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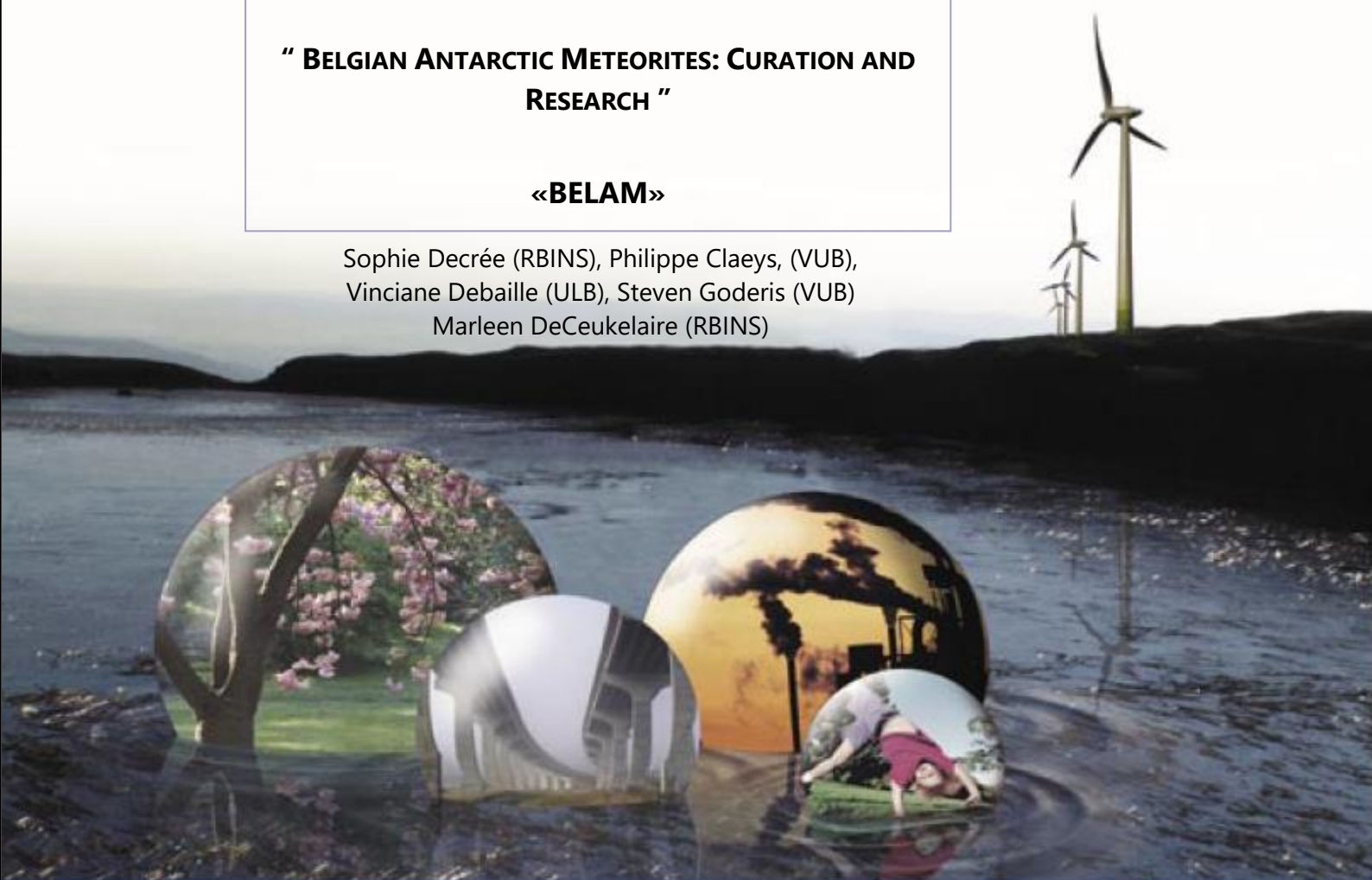
SCIENCE FOR A SUSTAINABLE DEVELOPMENT



“ BELGIAN ANTARCTIC METEORITES: CURATION AND RESEARCH ”

«BELAM»

Sophie Decrée (RBINS), Philippe Claeys, (VUB),
Vinciane Debaille (ULB), Steven Goderis (VUB)
Marleen DeCeukelaire (RBINS)



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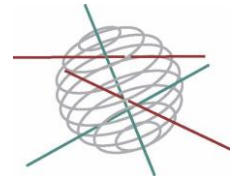
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FINAL REPORT

**BELGIAN ANTARCTIC METEORITES: CURATION AND RESEARCH
"BELAM"**

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ACRONYMS, ABBREVIATIONS AND UNITS

BELAM	Belgian Antarctic Meteorites
BELSPO	Belgian Science Policy
BRAIN	Belgian Research Action through Interdisciplinary Networks, a BELSPO programme
Darwin	Data Research Waterhouse Information Network (RBINS owned system)
EDS	Energy Dispersive Spectroscopy
EMAT	Electron Microscopy for Materials Science, University of Antwerp
ESA	European Space Agency
IT	Information Technology, service of RBINS
JARE	Japanese Antarctic Research Expedition (e.g. 51st in the 2009–2010 field season)
Mars	Plone® Open Source CMS/WCM by the Plone Foundation and friends
MoU	Memorandum of Understanding, between NIPR and Belgian partners
NIPR	National Institute of Polar Research, Japan
RBINS	Royal Belgian Institute of Natural Sciences
SAMBA	Search for Antarctic Meteorites (BELSPO-supported project of VUB-ULB with NIPR)
SEM	Scanning Electron Microscope
SLC	Scientific Loan Committee
ULB	Université Libre de Bruxelles
VUB	Vrije Universiteit Brussel

Summary

Context

The Belgian centers for high level meteorite research are VUB and ULB. VUB is conducting research in the field of impact craters and their geochemical and isotopic signature, especially platinoid metals and light stable isotopes to trace the origin of projectiles; ULB has expertise in isotope geochemistry and geochronology, for both radiogenic isotopes and heavy stable isotopes allowing research on planetary differentiation from meteorite investigation, and the chronology of the early solar system. Both universities collaborated in the search for Antarctic meteorites during joint field campaigns set up in close cooperation with NIPR and with the support of BELSPO. These Antarctic meteorites are highly valued because of their pristine quality, hardly affected by weathering phenomena occurring at the surface of the Earth. Since 2009, about 1200 meteorites have been gathered and provisionally stored in Japan. As they are shared property, half of the share has to come to Belgium, on condition that they would come in custody of an official curation center. Meanwhile RBINS, which is the main center for natural history collections in Belgium, had developed a meteorite collection of >500 meteorites which placed it at middle level of European meteorite collections but had no dedicated curation facilities for meteorites. In order to support Belgian networking for meteorite research, repatriate a unique collection of Antarctic meteorites of high value for research, and establish a national curation center for meteorites, which are all interdependent, BELSPO decided to support a project, introduced by VUB, combining curation and research.

Objectives

The objectives of this project, dedicated to Antarctic meteorites, are:

- (i) to establish and organise the meteorite curation facilities at the Royal Belgian Institute of Natural Sciences (RBINS), through renovation of the storage room and installation of the material required for the curation task.
- (ii) in collaboration with NIPR, to identify and classify the Antarctic meteorites, a crucial part of the curation work. The detailed description and accurate classification of the new meteorites, down to the sub-group level, will guarantee the quality of the research performed on these samples. The identified meteorites will be registered in an online database.
- (iii) to make the Belgian collection of meteorites available for local and international researchers. Clear rules for sample loan, destructive analyses, etc. will be established, based on existing rules and experience of RBINS, and in coordination with NIPR. A website developed and hosted by RBINS will display this information.

(iv) to set up a Belgian research network on meteorites, based on existing VUB-ULB collaboration and reaching out to colleagues in other institutions. The network will facilitate discussions and promote joint research, organise workshops and student exchanges, and stimulate participation in the meteorite curation work.

(v) to carry out quality research on the Antarctic meteorites recently collected.

Main conclusions and inputs in terms of sustainability

The main result of the project is the implementation of a curation facility for Antarctic meteorites at RBINS, including an equipped laboratory with a well-trained team, a database available to the worldwide research community, and established loan procedures. This will bring long-lasting benefits from the BELAM project and limit the critical issue of sustainability.

Now, the curation system at RBINS is functional, with qualified staff and sets of guidelines on registration, handling and arranging facilities for researchers, both in the repository and laboratory. This involves the capacity for identification and petrological characterisation of meteorites – making use of mineralogical and geochemical lab facilities at the different partner institutes – applied in synergy with the work done at NIPR and directed more particularly to the scientifically most interesting meteorite types, whereby VUB and ULB become the main partners. All samples can be accessed online by two ways that are linked, the Darwin data and loan handling system (Darwin.naturalsciences.be) and the quick access mars database system (mars.naturalsciences.be). The redaction of a Handbook of quality control of curation was a task for the postdoc researcher to describe the full chain of curation operations and protocols, intended as a cookbook for the curator and his staff (part for internal use), but it also provides guidelines for users interested in loans or special treatment of samples (part for external use). It is intended for guaranteeing continuity of the curation center.

Long-lasting and efficient curation at the RBINS is also ensured by three agreements signed by the partners, which resulted : an Internal Agreement on curation and research of Belgian Antarctic meteorites between VUB, ULB and RBINS, a Deposit agreement on Antarctic Meteorites between VUB, ULB and RBINS, including the functioning of a Scientific Loan Committee, and a MoU between NIPR, VUB, ULB, RBINS concerning scientific cooperation and ways of sharing the Antarctic meteorites. The Scientific Loan Committee is active for allocating samples for either research or exhibitions.

Dissemination of results and presentation of the new curation system is also beneficial to the sustainability of the curation facilities at the RBINS.

In the frame of the BELAM project, the exhibit of an outstanding meteorite found in Antarctica coupled to a national meeting was organized in 2014. A large scale international meeting was organized in Fall 2016 and brought meteorite curators from all over the world to visit the RBINS meteorite facility, and learn about Belgium ongoing meteorite research.

In terms of research, publications in peer-reviewed journals report the obtained results, which were presented in international conferences such as the annual Antarctic Meteorite Symposium at NIPR in Tokyo.

Finally, in order to ensure the sustainability of the curation, two BRAIN projects were formulated and approved for funding: The first project, introduced under Thematic axis 6: Management of collections by RBINS-ULB-VUB, is entitled 'Antarctic meteorites curation, digitalization and conservation' (AMUNDSSEN; 15/03/2016-15/09/2019). The proposal is dedicated to the conservation, classification, valorisation and digitalization of meteorites at the RBINS with the goal to improve the maintenance of this fragile collection, develop best practice meteorite curation protocols, provide the most appropriate sampling procedure and stimulate and facilitate the scientific usage of the collection by the international research community. The second project, introduced under Thematic axis 2, is entitled 'Belgian Antarctic Meteorites and Micrometeorites to document solar system formation and evolution' (BAMM!; 01/01/2017 – 31/12/2020).

This novel BRAINS project, gathering the same partners, builds on and expands the assembled expertise, and centers on a number of highly promising, but previously unexplored research opportunities provided by this valuable set of newly recovered extraterrestrial samples.

Keywords: *Antarctic meteorites, curation facility, meteorite research*

Samenvatting

Context

De Belgische centra voor onderzoek van meteorieten op hoog niveau zijn de VUB en ULB. De VUB verricht onderzoek op het gebied van impactkraters en hun geochemische en isotopische signaturen, vooral metalen uit de platinumgroep en stabiele lichte isotopen om de herkomst van projectielen te bepalen. De ULB heeft expertise in de isotopen geochemie en geochronologie zowel in de radiogene isotopen als zware stabiele isotopen. Dit stelt hen in staat onderzoek te verrichten naar planetaire differentiatie aan de hand van onderzoek op meteorieten alsook de chronologie van het vroege zonnestelsel. Beide universiteiten hebben nauw samengewerkt in de zoektocht naar antarctische meteorieten in gezamenlijke veldmissies in nauwe samenwerking met het NIPR en met de steun van BELSPO. Deze antarctische meteorieten worden bijzonder gewaardeerd vanwege hun zeer goede staat, nauwelijks aangetast door de verweringsprocessen aan het aardoppervlak. Sinds 2009 werden er zo'n 1200 meteorieten verzameld, deels bewaard in Japan. Aangezien ze gedeeld bezit zijn, zal de helft naar België moeten komen onder voorwaarde dat deze onder het beheer vallen van een officieel centrum voor curatie. Ondertussen heeft het KBIN, dat het centrum is van de natuurhistorische collecties in België, een meteorietencollectie van >500 meteorieten aangelegd, hetgeen het in de

middelmoet plaatst van Europese meteorieten collecties. Het ontbreekt echter een toegewijde curatie faciliteit specifiek voor meteorieten. Ten einde de Belgische netwerken voor meteorietonderzoek te ondersteunen, alsook om een unieke collectie antarctische meteorieten van hoge waarde voor onderzoek te repatriëren en om een nationaal centrum voor curatie van meteorieten op te richten heeft BELSPO besloten een door de VUB voorgesteld project te steunen dat curatie en onderzoek combineert.

Objectieven

De objectieven van dit project, gewijd aan Antarctische meteorieten zijn:

- (i) De curatie faciliteiten voor meteorieten op te zetten en te organiseren aan het Koninklijk Belgisch Instituut voor Natuurwetenschappen (KBIN) door de renovatie van de opslagruimte en het installeren van benodigd materiaal voor de curatie.
- (ii) Het identificeren en classificeren van de Antarctische meteorieten in samenwerking met het NIPR. De gedetailleerde beschrijving en nauwkeurige classificatie van de nieuwe meteorieten tot op het niveau van de subgroep zal de kwaliteit van het onderzoek op deze stalen garanderen. De geïdentificeerde meteorieten zullen te raadplegen zijn in een online databank.
- (iii) Het toegankelijk maken van de Belgische meteorietencollectie voor lokale en internationale onderzoekers. Duidelijke regels voor het uitlenen, destructief onderzoek, etc. zullen opgemaakt worden gebaseerd op bestaande regels en expertise van het KBIN en dit in samenwerking met het NIPR. Een website ontwikkeld en onderhouden door het KBIN zal deze informatie aanbieden.
- (iv) Het oprichten van een Belgisch netwerk voor meteorieten, gebaseerd op de bestaande VUB-ULB-samenwerking en de hand uitreiken naar collega's in andere instellingen. Het netwerk zal discussies vergemakkelijken, samenwerking in onderzoek promoten, workshops organiseren, het uitwisselen van studenten vergemakkelijken en participatie in de curatie van meteorieten stimuleren.
- (v) Het verrichten van kwaliteitsvol onderzoek op recent gevonden Antarctische meteorieten.

Algemene conclusies en input op het vlak van duurzaamheid

Het belangrijkste resultaat van het project is de implementatie van een curatie faciliteit voor Antarctische meteorieten aan het KBIN, inclusief een uitgerust labo met een goed getraind team, een database toegankelijk voor de internationale onderzoek gemeenschap en een gevestigde leen procedure. Dit zal langdurige voordelen met zich meebrengen voor het BELAM-project alsook de kritieke kwestie van duurzaamheid verbeteren.

Momenteel is het curatiesysteem aan het KBIN functioneel, met gekwalificeerde medewerkers en met richtlijnen voor registratie, manipulatie en herinrichten van faciliteiten voor onderzoekers zowel in de bewaarplaats als in het labo. Dit omvat de mogelijkheid tot identificatie en petrologische karakterisering van meteorieten, gebruik makende van mineralogische en geochemische labo faciliteiten aan de verschillende partner instellingen, toegepast in synergie met het verrichte werk aan het NIPR en meer bepaald gericht aan de interessante meteoriettypes op wetenschappelijk vlak, waarbij de VUB en ULB de belangrijkste partners worden. Alle data kan online geraadpleegd worden op de twee volgende manieren; het Darwin data en uitleen systeem (Darwin.naturalsciences.be) en de snelle toegang via het mars databasesysteem (mars.naturalsciences.be). Het herschrijven van een handboek over kwaliteitscontrole bij curatie was een taak voor een postdoc onderzoeker. In deze worden het volledige proces van curatie handelingen en procedures beschreven. Het is bedoeld als een "kookboek" voor de curator en zijn personeel (deels voor intern gebruik). Het is bedoeld om de continuïteit van het curatiecentrum te garanderen.

Langdurige en efficiënte curatie aan het KBIN wordt ook verzekerd door drie overeenkomsten getekend door de partners, die als volgt zijn: Een interne overeenkomst over curatie en onderzoek van Belgische Antarctische meteorieten tussen de VUB, ULB en het KBIN. Een overeenkomst omtrent stortingen in verband met Belgische Antarctische meteorieten tussen de VUB, ULB en KBIN inclusief de werking van een wetenschappelijk comité voor leningen en ten slotte een memorandum van overeenstemming (MoU) tussen het NIPR, VUB, ULB, KBIN omtrent wetenschappelijke samenwerking en verschillende mogelijkheden om de Antarctische meteorieten te delen. Het wetenschappelijk lening comité is actief bezig met de distributie van stalen voor zowel research alsook tentoonstellingen.

De verspreiding van resultaten en presentaties van het nieuwe curatiesysteem is ook bevorderlijk voor de duurzaamheid van de curatie faciliteiten aan het KBIN.

In het kader van het BELAM-project werd in 2014 de tentoonstelling van een uitzonderlijke meteoriet van Antarctica georganiseerd gekoppeld aan een nationale bijeenkomst. In de herfst van 2016 werd er een grootschalige bijeenkomst georganiseerd waarbij curatoren van meteorieten van over heel de wereld bijeenkwamen om de faciliteiten te bezoeken en te leren over het lopende onderzoek in België.

Op het vlak van onderzoek worden de resultaten gepubliceerd in peer-reviewed magazines. Deze resultaten worden ook gepresenteerd op internationale conferenties zoals het jaarlijkse Antarctische Meteoriet Symposium aan het NIPR in Tokyo.

Tenslotte werden er twee BRAIN-projecten opgesteld en goedgekeurd om de duurzaamheid van de curatie te verzekeren: Het eerste project, ingevoerd onder de thematische as 6: Beheer van collecties door KBIN-ULB-VUB noemt 'Antarctic meteorites curation, digitalization and conservation' (AMUNDSEN; 15/03/2016-15/09/2019). Dit voorstel is toegewijd aan de conservatie, classificatie, valorisatie en digitalisatie van meteorieten aan het KBIN met als doel het behoud van deze kwetsbare collectie, de ontwikkeling van best practice protocollen, de meest

geschikte procedure voor staal name formuleren en het stimuleren en faciliteren van het wetenschappelijke gebruik van de collectie voor de internationale onderzoek gemeenschap. Het tweede project, ingevoerd onder de thematische as 2, getiteld 'Belgian Antarctic Meteorites and Micrometeorites to document solar system formation and evolution' (BAMM!; 01/01/2017 – 31/12/2020). Dit nieuwe project met dezelfde partners bouwt voort op voorafgaande expertise en verruimt deze, waarbij dit project zich toespitst op een aantal veelbelovende maar nog niet verkende onderzoekpistes aangeleverd door deze waardevolle nieuw ontdekte buitenaardse stalen.

Sleutelwoorden: *Antarctische meteorieten, curatiefaciliteit, meteorietonderzoek*

Résumé

Contexte

La VUB et l'ULB sont des centres belges d'excellence en ce qui concerne la recherche relative aux météorites. La VUB s'intéresse plus particulièrement aux cratères d'impact et à leur signature géochimique et isotopique, en se focalisant plus spécifiquement sur les platinoïdes et les isotopes stables légers pour tracer l'origine des projectiles. L'ULB possède une expertise en géochimie isotopique et en géochronologie, analysant les isotopes radiogéniques et les isotopes stables lourds, ce qui permet l'étude de la différenciation planétaire et de la chronologie du système solaire primitif. Les deux universités ont collecté ensemble plusieurs centaines de météorites antarctiques à l'occasion de campagnes de terrain conjointes, en collaboration étroite avec le NIPR et avec le support de BELSPO. Ces météorites antarctiques ont une valeur importante considérant leur qualité unique, étant peu ou pas affectées par l'altération se produisant à la surface de La Terre. Depuis 2009, environs 1200 météorites ont été rassemblées et stockées de manière temporaire au Japon. Celles-ci sont partagées équitablement, une moitié devant être conservées en Belgique, à condition qu'elles le soient dans un centre de curation officiel. L'IRSNB, qui est le centre principal pour les collections d'histoires naturelles en Belgique, s'était enrichie auparavant d'une collection de plus de 500 météorites. Ceci l'a placé à un niveau intermédiaire pour ce qui concerne les collections de météorites européennes, sans toutefois posséder les installations propres et indispensables à la curation de ce type de matériel. Afin de matérialiser un réseau belge pour la recherche relative aux météorites, de rapatrier la collection unique et précieuse de météorites antarctiques, et d'établir un centre de curation national pour les météorites, BELSPO a décidé de financer un projet introduit par la VUB, combinant curation et recherche.

Objectifs

Les objectifs de ce projet dédié aux météorites antarctiques sont:

- (i) D'établir et organiser la curation des météorites à l'IRSNB au travers de la rénovation de l'espace de stockage pour ces dernières et de la mise en place des installations nécessaires pour les tâches de curation.
- (ii) En collaboration avec le NIPR, d'identifier et de classier les météorites antarctiques, ce qui constitue une partie cruciale du travail de curation. La description détaillée et la classification précise des nouvelles météorites, jusqu'au niveau du sous-groupe, garantira la qualité des recherches menées sur les échantillons. Les météorites identifiées seront enregistrées dans une base de données en ligne.
- (iii) De rendre la collection de météorites belges accessible à des chercheurs au niveau national et international. Des règles claires pour les prêts d'échantillons, les analyses destructives, etc seront établies, ces dernières étant basées sur les règles existant à l'IRSNB, en collaboration avec le NIPR. Un site web développé et abrité par l'IRSNB mettra à disposition ces informations.
- (iv) D'établir un réseau de recherche belge concernant les météorites, basé sur les collaborations existant entre la VUB et l'ULB, et s'étendant aux collègues d'autres institutions. Ce réseau facilitera les discussions et des recherches conjointes, de même que l'organisation de workshops, l'échange d'étudiants, et la participation aux travaux de curation.
- (iv) De mener une recherche de qualité sur les météorites antarctiques récemment collectées.

Conclusions principales et apports en termes de durabilité/pérennisation de la curation

Les principaux résultats du projet sont : (i) la mise en œuvre d'une curation effective pour les météorites antarctiques à l'IRSNB, incluant la création d'un laboratoire équipé des instruments nécessaires et avec une équipe formée à cet effet, (ii) une base de données rendue accessible pour la communauté de recherche internationale, et (iii) l'établissement de procédures de prêt d'échantillons de météorites. Le projet BELAM portera donc ses bénéfices à long terme, et limitera les questions critiques liées à la durabilité/pérennisation de la curation des météorites.

A présent, le système de curation à l'IRSNB est fonctionnel, avec une équipe qualifiée et une série de lignes à suivre en ce qui concerne l'inscription et la manipulation des météorites, ainsi que l'utilisation des installations dédiées (que ce soit dans le conservatoire ou dans le laboratoire). Cette démarche implique des compétences en matière d'identification et de caractérisation pétrologique des météorites. Celles-ci sont réalisées en utilisant les équipements des laboratoires de minéralogie et de géochimie présents dans les différentes institutions partenaires du projet, toujours en synergie avec le travail fait au NIPR. Un effort particulier est consenti pour caractériser les types de météorites les plus intéressants scientifiquement parlant, la VUB et l'ULB étant les principaux partenaires pour cet aspect.

Un répertoire de tous les échantillons peut être consulté en ligne via deux accès qui sont connectés : d'une part, le système de données et de prêt Darwin (Darwin.naturalsciences.be), et d'autre part, le système de base de données mars (mars.naturalsciences.be). Un chercheur de niveau post-doc a eu pour mission la rédaction d'un manuel de contrôle de qualité relatif à la curation. Celui-ci avait pour objectif de décrire la chaîne complète des opérations de curation et des protocoles appliqués, constituant *in fine* un ouvrage de référence pour le curateur et ses collaborateurs, mais qui fournit également la marche à suivre pour des utilisateurs extérieurs souhaitant emprunter des échantillons ou désirant un traitement particuliers de ceux-ci. Ce manuel vise à garantir une continuité des procédures au sein du centre de curation.

La curation efficace et de longue durée au sein de l'IRSNB est également assurée par trois accords signés entre les partenaires : (i) un accord interne sur la curation et la recherche appliquée aux météorites antarctiques, signé par la VUB, l'ULB et l'IRNSB ; (ii) un accord de dépôt des météorites antarctique, signé par les mêmes partenaires, incluant un comité scientifique pour la question des prêts ; et (iii) un MoU entre le NIPR, la VUB, l'ULB et l'IRSNB concernant la coopération scientifique et la manière de partager les météorites antarctiques. Le comité scientifique de prêt est apte à allouer les échantillons à la fois pour la recherche et pour des expositions. La dissémination des résultats et la présentation du nouveau système de curation constitue également une aide à la pérennisation de la curation à l'IRSNB. Dans le cadre du projet BELAM, l'exposition d'une météorite extraordinaire trouvée en Antarctique - couplée à une réunion nationale - a été organisée en 2014. Par ailleurs, une conférence internationale d'envergure a été organisée à l'automne 2016. Elle a réuni des curateurs de météorites provenant du monde entier. Ce colloque a permis de présenter les installations de curation de l'IRSNB, et de diffuser les recherches dédiées aux météorites menées en Belgique.

En termes de recherche, de nombreuses publications dans des journaux à comité de lecture présentent les résultats obtenus. Ceux-ci ont également été exposés dans des conférences internationales, notamment le symposium relatif aux météorites antarctiques organisé annuellement au NIPR.

Finalement, afin de garantir la pérennité de la curation, deux projets BRAIN ont été soumis et financés. Le premier projet, introduit par le consortium IRSNB-ULB-VUB sous l'axe thématique 6 « Gestion des collections », est intitulé '*Antarctic meteorites curation, digitalization and conservation*' (AMUNDSEN ; 15/03/2016-15/09/2019). Ce projet est dédié à la conservation, classification, valorisation et digitalisation des météorites conservées à l'IRSNB avec l'objectif d'améliorer la conservation de cette collection fragile et de développer les protocoles pour une meilleure curation, de fournir les procédures d'échantillonnages les plus appropriées et de stimuler et faciliter l'usage à vocation scientifique de la collection par la communauté de recherche internationale. Le second projet, est intitulé '*Belgian Antarctic Meteorites and Micrometeorites to document solar system formation and evolution*' (BAMMI!; 01/01/2017 – 31/12/2020). Ce nouveau projet BRAIN, rassemblant les mêmes partenaires, a pour vocation d'étendre

l'expertise précédemment acquise et de se concentrer sur des sujets de recherches prometteurs, mais sous-explorés dans les projets précédents, se rapportant aux échantillons extraterrestres récemment récoltés.

Mots clefs : *météorites antarctiques, curation, recherche dédiée aux météorites*

1. Introduction

Meteorites are the leftover building blocks of the Solar System, providing clues on its origin and evolution. They are classified in groups corresponding to different evolutionary phases of the Solar Nebula. Chondrites originated from the break-up of undifferentiated planetary bodies. Achondrites (iron, stony-iron and stones) derive from more evolved planetary bodies that have undergone differentiation comparable to the formation of the core, mantle and crust on Earth, and well as episode(s) of shock metamorphism during planetary collisions.

The value of meteorites to document astronomical, solar system and terrestrial processes does not have to be further demonstrated. They have supplied and continue to provide data on stellar evolution and nucleosynthesis, the chronology of the Solar System, the formation of planets, cosmic rays bombardment, the deep crust of Mars and the Moon, and the different types of asteroids. They are often used to "calibrate" the instruments of the orbiters and landers used in planetary exploration. Moreover, meteorites attract public attention; they are important reference objects in museums and contribute to the promotion of natural sciences.

Meteorites from Antarctica are especially valuable because they are preserved in near pristine state and show no alterations due to temperature changes, contact with soils and chemical interactions. They concentrate in areas with glacier ablation, such as the foothills of the Sør Rondane mountain region, which makes search operations in this area more rewarding.

The National Institute of Polar Research (NIPR, Japan) and BELSPO collaborate on meteorite research under the umbrella of the Statement signed in Tokyo in 2005 between the Japanese Ministry of Education, Culture, Sports, Science and Technology and the Belgian Ministry of Economy, Energy, Foreign Trade and Science Policy.

In 2009, the NIPR and the Vrije Universiteit Brussel (VUB, Belgium) signed an agreement regarding the sharing of the meteorites collected by Japanese and Belgian scientists in Antarctica during the 51st Japanese Antarctic Research Expedition (JARE 51) in 2009-2010. The field work and scientific activities from the Belgian side were framed into the BELSPO supported SAMBA project and also included the Université Libre de Bruxelles (ULB, Belgium). The 2009-2010, 2010-2011 and 2012-2013 field seasons in the Sør Rondane region of Antarctica near the Belgian station Princess

Elisabeth have yielded more than 1200 new meteorites, that are to be shared equally between the two countries. Recognizing the successful collaboration in collecting meteorites in Antarctica during the past years, the NIPR, the VUB and the ULB wanted to expand their collaboration in the coming years, and to include the Royal Belgian Institute of Natural Sciences (RBINS, Belgium), where the Belgian share of the meteorites is deposited for curation purposes.

2. Methodology and results

2.1. Methodology

A first work package, grouping objectives (i) to (iii) above, is to set up a state-of-the-art curation facility for meteorites at RBINS, using the following methodology:

- ✓ Gather experience from well-established collections, in particular at NIPR, which manages a large collection of Antarctic meteorites, by visiting these facilities, and organising workshops in Belgium to benefit from European institutions with an established meteorite curation system.
- ✓ Set up facilities and curation processes according to international standards. This includes the establishment of a repository, loan guidelines, quality control, and a handbook that will present the different curation directives at RBINS.
- ✓ Make the collection publicly available through an easily accessible online database, after identification and characterisation of the samples.

These tasks were carried out using the existing RBINS curation facility for geological-mineralogical samples, in close association with the ULB and VUB partners who are familiar with meteorite loan processes.

A second work package, grouping objectives (iv) and (v) above, is to develop state-of-the-art research on meteorites from the collection, using the analytical facilities in Belgium and the expertise available at universities and research institutions. Suitable partners for the research network will be involved in a national workshop and dedicated research has been performed, including participation in international conferences.

From a practical point of view, all Antarctic meteorites are first shipped and stored in Japan from where the Belgian share has to come, after initial description, eventual splitting into equal parts (for the majority of the meteorite specimens >50 g) and classification done at NIPR. This is a painstaking process that progresses slowly (despite being partly and gradually taken over by the postdoc). As a result, meteorites come to Belgium in batches of about 20 to 100 specimens. Altogether 415 specimens have been transferred, while half of the meteorites <50g are kept in Japan, according to the MoU. The transfer for the previous missions is now finished, and will resume with respect to

future missions. One particular specimen is the largest meteorite recovered by the Samba project, representing the 5th largest ever found on the East Antarctic shield, generously donated intact by NIPR (i.e. not shared in half) on condition that it is used for museum exhibit. A permanent exhibit at the Natural Sciences museum in Brussels is now realised in the hall of 250 years of Natural Sciences.

The partners of the network appear as complementary in this project, with (i) the RBINS managing scientific collections in most fields of natural sciences and making this material available to the scientific community; (ii) the VUB conducting research in the field of impact craters and their geochemical and isotopic signature, especially platinoid metals and light stable isotopes to trace the origin of projectiles. This leads to a better understanding of large-scale planetary processes; and (iii) the ULB having expertise in isotope geochemistry and geochronology, for both radiogenic isotopes and heavy stable isotopes. Privileged research themes include planetary differentiation from meteorite investigation, and the chronology of the early solar system. Representatives from VUB, ULB and RBINS are involved in the Scientific Loan Committee that decides on sample allocation for research and for exhibitions of Antarctic meteorites.

In this network, a post-doc was recruited for this project over a period of 4 years and shared her time between RBINS and VUB-ULB, thus constituting a link between the partners. The postdoc researcher participated in the whole chain of Antarctic meteorite handling and study, from registration and identification of all specimens and their website publication – which are conducted at RBINS – to focused and high level research on selected meteorite types– which is conducted at VUB and ULB.

2.2. Results

2.2.1. Long-term preservation of the Antarctic meteorites at RBINS

Loans: Sample deposit protocol and transfer agreement was completed in March 2013. A Scientific Loan Committee (SLC) was set up to decide on allocation of samples for research and exhibitions. It is composed of Philippe Claeys (VUB), Vinciane Debaille (ULB) and Marleen De Ceukelaire (RBINS). Its role and working method are described in the deposit agreement. Several meetings of the SLC were planned in the course of the project.

From 2012 to 2019, 21 loans (102 samples) were registered.

Repository: Besides, the storage room was reorganized. In June 2015, the Antarctic meteorites have been classified by type in the repository. Temperature and humidity sensors have been installed to make sure the conservation conditions in the room are optimal. In order to improve the meteorite conservation, silicagel bags were put in the

drawers containing the meteorites. In addition, a dehumidifier is now present in the room to better control the humidity of the repository.

Laboratory: The Meteorite laboratory, exclusively dedicated to meteorite preparation work (to avoid contamination), was moved to a room (of about 10m²) on the 7th floor of the De Vestel building. The main aim of this moving, which took place during the first semester of 2016, was to decrease the distance from the repository to the lab, and thus limit contamination of the samples during transport. The lab has been equipped with built-in furniture, and the necessary instruments. The main activity in the lab is the preparation of polished chips and general samples from meteorites response to specific requests. The manager of the lab and his assistant followed a special training at NIPR in December 2016 to improve the handling and processing of the samples at RBINS.

Receiving and handling the samples: The Antarctic meteorites were obtained from the joint Belgian – Japanese search campaigns (2009-2010, 2010-2011 and 2012-2013) to the Balchenfjella and Nansen ice field areas, to the east and south of the Sør Rondane Mountains of East Antarctica. All collected meteorites are all shipped to NIPR, Japan where they are kept under frozen conditions. Preservation of their quality requires controlled defreezing and conservation under climatized conditions. The next steps are measuring the specimens, cutting the >50 g specimens and preliminary classification so that each specimen has a unique code and can be identified based on its external physical properties. This is a lengthy process; the transfer of the Belgian share is slow and the BELAM work programme had to be accommodated to the pace of initial classification and transport in batches (either sent by special courier services or as personal luggage).

The steps following arrival of the specimens are related to their registration and usage: photographing and weighing the meteorites, completing the Darwin database; making polished thin sections or other preparations. These are carried out since the arrival of the new postdoc researcher and will continue till the end of the project, making full use of the newly installed meteorite lab.

415 new meteorites arrived according to their IG number (= definitive registration in the RBINS collection : IG32283:31; IG32340:24; IG32540:50; IG32628:51; IG32794:96; IG33222:42; IG33409:121) during the years 2012-2017. Definitive registration implies measurement of weight, photographs, individual file with at least provisional classification and introduction in Darwin database

2.2.2. Accessibility on-line (identification, characterisation, classification, databasing)

Official identifications

The task of classifying new meteorites runs through the whole project. It involves systematic SEM/EDS and optical microscopy work. Most of the Antarctic meteorites brought to Belgium are being classified at NIPR.

Statistical information on the entire meteorite collection available at RBINS:

Total number of specimens in years 2012-2018: 415

Total weight: 20.278 Kg (A12389 of ca. 18 kg in permanent display not included)

Ordinary chondrites: 145 (77 H, 54 L, 14 LL)

Iron meteorites: 2

Carbonaceous:7

Others: 7 (2 diogenite, 2 ureilite, 1 mesosiderite, 1 winonite, 1 unique sample)

Unclassified: 254

Database

Web access to the collection of Antarctic meteorites is possible in 2 ways.

All Antarctic meteorites have been registered in the Darwin database by postdoc L. Pittarello, on schedule according to the BELAM programme and calendar. [http://darwin.naturalsciences.be /search/view/id/759438](http://darwin.naturalsciences.be/search/view/id/759438) as an example]. Login is required for access to detailed information of the samples. Both samples and conditions for loan can be accessed.

A more rapid online access to the Antarctic meteorite collection is via Mars website, collection management system allowing more straightforward access, as a result of data transfer by M. DeCeukelaire: <http://mars.naturalsciences.be/geology/Meteorites/antarctic>.

To access select the module geology on the start page, clicking further to meteorites and Antarctica. Via listings, particular meteorites can be selected, via an automated transfer to the Darwin system.

2.2.3. Quality control and knowledge transfer

Redaction of a 'Handbook for Antarctic meteorite curation and allocation: The redaction of the handbook of quality control of curation is being updated continuously for best practices. Built on the concrete experience gained during the BELAM project, the purpose of this handbook is to leave a detailed description of all the curation tasks, and to assist RBINS in the daily management of the collection. It will deal with the reception of the meteorites, precautions in manipulating and long-term storage, weighing, photographing, databasing. It also describes the activities of the SLC, the loan regulations for external researchers (both general RBINS regulations and specific rules applicable to meteorites), the sharing of information with NIPR, and all laboratory and classification procedures etc. Part of it will be public, but most of it is intended for internal use. In addition, a record book on meteorite use has been set up in the lab, allowing several researchers and technicians to cooperate efficiently.

Establishing the RBINS as a curation center for Antarctic meteorites: A first step has been set by the recognition of RBINS as a meteorite type specimen repository (see 8.

References). Further, a national BELAM project symposium was organised on 14.11.2015 under the theme 'From Dinosaurs to Meteorites'. This symposium started from the connection between both themes by the end-Cretaceous Chixculub impact, dwelled on comparable research methodologies and on the importance for planetary sciences and finally brought the attention of the press and the public to BELSPO sponsored Antarctic research and the importance of meteorites for a natural sciences museum. Finally, an international workshop "Curation of Antarctic Meteorites: Concluding workshop of the BELAM (Belgian Antarctic Meteorites) project" was organized in October 2016. This workshop tremendously helped to establish the RBINS as a curation center for Antarctic meteorites.

3. Policy support

The BELAM project mostly aims at a long-term management of a meteorite collection and setting up the process of curation. This will bring long-lasting benefits to BELSPO, considering that the critical issue of sustainability is taken into account. In the course of the project, the partners of the project did their best to « secure » this curation until 2021 thanks to the ongoing project (see below). This was also the main concern of the follow-up committee. However, efforts should be paid by the authorities to keep it – and even develop it – for the following years.

3.1. Long-term continuation of the curation : New projects funded

The most direct way for a federal scientific institute to get high-level postdoc worker is through the BRAIN programme (Belgian Research Action through Interdisciplinary Networks). Taking into account the recommendations of the follow-up committee, two BRAIN projects were formulated and approved for funding. In addition, the RBINS-VUB partners are trying to hire a mid/long term researcher who would act as curator of the meteorite collection at the RBINS through the FED-tWIN program.

The first project, introduced under Thematic axis 6: Management of collections by RBINS-ULB-VUB, is entitled 'Antarctic meteorites curation, digitalization and conservation' (**AMUNDSEN** ; 15/03/2016-15/09/2019).

The proposal is dedicated to the conservation, classification, valorisation and digitalization of meteorites at the RBINS with the goal to improve the maintenance of this fragile collection, develop best practice meteorite curation protocols, provide the most appropriate sampling procedure and stimulate and facilitate the scientific usage of the collection by the international research community.

Three multidisciplinary approaches are proposed.

(1) The first part of this project relates to the most troubling problems of meteorite conservation: their rapid alteration, which even in the case of this freshly collected collection, is already observed within some of the specimens. To better constrain the rate of this weathering process and optimize the conservation conditions, a set of alteration/oxidation experiments are planned, with the aim to propose possible remediation processes. First, the current conservation state of the collection will be carefully assessed, and the most "at risk" specimens identified. The approach selected is to experimentally reproduce in accelerate the alteration processes by taking ambient conditions (humidity and temperature) to extreme levels. Experiments must be conducted over a certain amount of time (3 months) to obtain significant results in terms of best temperature and humidity conditions. The changes of regulations at the RBINS following the implementation of the ISO9001 norm entail the obligation to provide optimal conditions of preservation for the collections.

(2) We aim to provide on-line broaden access to rare and unique meteorite by digitizing thin sections of the most outstanding samples (achondrites and specific types of ordinary chondrites), providing directly online a navigable images obtained with the optical microscope and coupled to a detailed chemical map of the area at high-resolution, as produced by micro-X-ray Fluorescence. Such digitized thin sections will contribute to the study of RBINS meteorites, avoiding excessive handling (sawing, etc), and will help requesters in their sample selection.

(3) As a curation center recognized by the Meteoritical Society, the RBINS is committed to provide the best curation procedures possible. We plan to improve and advance the existing meteorite classification procedure already in use, e.g. by using working with thick sections instead of thin sections, when possible and possibly testing the use of Raman and micro-X-Ray Fluorescence (μ -XRF) procedures. Therefore, efforts will be devoted to defining and calibrating these new techniques using selected specimens recovered in Antarctica, in comparison with the classification work ongoing at the National Institute of Polar Research (NIPR, our Japanese partner). In addition, the procedure implemented at the RBINS during the BELAM project can still be improved and the AMUNDSEN project will seek, by meeting other curators, by visiting other curation centers by attending curation meeting in order to improve service towards the scientific community.

The second project, introduced under Thematic axis 2, is entitled 'Belgian Antarctic Meteorites and Micrometeorites to document solar system formation and evolution' (**BAMM!**; 01/01/2017 – 31/12/2020).

This novel BRAINS project, gathering the same partners, builds on and expands the assembled expertise, and centers on a number of highly promising, but previously unexplored research opportunities provided by this valuable set of newly recovered extraterrestrial samples.

Meteorites constitute the most primitive objects in the solar system and represent the building blocks of the terrestrial planets. Their petrographic, chemical and isotopic study sheds light on the evolution of planetary materials in the early solar system and documents planetary differentiation processes. However, as (micro)meteorites represent highly fragile material, optimal preservation conditions are needed to provide a reliable understanding of their formational history. Antarctic (micro)meteorites constitute an enormous volume of extraterrestrial material that was preserved under excellent conditions thanks to a dry and cold climate. Using the meteorites and micrometeorites recently collected in the Sør Rondane Mountains of Antarctica, the following two complementary approaches further constrain our understanding of the formation and evolution of solar system materials:

1) A detailed study of micrometeorites and their igneous textures to better document their parent body precursors (possibly not sampled by larger meteorites), quantify the continuum between unmelted and fully molten objects, and further constrain the effects of rapid melting, melt extraction and silicate-metal segregation on the petrological, chemical and isotopic characteristics of the precursor materials. One of the main focuses of this project is to fully characterize a peculiar group of micrometeorites that based on oxygen isotopes does not appear to be represented among macroscopic meteorites. In combination with more general characterization methods, in situ isotope analysis by LA-MC-ICP-MS (e.g., $\epsilon^{50}\text{Ti}$) will identify and characterize this potentially new group of solar system parent bodies.

2) A precise characterization of the isotope anomalies existing in bulk meteorite samples, and their counterparts in the constituent mineralogical phases measured by in situ mass spectrometry to better understand the presence and destruction of nucleosynthetic anomaly carrier phases during nebular and planetary processes.

Despite working on samples from different size fractions and aiming for essentially different goals, the two work packages converge by implementing state-of-the-art in situ isotopic analysis. The different partners will contribute their individual specialties, discuss and interpret the results together, and combine them into an integrated model. As coordinator, the Royal Belgian Institute of Natural sciences (RBINS) provides mineralogical expertise, while the partners from the ULB and the VUB contribute their expertise in isotope geochemistry. Efforts will also be made to disseminate the scientific results through conference presentations and international peer-reviewed journals. Considering the broad interest for extraterrestrial samples, our results will also be distributed to the general public and centers of education, using the broad outreach channels of the RBINS in particular.

In addition, the BMM! project further expands the Belgian Antarctic meteorite collection and encourages a reliable, long-term protective curation program of Antarctic meteorites at the RBINS, boosting at the same its position as a key Antarctic (micro)meteorite curation center in Europe. The Belgian meteorite classification expertise will be expanded, and implemented not only to Antarctic meteorites, but also to non-Antarctic samples. Last but not least, this project supports the preservation and,

through its research output, the valorization of the Belgium museum collections and national heritage.

This research offers a unique opportunity to implement a multidisciplinary approach (combined petrology, mineralogy, and geochemistry) and to assemble an international collaboration to study meteorites from the field to the in situ isotopic characterization of minute mineral phases using state-of-the-art analytical techniques, with the ultimate aim of improving our understanding of the early history of the solar system. Finally, the results issued from this project will be integrated within larger programs, such as those described in the Horizon 2020 European Union work program (COMPET-8-2014 program).

3.2. Long-term continuation of the curation : Nomination of a curator

Vinciane Debaille was appointed on 15.10.2014 by RBINS as scientific collaborator – scientific curator to represent RBINS at international meetings of curators.

4. Dissemination and valorization

Besides the major progress in terms of curation and conservation that are extensively detailed in the “2.2 Results” section of this report, it is worth mentioning that a lot of work was done regarding the diffusion and the valorization of the results. Apart from the scientific outcome, which can be evaluated thanks to the peer-reviewed papers and conference abstracts listed in the “5. Publication” section of this report, one can mention (i) the exhibit of an outstanding meteorite found in Antarctica coupled to a national meeting in 2014, and (ii) the organization of an international workshop at the RBINS in 2016.

4.1. National meeting and exhibit 2014

The national BELAM project meeting on 14.11.2014 consisted of a symposium and inauguration of a meteorite display. The symposium on Antarctic meteorites and their curation in Belgium “From dinosaurs to meteorites” attracted 54 registered participants from most universities and the federal research institutes from the poles nature and space for 9 presentations including a keynote lecture by D. Herwartz (Univ. Köln). The inauguration of a permanent Antarctic meteorite display attracted the press. This 18 kg meteorite is a proof of the successful collaboration between Japanese and Belgian researchers. It was found by the team of 5 Belgian scientists from the VUB and ULB, and 3 Japanese researchers from the NIPR during the 2012-2013 expedition to the Nansen Ice Field in Antarctica. This field mission, financed by BELSPO and NIPR was a real success. The team discovered 425 meteorites that are currently being inventoried. The meteorite that attracted most attention was the one of 18 kilogram. It concerns the largest specimen discovered in 25 years in East Antarctica. It is also the fifth heaviest

ever discovered in this part of Antarctica of the 16,000 specimens already found. [<http://we.vub.ac.be/dntk/nl/node/220>]

This specimen is therefore without doubt exceptional because of its size. The meteorite belongs to the "chondrite" type that is most common on earth. Therefore this exceptional specimen was not cut and reserved for exhibits. Thanks to the benevolent cooperation of NIPR this specimen was shipped to Belgium and is allowed to stay here on condition that it is exhibited. A temporary exhibit was made upon arrival.

4.2. International workshop

On October 3-4 2016 was organized the international workshop "Curation of Antarctic Meteorites: Concluding workshop of the BELAM (Belgian Antarctic Meteorites) project" at the Royal Belgian Institute of Natural Sciences. The rationale of the workshop was the following: "In the frame of the BELAM project, funded by the Belgian Science Policy (Belspo), a new curation facility dedicated to Antarctic meteorite was installed at the Royal Belgian Institute of Natural Sciences in Brussels. As the project is now finishing, we would like to present those facilities to the scientific community, as well as the scientific results obtained so far on the Belgian Antarctic collection. In addition, we would like to take the opportunity of this meeting for gathering worldwide experts in curation, in order to share experience and best practices." This workshop consisted of a symposium with 10 talks, a visit of the meteorite collection repository and meteorite laboratory and an afternoon of roundtable discussions. Eight international experts were invited: Cari Corrigan (USA-Smithsonian Institute); Luigi Folco (Italy-University of Pisa); Jérôme Gattacceca (France-CEREGE); Christian Koeberl (Austria-Natural History Museum Wien); Kevin Righter (USA-NASA-JSC); Caroline Smith (UK-Natural History Museum of London); Akira Yamaguchi (Japan-National Institute of Polar Research); Brigitte Zanda (France-Musée d'Histoires Naturelles de Paris). These experts gave presentations about conservation/curation in their research institutes. They also provided advices during roundtable discussions. A summary of the BELAM project was given through three introductory talks: Conservation and curation at the RBINS (Sophie Decrée, Marleen Deceukelaire, Vinciane Debaille); Report of the Belgian Antarctic missions (Steven Goderis); Belgian scientific research dedicated to Antarctic meteorites (Vinciane Debaille). Thirty-seven registered participants attended this workshop.

4.3. Research activities and scientific outcome

Research activities related to curation aspects concern service to the public and analytical methods for classification:

- Identification and classification of meteorites using magnetic susceptibility.
- Alteration experiments, to better constrain the rate of this weathering process and optimize the conservation conditions. Five samples of ordinary chondrites have been selected regarding these experiments.
- In-situ measurements of O isotopic composition on olivine in (micro-)meteorites

- In addition, many peer-reviewed papers have been published by the partners VUB-ULB (see section 5 here below)

5. Publication

5.1. Peer review (all publications are available on line)

2013

- Martin, C., Debaille, V., Lanari, P., Goderis, S., Vandendael, I., Vanhaecke, F., Vidal, O., and Claeys, P., 2013. REE and Hf distribution among mineral phases in the CV-CK clan: A way to explain present-day Hf isotopic variations in chondrites. *Geochimica et Cosmochimica Acta* 120 (2013) 496-513.

2015

- Belza, J., Goderis, S., Smit, J., Vanhaecke, F., Baert, K., Terryn, H., Claeys, Ph., High spatial resolution geochemistry and textural characteristics of 'microtektite' glass spherules in proximal Cretaceous-Paleogene sections: insights into glass alteration patterns and precursor melt lithologies, *Geochimica et Cosmochimica Acta*, 152, 1-38, 2015, doi:10.1016/j.gca.2014.12.013
- Chernonozhkin S. M., Goderis S., Lobo L., Claeys Ph., and Vanhaecke F. 2015. Development of an isolation procedure and MC-ICP-MS measurement protocol for the study of stable isotope ratio variations of nickel. *Journal of Analytical Atomic Spectrometry* 30: 1518-1530.
- Goderis S., Brandon A. D., Mayer B., and Humayun M. 2015. s-Process Os isotope enrichment in ureilites by planetary processing. *Earth and Planetary Science Letters* 431: 110-118.
- Imae N., Debaille V., Akada Y., Debouge W., Goderis S., Hublet J., Mikouchi T., Van Roosbroek N., Yamaguchi A., Zekollari H., Claeys Ph., Kojima H., and IPF members. 2015. Report of the JARE-54 and BELARE 2012-2013 joint expedition to collect meteorites on the Nansen Ice field Antarctica. *Antarctic Record* 59: 38-71.
- McKibbin, S., Ireland, T., Amelin, Y. & Holden, P. 2015. Mn-Cr dating of Fe- and Ca-rich olivine from 'quenched' and 'plutonic' angrite meteorites using Secondary Ion Mass Spectrometry. *Geochimica et Cosmochimica Acta*. 157, p. 13-27 15 p.

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- Pittarello L., Roszjar J., Mader D., Debaille V., Claeys Ph., and Koeberl C. 2015. Cathodoluminescence as a tool to discriminate impact melt, shocked and unshocked volcanics: A case study of samples from the El'gygytgyn impact structure. *Meteoritics & Planetary Science* 50, 1954-1969.
- Pittarello L., Baert K., Debaille V., and Claeys Ph. 2015. Screening and classification of ordinary chondrites by Raman spectroscopy. *Meteoritics & Planetary Science* 50, 1718-1732.
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- Van Roosbroek N., Debaille V., Pittarello L., Goderis S., Humayun M., Hecht L., Jourdan F., Spicuzza M.J., Vanhaecke F., and Claeys Ph. 2015. The formation of IIE iron meteorites investigated by the chondrule-bearing Mont Dieu meteorite. *Meteoritics & Planetary Science* 50, 1173-1196.
- Van Roosbroek N., Pittarello L., Greshake A., Debaille V., and Claeys Ph. 2015. First finding of impact melt in the IIE Netschaëvo meteorite. *Meteoritics & Planetary Science* 51, 372-389.
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2016

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Wilquet V., and the Planet TOPERS group. 2016. PLANET TOPERS: Planets, tracing the transfer, origin, preservation, and evolutions of their reservoirs. *Origins of Life and Evolution of Biospheres*, 46, 4, 369-384, 2016, doi: 10.1007/s11084-016-9488-z.

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