

BRGM. the French geological survey, is France's leading public institution for Earth Science applications, managing surface and subsurface resources with a view to sustainable development. Through partnerships with a range of public and private stakeholders, it has developed a focus on scientific research, providing information to support public policy development and international cooperation.



The "Weeping Rock" spring at the foot of Grainval cliff in Saint-Léonard, Normandy. The cliffs in the background are formed of Lower Senonian flint-bearing chalk. Rainwater absorbs carbon dioxide as it flows into the soil, enabling it to dissolve the chalk. When the water emerges into the open again, it heats up and releases CO₂, creating calcareous moss tufa, microscopic fungi and cyanobacteria. These processes of dissolution and precipitation are thus caused by living organisms. © Betty/Imaces

French Geological Survey 2021 Annual Report

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ike all businesses, BRGM has learned to live with the virus. We were able to regularly stay one step ahead of government health measures and to further upgrade the IT resources available to employees. Naturally, we need to remain vigilant.

Internally, we continued to fine-tune our organisation, setting up a Digital Geosciences division, transferring functional IT to the General Secretariat, and adjusting the governance of the Financial division. We had the dual

satisfaction of seeing our 2021 business forecasts confirmed while also generating significant profits. With these profits, and the proceeds from the sale of shares, we have been able to give the go-ahead for rebuilding BRGM's laboratories, which date back to the early 1960s.

Our clients in both the public and private sectors have also found a balance compatible with the pandemic. As a result, orders recovered significantly, making 2021 the best year yet in our current Objectives and Performance Contract (COP). The international market is still feeling an impact, but to a lesser extent than last year.

On the scientific front, BRGM seized the opportunity to take part in calls for tenders to participate in exploratory research programmes (PEPRs) commissioned by the ANR, with the purpose of significantly strengthening relations with the academic world. Following a highly selective process, BRGM has already been selected as co-leader of the "One Water" PEPR, with CNRS-INSU and INRAE. Decisions are pending for two other PEPRs: "Subsurface as a common asset" concerning the uses of subsurface and the associated conflicts, and "IRIMA", a programme on natural and industrial risks. BRGM was involved in securing France's supplies of strategic metals by actively contributing to a report on this subject, submitted to the government at the end of the year.

This report has already paved the way for positive policy decisions, which will hopefully be implemented in 2022. The time is ripe for this, with the fresh interest now being taken in issues relating to European reindustrialisation and national sovereignty.

For BRGM, 2022 is the year in which it will begin negotiations on its goals and performance contract (COP) for the period 2023-2027. It has started to make active preparations by taking a determined stance in its approach to the future. ■

Junon

Michèle Rousseau Chair and Managing Director

"In 2021, BRGM defied Covid-19, refined its organisation, improved its financial health and strengthened its scientific engagement with partners and clients."



Karst waterfall in the Kakuetta Gorge, Pyrénées-Atlantiques. © Philippe Crochet

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2021 highlights

15 January 2021

BRGM's new website wins a prize in the Top Com Corporate Business awards!

With its fresh content and graphics and new user paths, BRGM's new website claimed a prize in the Top Com Corporate Business awards. The site has been completely redesigned to better satisfy the needs of its audience.

The BRGM website is aimed at a broad public including: public-sector partners and local authorities, businesses, researchers, students, teachers and publis, journalists.

associations and members of the public. The website includes over 1,000 pages in French and English on a wide range of subjects: from scientific challenges to services, and from data to projects and references. The website also features a wide range of popularised topics relating to Earth sciences, as well as all our news.





26 March 2021

A new event on scientific advances

BRGM looks back at the major scientific advances made by the French geological survey. The programme includes video presentations of eight topics addressed as part of our six scientific challenges: geology and knowledge of the subsurface, groundwater management, risks and spatial planning, mineral resources and the circular economy, the energy transition, data and digital infrastructures.

21 June 2021

Recovery and exploitation of excavated earth: BRGM signs an agreement with Materrup

On 21 June 2021, BRGM signed a partnership agreement with Materrup, a company specialising in innovative construction materials. The aim is to create a value chain for excavated earth.

12 July 2021

BRGM acquires the European HRS4R label

BRGM was awarded the European HRS4R "Human Resource Excellence in Research" label, which seeks to ensure that best practices are applied to the recruitment and working conditions of researchers. On 21 June 2021, BRGM became the first French public industrial and commercial establishment (EPIC) to receive the HRS4R label. This label is an opportunity to pursue and consolidate a proactive policy that supports its scientific staff. More broadly, the measures implemented will benefit all BRGM staff by contributing to the improvement of working conditions in general.

22 July 2021 Visit of Guillaume Boudy, Secretary General for Investment

As part of a steering committee meeting for the 'Investments for the Future' Programme (PIA) in the Centre-Val de Loire region, held in Orléans, BRGM received an official visit from Guillaume Boudy, Secretary General for Investment (SGPI). The visit was organised around a presentation of BRGM, its strategy and examples of projects carried out under the 'Investments for the Future' programmes (PIA) 1, 2 and 3. The participants then went on to visit the Plat'Inn and PRIME platforms.



31 August 2021

BRGM and KERAN sign a scientific and industrial partnership agreement

BRGM and the KERAN group have signed a three-year framework agreement in order to strengthen their cooperation well into the future. BRGM, the French geological survey, and KERAN, a specialist in spatial planning and the environment, have identified four areas for potential cooperation: soil, groundwater, natural hazards, particularly in coastal areas, and post-mining.

17 September 2021

Frédérique Vidal, the Minister of Research, visits BRGM in Orléans

BRGM and its subsidiary IRIS Instruments welcomed Frédérique Vidal, Minister of Research, Higher Education and Innovation, to Orléans. This visit provided an opportunity to present the central role played by BRGM for the Priority Research and Equipment Programmes (PEPR) submitted as part of the recovery plan and to discuss with the Minister the solutions developed by BRGM for exploiting subsurface potential for the ecological transition, the energy transition and climate change. The visit continued at the premises of IRIS Instruments, where the the muon tomography imaging telescope developed with CEA/IRFU with the aid provided by the recovery plan, was presented. In an interview, the Minister stated that "BRGM and IRIS Instruments are excellent examples of dynamic French research".



23 September 2021

Investments for the future: OneWater, an exploratory research and equipment programme (PEPR) co-led by BRGM

Among the 4 priority exploratory research and equipment programmes selected by the international jury, the OneWater programme, run jointly by BRGM with CNRS and INRAE, was selected by the French government, following an initial request for aid of €53M. Led jointly by CNRS, BRGM and INRAE, the "OneWater - Water as a Common Good" programme has several partners: Ifremer IRD, Météo-France, University of Bordeaux, University of Lyon 1, University of Montpellier (I-Site MUSE), University of Grenoble-Alpes, University of Rennes 1, University of Strasbourg, University of Toulouse Midi-Pyrénées.





9 & 10 October 2021

Science Festival 2021 at BRGM in Orléans sees record attendance

For the 30th anniversary of the Fête de la Science, BRGM welcomed the general public to its scientific and technical centre in Orléans. More than 7,000 visitors came to the event. This year's theme was "the thrill of discovery". The activities and equipment of the French geological survey and of some thirty other organisations, laboratories and scientific associations in the Loiret region, were presented at the Village des Sciences during visits and science events. The Vélotour, a French cycling event, also passed through the Village on a specially-arranged route. In addition, BRGM researchers participated in several live broadcasts of Science programmes.



12 - 15 October 2021

Pollutec 2021: BRGM at the heart of environmental issues

As the largest geological survey in Europe, BRGM participated in 15 lectures and panel discussions at the Pollutec trade show. Nearly 40 researchers shared their expertise on environmental issues concerning the subsurface (spatial planning, the role of the subsurface in energy, the sea and coastlines, groundwater management, agriculture and the global climate).

20 - 22 October 2021

French Mineral Industries Society (SIM) Congress and Exhibition

The SIM Congress showcases the products and expertise of equipment manufacturers and service providers in the mineral industry sector. BRGM presented its experience in the fields of mineral resources and the circular economy.

1- 5 November 2021

27th Earth Sciences Meeting (RST)

BRGM attended the 27th edition of the RST in Lyon. This national congress encompasses all geoscience disciplines. Held every two years, the RST Earth Science meeting brings together players from industry, education and research. BRGM took part in several sessions. The latest BRGM publications were presented, in particular the new educational maps of Lyon and Paris and the latest guides in the Geological Curiosities collection.



20 December 2021

BRGM Formation: a trainee-satisfaction rate of 97%

BRGM Formation, with Qualiopi certification, provides a range of "standard" and "bespoke" training courses to develop scientific and technical competencies to meet the needs of a variety of organisations, including companies, design offices, government departments and regional and local communities.

INNOVATION

Innovation at BRGM: a new approach geared to practical applications

BRGM now clearly and deliberately organizes its programmes and the work of its researchers and engineers so that projects meet the real needs of economic players directly. In 2021 it set up a team to determine the application potential of research programmes.

Dominique Morin Head of Innovation

Applied research in the geosciences is one of BRGM's primary missions. Widespread awareness and a concerted effort for R&D are needed both for the institution as a whole and on an individual level for researchers and engineers so that everyone at BRGM is committed to innovation as an imperatively strategic objective. It is important to take this dimension into account from the outset of research work and to convince those who finance us that our research results are put to good use.

Example of a map showing the probability of gold deposits in Brittany, obtained with the DROP tool, which was awarded the BRGM innovation prize.



BRGM innovation award

This year it was awarded to the DROP project, an original method for optimising map construction by means of artificial intelligence, which produces highly operational maps for identifying mineral resource deposits.

Artificial Intelligence improves the analysis of surface and structural data, and enables better location and characterisation of substances. This will make it easier and cheaper to identify deposits, but also the sources of pollution and the perimeter of aquifers.

Innovative projects financed by the European Union

BRGM is a member of EIT Raw Materials, a European consortium supporting innovation to secure supplies of raw materials and their rational use. On the agenda are: the circular economy, field analysis of ground and subsurface constituents (SOLSA), citizen participation and improved knowledge transfer (Citizen Coop).

Development of data access platforms

Other projects include the development of data access platforms concerning risk (Vigirisks) and water; and projects in geophysics, on swelling clays or the injection of CO_2 into the subsurface, and the development of new energy recovery methods (POWERROAD).



This is particularly true for the exploitation of the subsurface, in a context of increasing scarcity of raw material resources, in particular rare metals. We need to convince economic players that our solutions are feasible and that we can implement them.

We have to think in terms of technically and economically viable solutions.

In practical terms, this means supporting research programmes to assess their potential applications. The principle has already been adopted and incorporated in methods, and increasingly so in 2021. BRGM teams must think in terms of technically and economically viable soluElectronic and electrical waste – a "goldmine" for strategic mineral resources. © BRGM

> "The need to challenge researchers in their ability to use methods to validate applications based on their work."

tions. An effort must be made to change our methodologies, with the teams having to adopt them to validate the application of their work.

This is mainly reflected in the increased practice of assessing applications and results at all stages of projects.

Researchers trained in assessment

BRGM's is investing firmly in these new assessment practices. This year, forty researchers and engineers were trained in the methodology, which enabled them to acquire a very rewarding skill-set.

Specifically, increased skills in innovation practices is achieved through courses designed to raise awareness of the innovation approach, with the Research Innovation Science & Technology (RIST) group, which is affiliated to the University of Paris Dauphine-PSL. But it also involves the acquisition of brainstorming methods, with the innovation consultancy Edwige, and the development of creative methodologies in a spirit of open innovation.

To sum up, BRGM is conducting an in-depth campaign of acculturation to innovation, in line with the challenges linked to the environment, climate change and the rational exploitation of subsurface resources. This enables us to be legitimately involved in innovative projects supported by Europe, such as those of the EIT Raw Materials, which is calling on BRGM to drive innovation in the responsible use of primary and secondary mineral resources.

As an illustration of this approach (see box), it is worth mentioning the BRGM innovation award, numerous projects in geophysics, the circular economy and risk management, among others. ■

SCIENCE WITH AND FOR SOCIETY

BRGM outreach to society

As an extension of its research and expertise missions, BRGM is increasingly developing science that is open to society. Science allows us to consider choices according to the knowledge available and the research in progress. In clarifying issues it enables a healthy democratic debate.

Philippe Freyssinet

Director, Research, Scientific Programme and Communication

Media coverage and communication of science has become a major challenge for an institution like BRGM, which has taken a stand on societal issues such as the ecological transition and climate change.

BRGM's science must be as open as possible and accessible to different types of public. The scientific mediation policy pursues a communication objective aimed both at the general public and also at school children. All these initiatives and many others allow us to reach more than 800,000 people each year.

Each year, many popular articles are written by the institution's scientists on topical issues and posted on theconversation.com for a wider audience. The journal Geosciences is published twice a year and provides an informed but non-specialist audience with insight into the issues surrounding the ground and subsurface.

Our new website also offers a dedicated and constantly evolving feature entitled: "Understanding Earth Sciences" to answer questions from the general public, with clear explanations and the various resources available (videos, podcasts, animations, computer graphics, etc.). For school audiences, we are developing the BRGM space on the national Éduthèque website, offering new content for teachers and students. We also regularly welcome school children and support the annual Geoscience Olympics. This process of opening up science to society has two main objectives:

• to give young people a taste for and interest in science and to encourage scientific callings;

• to offer adults the opportunity to decipher the major issues in the geosciences and thus establish a relationship of trust.

Our ambition is to open new spaces for exchange and to develop interactions. We believe that scientific mediation should range from the sharing of a common scientific culture to the support of researchers in public decision making through the different levels of participatory science or open science.

Explanation of the phenomenon of underground cavities during the Fête de la Science with Fred Courant from L'Esprit Sorcier. © BRGM - P. Vassal



3 questions for



"Promoting science outreach and developing the curiosity of the public is a public service"

"The general public needs to be made aware of natural and technological risks," explains Courant, the former editor and presenter of the TV programme C'est pas sorcier. "Scientific outreach is one of the missions that BRGM must seek to reinforce."

What was your main conclusion following the recent Report for the Ministry of Ecological Transition?

FRED COURANT – I coordinated the report on risk culture with a number of experts, at the request of Barbara Pompili, Minister for Ecological Transition. Our work highlighted the inadequate risk culture in France. Climate change will only intensify natural, technological and industrial disasters and risks. So the challenge is to raise awareness among the general public.

Fred Courant

Science journalist, founder of *L'Esprit Sorcier*, coordinator of the Report on Risk Culture for the Ministry of Ecological Transition

What role can an organisation like BRGM play in raising awareness?

f.C. – Science is everywhere. Scientific issues are at the heart of our lives, for example, in health, climate change and the environment, 5G, and so on. It's vital for the public to be well informed, primarily so that they can make decisions within the framework of our democracy.

So for any research organisation, it's important to communicate and to inform people about expertise, what areas are covered, and so on. You could say that promoting science outreach and developing the curiosity of the public is a public service.

BRGM is involved in all sorts of areas that have a direct impact on our lives: the coastline, water, soil disturbance and climate change.

This organisation, like many others, is already involved in science outreach. In 2016, for example, BRGM participated in the Fête de la Science national science festival and, with L'Esprit Sorcier, we have been putting together events and creating videos.

We need to go further, and I believe that science outreach should be at the heart of BRGM's activities. For example, the report recommends making Géorisques the reference website for risks in France, opening it up to all audiences (see Géorisques, the reference platform promoting a culture of resilience among all audiences, page 60). By making it more user-friendly, increasing vulgarisation or adding 3D, we could make it natural for people to get involved in "where we live"!

— More broadly, isn't there an issue concerning information quality?

f.C. — With digital technology and the explosion of social media, the transfer of information has become a real challenge. There are two ways to prevent fake news. The first is to re-establish the media in their role as fact checkers. The second is to enable those who have certified expertise to disseminate it directly. This is part of science outreach too. ■



GEOLOGY AND KNOWLEDGE OF THE SUBSURFACE

Developing geological knowledge to optimise the various uses of the subsurface

The mountain of Gros Morne de Gueule Rouge towering over the road to Cilaos (Reunion Island, 2012). © BRGM - S. Bés de Berc



BRGM produces and disseminates reference information relating to the subsurface on a variety of scales. Drawing upon the latest scientific and technological advances in order to investigate, understand and represent the subsurface, it is constantly seeking to acquire new knowledge and to improve its understanding of geological phenomena. The information acquired in this way is becoming increasingly complete, accurate, reliable and relevant. It can be exploited directly to develop more sustainable uses of the ground and subsurface. At the regional level, particularly in Africa, **BRGM** is drawing upon its expertise in geological mapping to provide strategic support for governments in their policies on mineral and water resource management in particular.









1 — Geodiversity-biodiversity links: translation of geological formations into lithology and then into codes compatible with ecological data, for the prediction of biotopes. @BR6M

2 — Aérovergne helicopterborne geophysics campaign in Auvergne. This project involves a survey drawing upon three geophysical methods to try to unravel the mysteries of the subsurface of this region.

3 — Volcanic edifice on the seabed of the abyssal plain of the western Somali basin (north of Mayotte, Mozambique Channel). Extract from the SISMAORE bathymetric map. © RRGM

New: educational maps of the subsurface

In order to make the subsurface more easily understandable for the general public, BRGM has developed a new mapping concept with an innovative key format explaining the type of rock and the chronological sequence of the main events that have taken place at the site.

The first maps cover the cities of Paris and Lyon as well as Sancerre/Pouilly-sur-Loire.

In this area, the map shows the subtle relationships between the land, the vineyards and the subsoil.

CarHab mainland France: mapping to support biodiversity objectives

Photo 1/ The CarHab project was set up by the Ministry for Ecological Transition to develop a national map of natural and semi-natural habitats. The role of BRGM is to draw up maps showing the potential distribution of vegetation and natural habitats on a scale of 1:50,000 based on the (chemical) nature of the rocks, prior to the modelling stage, which is rendered on a scale of 1:25,000. This predictive mapping is a real decision-support tool for spatial planning and environmental protection. Following on from the maps of mainland France, completed in 2021, BRGM will work on French overseas territories and the coastal fringe of French Guiana in 2022 and 2023.

Unified declaration for underground works (Duplos): a new online service

The Mining Code requires the declaration of any non-geothermal drilling to a depth of over 10 metres. This declaration can now be completed on the Duplos portal (duplos.brgm.fr). The information is sent to government departments, and primarily the DREAL, which generates a BSS code for each borehole. This unique identifier is then fed into the BSS (subsurface) database. To submit the end-of-drilling report, the drilling company can use either Duplos or DiaLog, an app for the technical description of boreholes, supported by the portal. This remote service was rolled out in 2021 in eight regions of mainland France, before being deployed across all French territories in 2022. In late 2021, over 300 accounts had already been created and 900 declarations filed.

AEROVERGNE: a helicopter-borne geophysical campaign with conclusive results

Photo 2/ In an area of 215 km² to the north of the Puys mountain chain in Auvergne, for the first time in mainland France, simultaneous testing was carried out using three methods of acquiring helicopter-borne geophysical data (magnetism, electromagnetism, gamma-spectrometry) in the specific geological context of bedrock under a cover of volcanic soil. Financed by ERDF funds for the Auvergne and by BRGM, the Aérovergne project highlighted the value of these surveys in improving knowledge of the subsurface of this region. This topic was the subject of a thesis in late 2021, financed by BRGM, Clermont Auvergne Métropole and the Volvic mineral water company.

The SISMAORE oceanographic campaign revealing the seabed north of the Mozambique Channel

Photo 3/ The SISMAORE campaign [<u>https://doi.org/10.17600/18001331</u>] led by BRGM has enabled the acquisition of new geophysical and geological data around the Comoros volcanic archipelago. This survey revealed the existence of two large recent tecto-volcanic fields and recent volcanic events all along the archipelago, as well as showing the architecture of the new volcano located east of Mayotte and its substratum. It also provided information on sediment evolution and major landslides. Data from SISMAORE are being analysed as part of the ANR Coyotes project <u>https://anr.fr/Projet-ANR-19-CE31-0018</u>, in order to gain a clearer picture of the gedynamic context of the archipelago for better risk management.

Martinique: mapping of surface geological formations for ground movements

Following on from the work in Reunion Island and Mayotte, the surface geology of Martinique has now been mapped on a scale of 1:25,000, covering over 60% of its territory. The methodology implemented by BRGM combines field acquisitions with helicopterborne electromagnetic data. This has made it possible to precisely map regolith formations, with a database of 5,767 outcrops and over 18,000 photos. These documents will be used in particular to produce new hazard maps of ground movements.

Cigéo: a new scientific programme for the storage centre project

BRGM is assisting Andra in developing its scientific programme for the characterisation and multi-scale modelling of karstic aquifers of Barrois limestone in eastern France. This surface area of the Cigéo site is set to house the surface installations of the future centre for the geological storage of radioactive waste. A thesis co-supervised by the University of Lorraine, Andra and BRGM is now under way. At the same time, a multidisciplinary R&D programme has been designed by BRGM and Andra and will be carried out over the coming years by various contributors. Project



Claude Delor Manader Cameroon





Thomas Fullgraf Geologist, head of the Gemman project in Malawi



Carol Zammit Manager, BRGM Limited branch in Malawi

Keys to fostering economic development in Africa

In both Cameroon and Malawi, BRGM's expertise was sought to update geological knowledge and develop mining potential. The aim of these long-term projects is to promote the economic development of these countries by giving the authorities greater independence to manage the geo-resources and development in their country.

In 2016, two BRGM teams set off for Cameroon and Malawi. In the first of these countries, BRGM, together with Cameroonian (BEIG3) and Finnish (GTK) partners, is implementing a capacity building project in the mining sector (PRECASEM). The first phase (2016-2018) covers 170,000 km²; by extending the programme to 220,000 km², the second phase (2019-2021) helped to update geological knowledge over almost the whole of Cameroon (80%)! "It was still a matter of updating and supplementing the country's geological map and carrying out geochemical exploration surveys, but this time we did not limit ourselves to mineral resources that might interest mining operators," stresses Claude Delor, project manager. "We also studied geomaterials, quarrying and building materials, ornamental rocks, etc., which could contribute to the local economic fabric in the short term.'

An innovative work tool

Under the "Cameroon 2" project financed by the World Bank, three 1:1,000,000 maps are being drawn up, showing geological, metallogenic and geomaterial overviews of the country. These are complemented by 18 geological maps on a scale of 1:200,000 showing mineral resources and geomaterials - 14 others were produced under Cameroon 1 - along with 12 geochemical maps. A geological and mining information system (SIGM) has been created to centralise, conserve, disseminate and enhance these data, also providing access to almost a thousand documents. "The SIGM is an innovative working tool for mining operators and government departments, but it is also a first-rate geoscientific knowledge aid for teachers, researchers, students, planners, local authorities, etc."says Marc Urvois, the manager in charge of the SIGM.

Finally, some sixty Cameroonian counterparts educated in geochemistry and geology and trained to manage, update and maintain the SIGM have developed their knowledge and skills under the PRECASEM project. Capacity building also extending to materials and equipment has been provided to upgrade the scientific infrastructure. The results of Cameroon 2, which will be released locally in December 2021, have been widely reported in the national media.

The Geological Mapping and Mineral Assessment of Malawi (Gemmap) project, funded by France via a framework agreement signed with this African country, was also completed in 2021. Implemented by a consortium led by BRGM, with partners from the geological surveys of Finland (GTK) and South Africa (CGS), Gemmap aimed to support the country's economic development by diversifying the mineral resources sector. This required an update of its geological map coverage and a new inventory of its mining potential. The whole country is now covered by forty 1:100,000 geological maps, ten geological maps and ten 1:250,000 structural maps, along with three 1:1,000,000 overview maps, including one of mineral resources.

Maps of natural hazards

For the purposes of the geological map of Malawi, seven field surveys have been carried out by several teams simultaneously. For the mineral occurrence inventory, geochemical surveys have been carried out in seven areas on the basis of updated data. Natural hazard maps have also been produced, showing areas subject to different types of risks, particularly floods, landslides and earthquakes. Gemmap has also provided 37 training courses to more than 300 Malawian trainees and students in the field and in the laboratory during internships and sessions and as part of degree courses, with master's degrees completed in Malawi, Ghana and Australia. "We have covered all the fields necessary for our counterparts to continue to deepen their geoscience knowledge," says Carol Zammit, assistant project manager. As in Cameroon, the laboratories have been equipped and renovated. A documentation centre has also been set up. In addition, an interim feedback conference was attended by 300 people over two days, including several mining operators.





1 — Field survey on a granite inselberg in the Djoum sector in the extreme south of Cameroon. © BRGM - C. Delor

 $\mathbf{2-1:1,000,000}$ geological map of Malawi. BRGM

3 — Extract from the 1:1,000,000 geological map of Cameroon. This type of geoscientific data is published on the new SIGM data portal (sigm.minmidt. cm), which contains almost 1000 documents, including the geological, geochemical and geomaterial maps produced during the Cameroon project. © BRGM Vallon de Savine (Vanoise National Park, Savoie). Geosystems and ecosystems are closely linked. Geological data are essential for studying biodiversity. BRGM provides valuable input for the Ministry, particularly for the mapping of natural habitats in France. © BRGM - E. de Martin



Claire de Kermadec

Knowledge project manager at the Ministry of Ecological Transition (DGALN - Directorate of Water and Biodiversity, Subdirectorate for the Protection and Restoration of Terrestrial Ecosystems, Biodiversity Policy Office)

"To study biodiversity, geological data are essential. BRGM makes this data available, but also and above all its expertise to enhance it."

— What role can BRGM play in a biodiversity project?

CLAIRE DE KERNADEC – We are well aware of the links between geology and biodiversity and their interdependence; geology shapes our landscapes and the ecosystems that cover them. BRGM therefore plays a major role, as it posseses a large amount of geological data and the unique expertise needed to exploit it. It moreover plays a key role in managing the inventory of France's geological heritage.

What particular role has it played in the natural habitat mapping programme?

C.K. – With the CARHAB project, undertaken by the Ministry of Ecological Transition, we are creating a nation-wide map of natural and semi-natural habitats to alert the public about biodiversity issues and help shape public policies in terms of spatial planning.

The geological data held by BRGM is also very valuable to the CARHAB programme as the methodology uses the available data to model natural habitats. We quickly realised that geological data play a predominant role in ensuring the quality of this modelling. Thanks to them we were able to identify natural habitats much more precisely! BRGM therefore helped us to improve our methodology and ultimately the quality of the results.

– How would you rate this collaboration?

C.K. – As very positive! BRGM, a long-standing and highly competent geosciences operator, has proven to be a crucial contributor to the programme! It makes its data available, but also and above all its expertise to enhance them.

In this innovative European project (see "CARHAB métropole: mapping to support biodiversity issues", page 15), both technically and in terms of scale and implementation at the national level, BRGM has also been a valuable partner, making several proposals. It has been a driving force in continuing this work in the French overseas territories and the coastal fringe of French Guiana, even though the CARHAB programme is still in its infancy in these regions.



GROUNDWATER MANAGEMENT

Promoting sustainable management of water resources in a context of global climate change

Tufa waterfall in the Jura. The Petite Source de la Cuisance is an underground river. Running through underground galleries, it emerges from the limestone massif to form a waterfall with numerous cavities formed in the tufa. @Andre Stock



The availability and quality of groundwater are affected by climate change and increasing urbanisation, as well as by agricultural and business practices. **BRGM** is seeking to better characterise and understand how aquifers work and to study the impact of these phenomena on large water bodies. To this end, it is developing predictive services to provide quantitative and qualitative forecasts of groundwater status. It is also studying the processes governing the transfer and transformation of diffuse pollution in aquifers. BRGM is developing technological solutions and governance tools to support the conservation and sustainable management of groundwater in French regions.







TACTIC* assesses the Impact of climate change on groundwater

Photo 3 / BRGM took part in the GeoERA TACTIC project. The objective was to contribute to harmonising assessments of the impact of climate change on groundwater and surface water. The results are intended to support EU policy-making and to provide decision support. Working with twenty partners from seventeen countries, BRGM has contributed to developing a toolbox and methods to assess the impact of climate change, together with a good practice guidebook for their selection and application, and the rollout of the GeoERA information platform. https://geoera.eu/projects/tactic9/

HOVER* studies the link between water quality and the geological context

The purpose of the GeoERA HOVER project is to study hydrogeological processes and the geological context controlling the dissolution and transport of natural and anthropogenic elements in groundwater, with particular emphasis on health and the environment. BRGM is project coordinator. The project has made it possible to better characterise the link between water quality and the geological context. A range of methods, models and tools have been developed to facilitate the assessment of water quality at the European level, and to better understand the disparities observed, particularly in terms of the types of aquifer.

https://geoera.eu/projects/hover8/

RESOURCE*: a method to classify karst aquifers and submit recommendations for management

As part of the GeoERA RESOURCE project, BRGM took part in developing a harmonised European methodology for classifying karst aquifers.

A typology has been adopted for managing these aquifers: the reserve index describes the potentially exploitable volume, while the vulnerability index describes sensitivity to pollution. BRGM has developed a tool to automate the digital processing of water level and flow monitoring in order to characterise the hydrodynamic operation of karst aquifers. This tool has already been applied to fifteen cases of karst aquifers across Europe. https://geoera.eu/projects/resource9/

AQUAREF, a review of contamination risks in groundwater sampling

Photo 2/ BRGM is a member of AQUAREF, the national reference laboratory for monitoring aquatic environments. Over the past fifteen years, BRGM has worked with the other members of the consortium - IFREMER, INERIS, INRAE and LNE - to improve the reliability of water monitoring data. In 2021, BRGM organised an intercomparison exercise on groundwater sampling. This provided a basis on which to review the risks of contamination for complex substances such as phthalates, perfluorinated compounds and certain body care products. BRGM has also provided technical data for the regulatory recognition of passive samplers: demonstration campaigns, guides, training, and reference systems for databases. https://www.aguaref.fr/

A thesis on karst basins to understand flooding

Photo 1/ BRGM financed and co-supervised a thesis on karst basins to provide a clearer understanding of flooding processes. The thesis looked at three regions in France and 120 measuring stations. It highlighted the key role of inter-basin underground flows and established a typology of the role of karst in flooding, thereby paving the way for improved modelling of flooding in karst basins for more efficient forecasting.

PROMISCES: supporting the deployment of the circular economy by preventing industrial pollution

How can we contribute to the development of a circular economy with zero pollution? This is the aim of PROMISCES, a European project coordinated by BRGM and scheduled to run until 2025 with twenty-seven partners from nine European countries. The project will seek to develop innovative solutions for monitoring, preventing and eliminating persistent pollutants in the environment. To this end, it is studying the origins, transfer pathways and fate of mobile and persistent pollutants such as perfluoroalkyl and polyfluoroalkyl substances (PFAS) in the environment. The focus is on innovative solutions: monitoring methods, prediction and decision-support tools, and new technologies to remove these potentially harmful pollutants from soil, sediment and water, including groundwater.

1 — CTD probe, measuring variations in the water level at the Passage de la Méduse, Aven Castelette (Var). © Spéléd/20 - T. Lamarque

2 — Sampling from a reconnaissance borehole (Gaye site). AQUAREF intercomparison test. © BRGM - J.-Ph. Ghestem

3 — Example of a result integrated in the EGDI platform: the European map showing potential recharge values. © 2022. GeoERA

* GeoERA projects co-funded by the European Union as part of the Horizon 2020 programme.



Nicole Baran Hydrogeologist, Research and Development Project Manager



Anne Togola Analytical chemist, Research and Development Project Manager

Emerging pollutants: better assessing groundwater contamination

Knowledge of groundwater quality is vital for shaping and deploying appropriate public policies. With the two projects ACCES and BEMOL, BRGM is seeking to better assess the presence and source of emerging pollutants by developing analytical methods and measurement campaigns.

The expertise of BRGM's scientific teams, ranging from analysis to understanding the behaviour of groundwater pollutants of emerging interest, enables them to detect and characterise molecules for which little research has been done up to now. BRGM has long been developing and deploying analytical methods in the search for new compounds in water.

BRGM does advanced research on emerging pollutants

There is a lot at stake. Two examples of contaminants that can reach groundwater are metabolites (or breakdown molecules) of plant protection products and secondly Bisphenol A, a plasticizer used in food packaging (food packaging plastics, cans and tins). The latter is classified as an endocrine disruptor, with adverse effects on the reproductive function, which has led to it being banned in France. The study of this type of pollutant is of major interest for guiding public policies, particularly in terms of the environment and health. It is necessary to detect them and trace their origins *via* field campaigns.

BRGM is addressing this issue in two research projects.

ACCES: a new analytical approach to assess the occurrence of metabolites of plant protection products

In France, there are about 350 active substances used in plant protection products.

Most of them can lead to the formation of metabolites, some of which could migrate to groundwater. To verify this, BRGM, together with the Dordogne Chamber of Agriculture, the Orleans Institute of Organic and Analytical Chemistry and the *Syndicat mixte des eaux de la Dordogne*, is implementing an innovative analytical approach: high-resolution mass spectrometry, which can determine whether or not there are metabolites present and if so, characterise them. The ACCES project, which will end in mid-2022, will establish the potential of this new analytical approach and provide some answers about the occurrence of certain metabolites in groundwater.

BEMOL studies the presence and impact of bisphenols

The BEMOL project, led by INRAE in association with BRGM and the University teaching hospital (CHU) of Tours, was completed in 2021, with a follow-up already underway. It is investigating bisphenols, particularly Bisphenol A (BPA), which is known to be an endocrine disruptor and harmful to the reproductive function of animals and humans. These compounds, including Bisphenol S (BPS), are used as substitutes for BPA: it is therefore important to study their presence in the environment, as well as the extent to which people are exposed and affected by them, given that the initial data obtained by the project partners point to similar effects for BPA and BPS.

In practical terms, BEMOL assesses the environmental exposure to bisphenols in the six departments of the Centre-Val de Loire region and their possible effects. What is the degree of environmental contamination of water with bisphenols? What levels of exposure lead to reproductive effects? How can BPS affect reproduction? What are the interactions with the metabolic status of individuals? Tests are carried out *in-vitro* and on a sheep model.

Thanks to the analytical developments and measurement campaigns carried out, bisphenols (mainly A and S) have been identified in the region for the first time. The effects of BPS relate to the alteration of hormone production of ovarian cells. It also changes the quality of the oocyte in ewes. The trials have also shown that indirect routes of exposure to bisphenols via the environment may affect fertility.







Partner interview



"BRGM's expertise in groundwater is essential for working on water in all its dimensions, at all scales."

How would you sum up the current water issues for a water-distribution authority like yours?

NICOLAS JUILLET – The SDDEA is 80 years old and moved to another level in 2015 when it went from providing technical assistance and advice to being an operator across the entire *département*. Indeed, since the promulgation of the NOTRe Act on drinking water, sanitation, rainwater and the management of aquatic environments and flood prevention (GEMAPI), all the municipal syndicates were disbanded and consolidated, and in the Aube the responsibility was transferred to the SDDEA, which manages water distribution for the whole region. The stakes are high. For example, the Aube *département* has 300,000 inhabitants, and to supply them with water there are no fewer than 200

Nicolas Juillet

Vice-President of France Eau Publique, President of the SDDEA (Syndicat Départemental des Eaux de l'Aube)

catchment points. Since it is impossible to study 200 catchment areas we need a more precise and rational method. In addition, climate change is affecting our region, as evidenced by the pressure on the resource during peak water consumption at harvest time. Its impact is starting to stretch all our capabilities to their limits, and we need to model it. It is a question of major investments in the long term, with a "Strategy 2100" to ensure that the water infrastructures are sustainable, as well as resolving practical technical problems of interconnection and development of infrastructures within a sustainable, well-designed framework.

- Why did you choose BRGM?

N.J. – Under these circumstances, we have to plan ahead: What is the projected level of abstraction? Which investments should be made in this context? How can we improve water quality given the transporting of emerging pollutants? (see *Emerging pollutants: better assessing groundwater contamination* page 24).

In this context, we already have long-standing exchanges with BRGM. A turning point was reached three years ago in the context of climate change, when it became a key partner. In a way, the syndicate has become a BRGM 'field laboratory'. Furthermore, BRGM's expertise in groundwater is essential for dealing with water in all its dimensions, at all scales.

In practical terms, what work is involved and what are the results?

N.J. – Ten drinking water supply systems are being established in the department depending on the geology of the ground. BRGM is working on models for forecasting the water table over time with assumptions about different climate change scenarios. This is done by locally adapting the global models at its disposal. In addition, it attempts to answer key questions, such as "what surface facilities will we need?" "In which agricultural *département*?" "How can we store or channel water instead of getting rid of it?"

BRGM must propose concrete and sustainable solutions. At this stage, we are fully satisfied with the first elements of this partnership, with a progress report to come and projected developments between now and 2026. The results of our work will be shared with our partners, particularly the Chamber of Agriculture.



RISKS AND SPATIAL PLANNING

Controlling isks and their isks and their impacts to impacts to impact to the ensure regional resilience impact of the ensure regional isks and the ensure region

Monitoring the displacement of fuel in the plurimetric pilot plant (PPM/ PRIME) as part of the SPLODGE project. The purpose of this project is to develop a method for locating and quantifying light petroleum hydrocarbons (in the form of pure products) in the unsaturated zone and roof of the aquifer, combining conventional diagnostic methods (drilling, measurements and analyses, etc.) with geophysical monitoring methods (permittivity and resistivity). These recognition methods are supported by multiphase modelling. (BBGM - D Benorter



Global change is making regions more vulnerable to natural hazards and anthropogenic pollution. **BRGM** has made risk science a cornerstone of its activities. To promote sustainable development and support the regions, it is implementing an integrated approach to the risk chain, from prevention to adaptation, through preparation, warning, crisis management support, recovery and remediation. **BRGM** is also involved in managing former mining or industrial sites and rehabilitating contaminated wasteland.

In particular, it promotes the recycling of excavated soil by developing characterisation methods to certify soil recovery potential and ensure its traceability.









1— Sargassum treatment pilot facility. © DEAL Martinique

2 — Karstic collapse measuring 6m in diameter and 3.5m in depth at La Levée de la Chevauchée in Saint-Jean-le-Blanc, north-central France. @ BRGM - B. Chevrier

3 — Example of a map created using the CoCliCo portal. Here, a map of low-lying areas below the high tide mark, with a 1m rise in the sea level superimposed. © RBRM

BRGM becomes a player in the CoCliCo project, a climate service for coastal adaptation

Photo 3 / The purpose of CoCliCo is to develop a climate service for coastal adaptation in Europe. The project will provide data on waves, surges, rising sea levels, flooding and erosion hazards, as well as on the vulnerability and exposure of people and infrastructure, based on several climate change, socio-economic and adaptation scenarios. The target observation scale of 25m complements the high-resolution submersion work conducted by BRGM as part of coastal risk prevention plans. The service will take the form of a platform, implementing the FAIR principles for research data management (Findable, Accessible, Interoperable, Reusable).

Karst risk on Avenue Gaston Galloux in Orléans

Photo 2/ BRGM has conducted studies on the karstic risk affecting a busy avenue in the city of Orléans, looking at aspects ranging from hazard mapping to the study of risk management strategies; Crossed by the Loire and providing fast access to the northern and southern sides of the town. Avenue Gaston Galloux is located in an area with a risk of karstic collapse, potentially causing craters up to 10m in diameter. BRGM has assessed the risk of ground movements through in-depth geotechnical studies and an innovative method. The resulting recommendations include a programme of investigations to clarify the risk, together with a series of proposals to integrate these phenomena into crisis management scenarios.

Fault characterisation and seismotectonic zoning on the island of Hispaniola

Following the earthquake that devastated the region of Port-au-Prince, capital of Haiti, on 10 January 2010, BRGM carried out several seismic microzoning operations in Haiti and the Dominican Republic. The results obtained were published in a summary study on the characterisation of active faults, with the implementation of seismotectonic zoning across the island of Hispaniola. In addition to providing an overall view of the two countries, these results provide an essential information base for a homogeneous assessment of seismic hazards in Hispaniola

West Indies: treating arsenic and chlordecone in sargassum

Photo 1/ LThe purpose of the ANR SargAs&CLD project coordinated by BRGM in partnership with the universities of Orléans, Pau, French Guiana and the Antillies, together with the company ADERA/ UT2A and the University of Texas, is to chemically characterise the juice from the sargassum washed up on the beach or stored inland in the Antillies. The purpose is also to suggest innovative methods for treating both arsenic and chlordecone, an insecticide that is bioaccumulated by sargassum. Lastly, the social acceptability of sargassum storage was analysed. This work made it possible to locate the arsenic and to analyse its speciation in sargassum cells. Analyses showed that arsenic is present primarily on cell walls and, more particularly, that it is found mainly in inorganic form. This suggests that arsenic, which occurs naturally

This suggests that arsenic, which occurs naturally in the sea, builds up spontaneously in sargassum, owing to its chemical similarities with essential nutrients such as phosphates.

Prioritisation of emerging chemical compounds in soils

The approach of the PREMISS R&D project is to prioritise emerging chemical compounds in soils (CECs). Coordinated by BRGM and carried out in partnership with Dutch and Belgian teams, PREMISS has made it possible to synthesise data on the occurrence of CECs in soil, sewage plant sludge, sediment and groundwater in France, Belgium and the Netherlands.

A prototype for prioritising CECs according to their concentration (in water and soil) and toxicity has been designed and tested for a set of compounds with heterogeneous properties.

SOILVal: soil quality and legal instruments

BRGM coordinated the European research programme SOILval, funded by the European platform SOILveR, which seeks to promote integrated and cross-border research on soil and land management. The objective was to assess how soil functions, and the associated ecosystem services are recognised and integrated in spatial planning and development in France and Wallonia. A legal analysis looked at the way in which soil quality is considered by legal instruments, while a state-of-the-art review studied soil reclamation solutions. Decision-making tools were produced to support the implementation of these solutions, and a knowledge review carried out concerning soil quality in France and Wallonia. Based on these results, a number of recommendations were drafted and are now available on the SOILveR website. www.soilver.eu/

DEPOLOND2, microwaves to volatilise organic pollutants

In partnership with SUEZ and EDF, BRGM conducted DEPOLOND2, a project whose purpose is to use microwave energy to volatilise organic pollutants. The experimental set-up consists of a 2m antenna (2.450 GHz, 2 kW) inserted in a column of sand in near-field conditions.

The results are promising and contribute to a clearer understanding of heating dynamics, owing to the presence of 62 temperature sensors. The next step will be to support the heating process by injecting air through the antenna in order to better diffuse the heat into the ground.



André Burnol Hydrogeochemical engineer/researcher



Behrooz Bazargan-Sabet Expert at the Hazard and Risk Prevention Division

Le Teil earthquake: triggered hydraulically due to a period of heavy rainfall?

What was the origin of the earthquake in the small village of Le Teil that caused serious damage in November 2019. Tectonics, or human activity that could have been a triggering factor? BRGM's work suggests it was triggered by hydraulic factors.

Le Teil in the Ardèche has 8000 inhabitants and was the epicentre of an earthquake. The village experienced high-magnitude seismic activity on 11 November 2019 at 11:52 am: local magnitude 5.4, and moment magnitude 4.9. There were no casualties, but major damage to property. People had to be displaced and the earthquake was felt as far away as Montélimar, some 7 km away (about 40,000 inhabitants).

The village is located on a known fault zone in the Rhone Valley. However, this was an event of rare magnitude in France. The last earthquake of this magnitude dated back to 1967, in Arette in the Bearn foothills of the Pyrenees, with a local magnitude of 5.3.

The earthquake in Le Teil had implications for the Cruas-Meysse nuclear power plant, 14 km away, which was shut down for a month, causing serious concern among the population in the region.

Reassessing earthquake hazards in France

This earthquake was a significant event and most unusual for France. Seismologists immediately began to look into the matter. There is a quarry near the epicentre, which has been worked for a long time by Lafarge Holcim France, and the CNRS very quickly took up the issue. A study carried out in December 2019 by a working group of the French scientific community led by the CNRS concluded that while the earthquake was probably natural and not induced by human activity, the presence of the quarry could nevertheless have been a triggering factor. BRGM, doing joint research with the Lafarge Holcim cement group, has put forward another hypothesis. The results show that the event was triggered by the reactivation of a fault by hydraulic overpressure.

A complete 3D geological model of the area

BRGM researchers created mechanical models to take into account the particular configuration of the surface topography, but also the history of the volumes of material excavated by the quarrying operation since 1850 and the geometry of the fault system. Soil humidity data acquired by the European SMOS satellite and modelling of the variations in height of the unsaturated zone using the BRGM ComPASS code showed that water infiltration affected the recharge, with hydraulic overpressure reaching a maximum precisely at the intersection of the fault system. This is an example of seismic action in the intraplate domain, with the possibility of simultaneous surface fractures on two distinct faults.

Hydraulic activation of the earthquake caused by heavy rainfall

The second stage of the work from February to May 2021 confirmed the initial programme and refined the results, in particular locating the area of maximum hydraulic overpressure at the intersection of the fault system.

This research confirmed the BRGM hypothesis: the earthquake could have been triggered hydraulically. BRGM demonstrates that there is of course no reason to dismiss a tectonic origin of the Le Teil earthquake. But it could also have been a tremor triggered by an external event: in this case, the hydraulic load due to a period of heavy rainfall in the month preceding the earthquake.

More broadly, the earthquake not only revealed the need to reassess the hazard in the area, but also reopened a debate on the nature of seismic activity in mainland France in the intraplate domain. BRGM is among the French organisations that collect seismological observations for France, and its role naturally includes this type of work.

This is also a highly original cross-disciplinary project combining geology, geophysics, geomechanics, seismology and hydraulics, and it opens up a new field of research on the subject of intraplate hydroseismicity on a European scale, all in connection with global climate change. Such hydroseismic hypotheses have already been put forward in the United States in the last 20 years. They have now been corroborated here in mainland France.





1 — 3D view of the fault system around the Le Teil quarry showing the intersection zones at depth. Geological model generated by GeoModeller © BRGM - Intrepid Geophysics. © BRGM

2 — Le Teil site near the epicentre of the 11 November 2019 earthquake. © BRGM - C. Allanic

3 — ComPASS code simulation of the hydraulic pressure variations on the La Rouvière fault in the month preceding 11 November 2019.





Stéfan Colombano Engineer/researcher

Treatment of emerging pollutants: reducing perfluoroalkyl and polyfluoroalkyl (PFAS) concentrations in groundwater

The Concerto project focused on perfecting a groundwater remediation technique and methods for analysing PFASs, which are particularly harmful, emerging pollutants.

PFASs are chemicals, specifically perfluoroalkyl and polyfluoroalkyl, which are commonly used in domestic and industrial settings. PFASs can be found in thousands of applications: stain-proof and waterproof coatings, oil-resistant coatings (for food packaging paper and cardboard), and compounds for fire-fighting foams and floor coatings. They have adverse effects on human health and the environment. In addition, as PFASs are particularly persistent over time, extensive site remediation using appropriate techniques will be required.

A major issue for groundwater pollution

These PFASs are among the pollutants of emerging interest. They are also known as refractory pollutants. This is because they do not degrade after they are used or released into the environment, due to their high chemical stability: in addition to their properties described above, they are only subject to slight alterations in air, water or sunlight. PFASs can therefore be transported far from a source of emission, and thus imperil the environment, by contaminating groundwater or surface water and accumulating in living organisms. Consequently, they are recognised as endocrine disruptors and even as potential human carcinogens. Work on their effects has already been done in animals.

However, PFASs are still relatively unknown: the techniques for their economically acceptable decontamination are not very advanced. This is a big issue, with a significant societal risk, involving health risks linked to toxic compounds in groundwater that will require substantial industrial cleaning-up.

Cleaning up sites and soils contaminated by PFASs

As this is becoming a major issue for many industrialists and the authorities, with its health and environmental consequences, BRGM, together with Colas Environnement, is working on the depollution of sites and soils polluted with PFASs, which is generally technically complex and costly. This is the purpose of the Concerto project, launched in the spring of 2020 and completed at the end of December 2020. This project has two parts: one concerning certain petroleum hydrocarbons that degrade with difficulty, and one for the emerging PFAS pollutants. With regard to hydrocarbons, a research phase on the petroleum products present in the soil, which account for 40% of soil pollution, was carried out at the Dunkerque refinery and in laboratory conditions with surfactants and biosurfactants (using an adapted injection technique). The process has improved conventional treatments of the compounds by more than 65%.

Good PFAS purification yields in the laboratory

For PFASs, with which we are concerned here, research was conducted in the laboratory at the BRGM scientific and technical centre in Orléans. A chemical decontamination process has been developed for some of these PFASs. Specifically, tests were carried out with a reducing agent, a catalyst and a diffusion matrix, which showed that it was possible to reduce PFAS concentrations in groundwater.

The effectiveness of different reducing agents was assessed by screening them. An analytical method was developed for 18 perfluorinated compounds found in the water. It enabled analyses of samples from the experiments to be carried out at low concentrations: from 20 to 100 ng/l, depending on the compounds.

The results of these experiments showed that good purification yields were obtained: a reduction of up to 70% in the concentration of certain PFASs in the groundwater!

A launch pad for the Green Deal PROMISCES project

These initial results will be developed, again in partnership with Colas Environnement, as part of the European Green Deal PROMISCES project, which aims to promote the "zero pollution" strategy for water, soil and sediments by 2025 in order to enable the application of circular economy principles. Fields of study: the origin, pathway and fate of pollutants that are easily spread and very persistent in the environment. Of strategic interest to BRGM, PROMISCES is its first experimental research project of this scale on PFASs, and will enable BRGM to display its expertise over the next three years.


1— Injectability tests of reagents in porous media. © BRGM – D. Depoorter

2 — Treatment of polluted soils by biopiles. © BRGM – F. Cazals

3 — Treatability tests on PFASs (perfluoroalkylated and polyfluoroalkylated). © BRGM - D. Depoorter





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The DPSM had a record year in 2021, in terms of the number of safety engineering projects managed. It completed a number of work sites, including the renovation of the water pumping stations at Godion and Cité Dincq, repairs to the roof at the Montredon site, safety work at the Abbaretz site, the Moïse shaft in Rive-de-Gier and the Sainte-Barbe shaft in Bézenet, and the installation of a drawdown system at Lochwiller. It also carried out emergency work, as in Saint-Étienne, where it was brought in to mitigate a sinkhole (see below). All these projects took place during the "vital" and fundamental technical transition of our automatic data acquisition systems: SCADA.

Saint-Etienne: emergency mitigation of a sinkhole threatening a business

One of the key missions of BRGM, which manages mining sites in France on behalf of the government, is to oversee the risks created by former mines through the DPSM (BRGM Mine Safety and Prevention). In 2021, for example, it carried out emergency work to ensure the safety of a commercial building and the surrounding area, when a mining sinkhole opened. A sinkhole is caused when a cavity beneath the surface begins to cave in and then suddenly collapses, crea-



ting a funnel effect. This is what happened on the night of 2 March 2021, under a commercial building in Saint-Étienne, in east-central France. A mining sinkhole of almost 1,000 m³ suddenly appeared in the middle of the night, following the collapse of a non-listed mine gallery, less than 20m below the surface.

The city of Saint-Étienne is built on mines. It has more mine cavities than any other French city of over 150,000 inhabitants, as the result of its coal mining activities in the 19th century. The city was built at the same time as the mines. Géodéris drafted a mine risk prevention plan that clearly locates these risks. However, events such as this may still occur on rare occasions, since the plan does not cover all the galleries.

This project is a good example of one aspect of the DPSM's work: to ensure the safety of former mining sites in an emergency situation where there is a danger to people and/or property. Fortunately, the crater formed in the middle of the night, but the human consequences could have been serious.

A building with three shops was seriously damaged. The roof collapsed in part and one of the surrounding walls developed a lean. BRGM began work two weeks after the event. It shored up the structure, plugged the crater with 800 m³ of concrete, rebuilt the paving base and repaired the underground networks, green spaces and car park. The project was completed in late April 2021, a little ahead of schedule, less than two months after the accident!

The lessons to be drawn from this event include: the fast response by BRGM, the efficient measures taken for safety and conservation, and the strong coordination between the DPSM, Géodéris and government services.



© BRGM - I.-L. Nédellec

Jean-Louis Nédellec Director of the Post-Mining Unit for Southern France, BRGM



Building and commissioning a drawdown system in Lochwiller

Photo 1/ Following the sinking of a 140-metre long geothermal probe in 2008, water from a deep confined aguifer (Lettenkohle and Muschelkalk) began to rise, seeping into the anhydrite layers of the Keuper. This anhydrite was turned into gypsum by a process of hydration, and began to push up the surrounding land, damaging buildings, disrupting the lives of local residents and bringing urban development to a halt. To mitigate or stop this phenomenon, it was decided to pump water out of the deep aguifer. The project aims to neutralise the upward circulation of water along the faulty geothermal borehole to prevent it from hydrating the Keuper levels.

The construction of the first 140-metre piezometer provided extensive information on local hydrogeology, with the execution of numerous tests and logs. These data were used during the course of the project to adjust the dimensions of the other boreholes.

In in its role as delegated project manager for the government, the DPSM built and commissioned a drawdown borehole associated with three control piezometers, This system has made it possible to prevent water from the deep aquifer rising up through the geothermal borehole.

UTAM South: water for heating and cooling from the former Gardanne coal mine

Since the spring of 2021, BRGM's Department of Mine Safety and Prevention has been using water from the former Gardanne coal mine, which closed in 2003, for heating and cooling the 560 m² of office space occupied by UTAM South. The Yvon Morandat shaft, the biggest mine shaft in Europe, contains approximately 60.000 m³ of available free water at a temperature of nearly 30°C. Water is pumped from a depth of over 300m and then reinjected into the base of the borehole. The water collected runs through a titanium exchanger on the surface to fill two 50 m³ steel tanks. It is then pumped out and used to deliver fluids at 40°C or 10°C in order to provide heating or cooling, depending on requirements.

Renovation of water pumping stations

Through its UTAM North entity, the DPSM manages 52 water pumping stations in the French départements of Nord and Pas-de-Calais, on behalf of the government. Sometimes, the stations are in an advanced state of dilapidation and require extensive renovations. This was the case of the Cité Dincq water pumping station in Waziers, northern France. Working in its capacity as delegated project manager, the DPSM fully renovated and upgraded this station in 2021.

Given that the station receives huge inflows of highly corrosive wastewater and anthropogenic waste, it was equipped, among other things, with an automatic screen to prevent clogging, a waste compactor to reduce the volume of some three tonnes of miscellaneous waste per year, and a second pump for use during dry weather to ensure continuity of service, using high-performance technologies. The civil engineering structures were also renovated, with the station acquiring high-quality external cladding, for a perfect fit with the urban fabric and the total satisfaction of local residents.

Management plan for the Auzelles colliery waste tip

Photo 2 / The DPSM was commissioned by the DREAL ARA to draw up a management plan for the Auzelles colliery waste tip, which is located in a Natura 2000 nature protection area in central France. This tip of approximately 4 ha has an estimated volume of 150,000 m³ of mine tailings containing high levels of lead, zinc and arsenic. It is also on steeply sloping ground (average gradient of 40%). A detailed understanding of this site was required in order to target and prioritise management measures. The DPSM placed instruments on the site and monitored it for two years in order to refine the conceptual design. Quantification of the transfer pathways showed that water erosion played a dominant role. A zone-based approach was implemented in order to find the best cost-benefit balance. For the different zones, the scenario recommended by the DPSM is based either on conventional solutions (containment) tried and tested at similar sites, or innovative solutions (phytostabilisation) with a lower environmental impact and that are also better suited to sites where access is difficult. The implementation of these management measures is being scheduled.

1 — Drilling in progress. © BRGM

2 — The Auzelles colliery waste tip. © BRGM - L. De Lary De Latour



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> The multimetric pilot plant (PPM) is used to investigate pollutant transport in soil, to be studied at a scale which is as close as possible to the natural environment, in order to predict environmental impacts and develop remediate.

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"A partnership that allows us to keep a leading edge in the pollution control market, thanks to the synergy between the expertise of BRGM researchers and the operational excellence of COLAS Environnement."

A few words about Colas Environnement and your R&D objectives?

ARNAULT PERRAULT – Colas Environnement is a subsidiary of the construction giant Colas. It is an engineering and pollution control company with about sixty employees, in a niche sector that is nevertheless of vital importance, since we clean up soil and groundwater. Colas Environnement is also involved in the redeveArnault Perrault Director of Colas Environnement

lopment of brownfield sites, to revitalize them for new uses, in line with the government's objective of "zero net soil sealing" by 2050.

Our R&D efforts are geared to meet two challenges. The first is to optimise our techniques to increase our competitiveness and lower the costs of treating wastelands, particularly those affected by heavy hydrocarbons, and the second is to deal with emerging pollutants of interest, in particular PFASs, synthetic organic substances used for domestic or industrial purposes.

How did the partnership with BRGM come about?

A.P. – BRGM has a sufficiently broad range of skills to respond to this dual research focus, which has enabled it to address both issues within the Concerto project (see *Treatment of emerging pollutants: reducing PFAS concentrations in groundwater* page 34).

We already got to know each other during the BIOXYVAL project (from 2017 to 2020) on solutions for managing complex pollution from industrial wastelands, and then on MOBILMOUSSE, which aims to improve the recovery of supernatants.

— How would you sum up your partnership?

A.P. – We complement each other perfectly: we know the markets and BRGM has the expertise.

Each party contributes its financial, human and technical resources. Of course, BRGM's multimetric research platform (PPM) is a real asset. These resources are supplemented by public and/or industrial funding.

As a scientific reference on polluted sites and soils, BRGM is extremely agile in that it can mobilise experts in many cross-disciplinary fields (biology, hydrogeology, chemistry, etc.) very quickly. It is a research catalyst for Colas Environnement.

This partnership is one of the elements that enable COLAS Environnement to remain at the forefront of the pollution control market, both *in situ* (without excavating, generally using shafts) and on site (materials are excavated and treated on site), thanks to the synergy between the expertise of BRGM researchers and the operational excellence of COLAS Environnement.

A patent is being filed for improved biopiles, developed jointly by BRGM and COLAS. Most importantly, with regard to PFASs, the collaboration gives us access to the major European Green Deal project PROMISCES on the development of innovative solutions to remove persistent pollutants from the environment.



MINERAL RESOURCES AND THE CIRCULAR ECONOMY

Securing the supply of mineral materials in a circular economy framework

The Uyuni salt flats, Bolivia, the world's largest lithium deposit. © Fotolia - V. Melnik



Ensuring access to mineral materials, which are essential for the digital and energy transformation, is a major challenge for both industry and governments today. Indeed, the health crisis has further highlighted the need to secure metal and mineral supply chains, which are now considered from a circular economy perspective in order to reduce environmental impacts. BRGM specialists have expertise in mapping the value chain of mineral

mapping the value chain of mineral materials and modelling their life cycle. BRGM uses their know-how to prospect for primary resources and to develop technological innovations for processing and recycling the materials. In particular, BRGM works with industrial manufacturers to help them secure supplies and meet their needs for eco-responsible technologies.



1 — Examination of a quarry face by a BRGM sedimentologist - "Sebastopol" limestone quarry (Middle Lutetian) in Saint-Vaast-les-Mello (Oise). © BRGM-D. Dessandier

2 — Comparison of an original stone ("Banc Franc", Upper Lutetian) from Notre-Dame Cathedral in Paris and "new" restoration stones (Cerite limestone, Upper Lutetian) from active quarries in the Oise region. @ BRGM-D. Dessandier

3-A team from BRGM installs a probe to measure the non-conservative parameters of water at the Kevitsa site (Finland). $$^{\odot}_{\rm RRM}$$

4 — Initial production of lithium carbonate from geothermal brines extracted as part of the EuGeLi project. Eramet Ideas R&D and Innovation Centre, December 2021.





Stone 1 from quarry Y

S. K

Stone 1 from quarry Z





When antimony in quartz provides information about mineralisation

BRGM has demonstrated the significant potential of antimony (Sb) and trace element concentrations in quartz as a tracer of mineralisation. Antimony (Sb) concentration levels (obtained by laser ablation coupled with mass spectrometry) are particularly high in the quartz found in five stibine-rich (antimony sulphide) deposits in the Massif Central. Different mineralising episodes were also clearly identified within a single deposit thanks to the trace elements present in the quartz.

EuGeLi: a world first that could open up the possibility of establishing a European lithium industry

Photo 4 / EuGeLi is a European project led by Eramet and its partners, including BRGM. The project aims to use local resources to produce "European-made" lithium, which is notably used to manufacture batteries. The initial results have been promising and the first kilograms of battery-grade lithium carbonate from European geothermal water were produced at the Soultz-sous-Forêts site, in the Bas-Rhin *département*. The issue now is to assess whether it would be possible to build a competitive blueprint to produce lithium batteries on an industrial scale in Europe, with a reduced carbon footprint, as a complement to the development of renewable energy sources.

It is now possible to know where gold comes from

As part of its work concerning the traceability of gold, BRGM has developed an innovative approach, mainly involving primary, eluvial and alluvial gold grains from French Guiana. BRGM has succeeded in identifying amalgamated gold (which is illegal in France) by analysing the mercury, using portable measuring devices to distinguish each legal mining operation tested based on a specific geochemical signature, supplemented by the characterisation of the mineral micro-inclusions, if necessary.

Which stones should be used to restore Notre-Dame de Paris?

Photos 1 et 2/ The restoration of the cathedral Notre-Dame de Paris, which was heavily damaged by a fire in April 2019. The restoration requires using "new" stones that are compatible with the original ones. Moreover, the new stones need to be available in far greater guantities than those normally required for maintenance work carried out on historic monuments. To meet this need, the public body in charge of the cathedral's conservation and restoration teamed up with BRGM to conduct an R&D programme aimed at identifying, characterising and selecting stones from guarries whose stones have compatible aesthetic and physical qualities. The research enabled us to produce a stone-selection quide for the restoration of Notre-Dame de Paris.

Iterams: new tools to optimise mining activities

Photo 3/ The H2020 Iterams project – aimed at improving the recycling of water and reclamation of tailings in mining operations – came to an end in 2021. During the project, BRGM developed a tool for assessing the geopolymerisation potential of mine tailings. It also developed innovative electrochemical probes to measure the non-conservative parameters of water online. Finally, it designed a method for assessing the environmental impacts of tailings ponds, with site-specific results that are more accurate than those obtained using the conventional generic approach.

Valomag: rare earth elements extracted from magnets in urban mines

Launched in 2019, the Valomag project aims to recover magnets from urban mines (electrical and electronic waste stockpiles) in order to produce new magnets or extract rare earth elements. BRGM has developed an innovative, mechanical, pilot-scale process that can be applied to used hard disks. The magnet recovery rate is close to 90% and has a purity level of 88%, making various reclamation solutions possible, including the hydrometallurgical extraction of rare earth elements. Developed by BRGM, this innovative and environmentally-friendly process produces didymium and dysprosium oxides, which have numerous industrial applications. A patent is currently being registered.



mineral





Sébastien Colin Geologist. geomaterials exnert



Anne-Sophie Serrand Geologist, mineral resources exnert



Gaëtan Lefebvre Mineral intelligence expert

Practical solutions to the specific problems of manufacturers

With its acknowledged geological expertise and in-depth understanding of the entire mineral-resource value chain. BRGM uses its know-how to provide manufacturers with concrete solutions to help them secure the raw-material supplies they require to operate, while also helping them address the increasingly sensitive issue of their environmental responsibility.

Industrial demand for mineral raw materials is constantly growing, across an ever-expanding variety of sectors. In this context, manufacturers are looking for solutions to secure their supply chain, while also trying to ensure a more environmentally-responsible use of these materials.

With this in mind, BRGM frequently receives requests from manufacturers to help address these issues, for example by identifying substances that can fulfil specific functions, finding new deposits, or assessing the potential of a particular deposit, etc. Today, new types of requests are frequently being added to the list, as Sébastien Colin, a geologist specialising in geomaterials, explains: "Manufacturers are interested in resource rationalisation, i.e. optimising the extraction and exploitation of substances and their potential by-products. They are also increasingly concerned about the environmental and societal issues surrounding the mineral resources they use, which can mean searching for substitutes and reorienting their consumption."

Solutions based on scientific expertise, with an educational component

Drawing on its expertise in the fields of geology and mineral-resource economics, BRGM can provide solutions for every type of issue that manufacturers may have, from upstream to downstream in the value chain. "We put together a multidisciplinary team, tailored to the request," says Nicolas Charles, geologist and project manager. Every year, around ten projects are carried out, with varying durations which may evolve over time. "Our status as a public-sector scientific institution provides our customers with the quarantee that the research and work conducted are reliable, supported by data and independent," adds Nicolas Charles. "We also have strict protocols that ensure the confidentiality of the data we process and the results we produce.

The deliverables vary according to the project, ranging from assessments of geological and mining potential, to reviews of substances, chemical or mineralogical analyses, database creation, recommendations, sector-based studies, methodological developments, etc.

"Our projects, presentations and deliverables are designed and produced to provide a precise and clear response to the problems submitted", notes Sébastien Colin. The fundamental aim

of these assignments is to produce scientific and educational reports that can be used directly by customers.

More user-friendly navigation

This is also the aim of Minéralinfo. Launched in 2014 and co-managed by the Non-Energy Mineral Resources Policy Office (French Ministry of Ecological Transition) and BRGM, the French portal for non-energy mineral resources (metals, industrial minerals and construction materials) makes key information available to government bodies, local authorities and businesses, as well as to the general public.

A new version went online on 18 October 2021. It was produced as part of a collaborative project involving BRGM's Georesources Department and Digital Infrastructures and Services Department. "An audit was carried out in 2019, including a series of workshops with the different categories of users," says Anne-Sophie Serrand, mineral-resources geologist and project manager. "This work helped identify their expectations and the improvements that needed to be made.

The new Minéralinfo site now functions on all devices (computers, tablets, smartphones) and has a clearer architecture that provides more user-friendly browsing, so it is easier to find the information you want. "We also rewrote and improved the content to make it more accessible to every kind of user, whether they be familiar with the field of minerals or not," explains Anne-Sophie Serrand. The site addresses several topics: mineral resources in France and their management; supply-chain security for the economy; responsible supply chains; recycling and the circular economy; research, innovation and training.

It includes various resources and data on raw materials, their natural environment and the associated regulatory frameworks, as well as the Écomine newsletters which present analyses and reviews of key strategic metal markets, raw-material criticality sheets, fact sheets about industrial rocks and minerals, regional quarry maps, and more.

The number of visits to Minéralinfo peaked when the new version was launched and then stabilised at a consistently high level. The first feedback about the site is expected in 2022. "The site's editorial committee is working on shifting the content presentation to a more educational approach, to make it easier for users to understand and appreciate," says Anne-Sophie Serrand.



1— The new Minéralinfo site is now accessible on all screens and has enriched and more accessible content. © BR6M

2 — Critical minerals for the European Union. © Commission européenne (2020)

3 — Andalusite quarry in Glomel, operated by IMERYS (Côtes d'Armor). © BRGM-N. Charles









Philippe Varin

Former Vice Chairman of the National Industry Council and Chairman of France Industrie, Chairman of the Board of Directors of Suez. Author of the Varin report on mineral resources

"In a context of tensions related to strategic mineral raw materials, BRGM is of particular importance and it will play a key role."

— In your report on mineral resources, you highlight the emerging shortage.

PHILIPPE VARIN – This changing world, under these new conditions which I would describe as low-carbon and very rich in metals, where mineral raw materials will be an issue for the energy transition, will be marked by new geopolitical tensions linked to the supply of critical metals. We will move from a world governed by oil players to a geopolitical situation marked by the US-China confrontation over access to metals.

We will also see exponential growth in needs, doubled for copper, tripled for nickel and quadrupled for lithium by 2030, all critical metals for batteries! There is a serious risk of shortages.

Acces to these raw materials must be secured and assistance should be provided for processing them in France, but also new regulations must be developed.

What is BRGM's contribution in this context?

P.V. – BRGM is particularly important.

In fact, it is essential and has major potential. I am convinced that it will have a key role.

Given the situation of Europe with regard to raw material extraction, we need to go international and increase the capacities of our mining companies. BRGM will therefore be a major player in guiding the process of securing strategic mineral supplies, naturally drawing on our substantial knowledge and skills in mining. Europe also needs investment funds and effective metals diplomacy. Led by BRGM in conjunction with French mining operators, the Critical Metals Observatory, which the State has just decided to set up, will be an essential tool. This is a unique opportunity to put all BRGM data to work.

— What about the locations and regulations?

P.V. – Processing adds substantial value. For batteries, an ecosystem similar to the gigafactories is proposed in Dunkerque. Magnets could be recycled in Lacq, which would meet 20% of requirements. But in addition to industrial platforms, we need roadmaps for R&D, knowledge and skills.; BRGM will be involved in drawing them up and monitoring them, and will thus contribute to our increased competence in battery chemistry and magnet metallurgy. Finally, regulation is a big issue. The European Union is introducing a battery regulation and a CO₂ footprint passport, and is working on responsible mining.

For the latter, a reference framework must be established. BRGM, a specialist in responsible mining, will provide invaluable advice and assessments.

I have full confidence in the BRGM management team to take on these essential roles.



SUBSURFACE POTENTIAL FOR THE ENERGY TRANSITION

Exploiting the properties of the subsurface to move towards carbon neutrality

With a geothermal doublet system, the hot water pumped out can be used by a heat network to heat homes or buildings, while the cooled water is fed back into the same reservoir via a second shaft. @BRM



The subsurface can play a significant role in the energy transition, which requires more diversified, renewable and carbon-free energy sources. The resources and properties of the subsurface can be used to produce or store energy, as well as to cut greenhouse gas emissions by capturing and storing carbon. The subsurface also offers space for the containment of radioactive waste. BRGM is developing research and expertise in these areas. It is particularly active at the regional level, where it is seeking to explore, study and exploit the potential of the subsurface. In this way, **BRGM** is promoting the implementation of economically viable systems with low environmental impact.









1 — Measuring gas flux in the ground in the vicinity of the Burning Fountain of Gua (south-eastern France), a natural source of methane and CO2 known since ancient times and used in the SECURe project as a natural analogue to develop monitoring measurements. (© BRGM-W Klonomann

2 – Map taken from the Geographic Information System developed as part of the GeoCO2 project, showing the temperatures of the geothermal resource in the Dogger aquifer and the location of industrial emitters in the Centre-Val de Loire region. The numbers next to the pink circles indicate the annual amount of CO2 emitted (in thousands of tonnes per vear). C RRGM

3 — Discretization of the electrical resistivity (ohm.m) of the study area in Bouillante, Guadeloupe, using the finite difference method to model the CSEM and MT electromagnetic data acquired on site. Our model takes account of variations in topography and the presence of the sea, since these have a significant impact on the behaviour of EM waves in the environment C RRGM

Using Minergies data for geothermal exploration

BRGM has carried out a quantitative analysis of existing seismic reflection data and well data on the Dogger aquifer in the Paris Basin. The aim was to set out a methodology, with recommendations for using these data in order to constrain the petrophysical characteristics of the reservoir between the wells. The results, obtained through two different approaches, are encouraging and confirm the value of the method for taking the risk out of low-cost geothermal projects.

A better understanding of geothermal reservoirs in volcanic island contexts

Photo 3 / Initiated by the Guadeloupe region, the Caribbean Energy Transition (CET) project was set up in 2019. It seeks to foster active cooperation on energy management and geothermal development in this region. BRGM is contributing to the creation of a Caribbean geothermal centre of excellence by developing exploration methods adapted to local characteristics in order to identify, characterise and model geothermal reservoirs.

Good practices in the environmental monitoring of subsurface exploitation

Photo 1/ Completed in 2021, the H2020 Secure project made a number of recommendations on good risk management for CO_2 storage and unconventional hydrocarbon reservoirs. BRGM's contribution concerned the environmental baseline of a site, which is essential for any monitoring strategy. Combining methodological and metrological developments with advanced statistical processing, its work has made it possible to define robust and dynamic criteria for discriminating between expected variations in the physicochemical parameters and any potential irregularities.

New: a dynamic observatory for near-surface geothermal energy

Accessible since late 2021 on the website <u>www.geothermies.fr</u>, the near-surface geothermal observatory gives access to the main characteristics of facilities and the technical data of their constituent structures. Backed by the subsurface database (BSS), the inventory receives continuous input from remote declarations for minimum-impact geothermal projects. For older data, the inventory is completed with the help of the French Geothermal Energy Association (AFPG) and industry stakeholders.

A film to raise awareness of the advantages of deep geothermal energy

In 2021, ADEME and BRGM produced a video for local authorities and the general public highlighting the advantages of deep geothermal energy. Available on the website <u>www.geothermies.fr</u> and the BRGM YouTube channel, this 3-minute film combines animated graphics with real imagery. It sets the scene for an inter-generational dialogue on sustainable energy, a field in which the first installations date back to the 1970s. This underlines the maturity of these promising solutions.

What are the prospects for coupling CO_2 storage and geothermal energy in the Centre-Val de Loire region?

Photo 2/ Developed by BRGM, the CO_2 -Dissolved concept involves storing industrial CO_2 in dissolved form in the water of an underground reservoir and giving the project economic value by recovering geothermal heat. Funded by the Centre-Val de Loire region, the GeoCO₂ project involved assessing the potential of this solution in the region. Results concluded that it would be feasible to build an industrial demonstrator for CO_2 -Dissolved within three to five years. In this way, the region will be able to inform and engage with industrial players, particularly small-scale emitters of CO_2 emitters, on the basis of these results.

BioREP: an experimental platform with growing appeal

BioREP (bioreactors for deep environments) is an experimental platform for studying deep environments and characterising the natural biogeochemical processes and/or industrial processes that take place there. It is recognised internationally. Since its founding in 2008, BioREP has gained three new devices along with a number of modules. It is involved in a growing number of projects, relating not only to energy, but also to water resources and natural risks. In 2021, it began collaborating with Ifremeer on the biogeochemical monitoring of magmatic fluid samples off the coast of Mayotte.

Subsurface potential for the energy transition



Timothée Dupaigne Regional hydrogeologist for Île-de-France, project manager for the Subsurface Database (BSS)



Charles Maragna Geothermal research engineer

The Greater Paris Metropolitan Area is developing near-surface geothermal energy, with the support of BRGM

How can the subsurface resources in the Greater Paris Metropolitan Area contribute to meeting the demand for energy to heat and cool buildings? BRGM was commissioned to carry out an assessment of the potential by identifying areas suitable for near-surface geothermal energy and evaluating the amount of heat that could be extracted. The study helped to improve knowledge in this field and to develop decision-making support tools.

It is a well-known fact that there is considerable heating potential in the subsurface of the Paris region, and the Greater Paris Metropolitan Council - which drew up its Climate-Air-Energy Plan in 2018 - intends to exploit this potential through near-surface geothermal projects (less than 200 metres deep) in order to provide heating or cooling for buildings. With this in mind, in 2020, the local authority commissioned BRGM to precisely assess the extent to which these underground resources could contribute to the area's energy needs and to develop tools that could be used to promote the deployment of this type of renewable energy. "The Ile-de-France region has more than 500 near-surface geothermal installations," explains Timothée Dupaigne, BRGM's regional hydrogeologist. "There is still plenty of room to develop this type of green energy, which has two key advantages, in that it is locally-sourced and not subject to the effects of climate change. So, it is available everywhere and on a permanent basis.'

Additional data incorporated in the Subsurface Database (BSS)

BRGM's geologists and geothermal specialists worked plot by plot to assess the potential contributions available in the subsurface using two techniques: vertical heat exchangers, which use a fluid circulating in probes placed in the subsurface to recover heat or coolness, and well-doublets, which directly exploit the heat from the aquifers contained in Lutetian and Ypresian-Cuisian rocks and in the chalk layers. To conduct its work, the team drew on the French Subsurface Database (BSS), the national database on subsurface structures managed by BRGM, while also adding new data to the near-surface geothermal section on operations carried out over the last few years. The project also enabled us to update our knowledge of near-surface aquifers.

"On each plot of land, we cross-referenced the geothermal resources in the immediate subsurface with the land available for drilling, in order to assess the amount of energy that could be extracted," explains Charles Maragna, a geothermal research engineer. The results were then aggregated at different levels; firstly, for each of the 2,861 IRIS grids (based on INSEE data) that cover the metropolitan area; then, for each of the 131 municipalities and each of the 12 local territorial administrative areas(ETPs) in Greater Paris and, finally, for the whole of the Metropolitan area. *"We mapped the near-surface geothermal potential at every scale,"* says Charles Maragna.

Now, all that remains to be done is to compare these assessments with the area's energy requirements in terms of heating, domestic hot water production, air conditioning and cooling in buildings, essentially offices and residential buildings. Overall, this represents an estimated annual consumption of 50.94 TWh. "Near-surface geothermal energy could cover 58% of this consumption," says Timothée Dupaigne. "In order to decarbonise heat production, it could replace around 25% of gas heating consumption, after connecting buildings to existing heating networks as a priority."

7 good reasons to choose geothermal energy

Carried out with the support of ADEME and in partnership with the Paris Urban Planning Workshop (APUR), this mission also produced a map-based interface that shows the existing boreholes and geothermal probes, at the desired scale. This service is updated in real time and is available free of charge on the geothermies.fr website, which is managed by BRGM. It is supplemented by a methodological report. *"These tools are invaluable for geothermal professionals, and especially for local authorities," underlines Timothée Dupaigne. "They can be used by authorities to define an energy mix that includes geothermal energy."*

BRGM is also involved in promoting near-surface geothermal energy among local stakeholders, by producing and distributing a guide entitled "7 good reasons to choose geothermal energy for the Greater Paris Metropolitan Area". In addition to the seven arguments set out, the guide includes eleven testimonies about successful projects. "It is a showcase for near-surface geothermal energy, to popularise it and raise awareness among supervising authorities." Lastly, this project with the Greater Paris Metropolitan Area has led to the creation of a national observatory for near-surface geothermal energy, in partnership with ADEME.





Subsurface potential for the energy transition





"The work carried out with BRGM has confirmed and refined our knowledge of the region's geothermal potential, which is spearheading the production of renewable heat energy in the capital."

What are the scientific and technological challenges for the Greater Paris Climate-Air-Energy Plan?

DANIEL GUIRAUD – This *Plan*, adopted on 12 November 2018 by the Metropolitan Council, puts forward an ambition based on three strategic and operational objectives: to achieve carbon neutrality by 2050, i.e. zero net emissions in line with the Paris Agreement; to massively reduce final energy consumption (a 50% reduction by

Daniel Guiraud

Vice-President of the Greater Paris Metropolitan Area'

2050 from 2005 levels); and finally to obtain a diversified and decarbonised energy mix by increasing the share of renewable and recovered energy in total energy consumption to 60% by 2050. The development of a sector such as surface geothermal energy is fully in line with these energy transition objectives.

— What is the status of the diagnosis of surface geothermal energy potential in Greater Paris?

D.6. – Although the development of the geothermal energy sector is desired and desirable in terms of the ambitions of the capital city, only a fraction of the geothermal resources of the region is currently used. This currently amounts to only 1000 GWh (1 TWh), whereas the study carried out by BRGM will show that the potential of surface geothermal energy alone is 30 times higher (29.75 TWh per year) than the total geothermal energy currently used.

BRGM has helped us develop appropriate tools: suitable communication tools and a precise diagnosis establishing the potential for the development of surface geothermal energy in the Greater Paris area.

— Can you tell us a little about the programmes?

D.G. – In partnership with ADEME and BRGM, the Greater Paris Metropolitan Area wished to develop tools to promote this sometimes poorly understood solution. The study programme falls under an agreement signed on 16 March 2020 between BRGM and the Metropolitan Council. It has two main phases: to establish a case for surface geothermal energy (0-200 m) and to study the potential for developing surface geothermal energy in the Greater Paris area.

– What is the outcome of this collaboration?

D.6. – The work carried out with BRGM has confirmed and refined our knowledge of the geothermal potential of the area, which is spearheading the production of renewable heat energy in the Greater Paris area.

This work will be included in our energy master plan, which is currently under development. The technical and strategic diagnoses were finalised in the summer of 2021 and the project is currently in the stakeholder consultation phase. An initial version of the energy master plan will be presented to the Metropolitan Council in April 2022.



DIGITAL DATA, SERVICES AND INFRASTRUCTURE

Powerful solutions for reliable and open geo-environmental data



BRGM is developing numerous digital tools and services to make geoscientific data useful and accessible in response to global changes. @BRGM 222



BRGM develops digital infrastructures and services that draw on its combined expertise in environmental, earth and data sciences to provide access to reliable, up-to-date information on the subsurface and the environment. In this way, it provides public and private organisations with the information and facts they need to respond to various issues linked to climate change, natural-resource management and risk management. These digital tools are used to structure, disseminate and exploit data from various different sources.

Based on an open science philosophy, they constitute a reference base about the state and properties of France's soil and subsurface, as well as the associated resources and natural risks.

des et Sóulle

1 — The RNDTS (French National Register for Waste, Excavated Soil and Sediments) website is a new online declaration tool, which BRGM was given the responsibility of developing. The site is specifically dedicated to the traceability of waste, sediments and excavated soil. © BRGM

2 — The Cameroon Geological and Mining Information System is an interactive data consultation platform. Six people were trained to use the site when it went live. © BRGM

3 — The aim of the Vigirisks platform is to anticipate and rapidly assess damage in the event of a natural catastrophe. Users are able to input several parameters and variables in order to generate various risk and hazard scenarios. © BRGM





Digitisation of the National Register for Waste, Excavated Soil and Sediments (RNDTS)

Photo 1/ In order to improve traceability, risk prevention and the management of waste, the Ministry of Ecological Transition commissioned BRGM to create a digital version of the National Register for Waste, Excavated Earth and Sediments (RNDTS). BRGM developed an application for entering and registering declarations, as well as an information website and email support for users. The technical architecture is designed to meet strong user demand: thousands of simultaneous connections and the storage of several tens of millions of declarations. The site has been online since the beginning of January 2022. https://rndts-diffusion.developpement-durable. qouv.fr/fr

Soil pollution: publication of CASIAS on Géorisques platform

The Map of Former Industrial Sites and Service Activities (CASIAS) has been published on Géorisques, the BRGM portal dedicated to natural and technological risks. CASIAS was created using information from the French database of former industrial sites and service activities (BASIAS) and incorporated in a new management system deployed by BRGM, which is consistent with the technical and regulatory data managed by Government departments (former BASOL database, SIS). One of the aims is to improve geolocation, in particular in terms of the surface area coverage at the cadastral plot level.

A geological and mining information system for Cameroon

Photo 2/ A SIGM (Geological and Mining Information System) now publishes the results of the geological and geochemical mapping programme in Cameroon. The database, which can be consulted on this interactive platform, covers a wide range of data: geological, geochemical, geophysical, mining and geomaterials. The information is presented on regional and national-scale maps. This SIGM is an innovative tool that can be used for work carried out by Cameroon's government services and mining professionals, as well as a knowledge base that can be used to support national and international education and research programmes. sigm.minmidt.cm

SCRREEN, a network of experts on critical raw materials

The European Commission has created a list of critical raw materials (CRMs), based on strategic supply chain risk. Within this context, the SCRREEN project aims to build a network of experts and consolidate knowledge on CRM value chains. BRGM was given the responsibility for developing the information system grouping together all the expertise and knowledge in this field. This information is confidential and intended to help European decision-makers with their CRM strategy. This is a strategic issue, particularly for the following industrial sectors: batteries, electric mobility, renewable energies, electronics, defence and aerospace.

Vigirisks, a predictive platform for natural risks

Photo 3 / Developed by BRGM, Vigirisks is a scientific platform for simulating risk scenarios. It aims to facilitate the rapid estimation of damage following a natural catastrophe, such as an earthquake, coastal flooding or earth movements. Engineers, researchers or risk-management experts can play out pre-configured scenarios. By modifying certain characteristics concerning the event, users can also create a customised catalogue of scenarios, or even develop scenarios themselves, under certain conditions.

GeolSuite, providing lithology data for Celsius Energy

The geothermal energy operator Celsius Energy, a subsidiary of Schlumberger, asked BRGM to enable it to make more specific searches concerning the lithology data published in graphic form on the InfoTerre platform, in order to use these data in its simulation tools for identifying geothermal potential. Drawing on the results obtained from GeolSuite, the one-stop portal that provides access to all the applications in BRGM's geological information system, BRGM created a specific API (application programming interface) for consulting lithology data, as well as a cartographic interface that provides an overall representation of the information.





Stéphane Loigerot Deputy Director of the Digital Technology for Geosciences Division IT Systems Project Manager

GéoRisques, the public reference platform for fostering a culture of resilience

Following a recent report on risk management culture by the Ministry of Ecological Transition, the GéoRisques platform developed by BRGM under the leadership of Fred Courant will be expanded and adapted to new uses. The aim is to make it a reference tool to foster a culture of resilience in France.

BRGM's DNA includes data and the creation of digital platforms for both professionals and the general public to help improve geoscience knowledge and, in particular, to provide information on hazards for decision-making purposes. Created 8 years ago, GéoRisques is now a long-running BRGM information system. It takes the form of a web platform at https://www.georisques.gouv.fr, making information available to everyone about the natural and technological risks in their area. GéoRisques has been a real success so far: it was used by 6 million people in 2021. The peak number of user logins occurs during climate events (such as the Cevennes storm episodes, which occur when warm and humid wind from the Mediterranean moves northwards). Paradoxically, however, the platform comes into its own in the BtoB sector, for example to produce hazard reports for a given postal address, a plot of land or a municipality.

There are on average 25,000 logins per day, mainly for professional use in the real estate sector, by notaries and property dealers.

Access to the main institutional hazard databases

Based on the open data policy promoted by the State, GéoRisques provides access to the main institutional databases on hazards and is therefore very heavily used, especially since the ELAN Act of 23 November 2018 on trends in housing, development and digital technology reformed real estate law and introduced a mandatory document, referred to under the acronym ERRIAL (controlled risk status information for buyers and tenants), in all transactions. In total, more than a million real estate transactions take place in France each year and the services provided by GéoRisques are always used. In particular, the platform can be used to produce a labelled digital ERRIAL.

How to develop a risk management culture in France

GéoRisques is both a website for the general public and an everyday work tool for a range of professions. It is about to change to become the reference platform for all user groups for fostering a culture of resilience. The *Report on Risk Management Culture*¹, drafted at the request of Barbara Pompili, Minister for Ecological Transition, and coordinated by the science journalist Fred Courant, points to an insufficient risk management culture in France.

Among the recommendations, GéoRisques was identified as a factor that could contribute not only to providing information, but above all to explaining how to deal with natural and technological risks. This report puts GéoRisques in the limelight and is an opportunity for BRGM to showcase the geoscientific information it produces on a daily basis in numerous fields related to risk management (marine submersion, cavities, clay, contaminated sites and soils, etc.), in addition to its digital and data management know-how. Accordingly, the website will be transformed. The aim is to make it more accessible in order to develop this culture of resilience. It will be supplemented in particular to offer educational content on major natural or technological risks. It will offer educational and entertaining content produced by a body in charge of fostering a culture of resilience. In particular, virtual reality technologies will be used to provide a more tangible and realistic view of the consequences of the relevant phenomena. The ergonomics of the website will be reviewed to ensure a more up-to-date and fluid user experience (new page formats, better integration of the flagship "My House / My Risks" service, etc.), based on a simplified visualisation using informative and interactive maps.

GéoRisques will in fact become a true ecosystem, with a new interface for the public on the one hand and, on the other, an information system based on the existing set-up, which will continue to be a tool for professional use, facilitating access to confirmed up-to-date risk data of all types and from all sources.

(1) Mission on transparency, information and participation for all in managing major technological or natural risks - Ministry of Ecological Transition, June 2021.







1 — The GéoRisques platform contains information related to both natural and technological hazards and is accessible in several forms. © BRGM

2-Visualisation of risks at an identified location accounts for more than 80% of user views. <math display="inline">0 BRGM

3 — The risk data for an area can also be downloaded in the form of a description containing all the relevant information. $\ensuremath{\mathbb{C}}$ BRGM





"BRGM is a key player in digital geosciences, and therefore a natural partner for Data Terra in developing a distributed data and service infrastructure on a national, European and international scale."

- What are the scientific goals of Data Terra?

FRÉDÉRIC HUYNH – The Data Terra research infrastructure is one of the three e-infrastructures making up the national roadmap in the field of Earth systems and the environment. Founded in 2016, Data Terra provides data and services for integrated knowledge and observation of the Earth system. Its mission is to implement and develop infrastructures for data and distributed services in order to observe, understand and predict developments against the backdrop of global change that we are

Frédéric Huynh

Director of the Data Terra research infrastructure and head of the Gaia Data project - EQUIPEX+/PIA3

seeing right now. In practical terms, Data Terra brings together 26 organisations providing researchers with multi-source and multi-sensor data processing services (satellite, soil, *in situ*, etc.) as well as advanced technical and computing resources (storage, on-demand processing, computing, AI, visualisation, etc.). Drawing upon this range of activities, we deliver value-added services to address scientific challenges.

— In this context, why BRGM?

F. H. - From a technical standpoint, we need to provide access to data that are, as I said, complex, multiple and dynamic. This access needs to be simple and transparent so that users can focus on scientific objects and processes. We needed to recognise the tendency to work in silos and the many obstacles facing us: the exponential increase in volumes and sources, changing requirements, the need for co-construction between science and engineering, the integration of artificial intelligence, and so on. And we had to provide interoperability as a key requirement. This being so, BRGM naturally emerged as a key partner, primarily for the ForM@Ter (Solid Earth) data cluster and the implementation of distributed platforms for FAIR data and services on behalf of Data Terra. BRGM joined Data Terra in 2017 and is extensively involved in ForM@Ter, of which it is a founding member. It is a major player in digital geoscience, and therefore a natural and even a key partner in terms of strategic added value.

— Can you provide specific work examples?

F. H. – Gaia Data has 21 partners. It's a groundbreaking eight-year project to develop a distributed data and service infrastructure to observe, model and understand the Earth system, biodiversity and the environment.

BRGM will manage and operate one of the nodes, and coordinate and develop services to support its use. Another example is the construction of the national thematic data warehouse for publications in the relevant disciplines. And we shouldn't forget the outlook for the future, with the deployment of Data Terra in Europe, as part of the EOSC in particular, and also at international level. We will need to meet challenges in terms of data interoperability, multi-source and multi-thematic services and the development of integrated approaches to the Earth system.

HUMAN RESOURCES

Pragmatic skills planning

The Human Resources department of BRGM has developed a global approach to managing jobs and career paths (GEPP), designed to provide the organisation with the skills it needs. It also places particular emphasis on career development opportunities and on the working conditions of employees, particularly researchers, in order to pursue improvements and build loyalty.

Isabelle Plaid Human Resources Director Marie Belossat Assistant Human Resources Director

BRGM is continuing the approach it rolled in 2018 for the management of jobs and career paths, while making any necessary adjustments. "In this way, we can combine various HR tools to develop a global vision of the skills present in the company, the mobility requirements of employees and the type of profiles that we need to recruit," explains Marie Belossat, Assistant Human Resources Director. This approach, combined with detailed knowledge of the labour market and particularly sectors with shortages, paved the way for the implementation of a first Employment Plan in 2021. This plan sets out BRGM's recruitment policy, giving priority to the skills required in the medium and long term.

"The employment plan will be updated regularly to adjust to constantly changing needs within the company," says Isabelle Plaid, Director of Human Resources. The momentum of the plan for managing jobs and career paths is reflected in a high rate of internal mobility: 6% in 2021, i.e. over 60 employees, compared with 4% in the Objectives and Performance Contract (COP) for 2018-2022. "You can see a real dynamic here, backed up by efforts to systematically open jobs to internal candidates," emphasises Marie Belossat. "This enables us to meet our skills requirements in a difficult context, while promoting the career development of our employees."

One goal: scientific excellence

BRGM is the first public industrial and commercial establishment (EPIC) to receive HRS4R certification. The Human Resources Strategy for Researchers seeks to improve the practices of research organisations with respect to the recruitment and working conditions of researchers. The objective is to deploy this European label more widely.

BRGM received HRS4R certification following an audit of its scientists and researchers and the development of an action plan to reach the expected standards on 49 criteria (recruitment, recognition, ethics, etc.). "The purpose of this process of continuous improvement, which concerns all BRGM employees, is to ensure the quality of our services and the skills level of our workforce," explains Isabelle Plaid. The idea is also to make BRGM more appealing to researchers and to build loyalty.



Towards a pact for 2024

The first plan for improving quality of life in the workplace was completed in December 2021. Taking the name of PACT-21 and based on a social barometer conducted in 2019, its purpose was to better disseminate and apply BRGM's strategy, to develop a culture of listening, dialogue and transmission, to optimise the organisation of work and to support the vision set out by HR.

This plan, which includes 36 actions, has reached a progress rate of 82%, a highly satisfactory result in the light of the health crisis. Illustrating the strong social dialogue at BRGM, its implementation was steered by a team made up of members of the management committee, staff representatives and local managers. A new barometer, planned for early 2022, will measure the impact of PACT-21. ■



**Staff provided by the National Miners' Rights Agency (ANGDM) to BRGM for post-mining activities.

SUSTAINABLE DEVELOPMENT

BRGM ramps up its sustainable mobility policy

BRGM actively seeks to promote more sustainable mobility on its various sites, since travel represents a significant part of the company's carbon footprint. Following a recent internal survey highlighting employees' commuting practices, the company put in place an awareness-raising scheme and drew up a new mobility plan.

Fabienne Boutreau CSR Officer Hervé Riolland Head of the Auditing Risks and Quality Department

Over the course of three weeks (rather than just one week), from 16 September to 7 October, BRGM organised a series of events and initiatives as part of the European Sustainable Development and Mobility Weeks. The company's 330 participants all promote a common philosophy, based on the idea that "every action can contribute to building a more sustainable future". In line with the "France in transition" scheme created by the Ministry of Ecological Transition, the programme included quizzes linked to the United Nations sustainable development goals (SDGs), documentaries, two walks through forest areas on the Orléans site and the traditional mobility challenge, which incites employees to give up using their private car and travel differently. "We wanted this year's programme to be based on solidarity," says Fabienne Boutreau, CSR Officer at BRGM's General Secretariat. "By converting the distance covered by the participants in the challenge into money, we managed to raise €750 for the Cent pour un Loiret association, which helps homeless families have access to housing and become more independent."

<u>A survey concerning the staff's intentions</u> to change their practices

During these three weeks, the staff were also shown the results of an internal survey on commuting practices, carried out in spring 2021 (not including the period of the health crisis). This 66-point questionnaire was sent to everyone who comes to work on BRGM's various offices and sites, whether in Orléans or in the various regions of France. It was completed by 575 respondents, i.e. a return rate of almost 50%, and supplemented by 546 comments. It enabled us to improve our knowledge of employees' travel habits and to assess their intentions as regards changing practices – for example, opting for an electric vehicle, a bicycle or public transport – while also identifying their motivation as well as potential obstacles. *"The results will provide input for the management's discussions with the staff Social and Economic Committee (French CSE) concerning the company's* Our service provider, Rodolphe Beaubois – landscape gardener and nurseryman – guided the staff along the walks organised on the Orléans site in collaboration with the CSE's Sustainable Development commission.



One of the electric vehicles used for moving around on the BRGM site in Orléans. © BRGM - C. Boucley



new mobility plan and the implementation of new measures aimed at encouraging employees to adopt a more sustainable form of mobility," says Fabienne Boutreau.

These same environmental concerns helped shape BRGM's business travel policy, which was completely overhauled on 1 July 2021. The new policy introduced a series of provisions to encourage the use of video-conferencing, train-travel and carpooling. "In addition to this, the agency that looks after the company business travel arrangements is now required to estimate the carbon footprint of each solution proposed to employees, in order to make them aware of the environmental impact of their journey and to help them make their choice", says Fabienne Boutreau.

Encouraging new ideas and solutions

Finally, over the course of the three weeks, the Orléans Metropolitan Council held two conferences to present the results of the *Assises de la transition écologique* (ecological transition forum) organised by the local authority during the first half of 2021. BRGM was invited to participate in this forum in a pilot study concerning sustainable mobility in civil society and thus contributed to the emergence of new solutions. This represents a host of opportunities that can be seized upon to promote the mobility of the future at regional level. ■

"The 2021 Mobility Challenge raised €750 for a charity, by converting the distance covered by the participants into financial aid."

Renewal of our quality and environmental management system certifications

BRGM's ISO 9001 and ISO 14001 certifications - obtained in 2004 and 2012 respectively acknowledge the company's efforts to ensure the quality and efficiency of its activities and control their environmental footprint. Both certifications were renewed in 2021 for three years, following an audit carried out by AFNOR in Orléans and in the various regional offices. This renewal demonstrates the effectiveness of the work carried out, further confirmed by our 94% customer satisfaction rating in 2021. The audit also highlighted the actions implemented to reduce BRGM's environmental footprint, for example: the expansion of our fleet of electric vehicles; greater consideration of environmental performance criteria in purchasing; the continuation of teleworking (following the Covid pandemic lockdowns); building maintenance focusing on improving energy performance, etc. "The auditors also appreciated the robustness of our risk analysis process, which is conducted ahead of every project in order to reduce the environmental impact," explains Hervé Riolland, Head of the Auditing Risks and Quality Department.

Board of Directors

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PROGRAMME DIRECTORS



KNOWLEDGE OF GEOLOGICAL SYSTEMS **Pierre Nehlig** Programme Director



SUBSURFACE IMAGING AND MODELLING Philippe Calcagno Programme Director







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MINERAL RESOURCES AND THE CIRCULAR ECONOMY



SUBSURFACE POTENTIAL FOR ENERGY TRANSITION

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Board of Directors and Committees

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January 2022

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ECONOMIC AND FINANCIAL AUDITING

Bruno Rossi, Jean-Pascal Codine

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lanuary 2022

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Rémi Pelon, Senior Mining Specialist - World Bank

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A positive 2021 net result for the BRGM group

In 2021, BRGM confirmed the recovery that had begun in 2020. The improvement in results was due to increased operating activity for BRGM EPIC and the favourable outcome of the ERAMET share sale for its subsidiary BRGM SA.

Along with four other public research institutes (INRAE, CIRAD, IFREMER and IRD), BRGM operates on behalf of the government under programme 172 of the Organic Act on Public Accounts (LOLF). BRGM also receives subsidies for public service expenditure (SCSP) under programme 181, for its activities in post-mining and support for public-policy development in particular.

At the BRGM Group level

The net consolidated profit for the group stands at $\leq 12M$ in 2021 (compared to $\leq 0.3M$ in 2020). The contribution of the different entities to this net result is as follows:

• In 2020, BRGM contributed €3.6M to the Group's consolidated operating result, which corresponds to its net social result of €12.7M adjusted to take account of entries for transactions with subsidiaries (mainly write-back for budget allotments to the BRGM SA subsidiary);

• BRGM SA contributed €7.6M, mainly due to the disposal of ERAMET shares;

• SAGEOS contributed €0.8M of income to the group in 2021, mainly as a result of the sale of CFG shares and dividends received from its subsidiaries and holdings;

• CFG, and IRIS INSTRUMENTS contributed €0.1M and +€0.4M respectively, while MPT IRIS Inc brought a loss of €0.4M.

At the BRGM EPIC level

BRGM EPIC's net result improved further in the 2021 financial year, with a profit of €12.7M compared to a loss of €1.6M in 2020. The operating result increased by €1.9M to €4M (compared to €2.1M in 2020). The financial result increased by €12.3M compared to 2020 and amounted to €8.7M in 2021 (compared to a loss of €3.6M in 2020).



+EAM BRGM Epic operating result in 2021



Operating expenses 2021 in millions of euros







Evolution of total expenses 2018–2021

in millions of euros







All these elements led to the payment of a profit-sharing bonus (\notin 1.9M) and will allow a contribution to the company savings plan in 2022.

The BRGM's total operating resources for 2021 amounted to €156M. Excluding reversals of provisions and expense transfers, resources related to current activity increased by 6.6% compared to 2020 and amounted to €140.6M. Its overhead amounted to a total of €152M in 2021. After restatement of provisions and a €6M contribution to a new pension fund, expenses related to ordinary activities amounted to €138.2M, an increase of 6.6% compared to 2020. The increase mainly concerns external operating expenses (+ €6.5M), due to the growth in activity. Personnel costs remained stable (at €68.2M).

Excluding post-mining activity, the level of SCSPs remains stable compared to 2020 (ξ 53.9M). The contracts and agreements amounted to ξ 51.8M, up by 5.3% compared to 2020. For business alone, the evolution is contrasted between international activity, which recorded an increase

of €1.8M compared to 2020, and French business activity, for which production decreased slightly by €0.5M.

Production for the Public Policy Support mission attained its highest level for six years at ≤ 29.6 M. On the other hand, public research activity financed by contracts and agreements (≤ 11.9 M) is down by ≤ 2.8 M compared to 2020. This is due both to an increasing decline in final co-financing rates for national public research projects and to the financial closure of European H2020 projects at a lower level than expected.

The post-mining activity benefited from both an increase in the SCSP allocated to it $(+ \in 1M)$ and a significant increase in its production under contract $(+ \in 5.2M)$.

The financial result of $\notin 8.7M$ in 2021 is the result of the increase in the value of BRGM SA (mainly due to the sale of ERAMET shares) and the dividends received from SAGEOS ($\notin 1.5M$).

Finally, corporate income tax due for the group amounted to $\leq 1M$ in 2021.

Evolution of resources under contracts for scientific research and support for public policy development support

in millions of euros exlusive of VAT

Contracts and agreements + invested assets	2019	2020	— 2021
European Union + ERDF	6.424	7.409	- 4.618
ANR + Carnot	2.047	2.071	- 2.410
Agencies other than ANR	9.678	9.096	— 8.900
Local and regional authorities	6.574	6.605	- 8.455
Government Ministries and agencies	10.957	12.990	— 16.299
Companies	2.628	2.216	— 1.127
Sub-total research contracts and agreements + policy support (APP)	38.309	40.387	— 41.809



Subsidiaries and holdings

The BRGM Group's subsidiaries and equity are divided between three holding companies, each corresponding to a specific sector.

SAGEOS is the holding company for all shares held in subsidiaries operating in geothermal energy, with, on the one hand, CFG Services for which it owns 66.6% of the capital, and on the other, Geothermie Bouillante in which it has a 15% holding (ORMAT Systems and the *Caisse des Dépôts et Consignations* own 63.75% and 21.25% of the capital, respectively) and in measurement instruments for geophysical, hydrogeological, hydraulic, geotechnical and mining surveys, where it has a 51% holding in IRIS Instruments (the Japanese OYO Group holds the other 49%). For the management of excavated soil, it has a 40% holding in Soltracing (with HESUS owning 50%). COFRAMINES and BRGM SA hold the BRGM Group's remaining equity in the mining sector (dormant companies with no activities or development planned, or companies under liquidation).

BRGM SA has held receivables from the *Société de Participation Minière du Sud Calédonien* (SPMSC) since 2005, when the BRGM Group transferred its share in the GORO project in New Caledonia to the SPMSC. ■



A busy year in 2021



CEO: Georges Picard Managing Director: Éric Lasne Turnover: €5.468M SAGEOS holding: 66.66% Staff: 20 employees

The Compagnie Française de Géothermie (CFG) is a leader in the geothermal energy market, with core activities in four areas: • Studies and consultancy in the field of geothermal resources; • Project design, engineering and management for all geothermal applications (including electricity production and spas); • Operational maintenance and monitoring of geothermal production facilities;

• Consultancy, services and products in the fields of corrosion and industrial microbiology.

CFG offers its clients its subsurface expertise for the design, implementation and operational monitoring of projects for all types of deep and shallow geothermal extraction and for a wide range of temperatures. CFG's expertise has extended its activities to include engineering services for geothermal loops and fluid conditioning.

To carry out its missions, CFG relies on two activities grouped together in a single production department.

The IMO division handles project engineering and management (upstream sector: resource characterisation, design and implementation);

• The MSE division handles operational maintenance and monitoring, (downstream sector: commissioning, operational maintenance and monitoring, rehabilitation).

The engineering and project management activity was sustained from the second quarter onwards with the management and supervision of a new Dogger doublet in Evry (91) and significant shaft rehabilitation work in France and Switzerland. Feasibility studies in the Île-de-France, Centre-Val de Loire and PACA regions suggest that there is good potential for the production of carbon-free energy in heating networks and in the industrial sector in the near future.

CFG has supported major energy operators in their current projects and the development of geothermal electrical generation projects in the overseas territories. These projects are revitalising the subsurface engineering sector in volcanic environments and enabling the redevelopment of know-how specific to this field of activity.

The microbiology consultancy activity on behalf of ANDRA continued, albeit at a lower level than that projected.

The maintenance and operational monitoring business was particularly busy in terms of maintenance work and sales of specialised shaft equipment.

Scheduled maintenance activities, of which there were seven this year, generated a lot of work, placing heavy demands on the technical teams in a health context which is still complex in 2021. In addition to these maintenance operations, we also had to deal with breakdowns that tested the responsiveness and availability of our teams.

The maintenance work led to the discovery of problems either with the production equipment or with the structures



Georges Picard CEO of CFG

themselves. The rehabilitation of the facilities generated equipment sales and rehabilitation work as prime contractor.

We should also note the equipping of two new doublets at Champs-sur-Marne and Vélizy with CFG technologies in terms of anti-corrosion treatment.

Production of Labège kits was very strong with the upswing of the oil and gas sector after two years of low demand and low prices.

Major orders were filled, notably for operators in West Africa.

In terms of of research and development, partnership projects were pursued in 2021 on various technical subjects such as the development of high-temperature submersible pumps, and the exploration of new options for coupling geothermal energy and CO2 reinjection.

Research work (with ADEME funding) on complete preparation of shafts with composite materials was finalised in 2021 with the development of a specific cementing methodology. From 2022, this work will be applied for the construction of two doublets incorporating this technology in Alfortville and Champigny-sur-Marne. ■



Complex rehabilitation operation with snubbing unit in Switzerland. © CFG

Towards a resumption of mining exploration



CEO: Catherine Truffert Turnover: **€5.9M** SAGEOS holding: **51%** OYO holding: **49%** Staff: **26 employees**

Catherine Truffert CEO, Iris Instruments

The health crisis and all its consequences remained a central concern for IRIS Instruments in 2021 and for its employees and customers. Their cohesion and professionalism enabled our teams once again to rise to the occasion to face this second atypical year.

Due to successive country restrictions, travel to scientific conferences, trade fairs and customer visits remained limited. However, digital communication tools were used to ensure that the bond with scientific, commercial and customer partners was not lost.

Financially, the company is performing well, driven equally by the mineral prospection, groundwater exploration and environmental markets.

The commercial success of compact resistivity meters (SYSCAL), designed for monitoring the first 250 m of the subsurface, is intensifying with uses that extend beyond traditional applications such as hydrogeology, monitoring of natural and anthropic risks, archaeology, etc. Consequently, these leading-edge electrical-imaging instruments, with their proven reliability, are now routinely used in the field of civil engineering.

Global mining exploration budgets increased significantly in 2021, driven by a growing demand for base metals and for critical metals related to energy transitions (transport and energy). IRIS Instruments was able to capitalise on this momentum with increased sales of resistivity and induced polarisation, deep-exploration systems for investigating beyond the first 250 metres. Although it is too early to predict, this enthusiasm for deep exploration is likely to be sustained.

IRIS Instruments is ready to meet the demand for deep mining prospection with the publication of its patent EP3572846A1 "High Power Transformer and Transmitter for Geophysical Measurements" and its range of instruments that are patented in the USA, Canada and Australia. With its 6kW of power, this transmitter will become an essential tool for deep monitoring, alongside FullWavers and more traditional receivers such as ELRECs.

Private sector equipment sales increased in 2021, indicating a significant economic recovery despite the difficulties operators still face in moving from one theatre to another.

IRIS Instruments continues its research and development effort in order to offer its customers solutions that meet their challenges. The company benefits from support under the French government's recovery plan in the context of its joint laboratory with the CEA/IRFU. Its success in responding to calls for projects also provides opportunities for high-quality collaborative research with BRGM and other scientific partners. This investment guarantees the performance of future instruments that will be offered to tomorrow's customers..

CCI Consult uses a SYSCAL PRO resistivity meter to monitor the subsurface of railway tracks in France. @IRSInstruments



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