STEVEN GODERIS ON THE GEOLOGICAL HISTORY MICROMETEORITES CAN REVEAL



© © International Polar Foundation

An expert in micrometeorites at the Vrije Universiteit Brussel (VUB) who won the 2010-2012 Baillet Latour Antarctica Fellowship, Dr. Steven Goderis has spent several seasons using the Princess Elisabeth Antarctica (PEA) as a base to collect micrometeorites.

Recently, he and his colleague Matthias Van Ginneken (along with a Belgian and international team) published a paper whose findings indicate that a large asteroid 100-150 metres wide fell to Earth and exploded about 5 km over the East Antarctic Ice Sheet about 430,000 years ago. The samples Drs. Goderis and Van Ginneken collected in the Sør Rondane Mountains close to PEA in 2018 and their subsequent analyses were key to determining what happened all those millennia ago.

According to the findings of the study, an asteroid broke up in the lower atmosphere over East Antarctica 430,000 years ago. How were you able to deduce this from the micrometeorite particles you and Matthias collected during your time at the Princess Elisabeth

Antarctica during recent research seasons?

We originally set out to sample more micrometeorites representing the flux of extraterrestrial material that has fallen to Earth over the last few million years, as the more particles you can extract, the rarer the types you might be able to find. At the same time, we wanted to check if perhaps we could find some microtektites - droplets of solidified melted material that were ejected during a large impact event in Southeast Asia approximately 790,000 years ago. Other teams had found those elsewhere in Antarctica a few years ago.

And we did find those micrometeorites and microtektites. But at Walnumfjellet in the Sør Rondane Mountains we also noticed that a fraction of the particles we extracted from the deposits did not display the textures and oxygen isotopic compositions typical of “normal” micrometeorites. Rather, these particles were more akin to meteoritic debris that was previously collected at Dome Fuji and Dome Concordia. While similar to the particles found at Dome Fuji and Dome Concordia, the Walnumfjellet particles are considerably more abundant and larger in size, implying that the meteortic debris collected at Walnumfjellet may have been closest to the site of impact.

Looking at the oxygen isotopic composition of the particles, we could deduce that we were dealing with an airburst explosion that happened quite close to the surface of the ice sheet. This explosion created hot jets of half-molten rock and vapourised material. But since this airburst event happened so close to the surface of the ice sheet, the remnants of the asteroid were able to interact with the ice. So what we found in the samples we collected at Walnumfjellet were hybrid beads. They had the chemical composition of a meteorite, but a very particular oxygen isotopic composition linked to Antarctic ice.

Based on the particle abundance and distribution, combined with numerical modeling, we determined that these particles formed from a relatively small body - only 100-150 metres across. What makes it unusual is that it managed to make its way through most of Earth’s atmosphere until it exploded at a very low altitude. Normally in these kinds of events, we see the meteor explode higher up in the atmosphere, usually about 30-50 km up. This particular asteroid managed to make it very close to the ground before exploding. So when it exploded, it still had a lot of momentum. We have only limited evidence for such events in the geological record, and most of these events appear to have been preserved in the cold and dry Antarctic environment.

Where exactly did you find these unique particles?

We found the remnants of this airburst event in sedimentary traps we sampled at Walnumfjellet. The idea is to study glacially-eroded surfaces that have been exposed to the atmosphere (and consequently cosmic rays from space) for at least three or four million years. Over the time that these rocks have been exposed, they’ve been collecting extra-terrestrial material that falls to Earth.

Mostly these traps collect the background flux of micrometeorites that arrive on Earth every day. We’ve found melted and unmelted micrometeorites of all types of textures and consistencies that have accumulated over the past few million years.

But we’ve also been finding a lot of other interesting material as well. Matthias - who had previously worked on micrometeorites in the Trans-Antarctic Mountains that divide East and West Antarctica - noticed very particular particles in the samples: larger spherules with small, aggregated spheres attached to them displaying distinct textures. These types of spherules are formed only in hot and dense vapour plumes, such as airburst events when a meteorite explodes close to the ground.

The meteoritic debris particles we found at Walnumfjellet are larger than those found in the Trans-Antarctic Mountains by a French-Italian team several years ago, which could mean that they were formed during a similar but possibly larger airburst event than the one that took place over the Trans-Antarctic Mountains.

Are these kinds of events relatively common, as far as you can tell?

We're still trying to figure out if events in which a moderately-sized asteroid makes it through Earth's atmosphere are fairly common or not. Our guess is that such events take place roughly once every 1,000 to 5,000 years. It's difficult to find evidence of these kinds of events in the geologic record. The only reason we find evidence of them in Antarctica is that the continent has excellent preservation conditions for micrometeorites. It's like the evidence has been stored in a big freezer. Anywhere else in the world, meteoritic debris indicative of this kind of event tends to be broken down and altered, and may disappear from the geologic record relatively quickly, or may just be extremely hard to find.

How were you able to determine the approximate time window when the airburst occurred from the spherule micrometeorites you collected?

We use cosmic ray exposure dating. You use various nuclides in a set of samples to determine how long they've been sitting on an ice-free surface, exposed to cosmic rays.

Walnumfjellet is actually a very flat surface that has been exposed to the elements for a long time. Japanese teams who have been to PEA to study the deglaciation history of the Sør Rondane Mountains had determined that Walnumfjellet has been deglaciated for about 1.9 million years. Our own analyses confirm this estimate. So our sediment traps could have captured anything over the period of time Walnumfjellet has been ice-free. It makes it a great place to look for micrometeorites.

The more refined ages for the airburst event come from the correlation of these particles with those trapped in the ice cores drilled at Dome Fuji and Dome Concordia. The ages of these ice cores are really well constrained based on glaciological models.

Among all of the micrometeorites you've found during your trips to Antarctica, are the ones indicative of this airburst event 430,000 years ago the most sensational you've found thus far?

We also found some microtektites at Walnumfjellet. Microtektites are different from micrometeorites in that they are glassy spherules that from when you have a big meteorite impact somewhere on Earth that creates droplets of glass that rain all over the globe. The Australasian strewnfield - a wide debris field covering parts of Southeast Asia and Australia that resulted from a major meteorite impact about 790,000 years ago - also extends to the Sør Rondane Mountains in Antarctica. A paper about those findings came out earlier this year in Geoscience Frontiers.

Having been ice-free for so long, Walnumfjellet is a great place to look for micrometeorites and microtektites, which provide evidence of large airburst and impact events. But while we only found a few microtektites from the meteorite impact 790,000 years ago, we found a lot more from the airburst event 430,000 years ago, which means Walnumfjellet may have been relatively close to the point of impact. And I'm sure we're in for a few more surprises in the near future. Antarctica really is one big treasure trove in this context. Wherever you go in these kinds of exposed mountainous areas, you'll always find something different. This is a great reason to go back to the Sør Rondane Mountains and take more samples in the

future.

How did the research collaboration come together?

A lot of Belgian researchers worked on this project. Matthias managed to get a good team together. Together, he and I sampled various locations in the Sør Rondane Mountains during the 2017-2018 field season under the Belgian Antarctic Meteorites and Micrometeorites (BAMM) project of the Belgian Federal Science Policy (BELSPO). The two sites with the most abundant and interesting samples were located at the southern edge of the mountain chain, at Walnumfjellet and Widerøefjellet.

Vinciane Debaille from the ULB and Philippe Claeys from the VUB, who have been linked with our meteorite hunting expeditions since they began more than a decade ago, were also involved in this project, as well as Sophie Decrée from the Royal Belgian Institute of Natural Sciences. Graduate students Bastien Soens and Flore Van Maldeghem, both VUB also contributed to this work.

But of course, as we don't have all the instruments or expertise needed to do the analysis here in Belgium, we had to look for international collaborators to help fill in gaps.

Felix Kaufmann and Lutz Hecht from the Museum für Naturkunde Berlin helped with the electron microprobe work. Shuying Yang and Munir Humayun at the National High Magnetic Field Laboratory in Florida conducted laser ablation ICP-MS measurements. Natasha Artemieva from the Russian Academy of Sciences took care of the modelling aspects. Due to their extensive experience on this topic, Kathryn Huwig and Ralph Harvey from the Case Western Reserve University and part of the ANSMET (Antarctic Search for Meteorites) Programme, as well as Matt Genge from Imperial College London helped us to interpret our results.

It may seem like a very niche topic, but it's actually very interdisciplinary in the sense that we combined a lot of different scientific expertise to perform the analysis.

Will the results of this study prompt further investigation into these kinds of events?

Now that we know these kinds of events have happened in Antarctica (in addition to the airburst event we've discovered, a similar event occurred 480,000 years ago, as well as one three million years ago in the Allen Hills) the next step is to determine whether each of these events have distinctive "fingerprints" in terms of the textural and chemical composition of the particles that these events produced.

Once we have a good understanding of why we see textural and chemical differences in the particles produced by these events, we'll be able to go into the geological record and look for indications of such events in ice cores, sediment cores, and so on.

There are only a handful of scientists working on these kinds of topics. We've got a lot of ground to cover to learn more. It will likely keep us busy for many more years.

Knowing more about the scale of these events and how frequently they happen is important for global security. How often do you believe events on this scale occur?

Based on our current knowledge, the range in the timeframe is really long. I've mentioned this type of event can occur once every 1,000 - 5,000 years, but it could be once in every 10,000 or 100,000 years. We're basing our estimates on only a few events, so we need more data to have a clearer picture. The more effectively we can trace these events in the geological record, the better the constraints on the time frame we can provide.

It's also important to try and predict the scale of the environmental effects such events can have. If an airburst event like the one that happened 430,000 years ago over East Antarctica takes place in an unpopulated area, the consequences for society would be more limited. But if it occurs over a highly populated area, the blast could completely destroy a large city with damage up to hundreds of kilometres from the impact site, while at the same time devastate today's global communications system.

Unfortunately, we're talking about objects that are too small to be detected well in advance. The ground searching programmes typically focus on objects of 1 km and larger. Bodies that are 150 metres wide are often overlooked or not detected in advance, yet they can still do significant damage.

For example, the Chelyabinsk meteor that fell in Russia in February 2013 with no warning was only about 15 metres wide and exploded 23 km above the ground. But as it occurred over a populated area, it injured thousands of people, mostly due to broken windows and damaged buildings that resulted from shockwaves created by the airburst.

The Tunguska event in 1908 over Siberia is thought to have been an airburst event of a meteor about 100 metres wide, so something similar to the event from 430,000 years ago that we've investigated. While it happened in a remote area of Siberia and only a handful of people were injured or killed, the airburst flattened an estimated 80 million trees over an area of more than 2,000 km2 .

However, we should bear in mind that the majority of the planet is not densely populated. Two-thirds of the plant is covered by ocean, and the majority of landmasses on the planet aren't densely populated. So it would be extremely unlucky if such an event were to occur over a populated area.

Do you have plans to go back to PEA in the coming years to collect more micrometeorites and microtektites?

Nothing concrete has been decided so far. My colleagues and I would like to go back to the western part of the Sør Rondane Mountains to finalise sampling efforts there. But eventually it would be nice to go to the eastern part of the Sør Rondane Mountains and the Belgica Mountains, and perhaps even to the Yamato Mountains with our Japanese colleagues to do some sampling there. Hopefully we'll be able to secure some funding to go back to PEA so we can do this sampling once the pandemic is over. I'm sure there are a few more surprises to be found in this area.

I would like to stress that the sampling work we've been able to do has only been possible thanks to the existence of the Princess Elisabeth Antarctica and the excellent logistical support we've received from the International Polar Foundation team at the station.