

A Geological Expedition to Ilímaussaq and Tuttuttooq, South Greenland



Emily Madoff, Yasamin Bayley, Aithne Lawrence, Nina Brendling and Tesni Morgan

June – August 2022

Preface

We are a group of geologists from the University of St Andrews who undertook a 6-week expedition to Ilímaussaq and Tuttutooq in South Greenland from June – August 2022. This fieldwork formed the foundation for Emily's PhD, and Yasamin, Nina, Aithne and Tesni accompanied to assist with the PhD research as well as complete individual research projects of their own. The aim of our expedition was to create geological maps and sample two field areas which contain layered igneous intrusions. Layered igneous intrusions across the world host strategically important ore deposits, however the mechanisms of layer formation and critical metal enrichment remain highly debated. By further understanding how these intrusions form and evolve, we can improve the efficiency of ore exploration and extraction, reducing the environmental impact of the mining industry. The expedition comprised 4 weeks of fieldwork at Ilímaussaq, followed by a week of fieldwork at Tuttutooq. A few days both before and after the fieldwork were spent in Narsaq where we were able to meet locals and learn more about the history of the area. The expedition proved to be very successful, collecting plenty of rock samples to fuel research for years to come. The whole expedition team is incredibly grateful for the financial support from various organisations which allowed us to have this once in a lifetime experience. Our expedition to Greenland is one that we will cherish for the rest of our lives.

Emily Madoff – Expedition Leader

Expedition Team



Emily Madoff

Age: 26

Nationality: American

Degree: PhD in Earth and Environmental Science

Favourite Mineral: Fluorite

Favourite Field Snack: Cup of soup

Emily is happiest when out in nature surrounded by beautiful landscapes. Her love of physics and chemistry, combined with her curiosity of how landscapes form, fuelled her passion for geology. Emily specialises in structural and mapping geology, with a particular interest in how these can be used to study economic ore deposits. Emily is grateful for the opportunities she has had to pursue geology around the world, including work in Scotland, the US, Sweden, Pyrenees, Alps and now Greenland. In her free time Emily likes to go hiking and cook; Emily particularly loved being the head chef on the expedition and was surprised to have a newfound love of spam.



Yasamin Bayley

Age: 23

Nationality: American

Degree: MSc in Strategic Earth Resources

Favourite Mineral: Labradorite

Favourite Field Snack: Snickers

Yasamin has always been driven by a sense of adventure especially when science is involved. Having always enjoyed spending her free time outdoors, particularly enjoying backpacking and winter sports, the opportunity to couple wild camping with geology in South Greenland was a dream come true. Yasamin's geologic interests are in understanding the mineralisation and petrogenesis associated with critical metals and minerals essential to our daily lives and energy needs. She was able to delve into this topic during her MSc dissertation where she was able to visit both Southern Sweden and South Greenland to obtain samples. One of her favourite aspects of geological research is field mapping and seeing as many different rocks and landscapes as possible. Being able to visit a world-class REE deposit in South Greenland as part of a structural mapping expedition has added invaluable measure to her geologic skills and interests, as well as being an experience she will treasure for a lifetime.



Nina Brendling

Age: 21

Nationality: English

Degree: MGeol

Favourite Mineral: Glaucophane

Favourite Field Snack: Soreen Bars

Nina's interest in geology began from her love of hiking and climbing in her home town of the Lake District. This has only increased during her studies, having had the opportunity to visit iconic locations such as the Alps and Siccar point. She has a particular interest in structural geology and geochemistry. She is extremely grateful for the opportunity to visit Southern Greenland, getting the chance to see such a unique part of the world and study the world-class geology of the area, developing her fieldwork skills.



Aithne Lawrence

Age: 21

Nationality: Scottish

Degree: MGeol

Favourite Mineral: Grossular Garnet

Favourite Field Snack: PB & N (peanut butter and nutella tortillas)

From a young age, Aithne spent her time hiking, swimming, kayaking, sailing and learning camp craft, in and around the ancient Scottish highland landscape. It was during this time she became fascinated with the geological processes that form the spectacular features she had come to know so intimately. As a geology undergrad student she has undertaken many fieldtrips throughout Scotland and the Swiss-Italian alps, which have been critical to her learning. However, none have been more influential than the 2022 Ilímaussaq expedition which strengthened not only her outdoor and fieldwork skills, but also her passion for the Arctic which she aims to continue exploring in the future.

**Tesni Morgan**

Age: 21

Nationality: Welsh

Degree: MGeol

Favourite Mineral: Eudialyte

Favourite Field Snack: PB&J
Tortilla (I didn't even like PB
before Greenland!)

Tesni has always seen herself studying the natural world, beginning with flora and fauna and finding a keen interest in mineralogy and the larger mechanisms that build our Earth. She finds satisfaction in projects that are of practical use to society in a changing climate, focusing on sustainable mining and its role in the green energy transition. She finds her time best spent in the outdoors and enjoys the fieldwork aspects of her course the most rewarding, whether it be as far afield as Greenland, the Italian Alps or closer to home in northwest Scotland, with the intent on continuing this passion to a career based in the field. Additionally, Tesni finds inspiration from the outdoors in her art, and enjoys landscape and botanical sketching and photography. Tesni valued her experience at Ilímaussaq, South Greenland, in developing her skills as a field geologist and solidifying her aspirations to pursue an outward bound career once she graduates.

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Introduction

Where did we go?

Our expedition was to Ilímaussaq and Tuttutooq in South Greenland (**Figure 1**). We flew into Narsarsuaq, and then took a boat from Narsarsuaq to Narsaq. After spending a night in Narsaq to organise our supplies, we took a boat from Narsaq to Ilímaussaq where we spent 4 weeks wild camping and completing fieldwork. We then took a boat from Ilímaussaq to Tuttutooq where we completed a further week of wild camping and fieldwork, before returning to Narsaq, and then finally flying out of Narsarsuaq.

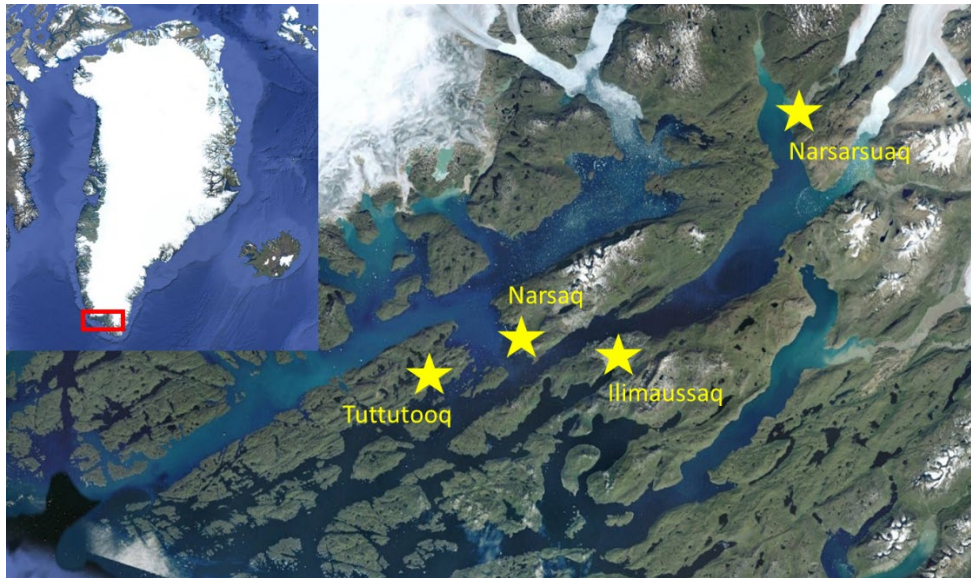


Figure 1: Location map of the expedition.

Why layered intrusions?

When a geologist studies an igneous intrusion, we are studying the fossilised remnant of magma that was travelling through the Earth's crust. Due to various geological processes including plate tectonics and erosion, these fossilised magma bodies can be brought up to the Earth's surface for geologists to investigate. A layered igneous intrusion is as the name suggests: an igneous intrusion that contains layers within it, like a layered cake. What is particularly interesting is these layers often contain economic ore deposits that our society uses in our everyday lives, including Iron, Titanium, Nickel, Copper, Platinum Group Elements (PGEs), Phosphorus, Rare Earth Elements (REEs) and more. Although we have been mining these types of intrusions for many years, we still do not quite understand how these layers form. If we can better understand the formation of these intrusions, we can increase the efficiency of our ore exploration and extraction, minimising the environmental impact of the mining industry.

Why South Greenland?

Layered igneous intrusions exist all around the world, so why did we choose to study them in Greenland? Ilímaussaq, a layered igneous intrusion in South Greenland, is incredibly well exposed and therefore is an ideal natural laboratory to study geological processes (**Figure 2**). Additionally, Ilímaussaq contains two world-class REE deposits, with REEs being an incredibly important resource for the development of green technology such as wind turbines.



Figure 2: Photo of the layers at Ilímaussaq. Note the continuous horizontal white and black lines that cross the hillside.

Similar to Ilímaussaq, the island of Tuttutooq contains layered igneous intrusions to study which are also well exposed (**Figure 3**). It was decided to also study these intrusions as we would be able to compare and contrast what we observed with Ilímaussaq.



Figure 3: Photo of finer-scale igneous layering at Tuttutooq.

Aims of the Expedition

1. Create 1:5000 scale geological maps, with particular focus on structures and textures within the rocks.
2. Create stratigraphic logs of key outcrops with igneous layers.
3. Conduct orientated rock sampling for further lab analysis back in the UK.
4. Gain experience in organising an extended expedition to the Arctic and develop fieldwork and wilderness skills.

Expedition Journal

December 2021 – June 2022: In December 2021, Emily interviewed St Andrews geology students to form the expedition team. Once Yasamin, Nina, Aithne and Tesni were selected to join the trip, the whole group worked together to plan the logistics for the expedition. This included organising food and supplies and shipping it to Narsaq three months ahead of the expedition, applying for scientific permits to conduct our research and collect samples, organising boats and safety communications with the local company Blue Ice Explorer, applying for funding and other health and safety logistics.

June 20th – 23rd 2022: The expedition team travelled to Ilímaussaq from Edinburgh via Copenhagen, Narsarsuaq and Narsaq. In Narsaq the group collected the shipment of food and supplies and prepared to load everything onto the boat. We all enjoyed our first time seeing icebergs!



June 24th – 25th 2022: Upon arriving at Ilímaussaq, we determined where basecamp should be and then set up camp. We had to hike in over 750 kg of equipment to basecamp which whipped us into shape quickly! We found a nice patch of ground behind an empty, boarded up cabin and decided that would be the best spot. Although we could not go inside, it proved to be a good wind shield during wet, gusty meal times.



June 26th – July 25th 2022: Once camp was set up, we spent a month completing our geological mapping and sampling at Ilímaussaq. Each team member had their own individual mapping area, however we always mapped in groups of two and three for safety purposes. Days started at 7:30 when we would collect and boil water for porridge, tea and coffee. We would set off at 9:00 to hike in to our mapping areas; the hikes varied from 30 minutes to 3.5 hours depending on which area of the intrusion we were mapping that day. Due to the long daylight hours, we were able to map until 18:00, at which point we would hike back to camp for dinner around 20:30/21:00. After dinner we would review our maps and discuss any areas of interest we had encountered that day. Our full days meant we slept very well at night, and we all enjoyed falling asleep to the sounds of arctic foxes.

July 8th 2022: Following two successful weeks of mapping and sampling, Yasamin left the expedition to start her lab work for her Master's thesis. The boat that picked her up, in turn dropped off more expedition members to assist with the PhD fieldwork. We were joined by Dr Will McCarthy and Dr Craig Magee (two of Emily's PhD supervisors), and Brogan Smith (a master's student at the University of St Andrews). Their arrival with bread, fresh fruit, potatoes and boxed wine was warmly welcomed. Craig and Brogan stayed for 11 days, and Will was with us for the rest of the expedition.





July 26th – July 30th 2022: After a month of fieldwork at Ilímaussaq, we were picked up and dropped off by boat at Tuttutooq for a further week of geological mapping and sampling.



July 31st – August 3rd 2022: After our week of working at Tuttutooq, a boat picked us up and brought us to Narsaq where we spent two days exploring the town and meeting locals. We were able to go to the Narsaq Museum where we learnt more about the wildlife and culture of Greenland. We also prepared to ship all of the rock samples we had collected (over 950 kg of rocks!). Prior to our flight, we were able to go to the Narsarsuaq Museum where we learnt about the colonisation history of the local area as well as the part Narsarsuaq played in WWII as an airbase and weather station. We had a smooth journey home and we made it back to Scotland, where we were joined by our rock samples only a few weeks later.



Obstacles during the expedition

Although most of the expedition ran incredibly smoothly, a few obstacles were presented along the way that helped us further develop our planning and fieldwork skills. The most prevalent obstacle was the intense presence of biting insects throughout the trip. Thankfully, we were aware this would likely be a problem ahead of the expedition, and brought appropriate kit including bug nets and bite cream. Each day we had to find the balance between wearing clothing that would keep the bugs from biting, but also not be too warm for our lengthy hikes.

Additionally, getting fresh water at both Ilímaussaq and Tuttutooq proved to be difficult. At Ilímaussaq we had to climb down a steep cliff to fetch water. Thankfully we had large water containers that we had brought for our rock sampling, and these served a dual purpose as water carriers for camp. At Tuttutooq, there was no fresh water within multiple kilometres of our camp. Here we devised a system with a tarp where we could put icebergs in the tarp to melt throughout the day. In the mornings we would melt icebergs on our camp stove for breakfast.

At Ilímaussaq there were multiple large rivers that ran through the field area. While this provided a nice water source while we were hiking, it made us think carefully about how we would plan our routes to our various mapping areas as the rivers could only be crossed at very specific points. This occasionally meant hiking an extra hour to get to our desired destination, but more often resulted in very wet boots and trousers. We decided to carry sandals with us while hiking so that we could keep our boots dry at river crossings.

Lastly, we had a problem with heavy rainfall flooding the wooden boxes where we stored our food. This resulted in some of the food, including a lot of our pasta supplies, being soaked through and unable to be eaten. We were able to rearrange our tarps so that we could cover some of the boxes to prevent further damage. We also had to re-think our rationing plan and eat fewer carbs with the tinned food we had brought.



Scientific Outcomes

For Emily's PhD, the fieldwork completed was targeting three main questions regarding the layered intrusions at Ilímaussaq and Tuttutooq:

1. Do mineral fabrics and textures within the layered kakortokites at Ilímaussaq support an open or closed magmatic system for the formation of the layering?
2. Can evidence of multiple sill injections and/or syn-magmatic faulting be identified within Ilímaussaq?
3. What mechanism formed the layering within the Giant Dykes at Tuttutooq?

Now that Emily has completed the fieldwork in Greenland and collected the necessary rock samples, she will conduct lab analysis for the rest of the PhD, including rock magnetism, petrography, electron backscatter diffraction and crystallographic preferred orientation, to try and answer the geological questions stated above.

Yasamin, for her Master's thesis, was investigating Rare Earth Element enrichment processes within layered intrusions, and comparing Ilímaussaq with another, similar layered intrusion in Sweden called Norra Karr.

For their MGeol mapping projects, Tesni, Aithne and Nina created geological maps of Ilímaussaq. Aithne will be continuing work on her area by completing lab work over the following year. Each of them set out with different geological aims to assess during their mapping:

- Tesni: This project focussed on the distribution, morphology and the mineral composition of the pegmatites to assess the value of pegmatite-targeted exploration in the area and their associated Rare Earth Element potential.
- Aithne: This project focussed on a deformation zone within Ilímaussaq, to assess the magnitude and distribution of shear, and further examine the presence of a hypothesized fault in the intrusion.
- Nina: This project focused on naujaite inclusions within Ilímaussaq to assess their mode of emplacement and further understand the crystallisation history of the intrusion.

As a group, various key field observations were made. These observations are outlined below:

Ilímaussaq

- The modal layering of the kakortokites is oblique to mineral foliations, suggesting at least two, sequential magmatic processes took place to form the igneous layering.
- Evidence of magma mingling and intrusive relationships across the intrusion are indicative of a dynamic magmatic environment, and potentially represent magma replenishment events.
- Pegmatite concentrations are at their highest where different rock types intersect. Pegmatites in close proximity to naujaites had the highest concentrations of eudialyte, the main mineral that contains Rare Earth Elements at Ilímaussaq.
- The long axis of naujaite inclusions are typically parallel to the fabric of the surrounding rocks, indicating a potentially intrusive relationship between the naujaite inclusions and the surrounding rocks.

Tuttutooq

- Our mapping found a new morphology of one of the layered intrusions, updating the existing distribution of these intrusions on Tuttutooq.

- The igneous layering is thickest in the centre of the layered intrusion, and thins out towards the edges. Additionally, the layers form lens shapes and cross-cut each other. These observations indicate a dynamic magmatic process formed the igneous layers.

If you are interested in learning more about the geology from our trip, please contact us and we can provide reports and geological maps from the expedition. If you want to continue following the research journey, Emily has a twitter where she provides updates on the work (@EmilyTheGeo).

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We would also like to thank Dr Will McCarthy, Dr Craig Magee and Brogan Smith for their assistance out in the field. Additionally, advice from Dr Will Hutchison and Dr Madeleine Humphreys helped make the expedition such a success.

Summary of Expenses

Category	Item	Cost	Total
Travel	Flights	£6,000	£6000
Accommodation	Copenhagen Hotel	£400	£400
Blue Ice Explorer Logistics	Boat transfers, Narsaq Accommodation, Safety Equipment, Fuel	£4,760	£4,760
Food	Expedition Food	£1,100	£1,100
Shipping	Return Pallet Shipment	£2,900	£2,900
Equipment	Camping Equipment	£1,500	£4,000
	Sampling Equipment	£2,500	
Total Spend			£19,160