

# Geological Expedition to Wedel Jarlsberg Land and Sørkapp Land, Svalbard: The timing of Iapetus opening and its implications for understanding the break-up of Rodinia and evolution of Baltica

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## Introduction

This expedition formed part of a project trying to define the timing of formation of the paleo-continent Baltica. Formation of Baltica occurred as a result of the break-up of the ancient super-continent Rodinia, which also led to the opening of the Iapetus Ocean. In July 2021, two weeks of fieldwork was carried out in Wedel Jarlsberg Land and Sørkapp Land, SW Svalbard, focussing on the study of Neoproterozoic and Cambrian geological successions. Understanding continental break-up and opening of oceans is fundamental for reasoning about geological evolution of the planet Earth. It is hoped that research completed following this expedition will contribute to important knowledge about processes responsible for continental break-up and opening of ocean basins.

My role within the fieldwork was primarily assisting with sample and structural measurement collection along with documentation of rock outcrops, as the project is not directly a part of my PhD research. However, I did spend one day collecting rocks for a small research project which I will undertake, dating mafic volcanic rocks from Chamberlindalen. The expedition offered me a unique opportunity to experience field research in the High Arctic, in an area few people are able to visit. The stunning scenery and wildlife made it an unforgettable experience! I was also able to build my geological skills by learning from other more senior members of the team, which I will be able to apply to my own future research. They say that “the best geologist is the one who has seen the most rocks”!

Although the main funding for the fieldwork was secured prior to my involvement in the project, my place on the expedition was only guaranteed if I was able to get my own funding. Therefore I am very grateful to the Gino Watkins Memorial fund for allowing me to take up this opportunity.

## Expedition Members

- Myself - Isabel Carter (PhD student at AGH University of Science and Technology, Kraków, Poland and Uppsala University, Sweden)
- Expedition Leader - Prof. Jarosław Majka (AGH-UST and Uppsala University)
- Deputy Expedition Leader - Dr. Karolina Koźmińska (AGH-UST)
- Prof. Maciek Manecki (AGH-UST)
- Prof. Stanisław Mazur (Polish Academy of Sciences, Kraków, Poland)
- Prof. Jane Gillotti (University of Iowa, Iowa City, USA)
- Dr Michał Bukala (Polish Academy of Sciences)
- Dr Christian Schiffer (Uppsala University)
- Margot Patry (PhD student, AGH-UST and Uppsala University)
- Riccardo Callegari (PhD Student, AGH-UST and Uppsala University)
- Megan Koch (Fulbright exchange student, AGH and University of Iowa)
- Daniel Buczek (PhD Student, University of Wrocław, Wrocław, Poland)

In addition to the 12 scientific members of the team, the expedition boat ‘Ocean B’ was crewed by Captain Andrzej Górajek, Halina Górajek and Wojciech Pasieczny.

## Expedition Route

The expedition took place on 11-25<sup>th</sup> July 2021, based on board the sailing boat ‘Ocean B’. Start and finish was in the town of Longyearbyen. The following localities were visited: Hyttevika (Wedel Jarlsberg Land); Torellbreen and Vimsodden (Wedel Jarlsberg Land); Sørkapp (Sørkapp Land); Hornsund (Wedel Jarlsberg Land); Chamberlindalen (Wedel Jarlsberg Land); Antoniabreen (Wedel Jarlsberg Land). The route taken can be seen on the map below (figure 1).

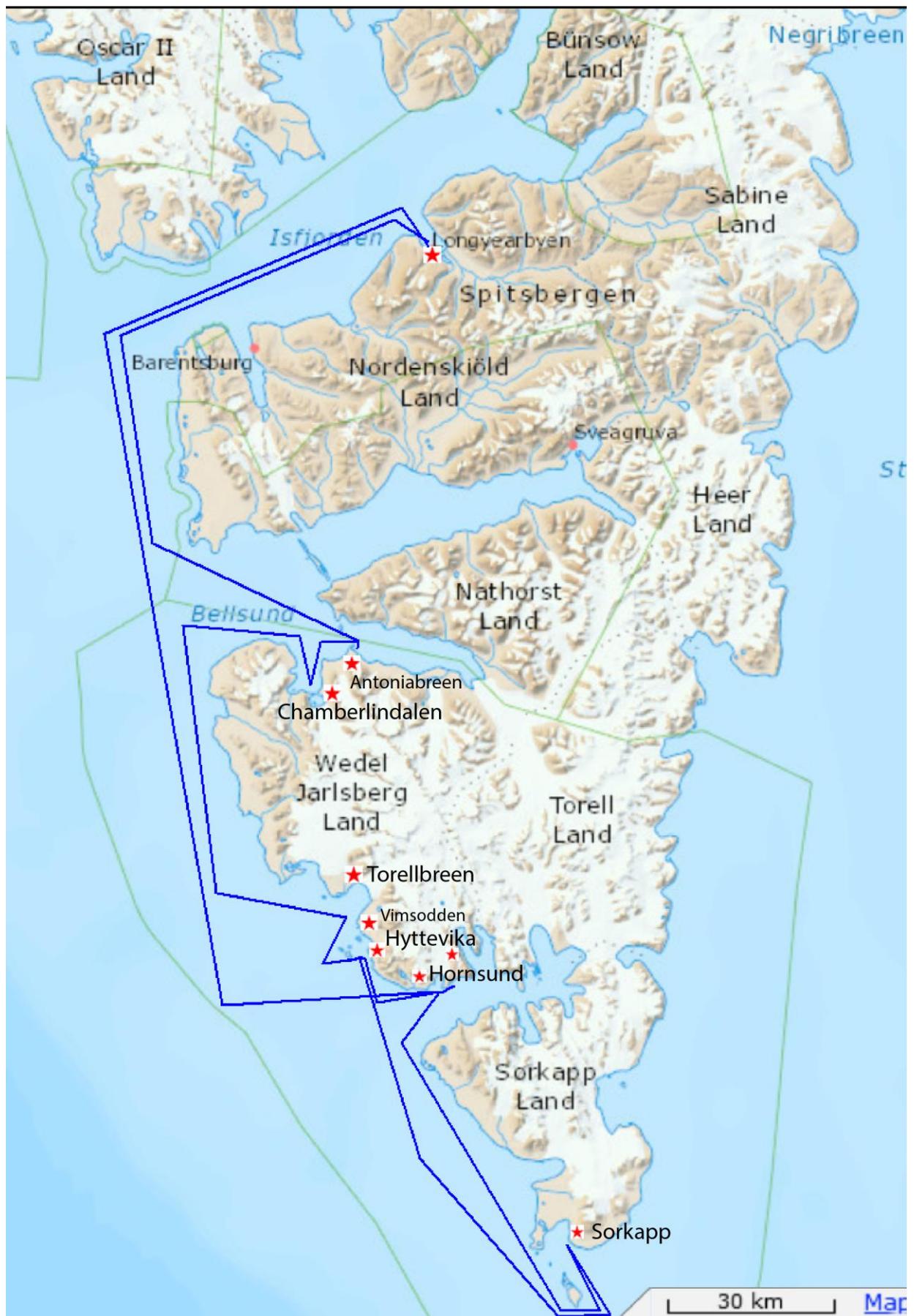


Figure 1 – Map of route taken and locations visited

## Geological Background and Scientific Aims

It is widely accepted that the Iapetus Ocean opened in the latest Neoproterozoic, but the exact timing of this event is still debated, with different studies giving timings between 616-550 Ma (a range of 66 million years). This project aims to test the following hypotheses: (1) the true Iapetus Ocean did not open until the Cambrian, and (2) the opening was fully controlled by the location of the mantle plume. According to a classical view based on magmatic ages, opening of the Iapetus and Tornquist Oceans was completed already in the early Ediacaran. However, other global examples have demonstrated that actual timing of break-up can be much younger than rift-related magmatism. The contradiction described between the age of mafic magmatism along the fossil margins of the Iapetus-Tornquist Ocean and plate tectonic models has never been clearly articulated and discussed in the geological literature.

A characteristic feature of passive continental margins is the presence of break-up unconformities. Such unconformities provide a better constraint on the actual time of breakup than the ages of igneous rocks associated with rifting. However, there have been no studies focused on identification and dating of break-up unconformities along the fossil passive margins of the Iapetus and Tornquist Oceans. The classical Neoproterozoic to Cambrian sedimentary sections exposed in southwestern Svalbard bears a record of Cryogenian glaciations and Cambrian sedimentation disrupted by unconformities within and (possibly) above the Neoproterozoic strata. Evidence for late Neoproterozoic tectonometamorphic events in the area has also been documented.

The core objective of this expedition and subsequent scientific research is to complete complex structural, petrological and geochronological studies in key localities of south-western Svalbard, in order to address the core aim of more closely defining the timing of Iapetus Ocean formation. If we are able to demonstrate a much younger age opening of the Iapetus and Tornquist Oceans, the plate tectonic models for late Neoproterozoic and early Palaeozoic will have to be significantly revised. This research will add to the global understanding of continental break-up and ocean opening processes as well as the specific, more regional knowledge about the Neoproterozoic-Cambrian geological history of Iapetus and Baltica. The potential revision would also affect the time when complex life on Earth commenced its rapid expansion.

The classical paradigm says that the Svalbard Caledonides represent the Laurentian margin of Iapetus. However, several lines of evidence point to an ambiguous origin of at least south-western Svalbard. Laurentian origin of the Cambrian rocks in south-western Svalbard is primarily based on the occurrence of a trilobite fauna (supposedly) typical of the Laurentian margin. Hence, the whole Caledonian succession exposed on Svalbard was assigned to Laurentia. However, south-western Svalbard is dominated by a large-scale system of late Caledonian anastomosing shear zones that juxtapose basement blocks with both classical Laurentian and proposed Baltican affinities. Therefore, re-examination of Cambrian sequences, commonly separated by the aforementioned shear zones, is needed. This will include provenance studies (using detrital zircon), inspection and dating of the Neoproterozoic-Cambrian boundary, and characterization of fossils. The data obtained in this region should provide a unique insight into the development of the early Iapetus.

In order to carry out these aims, the field localities visited on the expedition were broken down into 3 main sub projects, and 2 minor sub-projects:

1. Isbjørnhamna Group – Collecting samples from the Barrovian metamorphic rocks of the Isbjørnhamna Group and equivalents, in several localities on SW Wedel Jarlsberg Land and Sørkapp Land. These will be used for thermobarometry and dating using allanite and monazite, to further define the metamorphic history of this unit. This sub-project forms part of the PhD of Margot Patry.
2. Cambrian-Neoproterozoic boundary - Collecting samples of sedimentary rocks from either side of the boundary, and examining points where the boundary contact is outcropping in order to determine whether it is tectonic or unconformity contact. The samples will be used for detrital zircon studies. This sub-project forms part of the PhD of Riccardo Callegari.
3. Vimosodden-Kosibapasset (V-K) Shear zone – Collecting samples and structural measurements from throughout the region of the shear zone between Torrelbreen and Werenskioldbreen on SW Wedel Jarlsberg Land. These will be used to establish a chronology along the shear zone, and help in reconstruction of strike-slip events in the circum-Arctic region during the Paleozoic. This sub-project is the work of Megan Koch.
4. Chamberlindalen – Samples were collected of mafic metavolcanic rocks and ultramafic bodies in Chamberlindalen, NW Wedel Jarlsberg Land. I (Isabel Carter) will be dating these metavolcanic rocks using zircon and baddeleyite, which will hopefully represent a date for lapetus rifting. The ultramafic rocks will be analysed by Daniel Buczko.
5. Pseudotachylites – A pseudotachylite previously identified at Antoniabreen, NW Wedel Jarlsberg land, was collected for analysis by Michał Bucała

## Logistics

Due to large distances between the target outcrops and need of crossing fjords, the fieldwork was performed with logistic help of a sailing boat, 'Ocean B', operated by Polish company Natango which has extensive experience of sailing in Svalbard & the Arctic. The boat was used as both transport and accommodation/base camp. This allowed us to maximise the amount of localities which could be visited during the short duration of the expedition, and also meant that there was no need for building camps in a region populated by polar bears. Access to field locations was made using rubber boats and then moving on foot from shore. Fieldwork was carried out in groups of at least 3, with 2-3 groups generally operating on different tasks at the same time in a given area.

Safety measures included carrying of flare guns and a rifle at all times whilst on shore, having accommodation on the boat, and wearing survival suits during rubber boat trips. During a several-day stay on shore by one party, they stayed in a polar bear proof ex-hunting cabin. The expedition team included senior scientists with extensive experience organizing and performing research in the Arctic areas, thus ensuring a properly planned expedition which was able to successfully and safely carry out the project aims. The expedition was scheduled for July as this is generally the time at which Svalbard has most stable weather, however fieldwork would not be conducted during periods of bad weather which would cause a safety concern or severely impede our ability to carry out effective research. Additionally, the use of rubber boats to access the shore meant that we were unable to land and carry out fieldwork during periods of high winds. Luckily, over the two weeks of the expedition, we only had one day disrupted by wind and half a day by heavy rain.

Due to the ongoing COVID-19 pandemic, finalisation of the expedition going ahead was done only a couple of months before its start date. Until only a couple of weeks before the expedition start, it was unclear whether we would have to quarantine in mainland Norway for 10 days prior to continuing to Svalbard. Luckily, travel restrictions were changed and remained in our favour, meaning that no quarantine or COVID tests were necessary (only a proof of vaccination).

### Summary of Expedition

On 8<sup>th</sup> July we started our expedition by flying to Oslo from Krakow, via Warsaw. The following day we flew from Oslo to Longyearbyen. The first taste of Svalbard is cold and drizzly, but by the time we had shuttled all of our bags and got settled into the rooms (at Mary Ann's Polar Rigg), the weather had cleared up to be pretty nice - though still a lot colder than the 30 degrees we left behind in Poland! The afternoon was spent wandering around town, doing some shopping for last minute supplies, and taking photos. I made my first acquaintance with the divebombing skuas, birds which are very protective over their nests to the point that they will not be afraid to literally 'skewer' you if you get too near!

On the 10<sup>th</sup> we were meant to board the boat and set off, however a problem with the clutch meant that we had to wait in town another day for the new part to be fitted. The situation could have however been a lot worse, as had the exact part not happened to be available in Longyearbyen, we could have been waiting many days for the part to be shipped from the mainland. The day was spent visiting the museum, finalising expedition logistics, and discussing some of the geology we were to see in the days ahead. Most of the next day was also spent waiting around at the hotel, but finally in the afternoon we were able to start moving things onto the boat, and finally set off after dinner in the evening. The evening was spent on the upper deck admiring the views as we sailed down the fjord in the sun. I slept well overnight despite the fact that there were 3 of us in a very cramped cabin, however the next morning was significantly less fun! We were still sailing towards Horsund by the time we woke up in the morning, but by now we were in open sea and it was very foggy and rough. Many of us first-timers (including me) experienced seasickness, so most of the day was spent in bed. Luckily it did not last past the first day, as throwing up over the side of the boat was not an experience I was keen to repeat. In the late afternoon, to our relief we finally reached Hornsund, where we landed at the Polish Polar Station to pick up some of the University's expedition gear which is stored there (figure 2).

In the early morning of 13<sup>th</sup> July, the boat sailed from Hornsund to Hyttevika, a bay 10 km or so up the coast which was to be our base for the next few days. By breakfast we had already lost one French press to the sea, as it was accidentally thrown overboard by one of the postdocs! We landed at Hyttevika, where there is a small 'cottage', an old hunters cabin which has been used for the last 30+ years as a base for geologists working in the area (figure 3). It is little more than a glorified weatherproof (and supposedly bear proof) shed, but my supervisor and others in the department have spent many months staying there over the years that they have worked in this area of Svalbard. The main targets for my group on the first field day involved hiking a little way down the coast to a point known as Ryssepynten. We sampled a shear zone in mica schists at the edge of the Isbjørnhamna formation, and a layered quartzite in the Eimfjellet group which was nicknamed the 'bacon rock' due to its stripy appearance.

The next day we hiked up Gangpasset (figure 4), a pass over a lot of glacial moraine and snow patches (totalling about 5 hours of strenuous hiking), to reach a couple of outcrops of kyanite schist. In the valley, it took us about an hour to locate the correct outcrop, as we were trying to relocate a sample taken 19 years previously and the GPS location was not hugely accurate! After sampling we

still had a long hike back, this time heading straight down the valley towards the coast, and then north along the coast. Several river crossings mean that our boots were completely soaked before long. We persuaded the boat captain to pick us up from Ryssepynten, which meant a rough half an hour rubber boat ride through open sea, but saved us a couple of extra hours hiking to Hyttevika. By the time we reached the boat it was almost 10pm and we were all extremely tired. Luckily our final day based at Hyttevika was much easier, we just revisited the outcrops visited 2 days previously to take some more structural measurements and have some further discussions. In the evening the boat was moved a couple of hours north up the coast, to in front of the Torellbreen Glacier (figure 5).

The first day at Torellbreen (16/07), high winds meant that we were unable to land using the rubber boat, so the day was spent on the boat. I did at least manage to have a (cold!) shower, the first of the trip as limited water supplies meant that we had to ration how many we took. The next day, the winds had died down enough to get to land and do some work, however wind direction and icebergs curtailed plans for some reconnaissance work on Torellkegla which I was meant to be joining. Instead, I spent the day with another group working on the V-K shear zone on Vimsodden, which was generally an easy day working near the coast once we had crossed over some large tidal mud flats. The shear zone rocks were mostly phyllites, but also included a highly sheared conglomerate. In the late evening we set off sailing for Sørkapp Land, the southern tip of Svalbard, leaving behind the group working on the V-K shear zone for a few days to stay in the 'cottage' at Hyttevika.

In the late morning of the 18th we arrived at Sørkapp. It was very foggy, but still we headed out for an afternoon of fieldwork as we are only scheduled for a few days here (due to exposure of sailing to reach it, we were restricted to the short good weather window). We sampled mica schists in a unit possibly part of the Isbjørnhamna group, which here forms a N-S pressure-temperature gradient (figure 6). By the late afternoon as we finished work for the day, the fog and cloud cleared to give a beautifully sunny evening. The next day we landed again at Sørkapp to finish work sampling of the schists, the weather was generally OK with only a little rain. We finished fieldwork early afternoon in order to sail back to Hornsund, our next locality for fieldwork.

On our first day anchored in Hornsund (20/07), I went with my supervisor and one of the other PhD students to visit another part of the Isbjørnhamna group in Ariedalen, behind the Polish Polar Station. Just as we landed, we heard from the group stationed at Hyttevika that they had just seen a polar bear passing by, and it could be heading our way! Luckily, the walk to the valley passed without incident or any signs of the bear. We searched mainly through the scree blocks, looking for rocks showing signs of partial melt and the beginnings of migmatitisation, which has not been documented in this region before. The second day at Hornsund started late due to the first proper rainy day, but began to clear late morning, and had stopped completely shortly after we had landed on shore. The aim was to collect samples from sediments either side of the Cambrian-Precambrian unconformity, part of another PhD student's project. The day was billed as 'easy', but involved a steep climb halfway up the mountain, mostly on loose scree. In the late afternoon we moved the boat to in front of the Polish Polar station (figure 7), so we could return our rubber boat and some other equipment to storage. We ended up being stuck there for the whole evening, when the motor bringing up the anchor on the boat broke down! Luckily as we were parked outside the Station, we were able to retrieve some spare parts, and the captain was able to fix it so we could set off.

After picking up the second group at Hyttevika early the next morning, we sailed back up to Torellbreen so that a few final tasks could be finished at Vimsodden. Several of us had no fieldwork to do, so we had a free day on the boat. As it was a nice sunny day, it meant we could relax and take

in the views over the glaciers, and a couple of us even had a brief dip in the sea! Overnight we continued sailing to our next stop, Bellsund.

The first day in the Bellsund region we did fieldwork in Chamberlindalen (figure 8), and finally I had the chance to collect some samples of my own. I collected large quantities of greenstone, metamorphosed pillow basalts and alkali volcanic rocks, which will eventually be used for zircon and baddeleyite dating. The total amount of rock collected was probably over 50kg, so luckily I had several volunteers to help carry the rocks! It was a lovely sunny day, and the valley was green and picturesque, probably some of the best scenery of the whole trip. In the evening, on our way to our final stop, the nearby Fleur de Lys bay in front of Antoniabreen, we got a great close up tour past a walrus colony (figure 9). The final day of fieldwork was a fairly easy and relaxed half day, to look at mylonitised augen gneisses in front of Antoniabreen. In the evening we set off for Longyearbyen, and had our last night on the boat party (complete with gin, vodka and polish sea shanties).

On 25<sup>th</sup> July we arrived in Longyearbyen just in time for breakfast, then unloaded the boat and moved everything back to the hostel. A few team members had a flight in the afternoon so we waved them off, before some final wandering around town and pizza at the pub in the evening. The final morning was spent doing some errands around town and packing the rocks to be taken back, before finally it was time to head to the airport and catch our flight home. My field season was however only halfway done, as I flew directly to Sweden to do 3 weeks of fieldwork in the mountains of Västerbotten and Jämtland, for my own PhD project.

## Conclusions

The expedition overall was a success, with all major scientific aims being completed. We were lucky to experience no considerable delays or cancellations due to weather, COVID-19 or other factors. Hopefully, the data and samples which were collected will lead to exciting scientific results, maybe even leading to revisions of current geological models!

From a personal perspective, participation in expedition was an exciting opportunity to experience fieldwork on Svalbard, something which I have wanted to do for many years, and it has only strengthened my passion for Polar research. I was also able to improve my fieldwork skills, both geological, and working in challenging Arctic terrains. I have improved my knowledge of the geological history of Svalbard, and of the Caledonian Orogeny as a whole. Much of the skills and knowledge which I have learned will be invaluable to my own future work. I only hope that I will one day get another opportunity to visit this stunning place!

I am very grateful to the Gino Watkins Memorial Fund, and also the Andrew Croft Memorial Fund, for providing me with the funding to participate in this expedition. I would also like to thank Jarosław Majka, for organising the expedition and allowing me to partake in it; Andrzej, Halina and Wojciech for sailing, feeding us and generally making the expedition possible; and the rest of the expedition team for making it such a fun trip. Funding for this project was provided by the National Science Centre of Poland, the Norwegian Research Council, the National Science Foundation (USA), the Ymer-80 Foundation (Sweden), and the Svalbard Science Forum.



Figure 2 – Expedition team outside the Polish Polar Station, Hornsund. Me: back row, second from right.



Figure 3 - Cottage at Hyttevika



*Figure 4 - Hiking over Gangpasset*



*Figure 5 - View over Torellbreen from the deck of Ocean B*



*Figure 6 - Geologists at work, Sørkapp*



*Figure 7 - Polish Polar Station, Hornsund*



*Figure 8 - Reindeer in Chamberlindalen*



*Figure 9 - Walrus Colony, Bellsund*