Expedition Bjurälven would like to express sincere gratitude to the main sponsors in 2015, Ursuk and Klättermusen. Diving in Bjurälven is to a large degree about fighting the elements, both on the surface and under water. Using drysuits provided by Ursuk and expedition clothing provided by Klättermusen made the fight much easier, enabling us to concentrate on the exploration.

Several other companies helped us to achieve our goals safely in 2015: Oceanic Tech, Dykmagasinet i Karlstad, Northern Lights Scuba, Scubamafia and Deep Bots. Their products and support made the Expedition safer and helped us to achieve our goals. Dykarna.nu, Sweden's largest diving community and ESRI Sverige, company that provided the surface mapping software, as well as the Swedish National Land Survey and Agisoft are acknowledged for their support of the expedition.

As usual, the local authorities and population have been backing us up to a 100%, making the expedition possible. We would like to thank the population of Stora Blåsjön and the authorities in the Jämtland county, restaurant Fjällripan, Ica Stora Blåsjön and Ica Gäddede as well as Mikkes Skoteruthyrning and Frostviken Outdoor.

Figure 1 The basecamp and the entrance to the Dolinsjö cave

The first winter expedition to Bjurälven valley was launched in 2007 after many years of unsuccessful attempts to dive what was thought to be the most promising flooded cave in the region, Dolinsjö cave. Attempts to dive it were previously unsuccessful due to very strong current, up to 20 knots, that rips through the cave system summertime. The entrance to the cave was discovered as early as in the 70-s by Bo Lenander, who is also a member of the current expedition crew. Wintertime, the water is much calmer and hardly any current can be detected. Thus, in 2007 divers of the first Expedition Bjurälven could enter the cave and map some 50 meters of the passages beyond the entrance. The success story continued and 8 years later the cave is more than 1,7 kilometers long. Dolinsjö cave is now the longest water-filled cave in Sweden. Logistics are also much simpler during winter, when all the equipment can be transported to the cave entrance using snow mobiles without risk of damaging the fragile vegetation in the national park where the cave is located. Thanks to excellent cooperation with authorities, diving and exploration in Bjurälven is able to continue every year.

Summary and goals

The overall goals of Expedition Bjurälven are:

1. Explore, map and document caves in the Bjurälven valley
2. Promote the caves in the area and the local community of Stora Blåsjön
3. Contribute to scientific research through cooperation with universities

When the 2014 Expedition came to an end, a significant discovery was made by divers. At the far end of explored area, a tunnel with flow was discovered. The tunnel was significantly larger than the rest of the cave explored up to that date and measured some 6-8 meters in width and was 2-3 meters high. It was proposed that the divers had finally reached one of the main tunnels of the cave system. It was clear though, that a significant effort would be needed during the following expedition to explore the new area. The tunnel was discovered in sump 3, nearly a kilometer away from the entrance. To reach it, divers had to first dive through sump 1 (approximately 450 meters long), then cross the first dry section (approximately 100 meters long with a low crawl at the end) and carry over all the equipment to sump 2 which was only 50 meters long and 2-3 meters deep. After the second sump, another dry section had to be crossed with a small climb to be negotiated at the start. After that, divers could enter sump 3 to finally reach the exploration area after some 70 meters. The goal in 2015 was to put as many teams as possible in sump 3 to survey and document the large tunnel discovered in 2014 and see if there are any further leads. Another goal of the expedition was to assist the camera crew, sent by Klättermusen in documenting the efforts of the expedition. There was also some cooperation with Gothenburg and Linköping universities in the fields of biology where samples were to be collected by divers for further analysis.

Exploration

During the 2015 Expedition, as many as four dive teams were able to reach areas beyond sump 1. Three dive teams successfully reached sump 3 on several occasions and surveyed 391 meters of the new cave passages. Surprisingly, both the upstream and the downstream ends of the previously discovered large tunnel were found to be blocked by debris with only small passages remaining where all the flow was directed. The teams attempted to negotiate the smaller tunnels to find a way past the collapses, but it was deemed too risky due to high flow and unstable conditions and the efforts were abandoned. This discovery explains the evidence of periodic strong flow in the dry sections of the cave: summertime, when the current is strong, the small

opening in the collapse downstream in the main tunnel is not enough to let all the water pass so a portion of it is directed into the side tunnels, the tunnels that have been explored by the divers up until now. A total of 71 man-dives were conducted during the expedition with longest exposure time of 400 minutes.

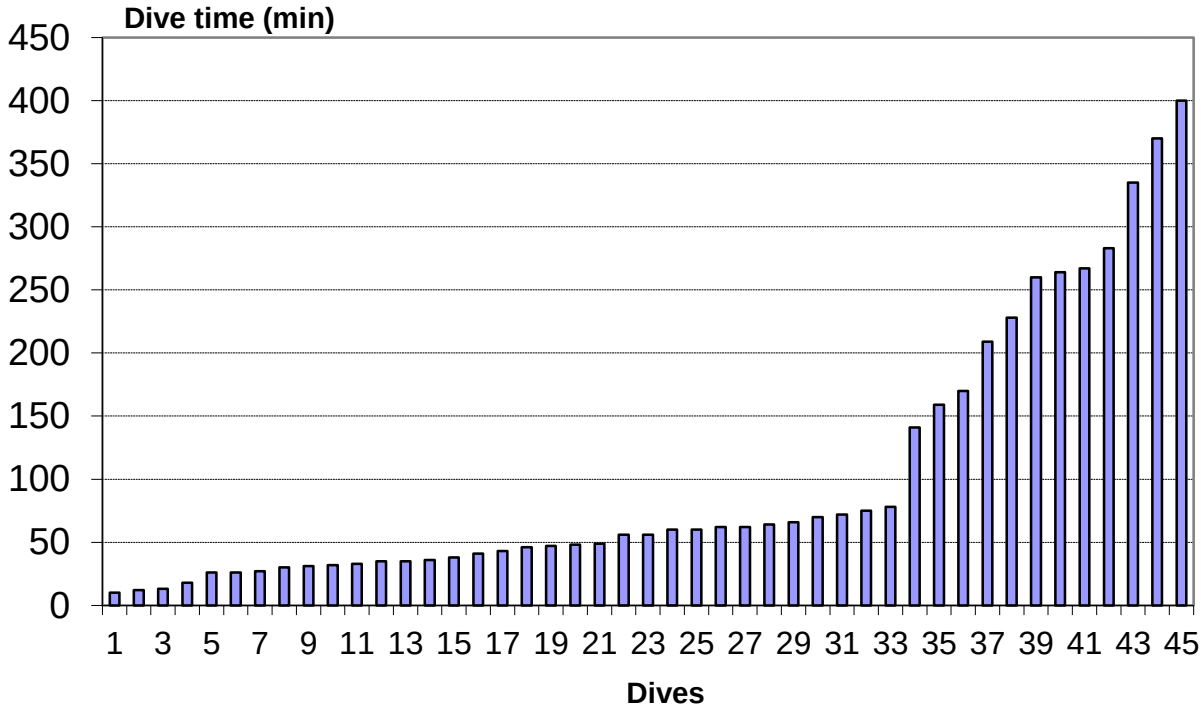

Table 1 Dive statistics

The total known length of the Dolinsjö cave is close to 1800 meters, although only 1500 meters can be presented as a map today. A number of old measurements will have to be repeated in 2016 in order to obtain an accurate up-to-date map. A significant work was also performed after this year's expedition to transfer all the date to a new mapping software, Therion, which will be used in the future. The teams also discovered a lead in sump 2, which allows hoping for the exploration to continue in 2016.

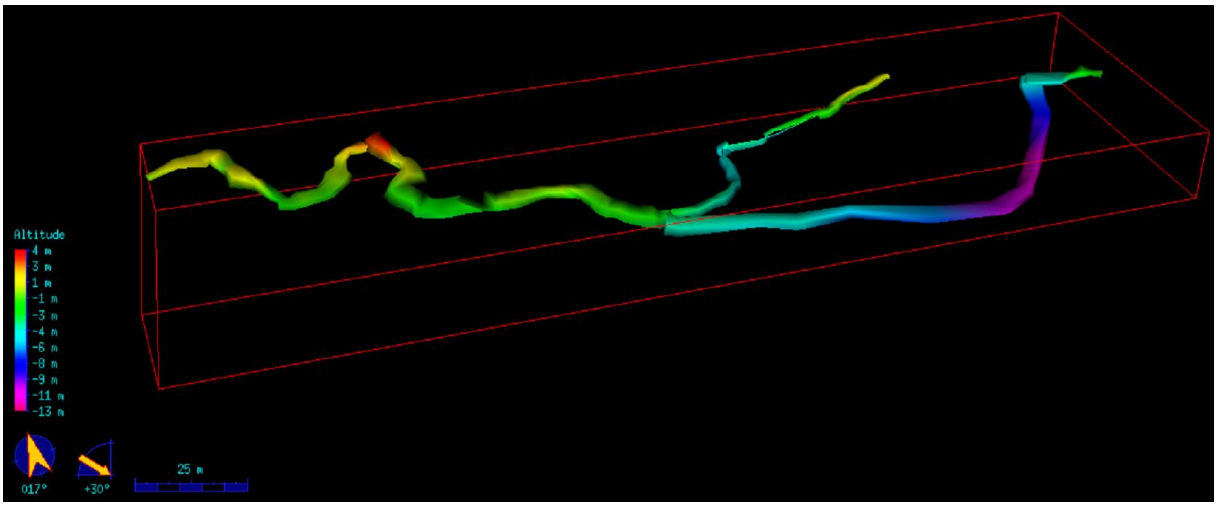

Figure 2 Section of the Dolinsjö cave, discovered and surveyed in 2015. Cut-of is at the end of the second dry passage. The large tunnel with flow, discovered in 2014, can be seen at the T-intersection.

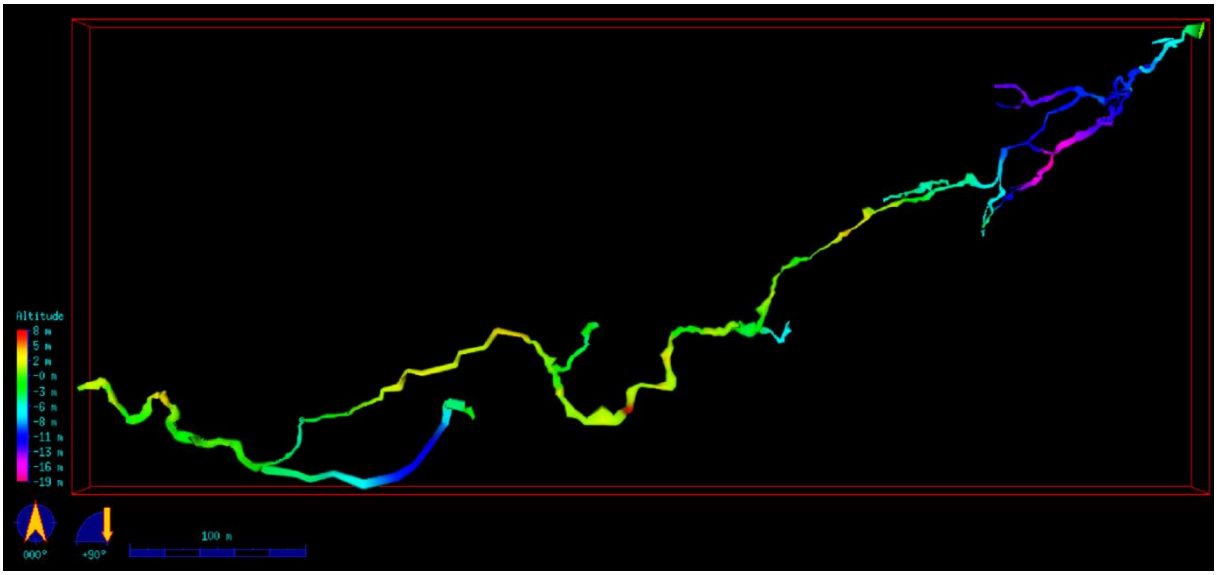

Figure 3 All of the mapped tunnels in the Dolinsjö cave. The total mapped length is close to 1500 meters, while several hundred meters more need to be re-mapped.

Documentation and media

This year, an external film crew accompanied the expedition during most of the week. The team was sent by Klättermusen and the goal was to produce a high-quality film about the expedition, capturing both its spirit and the accomplishments during the week. The video was released on Vimeo in June and at the moment of writing already has over 100.000 views. The popularity of this film was clear when such media channels as The Guardian, NRK (Norwegian National Television) and National Geographic chose to feature it on their websites. The film also appeared on facebook pages of such entities as the National Association for Cave Diving. The film can be seen here:

https://vimeo.com/129753793

The expedition was also covered by a number of newspapers, radio and TV channels in Sweden and Norway.

GPS positioning and magnetic field tracking

To produce an accurate cave map it is important to know how measurements, done in the cave, correspond to the map of the terrain above. To adjust the position of the cave map in relation to the terrain, some reference points in the cave were provided using a transmitter, tagX6V, which emits a vertical magnetic field (32 kHz). With a direction finding receiver, M-15R, the point on the ground surface (ground zero), where the magnetic field is vertical, can be found. It is located straight above the reference point in the cave, and the accuracy of the measurement are some decimeters. By measuring the horizontal distance from this ground zero to the circle where the magnetic field leans 49.5^{O} and then multiply it with 2, the approximate (+/- 10%) vertical distance to the transmitter in the cave can be calculated.

The transmitter consists of a 630 mm diameter antenna (aluminum bicycle wheel rim) which is fed with 32000 Hz 1W current from an attached electronics unit. This circular antenna is positioned horizontally over the reference point using a built-in spirit level. The direction finding receiver (32768 Hz) is provided with a frame antenna (50 turns 1 mm copper wire, 530 x 530 mm) with two spirit levels (90^{O} and 49.5^{O} from the horizontal plane). The signal that can be heard in the direction finding receiver's headphones is an interrupted 768 Hz tone. True

guiding to the position of ground zero is given in a circular area with a diameter of approximately the depth doubled. Outside this area, the magnetic return field is vertical and of varying weak strength. It is therefore important to know the approximate position of the ground zero – specially in rough terrain with deep snow. It is both physically hard and time consuming to do direction finding under such circumstances.

The transmitter was the same as used in 2014. The new developed direction-finding receiver was found to be very sensitive and easy to use. The useful range for this measuring system is approximately 300 m through limestone. The direction finding system used is developed and built by Bo Lenander, one of the cave divers.

Figure 4 Mats Fröjdenlund and Bo Lenander with equipment for GPS positioning and magnetic field tracking

Starting with 2014, fixed points were marked out in the cave with the help of stainless steel trays labelled FP01, FP02, and so on. Using the electromagnetic direction finding equipment we have obtained relatively accurate positions on the ground surface directly above the fixed points down in the cave. Also, the depth from the surface (or the snow surface) down to the fixed point has been obtained for each point. In order to make a 3D and georeferenced cave map, we need to know both the ground surface elevation, the depth of the cave and its X and Y coordinates. For this purpose, the National Land Survey/SWEPOS (https://swepos.lantmateriet.se) during the expeditions in 2013, 2014 and 2015 have kindly lended us both GNSS equipment (**G**lobal **N**avigation **S**ystem **S**atellite = GPS and GLONASS) and communication equipment with connection to the SWEPOS correction services. Network RTK (**R**eal **T**ime **K**inematic) is a technology for accurate GNSS positioning in real time. The technique is based on the support system of fixed reference stations, such as SWEPOS. The so-called correction data is calculated at the SWEPOS command centre and sent to the user's GNSS equipment. The user can then get a position in the reference system SWEREF 99 with uncertainty on the centimetre level.

Our equipment consists of a Leica Viva GS15 rover with built-in 3G modem on a 2.5 meter high carbon fibre rod and a Leica CS10 field computer. For receiving of correction data from SWEPOS we also borrowed a Net1 modem M-90. To obtain these correction signals connection with the 3G mobile network or Net1 network is required. The equipment was tested at the National Land Survey before departure and transported to the base camp where we measured the fix point in Dolinsjön to get a reference point (FP01). During the 2013 expedition, we found out that the correction signal via Net1 or Telia could not get into the equipment in Bjurälvsdalen. The signal strength from Net1 Base in Jormvattnet, located in 179 degree azimuth and 18 km was too low to get SWEPOS to work. In 2014 we supplemented the equipment with directional antenna for both the 450 MHz band and directional antenna for WiFi link (2.4 GHz), but the signal strength of Bjurälvsdalen remained below the level of stable communication with SWEPOS via the Internet. In 2015 we also acquired a wideband directional antenna for 3G/4G network to try to connect us to Telia's base station on Mesklumpen. Partly Telia had promised to upgrade the existing base station from 2.5G to both 3G (voice / data) and 4G (data traffic) but also here the topography posed a problem and we could not establish a connection to Telia. Therefore, it was decided again that the measurements would be conducted with long-term measurements (at least 15 minutes at each site) as the RINEX method (**R**eceiver **In**dependent **Ex**change Format). This technique is very useful in areas with poor mobile coverage.

Our borrowed GNSS equipment was then used to measure the directions finding points that was measured with the tracking device that Bo Lenander has invented. The measurement information from the field computer was transferred nightly to an Excel file with X, Y and Z values in SWERREF 99 TM format. We also included the depth value and time for the measurement. To visualize the points on the aerial photo we were using the GIS software ArcGIS® from Esri.

In 2016 we have measured four new fix points along Dolinsjögrottan (FP11, FP14, FP20, FP21 (= EOL)). Dolinsjön (FP01) was measured again and the Övre Bjurälvsgrottan (FP38, FP39, FP40) were measured together with the Svenonius cave and a dolin in the Colosseum. The measurement values for Övre Bjurälvsgrottan and the Colosseum were a bit lower quality than Dolinsjögrottan due to satellite coverage. The equipment was returned after the expedition and we hope to borrow an equivalent system for the Bjurälven Expedition 2016. Our “Pay back” to the National Land Survey is to give a presentation about the expedition and our experience at any time.

Three weeks after the expedition we received the post processed GNSS data from the National Land Survey. Our assessment now is that the XYZ values of the points lie within +/- 50 centimetres thanks to the correction of the data, see figure 1.

The plan is that the Swedish National Land Survey through Metria AB will perform the laser scanning (LiDAR) over the mountains in 2015. Then we will easily be able to measure the depth of all dolines (sinkholes) using GIS and build a 3D surface model over the terrain.

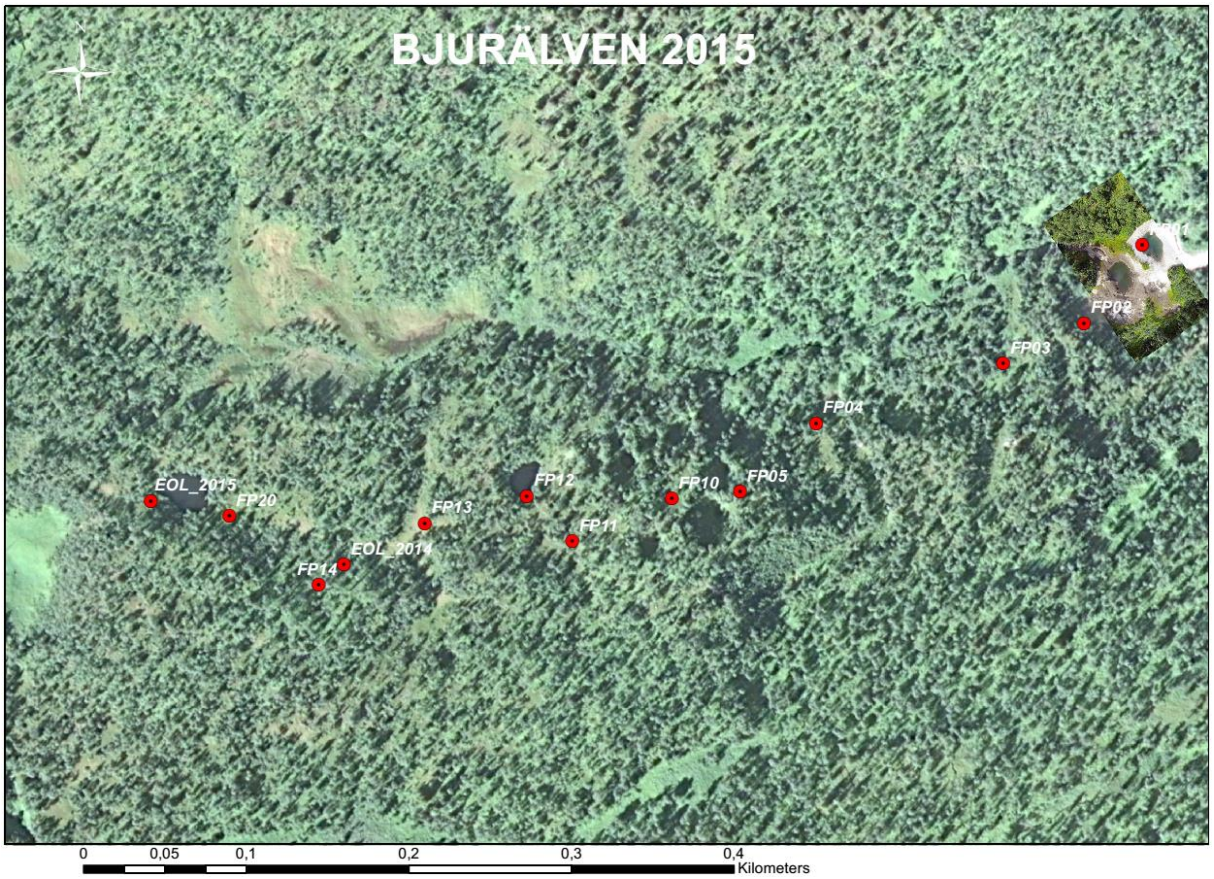

Figure 5 Fixed points in the cave plotted on a surface arial image

Experience gained from measurements in 2015:

Good:

+ Loan of advanced equipment from the National Land Survey, and post processing of data

+ Best measurements in the project so far

+ Georeferencing in three dimensions was made possible

Difficulties:

- The terrain features, deep valleys

- It was difficult to get so called fix solutions. Fix solutions give us good measurements down to cm-level. Code solution is less good value and is located on the dm-level up to the meter level.

- Non-real-time correction because we have not managed to contact SWEPOS neither using Net1 nor Telia services. Simply too much sparsely populated areas!

- Not enough experience of the equipment

Science and research

In 2015, the expedition members retrieved biological samples for research in Linköping and Göteborg universities. In the future, the expedition would like to increase its cooperation with academic environment and the work of attracting research projects will continue throughout

2015 and 2016. Expedition Bjurälven possesses resources, valuable in such a cooperation since several of the members hold advanced academic degrees and can carry out field work.

Figure 6 Exploring the first dry passage in the Dolinsjö cave

The expedition through the eyes of a new member

The amount of divers in the expedition is limited by the logistics. Yet, almost every year, specially selected and invited new members are given the opportunity to join the research and exploration effort. Some may be selected due to their deep knowledge and long experience in one of the areas that can be beneficial for the Expedition. Others are selected due to other qualifications in other areas and given opportunity to develop their diving skills together with the rest of the expedition members. New member in 2015, Emelie Eldridge shares the impressions from her first expedition Bjurälven:

"When I started diving in 2011, a whole new world opened up for me. Since then, my love for water and the underwater environment has grown only stronger. I used to read everything, related to diving, and Expedition Bjurälven was one of the adventures I read about – an extreme expedition that seemed only be suitable for very experienced divers. This year, 2015, I was given the honor opportunity to join the expedition myself!

On the first day, I was met by glittering snow and bright sun – unbelievably beautiful winter landscape in the North. The old school, housing the expedition, smelled newly made coffee and everybody gathered for a kick-off meeting. The arrival was followed by a lot of work which consisted of bringing all the equipment out to the remote mountain site and establishing a base camp. Everything went smooth; organized chaos directed by experienced leaders. From day one, I felt the warm welcome into the team – I received all information I needed and felt like home.

Shortly after, I sit on the edge of the ice, my feet in the water. Small flakes of ice are all around on the surface and I feel my heart pounding in my chest. There are plenty of people around me, but I hear nothing and see nothing but the water surface in front of me. After seeing all the movies, pictures and reading all the reports, I am finally here, ready to enter the cave through the tight entrance. My God, what am I doing – is my last thought as I glide down into the cold water.

During the expedition, the camp and the cave are hubs of major activity. Dive teams carry out their tasks, mapping and documenting and exploring. When I got past the entrance for the first time, I just stopped and held still for a long while, watching the beautifully faceted walls of the cave, a sleepy fish holding its position a couple of meters from me and the first safety bottle I can make out in the darkness. I can barely believe that I am finally here, inside the cave. I got to experience this several times throughout the week, all in small steps and under careful guidance of the other expedition members.

Everyone has got his or her role in the expedition. I had mine as well and my main duty was to help out in the basecamp and to assist the divers preparing for their dives. Working with a variety of different tasks, we all have the same goal and no task is too small. The atmosphere is warm and welcoming – I am already looking forward to next year!".

Photogrammetry

A novel technique for cave survey and documentation was tested during Expedition Bjurälven 2015. Photogrammetry combines underwater imaging (either photo or video) with digital image processing. A specially designed computer program analyses the data in order to detect distinctive features in multiple image frames. Combining these, an accurate digital 3-D model of an object is created. Such a model contains large amounts of data. Traditional cave survey

might include 20-100 measurements for every 100 meters of the surveyed cave, while photogrammetry allows processing of more than 3 million measurements for the same area, collected by digital analysis of the images taken there. We believe this is the first time photogrammetry is utilized in underwater cave survey and the technique has proved itself to be very promising. Advantages of the technique are the accuracy of the measurements (human factor is removed) and that large areas of a cave can be surveyed relatively fast with very high accuracy. Current drawbacks of the technique is that more equipment is needed to conduct a survey (imaging and image processing equipment as well as the software) and that the technique is sensitive to bad visibility as well as the skills of the operator.

Agisoft Oy generously provided us with their Photoscan Pro program for image processing, which performed in an excellent manner. In 2015, we used the time in the cave to fine-tune the technique finding correct cameras, lenses, lights and so on. Already this year though we are able to create very good and accurate models of different sections of the cave. Goal for the next year's project is to create a 3-D model of the whole cave system.

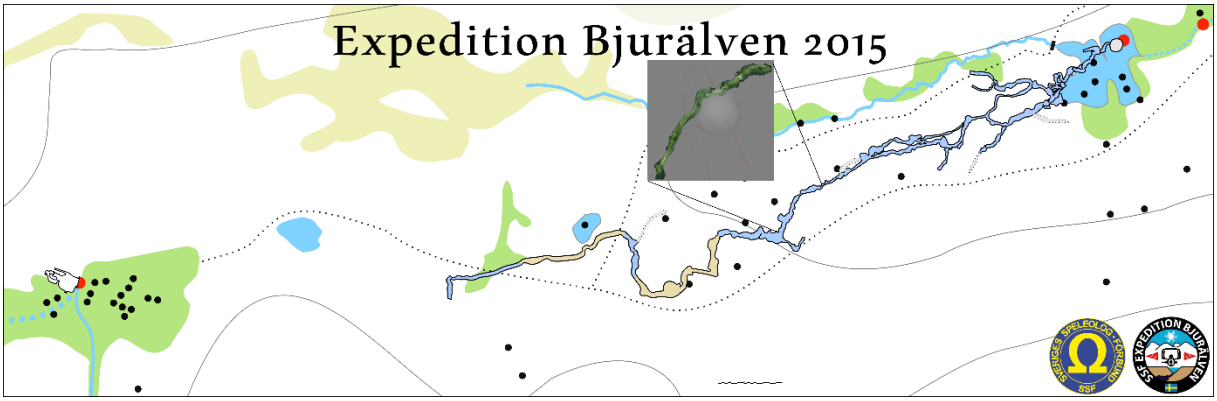

Figure 7 Profile map of a cave section, created using photogrammetry

Figure 8 An image from the cave used to create a 3-D model

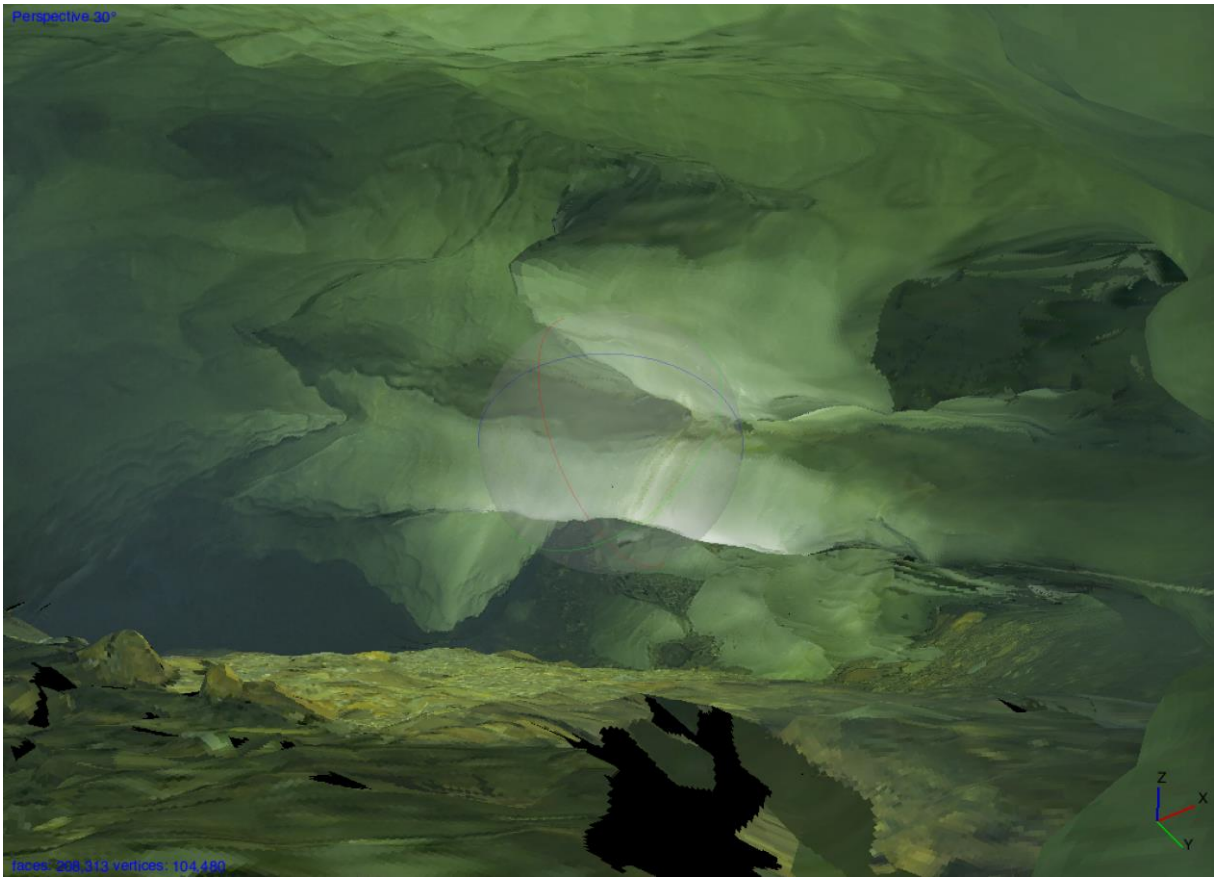

Figure 9 The same are of the cave, digitalised and turned into a 3-D model

Goals for next year

The overall goals of the expedition, stated in the introduction, remain also for the next year. An effort will be made to explore the new lead located in sump 2. There is also a need to perform remapping of some cave sections due to inconsistencies discovered in the old data and an important goal will be to produce an accurate and up-to-date map of the whole cave.

As usual, capturing high quality video and still images will be in focus. There will also be a focus on more coordinated attempt to assist scientific research through cooperation with universities. Further goals of the expedition will be decided by the members on the October meeting.

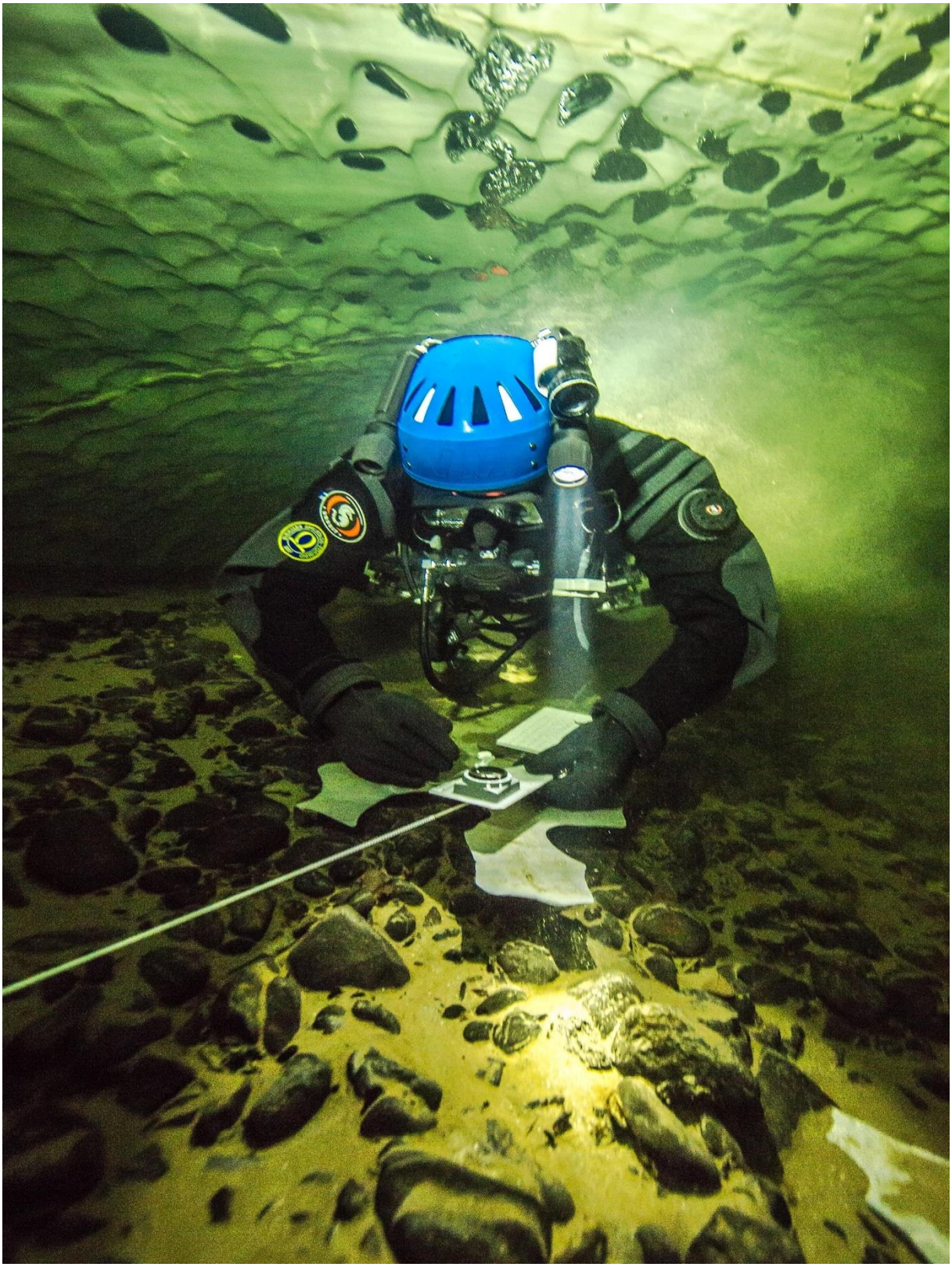

Figure 10 Mapping in sump 3