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BELGIAN PRINCESS ELISABETH STATION

FINAL REPORT

SEARCH OF ANTARCTIC METEORITES: BELGIAN ACTIVITIES

"SAMBA"

EA/XX/06

Promotors

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SUMMARY

The SAMBA project brought together scientists from the VUB and ULB, as well as the National Institute of Polar Research (NIPR) to collect and study meteorites from Antarctica. During the period 2009 – 2015 that the SAMBA project was operational, 3 joint Belgian-Japanese expeditions were organized to the blue ice fields of East Antarctica to collect meteorites. The PE station provided logistic support. A total of 1279 new meteorites were collected and shared equally between the two partners. The SAMBA project resulted in a significant increase (3x) of the Belgian meteorite collection; the country now possesses one of the largest Antarctic meteorite collections in Europe. The pristine ice fields of Antarctica contain unique accumulations of extra-terrestrial material that can be harvested for scientific purposes in order to unravel the origin of the Solar System and the early history of planetary bodies including Earth. The SAMBA project also reinforced the scientific and logistic collaboration between Japan and Belgium. A modern curation facility has been set up at the Royal Institute of Natural Sciences in agreement with the procedure used by the NIPR in Tokyo. The samples recovered by the SAMBA project constitute the core of several ongoing research programs at the national and international level. SAMBA established Belgium as a key player in Antarctic meteorite recovery proximal to the South Pole.

Keywords
Antarctica, blue ice fields, meteorites, solar system, planets

1) INTRODUCTION:

This report summarises the results of 3 meteorite search expeditions in Antarctica carried out jointly by Belgian and Japanese scientists, using the Princess Elisabeth station as logistic base between the years 2009 and 2015. Over 1200 new specimens were recovered, more than tripling the existing Belgian meteorite collection. After processing and classification jointly in Tokyo and Brussels, the new specimens are now available for research to the scientific community.

The SAMBA project is perhaps somewhat particular within the BELSPO-BELISA framework because its main Antarctic focus lies essentially in the **recovery of extra-terrestrial specimens**, concentrated in the blue ice fields. The newly collected meteorites first have to be processed, classified and documented, before they can be used for research to unravel the evolution of the early solar system and the formation of planetary bodies. Therefore, SAMBA must be considered primarily as a *sample return project*, perhaps in the same philosophy as the space sample return missions (such as Exo-Mars, Genesis, Stardust, Hayabusa etc.). However, through its success and the large amount of new meteorites recovered in the region surrounding the Princess Elisabeth station, the SAMBA project now constitutes **the base** of several other research initiatives funded by BELSPO such as the Inter-University Attraction Pole *Planet-Topers*, the BELAM or ADMUNSEN projects all funded by BELSPO, the VUB Strategic Research obtained by Ph. Claeys, or the ERC Starting grant “ISoSyC” of V. Debaille, as well as several other projects supported by the Flemish and French funding agencies (FWO & FNRS).

A) The importance of meteorites

Meteorites constitute the leftover building blocks of the Solar System. As such, they provide valuable clues to its origin and evolution as well as to the formation of the planets. The majority comes from the asteroid belt between Mars and Jupiter. Extremely rare ones were ejected from the deep crust of the Moon and Mars during large impact events. The meteorites are classified in groups corresponding to different evolutionary phases of the accreting Solar Nebula. The most primitive, the carbonaceous chondrites, together with the other chondrites, originated from the break-up of small size undifferentiated planetary bodies. The term undifferentiated implies that they have not evolved geologically since the formation of the solar system. The carbonaceous chondrites present almost the same chemical composition as the sun and resulted from the condensation of the solar nebula, almost without any fractionation or changes. The chondrules (former molten droplets with a round shape) and Ca – Al Inclusions (CAI) found in these meteorites were the first refractory phases to condense (> 1800 K) out of the Nebula. The radiometric dating of these CAI from the Acfer 059 meteorite using the U/Pb system places the origin of the Solar System at 4567.2 ± 0.6 Ma. Carbonaceous chondrites also contain complex organic compounds (ex. amino acids) and contribute to understand the origin of life on Earth. The other groups of meteorites (iron, stony-iron and achondrites) originate from more differentiated or more evolved planetary bodies that have undergone several episodes of planetary evolution comparable to the formation of the core, mantle and crust on Earth, and well as episode(s) of shock metamorphism during collision events. Access to these samples from space offers a unique of window to the mineralogy of the unreachable deep Earth. The value of meteorites to document astronomical, solar system and planetary formation processes does not have to be further demonstrated. Meteorites continue to provide data on stellar evolution and nucleosynthesis, the chronology of the solar system, the formation of planets, cosmic-ray bombardment, the deep crust of Mars and the Moon, the different types of asteroids and are often used to “calibrate” the instruments of the orbiters and landers used in planetary exploration (for example Spirit or Pathfinder).

B) Meteorites in Antarctica

In 1969, for the first time a Japanese glaciologist discovered nine meteorites lying on the ice in the region of the Yamato Mountain in East Antarctica. Today, samples collected in Antarctica represent ~ 70 % of all known meteorites. Their study has greatly improved knowledge concerning the formation of the Solar system and the planets. Although they fall evenly over the Earth, the ice fields of Antarctica concentrate rare and precious meteorites. Low temperature and extreme dryness at the South Pole preserves them from terrestrial weathering. A meteorite falling over Antarctica is quickly buried in snow, and over the seasons sinks progressively deeper to end up enclosed in ice as the snow crystallizes under pressure. Ice flows like a sluggish hydraulic system. The buried meteorites are entrained in the ice movement outward towards the edge of the continent, and unfortunately for the majority of them, ultimately into the ocean. However, when an obstacle, such as a mountain chain stops or slows down the ice flow, the strong winds strip the superficial snow and slowly ablate the ice. Over time, the meteorites trapped deeply into the layers are brought back to the surface as the lost ice by ablation is replenished by upstream ice at depth. The patches of stagnant ice flow are referred to as meteorite stranding surfaces. With patience, a good eye and some luck, numerous meteorites can be collected in the blue ice fields of Antarctica (Figure 1).

Over the last thirty-five years, the USA and Japan have dominated the searches for meteorite in Antarctica. Japanese expeditions mostly collect meteorites in the Yamato Mountains in Eastern Antarctica, while the Americans concentrate on the other side of the continent around the Transantarctic Mountains, working from the McMurdo base. Indeed the blue ice fields surrounding the Belgian station PE rank among the best in terms of meteorite abundance. Several rare and precious samples such as Martian (e.g., Yamato 793605 and 000593) and Lunar (e.g., Asuka 881757 and Yamato 793274) meteorites were recovered in Eastern Antarctica and have contributed to major advancements in planetary sciences.

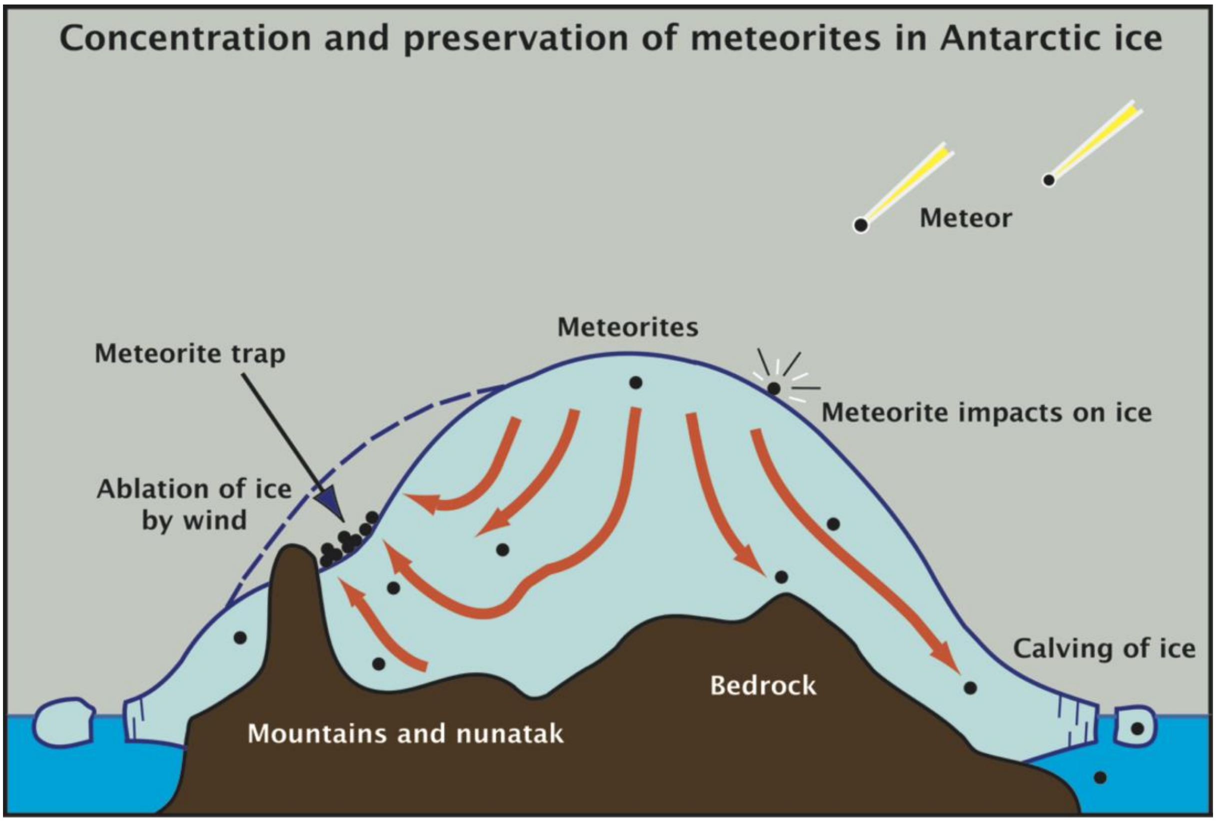

Figure 1. Scheme showing the fall of meteorites on the Antarctic ice, their transport by flowing ice, and the barrier effect of mountains leading - thanks to the wind ablation of ice - to the accumulation of these precious samples in stranded areas, such as the Nansen Ice Field. Unfortunately, a large fraction is also lost at sea.

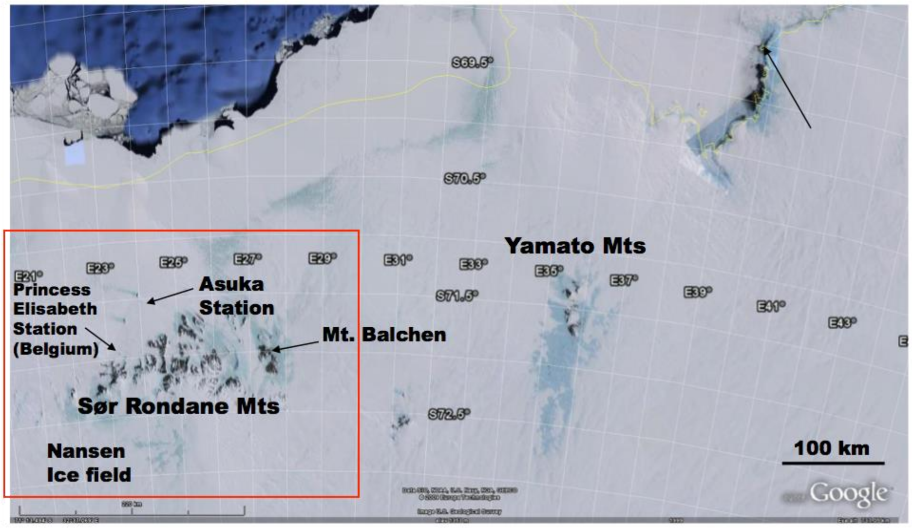

Figure 2. Map of part of East Antarctica with the location of the Belgian PE station, the former Japanese Asuka base (now closed) and the Yamato mountains where the first meteorite was discovered in 1969 by Japanese scientists. The Balchen region and Nansen ice field searched by SAMBA are also shown.

Today, as the stranded meteorites are slowly but regularly replenished by ice movement many more samples remain to be found. PE constitutes the perfect logistic base for such enterprise. The SAMBA initiative recovers these unique meteorites and brings them back to the laboratory for detailed studies. The region covered by the SAMBA meteorite searches is shown on Figure 2.

C) Development of a Belgian – Japanese meteorite network & Antarctic meteorite management

In 2008, before the initiation of the SAMBA project, contact had been established between the VUB and the National Institute of Polar Research in Tokyo (NIPR-Japan) with the goal of developing joint meteorite search expedition in East Antarctica, using the newly established Belgian Princess Elisabeth (PE) station as a logistic base. In 2009, a Memorandum of Understanding (MOU) was signed between BELPO, the International Polar Foundation and the NIPR concerning collaboration in logistics and the search for meteorites in and around the PE station. A more specific MOU/Agreement (see annex) was jointly signed between VUB-ULB and NIPR concerning the sharing of the newly collected samples. In short, this agreement specifies that the two countries share the meteorites equally on a 50-50 basis. This allocation is carried out by cutting/braking a slice out of the larger samples (> 50g). The sharing of the smaller samples (<50g) will be discussed on a case-by-case basis to avoid wasting precious small samples and at the same time making it possible to study unique specimens.

At the same time, Belgium and more particular the VUB and ULB agreed to set up in Brussels a meteorite curation system based on the procedure existing at the NIPR. Upon establishment of this facility, the Belgian share of the meteorite collection was to be shipped to Brussels, after processing at the NIPR (defreezing, photography etc). The two countries carry out the preparation and classification of the newly collected samples according also to the NIPR procedures. The curation facility and classification procedures were started within the SAMBA project. In 2012, curation and classification procedures were transferred to the newly initiated BELAM project (*Belgian Antarctic Meteorites: Curation and Research*, also funded by BELSPO) after the decision was taken that all the meteorites collected by the SAMBA project would rejoin the Belgian collection hosted at the Royal Belgian Institute of Natural Sciences, in the Vautier Street in Brussels. A new MOU was signed between NIPR-VUB-ULB and RBINS for this purpose in 2013. The ~ 1300 SAMBA specimens are now part of the Belgian meteorite patrimony, and greatly enhance the country’s extra-terrestrial material collection. These samples, curated by RBINS with VUB and ULB participation are available to the national and international planetary science community.

D) Logistic, training and transport

The organization of the joint Belgian-Japanese meteorite searches relies on extensive discussion and preparation by the members of both teams. Mutual visits by the participants were organized in Brussels and Tokyo to prepare the expeditions and select the most promising zones to be investigated. Discussions between VUB-ULB, NIPR, BELSPO and the International Polar Foundation ensured the proposed logistics (fuel, food, skidoo, etc.), amount of cargo to be transported back and forth and well as the selection of the base camps, and schedules for moving camps etc. (Figure 3). The first two missions benefited from the presence of Belgian military personnel (Sergeant Majors Jesko Kaczynski and Sanne Bosteels) who were in charge of logistics and repairs but also contributed to the search for meteorites along with the scientific team. Their technical competences, organizational skills as well as team spirit were major assets to both missions. The Belgian army also organized pre-expedition training in the Ardennes. Crevasse climbing, skidoo riding etc. were also practiced upon arrival to PE. These skills are capital, as on the Nansen plateau, the meteorite team was fully isolated and had to rely on it own resources and skills in cases of problem. The SAMBA project fully acknowledges the fantastic support provided by the Belgian army during the first two expeditions.

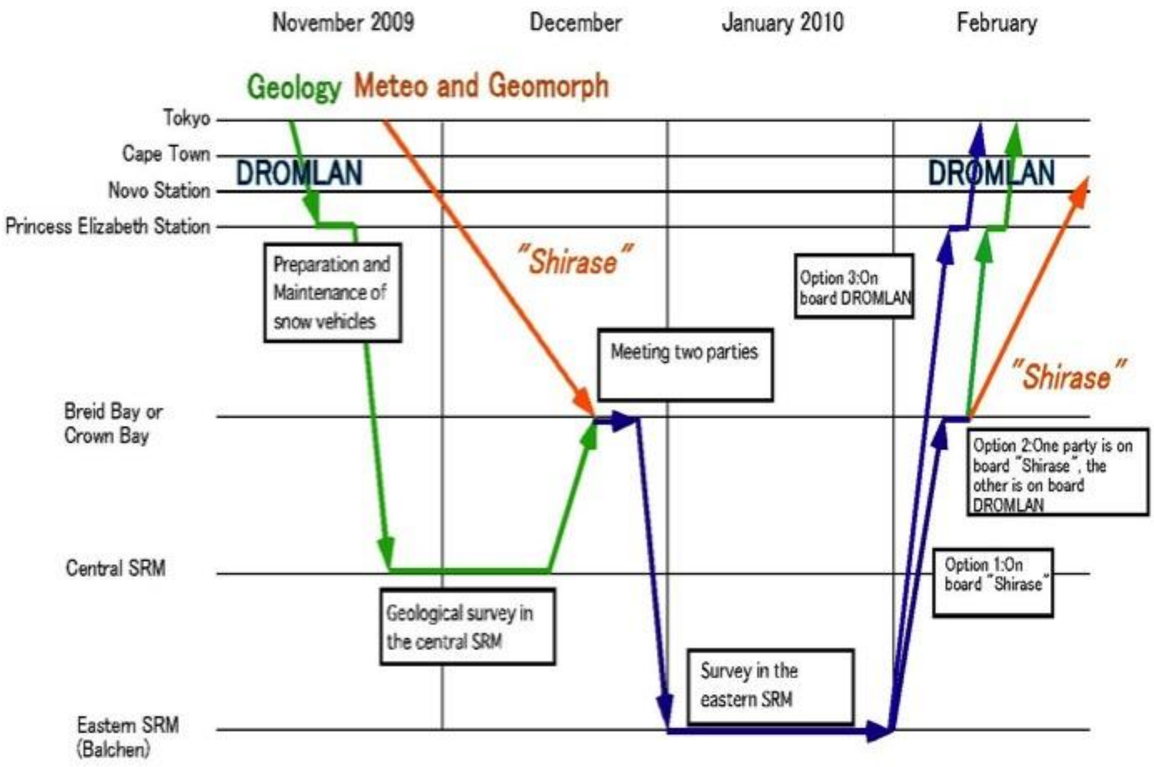

Figure 3. Example of preparation/planning schedule for the 2009-2010, JARE 51 expedition (meteo = meteorite search) as agreed by the Belgian and Japanese expedition members.

The transport of passengers and cargo occurred via Cape Town, to the Russia base Novolazarevskaya using DROMLAN and Antarctic Logistics Centre International (ALCI). The flight time is 6 to 7 hours. The final part of trip to PE occurs through small feeder planes. The cargo transport is of particular concern as the collected meteorites are sent frozen to the NIPR in Tokyo to undergo a defrosting procedure under vacuum to avoid contamination and weathering. Upon arrival to PE skidoo and crevice training take place. Time is also devoted to the final logistic prepration before spending 6 weeks in the field away from the comfort of PE. After this acquaintance period at PE, the expedition travels with all the necessary cargo (fuel, food, skidoo) to the selected location on the blue ice field (Figure 4). A camp is set up with different containers (sleeping, cooking etc.) in an area protected from the strongest winds blowing on the plateau (altitude >2900 masl).

Figure 4. Convoy of snowmobiles carrying the different containers (living, sleeping) and field gear (fuel, skidoo etc.) to set up a first base camp in the Nansen ice field during the 2010-2011 expedition. The logistic and quality of accommodation constitute important component in the success and safety of such an expedition. Such a convoy was used for opening the way from PE to the Nansen ice field in 2010-11 (see 2 below).

2) METEORITE SEARCHES – METHODOLOGY AND RESULTS

A) First expedition 2009–2010 to the Baljenfella: *Learning the rope*

In 2009, Dr. Steven Goderis (VUB) accompanied the Japanese expedition JARE 51 to the Balchen region, some 200 km from Princess Elisabeth (Figure 5 & 6). This expedition combined the study of the local geology with the recovery of meteorites. After a month on the famous Japanese icebreaker Shirase sailing from Perth (Australia), the ship arrived to Crown Bay where the spectacular unloading took place by use of helicopters. The team assisted in the construction of the convoy on ice shelf and left for the Balchenfjella area (~1600 m altitude) to the East of the Sør Rondane Mountains after only a few days. The highly successful meteorite searches under fortuitous weather circumstances led to the recovery of 635 meteorite fragments in the next 6 weeks, the total weight is about 20 kg, including a 5 kg ordinary chondrite (Figure 7). This grand total included several rare types, such as ureilites and irons (Figure 8). The meteorites are termed Asuka-09 to follow the previously used NIPR nomenclature, which refers to the locations and former research station.

Figure 5. A team consisting of six Japanese and two Belgians, three of which are researchers (H. Kojima, H. Kaiden, and S. Goderis), the first meteorite search party around the Sør Rondane Mountains since November 1990 focusing on the Balchenfjella area, east of PE.

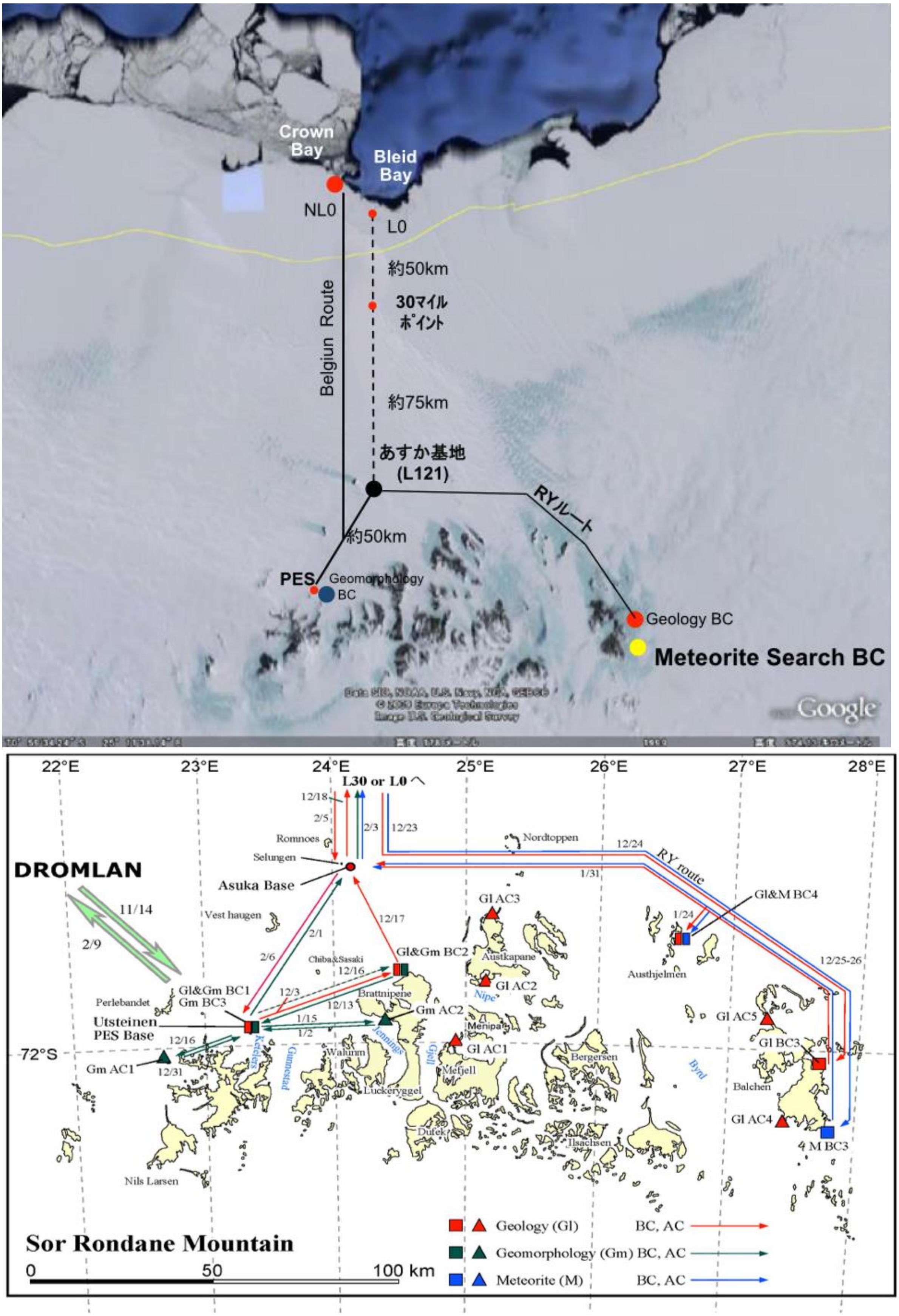

Figure 6A (above) Itinerary of JARE51 from Crown Bay to the Balchenfjella field where the meteorite search tool place. B (below) showing the precise route of the 3 JARE51 teams, focusing on Geology (red), geomorphology (green) and meteorite (blue).

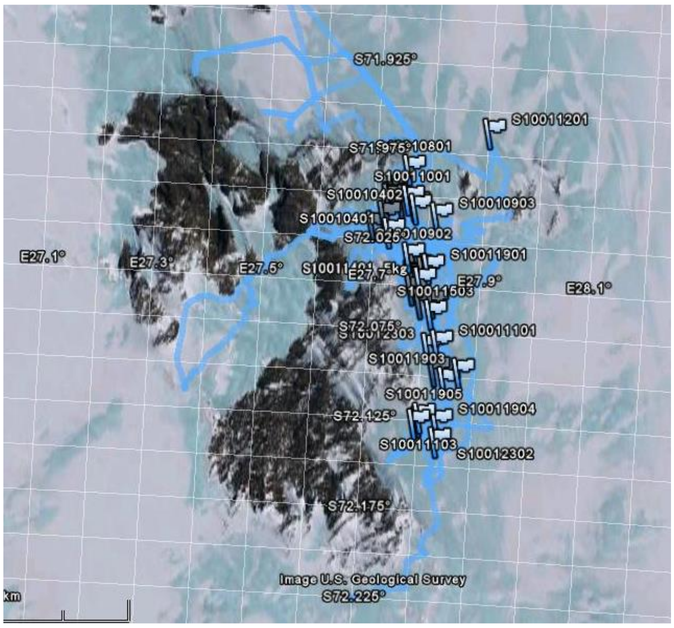

Figure 7 showing the base camp, the region searched for meteorites and the precise location of the collected samples on google maps.

Figure 8 showing the recovered precious and rare 211 g ureilite (left) and smaller iron meteorite (92g)

The primitive achondrite ureilite made of olivine and pyroxene shown above is currently under investigation by the VUB-ULB team to document its origin and formation process.

B) Second expedition 2010–2011, *opening the way to the Nansen ice field*

The next year, an exploratory mission was organized to open the difficult route from PE to the high altitude (2900 m) Nansen ice field located ~ 140 km to the south, on the south side of the Sør Rondane Mountains. The camp was set up on the plateau, with the containers shielded from the gushing winds by a large snow-wall (Figure 9). The goal was to scout this region for its meteorite potential. This small expedition was composed of Steven Goderis, Vinciane Debaille (ULB) and Hiroshi Kaiden (NIPR) as invited Japanese partner. The team spent 4 weeks in the Nansen ice field, in January 2011. Because the number of participants was limited, and because of adverse conditions, cold temperatures and very strong winds, the team collected less than 10 kg of samples (218 fragments) in the northwestern part of Nansen (Figure 10). Nevertheless, the strong potential of the Nansen ice field in terms of meteorite collection is confirmed.

Figure 9. Base camp of the 2010-2011 expedition hidden behind an erected wall of ice for protection against the very strong winds. Weather conditions were difficult during most of the stay on the Plateau and significantly restricted the searches, and by consequence the amount of meteorite found. However, the strong potential of the Nansen ice field for meteorite recovery was clearly established.

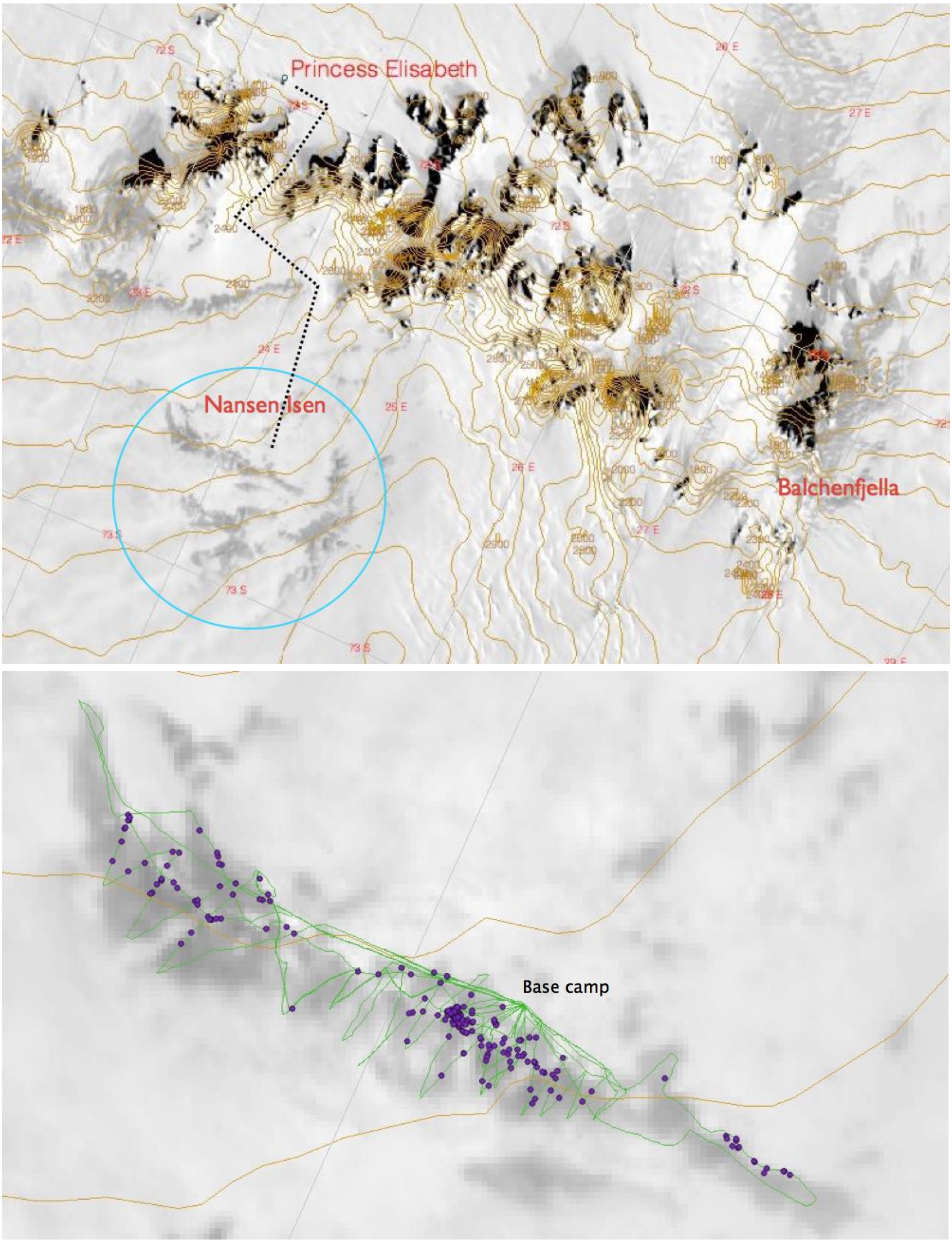

Figure 10. Above image shows the location of the Nansen ice field, to the south of PE and the new route opened to reach it. Lower image shows the location of the camp, the skidoo track in green and the location of the collected meteorites (purple dots). Only a fraction of the Nansen ice field was explored but highlighted the strong potential of the region.

C) Third and largest expedition 2012-2013: *The consecration*

In 2012-2013, a much larger expedition returned to the Nansen ice field, under the leadership of Vinciane Debaille. It counted 8 scientists, 5 Belgian from ULB and VUB (4 females) and three Japanese, two from NIPR and one from Tokyo University. They spend 6 weeks on the plateau, collecting more than 400 meteorites including a unique sample weighing ~ 18 kg (Figure 11), the largest meteorite recovered in East Antarctica over the last 25 years. The strategy was improved during this campaign. The base camp was moved to a new area after the first zone was harvested (Figure 12). This expedition was a clear success: more than 75 kg of meteorite were recovered. However, one third of the Nansen ice field remains unexplored and could be targeted for a future mission (Figure 12).

Figure 11. Find of the 18kg chondritic breccia, below close up on this large specimen, and the present display at the RBINS.

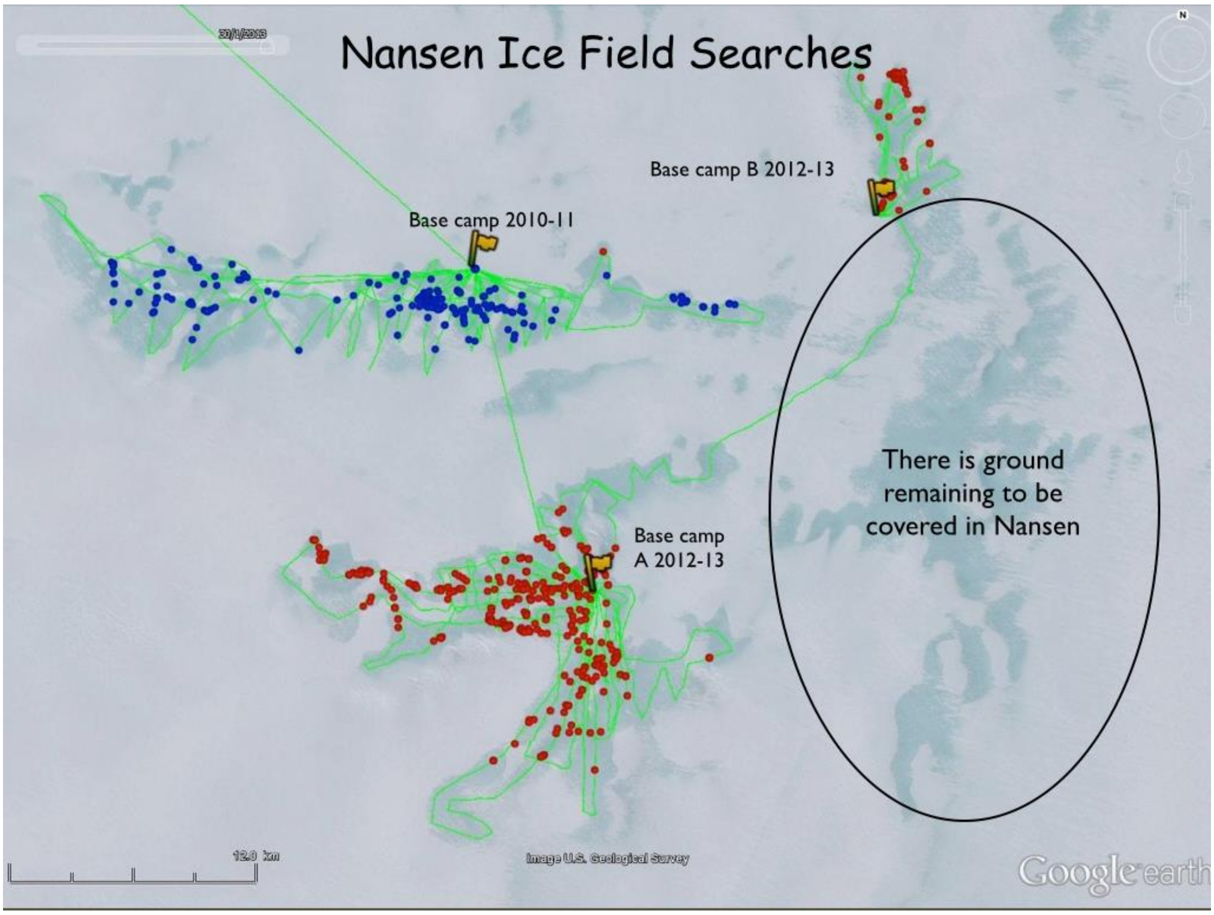

Figure 12. Summary of the two missions to the Nansen ice field (2010-2011 in blue and 2012-2013 in red) with the position of the base camps, the search tracks in green and the dots indicating the sample location. This map documents the zone remaining for future meteorite exploration.

Together with the meteorite collection at the indicated location, blue ice was also sampled to understand the Nansen ice field meteorite trap and document past climates in this region of Antarctica. The isotopic composition of ice reflects past climatic conditions in which the ice was formed. This information has been widely used over the past decades to better understand the Quaternary climate in Antarctica and its evolution during the successive glacial-interglacial transitions. The most common way to sample ice for such analyses is through deep ice coring, which typically occurs over depths of several hundreds of meters up to a few kilometers. This method has the advantage of having a clear age-depth chronology (the deeper, the older the ice), but has the disadvantage of being very expensive (high logistical costs) and only limited quantities of ice are available (as the diameter of the core is fairly small). More recently, researchers are therefore trying to use surface ice for palaeoclimatic purposes. Large quantities of surface ice can be sampled (which is needed for some analyses) and the method is logistically simple, rapid and inexpensive. The major challenge of using surface ice for palaeoclimatic purposes resides in determining the age of the ice. One of the goals of our mission was to contribute to this new research field. As the meteorites retrieved on the Nansen blue ice field are transported within the ice until they reappear at the blue ice surface, their terrestrial age gives an upper boundary for the age of the ice.

During the 2012-13 SAMBA expedition, a total of 187 surface blue ice samples were collected on the Nansen blue ice field (Figure 13). The sampling procedure consisted of removing the upper 3-5 centimeters of surface ice, after which the underlying ice was crushed and stored in sealed bottles of 60 ml. These bottles were transported to Belgium and analyzed in the stable isotope laboratory of the Analytical, Environmental, & Geo-Chemistry (AMGC) research unit at the VUB. The deuterium excess and δ^{18}O of the samples was measured with a Picarro L2130-i analyzer. The results showed a clear spatial pattern, with 3 distinct zones (see Figure 13):
- SE part of Nansen B: low δ^{18}O values, typically around -48‰ to -44‰
- NE part of Nansen B: high δ^{18}O values, typically around -40‰ to -36‰
- NW part of Nansen B: low δ^{18}O values, typically around -48‰ to -44‰

The low values in the SE and NW zone reflect cold conditions, while the higher values in the NE zone represent warm conditions (same signal is in the deuterium excess). The strong contrast between the zones and the difference in magnitude suggests 2 zones with glacial ice (SE and NW) and one zone with interglacial ice (NE). This large-scale interglacial-glacial-interglacial transition is to date one of the largest that has ever been observed. To get an insight in the age of the ice, the terrestrial age of meteorites collected during our expedition are now being determined by the group of Prof. Dr. A.J. Jull at the NSF-Arizona Accelerated Mass Spectrometry (AMS) facility. The selected meteorites are all have a weight above 1 kg and are therefore above the wind transport threshold. The ice age chronology will help us to better understand why the Nansen ice field is such a meteorite retrieval hotspot.

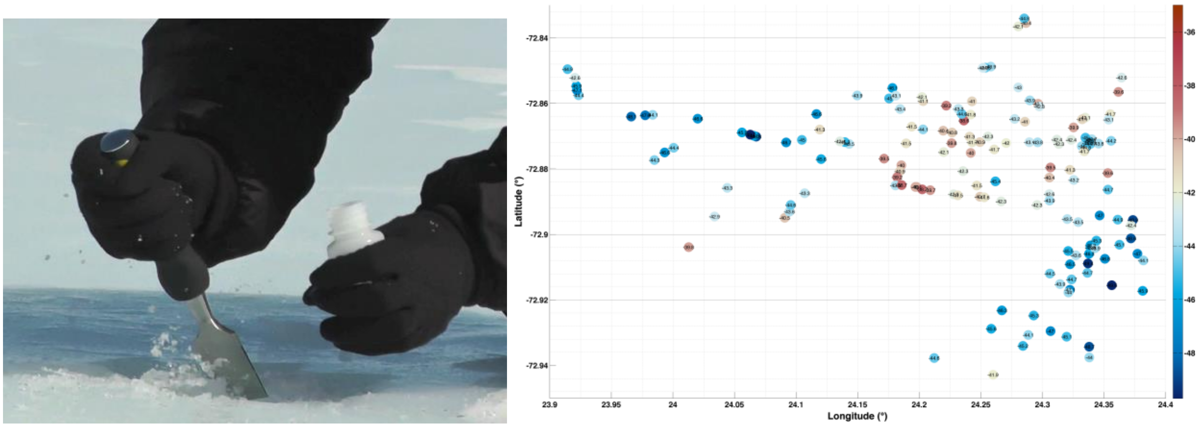

Figure 13. Sampling of blue ice and δ18O values of surface blue ice samples collected on the Nansen blue ice field during the 2012-2013 SAMBA expedition.

Because of logistic reasons, a delay was observed between the arrival at PE and the actual departure for the Nansen Ice Field. This delay has been used for sampling snow in the dry valley close of the PE station (1 day) with the goal of characterizing the composition and origin of its atmospheric dust particles component, as Antarctica is supposed to be preserved from (most) of the anthropogenic contamination. This material is the main subject of a new ULB project under the leadership of N. Mattielli and with international collaborations (Université de Lille, France). The fine dust grains extracted from this snow is being analyzed at the ULB and VUB for major and trace elements as well as isotopic signatures in the framework of the PhD thesis of Aubry Verstraeten at ULB.

D) ANSMET invites SAMBA in 2013-2014: *The International recognition*

Following the success of the SAMBA project, Dr. Vinciane Debaille (ULB) was solicited to participate in the 2014-2015 American meteorite expedition, supported by NASA (Ansmet) on the other side of the continent in the Transantarctic Mountains. The team of 8 persons (2 field guides, 5 scientists and 1 NASA astronaut) used the US McMurdo station as a base for flying through the Transantarctic Mountains and reach the Davis Nunatak. They spent 1 month on the field, under tents (Figure 14) and collected 530 meteorites, not only on the ice, but also in moraine area (Figure 14). The mission was very instructive as it gives a new insight on potential new places for collecting meteorites in the Sor Rondane Mountains. This invitation is a clear international recognition of the work done thanks to the SAMBA project.

Figure 14: Left: base camp of Ansmet in the Davis Nunatak. Because all the transport is organized by flying from McMurdo up to there, tents are used. Food is kept frozen outside in boxes. Solar panels are used for power. Right meteorite search in the moraine, each red flag indicates a meteorite sample.

E) How meteorites are found?

Skidoos are most commonly used to search the vast ice fields for meteorites as these black rocks stand out on the white ice (Figure 15). In other locations, for example near a moraine field, searches can also be done on foot. With the skidoos, a team covers 15 to 30 km per day, which takes 4 to 6 hours, depending on the weather conditions. Generally, they adopt a V-shape formation, with the field guide in front to spot crevasses or any other potential risk. There is between 20 to 50 m between each driver, depending of the visibility and the potential dangers of the field. Terrestrial rocks are rare in the blue ice fields, and if necessary meteorites can be distinguished by the presence of a fusion crust, formed by heating during their rapid passage through the atmosphere. When a meteorite is spotted, GPS position and pictures with a scale are taken of the meteorite (Figure 16). The new sample is carefully put in a plastic back without being touched by hands to avoid any biological contamination, labelled, and all available data are recorded in a logbook. Everybody then retakes his/her place in the V-shape, with the meteorite tucked away in a bag.

Figure 15. V-shaped formation on skidoo that maximize meteorite recovery in blue ice field regions.

Some precautions have to be taken when collecting these precious samples to minimize terrestrial contamination, such as i) never touch the meteorite with bare hands, ii) never use a magnet on it, iii) never put the meteorite in a warm place, such as a jacket pocket, it would defreeze and weathered at the water contact, iv) collect it for a personal collection, which is forbidden according to the Antarctic treaty. It also must be understood that most meteorite cannot be classified or identified in the field. It is therefore imperative to collect all field information with care, and ensure the safe transport of the meteorite to the lab where classification will occur.

Figure 16. Meteorite recovery identification, photography, labelling GPS and bagging procedures.

F) Meteorite processing

The collected meteorites have to remain frozen. For long (terrestrial ages up to several 1000 years) these meteorites were protected from weathering by snow and ice, and it must be avoided that water percolates and penetrates into the rock during the thawing process. Therefore, the recovered meteorites are first sent to Japan frozen. They are packed at PE and shipped in a freezer all the way to Cape Town, where shipping is organized to Japan in the same conditions. At the NIPR, one by one, they undergo defrosting according to a specific procedure, under vacuum (Figure 17). The ice becomes vapor, instead of H_2O liquid. This way, the meteorite remains absolutely dry, pristine and uncontaminated; ready to undergo all kinds of research experiments in the laboratory to unscramble its message about the birth of the solar system and the planet. This procedure is very slow, which explain the fact that not all newly collected meteorites are directly available for classification and study. However it is indispensable to guarantee the pristine quality of the samples.

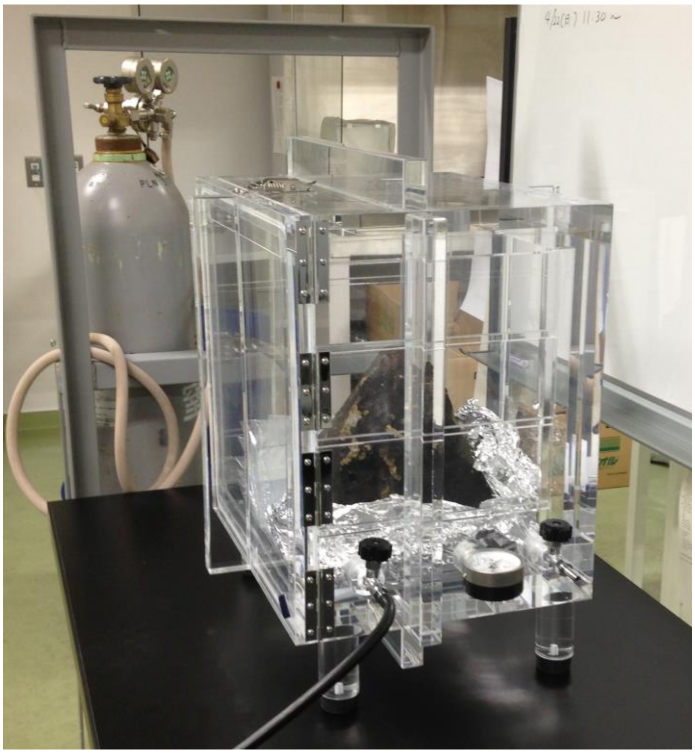

Figure 17 showing the defrosting under vacuum of the 18kg meteorite recovered during the 3rd SAMBA mission to Antarctica at the NIPR. During the first three expeditions, this delicate operation took place at the NIPR, due to the advance experience of the Japanese in this procedure. Now that through the BELAM project the RBINS meteorite curation facility is fully equipped, such procedure could also be carried out safely in Brussels.

G) Recovered meteorites

The SAMBA operation collected 1279 new meteorites during its 3 campaigns, which contribute to the Belgian extra-terrestrial sample collection hosted at the RBINS and are now fully available for the research community in planetary science worldwide (://mars.naturalsciences.be/geology/Meteorites). This contribution is significant as these finds do position Belgium as a major player in the search for Antarctic meteorites. As a result of the SAMBA project, the RBINS now possesses one of the largest Antarctic meteorite collections in Europe.

Where are meteorites found today on Earth? Historically, collection after observed falls provided some famous specimens (Orgueil, France or more recently Chelyabinsk, Russia) but are statistically rare, which may change with the introduction of fireball monitoring systems (see Fripon http://ceres.geol.u-psud.fr/fripon/?lang=en). The same applies to random finds. Field campaign in dry zones such as Antarctica and dry hot desert provide the largest fraction of modern finds. Today, more than 54000 officially named meteorites are categorized worldwide, of which more than 75% originate from Antarctica (Table 1). These number attest for the importance of collecting meteorites in this part of the world.

Location	*Number of meteorites*
Antarctica	40870
USA	2134
Libya	1499
Australia	746
Algeria	747
North West Africa	8338
Oman	3881
India	149
Russia	160
France	85
Belgium	4

Table 1. Showing the number of Antarctic meteorites compared to other locations, enquiry made in July 2015 on the Meteoritical Society database.

The Asuka meteorites recovered from the region of the Sør Rondane Mountains and surroundings in East Antarctica represents today approximately 6% of all the meteorites worldwide. This number includes the specimens collected during the Japanese campaigns in the 1985 – 1991 period, plus the 1279 new meteorites recovered by the joint SAMBA-JARE missions between 2009 and 2015 (Table 2). This is clearly a significant contribution to the scientific knowledge about the orgin of the solar system and formation of planets as **all** these samples are fully available for research by the international community through the NIPR and RBINS curation facilities.

Field season	*Mission*	*Nr. Meteorites*	*Location*
1986-87 (Asuka 86)	JARE-27	3	Mt. Balchen
1987-88 (Asuka 88)	JARE-28	352	Mt. Balchen + Nansen
1988-89 (Asuka 89)	JARE-29	1597	Nansen ice field
1990-91 (Asuka 90)	JARE-31	48	Mt Balchen
2009-10 (Asuka 09)	**JARE-51 - SAMBA**	**635**	**Mt Balchen**
2010-11 (Asuka 10)	**SAMBA**	**218**	**NW Nansen Ice Field**
2012-13 (Asuka 12)	**SAMBA – JARE-54**	**425**	**Nansen Ice Field**
SAMBA total contribution		**1279**	
Total Sør Rondane region and surroundings		3279	NIPR-Belgium

Table 2. Comparing the recent SAMBA collection with the previous ones carried out by the NIPR some 20 years ago. The SAMBA collection documents a replenishing of the field over a ~ 20 year period, and highlights the potential of further meteorite search in this region of East Antarctica.

H) Fieldwork and recovery of micrometeorites in the surrounding of the Belgian Princess Elisabeth (PE) station

The recovery of and work on micrometeorites was supported by the Antarctic *InBev Baillet Latour grant* received jointly by Steven Goderis and Vinciane Debaille in 2010. Although this project is not effectively part of SAMBA, it benefited from the logistic and experience of the SAMBA project and would not have been possible without it. Indeed, micrometeorites were recovered from the Sør Rondane region surrounding PE during the 2010-11 and 2012-13 SAMBA expeditions. The results are briefly presented below.

Two field expeditions were conducted in the Sør Rondane Mountain and surroundings to test the potential of local granitic and gneissic lithologies to yield high concentrations of micrometeorites, similar to the discoveries in the Transantarctic Mountains by French-Italian teams. In 2010-2011, during the joint Belgian – Japanese searches for normal-sized meteorites in the Nansen ice field, Steven Goderis carried out a preliminary exploration of several outcrops in the region surrounding PE (~ 20 km), as well as on the Southern side of the Sør Rondane on his way to the Nansen ice field. He collected a couple of kg of fine-grained material, deposited into cracks of Sør Rondane granites and gneisses. This material was studied at the VUB during the year 2011 – 2012, and yielded small and rather weathered potential micrometeorites. However, the quantity recovered was smaller and less pristine than reported from the Transantarctic Mountains. Several factors can affect the concentration of these micrometeorites in weathered lithologies, in particular the exposure time of the surface. Although the Sør Rondane and Transantarctic mountain present many similarities in term of exposure time and weathering, the French-Italian team relied on helicopter drops at mountain summits to collect the most promising sampled. It was concluded that the main reason for the lower yield was most likely the lower topography of the nunataks, selected for this preliminary study. Shielding from the strongest winds was thought to be another important factor. Planning was made to aim for higher and more wind-exposed, and consequently denudated, outcrops during the next field season. However, this implied significant climbing and mountaineering expertise. Locations were selected using satellite imaging, google Earth and geological maps of the PE region.

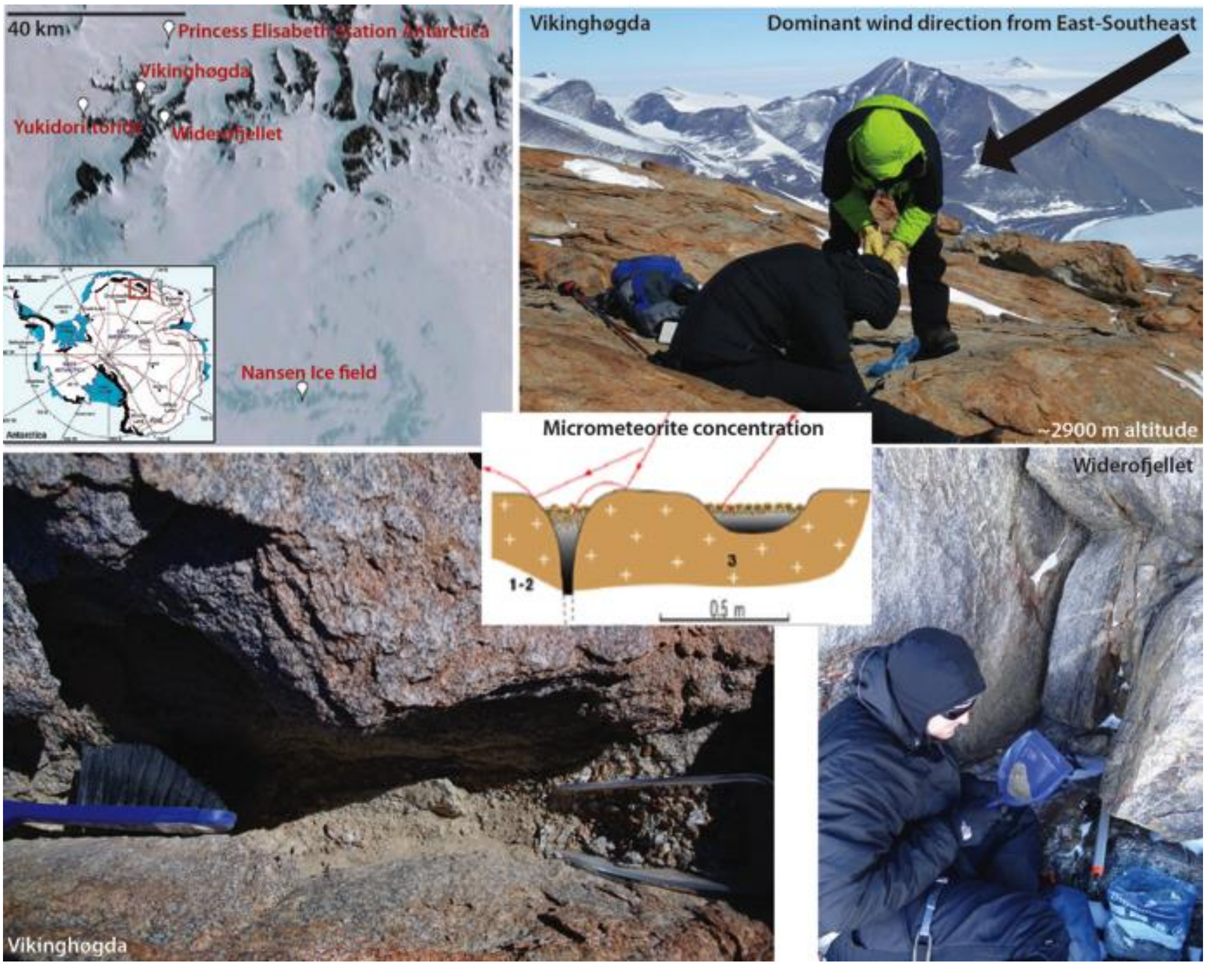

Figure 18. Map of sampled localities in the western part of the Sør Rondane Mountains, relative to the Princess Elisabeth Station Antarctica and the Nansen Ice field, with examples of the micrometeorite traps and the collection procedure at the very top of the Mountain.

In December 2012, based on this first experience, Steven Goderis spent a month at PE. Accompanied by a guide with mountaineering and climbing expertise, he reached much higher altitude outcrops and sampled granitic/gneissic lithologies. The focus was put on high-altitude, wind-exposed areas in relative proximity to the station, as it took an entire day (~12h) to reach the exposures (climbing ~1000-1500 m), sample these, and return to the station. These climbs and descents (with extra kilograms) were especially challenging considering the cold temperatures and slippery conditions. Figure 18 shows the locations of the Yukidori-toride, Vikinghøgda, and Wideroefjellet Mountains, where potentially micrometeorite-containing sediments were sampled, relative to the Princess Elisabeth Station and the Nansen Ice field, where the normal-sized meteorites were collected.

I) Analytical development for application of isotopic analyses to small mineral phases within (micro)meteorites

Because of the processing highlighted above (F) and the need for proper meteorite classification (now theme of the BELAM & AMUNDSEN projects, see C above), there is a significant lag time between the collection of new meteorites on the Antarctic ice fields and their availability for research. Clearly, this lag time was under-estimated when the SAMBA project was first written in 2008-2009, mainly due to unfamiliarity with the complexity of meteorite processing and classification used by the NIPR. It is only in 2014-2015 that the majority of the sample is becoming available for research as illustrated by the publication list.

Another aspect of this project focused on the development/refinement of existing analytical techniques for the determination of isotope ratios and trace element concentrations to sub-mm samples. This work was carried out using the instrumental facilities at the VUB, ULB and Ghent University, through an instrument sharing agreement (VUB-UGent-KULeuven). The following instruments are used for the cosmochemical-geochemical characterization of the newly collected meteorites. The NuPlasma Multicollector - Inductively Coupled Plasma - Mass Spectrometer (MC-ICP-MS) available at the ULB and the Neptune MC-ICP-MS from the Dept. of Analytical Chemistry at Ghent University are used in parallel, and for various applications according to the best-suited instrument. The Thermo Element 2 High Resolution ICP-MS (HR-ICP-MS) available at the VUB and Thermo Element XR HR-ICP-MS from Ghent University were used respectively for solution and laser ablation work. Trace elements were also determined using the Agilent quadrupole ICP-MS at the ULB. The µXRF Bruker Tornado instrument at the VUB produced high-resolution elemental maps (25µm) for major and trace elements within meteorites. Scanning electron microscopes with Energy Dispersive Analyzer, Raman spectroscopy, and classical microscopy techniques were also used. Transmission Electron Microscopy was also used in collaboration with the group of Dr. D. Schryvers at Antwerp University. Thanks to the SAMBA project, a clean lab has been renovated at ULB and now provides state-of-the-art facilities for purifying the reagents used for any protocols, and clean space for elemental purification

An important step was the realization of inter-calibration between the different instruments, in particular the two MC-ICP-MS, which are available in Brussels and Ghent. A scientific paper authored by Dr. Virginie Renson, who was in part supported by this project, is currently being written focusing on the comparison of the results of Pb isotope systematics (^{206}Pb, ^{207}Pb, ^{208}Pb) measured on both instruments. Working on small and rare samples, such as (micro)meteorites, implies meticulous characterization of reference materials and methodology testing on other extraterrestrial materials. This approach was adopted for ^{176}Lu-^{176}Hf, ^{60}Fe-^{60}Ni, ^{182}Hf-^{182}W, ^{146}Sm-^{142}Nd and ^{107}Pd-^{107}Ag at the ULB. In addition, laser ablation (LA-) ICP-MS was optimized to the determination of particular element concentrations in specific mineral phases of meteorites by application of multiple internal standards (^{24}Mg, ^{29}Si, ^{44}Ca, ^{47}Ti, and ^{57}Fe). At Ghent University, Steven Goderis implemented platinum group element determination methods specifically designed for rare extra-terrestrial materials. A laboratory for ultra-high precision Os isotope measurements is also being set up. The siderophile/chalcophile behavior of highly siderophile elements (HSE) together with the long-lived radiogenic decay of ^{187}Re and ^{190}Pt to ^{187}Os and ^{186}Os with half-lives of 41.5 Ga and 488 Ga respectively, make the Os isotope system unique and powerful in i) tracking exogenous meteoritic components in (extra)terrestrial materials, ii) constraining the timing and evolution of primitive and evolved meteorites, iii) elucidating accretion and differentiation of the terrestrial planets including Earth, and iv) last but not least studying potentially recorded nucleosynthetic isotope anomalies carried by pre-solar grains, as curiously of all planetary materials characterized to date only ureilite meteorites show resolvable nucleosynthetic Os anomalies. Lithium (^{7}Li/^{6}Li) and boron (^{11}B/^{10}B) methodologies were also developed on the Neptune MC-ICP-MS. This work resulted in several peer-reviewed manuscripts (see publication list).

3) POLICY SUPPORT

The SAMBA project contributes to the fulfilment of the Belgian Science policy in Antarctica by adding a planetary/cosmochemistry component to the existing activities supported by BELSPO. As the meteorites are collected fully for scientific research and not to increase private collections, this project is in full agreement with the Antarctic Treaty. The unique accumulation of meteorites in specific zones of the blue ice fields is a unique opportunity to collect rare samples that are used to document the origin of the solar system and the formation of planets. Also, the characterization of meteorites offers ground-true information that supports space exploration programs of ESA and NASA by for example allowing the calibration of instruments. This is important, as Belgium is an established ESA partner with major responsibilities in this domain.

The skills of the ULB-VUB partners in meteorite research and collection have been internationally recognized by the way of invitations to participate in (1) the Antarctica meteorite collection campaign funded by the NASA and (2) the Horizon 2020-Compet 8 program, at a European level (project Euro-Cares, main PI: Natural History Museum of London). The SAMBA project is at the root of this scientific expertise. As a consequence, the ULB-VUB pole could provide expert advice to the policy-makers in the field of space research and Antarctica programs. In terms of societal impact, the SAMBA project expanded the RBINS meteorite collection and encourages a protective curation of Antarctic meteorites deposited at the Royal Institute of Natural Sciences. This project therefore plays a role in the development preservation of the national heritage (Museum collection) in Belgium. An important output of this project is the communication of the results towards a broad audience - among others by way of meteorite exhibitions - it also has an important function in the public awareness of scientific issues relating to planetary/extra-terrestrial matters (Figure 11). Meteorites are known to draw crowds to musea. In conclusion, the SAMBA project provided unique material for museum display and education of the general public for years to come, as illustrated by the success the discovery of the large 18kg meteorite generated in the press and general public (see for example http://deredactie.be/cm/vrtnieuws/videozone/archief/programmas/journaal/2.26948/2.26949/1.1559328).

4) DISSEMINATION AND VALORISATION

The results of the SAMBA project are disseminated to the scientific community via the traditional channels of peer-reviewed publications in international journals and oral or poster communication at scientific meetings (see list). To the general public and policy makers, the SAMBA output is communicated through conference and invited presentations in schools, musea, astronomy observatories, and clubs, mineral collectors etc. The SAMBA project brought back unique meteorite specimens that have been/are/will be the subject of temporary or permanent exhibits at musea, and the planetarium. They are also used for school visits at the VUB and ULB. The website of the International Polar Foundation also widely reported the progress of the SAMBA project. In November 2014 a symposium was organized at the RBINS, from Dinosaurs to meteorites to celebrate the permanent exhibit of the 18 kg meteorite recovered by SAMBA. The joint Planet-Topers – SAMBA expedition blog (http://antarctica.oma.be/) covering the 3rd meteorite search attracted a vast international audience (up to 120000 hits in December 2012).

5) PUBLICATION LIST

The list below presents all peer-reviewed international publications related directly or indirectly to the SAMBA project till Summer 2015 (members VUB green, ULB blue, NIPR partner purple). The analytical developments carried out and/or the equipment acquired in the framework of SAMBA let to a great deal of publication at both VUB and ULB. Analyses of the list shows that the publications *directly* related to the meteorites collected in Antarctica start to appear in 2014; this is due to the time required for sample processing and classification (see F), which was perhaps underestimated at the start of the project. However, as the SAMBA collection constitutes the base of many other projects, this list is expected to grow significantly.

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The list of conference abstracts and proceedings can be found on the VUB and ULB publication databases under the name of the Pi's of the SAMBA project at respectively:
VUB – Ph. Claeys:
https://cris.cumulus.vub.ac.be/portal/en/persons/philippe-claeys%289592892d-34aa-4932-ae74-37f407c45f35%29.html
VUB – S. Goderis:
https://cris.cumulus.vub.ac.be/portal/en/persons/steven-goderis%28f2d6b352-573a-4e9a-a90d-2989f100d763%29.html
ULB – N. Mattielli :
http://difusion.ulb.ac.be/vufind/Search/Home?lookfor=Nadine+Mattielli&sort=pubdate+desc&submitButton=Recherche&type=general
ULB – V. Debaille
http://difusion.ulb.ac.be/vufind/Search/Home?lookfor=Vinciane+Debaille&sort=pubdate+desc&submitButton=Recherche&type=general

All the above listed publications are also available electronically via these websites.

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NB: There was no follow up committee; its role was played by the narrow collaboration and constant interaction with the NIPR at every step of the SAMBA project.