire	50	150	3
Lighters	Lighters	50	150	3
Waterproof/windproof matches	Waterproof/windproof matches x15	50	100	2
Pocket tissues	Cushelle tissues	20	1260	63
Spare laces	Generic	20	20	1
Power				
Large solar panel	MSC 90W	2500	2500	1
Medium solar panel	MSC 20W	368	368	1
Small solar panel	MSC 15W	320	640	2
Large power bank	Poweradd 23Ah Pilot Pro2	1500	1500	1
Small power bank	MSC 10Ah (IP68)	230	690	3
Backup battery	Aceyoon powerbank 20Ah	1000	1000	1
Battery powered lamp	MSC 10Ah lamp	240	240	1
Neoprene sleeve for batteries	Techgear slim neoprene case (for Poweradd)	50	50	1
DC cable adapters	Generic	50	50	1
Charging cable for laptop	Omnicharge DC to USB-C adapter	50	50	1
Scientific equipment				
Anemometer	Generic	50	50	1
Vortexor	Home-made	100	100	1
DNA extraction kit	QIAGEN powersoil kit (x30 runs)	300	300	1
Flowcells	Oxford Nanopore R9.4	100	200	2
ONT reagents	LRK001 reagents	800	800	1
Tubes	DNA Lo-Bind tubes	100	100	1
Pipettes and tips	Pipetteman pipettes	800	800	1
Small Pelican case	Peli 1060 case	200	200	1
Small tupperware	Flowcell carrying case	100	100	1
Pelican laptop case	Peli 15" laptop case 1095	400	400	1

Laptop and power cables	Dell XPS 13 1TB SSD 16GB RAM	1230	1230	1
Centrifuge	Dremel 7750	700	700	1
Homogeniser	Terralyzer	2000	2000	1
Probe thermometer for flowcells	LCD Digital Aquarium Thermometer (-20C to +70C)	300	300	1
Tracking thermometers	Elitech RC-5+	200	400	2
Hand warmers for science	6-pairs HotHands Instant Hand Warmers	400	800	2
		TOTAL (kg)	203	

16.3 Appendix III: Medical Kit List

Item	**No.**	**Notes**	
Mountain First aid kit	2	Group supplies - see right	Lifesystems Mountain first aid kit (listed x1)
Materials			**General**
Cling film	1		1 x Primary Care Leaflet
Antiseptic swabs	20		1 x Tweezers
Elastoplast waterproof plasters	2		6 x Safety Pins
Blister plasters (pack)	4		1 x Scissors 5.5cm Blade
SAM splint	1		1 x Shears 6cm Blade
Steri-strips 6x100 (x10)	2	For sealing minor open wounds	1 x Glo Stick
Israeli Trauma Bandage	1	For puncture wounds	
			1 x Spot Check Thermometer
Painkillers			2 Pairs Vinyl Gloves
Paracetamol tablets (16-pack) 500mg	96	2 x 4 daily Enough for each person to have 4-days worth	Resuscitation face-shield
Ibuprofen tablets (16-pack) 400mg	36	1 x3 daily Enough for each person to have 4-days worth	
Cocodamol 30/500mg	48	1-2x4 daily max - Enough for 2 day per person	
Allergy			
Pririton - Chlorphenamine 4mg (sedating)	24	1x4/day for severe itching allergy. Enough for 2 days per person (boots)	**Bandages**
Loratidine (non sedating)	15	1 daily for allergy (non sedating) Enough for 5 days per person	2 x Open Woven Bandages 7.5cm x 5m

Prochlorperazine 3mg Buccastem	10	1-2 tablet twice daily - dissolve in lip - Enough for 1 day per person	1 x Crepe Bandage 5cm x 4.5m
Loperamide capsules (2mg)	48	<8/day for diarrohea. Enough for 2 days per person (boots)	1 x Crepe Bandage 7.5cm x 4.5m
DulcoEase - Docusate 100 mg (30-pack)	1	Stool softener for constipation (careful - high doses act as a stimulant laxative)	1 x Triangular Calico Bandage 90 x 127cm (2 x in EU kit)
Dioralyte (6 sachets)	2	ORT to treat diarrohea	Preparations, Disposables & Tapes
Antibiotics			8 x Hygienic Cleansing Wipes
Amoxicillin (500 mg tablets)	21	1 capsule 3 times per day. None allergic to penicillin. Broad spectrum	1 x Micropore Tape 1.25cm x 5m
Co-amoxiclav (375 mg tablets)	21	1 table 3 times a day for chest/skin infections). None penicillin allergic	1 x Zinc Oxide Tape 1.25cm x 2m
Skin			1 x Duct Tape 2m Roll
Canestan HC tube	1	3xdaily. Eczema and fungal/crotch rot (antifungal)	10 x 4-Ply Gauze Swabs 5 x 5cm
Silver sulfadiazine (20g)	1	Topical antibiotic for burns	2 x Burn Gel Sachets 3.5g
Savlon tube	1	Topical antiseptic	**Dressings**
Aloe vera cream	1	For frostbite and general moisturiser	1 x Pack of Assorted Plasters
			1 x Medium Wound Dressing 12 x 12cm
Paperwork			2 x Low Adherent Dressings 5 x 5cm
Insurance details of all			1 x Low Adherent Dressing 10 x 10cm
Evacuation protocol			1 x Small Plaster Fabric Strip 4cm x 1m

Emergency contact details			3 x Wound Closure Strips
Instructions on all drug use			1 x Small Eyepad Dressing
List of contents (this)			2 x Blister Plasters
Pencil and notepad			

16.4 Appendix IV: Expedition diary

10-14 April - Pre-Expedition start in UK

The team gathered in Caterham on 10th April to begin final expedition preparations. We spent three days packing, re-packing our pulks, buying our provisions and last minute gear. We also finalized pre-expedition documentation, sharing a detailed expedition plan with the Vatnajökull's Search and Rescue team.

An original copy of J.A. Beckett's "Iceland Adventure" arrived on time for us to pack it in our pulk. We were all quite taken by being able to take a tangible connection to the 1932 expedition with us onto the ice.

We took the first flight to Reykjavik on 14th April, and were collected from the airport by Sam Cornish (our in-country logistics support), Joe Cornish, and Daniel Bergmann, a local Icelandic photographer. Daniel had two vehicles adapted for Icelandic terrain which he agreed to drive us to Hofn with. Our eleven bags, 3 pulks and bodies fitted. Phew.

15-17th April - Waiting for a weather window in Iceland

We drove along the ring-road from Rekjavik to Hofn, on the way dropping our technical gear off at the Vagnasstadir hostel. In Hofn, we waved farewell to Sam, Joe and Dan who continued their journey driving round the island in search of better weather for photography.

At this moment in time, the weather was not on our side: a high pressure spell over Norway was sending wet, warm southerlies towards Iceland, generating significant amounts of precipitation on the south-east coast. The forecast for the next week was, according to all recommended sources, rain. This left the team - Oli, Glen, John-Henry - in Hofn exploring the town, seeking relics and connection to the 1932 team, drinking coffees, and religiously checking the forecast.

Our first attempt at historical rephotography began inauspiciously. Oli asked a local Icelander whether they could recognise the location of the photographs we wanted to re-take in Hofn. Yes, they said. But you are in the wrong Hofn. You are 400km away from the right one. The original team had spent time in two Hofns during their time in Iceland, a detail we had missed. Hopefully other elements of the expedition were better prepared.

Our other attempts at connecting with history were more successful. Notably, we met Siggi, the great-grandson of the brother of the 1932 mountain guide and found a copy of the guide's diary in the local library. At least our trajectory was positive.

A short weather window appeared in the forecasts for the 18th. On discussion with Bjarney, the guide responsible for taking us onto the ice-cap, we agreed to be dropped on the ice in this window. We therefore moved camp to the Vagnasstadir hostel, base-camp for our drop-off.

18th April - Drop-off on the ice

We left the hostel in a convoy of vehicles driving towards Joklasel hut at 9:30am. Within an hour, we were at 530m in rain and cloud. We shifted our gear onto a snow-cat which took us on to the ice-cap proper and up to 800m, slightly above Joklasel hut. This was a real result. We estimated an 8 hour weather window of dry conditions before more rain fell. The higher we got, the lower the chances of rain.

In the convoy with us were a team including Wendy Searle, in training for a female speed record for a coastline to South Pole journey and Louis Rudd, the Antarctic explorer. They were wearing more serious polar gear than us, and speak with a body of experience behind them. As the snow-cat trundled up the ice-cap, our nerves admittedly built.

As we were dropped off, around 11ish, the weather began to clear and we saw the sky for the first time since arriving in Iceland. The weather was perfect (for 6 hours at least), and we could see. We needed to push to get to the snowline.

We began immediately on skis. After 5 minutes Oli, first time on cross-country skis, fell and cut his finger against the ski's metal edges. After an hour, Glen ripped half the lacing of his boot irreparably and after 3 hours, John-Henry's pole snapped clean in two. Given the circumstances and the rapid introduction to pulk-hauling, we made good progress up Skalafellsjökull.

Our route up the crevasses field was safe, and we never experienced any crevasses and a pair of passing snowmobiles complemented our route-finding up the glacier.

By 5pm, the rain began and our weather window closed. We'd reached 1200m, but it still wasn't high enough to avoid the damp soak. Everything began to become wet through, and so we put up our tent, and followed the protocol we'd developed in the UK. Once the tent was up, Glen moved inside to protect the flowcells and dug our porch, as Oli and John-Henry readied the outside.

Given the wetness of the whole situation of our first night on the ice, the parallels of reliving the 1932 team's first experience living on the ice-cap in 'Camp Driblet' was not lost on us.

19th April - Camp Driblet in 2019

Rain all day. We remained tent-bound. Whenever we moved outside to fix something, or get something, we were soaked to the core. Oli was very cold all day and slept in his sleeping bag most of the day.

20th April - Onto the plateau

By 9am, the rain had turned to snow and we decided to make another push towards the snowline. We packed up according to previously agreed protocol - Glen tidying the inside of the tent keeping the flowcells warm, as Oli and John-Henry packed the pulks.

We moved up the final section of the crevasses field in complete white-out, with John-Henry's eyes tested at the front of the rope. Without an InReach device, the ascent would've been totally different, and we would've been forced to wait for better visibility.

We ate lunch in a storm shelter as the worst of the wind and snow came through, and thought we made it onto the plateau at around 2pm (our pulks no longer gave *quite* so much drag). By 3pm the sun finally broke through again and the cloud lifted slightly. We could see an ice-cap, and our place within it!

21st April - Pushing north

10hours, 22km, and three tired men. We woke at 6am, having missed two previously set alarms, and were on the move by 8:30am. The terrain was poor, changing every

5metres from fresh snow to sheet ice. We switched to snowshoes to navigate the challenges of both. Physically, we began to display some wear. Oli developed bad blisters on his feet, and we all mentioned quite sizable bruises on our hips.

We made a collective decision to change our route, and shift our traverse target to Thobergsvatn, rather than the hut on Kverkfjöll. In doing so, we decided to avoid some very poor weather forecasts for Kverkfjöll, and to follow the original 1932 route, allowing more time for science and exploration rather than hauling.

22nd April - Whiteout skiing

20km covered with good skiing - some glide! - and lots of time in whiteout. The agreed highlight of the day was seeing a flock of birds through the white-out, quite something given our location.

23rd April - Approach to Thobergsvatn

We set early alarms for 5am to avoid a rainy warm front coming in. We moved ~8km down the glacier (but still felt like we were dragging the pulks uphill). That said, the snow conditions were good and there was some glide to our skiing.

Visibility had been poor all day, and as we reached the very northern edge of the ice-cap things were no different. We could make out rocks and crevasses, but were unsure about our distance from them relevant to us. We made a decision to pitch camp and wait until we could see properly again.

Midday came, and out of sync with our forecast, the sky cleared. As the whiteout lifted, we realized what we thought rocks were in fact mountains, and that the actual edge of the ice-cap was a few kilometers further away than originally thought.

The weather continued to brighten and we decided to scout a route off the ice and onto rock. We skiied pulk-free (a treat to glide!) until the beginning of crevasses, and roped up. After a few misdirected efforts down - blocked by crevasses, rivers - we ascended a little summit to give a view on the area. From the summit, we spotted a crevasse free descent and a big snowbridge over the river between the ice and the rocks. We'd completed a south-north, land-to-land traverse of the Vatnajökull!

As we returned to the tent, the winds grew to ~60kmph. At Kverkfjöll, our destination before the change of plan, the winds were apparently 120kmph and higher. We were happy with our decision to modify the route.

We continued to read chapters of the 1932 book in the tent, reading their journey in parallel with our own. Our respect for their team grows and grows every page.

24 April - Summit of Dome 1

We enjoyed a lie-in to celebrate our safe outwards traverse, and rolled around in sleeping bags until 10am. We all agree on our appreciation for the addition of cinnamon to our porridge in the morning.

The aim for the day was further exploration of the land north of the ice-cap, in particular, the summits of the lava dome the 1932 team called Dome 1 and the 1932 base-camp.

First, we arrived at the basecamp, just underneath Dome 1. Well-sheltered as described in their book and conspicuously clear of any big rocks. As we explored the area, we found vegetation (mosses and even some flowering plants) which boded very well for Glen's scientific effort.

We reached the summit of Dome 1 without any concern. At the top, we found metal cans weathered with time but clear relics of the original 1932 team, and above all their cairn! We retook photographs in the 1932 style ("Glen, change your posture!, Oli, cheeky grin!, John-Henry, stop smiling!"). This was the first moment the physical presence of the 1932 team felt real. We were stood as they had stood, feet perched on a cairn they had built. We descended from Dome 1 filling the mountains again with the sound of the Bonnie Banks of Loch Lomond.

April 25th - Genome sequencing

Up until this point, the morning routine had been quite straightforward. The team woke up, complained if it was early, and slowly John-Henry would get out of his sleeping bag to light the stove and melt snow whilst Oli and Glen napped. This morning Glen, ready with anticipation of the day of lab experiments, was ready to go in the porch before the others were awake, and therefore volunteered confidently to light the stove. The ensuing effort nearly set fire to the tent and our belongings, as a

petrol fire grew inside the tent. "Oh Dear, Oh Dear, Not Good" Glen said quietly as he placed a fire blanket around the flames. The situation ended safely, but it served as a reminder to us all of our isolation in this remote, dangerous environment.

The day was the scientific focus of the entire expedition. It was the day we would finally attempt to achieve the first example of entirely off-grid genome sequencing in a polar-style environment. Glen had been protecting his flowcells through the days and kilometers for this moment.

We skiied and hiked our way to Hveragil gorge, a hot spring gorge described by the 1932 team, and a guaranteed location for some form of life. Access to the gorge itself was tricky to accomplish and took some time. John-Henry and Glen eventually managed to abseil down into the gorge. The gorge smelt of sulphur, and the water was above bath temperature. Glen spent 30mins sampling.

We skiied back to the camp, had a quick dinner and Glen began his extraction and sequencing protocol. In a sentence, we became the first team to sequence DNA off-grid in a polar-style environment. Kudos to Glen.

April 26th - Rain & rest in the north

We woke late after the extended sequencing effort last night. We'd been up late ensuring activity on the laptop for the sequencing effort. "We" really means Glen, as Oli and John-Henry fell asleep accidentally pretty swiftly.

After the fire in the tent, John-Henry was more conservative with the stove, melting ice for breakfast outside. The weather deteriorated through the course of the day and we had, as planned, as restful morning.

In the afternoon we'd reached cabin fever and skiied out to a dust cone, which we sampled and tried to sequence to no avail. We ran out of battery on the dremel drill and resorted to blowing reagents through rather than centrifuging.

By 9pm, the clouds and rain around the camp lifted to reveal our surrounding landscape - the blacks and greys of the Icelandic interior desert - now with an additional covering of snow.

Moods and spirits of the team were strong and well. With many of the core objectives of the expedition complete, we appreciated that we could now focus on other topics and not stress about anything other than getting back safely.

April 27th - Rephotography

Again we began the day in poor visibility and rain. By midday, there were signs of clearing and by 1pm the sky was cloudless. Immediately we put on our skis and headed towards the Skarpajedinsjokull, seeking to do some rephotography. Our target was an image of a glacier cascading down from Kverkfjöll, and named after Skarpajeddin, the mountain guide for the 1932 team. We managed to capture a roughly equivalent photograph, but we appreciated the challenges of rephotography with differences in season and light affecting the ability to replicate images.

It was the first time we truly saw and experienced full sun on the Vatnajökull and John-Henry lost his bet that we would have no bluebird days in Iceland. He now owes the the team beers for the moment without clouds. Under the sun, we enjoyed downhill skiing races across the snow with many catastrophic falls.

With the sun, we ensured all devices were charged ahead of our "marathon sequencing" effort.

April 28th - Marathon genome sequencing

We woke at 5am to set up and launch a "marathon" sequencing run. Using solar power alone, we aimed to run a pretty intense sequencing program on the laptop using only on our power packs and solar panels.

Glen was in charge of monitoring the laptop, charging the batteries and getting the solar panels at an optimum angle to the sun. John-Henry and Oli were in charge initially of entertainment, but quickly grew bored and went for a ski.

They skiied to summits in the area to take 360^{o} panorama shots of the summits of key lava domes for uploading onto Google Maps to build the "community knowledge" of the area around Vatnajökull. As we took photographs, the weather closed in and snow began to fall. We returned to the camp to entertain Glen once again, who had been busy focussed on his science. In the end the sequencing ran for over 20 hours, and read over 100K strands of DNA.

April 29th - Summit skiing

After 20hrs+ sequencing, our laptop gave way to its battery constraints. Oli and John-Henry fell asleep whilst Glen stayed awake until late, checking the laptop at 30min intervals.

During the day we relaxed again in the morning, charging drones before conducting some more 360º photography and summit skiing.

April 30th - Climbing the needles

Scrambled eggs for breakfast drew moans from the entire team. We spent the morning conducting a kit check and stock count for the return journey, in addition to some scientific filming of Glen.

The afternoon's target was an ascent of the 'needles' which overlook the camp, at the foot of Kverkfjöll. Glen and John-Henry made an ascent, with Oli capturing it on drone. The rock is loose and dangerous, despite its natural beauty.

We return towards camp via Dome 1, and see the cairn has thawed. We move rocks and the metal boxes around, and stumble across a tin with a sheet of paper inside. The paper has the signatures of the 1932 team. Unreal.

1st May - Beginning of the return journey

Whiteout all day.

After the magical colours of the sunset last night (reds, oranges, scarlets lighting up Kverkfjöll and the volcanic plan), today was especially grey. Despite the grey, there was limited wind, and so we moved forwards into the white, into the nothingness at good speed. The snow has changed character since our outbound traverse, now pocked with marks of rain, and was easier going than on our first crossing.

Unencumbered by the responsibility for the flow cells, Glen wanted to get to know the Inreach on the return leg, and therefore led the trail away from Kverkfjöll. Before we departed, we took a toast with Icelandic gin to the camp.

2nd May - Freezing rain

We woke at 7am, ready for another day on the traverse, and as we poked our heads out of the tent were met with a scene which had begun its process the evening before. Everything: our tent, skis, pulks, were covered in a rind of ice ~1cm thick. Freezing rain had coated everything.

John-Henry spent much of the morning de-icing the skis with salt, with our tent brush, and with around 4L of boiling water. Once the skis were ready, the entire team spent a few hours dis-entombing the tent from tent from the ground, but a few pegs were broken or bent in the process.

Once we were on the move, progress was rapid as the ground was hard and our loads increasingly light. As we set up the tent at the end of the day the wind built to ~35kmph, and began to create pockets of dense spindrift where we left our tracks.

3rd May - Another bluebird (!)

We woke with the porch of the tent almost filled to the brim with spindrift. We were surrounded by 1m deep dunes of spindrift on the leeward side of the tent, whilst the remainder of the plateau was completely clear of snow. We spent the morning digging out the porch. Top of the conversation list was the fact that the wind last night had filled our tent with snow, and it had only hit 35kmph. We shuddered at the idea of 100kmph.

By 10am, the wind died down and we began to pack the gear. By 11am, it was totally still and we had blue sky. The skiing for the day was average in condition, with some icy pockets, some deeper sections of powder.

We lost sight of the Kverkfjöll range, and toasted its memory with a bottle of gin. We set camp after ~15km hauling at 4pm and spent the rest of the day in beautiful sunlight. The temperatures were -10°C, but the blue skies allowed all batteries to recharge fully for drone-flying.

4th May - Descent to Joklasel

We woke to another blue sky day, and spent much of the morning filming on the plateau, enjoying our final day on the ice. We took every drone shot iteration possible of the team skiing on the ice. Our ski was down the crevasse field we had painstakingly come up in white-out. In clear conditions, all crevasses were visible, our 'Camp Driblet' was visible, the mountains were visible. We all took heavy tumbles going at speed on the descents, most notably Oli having some pretty big crashes.

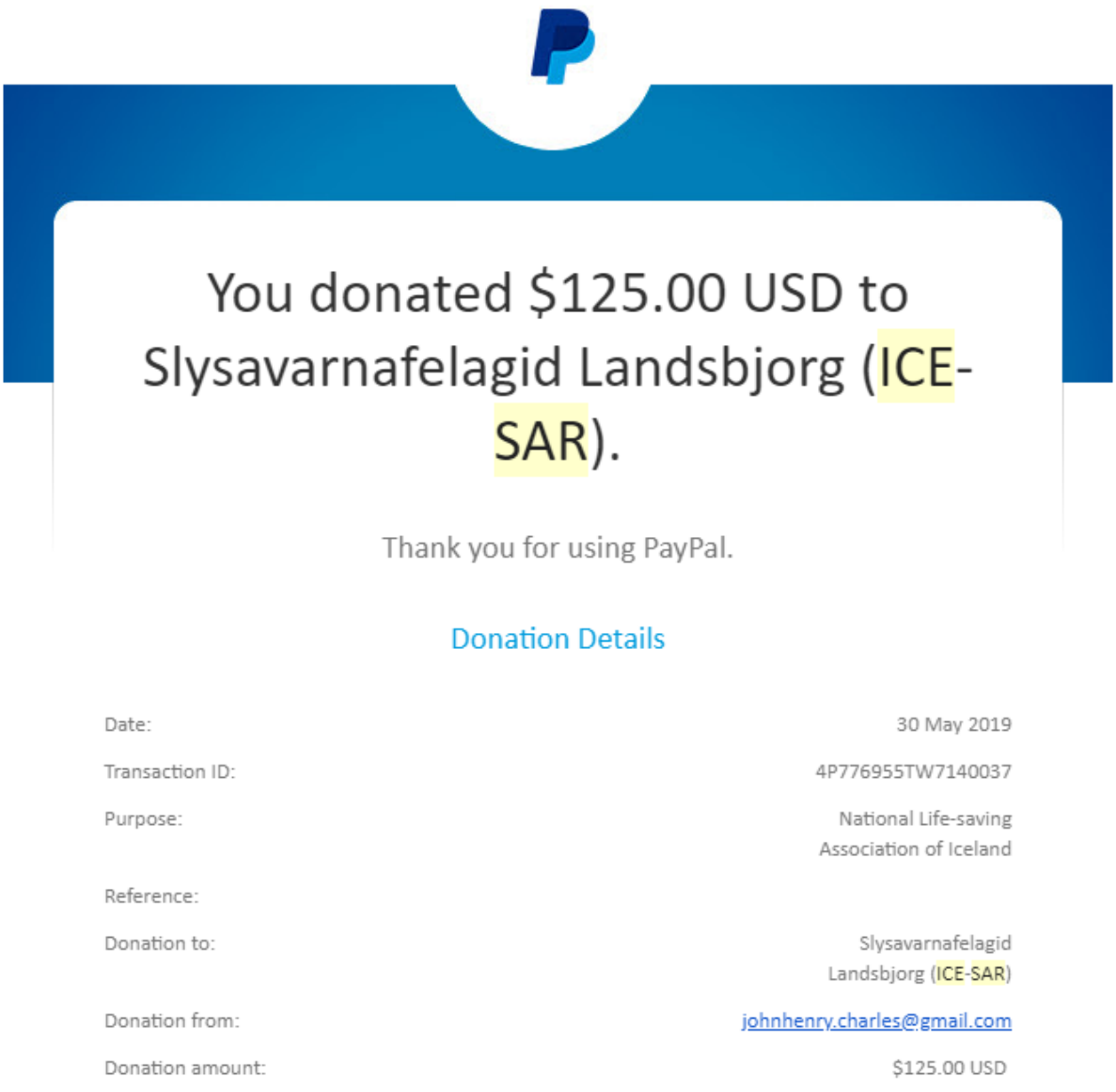
We camped ~600m from Joklasel hut, just behind a small hill on solid ground. We placed our skis and poles as safety guards to ensure we were not struck by some unassuming snowmobile. We read the last few pages of "Iceland Adventure" and toasted a successful crossing with a few whiskeys.

5th May - Collection and expedition end

The day after we were picked up at midday, and taken back down to the Vagnasstadir hostel, and Hofn.

16.5 Appendix V: Carbon offset

16.6 Appendix VI: SAR donation



You donated $125.00 USD to Slysavarnafelagid Landsbjorg (ICE-SAR).

Thank you for using PayPal.

Donation Details

Date:	30 May 2019
Transaction ID:	4P776955TW7140037
Purpose:	National Life-saving Association of Iceland
Reference:	
Donation to:	Slysavarnafelagid Landsbjorg (ICE-SAR)
Donation from:	johnhenry.charles@gmail.com
Donation amount:	$125.00 USD

16.8 Appendix VII: Vatnajökull National Park permits

16.8.1 Drone permit

UAV permit application for use within Vatnajökull National Park

VATNAJÖKULSÞJÓÐGARÐUR
NATIONAL PARK

Please email application to: steinunnhodd@vjp.is

General use of UAVs (drones) is not permitted within Vatnajökull National Park. The reasons are: Protection of wildlife within the park; Visitor safety; and the park's objective of quality experience for its visitors. This is in accordance with regulation about Vatnajökull National Park (608/2008), article 9.

Park managers can permit the use of drones when guaranteed that such use will not contravene with any of the three reasons stated above. Separate permits are issued if the use is a part of scientific research or large-scale film projects (contact steinunnhodd@vjp.is for further information).

This application form is for all UAV use that is **neither a part of a scientific research or a large-scale film project**. Applications must be submitted with at minimum 7 days notice. Vatnajökull National Park can not guarantee that the application will be processed if it arrives later.

Note must be taken that police and ICE-SAR personnel are exempt from seeking permit when the drone use is part of law enforcement or search & rescue operations. The drone use of the previously stated personnel has however to be reported to the park authorities.

Applicant information

Name: Oliver Vince Submitted as part of the film making for the Return to Vatnajokull expedition (www.sledgereport.com)
Address: St Catherines College, Manor Road
City: Oxford
Postcode: OX1 3UJ
Country: UK
Email: oliver.vince94@gmail.com
Mobile phone number while in Iceland: +447591109707
Has the applicant received any certified UAV training? No (*if yes, please attach a copy of certificate*)

UAV information

Manufacturer: DJI
Type: Mavic Pro
Weight: 734g

Serial number:
Does the drone have a liability insurance cover? No (*if yes, please attach a copy of certificate*)

Flight locations within the national park

Please fill in as many locations as needed. If more than three, please copy location tables and paste as often as needed. Remember to update location numbers. Please be as specific as possible with locations, stating name of place or GPS coordinates.

Location #1: Locations on the South Coast
Date: 16-19th
Time of day: Daytime
Duration of flight(s) - minutes: approx. 120mins (dependant on weather)
Objective of flight: Obtain cinematic footage of our approach to the icecap for the promotion of our scientific results to wider audiences after the expedition.

Location #2: Joklasel to Kverkfjoll icecap traverse
Date: 19th-27th April 2019
Time of day: Daytime
Duration of flight(s) - minutes: approx.. 200 minutes (dependant on weather and power)
Objective of flight: Obtain cinematic footage of our ski traverse across the icecap for the promotion of our scientific results to wider audiences after the expedition.

Location #3: Kverkfjoll
Date: 28th- 5th April
Time of day: Daytime
Duration of flight(s) - minutes: approx.. 200 minutes (dependant on weather and power)
Objective of flight: Obtain cinematic footage of our basecamp at the end of the icecap for the promotion of our scientific results to wider audiences after the expedition. Also to obtain high resolution images of the glacial tongues around Kverkfjoll for the purposes of comparison with the icecap locations in 1932 (see scientific and filmmaking permit applications for more context here)

Applicant´s information:

Oxford, 15/02/2019

Place and date

Applicant´s signature

To be signed by park warden :

7/3 '19 Fellabær

Place and date:

Ágnes Bríet Birgisdóttir

Signature:

16.8.2 Filming permit

Application for a permit for film-making, advertisement making and permits for other such activities in the Vatnajökull National Park

Information on the applicant

Applicant: Name and ID No./State Reg. No.	Oliver Vince
Address	St. Catherines College, Manor Road, Oxford, UK
Telephone/Mob./Fax and e-mail	+447591109707 oliver.vince94@gmail.com
Representative of the applicant if the applicant is a legal entity	
Project supervisor	

Name and short description of the project:

The filmmaking proposed here will occur as part of the outreach objectives of the 'Return to Vatnajökull' expedition (www.sledgereport.com). This expedition aims to retrace a route from Joklasel to Kverkfjöll that was performed by a team in 1932. One of our aims is to re-take a selection of their photos and make these publicly available so that changes in the environment can be observed in the spanning 87 years. Another of our aims is to perform a microbial taxonomic survey of the sediment near the Gengissig lake. The application for this scientific project has already been submitted to you separately.

The purpose of this film will be to communicate the story of our journey across the icecap and to communicate our scientific results to a wider audience. This will hopefully increase the wider interest in our scientific results and encourage expedition teams in the future.

I am an amateur film maker, and a selection of my previous work can be found here: www.timefliesmedia.com. This will be a small-scale film project that is a personal interest of the team members. If the filming goes well, we will aim to submit the film to Adventure Film Festivals.

If you have any further questions about our filmmaking objectives, or my experience as a UAV operator, please do not hesitate to ask.

Number of participants

Total number of employees involved in the project: 3 team members on the icecap crossing, they will not be employed

Further breakdown, e.g. number of actors and extras, technical personnel, service personnel, etc.

No significant other participants in the film (with the exception of possible short clips of other people we meet on the journey). We will be carrying minimal camera equipment as it will all have to be carried in our pulks.

Other details e.g. number and size of cars, set, scenes, aerial shooting, animals etc.

We will be travelling from Joklasel to Kverkfjoll on skis, pulling pulks, and will be filming our journey. We will be carrying a selection of handheld cameras and a DJI Mavic drone. A separate application will be submitted for use of the UAV. The drone flights will be used to obtain short cinematic clips of the team on the icecap and to collect high resolution images of the glacial tongues on our icecap traverse route. All UAV flights will be conducted with the utmost respect for the natural environment and other teams that we meet around the icecap.

Timeline and duration of the project:

We are currently planning to be in the National Park from the 16th of April 2019 to around the 6th of May depending on how the weather conditions affect our journey.

Location inside the National Park:

We will be traversing the icecap between Joklasel and Kverkfjoll. Possible inclusion of extra shots from the South Coast, eg. Jokulsarlon and Hofn, but the focus of the film will be on the traverse

I, the undersigned, hereby confirm that I have studied the provisions of Act No. 60/2007, Regulations No. 608/2008 and the regulations on photo-taking and film-making in Vatnajökull National Park and I warrant that those who are involved in the project shall comply with these procedures in every detail.

Oxford, UK, 15/02/2019

Place and date

Signature of the applicant/representative

7/3 '19 Fellabær Ágnes Bríet Sigrísdóttir

Permit granted

16.8.3 Research permit

Application for a research permit for the Vatnajökull National Park

Information on the applicant/researcher

Project name	Return to Vatnajökull Expedition
School/Establishment/Firm	Imperial College London, Abersytwyth University, University of Akureyri
Project supervisor	Dr Arwyn Edwards, Senior Lecturer in Biology, Abersytwyth University
Applicant: Name and ID No./State Reg. No.	Glen Gowers
Address	8a Cavendish Parade, Clapham Common Southside, London, UK, SW4 9DW
Telephone/Mobile/Fax	+447854991424
E-mail	glgowers@gmail.com

Date, timeline and duration of the project:
20th April – 20th May

Location inside the National Park:
Gengissig lake, Kverkfjöll Mountain Range

Description of the project, purpose and execution:

The research proposed here will occur as part of the scientific objectives of the 'Return to Vatnajökull' expedition. This expedition aims to retrace a route from Joklasel to Kverkfjöll that was performed by a team in 1932. Our aim is to re-take a selection of their photos and make these publicly available so that changes in the environment can be observed in the spanning 87 years. In 1932 they published a taxonomic survey of plants and animals they encountered in the Kverkfjöll mountain range. Taking inspiration from this survey we are proposing to perform a microbial taxonomic survey of the sediment near the Gengissig lake (64.7474453° N 16.6326571° W). We plan to use cutting edge 'Oxford Nanopore' sequencing devices that enable sequencing to be performed in-field therefore requiring no sample collection. This work would be performed under supervision of Dr Arwyn Edwards in collaboration with an Icelandic research group at the University of Akureyri.

Description of methods for sample taking, if part of the research:

Sequencing will occur on-site with DNA extracted from the soil using a well-known protocol. Oxford nanopore sequencing will be performed in-situ therefore no samples will be collected and taken off the National Park. Data will be collected on a laptop and will be analysed in collaboration with our Icelandic collaborator in Akureyri.

Other information that the applicant wants to submit:

Information on the expedition more broadly can be found at www.sledgereport.com. Alternatively please do not hesitate to contact me directly for more information. We would like to complete this work in as close communication with the park authorities as possible to ensure a cohesive relationship.

I, the undersigned, hereby confirm that I have studied the provisions of Act No. 60/2007, Regulations No. 608/2008 and the work procedures for research of nature, the natural environment and cultural remains in the Vatnajökull National Park and I warrant that those who are involved in the project shall comply with these procedures in every detail.

London, 29.01.18

Place and date

Signature of the applicant/representative

5/2 '19 Ágnes Brá Birgisdóttir

Permit granted

(Please email application to Steinunn Hödd Harðardóttir: steinunnhodd@vjp.is)

16.9 Appendix VIII: Peer-reviewed manuscript

genes

MDPI

Article

Entirely Off-Grid and Solar-Powered DNA Sequencing of Microbial Communities during an Ice Cap Traverse Expedition

Glen-Oliver. F. Gowers [1,2,3,*], Oliver Vince [1,4], John-Henry Charles [1], Ingeborg Klarenberg [5,6], Tom Ellis [2,3] and Arwyn Edwards [7,8]

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2 Imperial College Centre for Synthetic Biology (IC-CSynB), Imperial College London, London SW7 2AZ, UK; t.ellis@imperial.ac.uk
3 Department of Bioengineering, Imperial College London, London SW7 2AZ, UK
4 Institute of Biomedical Engineering, University of Oxford, Oxford OX3 7DQ, UK
5 Faculty of Natural Resource Science, University of Akureyri, 600 Akureyri, Iceland; ingeborg@unak.is
6 Faculty of Life and Environmental Sciences, University of Iceland, 101 Reykjavík, Iceland
7 Institute of Biological, Environmental & Rural Sciences (IBERS), Aberystwyth University, Aberystwyth SY23 3DD, UK; aye@aber.ac.uk
8 Interdisciplinary Centre for Environmental Microbiology, Aberystwyth University, Aberystwyth SY23 3DD, UK
* Correspondence: glgowers@gmail.com

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check for updates

Abstract: Microbial communities in remote locations remain under-studied. This is particularly true on glaciers and icecaps, which cover approximately 11% of the Earth's surface. The principal reason for this is the inaccessibility of most of these areas due to their extreme isolation and challenging environmental conditions. While remote research stations have significantly lowered the barrier to studying the microbial communities on icecaps, their use has led to a bias for data collection in the near vicinity of these institutions. Here, miniaturisation of a DNA sequencing lab suitable for off-grid metagenomic studies is demonstrated. Using human power alone, this lab was transported across Europe's largest ice cap (Vatnajökull, Iceland) by ski and sledge. After 11 days of unsupported polar-style travel, a metagenomic study of a geothermal hot spring gorge was conducted on the remote northern edge of the ice cap. This tent-based metagenomic study resulted in over 24 h of Nanopore sequencing, powered by solar power alone. This study demonstrates the ability to conduct DNA sequencing in remote locations, far from civilised resources (mechanised transport, external power supply, internet connection, etc.), whilst greatly reducing the time from sample collection to data acquisition.

Keywords: metagenomics; nanopore; polar; expedition; microbial sequencing

1. Introduction

As the Earth's climate continues to warm, the role that microbial ecosystems play in anthropogenic climate change is becoming increasingly apparent. As these microbial communities affect the climate, they, too, will be affected [1] and may further amplify climate change [2]. It is crucial that our understanding of this interaction improves to inform our collective knowledge of how climate is changing [1]. Our understanding of these microbial communities naturally correlates well with the ease of access for sample collection [3,4]. In particular, polar environments suffer from logistically challenging sample collection and shipping. Hence, polar environments remain poorly understood

at this microbial level despite the polar cryosphere representing approximately 14% of the Earth's surface [5]. Traditionally, samples must be collected on site using sterile equipment and transported back to a laboratory under appropriate conditions, such as under dry ice. Logistics are further hampered by clearing customs and other delays in transit. This often results in a significant length of time from sample collection to sample analysis. During this time, the composition of the microbial community can change or degrade.

One solution to these issues is to bring the laboratory closer to the sample collection site. This has been achieved by building remote institutions and research stations, for example networks of Arctic stations (https://eu-interact.org/) and the many research stations on the Antarctic continent [6]. Whilst this minimises the time and logistic requirements of sample analysis, this benefit is greatest for study sites in proximity to field stations [7]. For example, a recent meta-analysis showed that 31% of Arctic ecology citations are derived from work within a 50 km radius of just two field stations [7].

Conventional characterisation of microbial communities relies on DNA sequencing, since most microbes remain uncultured [8]. Both high throughput metagenomic sequencing and amplicon sequencing are typically applied with the intention of revealing the proportions of microbial species present in a particular sample [5,9,10]. Over the last decade, short read sequencing has been used predominantly. This requires a full genomics laboratory to house large, bulky equipment. In recent years, long read sequencing has seen increased use. Oxford Nanopore sequencing can produce significant amounts of read data (Mbp—Gbp) from a small device capable of being run directly from a laptop [11]. Previous studies have capitalised on the small-form factor of this device to conduct sequencing efforts at the site of sample collection. For example, portable long-read sequencing was used to sequence plant virus genomes in real time to inform crop management in sub-Saharan Africa [12]. It has also been proven to provide early detection and epidemiologic surveillance of Ebola and Zika virus' during epidemic outbreaks [13,14]. The clear advantage of this technology is that the device can be run in low-resource environments. This is largely because sample preparation requires a minimal molecular biology set up and the sequencing run itself requires only a laptop, a Nanopore MinION device, and a Nanopore flowcell. This device has also been taken underground to demonstrate the ability to sequence at inhospitable sub-surface levels [15]. It is a clear progression to then apply these minimal-infrastructure techniques to polar environments. Temperature regulation is a key challenge in these environments as nanopore flowcells are extremely sensitive to freezing. Teams have previously conducted DNA sequencing in polar environments using Oxford Nanopore devices. Johnson et al. conducted on-site calibrations in the Antarctic Dry Valleys and further sequencing from samples at a research station [16]. Edwards et al. similarly performed sequencing at an Arctic research station following sample collection nearby [10]. Edwards et al. further successfully achieved in-field sample-to-data collection at a field camp in Greenland (67° N) using a combination of a generator and battery power that was flown in [10].

Thus far, the ability to sequence DNA off-grid has been limited by access to vehicles and generators. This study aimed to minimise the infrastructure required for off-grid DNA sequencing by utilising solar power alone for all DNA extraction and sequencing in a polar environment. Due to both long days in the summer and reflective ice and snow, solar energy is in no short supply in polar environments, and therefore provides the perfect compromise between portability and renewable power availability. This demonstrates that a sequencing effort could be successfully completed midway through an ongoing, unsupported expedition alongside the other physical and psychological challenges associated with survival in such a challenging environment. Data collection was conducted in a tent after the expedition team had conducted a ski traverse of Europe's largest ice cap (100 km) over 11 days and used solar power alone. This study occurred at least 60 km from the nearest civilisation and at least 135 km from the nearest research facility. Crucially, everything required to conduct this metagenomic study was transported in a sledge along with all equipment required for long-term polar survival.

2. Methods

2.1. Hardware Logistics

The entire laboratory setup was contained within two 9 L boxes in addition to a laptop (in waterproof/shockproof case) and 90 W solar panel (Table 1). This was packed into the back of a 50 kg rated polar sledge (Aguille Alpine Trail Pulk, Cumbria, UK) and occupied ~30% of the sledge volume.

Table 1. Contents of the sledge-based miniaturised laboratory.

Reagents	Consumables	Hardware	
Qubit reagents	DNA Lo-bind tubes	Nanopore MinION device	Meat thermometer
Qubit standards	Qubit tubes	Tube racks	Temperature loggers (2) [1]
AMPure beads	Sterile sample bags	Dremel drill	Magnet
80% ethanol	P1000 tips	DremelFuge adapter	Waste container
QIAGEN Powersoil kit	P200 tips	Hand-powered centrifuge	Laminated protocols
Nanopore LRK001 kit	P10 tips	Terralyser	Pen and notebook
Nanopore RAD004 kit	Nanopore flowcells	Qubit 4	90 W compact solar panel
	Gloves	USB vortex	Dell XPS 13 laptop
	Parafilm	20 Ah power packs (3) [1]	
	Falcon tubes	P1000 pipette	
	Hand warmers	P200 pipette	
	Sterile loops	P10 pipette	

A complete DNA sequencing laboratory is miniaturised into two 9 L boxes pulled by sledge and ski across the Vatnajökull ice cap, Iceland. The contents of the two 9 L boxes comprise a functioning DNA sequencing laboratory with components listed. [1], the number refers to quantity.

During the flight to Iceland, kit was stored in three different conditions: [cargo] Hold (ambient), Hold (polystyrene box with 4 °C ice packs), and hand-luggage (Table S1). During the ice cap traverse (route shown in Figure 1A) three temperature zones were also established, kept on person ("Chest—warm"), taken into the tent each night ("Tent—box"), and left outside in the pulk ("Pulk—box") (Table S1). The temperature environment of "Chest—warm", importantly, contained the nanopore flowcells that are destroyed if allowed to freeze. To control the temperature of the flowcells they were kept in the sleeping bag at night inside a Peli™ Case 1015 (Peli Products Ltd, Glossop, UK) and during the day items were kept inside a generic airtight plastic food container with foam padding for thermal insulation. This case was kept in a travel bag with a strap around the carrier's neck. Temperature of the flowcells was constantly recorded ("Hold (polystyrene box)" during flight and "Chest-warm" during ski traverse) using a battery powered automatic temperature logger. This method maintained a temperature between ~+9 °C and ~+30 °C despite ambient outdoor temperatures reaching −17 °C (Figure 1B). Overheating during exercise on warmer days became a potential issue. Temperature was continuously monitored using an aquarium thermometer taped to the outside of the plastic food container with the readout monitor clipped to a rucksack strap. Therefore, temperature control could be achieved by moving the case between clothing layers.

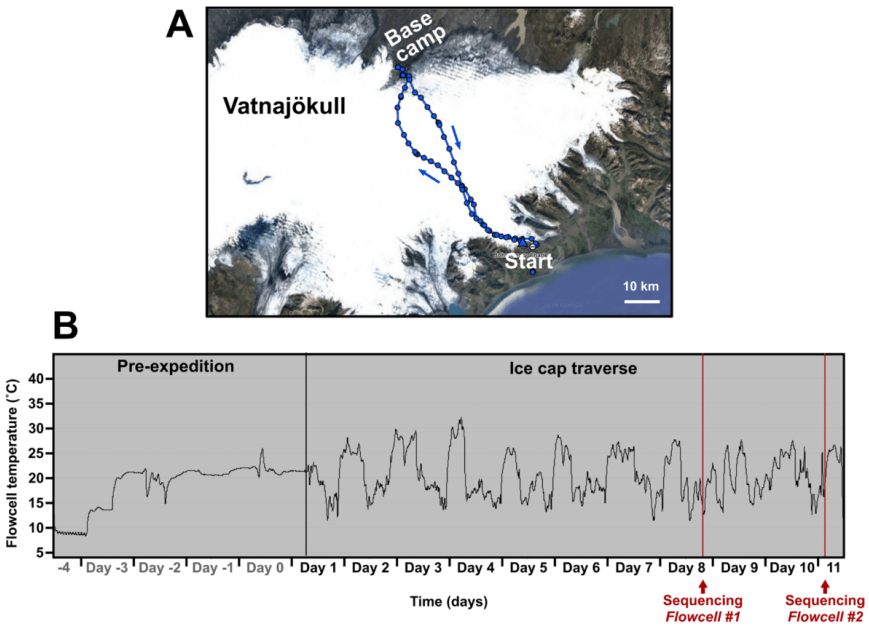

Figure 1. Flowcells were maintained above freezing using body heat for the outbound eleven ski days. (**A**) Pulks (including the DNA sequencing equipment) were pulled by ski for seven days on the outbound journey to the "Base camp" on the northern edge of the ice cap. The return journey was reduced to four days due to more favourable ski and weather conditions. (**B**) Temperature log of the flowcells from leaving the UK to the start of the second sequencing run. During Day −4 the flowcells were kept in a polystyrene box with cool packs equilibrated to 4 °C and put in the hold during the flight. Days −3 to 0 were spent travelling to and staying at a hostel where flowcells were kept indoors at room temperature. Days 1 to 7 were spent traversing the icecap. Spikes in temperature correspond to night time where flowcells were kept inside the sleeping bag. Days 8 to 11 were spent at "Base camp" on the northern edge of the ice cap. Sequencing runs #1 and #2 (red lines) occurred at the base camp on Day 8 and Day 11.

2.2. Sampling

Samples were obtained from the Hveragil hot spring gorge, Iceland (decimal degree (DD) coordinates: 64.683067, −16.527890) following a ~60 km traverse of the Vatnajökull ice cap (starting decimal degree (DD) coordinates 64.255293, −15.863259) by ski and sledge (Figure 2A). A metal spoon sterilised with ethanol was used to collect the sample into sterile sample bags. The sample consisted of soil approximately 3 cm under the surface of mosses and liverworts located on an overhanging rock 30 cm above the hot spring water surface (water at approximately +60 °C [17]). Samples were then transported on foot and ski at ambient environmental temperature to the tent located 3 km from the sample collection site (Figure 2B).

2.3. Battery-Powered DNA Extraction

DNA was extracted using the QIAGEN PowerSoil® kit (Qiagen, Hilden, Germany) according to manufacturer's instructions except for the following changes. Centrifugation steps were performed using a pre-charged Dremel™ 7750 battery-powered drill (Dremel, Prospect, IL, USA) with a 3D-printed tube holder (https://www.thingiverse.com/thing:454962). Centrifugation steps were performed on

"medium" speed (level 2) for bursts of 30 s, checking for the sufficient outcome each time to minimise battery usage. PowerBead tubes were vortexed for 30 s using a TerraLyzer™ (Zymo Research, Irvine, CA, USA) with a pre-charged 12 V battery. DNA was eluted using solution C6 (sterile elution buffer) pre-heated to body temperature by holding in a gloved hand. Extracted DNA was quantified using a Qubit™ 4 fluorometer (Thermo Fisher Scientific, Waltham, MA, USA) and dsDNA HS kit according to manufacturer's instructions powered by a PowerAdd Pilot Pro2 20 Ah power pack. During sample preparation all solutions were kept around 20 °C using hand warmers inside a closed sleeping bag. DNA concentration was performed after extraction using 0.5× Ampure XP beads (Beckmann Coulter, Brea, CA, USA). Beads were pelleted using a strong magnet and washed with 80% ethanol. Elution was carried out with deionised water. The laboratory setup is shown in Figure 2C.

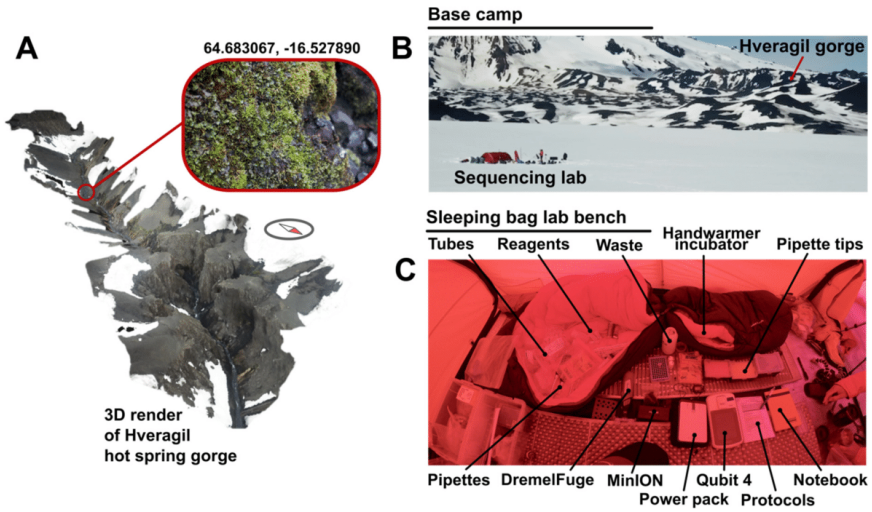

Figure 2. DNA extracted from Hveragil hot spring gorge. (**A**) 3D render of Hveragil hot spring gorge from a drone flight highlighting the location of sample collection (decimal degree (DD) coordinates: 64.683067, −16.527890). Render completed using footage from a Mavic Pro Drone (DJI, Shenzhen, China) and Pix4Dmapper software (Pix4D, Lausanne, Switzerland). (**B**) Landscape photograph indicating the location of sample collection "Hveragil gorge" and the base camp where DNA extraction and sequencing took place ("Sequencing lab"). (**C**) A photograph showing the set up for tent-based DNA extraction in a sleeping bag lab. Items displayed are labelled. Terralyzer for bead beating is omitted from the photograph.

2.4. Solar-Powered Nanopore Sequencing

Extracted DNA was prepared using the field sequencing kit LRK001 (Oxford Nanopore Technologies) according to the manufacturer's instructions. The 80 °C water bath was achieved by filling an insulated mug (Thermos L.L.C, Schaumburg, IL, USA) with boiling water and cooling it to 80 °C with ice as appropriate. Temperature was monitored using a standard meat thermometer. The prepared DNA library was loaded onto R9.4.1 flowcells. Sequencing was powered by one PowerAdd 20000 mAh battery and two Aceyoon 20000 mAh powerbanks, all fully charged using a 90 W Solar Panel (Mobile Solar Chargers, Somerset, UK), capable of generating approximately 20 V even in moderate cloud cover, prior to any sequencing run.

2.5. Data Analysis

Data from Flowcell #1 was locally basecalled by offline MinKNOW (v18.12.9) (Oxford Nanopore, Oxford, UK) during the run on a Dell XPS 13 i7 laptop with 16 GB RAM and 500 GB SSD. Data from Flowcell #2 was basecalled offline after the run using Guppy (v3.0.3) (Oxford Nanopore, Oxford, UK). FASTQ files from both sequencing runs were concatenated and uploaded to Kaiju (kaiju.binf.ku.dk) for taxonomic classification upon return to civilisation due to code errors running Kaiju offline in situ. Reads were compared to the "NCBI BLAST nr + euk" reference database using the "Greedy" setting, allowing mismatches with standard parameters (minimum match length 11, minimum match score 75, allowed mismatches 5).

3. Results

3.1. Sequencing DNA Remotely Using Solar Power

Two nanopore flowcells were taken on the expedition. A quality check was performed prior to departure and just prior to sequencing for each flowcell (Table 2).

Table 2. Flowcell quality check results performed prior to expedition departure on Day −4 and also immediately prior to each sequencing run on Day 8 (Flowcell #1) and Day 11 (Flowcell #2).

ID	Number of Active Pores	
	Prior to Departure Day −4	Prior to Sequencing Day 8 (#1) and 11 (#2)
Flowcell #1	1375	1320
Flowcell #2	1180	1183

Flowcell #1 retained 96% of the initial active pores while Flowcell #2 appeared to gain three active pores during the pre-expedition logistics and the ski traverse. These results validated our temperature control approach using body heat to maintain an above-freezing temperature during a lengthy ice cap traverse.

Within 5 h of sampling, 6.54 µg DNA was extracted in 100 µL (65.4 ng/µL) from Hveragil hot spring gorge by pooling and concentrating four separate extractions. The first sequencing run was performed on the ice cap immediately after with local basecalling activated. This was to ensure the sample contained DNA of sufficient quality for a successful sequencing run. The laptop was fully charged the day before (Day 7, Figure 1B) using power banks, which had been charged by the 90 W solar panel. This first run was started at ~8:00 p.m. on Day 8 and lasted for 5 h on laptop battery alone due to the low ambient temperature (2–8 °C). This run yielded 19,839 reads that were basecalled in real-time during the run.

To determine the maximum amount of data that a single flowcell could yield in a single solar-powered run a fresh DNA library from the same DNA extract was added to Flowcell #2. Two further additions of this DNA library were used to maximise cumulative throughput (Figure S1). Prior to the second run, three battery packs and the laptop were charged the day before (Day 10) using the solar panel. Sequencing began at 6.30 a.m. (Day 11) with local basecalling disabled and screen brightness reduced to minimise power consumption. During daylight hours power was fed into the laptop using the PowerAdd via the 90W solar panel (Figure 3A). To maximise charge efficiency the powerbank was disconnected when the laptop charged to over 80% and was reconnected when the charge dropped below 60%. This was maintained until around 6:00 p.m. when insufficient solar power could be generated to charge the powerbank. Sequencing ceased once all power was exhausted from all three powerbanks and the laptop battery at 2:00 a.m. (Day 12). Interestingly, only approximately five active pores remained at this point, indicating that sequencing was not limited by running out of power (Figure S1). This second run yielded 113,699 reads and lasted 19 h 45 min. The total sequencing time for the expedition was over 24 h and yielded 133,538 reads and 185.9 Mbp of data (Figure 3B).

A large number of "short" reads (dark red, Figure 3B) result from aggressive bead beating, required to extract DNA from complex soil matrices, and the transposase step in the DNA library preparation. Despite this we still see a large number of reads extending to 5 kb in size and beyond.

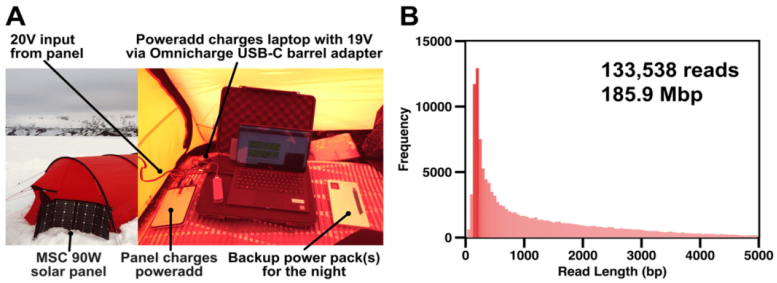

Figure 3. Two off-grid sequencing runs yielded almost 190 Mbp of data. (**A**) The solar power strategy for powering a laptop running Oxford Nanopore offline MinKNOW software (v18.12.9). Items shown are labelled. (**B**) Read length distribution for pooled sequencing runs. For simplicity only reads <5000 bp are shown.

3.2. Metagenomic Analysis

Basecalled reads from both runs were pooled and uploaded to Kaiju for taxonomic classification. A total of 44% of the total reads (58,520) were successfully aligned to the reference database. This number is lower than was anticipated based on previous work where we have seen values between 60% and 95%. Considering the remoteness of the sampling location this is likely to represents uncharacterized microorganism species. A wide range of classes of bacteria were observed, as well as 2% eukaryotes and 0.4% archaea (Figure 4, Tables S2 and S3). Due to sample collection at the edge of a geothermal stream, 10 thermophilic bacteria were identified by taxon classification of three or more reads (*Chloracidobacterium thermophilum*, *Anaerolinea thermophila*, *Crenotalea thermop*, *Sphaerobacter thermophilus*, *Fontimonas thermophila*, *Spirochaeta thermophila*, *Symbiobacterium thermophilum*, *Schleiferia thermophila*, *Novibacillus thermophilus*, and *Pseudonocardia thermophila*). Simultaneously, 1009 reads were assigned to organisms from the Cyanobacteria phylum with the Nostocales order being most abundant (371 reads). Within Cyanobacteria morphospecies *Nostoc* (83 reads), *Oscillatoria* (29 reads), *Phormidium* (21 reads), and *Pseudanabaena* (9 reads) were identified which are characteristic of microbial mats in polar regions [18].

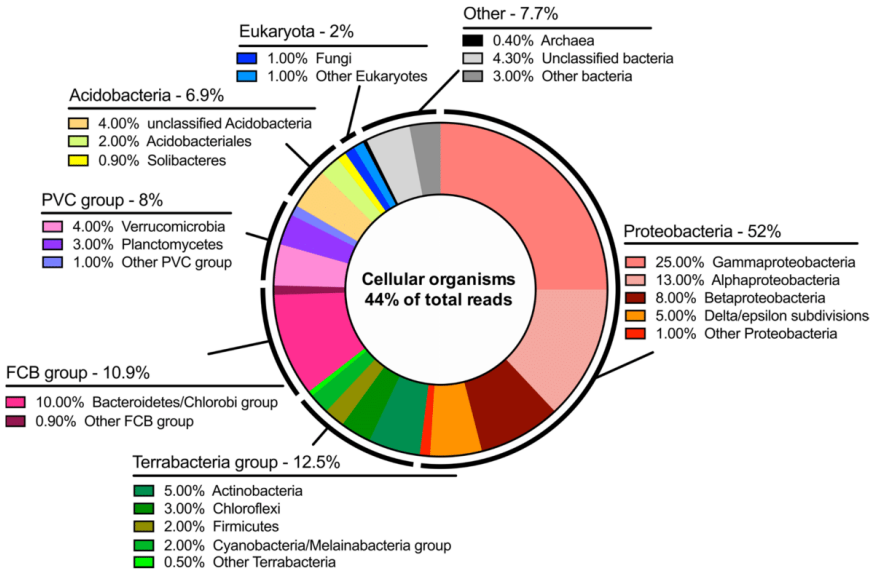

Figure 4. Metagenomic protein-level taxonomic identification from both sequencing runs combined. Kaiju output is shown for 44% of reads that successfully aligned to the NCBI reference database and assigned to "cellular organisms". The relative percentage of reads assigned to "cellular organisms" of each group of organism is shown. PVC group, superphylam named after three important members Planctomycetes, Verrucomicrobia, and Chlamydiae; FCB group superphylam named after three important members Fibrobacteres, Chlorobi, Bacteroidetes.

4. Discussion

In this study the successful miniaturisation of a DNA sequencing laboratory such that can be hauled by human power within a larger self-supported expedition is demonstrated. The experimental outcomes prompt some observations that may aid future similar off-grid projects. First, the DremelFuge 3D printed attachment (FormLabs clear photopolymer resin) became brittle at lower temperatures and at one point cracked during centrifugation. This both posed a safety risk and nearly derailed the DNA extraction protocol. While a backup manual centrifuge was taken [19] it too suffered from being brittle at lower temperatures. It is therefore recommended that future teams pick a more suitable resin for lower temperatures. Furthermore, there were issues keeping the Dremel drill charged using battery packs and, as such, the existing battery charge from before departure was relied upon. Since returning the Myspin 12 (Thermo Scientific, Waltham, MA, USA) has been used, which was successfully run from the PowerAdd power bank at 12 V. Due to its small footprint it is recommend future teams use this instead of the DremelFuge.

The dichotomy of microorganisms identified at Hveragil hot spring gorge was particularly intriguing. There was a sizable number of reads assigned to both cyanobacteria characteristic of the cold polar regions and thermophilic bacteria. It is believed that this indicates the interesting microenvironment present in hot spring streams fed by meltwater from the Vatnajökull ice cap [17], resulting in a microbial population with presumably extremely diverse metabolisms. Naturally, this study demonstrates the methodology of entirely off-grid metagenome sequencing and future studies are needed to probe the microbial taxonomic distribution in this area further.

Additionally, it is worth noting that approximately 56% of the data generated could not be aligned to the "NCBI nr + euk" database. This number drops to 48% when a stringent quality threshold is

applied to the reads. Therefore, it is expected most of this number represents organisms that have yet to be cultured and have their genomes characterized. While it may be expected that some of the data was from unknown organisms it is surprising that it was so high. Naturally, Hveragil gorge, on the northern edge of the ice cap, is among the most inaccessible places in Iceland. This, in combination with the interesting geochemistry of the area leads to the conclusion that 56% represents a pool of interesting organisms and metabolisms that could be later isolated and studied further.

This entire metagenomic study was conducted off-grid, on the ice, and all while over 135 km from the nearest research facility as the crow flies. Off-grid sequencing reduced the time from sample-to-data to under 5 h compared to >days/weeks for sample collection and transport back to a research institution. In this way potential bias that may be introduced due to lengthy transport times often under suboptimal storage conditions is avoided [10]. This off-grid DNA sequencing method requires minimal infrastructure, and therefore lends itself to being integrated into a scientific program of the many expeditions that set out to the most remote corners of the polar world. This work represents a blueprint for a minimal and sustainable remote laboratory that, permitting technological advancements, could be adapted to perform other types of in situ sample extractions and downstream transcriptomics, metabolomics, or proteomics studies. By aiding the wider distribution of DNA sequencing capabilities, we hope to improve our collective understanding of the microbial communities that exist in some of the planet's most remote environments and the role that they play in our changing climate.

5. Conclusions

In this study, a microbial metagenomic analysis was conducted entirely off-grid using a laboratory small enough to be transported using human-power alone. Over 24 hours of continuous DNA sequencing using a MinION Oxford Nanopore device was conducted during a 3-week unsupported expedition on Europe's largest icecap, the Vatnajökull in Iceland. The use of solar alone to power this sequencing effort demonstrated that microbial DNA sequencing can be conducted sustainably and repeatedly during an ongoing expedition, alongside the other physical and psychological challenges associated with survival in extreme environments. The method demonstrated here removes the need for sample transportation, and it is anticipated that this will enable researchers to study microbial populations in more remote corners of the planet, far from research stations.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4425/10/11/902/s1, Figure S1: Cumulative Throughput plot from sequencing run #2 shows that at the time power ran out and sequencing was stopped the cumulative throughput was essentially at a maximum, Figure S2: Read quality distributions for a standard laboratory Nanopore run and this study. Table S1: Location of items during the flight to Iceland and during the ski traverse, Table S2: Phyla taxon classification from Kaiju (see Table S3) used to construct Figure 4, Table S3: Taxanomic identification by Kaiju.

Author Contributions: G.-O.F.G., J.-H.C., and O.V. conducted the ice cap traverse and DNA sequencing effort; A.E., I.K., and T.E. provided significant technical and logistical assistance prior to departure of the expedition as well as assisting with data interpretation and manuscript editing post-expedition.

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Conflicts of Interest: Arwyn Edwards (A.E.) has received financial support from Oxford Nanopore Technologies Ltd (ONT) to attend and present work on in-field DNA sequencing at Nanopore Community Meetings 2017 and 2018, and London Calling 2019. ONT have also provided A.E. with free reagents for outreach work. ONT have played no role in the design, execution or interpretation of this study.

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16.10 Appendix IX: Meal plan

Our meal plan consisted of full rations for 21 days, with some extra dried breakfasts/dinners for consumption in case of expedition delay. As our expedition lasted for 18 days, we ended our expedition with a considerable safety margin. Our calorie count totalled between **4700 and 5200 calories per person per day**. This was an ample quantity and gave us the energy required to live comfortably on the icecap. If conducting a future expedition, we would recommend a similar calorie count and safety excess of food in case of expedition delay. Below is a rough outline of the foods that we took.

On our expedition, we didn't want for anything food related. The variety and taste of Expedition Foods meals provided sufficient variation each day, the lunches were tasty and the amount of snacks that we took made the tougher times much more enjoyable that they otherwise would have been.

Food	Calories	Weight (g)	Price	Brand
Breakfast (~865 calories)				
Freeze dry meal	800	180	5.24	Expedition Foods
Hot chocolate	116	28	0.24	Cadbury's
Nescafe coffee 3 in 1 (sachet)	65	12	0.32	Nescafe
Lunch (~1450 calories)	**2 x oatcakes, 1 x Primula, either 3x Pepperami or half saucisson, 2 x Babybel**			
Plain oatcakes (8 per pack)	288	73	0.25	Nairn's
Cheese Oatcakes (8 per pack)	312	73	0.25	Nairn's
Primula original (tube)	350	150	1	Primula
Primula with chives (tube)	324	150	1	Primula
Primula with ham (tube)	318	150	1	Primula
Primula with prawns (tube)	306	150	1	Primula

Peperami (single stick)	113	22.5	0.25	Peperami
Half a saucisson	420	100	1.25	Tesco
Babybel (single)	61	20	0.33	Babybel
(Communal squeezy Jam, peanut butter, marmite, honey for rest days)	300			
Snacks	**3-5 per day**			
Jordan's cereal bar (red berries)	120	30	0.35	Jordan's
KitKat (4-finger)	209	41.5	0.65	Cadbury's
Snickers (normal bar)	245	48		Cadbury's
Twix (twin bar)	250	58		Cadbury's
Whispa	199	39	0.6	Cadbury's
Double Decker	250			Cadbury's
Mars (normal bar)	229			Cadbury's
Dairy Milk (45g bar)	240	45		Cadbury's
Kvikk Lunsj (Norwegian Kit Kat for JH - already bought)	258		0.5	Freia
Jaffa cake roll				
Brunch bar	140	32		
Tesco flapjack	143	34		
Soreen	386	30		
Topic				
Trail mix pack (high on dried fruit)	250			Combo
Jelly babies (big pack)	660			
Peanut butter pretzels				
Pork scratchings				
Beef Jerky				
Banana chips				
Roasted/salted peanuts				
Other nuts				

Lollipop (single)	55			Chupa Chups
Day food drinks (x1 per day)				
Nescafe coffee 3 in 1 (sachet)	65		0.32	Nescafe
Hot chocolate				
Dinner starters: (x1 per day)				
Mugshot Roast chicken	204	55	0.8	Mugshot
Mugshot Tomato and Herb (V)	260	64	0.8	Mugshot
Mugshot Sweet & Spicy Noodles (V)	238	67	0.8	Mugshot
Mugshot Creamy Cheese (V)	258	68	0.8	Mugshot
Ainsley Harriott Morocan Medley Cous Cous (V)	179			Ainsley
Ainsley Harriott Spice Sensation Cous Cous (V)				Ainsley
Ainsley Harriott Sun-Dried Tomato and Garlic Cous Cous (V)				Ainsley
Ainsley Harriott Roasted Vegetable Cous Cous (V)				Ainsley
Ainsley Harriott Wild Mushroom Cous Cous (V)				Ainsley
Cup a Soup Minestrone	85		0.4	Cup a soup
Cup a Soup Cream of Vegetable (V)	136		0.4	Cup a soup
Cup a Soup Potato and Leek (V)	115		0.4	Cup a soup
Cup a Soup Asparagus (V)	127		0.4	Cup a soup
Cup a Soup Beef and Tomato	83	88	0.4	Cup a soup
Cup a Soup Cauliflower and Broccoli (V)	108		0.4	Cup a soup
Cup a Soup Chicken	119		0.4	Cup a soup

Dinner mains: (x1 per day)				
Freeze dry meal	800			EF
(plus tabasco, salt and pepper etc.)				
Desserts:	**(freeze dry meal on traverse days, other on basecamp days)**			
Freeze dry meal	450			
Hot Chocolate	80			Cadbury's
Dairy Milk (45g bar)	240	45		Cadbury's
Dried mangoes	100			
Terry's Chocolate Orange (1/3)	300	80		Terry's
(Plus group treats e.g. tinned fruit, maom, sardines). We ended up taking lots and lots of these. Tinned mango was a special treat (but not for the person carrying it).				